

Ore Deposits
of the
United States, 1933-1967

THE GRATON-SALES VOLUME

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53. Ore Deposits of the Park City District with a Contribution on the Mayflower Lode

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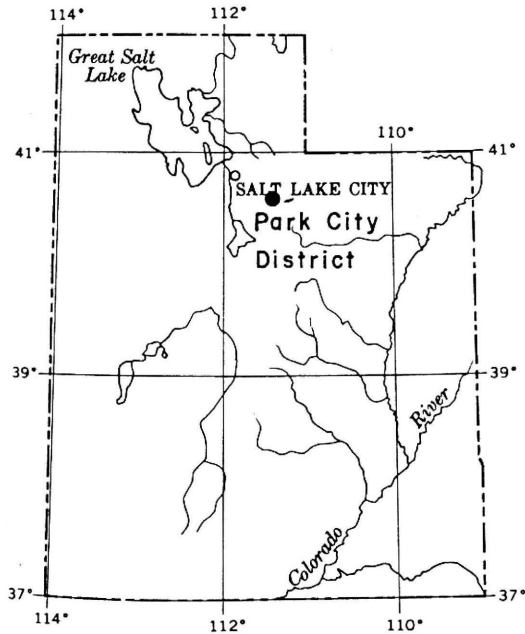
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ABSTRACT

The Park City District, Utah, is situated in the Wasatch Range at the intersection of the westward extension of the axis of the Uinta Range. Ore has been mined almost continuously from the first discovery in 1869 to the present day, with a total production of over 14 million tons.

Sediments of Carboniferous to Triassic age have been folded into the northerly plunging Park City anticline and subsequently modified by thrust faulting, diorite and diorite porphyry intrusions, and strong east-west normal faulting during the Laramide orogeny. Younger andesitic volcanics partially cover the eastern edge of the district.

The ore bodies occur as both lode and bedded replacement deposits over widely scattered localities. Near surface, high-grade silver "bonanza" ores were mined in early days from the Ontario and Daly Lodes, which occur along the east-west zone of faulting near the

center of the district. Other lode or fissure deposits were found along the Mayflower and Hawkeye faults to the east and southeast.

Large bedded replacement silver-lead-zinc ore bodies associated with east-west zones of fissuring, have been mined from favorable horizons in the Park City Formation in the Daly West and Judge mines. A series of long, narrow, high-grade, replacement ore bodies occur in the Silver King mine at a single horizon in the Park City Formation. Ore is currently being mined from strong bedded replacements in the Humbug Formation near the apex of the Park City anticline.

Factors controlling ore deposition are: magmatic source, structural feeder systems, and favorable host rocks. Ore deposition along favorable beds is primarily a function of physical conditioning and secondarily of chemical composition.

INTRODUCTION

Over the years the Park City district has been studied in part by many qualified and distinguished engineers and geologists. However, due to the inevitable problems concerning ownership, boundaries, apex rights, and company policy, there has been very little interchange of engineering and geological information among the various companies until recent years. The consolidation of the greater part of the district into the holdings of one corporation, the United Park City Mines Company, has made it possible to correlate a great backlog of information pertaining to geology and ore deposition. This has been especially successful through the full cooperation that now exists between this company and the Hecla Mining Company, which now operates New Park Mining Company's Mayflower mine.

Of the many geological investigations and reports that have been made on the various mines, few have found their way into print. United States Geological Survey Professional Paper 77, by John M. Boutwell (2) was published in 1912 and is still the best known and most exhaustive study written on the district.

It remains an excellent volume of source material today.

The compilation and correlation of data accumulated over the years and the remapping of many of the old mine workings have made it possible to enlarge greatly the geological knowledge of the district as a whole and of specific ore bodies in particular. The information contained in this paper is based on these studies.

HISTORICAL INFORMATION

There has been an almost continuous history of mining in the Park City district from the time ore was first discovered to the present day. The first discovery was made on the Walker and Webster claim in 1869. The Ontario Silver Mining Company was organized in 1872, and the main impetus of location and discovery came with the opening of the Ontario vein. From that time Park City became known as one of the great "bonanza" camps of the west.

Prospecting and discovery progressed along the western extension of the Ontario vein. The Daly Mining Company was organized in 1885 with claim holdings immediately west of the Ontario Company. The Daly Judge Mining Company was also organized in 1885 with holdings to the extreme westerly limit of the district. The Daly West Mining Company came into existence in 1892 with a block of claims lying between the Daly ground and the Daly Judge property along the Ontario and Daly structural zones.

In 1892, the Silver King Mining Company was also established and soon held a large block of ground north of the other companies. The Silver King mine later became one of the major producers in the district.

In 1920, the Park Utah Mining Company

was organized, and new ore was discovered below the old Hawkeye-McHenry discovery along the Hawkeye Fault east of the older mines. The New Park Mining Company was incorporated in 1932 independently of the other mines and became a major producer along a strong vein zone in the southeast section of the district.

In 1953, the Park Utah Consolidated Mines Company, which was composed of the Ontario, Daly West, and Daly Judge mines and which owned a large interest in the Daly Mining Company, consolidated with the Silver King Coalition Mining Company to form The United Park City Mines Company.

Two companies, The United Park City Mines Company and New Park Mining Company, now own over 90 per cent of the district. The balance is divided among smaller companies, some of which have been important producers in the past and include the New Quincy Mine and the Park City Consolidated Mine. The Silver King Western, Park City Utah, the American Flag, and the Keystone Mining Companies also have claims in the district.

Statistics of Mine Production

A summary of the production records of the various mines so far as they are available is set forth in Table I. The grade of ore produced from the various ore bodies is summarized in Table II.

PHYSIOGRAPHIC HISTORY AND PRESENT TOPOGRAPHY

The Park City district lies on the eastern slope of the north-south trending Wasatch Range where it is intersected by the westward

TABLE I. Park City District—Summary Production Record 1875 to 1964

Mining Company	Years	Tons Mined	Oz. Gold	Oz. Silver	Lbs. Lead	Lbs. Zinc	Lbs. Copper
Ontario Mine	1875-1964	2,238,594	41,289	55,710,608	164,231,209	210,350,684	3,911,102
Daly West & Judge Mines	1899-1951	4,265,346	79,051	51,264,289	744,384,966	401,616,365	31,831,461
Daly Mine	1886-1950	554,088	18,717	12,734,946	11,166,664	10,877,183	371,628
Park Utah Mines	1920-1951	1,238,778	168,264	21,690,417	104,032,694	136,311,084	6,003,021
Silver King Mine	1882-1964	4,698,609	200,224	86,126,781	1,334,765,435	331,859,041	45,801,007
New Park Mine	1936-1964	1,645,501	464,564	10,037,160	182,256,534	224,791,927	21,951,133
Totals		14,640,916	972,109	237,564,201	2,540,837,502	1,315,806,284	109,869,352

Source: Production records of various mines as indicated.

TABLE II. Park City District—Grade of Ore Produced by Ore Bodies 1875-1964

	Years	Tons Recorded	Oz. Gold	Oz. Silver	Per cent Pb	Per cent Zn	Per cent Cu
Ontario Lode							
Era 1	1875-1902	655,126	.030	58.2	—	—	—
Era 2	1902-1924	169,111	.026	24.8	2.0	—	—
Era 3	1924-1942	126,000	.027	29.8	2.9	3.3	—
Ontario Replacement Ore	1954-1964	981,797	.025	5.80	6.40	8.67	0.14
Daly Lode							
Era 1	1886-1902	278,068	.03	58.2	—	—	—
Era 2	1902-1924	20,103	.03	15.0	7.5	8.5	—
Hawkeye Lode							
P.U. West Ore Body	1920-1932	1,117,778	0.13	15.0	4.6	6.2	0.2
P.U. East Ore Body	1920-1932	110,000	0.09	46.0	1.2	—	.02
Mayflower and Pearl Lodes	1936-1964	1,645,501	0.281	6.10	5.55	6.84	.67
Roll, Middle, Back, & 1240 Veins							
Replacement Ore	1909-1924	3,478,600	.026	25.33	14.1	12.1	—
Silver King Replacement Ore	1882-1951	3,420,000	.024	18.45	13.52	10.68	.495
Crescent Zone	1882-1952	1,092,056	.021	7.88	12.10	5.27	0.21

Source: Assay records from mining companies.

extension of the axis of the Uinta Range. This axis trends almost normal to the Wasatch front.

This segment of the Wasatch Range contains an area of complex geology, with its structure a composite of the north-south folds and thrust faults characteristic of the Wasatch Range that may have been modified by the east-west trending anticline which dominates the Uinta structure. This zone of structural intersection is further complicated by large intrusive bodies in a stage of early dissection (7).

From the high ragged crest of the Wasatch Range, the western front falls off abruptly 5000 to 6000 feet to the desert below. The eastern slopes, in marked contrast, give way gradually to plateaus and high mountain meadows. The meadows in turn are drained through deep, sharp canyons with ungraded bottoms and ungraded side cataracts that drain westward to the desert floor.

The town of Park City is located at the junction of three canyons which descent northeasterly from the main range and open out into a broad highland meadow originally called Parley's Park. Access to the mines is provided by these canyons and through numerous tunnels driven for drainage purposes.

GEOLOGIC HISTORY

The sedimentary rocks of the Park City district, including the deepest horizons penetrated by the mine workings, have an aggregate thick-

ness of something over 7000 feet. Not all of these formations are exposed on the surface and therefore do not show on the surface geology map. Boutwell (2) has adequately described the general occurrence, outcrop, and location of the formations exposed on the surface. The excellence of his basic work is still recognized today.

No attempt will be made in this paper to repeat much of Boutwell's general geologic descriptions. However, much information of great significance has been gained over the ensuing years since 1912.

Stratigraphy

Probably the greatest contribution to the geological knowledge in the district since the days of Boutwell's report lies in the detailed study of stratigraphy. Bedded replacement ores have played an important role in the district with their principal loci in certain stratigraphic horizons. Bedded ores remain today of prime importance, and a continuing study of their stratigraphic relationships is essential and of tremendous economic importance in the search for new ore.

The most significant contribution to the stratigraphy of the district has been the resolution of the undifferentiated limestones that underlie the Weber Quartzite into distinct units. These rocks formerly were referred to as the Wasatch Limestones. The work of mapping and measuring these units and correlating them

with the known formations has been completed to the deepest horizons penetrated (Figure 1).

The oldest formation penetrated in the district is exposed in New Park Mining Company's Mayflower mine and is correlated with the Madison Formation of the Big Cottonwood district. The Madison is dated as early Mississippian age (7, p. 24). The youngest consolidated formation found in the district is the Nugget Sandstone of early Jurassic age. Only the basal units of this formation are exposed along one of the highest ridges. Thus, formations that range in age from Carboniferous through early Jurassic are represented in the district. In addition, much younger volcanics and unconsolidated Quaternary deposits also are present.

The formations from the oldest to youngest are the Madison, Deseret, Humbug, and Doughnut of Mississippian age; the Morgan and Weber of Pennsylvanian age; the Park City with fossils of both Pennsylvanian and Permian age; and the Woodside, Thaynes, and Ankareh of Triassic age (2).

MADISON FORMATION Only the upper 120 feet of the Madison has been penetrated to date in the district. It is found on the 2000 level of the Mayflower mine. Correlation of this unit with the nearest surface exposure of the Madison in Big Cottonwood Canyon is only tentative since metamorphism has altered its appearance and obliterated any fossils in the mine area. The lithology of the underground exposure more nearly resembles the Madison than any other formation and its position in the stratigraphic sequence corroborates the correlation.

The upper 120 feet is described as interbedded thin- to medium-bedded dolomitic limestone, shaly limestone, and white dolomite underlain by light gray to white dolomite with occasional beds of white and black limestone and a few irregular bands of chert. The difference in the underground lithology with that of the surface as described by Calkins (7, p. 23) probably can be accounted for by proximity to large intrusive bodies and the possible presence of some introduced minerals.

No ore has been found in the formation as yet, and its real economic importance remains to be tested.

DESERET FORMATION The Deseret Formation is exposed in many of the mine workings in the center of the Park City anticline. In nearly all of these exposures, it is in close proximity to large intrusive bodies and, therefore, has been metamorphosed to various degrees.

The lower contact with the Madison Formation appears to be conformable in the one location where it can be seen. The upper contact is conformable with the Humbug Formation.

The formation, as measured in the Mayflower mine, is approximately 760 feet thick. The upper 260 feet is composed of massive-bedded, white to light gray, marbleized limestone with some dolomite and sandy(?) limestone. In the Ontario mine the upper section often displays a triboluminescence which is unique to this formation. The middle 350 feet is a massive, white, sugary dolomite with some chert. The lower 150 feet is made up of black dolomitic limestone, thin pale gray chert bands, and a narrow zone of light gray, vuggy dolomite underlain by a few feet of black, shaly limestone.

HUMBUG FORMATION Overlying the massive white limestones and dolomites of the Deseret Formation is a series of interbedded limestones and sandstones. In the Ontario mine the Humbug consists of limestone, sandy limestone, quartzite, sandstone, and calcareous sandstone irregularly repeated in a section about 350 feet thick.

Identification and correlation of these beds with the Lower Humbug Formation of the Cottonwood-American Fork area as described by Calkins (7) was made on the basis of lithologic similarities. Garmoe (11) measured the Humbug in the Cottonwood district and mapped extensively in the Ontario and Mayflower mines. He also concluded the interbedded series in these mines was the Humbug Formation.

The detailed stratigraphic section for the Humbug in the district has been compiled from mapping underground workings in a rather small area of the Ontario mine. How well the detailed lithological sequence can be expected to extend beyond this limited area has yet to be determined. However, drill hole data at some distance from the Ontario mine indicate that the overall nature of the formation is maintained throughout much of the district. Writers in other districts have observed the formation to be lenticular in nature, with thickening, thinning, and lensing out of various horizons apparently being commonplace (11, p. 21; p. 26-27). Due to the limited area exposed by mine workings, these lithologic variations have not been noted except between the Ontario and the Mayflower mines where metamorphism may have masked the similarities.

For mapping convenience, the formation has been divided into two units. The upper consists

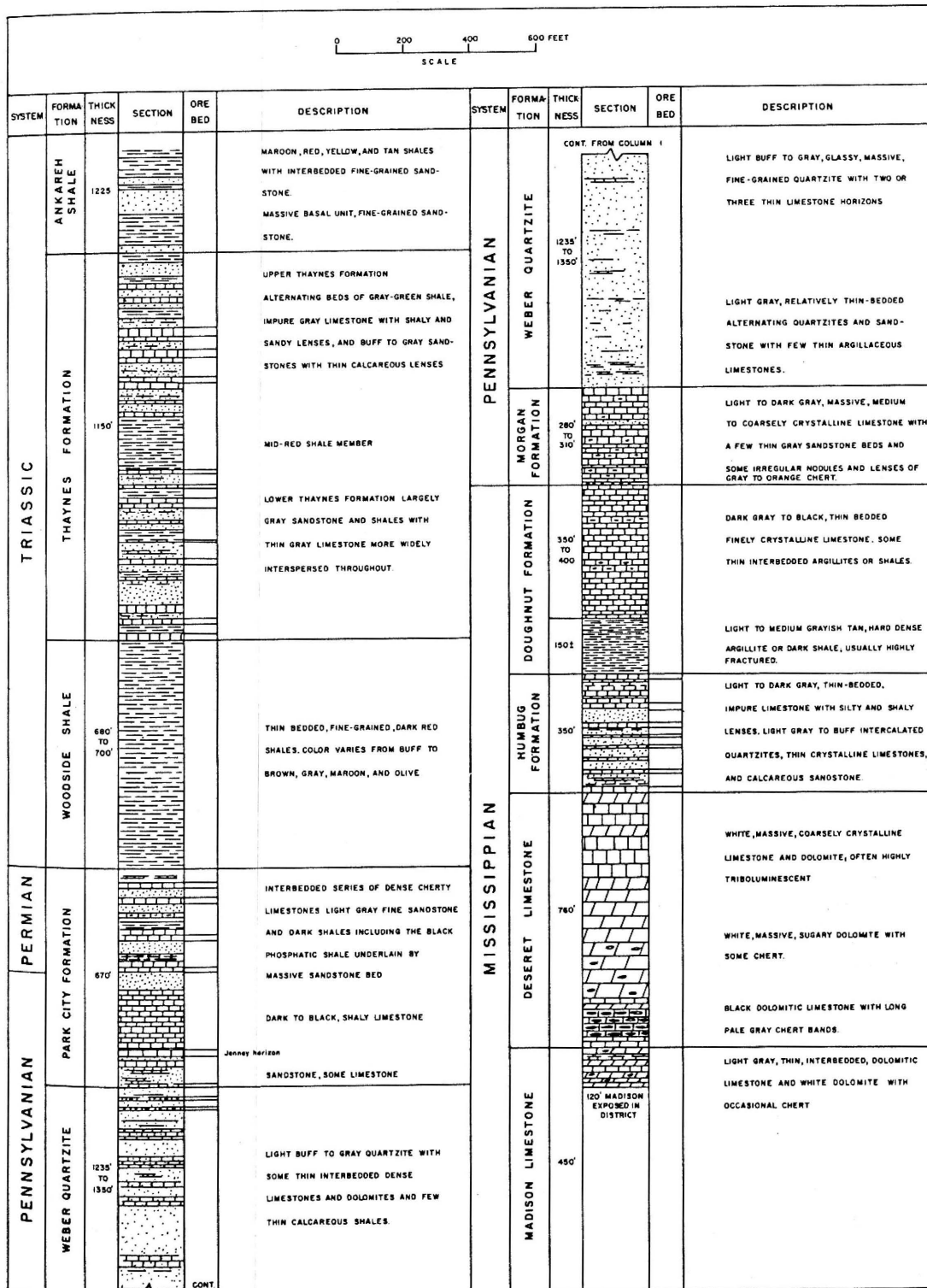


FIG. 1. Stratigraphic Column of the Park City District, Utah.

of 100 feet of white to gray crystalline limestone with shaly and muddy partings and thin, interspersed siltstone or mudstone lenses. The lower unit is referred to as the Quartzite-Sandstone Series and consists of about 250 feet of interbedded quartzite, limestone, and sandstone members ranging from 3 to 40 feet in thickness. Since various intervals of the entire formation have been replaced extensively by ore, the units have been carefully mapped and identified in detail throughout the mine.

DOUGHNUT FORMATION The Doughnut Formation, as measured in the Park City district, consists of from 350 to 400 feet of black to dark gray, hard, thin-bedded, siliceous and silicated limestone, with some thin, interbedded shales or argillites. The base of the Doughnut is marked by a prominent argillite bed approximately 150 feet thick, the bottom of which is tentatively assigned the Doughnut-Humbug contact.

Calkins (7, p. 26-27) originally included the dark limestones of the Doughnut with the Humbug Formation, but lithologic dissimilarities between the dark limestones and argillites of the Doughnut and the lighter-colored limestones and sandstones of the Humbug beds make the division at the base of the thick argillite a logical contact for purposes of underground mapping.

Underground exposures of the Doughnut in, or adjacent to, the mineralized areas in the district have shown it to be very unreceptive as a host rock for mineral replacement. The dense siliceous and silicated nature of the metamorphosed limestone renders it nearly impermeable, and the basal argillite bed has been found to cap many replacement ore bodies occurring in the upper Humbug Limestones. Some ore does occur as vein filling in the Doughnut Formation in strong structural zones.

MORGAN FORMATION* Garmoe (11, p. 24-25) described the Morgan Formation in the Big Cottonwood district as 329 feet of predominantly gray, fine- to coarse-grained, well-bedded, crystalline limestone with irregular chert nodules and lenses scattered throughout. This same description applies to the Morgan Formation of the Park City district except for its being slightly thinner with local color

* Recent work by the U.S. Geological Survey has correlated the Morgan Formation with the Round Valley Formation of northern Utah, and the U.S. Geological Survey stratigraphers have adopted the Round Valley nomenclature for the Park City district.

variations and bleaching due to metamorphism. The formation is 280 to 310 feet thick and is essentially homogeneous throughout, with only minor changes in lithology and thickness of beds. Irregularly spaced nodules and lenses of white, gray, orange, and pinkish cherts are characteristic of the entire formation and are diagnostic of the Morgan in contrast to other limestone formations in the district.

Both Calkins and Garmoe mapped a thin conglomerate at the base of the Morgan Formation and noted what might be a slight angular unconformity in the Big Cottonwood district. No conglomerate or angular unconformity can be noted in the few places the Morgan-Doughnut contact can be seen underground in the Park City district. However, the abrupt lithological change and the paleontological break from Pennsylvanian to Mississippian fauna are indicative of a time lapse that could well be represented by an unconformity.

The top of the Morgan Formation is marked by an abrupt, distinctive change in lithology from limestone below to Weber Quartzite above. The contact is conformable in those few places where it is seen.

WEBER QUARTZITE The Weber Quartzite of the Park City district was named after stratigraphic and paleontologic studies allowed correlation with the massive gray quartzite found in Weber Canyon by geologists of the Fortieth Parallel Survey (2, p. 45). Prior to this correlation, the thick quartzite section in the district was called the "Ontario" Quartzite after the name of the principal mine that was opened in it. Though no fossils have been found, the formation is clearly of Pennsylvanian age, being both overlain and underlain by Pennsylvanian Formations.

The greater part of the section is quartzitic rock although the lithology ranges through nearly all gradations from orthoquartzite, through sandstone, calcareous sandstone, argillaceous sandstone, sandy limestone, argillaceous limestone, and a few thin, quite pure limestones and dolomites (15, p. 3).

The formation has been tentatively divided into three units; the Upper, Middle, and Lower sections. The upper unit consists of five or six rather thin limestones and dolomites alternating rhythmically with thicker quartzite intervals for a thickness of approximately 360 feet. The middle unit is made up of about 560 to 580 feet of quite clean, massive, fine-grained orthoquartzites with only two or three thin limestone horizons. The lower unit consists of approximately 300 feet of thin-bedded,

alternating quartzites, sandstones, and thin argillaceous limestones.

A total section of about 1235 feet has been measured and described in detail through underground mapping. Other geological evidence is sufficient to establish the total thickness as between 1215 and 1350 feet.

PARK CITY FORMATION The Park City Formation has been named after the district in recognition of the important part the formation has played as a host rock for the rich ore bodies discovered early in the district's history.

Outcrop exposures of the formation are very poor, although it covers a considerable surface area in the district. The exposures are irregular and greatly interrupted by faulting and intrusion. Only isolated intervals are sufficiently exposed to reveal much lithologic information. The wealth of stratigraphic detail on the formation is provided from drill holes and numerous underground workings, including stopes, where large tonnages of ore have been mined from its horizons.

One of the most obvious characteristics of the formation is its heterogeneous lithology as compared to the overlying and underlying formations. For the most part the formation is limestone, but it also contains sandstone and thin shales and has a narrow phosphatic horizon near the middle. The limestones range from massive, gray, and finely crystalline to thin-bedded, black, and fossiliferous with very thin shaly partings. The limestones often are separated by thick to thin horizons of sandstone, quartzite, and sandy limestone. These units add up to a total thickness of approximately 670 feet.

The contact of the Park City with the Weber Quartzite is difficult to establish precisely in most underground exposures throughout the district. The lowest member of the formation consists of an arenaceous limestone and/or calcareous sandstone that changes to quartzite at the contact. The base of the lowermost calcareous bed has been arbitrarily established as the break between the formations, but in actual practice it is often very difficult to find.

The change of lithology between the Park City Formation and the Woodside Shale adds credence to the established paleontological break between the Park City fauna of Pennsylvanian-Permian age and the Thaynes fossils of Triassic age. The Woodside Shale apparently is devoid of fossils but has been assigned with the Thaynes to the Triassic by Boutwell (2, p. 52) because of their lithologic similarities. Although no unconformity can be noted

between the Park City Formation and the Woodside Shale, there is a sharp, distinct break between the upper massive limestones of the Park City and the thin shales of the Woodside.

WOODSIDE SHALE The Woodside Shale is a single lithologic unit of rather uniformly thin-bedded, fine-grained, dark red shale. A few intervals may show increased coarseness of sandy material, and color variations of buff, brown, gray, and olive may be noted throughout. Its characteristic topographic expression is a smooth unbroken slope usually with much vegetation.

The best sections of the Woodside have been measured in underground workings. In addition to the section through the Silver King Consolidated shaft referred to by Boutwell (2, p. 52), the Woodside has been thoroughly exposed in the Spiro tunnel and partially revealed in numerous other underground areas. The exact thickness has been difficult to measure because of faulting in all exposed areas and lack of marker beds by which the horizons can be correlated. However, because of the great amount of work that has been done in the formations both above and below the Woodside, its thickness can be confidently placed somewhere between 680 and 700 feet.

The Woodside Shale has no direct economic importance as far as ore occurrences are concerned, and, since the district has been largely drained of water to an elevation mostly below the shale, it is no longer an important factor in mine drainage.

THAYNES FORMATION The Thaynes Formation is one of the most extensively exposed formations in the district. It forms the ridges and canyon walls of a large portion of the northwest section of the district and also has been mapped on the eastern flank of the Park City anticline. A good partial section is exposed in the Ontario Number Two drain tunnel.

The formation has been found to be conformable with the Woodside Shale, which underlies it, and also with the overlying Ankareh Shale. Much shale and other more coarse detrital material are abundantly interbedded with thin-bedded limestones. The formation is divided into an upper and lower section of nearly equal thickness by the Mid-Red Shale Member. The upper part is found to be more calcareous than the lower, and, though the true limestone horizons are few and narrow, much of the total section is of calcareous nature.

The quite pure limestone horizons both in

the upper and lower sections have proved susceptible to replacement by ore in many places throughout the district. This is particularly true along Crescent ridge, where the first mineral discovery was made, and in the old Crescent and Pinyon mines of the same area. Since the formation has proved to be of such economic interest in the past, it is natural that much effort should be expended in determining its true character and thickness.

The formation has been mapped in great detail and a comprehensive columnar section is now available. Various ore horizons have been identified and named for the best known ore replacement that has occurred in them. The total thickness of the formation has been measured at about 1150 feet but undoubtedly will differ somewhat even in the district. The various lithologic units have proven to be very persistent throughout and can be counted on to retain their relative places in the stratigraphic sequence. In other words, identification of various members in the formation is possible by observing the lithological sequence through a number of units and correlating them to the type section.

For purposes of identification, the contact between the Thaynes Formation and the Woodside Shale has been set just under the lowest limestone horizon.

ANKAREH SHALE AND NUGGET SANDSTONE
The youngest consolidated sedimentary formation in the district is the Nugget Sandstone, and only the lowest part of it is exposed along Jupiter ridge in the northwest corner of the district.* It is conformably underlain by the Ankareh Shale, which is best exposed along the ridge between Park City and Big Cottonwood canyon. For our purposes, these formations have been described adequately in other publications (2 and 7) and will not be elaborated upon here since they are of no economic importance in the district. They outcrop largely beyond the mineralized zone, and nothing of economic value has been found in them.

IGNEOUS ROCKS Igneous rocks make up nearly one third of the area of the Park City district. They occur generally along the southern part of the district, and intrusive rock is closely associated with many of the ore bodies. In general, there are three main petrographic

* Recent mapping by the U.S. Geological Survey indicates the sandstone on Jupiter ridge to be a member of the Ankareh Shale rather than the basal Nugget Formation.

types occurring in distinct areas; they are diorite and diorite porphyry intrusive rocks and extrusive andesite.

The diorite forms the most rugged and precipitous ridges and the highest peak in the region. It is found in the extreme southwest corner of the district and extends into Big Cottonwood and Snake Creek canyons. It is a dark-gray, rather fine-textured granular rock that contains little quartz but so large a proportion of orthoclase as to verge on monzonite. Mafic minerals consist of biotite, hornblende, and augite, accompanied in places by hypersthene (7, p. 34).

The diorite porphyry has the widest extent of the igneous formations within the area and is found mainly in stocks in the eastern and southern parts of the district, but small isolated bodies occur in the west and northeast portions. In the more mineralized part of the district, this porphyry takes the form of irregular tongues and dikes issuing from the stocks. A few sills are present.

The rock generally has a dark-green groundmass with large white feldspar phenocrysts, the dark small crystals being hornblende, biotite, and some augite. The groundmass even under a hand lens appears to be an extremely fine crystalline mass of poorly formed minerals (2, p. 69, 79-87).

There are considerable differences throughout the region in the appearance of these two types of diorite. In composition, however, such rocks stand well within the limits of each petrographic type, with perhaps the exception of some additional quartz in areas that properly would change the designation to quartz diorite and quartz diorite porphyry.

The only extrusive rock in the district is a small area of Keetley Volcanic Series. These volcanic rocks are found in the extreme northeast corner of the district and stretch eastward for many miles. The andesite is a pinkish or greenish rock, commonly gray on fresh fractures, with a speckled appearance. In the hand specimen, these colors seem confined to a dense, fine-grained groundmass in which are scattered phenocrysts of feldspar, hornblende, and mica (2, p. 70).

Structure

The general geologic structure of the district is dominated by the Park City anticline, the axis of which trends nearly north-south and plunges gently to the north through the very center of the district. To the west of the anticline, the formations form a gentle adjacent

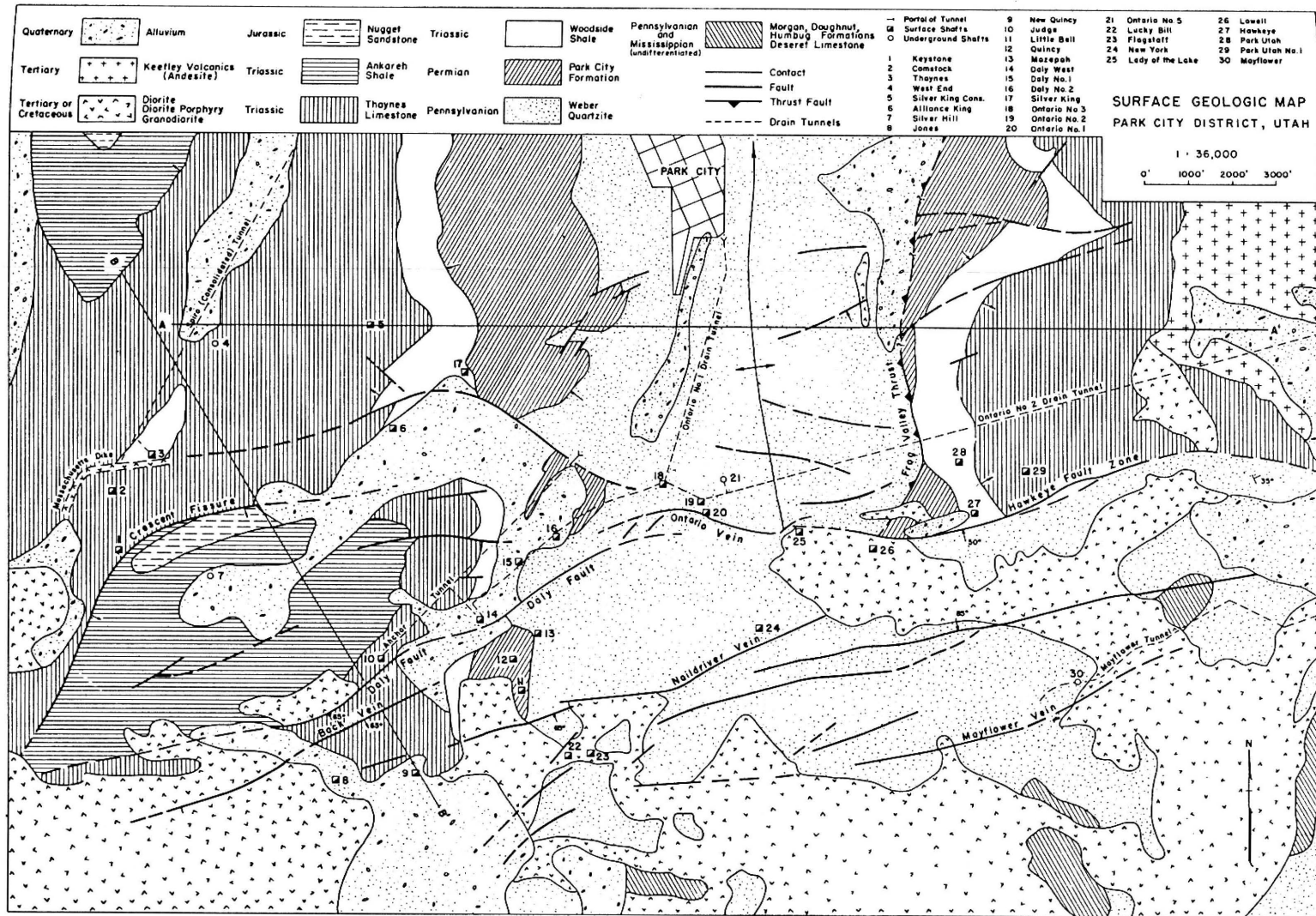


FIG. 2. Surface Geologic Map, Park City District, Utah.

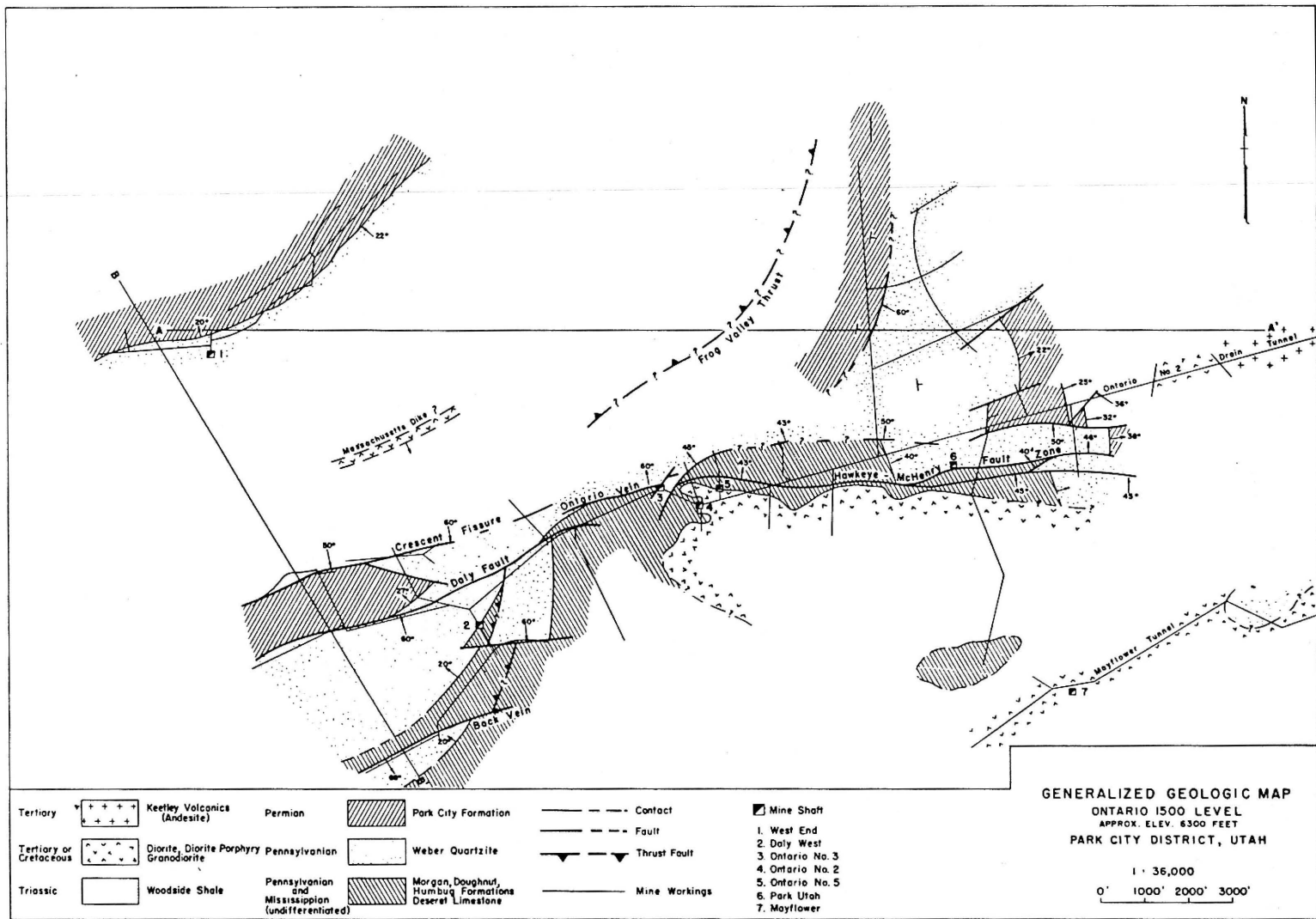


FIG. 3. Generalized Geologic Map, Ontario 1500 Level.

syncline roughly paralleling the anticlinal axis and plunge, although with much broader flanks. The western flank of the syncline extends beyond the district into Big Cottonwood area. It is sufficiently broad to make the mineralized zone appear as a gently curving monocline dipping to the northwest. The formations along the eastern flank of the anticline dip under the andesite and are buried by it.

These broad general folds are severely modified by intrusion and strong east-west faulting roughly normal to the fold axis by which minor folds or flexures have been superimposed upon the broader features. Boutwell (2, p. 94-96) has described most of these structural features very adequately in his early studies of the district. Work since that time has resulted principally in further delineation and definition of these major structures and their relationship to ore occurrence. The generalized surface geology map (Figure 2) illustrates the principal features as known to date, and the map shows only minor changes from Boutwell's original mapping. Underground mapping on a large scale has added a great deal of additional detailed information to the geologic pattern. Figure 3 shows the district geology in nearly one horizontal plane through corresponding levels of the various mines. Figures 4 and 5 are sections through the district as indicated on Figures 2 and 3.

Piecing together the structural elements of the district to establish the geologic history has produced the following general conclusions with which are included a brief discussion of the major faults and their genetic relationship to the ore bodies.

Probably the oldest faulting in the district was described by Boutwell as a "great compound overthrust fault" (2, p. 96) named the Frog Valley Thrust. It strikes roughly north-south and is exposed about 1 mile east of the town of Park City. This fault thrusts Pennsylvanian Weber Quartzite into contact with the Triassic Thaynes Formation and overlaps both the Woodside and Park City Formations. It probably is related very closely in age to the folding and predates nearly all the normal faulting in the district. Other small thrust faults, which also predate the normal faulting, have been mapped underground in the Silver King mine. They probably are related directly to the Frog Valley Thrust system. Correlation of this major thrust zone on the surface with underground exposures has been difficult to make with any degree of certainty. The recent discoveries, made during development work in the Daly Judge area, of repeated strati-

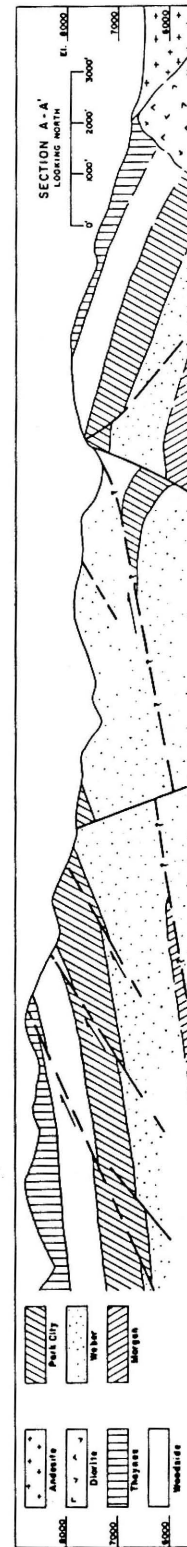


FIG. 4. Geologic Section A-A'.

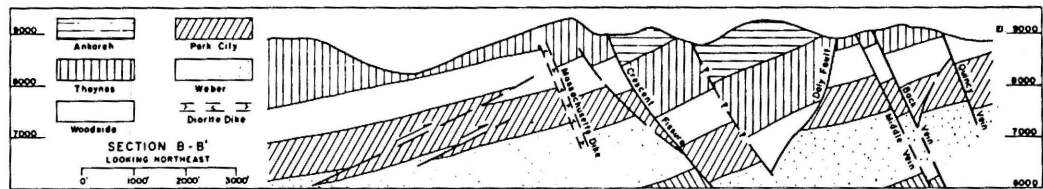


FIG. 5. Geologic Section B-B'.

graphic intervals and extensive thickening of the formations indicate the location of the underground trace of the fault.

Intrusion and major normal faulting apparently are related closely in age throughout the district. They are later than both folding and thrusting. Diorite and diorite porphyry make up the large irregular stocks that extend roughly east and west along the southern limits of the district. A continuation of these igneous intrusions follows generally the same trend into Big Cottonwood and Alta Districts. However, in these districts, the rock is a granodiorite or quartz monzonite.

In conjunction with the general trend of the intrusion, a strong zone of east-west normal faulting extends through the very center of the district. A large portion of the ore bodies are related directly to these structures. At the eastern limit of the district is the Hawkeye-McHenry fault, a strong, north-dipping, normal fault that is nearly coincident but marginal to the diorite porphyry contact. One of the major ore bodies of the district was found along this fault zone as fissure-lode ore where the fault splits into an almost classic cymoid loop structure (Figure 6). The offset of this

fault is extensive with relative movement between the two walls being of the order of 600 to 800 feet.

Another strong normal fault has been discovered underground north of the Hawkeye-McHenry called the Jefferson Fault. It roughly parallels the Hawkeye both in strike and dip for several thousand feet and appears to converge with the Hawkeye to the west. There is no evidence of this fault on the surface, and it is possible that it converges with the Hawkeye updip before reaching the surface.

To the west, in the very heart of the Ontario mine, the diorite porphyry noses out, and both the Hawkeye and Jefferson Faults are lost in a series of northeasterly en echelon faults that eventually swing into the Ontario Fault-Vein zone that then continues westerly. The Ontario is termed a fault-vein because the hanging wall has moved 200 to 300 feet relative to the foot-wall and because it is strongly mineralized over a long distance along its strike length.

As the Ontario structure continues to the west, it eventually dies out after strong spurs or horsetails split off between it and the Daly Fault. The Daly Fault, also a strong, north-dipping, normal structure, then appears to take up the displacement and grows stronger as it extends westward where it eventually is lost in the Clayton Peak Diorite. The Daly may also be termed a fault-vein over the part of its strike length that is mineralized.

Other major normal faults, all trending roughly east-west, though with considerable individual variations, are found through the district. The Crescent Zone, which constitutes a strong, normal, south-dipping structure directly opposite the Daly Fault, also appears to be part of the general east-west zone of structural weakness and has ore occurrences along it. The Massachusetts-McGregor Fault-Dike system extends for several thousand feet through the Silver King area north of the central fault system. The Middle and Back Vein Faults occur similarly to the south, all of which have major ore occurrences related to them. The Mayflower Fissure in the southeast corner of the district is also an east-west trending normal

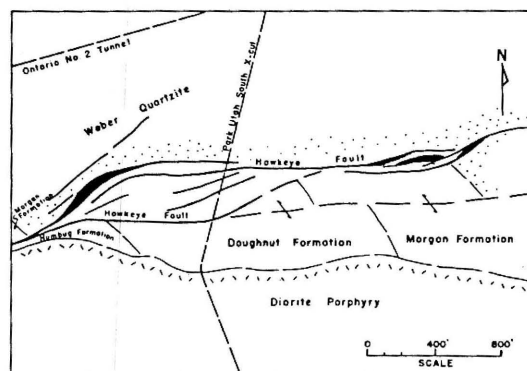


FIG. 6. Geology Plan Map, illustrating Hawkeye Fault, Cymoid structure, and ore bodies, Park Utah Mine.

fault having some displacement. It is the host, along with minor horsetailing fissures, for persistent, high-grade ore bodies between quartz diorite wall rock.

Smaller related fractures are found associated with nearly all of the faults that constitute the central fault system. They are usually steeper than the main structure, and little or no movement is indicated on them. These subsidiary fissures may play a very significant role in the formation of many of the ore bodies.

Because mineralization is associated with most of these major faults in different amounts, it is believed that they are primarily pre-mineral structures. However, evidence of strong, post-mineral movement has been observed along nearly all of the faults making up the central zone of weakness. This is also true of some of the other faults in the district. It, therefore, must be assumed that there has been a history of repeated movement along these structural elements. In fact, even during the history of mining operations, movement measured from a few inches up to several feet has been observed along the Crescent Fault. The nature of the heavy ground and squeezing clays along some of the other faults also may be indicative of their dynamic nature to the present day.

Age of Mineralization

Mineralization in the district closely followed intrusion and faulting that, in turn, were later than folding and thrusting. The great structural deformation of the Wasatch Range generally has been assigned to the Laramide revolution (late Cretaceous to early Tertiary age) with intrusion shortly following.

These conclusions are valid for the Park City district where the youngest sediments, those of Jurassic age have been both folded and intruded, thus making these events at least later than Jurassic time.

The Clayton Peak diorite of the district is related genetically to the Alta granodiorite and the Cottonwood quartz monzonite immediately to the west. Calkins and Butler (7, p. 35) consider the sequence of intrusion to be Clayton-Alta-Cottonwood, but only the Clayton-Alta relationship has been definitely established by field evidence. Considerable age dating work has been done on this series of intrusions. Lead-Alpha ratio dates made by the U.S. Geological Survey (12) have been reported as: Clayton—40 to 48 m.y.; Alta—54 m.y.; and Little Cottonwood—46 m.y. Aldrich (13, p. 463) reported a 25 m.y. Rb/Sr date for the

Cottonwood stock. Armstrong (16, p. 167-168) summarized previous age dating work and, using K/Ar ratio dating, established the age of the Alta stock at 39 plus 6 or minus 2 m.y. and the Cottonwood stock at 22 plus 3 or minus 2 m.y.

All of these dates fall well within the limits of the Tertiary period and range from Eocene to Early Oligocene in age according to recent geologic time scales (14).

In summary, field relationships of the diorite and diorite porphyry intrusions in the Park City district establish the age of intrusion and subsequent mineralization as post-Jurassic. However, recent age dating has refined the date of intrusion to Eocene time or the Early-Middle Tertiary period.

ECONOMIC GEOLOGY

The Park City district encompasses many ore bodies scattered over a wide area, each with its own peculiarities, but which generally fit into classifications as lode- or vein-type deposits, bedded replacement deposits, or irregular replacement deposits. These deposits occur in an area approximately 3 by 5 miles and over a vertical range of several thousand feet. Only in the Mayflower and Ontario mines does the ore persist continuously downward over this vertical range as a single ore shoot. The various types or forms of ore bodies differ greatly from mine to mine; these differences and their degrees continuity depend on their geologic environment; i.e. host rocks and structural control. An adequate description of these various forms and their mineralogy can best be done through brief descriptions of each type of ore body according to its geologic setting.

Lode Deposits

Many of the ore bodies that are best described as lode deposits also have some bedded replacement ore associated with them at certain stratigraphic horizons. However, where the dominant factor is vein control, they are classed as lodes.

The principal lode deposits of the district are found along the Ontario, the Daly, the Mayflower, and the Hawkeye Faults. These ore shoots have proved to be both rich and persistent over vertical ranges of from several hundred to 1500 feet or more. The Mayflower Lode is the only one in which mineable ore continues below the deepest present workings on the 2400 level as well defined shoots.

ONTARIO AND DALY LODES The discovery of the Ontario Lode marked the real beginning of mining in the district. High-grade silver ore persisted from the surface to a depth of about 1300 feet. Below this depth, the fissure system widened and the mineralization became spotty and of lower grade with an increase in zinc and pyrite. The main Ontario Fissure has been explored continuously along its strike for approximately 5000 feet, with ore mined from intervals which total about 4500 feet of this length. Near the western end of the Ontario Fissure, the ore crossed over on three prominent southwest-striking spurs to the Daly Fault where ore was mined for approximately another 2500 feet along the strike of this fissure.

The upper portions of the Ontario and Daly Lodes occurred between walls of Weber Quartzite which had been highly shattered and brecciated in the zone of faulting. The open fracture zones provided ideal passageways and sponges for mineralizing solutions and also later for tremendous volumes of surface water that continually plagued the early mining operations.

When the zone of fissuring was traced below the quartzite at the 1300 level into the Morgan and Doughnut Limestones, several changes in its character were noted. The fracture zone became less distinct, narrowed considerably, and contained much less mineralization. In essence, this change of wall rock marked the lower extremity of the higher-grade, continuous ore shoots of the Ontario and Daly Veins.

The eastern end of the Ontario Vein Zone was found to terminate against a system of northeast-trending transverse faults, the strongest of which was called Number Nine Fault by Billingsley and Lyon (3). These faults, which Billingsley numbered in sequence, make up the en echelon system spoken of earlier as lying between the Hawkeye and Jefferson Faults and the Ontario Vein Zone. Some of these northeast transverse faults, particularly the Number Nine, may persist for some distance along their northeast trend, which incidentally approximates the surface northward bulge of the diorite porphyry intrusive.

To the west, the ore of the Daly Lode feathered out along the Daly Fault, which remained barren for about 1000 feet before the Daly West Lode was encountered. The ore of the Daly West shoot was mined for approximately an additional 2500 feet in the Daly West property and another 2000 feet westward in Daly Judge ground. The average vertical depth from which ore was produced along the Daly in these mines was only 650 feet. The ore of the Daly West and Judge shoots was neither

as rich nor as persistent as the main shoots to the east, although the bedding replacement ore adjacent to the Daly Fault near the Judge shaft proved to be extensive and high grade.

Mineralogy Boutwell's observations concerning the ores mined in the upper levels of the Ontario and Daly mines show that these deposits should be characterized as argentiferous lead ores with some zinc and in certain places copper (2, p. 116). These conclusions are confirmed by more recent findings even to the deepest levels. As the mines have gone deeper, zinc and pyrite have become more prominent.

The primary ores contain argentiferous galena, sphalerite, and tetrahedrite-tennantite occurring with pyrite and quartz gangue. The silver content of the galena differs in the various ore shoots, though the high-silver contents in general occur with the tetrahedrite which usually is intergrown intimately with galena and sphalerite.

Except for secondary minerals and oxidation products, the mineralogy of the ores throughout most of the district is quite simple. The mineralogy shows only one main stage of ore mineralization. Some evidence may indicate a repeated surge of ore minerals in the deeper Ontario workings associated with local brecciation, but positive criteria are lacking. There was little change in mineralogy between ore surges if such exist.

By megascopic examination, the paragenesis of the minerals appears to be quartz, pyrite, sphalerite, galena, tetrahedrite, and calcite. Pyrite occurs both earlier and later than the other sulfides, as well as being contemporaneous with them. The very late stage pyritic mineral is reniform in habit and may present deposition by ground water, as may the many calcite veinlets.

Production and Grade The production along the Ontario and Daly Lodes can best be divided into three eras. In the first era, 1875 to 1902, the rich bonanza-type ore was mined from both properties. According to Kildale (9, p. 9), the oxidized ores usually contained much cerussite, anglesite, and iron oxides, along with bindheimite, massicot, argenite, hornsilver, malachite, azurite, and chrysocolla. During the years of the first era when these oxidized ores were mined, along with much of the primary ores at greater depth, the Ontario mine produced 655,126 tons assaying 58.2 ounces of silver per ton with .03 ounces of gold and from 1 to 3 per cent lead on the lower levels. The ore was mined for silver, and often the gold and lead were not reported. Over nearly the same era (1886-1902), the Daly mine produced 278,068 tons of ore of

approximately the same grade. (No assay record available.)

The second era, 1902 to 1924, saw most of the ore produced by leasers in the Ontario mine, and mining was virtually at a standstill in the Daly mine except for World War I years and shortly thereafter. The Ontario produced 169,111 tons assaying .026 ounces gold, 24.8 ounces silver and 2 per cent lead during this period. The Daly production is recorded as 20,103 tons estimated at .03 ounces gold, 15.0 ounces silver, 7.5 per cent lead, and 8.5 per cent zinc.

A third era of production can be ascribed to the Ontario mine from 1924 to 1942. This ore did not occur on the Ontario vein, but east of Number Nine Fault along the Hawkeye Fault zone and was known as the Dunyan Vein. The ore occurred in small narrow shoots between Weber Quartzite on the hanging wall and "Wasatch Limestones" on the footwall from the 1000 to the 600 level. Approximately 126,000 tons were produced averaging .027 ounces gold, 29.8 ounces silver, 2.9 per cent lead, and 3.3 per cent zinc.

MAYFLOWER LODE The Mayflower mine is located in the southeast corner of the district near the center of a major block bounded on the north by the Hawkeye Fault and on the south by the Little Bell Fault. The Little Bell Fault is described as the Cottonwood Canyon Fault by Boutwell (2, p. 193). Within this fault block, some 7000 feet wide at the surface, a system of linking faults is the controlling structural feature of the Mayflower vein system. The mine is on the eastern limb of the Park City anticline where the surface is largely Weber Quartzite, bounded on three sides by Tertiary diorite stocks.

The Mayflower Vein System consists of four easterly to northeasterly striking veins. From north to south these are the Pearl, Pearl Split, Number Three, and Mayflower veins. They are lead-zinc veins containing important amounts of gold, silver and copper; the principal gangue mineral is quartz. Though these veins are interconnected, there is a considerable mineralogical difference between the Mayflower vein and the other three. The veins also differ texturally and structurally.

Pearl Vein The Pearl Vein strikes about N80°E and dips from 80° to 90°N. Development of the vein has been entirely in quartz diorite and diorite porphyry. It was of no economic importance in the upper levels of the mine, but there has been marked improvement in the length and strength of mineralization with depth. Ore shoots on the Pearl were gen-

erally short, with 100 to 200 feet of strike length being common. However, new work on the lower levels has developed continuous ore on this vein for up to 800 feet. The vein weakens to the west and has not been clearly identified in the sediments.

The Pearl is a strong, narrow vein characterized by a band of friable, sugary quartz with lacing strands of sulfides. Banding of the vein minerals, open cavities, crustification, and comb structures are common and suggest epithermal mineralization. The vein and the wall rocks for as much as a few feet from the vein are almost always chloritized.

The sulfides are pyrite, galena, sphalerite, and chalcopyrite. Hematite is common, and occasionally rhodochrosite and rhodonite are encountered. In several of the Pearl ore shoots, the content of lead and zinc is negligible. Gold is of primary economic importance, and the silver-copper content is also considerably higher than in the Mayflower vein. The gold is very fine-grained, and it occurs with the sulfides and occasionally with hematite. It is found consistently with chalcopyrite, but its occurrence with pyrite, sphalerite, galena, and hematite is unpredictable. The occurrence of silver is dependent upon the presence of gold, but there is no consistent ratio between the two.

Pearl Split Vein The Pearl Split is a narrow linking vein between the Pearl and Mayflower veins. This vein resembles the Pearl in character and minerology, but ore shoots have been short and tonnages small. The Pearl Split strikes from N30°E to N40°E and dips from 70° to 80°NW. It reached a maximum strike length of 550 feet on the 1270 level but has shortened to 50 feet on the 2000 level.

Number Three Vein The Number Three Vein is also a linking vein between the Pearl and Mayflower veins. Unlike the Pearl Split, it subparallels these veins in strike and forms a cymoid curve between them. It is a well-defined structure on the 1630 level and is a strong vein below the 1880 level.

In contrast to the sharp-walled, well-defined Pearl Vein, the Number Three Vein is structurally quite different. Cymoid loops are common, and often it is an ill-defined vein made of interlacing stringers of quartz with banded sulfides and hematite. Chloritization of the immediate wall rocks is strong. Ore shoots differ in strike length from 100 to 300 feet.

The mineralogy of the Number Three Vein is similar to the Pearl. Quartz is the principal gangue mineral, hematite is nearly always present, and rhodochrosite and rhodonite occur occasionally. The sulfides are pyrite, sphalerite, galena, and chalcopyrite. As in the Pearl

Vein, gold is associated with the chalcopyrite and to a lesser extent with the other sulfides and hematite.

Mayflower Vein The Mayflower vein strikes from N60°E to N80°E and dips from 60° to 70°N. It has been the most productive structure in the mine, but the vein has become weaker on the lower levels in contrast to the radical improvement of the Pearl and Number Three veins.

The Mayflower Vein has been mined from near the surface to the 2000 level, but the most productive zone has been from the 600 level to the 1755 level. While most of the Mayflower production has come from between diorite wall rock, some significant ore has been mined in the sediments. Limestones of the Morgan, Doughnut, Humbug, and the upper Deseret Formations have been host to replacement ore shoots along the western end of the vein zone.

Quartz is the principal gangue mineral, with some calcite, rhodochrosite and rhodonite usually present. Pyrite, sphalerite, and galena are the principal sulfides, with chalcopyrite occurring in minor amounts. Hematite is not uncommon, and gold and silver occur only in minor amounts. In the western end of the Mayflower Vein Zone on the 1500 and 1630 levels, there are small ore shoots in which the principal ore minerals are enargite, argentiferous tetrahedrite, chalcopyrite, and chalcocite, with lesser amounts of galena and sphalerite.

HAWKEYE LODGE As early as 1870, rich silver ore had been discovered along a strong fault zone in McHenry canyon on the Hawkeye claim. George Hearst, who later founded Hearst publications, first came into the Park City district to examine the Hawkeye-McHenry mine in 1872 but rejected the property because of heavy water flow and spotty ore occurrences. It is said that while he was returning from making this examination that he met Rector Steen, who had just opened up the Ontario claim in Ontario canyon and forthwith purchased the claim to form the nucleus of the Ontario Silver Mining Company (10, p. 11).

In the early 1920's, a crosscut was driven south from the Ontario Number Two Drain Tunnel to intersect the Hawkeye Fault about 1500 feet below the surface. Ore was found and developed by the Park Utah Company on two ore shoots along the Hawkeye. Its ore shoots were termed the Park Utah East and West ore bodies (Figure 6).

According to Hewitt (6, p. 2), all the ore

found in the Park Utah occurred as fissure ore, with the exception of a small amount of bedded ore in the "Wasatch Limestone." The width of the fissures ranges from 3 to 80 feet, and dip fluctuates between 40° and 50°N. The ore shoots differ in length, with 900 feet being the maximum, and are lenticular in outline. The fissures in which the ore occurs show a series of parallel bands of sulfides with alternating bands of altered limestone across the width of the lode.

The major ore shoots extended from about the 1950 level up to the 450 level where they lensed out. The deepest surface workings of the earlier decades lacked just 50 feet of reaching these lower shoots. Between the 1850 and 1950 levels, the main vein split into a number of tight, narrow stringers and became uneconomic in grade.

The wall rock on the hanging wall of the ore shoots is composed almost entirely of Weber Quartzite. The quartzite occurs in the footwall of the ore only in the upper levels. The displacement along the Hawkeye Fault in this vicinity is on the order of 800 to 1200 feet.

Stephens (8, p. 4-5), one of the last geologists to study the Park Utah ore bodies, stated "The type of wall rock appears to have influenced the localization of the Park Utah ore bodies. The Weber Quartzite, which forms the hanging wall of the structure where the ore bodies occur, allowed for lateral control of vein material. The 1950 level was driven near the base of the Weber Quartzite, and it is very possible that one of the reasons for the Park Utah Vein splitting into a number of stringers at this elevation was due to a change in wall rock."

Stephens also reported that the termination of commercial mineralization at the 1950 level was partially due to structural conditions involving the flattening and disappearance of the plunging arc structure that controlled the west ore shoot between the 800 and 1800 levels (8, p. 5).

This structural arc occurs on the nose of a cymoid loop along the Hawkeye and is repeated again to a lesser extent in the zone of the East ore body. Apparently the open nature of these structural loops flattened and disappeared in the less competent limestones underlying the Weber Quartzite.

Mineralogy of Park Utah Ore Bodies In the Park Utah West ore body, the upper zone from the surface to the 800 level consisted of galena with minor amounts of sphalerite, all of which contained much silver. Probably

much of this was due to supergene enrichment. The intermediate zone, from the 800 to 1800 levels, consisted of much quartz, galena, and sphalerite, with some silver-rich tetrahedrite-tennantite (6, p. 7). This ore shoot produced 1,117,778 tons of ore averaging 0.13 ounces of gold, 15.0 ounces of silver, 4.6 per cent lead, 6.2 per cent zinc, and 0.2 per cent copper.

The East ore body extended upward only to the 1100 level and was oxidized between the 1100 and the 1400 levels. In the oxidized zone, the vein consisted of rusty quartz with occasional green copper stains. The recoverable metal was almost entirely silver. In the sulfide zone, the vein was essentially quartz with tetrahedrite-tennantite and argentite accompanied by a small amount of galena and sphalerite. On the deepest level, the vein contained only a scattering of galena and sphalerite. This ore body produced approximately 110,000 tons of ore with an average grade of .09 ounces of gold, 46.0 ounces of silver, 1.2 per cent lead, and 0.2 per cent copper.

OTHER FISSURE DEPOSITS In the Park City Consolidated Mining Company's ground north of the Ontario Number Two Drain Tunnel, a system of narrow veins was developed and mined between Weber Quartzite walls from approximately the 300 to the 1400 foot levels. The ore occurred as rather narrow shoots in a series of veins, the strongest and best mineralized being called the East Crescent Vein-Fault, which has about 250 feet of vertical displacement.

The ore was of high silver content and contained tetrahedrite, argentite, and ruby silver minerals in a quartz-manganocalcite gangue (9, p. 9). No records are now available to the writer as to the actual production and grade of these ore bodies.

Besides the principal lodes already described, there are many more of less importance as fissure deposits, but they are related to extensive bedding replacements. Generally speaking, these fissures or vein occurrences are quite scattered and have a limited extent both in strike and dip. Rather than attempt to describe them any more fully here, attention will be called to many of them under replacement deposits.

Replacement Deposits

In an attempt to describe the replacement deposits of the Park City district, it will be useful to divide them geographically. This can

best be done in terms of the older mine units that now make up the integrated United Park City Mines property.

The bedded replacement deposits of the old Daly West and Judge mines can be grouped into approximately the same geologic environment. The replacement ores of the Silver King mine are unique and can best be discussed separately. The latest discovered replacement ores in the Ontario mine differ extensively from the others, and their description will complete the geologic picture as it is presently understood.

REPLACEMENT ORE IN THE DALY WEST AND DALY JUDGE AREA There are four principal replacement deposits in the Daly West and Judge areas that have been historically referred to as vein zones by name. Throughout the discussion of this paper, these ore shoots will be referred to by the nomenclature that has been inherited from past history regardless of improper usage.

The replacement deposits of this area all occur in the Park City Formation as it warps into the gentle syncline to the west of the Park City anticline. This portion of the broad synclinal fold of the Park City Formation lies between the strong Daly Fault on the north and the irregular intrusive contact on the south. It has provided the structural setting for the introduction of replacement ores along four generally east-west trending "vein" systems; these are primarily mineralized faults or fault zones of quite small displacement that have provided the ore solutions with access to the favorable beds.

The Park City Formation in this general area has been metamorphosed more than in other parts of the district due to the large intrusives immediately to the south. The metamorphism is apparent mainly in the bleaching and discoloration of the beds, particularly the darker horizons; there was also some hardening and recrystallization and minor introduction of silicate minerals.

The four ore zones from north to south are called, respectively, the Roll Vein, the Middle Vein, the Back Vein, the 1240 Vein and will be described in that order.

Roll Vein The Roll stope occurs along the strike of a sharp, steep, south-dipping fault, having only about 50 feet displacement. The fault (the Roll Fissure) nearly intersects with the Daly Fault at the Judge shaft and trends easterly therefrom. The ore is confined to one horizon of the Park City Formation. This horizon consists of a cherty limestone bed from

18 to 22 feet thick that lies between two narrow quartzite members about 100 feet above the Park City-Weber contact. The ore bed in the Roll stope was first described by W. P. Jenney (1) and has proved to be by far the most significant ore horizon in the entire district. It is still called the Jenney Bed today. This same horizon also makes the host rock for the great bedded deposits of the Silver King "Vein" system, as well as the other replacement deposits of this area.

The Roll replacement occurrence is an irregular blanket deposit averaging about 200 feet in width. The stope is thicker in the middle at its intersection with the Roll Fissure and thins out toward each edge. The stope extends from the Judge 1200 level up the dip of the bed nearly to the surface in the Daly West mine, over 2000 feet in rake. No ore occurs either stratigraphically above or below the bed over its entire greater length, but at a point just below the Judge 1200 level where the Roll Fissure nearly intersects the Daly Fault some irregular massive replacement ore has been found in lower horizons in the broken and mineralized ground between the two faults. This ore zone probably represents a segment of the main channelway through which mineralizing solutions came that fed the Roll Deposit.

The ore along the Roll Fissure was primarily argentiferous galena, with some tetrahedrite and sphalerite. These ores showed considerable oxidation as the zone neared the surface. Approximately 123,000 tons were mined from this ore shoot.

Middle Vein The Middle Vein Zone is made

up of a series of fissures and small faults in association with some steep, south-dipping diorite porphyry dikes. This structural zone strikes nearly parallel to the Daly Fault and swings from about a $S70^{\circ}W$ trend to nearly east-west along the zone of mineralization. The ore occurs as bedding replacements, in the Park City Formation at two specific horizons along the zone of dikes and fissuring.

The most prominent and productive horizon again is the Jenney Limestone Bed and the limestones slightly below and above it in the areas of strongest fissuring. This horizon produced ore along a total strike length of over 6000 feet, was up to 150 feet in width, and ranged from 25 to over 100 feet in thickness, diminishing to zero on the outer edge of the mineralized zone.

In 1923, another ore body was discovered along the Middle Vein Zone as a bedding replacement near the very top of the Park City Formation in what were called the 920 Horizons. This section of the Park City is composed of interbedded, narrow sandstones or quartzites and dense massive limestone. These beds are not so distinctive as the Jenney Bed but seem to have the same characteristics as to favorability for ore replacement, although to a lesser extent. The 920 ore body extends over a distance of approximately 4500 feet and is somewhat narrower than the Jenney ore body.

Both ore bodies occur at the bottom of the structural trough formed by the Park City Syncline as will be noted in Figure 7. They are very similar in grade and mineralogy. The ore feathered out on both flanks of the trough

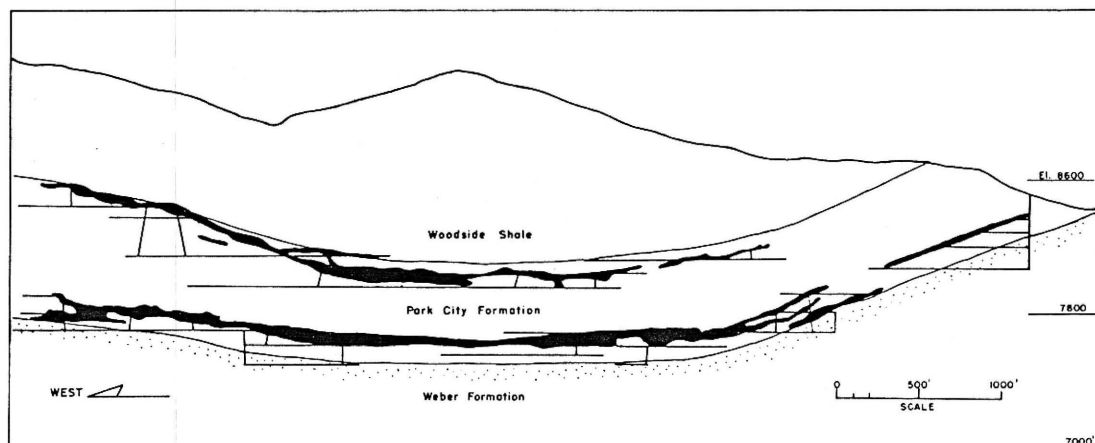


FIG. 7. Longitudinal Section Middle Vein Stopes, Judge and Daly West Mines.

although the structural elements of the vein zone, i.e. fissuring and porphyry dikes, continue beyond the limits of the ore both to the east and to the west.

The ore minerals are the same as those occurring in the Roll stope and are contained in a gangue composed principally of pyrite and quartz. It may be noted that the western limits of both ore beds become highly pyritic before terminating along the fissure system.

According to the record, 2,587,900 tons of ore were mined from the Middle Vein System. Some 1,663,900 tons came from replacement along the Jenney Horizon and 940,000 tons from the 920 Horizons. A compilation of the average grade of ore mined from the Jenney Bed, together with some ore mined from the Back and 1240 Vein bedded deposits in the Judge mine from 1909 to 1924, assayed as follows: Gold .026 ounces, Silver 25.33 ounces, Lead 14.1 per cent, and Zinc 12.1 per cent.

Back Vein The ore occurrences along the Back Vein are found along a well-defined fault-vein of about 250 feet vertical displacement, dipping steeply to the south. The Back Vein Fault nearly parallels the Middle Vein Zone both in strike and dip and lies about 300 feet to the south. The ore occurs in rather definite shoots, with barren zones between, both as fissure ore and as bedding replacement ore in the favorable horizons immediately adjacent to the fissure. Figure 8 illustrates the manner of replacement along the fissure with bulges into the favorable beds along both the footwall and the hanging wall.

As in the case of the Roll and Middle Vein stopes, the most significant ore is found bedded along the Jenney Horizon. However, bedded ore along the Back Vein was mined from at least four different horizons in the Park City Formation. Beginning with the Jenney near the base, these horizons have been named the Jenney, the 1243 Quartzite, the 1254 Sandstone, and the 920 Horizon.

In developing the Back Vein Fissure, it was found that none of the ore shoots appeared to have any significant downward extension into the Weber Quartzite. In fact, no ore was mined below the lowest Park City-Weber contact. In very recent years, new work has opened the Back Vein again below the Weber Quartzite, and significant ore has been found along the fissure where the Morgan Limestone makes up the footwall of the fault with Weber Quartzite in the hanging wall. In following the ore up dip, it was found that as soon as the structure was included between Weber

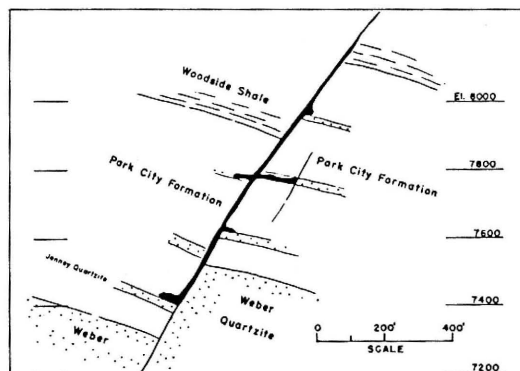


FIG. 8. Cross Section Back Vein, Judge Mine.

Quartzite on both walls, the ore abruptly narrowed and became largely uneconomical to mine.

The 1240 Vein The 1240 Vein ore body occurs along a rather small fissure zone that intersects the western part of the Back Vein and diverges to the east from it for about 1000 feet. The ore was introduced entirely as a bedding replacement along the 920 Horizons and was mined with the Back Vein Deposit.

Approximately 662,700 tons of ore have been mined from replacement and fissure deposits along the Back Vein, and 105,000 tons from the 920 Beds along the 1240 Vein. The mineralogy and grade of these stopes very closely resemble the Middle and Roll ore bodies.

REPLACEMENT DEPOSITS IN THE SILVER KING MINE The history of successful operation of the Silver King mine has resulted largely from ore production from a series of long, narrow, manto-type, bedded deposits of high-grade ore in the Lower Park City Formation. The ore deposits were formed along the northwest flank of the Park City anticline and extend westward nearly to the trough of the adjacent syncline, some 10,000 feet distant. These replacement deposits are confined almost wholly to the Jenney ore bed and have been mined over a vertical range of nearly 2000 feet along five "vein" systems with little change in grade.

The Park City Formation in the Silver King area is fresh and unaltered, even in close proximity to the ore bodies. No bleaching or other metamorphic effects such as appear in the Daly West and Judge mines are in evidence throughout most of this wide area. The only igneous

rock in the area is represented by the diorite porphyry dike associated with the Comstock-Massachusetts Fault, which trends through the entire Silver King and Silver King Western ground. The dike zone appears to be unrelated to ore over the greater part of its strike length.

Structurally, the ore bodies occur along a monocline dipping approximately 20°NW and striking from N70°E to N80°E as the beds bend from the flank of the anticline toward the trough of the syncline in the northwest quadrant of the district. The strata of the monocline are broken by several, very early, quite minor thrust faults that generally strike with the beds and cut them at low angles.

Later normal faulting has superimposed a series of steep, east-west fissures and minor faults through the earlier structure. These small faults and fissures lie to the north of the Crescent Fault and the other structures of the central zone of faulting; they are the apparent feeders for the replacement deposits. Most of the fissures have little or no displacement. They die out very rapidly in the overlying, incompetent, shaly limestones of the Park City Formation but produce a shattered or broken zone in the underlying quartzites; they are, therefore, confined largely to the lower portion of that formation.

The early, low-angle thrust faults do have some influence on the localization of the ore shoots. Their effect is largely one of ground preparation through breaking and crushing to provide intragranular porosity and permeability for ore deposition. In the extreme northwest section of the Silver King mine, one thrust zone is confined mainly to the Park City-Weber Interface. Brecciation and crushing have occurred along these beds to the extent that nearly all of the ore runs in the vicinity have been confined to the thrust zone instead of replacing the usual Jenney Horizon above (Figure 9). In other parts of the mine, the thrust faults have effected a repeat of the Jen-

ney ore bed along a particular vein zone, and ore has been mined from both above and below the fault plane.

One of the most significant features of these bedded ore runs is the fact that no ore has been found stratigraphically above the Hanging Wall Sandstone which lies on top of the Jenney ore bed. This can probably best be accounted for by the weakness of the fissure systems that do not break the shaly limestones overlying the Jenney bed sufficiently to permit introduction of mineralizing solutions. Thus, in effect, the feeder has been capped above the ore bed, consequently forcing the mineralizing solutions laterally along the strike of the fracture zone to the great lengths indicated.

Mineralogy In general these ores are free milling sulfides with some oxide masses of smelting grade (2, p. 121). The minerals from the primary zone are mainly galena, tetrahedrite, sphalerite, and pyrite. The galena is in both coarse and finely cleavable masses. Calcite and quartz form the gangue. In the oxidized portions, anglesite, cerussite, bindheimite, and malachite also are found.

Production and Grade The bedded deposits of the Silver King "Vein" System account for about 73 per cent of the total tonnage produced from the Silver King mine and over 77 per cent of the total value of ore mined.

A total of 3,420,000 tons of ore has been produced from these types of deposits in the Silver King mine with an average assay as follows: Gold .024 ounces per ton, Silver 18.45 ounces, Lead 13.52 per cent, Copper .495 per cent, and Zinc 10.68 per cent.

REPLACEMENT AND FISSURE DEPOSITS RELATED TO THE CRESCENT ZONE With the exception of rather small ore shoots occurring along three or four fissures other than the main bedded replacement ore runs, the remainder of the production from the Silver King mine has come from the Crescent Zone.

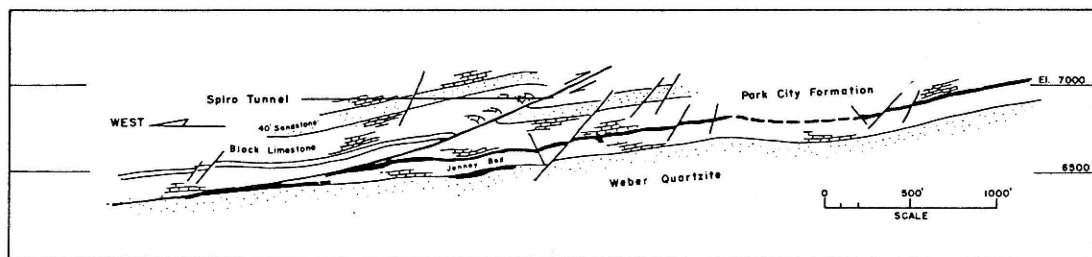


FIG. 9. Longitudinal Section Silver King Replacement Ore Bodies, Silver King Mine.

TABLE III. Production and Grade Crescent Zone
(Estimated Tonnage from Smelter Returns)

	Tons	Oz Au	Average Grade			
			Oz Ag	% Pb	% Zn	% Cu
Crescent Mine 1882-1891	159,283	.031	11.63	16.86	—	0.31
Kearns-Keith Mine 1904-1906	25,391	.043	7.05	14.90	—	0.07
Keystone Mine 1923-1926	96,000	0.15	5.04	11.20	4.50	—
Silver Hill Area 1907-1952	811,382	.019	7.50	11.33	6.01	0.19
Total Production Crescent Zone	1,092,056	.021	7.88	12.10	5.27	0.21

Source: Production records Silver King Coalition Mining Company.

The Crescent Zone has been defined by Boutwell (4, p. 30) as

“. . . essentially a zone characterized by fracturing, faulting, intrusion, and mineralization.”

Thus the Crescent Zone is made up of three distinct geological features:

- (1) The Crescent Fault, which previously has been described briefly as making up a part of the central fault system. This fault has a vertical displacement of 1300 to 1400 feet in the Silver Hill area, mostly along the principal fissure but with subsidiary fractures both in the hanging and footwall. It can be traced on the surface for at least 10,000 feet and persists through the deepest mine working approximately 3000 feet below the surface. It curves through a rough crescent shape concave to the southeast and dips generally about 60°S.
- (2) The Crescent Dike, which is composed of diorite porphyry; it occurs mainly along the hanging wall of the Crescent Fault in the Silver Hill area but is also found in places along the footwall. It is not continuous along the entire extent of the fault.
- (3) The Crescent ore zone, which comprises both small fissure-type deposits, on, and parallel to, the fissure and dike, and larger bedded-type replacement deposits in the immediate proximity of the fissure.

The flat bedded replacement deposits occur in the limestone beds of both the Thaynes

and the Park City Formations, especially in the footwall of the Crescent Fault up to a distance of 150 feet from the main fissure. Veins occurring in subsidiary footwall fissures usually appear to be distinct feeders to the beds of ore.

In the Silver Hill area, 12 different horizons in the Park City Formation have been found replaced by ore in economic quantities. This is the largest number of distinct ore bearing horizons found in this formation anywhere in the district. These ore beds are usually quite pure limestones sandwiched between sandstone or more impure limestone beds. However, even in the Crescent Zone, the Jenney ore horizon is still the most extensively mineralized bed (Figure 10).

It is interesting to note that early litigation concerning apex rights over bedded ore occurring along the Crescent brought a ruling from the Supreme Court as follows in part:

“. . . the bedded deposits must be considered part of the vein . . .”

“The fact that each of these bedded deposits has been discovered by exploring the fissure and not otherwise, and that once ignore the fissure and there is no other index to their existence is strong evidence of their essential unity with the fissure . . .” (5. p. 8).

Thus, legally at least, the bedded deposits are definitely part of the Crescent Zone and are subject to Crescent apex ownership.

Some of the earliest ore discoveries in the district occurred along the Crescent Zone near the surface where the Thaynes Formation forms the footwall of the fault. The Walker

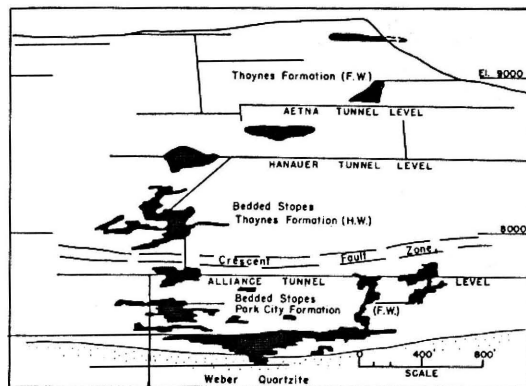


FIG. 10. Longitudinal Section Crescent Zone, Silver King Mine.

and Webster claim, the earliest filed in the district, was situated over an outcrop of bedded replacement ore in the Thaynes immediate to the footwall of the Crescent Fault. This stratigraphic interval in the formation has since been designated the Walker and Webster Horizon. Several other favorable beds have been mined both in the Upper and Lower Thaynes sections along the Crescent, as have narrow fissure deposits occurring as thin veins in the footwall of the main fault.

Mineralogy According to Boutwell (2, p. 122) the character of the bedded ores in the two formations, Park City and Thaynes, is distinctly different. He states that, in general, the bedded ores in the Thaynes are of lower grade than in the Park City and usually have a higher percentage of sphalerite, iron, and silica. Whether this generalization will hold true in considering only the ores associated with the Crescent system is now somewhat in question. In general, the Crescent ores in both the Park City and the Thaynes Formations are lower in grade and higher in iron and silica than the bedded deposits associated with the other systems thus far mentioned.

REPLACEMENT DEPOSITS IN THE ONTARIO MINE The most significant economic development in the district over the last fifteen years has been the discovery and exploitation of replacement ores in the Humbug Formation. The first of such replacement ores was discovered along the very crest of the Park City anticline in the Ontario mine.

In the area of mineralization, the Humbug strata swings rather sharply around the nose

of the northerly plunging anticline. The formation is truncated on the northwest flank by Number Nine Fault and is cut off on the south by the Hawkeye Fault, as illustrated by Figure 11. The block of Humbug between the two major faults is the host rock for two distinct ore shoots, one trending down the northwest flank of the anticline and the other down the northeast flank. The ores from both shoots come together at the crest on the 1300 level just below the Doughnut Argillite Horizon, commonly referred to as the Doughnut Shale. The argillite appears to be an effective cap to the mineralization and marks the top of the replacement ores in this structural zone.

The ore of the northwest shoot occurs as an irregular bedding replacement through a considerable thickness of Humbug strata along small, steep, mineralized fissures trending a few degrees north of east. These fissures or fractures are undoubtedly tension cracks between the two strong faults on the north and south, for they generally terminate against both the Hawkeye and Number Nine at the bottom and top.

The ore minerals are lineated along the bedding planes, but the ore zone cuts across bedding from one horizon to another along the trend of the fissure system. Replacement may occur through practically the entire Humbug section in a particular zone of fracturing. However, the ore is not a single massive replacement but rather a series of bedded replacements separated by barren horizons. Correlation of these horizons in the zone of fissuring and mineralization is made very difficult due to

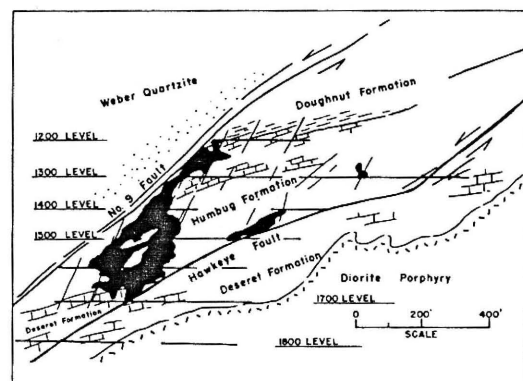


FIG. 11. Cross Section Northwest-Flank Ore Bodies, Ontario Mine.

minor displacement along the many fractures.

In following the west flank ore body down the rake, it was found to terminate abruptly against the Hawkeye Fault at the contact between the Humbug and Deseret Formations. Again see Figure 11. Deeper workings below the lowest ore betrayed no sign of mineralization or feeder system along the Hawkeye Fault. Subsequent geologic study indicates that there has been considerable post-mineral movement along the Hawkeye. This late faulting apparently cut off and displaced the Humbug fractures from the original fissure system through which the ore was introduced into the receptive beds from their source in the footwall of the fault.

The replacement deposit down the northeast flank of the anticline shows substantial variation from that along the northwest flank. To the east, the Hawkeye and Number Nine Faults become more divergent until Number Nine may be en echelon to, or swing directly into, the Jefferson Fault that nearly parallels the Hawkeye at some distance to the north.

Instead of replacing a series of beds along the steep fractures, the top of the east flank ore body replaced only one bed selectively at the contact of the Upper Limestone Unit and the Quartzite-Sandstone Unit. The ore shoot extended down the dip of the beds for approximately 800 feet along this horizon. It averaged about 150 feet in strike length and ranged from 6 to 20 feet in thickness. Little or no fissure control could be noted down the rake of the ore zone although, in some stopes, areas of thickening could be correlated with vertical, north-east shear zones extending through the stope.

At a point 800 feet down the rake this bed of ore abruptly ended, but, as will be noted in Figure 12, other lower horizons were found to be replaced in its stead. As the ore was followed progressively deeper, a greater number of Humbug beds have been found to be mineralized, and more definite fracture zones have been identified with the replacement ore. Mineralization has become more widespread both laterally and through a greater number of strata in the deepest part of the present mine workings. In the deeper levels, it has now come more nearly to resemble the northwest flank type of ore replacement.

Mineralogy The character and mineralogy of the Humbug replacement ore bodies are very similar to other ores already described, particularly those along the Crescent Zone. There is a marked increase in sphalerite and pyrite at depth with a slightly decreased silver

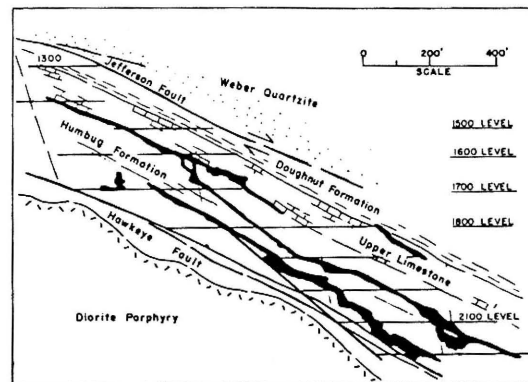


FIG. 12. Cross Section Northeast-Flank Replacement Ore Bodies, Ontario Mine.

to lead ratio in the galena. Some small areas of high silver ore are still being found with tetrahedrite carrying the additional silver.

Production and Grade Approximately 981,797 tons of ore have been produced from the Humbug beds in the Ontario mine to date with an average grade as follows: Gold .025 ounces per ton, Silver 5.80 ounces, 6.40 per cent Lead, 8.67 per cent Zinc, and .14 per cent Copper.

GENESIS

Some concept of the source of the ore solutions that caused deposition of the Park City ores of course is most fundamental to an understanding of their genesis. All other factors may exist in ideal configuration without formation of an ore body unless a source of the mineralization is present in the system. The area or zone in which a new ore shoot might be found is the most difficult geologic factor to predict in the search for new ore. In the Park City district, there is considerable evidence that the ore-bearing solutions had their origin in the diorite and diorite porphyry intrusions. Feeders for several ore zones in the sediments have been followed to the igneous bodies. Mineralization has been found widely scattered over most of the district to a greater or lesser extent.

Given a source, the next essential requirement is the nature of the plumbing system by which the solutions seek the best escape route from heat and pressure. The structural elements of faulting, fissuring, and intrusion

make up the plumbing system from the source of mineralization to the host rock, and in the Park City district are often the major faults and dike zones as described previously. Usually it is not the main fault strand with its heavy clays that forms the conduit for mineralizing solutions but the steeper tension cracks and subsidiary faulting genetically related to it that actually provide passageways. Where the structure is as open and brecciated as the Ontario Lode System, the ore and gangue minerals are deposited in the zone of fracturing as fissure filling and replacement of wall rock. Where the structure is tight and impervious or where it becomes so up dip from the source due to a change in wall rock, such as with the long ore runs of the Silver King "Vein" Systems, then ore bearing solutions must still find the path of least resistance, which in this case is nearly always along the horizontal rather than the vertical plane. Even the minute detail of the bedded replacement stopes illustrates the necessity of channel ways or fracture zones whereby the mineral-rich solutions can be provided access to the rock chemically favorable to replacement.

CONCLUSIONS

The concept of favorable ore beds has been greatly stressed in this paper. The fact that certain horizons are more susceptible to ore replacement than others can be attributed to two factors: (1) the permeability of the favorable horizon prior to ore deposition or the permeability of the beds adjacent to this horizon and (2) the chemical composition of the rock of which the horizon is composed.

It is interesting to note that nearly every favorable bed in the Park City district immediately overlies or is between quartzite or sandstone. The irregular massive replacement ore bodies occurring in a few places in the good limestone and dolomite beds of the Deseret Formation are not related to bedding but are controlled by fissuring and fractures, with replacement only extending a few feet outward from the fissure zone. Though the rock is chemically favorable, it is not sufficiently permeable to allow for significant replacement.

The geologic evidence seems to indicate that the favorability of most, if not all, of the ore beds in the district is primarily a function of their physical conditioning which allows for ingress of the ore-bearing solutions to the favorable carbonate horizons. The chemical com-

position of the rock appears to be of secondary importance.

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Breccia Structures in the Ontario Mine, Park City District, Utah

W. J. GARMOE*

Distinct areas of mineralized and non-mineralized brecciated rock are found in the Ontario Unit of the United Park City Mines. These breccias contain an appreciable fraction of the present ore reserves and probably will become even more important as deeper levels are developed.

Three ages of breccia have been recognized in the Ontario Mine to date: (1) Pre-mineral breccia that may or may not be mineralized, (2) early post-mineral breccia with mineralized fragments, and (3) late post-mineral breccia that is younger than and cuts through (1) and (2) above. These age relations are known from detailed underground mapping.

Locally, both pre-mineral and post-mineral breccias have sufficient lead-zinc-silver content, either as matrix or fragmental material, to constitute ore. Ore-grade breccias occur throughout a vertical range of over 1000 feet and are found in both the Humbug and Deseret formations from above the Ontario 1300 level to below the Ontario 2200 level. The mineralized breccias, which are difficult to distinguish on mine maps, are not well delineated by underground workings, and their horizontal outline and vertical extent are not known beyond the immediate mining areas. The greatest amount of truly mineralized breccia is exposed on the 2200 level.

Unmineralized pre-mineral breccia is an irregular, vuggy, fine to coarse conglomeration of blocky limestone with minor amounts of quartzite. The matrix of the breccia is composed of greenish-gray, finely comminuted rock flour that is altered to a clayey material.

Mineralized pre-mineral breccias contain pyrite, galena, and sphalerite with spotty quartz and minor amounts of tetrahedrite (freibergite?) as a cementing matrix. The sulfide minerals surround and fill void spaces between individual rock fragments. In many cases, the sulfide minerals completely replace the limestone and quartzite rock fragments and form a solid mass of sulfide with minor quartz. The edges of

the mineralized breccia are very irregular and either pass abruptly or gradually into unbrecciated rock or unmineralized breccia.

Early post-mineral breccia is distinguished from pre-mineral breccia only by varied amounts of fragments of brecciated or finely comminuted quartz and sulfide minerals in the matrix. The distribution of the early post-mineral breccia is generally similar to that of the pre-mineral breccia. The two types of breccia merge into one another and contacts are not readily identified.

Late post-mineral breccia crosscuts early post-mineral breccia and pre-mineral mineralized breccia. The late post-mineral breccia is mostly devoid of metallization except for an occasional included small fragment of sulfide mineral. The breccia filling consists of strongly clay-altered metasediments of the basal Doughnut formation. The contacts between the late post-mineral breccia and the earlier breccias are sharp with no apparent mixing of fragments of the immediate wall rock.

The breccias, which steeply crosscut the moderately dipping sedimentary beds on the northeast limb of the Park City anticline, occasionally will follow a particular sedimentary bed for a short distance. Breccias are not known within the igneous rocks of the district. At depth, several of the irregular lenticular breccia zones occupy the same structures as some igneous dikes and small intrusions.

The mechanism for the emplacement of the Park City breccias is not understood. While some of the brecciation identified to date can be attributed to original sedimentary structures, the structural breccias may have developed from solution and removal of underlying limestones and subsequent collapse of the overlying rocks. The solution of carbonate rocks may reflect leaching accompanying igneous or mineralizing activity. Another possibility is that brecciation associated with predetermined structures may have resulted from fluidization or gas release accompanying igneous activity.

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