CONTACT INFORMATION
Mining Records Curator
Arizona Geological Survey
416 W. Congress St., Suite 100
Tucson, Arizona 85701
602-771-1601
http://www.azgs.az.gov
inquiries@azgs.az.gov

The following file is part of the Grover Heinrichs Mining Collection

ACCESS STATEMENT

These digitized collections are accessible for purposes of education and research. We have indicated what we know about copyright and rights of privacy, publicity, or trademark. Due to the nature of archival collections, we are not always able to identify this information. We are eager to hear from any rights owners, so that we may obtain accurate information. Upon request, we will remove material from public view while we address a rights issue.

CONSTRAINTS STATEMENT

The Arizona Geological Survey does not claim to control all rights for all materials in its collection. These rights include, but are not limited to: copyright, privacy rights, and cultural protection rights. The User hereby assumes all responsibility for obtaining any rights to use the material in excess of "fair use."

The Survey makes no intellectual property claims to the products created by individual authors in the manuscript collections, except when the author deeded those rights to the Survey or when those authors were employed by the State of Arizona and created intellectual products as a function of their official duties. The Survey does maintain property rights to the physical and digital representations of the works.

QUALITY STATEMENT

The Arizona Geological Survey is not responsible for the accuracy of the records, information, or opinions that may be contained in the files. The Survey collects, catalogs, and archives data on mineral properties regardless of its views of the veracity or accuracy of those data.

MINING 111A 3C-1.COTTONWOOD, ~~UTAH~~. PARK CITY, UTAH.

As shown on Speiker block diagram B,the highlands on the W resulting from the mid-K orogeny in central Utah were being worn down in late Colo or mid Indianola time,while the trough E of them continued to sink.Toward end of Indianola (between middle and late Montana)Spieker's Early Laramide Orogeny occurred,involving sharp folding and uplift of the seds.in the trough;advance of geanticline to E,toward Colo.plateau. Before this,in Ku,Park City and Cottonwood were under the flood plain or the sea to the E of the active highlands and presumably the seds.there were undisturbed. But the early Laramide orogeny caught these districts up in its activity,so that doming and folding of the sediments presumably occurred at this time.If so,the supposed arcuate folds at Cottonwood,parallel to those of Ophir-Bingham,much closer to the Sheeprock uplift,are not related to the latter folds.Single deformation

For Ophir-Bingham,and probably for Tintic,by analogy ,there are on the other hand two distinct periods of deformation.(1) formation of the arcuate folds,(2) inception of Uinta axis with its disruption,uplift,intrusion and metallization.Hence Ophir,Bingham and Cottonwood-Park City intrusion & metallization may all have formed at same time,in Early Laramide orogeny.

As shown by Spieker USGS PP 205D,migration of geosynclinal troughs eastward and accompanying orogenies showed,from Nevadian,end of Jurassic on, a steeping up of frequency and intensity and a crowding together in space as well,from west to east . In the area of the E Great Basin,the fossil trough of thick Cambrian (main NNE trough on Paleotectonic Map of S Nevada & E Utah) is over 150 mi.west of the trough of thick Penn.,while thick Penn and thick Ju overlap,and thick Ju practically coextensive with thick K. Thus approaching Laramide epoch the tempo of deformation increased and the sites of crustal sagging,altho' trying to move east,were held up by some obstacle which showed its opposing power as early as Ju.Must be embryonic Colo plateau. Note on Ku map how orogenic belt crowds around plateau,Utah trough does likwise.

INSERT (p. 3)

More on compression in this region: Gilluly in Stockton-Fairfield paper ascribes Uinta uplift to "tangential compression" which "decidedly overturned" the mt.mass "to the north". But on p.72 he says:"There is little doubt that the igneous intrusions in the Cottonwood & Park City districts have been effective factors in the deformation of those districts,and although they are crosscutting and cannot be called laccolithic in shape they are assuredly either the causes or the accompaniments of a decided transverse upwarp which is doubtless correctly attributed to a westward extension of the Unita folding." Since the domes can have formed only by vertical movements,the cause of the transverse upward must be vertical,not tangential compression.

Result of this crowding of eastward-moving orogenies against the Plateau buttress is a telescoping of orgenic events within same area. Hence Ophir-Bingham second or Uinta axis orogeny may be contemp. with deformation & & metallization at Cottonwood-Park City.

Cottonwood-American Fork District, Utah. Sel-Refs. p. 14.

Ref. F.C. Calkins & B.S. Butler: Geology & Ore Deposits of the Cottonwood-American Fork District, Utah. USGS PP 201, 1943.

5/17/54 Production, 1867-1940, $34,000,000, in Ag, Pb, Cu, Au, Zn, in order named. But interesting structurally.

Regional setting has been described. Cottonwood close to apex of the dome which centers roughly around Little Cottonwood stock; Park City, associated wi with a line of other stocks, lies on E flank of dome, where folding merges into plunging folds with N-S trends.

Columnar section, on plan shows a mere 10,000' Cambrian thru Trias. seds. Beltian partly confused with lower Cambrian qtzite, probably thicker than sh shown. Mainly competent up thru Penn. Above that incompetent but largely eroded, can't tell behavior.

As shown on sections, and as at Pioche, beds cling to qtzite basement and true folding, except sharp flexing around edges of dome apex and Little Cottonwood stock, is lacking. Plan shows E half of dome. Fractures and faults radiate from the dome apex, or rather, from L.C. stock, slightly S of apex. Some synthetic flts lie along E margin of stock (Sec. C) Some overturned E, down flank of dome (Sec. B). W-dipping antithetic faults on E flank of dome, tend to curve around dome; only a few on plan, more on sections. Sec. D, note greater dip-slip on flatter of the 2 antithetic flts. Also Sec. C.

Thrusts: drag effects show upper plate moved E, but sections C, D, show thru thrusts dip gently E, away from instead of toward uplift. According to Calkins thrust planes originally dipped W, but have since been tilted to E or uplifted on W.

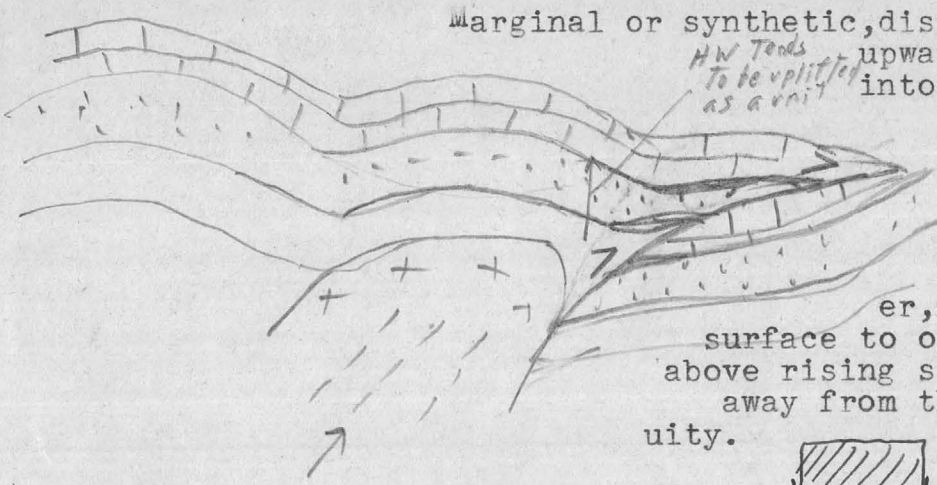
The stocks shown on the map,and associated dikes,cut these flat thrusts so movement was complete on the thrusts before intrusion. Nevertheless the thrusts are connected with uplift of the dome,presumably a feature connected with intrusion of the Little Cottonwood Dome,as Gilluly,in his speculations on origin of Ophir dome,allows;for Calkins says,p.54:

"The prevailing strike of the overthrusts is northward,though their out crops are in a measure convex toward the east"(i.e. concave toward the do dome,concentric with its periphery)"like those of the sedimentary strata," .See map;also Link uplift experiment,Deformation Plate II#7.

May omit: Calkins,p.54,"The prevailing easterly dip of the overthrusts.. ,.is a result of later movement;and this movement was similar to that whic originally produced the overthtusts in being an eastward pushing over..It is easy to imagine the effect of a continued stress of this character on amwest-dipping overthrust when for some reason the eastward sliding of the upper plate is arrested:the fault plane would first become tilted eastwar and it might,by a persistance of the stress,at last be overturned.

The sections show that if intrusion and doming came after the thrusting the thrusts dipped west,as Calkins thinks,before the doming.Flatten out the flexed beds. But if the thrusts had been formed by compression from the west(Calkins) and tilted to the east to the flat posture shown in the sections,nothing could have prevented continued use of these breaks for eastward shoving of the rock plates above them,so long as a shove from the west persisted. Because marginal thrusts or any thrusts are disruptive flts.,like those formed with engr,test lab tests for compressive and shearing strength.where yield pt.has been reached and the specimen disrupt ed. Further testing yields no more light on strength of specimen because with comtinued application of stress specimen simply flies apart.

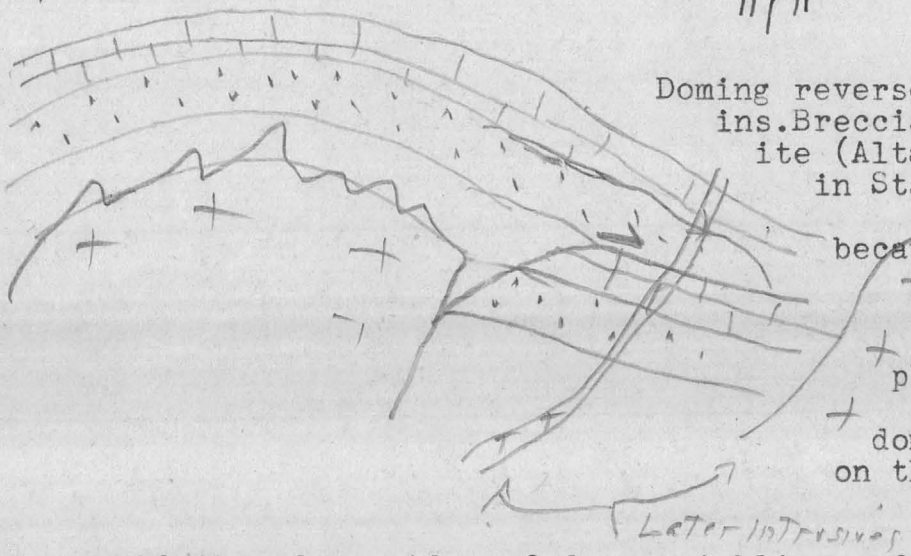
INSERT Structural map of Sheeprock-"asatch area suggests dome started to push up a syncline:



Marginal or synthetic, disruptuve flt. generated by upward shove of stock, E side, rises into frame and makes out along W-dipping bed ~~for 2 reasons: (1)~~ because shove up and to E persists, merely turns around a corner; ~~(2)~~ thrust movement combination of shear upper plate gliding past lower, and tension, tendency for thrust surface to open, pull apart, because block above rising stock uplifted, pulled up and away from thrust surface, one of discontinuity. Hence ore locus, see below. Cf. Alma, Colo.

Cf Goodsprings

12/13/54



Doming reverses dip of thrust a la Calkins. Brecciation of ls. below hard qtzite (Alta thrust) probably started in Stage 1, but there might be further brecciation now, because accentuated doming of competent Belt and lower G strata would at this stage tend to pull qtzite in upper plate of thrust back, up the present dip, up flank of dome, reversing earlier movement on thrust at least enough to brecciate the ls. Soft shale would flow down sides of dome, wrinkling and foldong.

With regard to stocks and dikes that cut the thrusts, above notions give hunch on some of mechanics of intrusion. Igneous massives are commonly cut by dikes of almost the same stuff, which wander off and pentrate cover & sides as well. Main mass congeals, becomes brittle on top; upthrust, probably of magma. from below domes not only the cover but the top of the intrusive as well, cracking both its congealed top and its cover as well in the process. These cracks, radial or concentric or random, tap chambers in the mass at dept still molten, somthat dikes and apophyses spread upward and outward along the these cracks. This intrusive cuts Alta thrust altho thrust itself presumed to have formed in response to upward shove of intrusive mass below.

The greatest thrust movement on these minor thrusts may have taken place in the first stage, as Calkins found in the field; the dome is not very large and the accomodation to stretching accomplished by the "creep" stage of thrusting would be moderate. Nevertheless, since the thrusts at this stage dipped east, down-slope, they would be very convenient tracks for such down-slope movement.

Concerning the antithetic faults, critteria for such faults are:

1. They dip toward the uplift core, and/ore away from the adjoining basin, if any.

2. Where beds lay flat before faulting, the beds dip opposite to the faults, at roughly the complentary angle.

3. The flatter the faults the greater the displacement.

4. In general, since such faults rotate downslope as far as they can and then are replaced by steepr, younger faults which rotate in turn, it follows that the steeper such a fault, the younger it is compared to the flattest faults.

Sections show maximum displacement on flattest faults. Calkins says that in general the steeper faults are the younger.

12/12/52

Breccia zones associated with the (pre-mineral) thrusts were mineralized. In general, the OBs are closely grouped around the NE row of stocks starting with Little Cottonwood on the West (few mines) passing through Alta stock (moderate production) and culminating on the east in the vastly productine Park City stock. A north and a south bulge in this NE belt is caused by ore making N and S along the thrust zone. These thrust ore bodies are among the major ones of the district. Synthetic faults around the intrusions especially those paralleling the whole row of stocks (E by N) furnished ore channels. Continuing doming after stocks congealed on top at least would form fissures along surfaces of discontinuity between the granitic masses and the seds. The flanks would tend to pull away; there would be tension as well as shear.

The chief antithetic faults aremainly post-mineral; supporting Spurr's notion that mineralization starts with an early stage of uplift (fissure stage, Pioche, Frisco etc.), with uplift culminating after ore deposition.

1/6/50

Ore Deposits: Classified as

Cardiff Py tetrahedrite PbS- Qz

1. Deposits associated with fissures; these include those mainly in fissures and replacement ore bodies in the CR in and near fissures. Where however CR is ls., replacement is so extensive that the OBs are described under bed deposits. Veins in stocks unimportant. Fissure deposits in qtzites and siliceous shale of the Cambrian and Algonkian, both above and below Alta thrust. Example Cardiff mine, OB along intersection of Cardiff steep NE fissure (radial off dome) and thrust surface/Ore makes out from fissure along thrust zone, replacing the fault-brecciated ls. Miss- ev. lower plate. This and other fissures in the qtzite, where they carry ore, show ore and gangue minerals mainly cementing shattered qtzite, but to some extent replacing the latter.

Py PbS ZnS

2. Bed deposits. Most productive. By extensive replacement of ls. beds next to fissures. Note dependence on fissures as with Pioche, Gold Hill, Frisco. As at Pioche, Frisco, the OBs are tabular, and pitch with the line of intersection of the replaced bed and the fissure; latter are radial, striking mainly NE. Favorable horizons: (1) ls. bed in Ophir shale (cf. Pioche, brittle, narrower bed in soft shale); (2) dolomites in Maxfield ls. Examples Carbonate, Michigan Utah in part, These in dolomites of Maxfield ls.

Tetrahedrite qs

Tetra. has Pb, As, Sb

In ls bed, Ophir shale: Columbus, Alta Con., S Hecla, Pittsburg.

Qrs Py

3. Thrust fault zone deposits. Next to bed deposits in production. With Alta thrust Cambrian qtzite overrides Carb. ls. Ls in lower plate much brecciated, crushed. The strong overriding qtzite brecciated the ls much more strongly than did overriding Ophir shale. Hence main such deposits are where qtzite overlies ls.

PbS ZnS Py Tetrah

5/18/54

The crushed zones nearly parallel the beds, ore by replacement of brecciated ls.. Py, ccpy. bornite, terahedrite. enargite, galena, ZnS. Cardiff, Columbus, Rexall, Wasatch, Cottonwood-Atlantis.

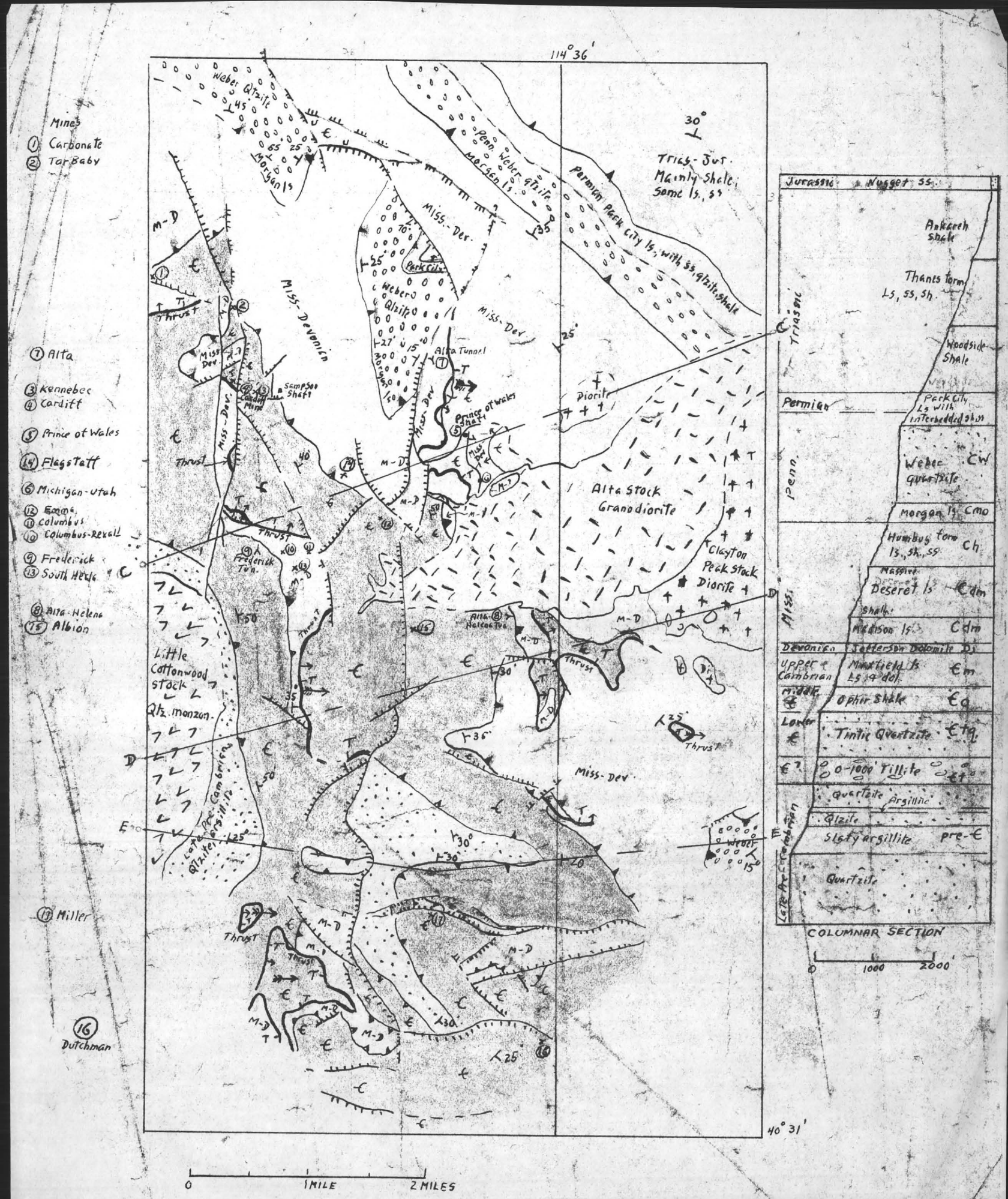
12/21/51

Hence the thrust zones perform a role similar to that of favorable ls: they are loci of deposition rather than channels; the immediate channels were the fissures. Feeding the fissures however were very probably the steep segments of the thrusts; these deeply transgressive synthetic faults, along intrusive margins, operating while uplift was going on, might readily permit upward flow of solutions by jerky small fault movements keeping the fault zone open. Note in section 2, p. 101, how tensional conditions dominated in the flat segments of the fault. With massive beds being uplifte on the W, they would tend to pull apart in the hinge area as shown. Even in the earlier stage of Section 1 tensional conditions would tend to pull the beds apart to some extent.

After mineralization continued uplift finally broke the cover, forming the post-mineral antithetic faults that fault the thrust ore bodies.

~~Paxxxxxxxxxx~~ Cottonwood illustrates the necessity of knowing initial conditions at start of a given deformation. The beds were not flat at start of Cottonwood doming, they were flexed into a syncline. Many beds were very competent. Ore deposits are only rarely formed along thrusts; most small or moderate size thrusts come from bending over of a synthetic fault by flow of soft sediments down flank of arch. - Openings lacking. Aspen, Castle Creek flt in soft Cretaceous.

COTTONWOOD DISTRICT, UTAH.
GEOLOGIC PLAN
After Calkins & Butler, U.S.G.S. P.P. 201 (Plate 19)



COTTONWOOD DISTRICT, UTAH
GEOLOGIC PLAN
After Calkins & Butler, U.S.G.S. P.P. 201 (Plate 19)

GSAS. P. 68, 1961, p. 298-299

WILSON, JOHN C., *202 S. Berkeley, Pasadena, Calif.*

Multiple Intrusion in the Alta Stock, Utah

104

DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

BULLETIN 620—I

A RECONNAISSANCE OF THE COTTONWOOD-AMERICAN FORK MINING REGION UTAH

BY

B. S. BUTLER AND G. F. LOUGHLIN

WITH

NOTES ON HISTORY AND PRODUCTION

BY

V. C. HEIKES

MINING
U. OF C.
ASSOCIATION

Contributions to economic geology, 1915, Part I
(Pages 165-226)

Published December 13, 1915

WASHINGTON
GOVERNMENT PRINTING OFFICE
1915

DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Bulletin 620—I

A RECONNAISSANCE OF THE COTTONWOOD-AMERICAN FORK MINING REGION UTAH

BY

B. S. BUTLER AND G. F. LOUGHLIN

WITH

NOTES ON HISTORY AND PRODUCTION

BY

V. C. HEIKES

Contributions to economic geology, 1915, Part I
(Pages 165–226)

Published December 13, 1915

WASHINGTON
GOVERNMENT PRINTING OFFICE
1915

CONTENTS.

ILLUSTRATION.

A RECONNAISSANCE OF THE COTTONWOOD-AMERICAN FORK MINING REGION, UTAH.

By B. S. Butler and G. F. Loughlin.

INTRODUCTION.

The data on which this report is based were obtained in the summer of 1912 during a reconnaissance of the mining districts of Utah made in a general study of the ore deposits of the State, and it was originally intended to publish the description in the general report, which is now nearing completion and which will include an account of the region herein described. Owing to the unusual interest now being shown in the region, however, it seems desirable to issue this description in advance of the report on the entire State.

The report is based on a reconnaissance quite insufficient to permit a thorough study of the very complicated geology, but the attempt was made to determine the main features of stratigraphy, structure, and ore deposition, and it is hoped that the results here presented will be of assistance to those engaged in mining. It should be borne in mind that both the descriptions and the map, though expressing the general features of the district, lack the detail desirable for the laying out of mining development. Such detail can be procured only by very careful mapping. A portion of the Park City district, mapped by Boutwell, Irving, and Woolsey, is shown on the map (Pl. VI) to indicate the relation of the region discussed to that district. The map of the Park City district as a whole is published in Professional Paper 77 of the Survey.

The Cottonwood-American Fork mining region includes the Big Cottonwood, Little Cottonwood, and American Fork districts, which are situated in the central part of the Wasatch Mountains just southwest of the Park City district. Its approximate limits are parallels 40° 30′ and 40° 40′ and meridians 111° 34′ and 111° 45′. Alta, the principal town, is centrally located, near the head of Little Cottonwood Canyon, about 20 miles southeast of Salt Lake City. Each of the three districts is named from a prominent canyon, which heads near the main divide and extends westward to the front of the range.

The districts are separated from one another by the divides bounding the canyons.

The Big Cottonwood district is the northernmost of the three and is reached in summer by automobile stage from Salt Lake City to Brighton (Silver Lake), a summer resort near the head of the canyon. Ore is hauled by wagon down the canyon to the smelters in Salt Lake Valley.

The Little Cottonwood district is between the other two and includes Alta, the principal settlement of the region, which is reached by stage from Sandy, 16 miles to the west, in Salt Lake Valley. Ore from most of the Little Cottonwood mines is conveyed by aerial tramway about 5 miles to Tanners Flat, and thence about 2 miles by wagon to Wasatch, the terminus of a spur line which connects with the Denver & Rio Grande Railroad at Midvale. The railroad follows the course of the old tramway, which was abandoned years ago.

The American Fork district, the southernmost of the three, is reached by wagon from the town of American Fork, on the Denver & Rio Grande and the San Pedro, Los Angeles & Salt Lake railroads. The town is about 20 miles from the more important mines, which are grouped near the head of the canyon. A stage has been operated intermittently between the town and the mining district. In the early days a railroad was built for a distance of about 16 miles up the canyon, but it was demolished in 1878 and its iron sold.

A few notes on the Alpine mining district, which lies about 5 miles north of the town of American Fork, west of the area shown on Plate VI, are given on pages 223–224.

PREVIOUS WORK.

No detailed geologic work covering the entire region has ever been undertaken. The first geologic mapping was done by the geologists of the Fortieth Parallel Survey in 1869,[1] and their map, published in 1877, has been of great assistance to all engaged in the study of the region since that time. The general geology of the middle Wasatch Range was briefly described by Boutwell.[2] Descriptions of certain mines studied in 1880 were published in the report of the Tenth Census of the United States, extracts from which are quoted in the following pages. The glaciation of the region has been described by Atwood.[3] No recent study of the geology of the region as a whole was undertaken until the writers' reconnaissance in 1912. In that year a study of the stratigraphy and structure of the Cottonwood special quadrangle, which covers the area between the meridians 111° 34′

[1] U. S. Geol. Expl. 40th Par. Rept., vol. 2, pp. 342–366, 1877.

[2] Boutwell, J. M., Geology and ore deposits of the Park City district, Utah, with contributions by L. H. Woolsey: U. S. Geol. Survey Prof. Paper 77, p. 41, 1912.

[3] Atwood, W. W., Glaciation of the Uinta and Wasatch mountains: U. S. Geol. Survey Prof. Paper 61, 1909.

and 111° 40′ shown on Plate VI, was made by F. F. Hintze, jr.[1] Hintze's results in part duplicate and in part supplement those of the writers. Additional confidence in the accuracy of the interpretation of the general stratigraphic and structural relations is felt from the fact that Hintze and the writers, studying the area independently, arrived at substantially the same conclusions.[2] Other papers which deal with certain features of the geology of the region are cited in the following pages.

Since the beginning of the recent activity in mining around Alta, several articles on the new developments have appeared in mining journals and newspapers. Among the more important of these are the following:

Ryan, G. H., The strike in the Cardiff: Salt Lake Mining Review, Nov. 30, 1914, p. 15. Describes the relation of the newly found ore body to local geologic structure.

——— Some Alta activities [special correspondence]: Eng. and Min. Jour., Apr. 17, 1915, pp. 689–690. Shows the replacement ore bodies along limestone-quartzite contact to be connected with ore-bearing fissures, and describes developments in the Cardiff, Columbus Extension, and South Hecla mines.

Howard, L. O., Mining in Utah: Min. [and Sci.] Press, Sept. 18, 1915, pp. 445–446. Describes conditions existing in the Big and Little Cottonwood districts, especially as regards the intrinsic value of mining shares. Accompanied by map showing claim boundaries of principal properties.

TOPOGRAPHY.

The region extends from the crest of the Wasatch Range to the edge of Salt Lake Valley and is therefore one of strong relief. The west base of the range has an approximate elevation of 5,000 feet, and the highest summits, between the upper parts of Little Cottonwood and American Fork canyons, attain altitudes of almost 11,500 feet above sea level. Alta, around which are located the principal mines in Little Cottonwood Canyon, is at an elevation of 8,700 feet and lies just north of Mount Baldy and Twin Peaks, the highest summits of the region. Brighton, or Silver Lake, also has an elevation of about 8,700 feet and is surrounded by summits attaining over 10,000 feet. Similar contrasts in elevation are found in the American Fork district.

The effects of recent glaciation are strongly expressed. The slopes are usually steep and smoothed; many of them include considerable areas of bare, polished rock, and others contain extensive deposits of drift that effectively conceal the bedrock geology. The canyons have the U shape, branch canyons are of the "hanging" type, and

[1] Hintze, F. F., jr., A contribution to the geology of the Wasatch Mountains, Utah: New York Acad. Sci. Annals, vol. 23, pp. 85–143, pls. 1–6, 1913.

[2] Loughlin, G. F., Reconnaissance in the southern Wasatch Mountains, Utah: Jour. Geology, vol. 21, pp. 436–452, 1913.

the heads of canyons have the basin or cirque form—all characteristic of glaciated areas.

The region is one of considerable precipitation, including heavy snowfall which greatly interferes with winter operations. Since the removal of the timber, which was abundant in the early days, snowslides have been a menace to life and property. It is stated that in the Little Cottonwood district alone about 300 lives have been lost and much property destroyed as the result of snowslides.[1] At the higher elevations the snow remains until late in summer, and in years of especially heavy fall it may not entirely disappear before the snows of the next autumn begin to accumulate.

Water is abundant and of excellent quality. The creeks in the three main canyons furnish hydroelectric power which is used by several of the mines and is sufficient to supply any requirements of the mining region and of the neighboring towns in Salt Lake and Utah valleys.

GEOLOGY.

GENERAL FEATURES.

The formations of the Wasatch Range as a whole represent practically all the geologic periods from Archean to Tertiary. The sedimentary formations have a general northerly strike, and their prevailing dip is eastward, but they are affected by north-south folds, as in many of the ranges of western Utah, and in places by overthrust faults of moderate to great extent. Within the Cottonwood-American Fork region, however, the stratigraphic succession is present only in part and is interrupted by unconformities. The prevailing northerly trend of the formations is obliterated by a local doming around a prominent intrusive stock. The rocks have also been displaced by an overthrust fault, which appears to have been produced by pressure from the east, whereas those in northern Utah, southern Idaho, and southwestern Wyoming are attributed, in large part at least, to thrust from the west.[2]

SEDIMENTARY ROCKS.

Age.—The sedimentary formations within the Cottonwood-American Fork region are of pre-Cambrian, Cambrian, Devonian, Carboniferous and Triassic age. They may be divided into two main groups—the quartzite and shale series, of pre-Cambrian and Cambrian age—and the great limestone series, the "Wasatch limestone" of the

[1] Palmer, Leroy, Modern milling at Alta, Utah: Salt Lake Min. Rev., vol. 8, p. 17, 1906.

[2] Richards, R. W., and Mansfield, G. R., The Bannock overthrust: Jour. Geology, vol. 20, No. 8, pp. 681–709, 1912. Blackwelder, Eliot, New light on the geology of the Wasatch Mountains, Utah: Geol. Soc. America Bull., vol. 21, pp. 517–533, 1910.

Fortieth Parallel Survey geologists, which is mostly of Mississippian (lower Carboniferous) age, but also includes strata of Devonian, Cambrian, and in some places, perhaps, of other ages. Owing to the overthrust fault which has caused a part of the quartzite and shale series to override the lower limestone beds, the stratigraphic sequence in Little Cottonwood Canyon appears to be as follows: A thick basal series of quartzite and shale, a "lower limestone," an "upper quartzite," and the great upper limestone covered by later formations. The "lower limestone" and "upper quartzite" were called, respectively, the "Ute limestone" and the "Ogden quartzite" by the geologists of the Fortieth Parallel Survey, but the work of the writers and of Hintze has shown that these formations are not continuous throughout the region, also that the "lower limestone" contains Mississippian fossils, and, therefore, can not be the same as the Ute limestone, which is of Middle Cambrian age, whereas the topmost shaly beds of the "upper quartzite" contain fossils of Middle Cambrian age.

Pre-Cambrian rocks.—The pre-Cambrian rocks of the region consist of a series of quartzite, schist, and slate, or shale, about 11,000 feet thick. They make up the peaks north and south of Big Cottonwood Canyon and form the north boundary and part of the east boundary of the granodiorite stock along Little Cottonwood Canyon. Their strike is generally parallel to the granodiorite contact. They dip very steeply to the north, with numerous contortions, in the western part of Big Cottonwood Canyon, but the dip becomes less steep farther east and is as low as 30° along the divide northwest of Alta. The quartzite members of this series are prevailingly light gray, though some are reddish and purplish brown. The slate and shale members are black, drab, greenish, and purplish, and some of them have a strong slaty cleavage. Mud cracks and ripple marks are commonly present.

Near or at the top of the pre-Cambrian section is an unusual conglomeratic bed in which pebbles and bowlders are embedded in a very fine matrix. The character of this conglomerate strongly suggests that it is of ancient glacial origin, as suggested by Hintze, who has studied the rock in some detail.[1]

Cambrian quartzite and shale.—The Cambrian strata are separated from the pre-Cambrian by a slight angular unconformity, which is marked by a basal conglomerate. These strata include quartzite, shale, and limestone. The quartzite and shale band extends from a point north of Big Cottonwood Canyon southeastward to the upper part of American Fork Canyon. In the area north and south of Alta it appears as two parallel bands, separated by a band of shale

[1] Hintze, F. F., jr., op. cit., pp. 99–101.

and limestone along the course of the overthrust fault. Southwestward from the head of American Fork the Cambrian quartzite and shale, as well as the pre-Cambrian strata, are cut off by the granodiorite intrusion. Along the lower half of American Fork Canyon and in the frontal hills east of Alpine the Cambrian quartzite is exposed at three localities, where small, faulted domal uplifts have brought it above the present surface.

The dip of the quartzite in the Big Cottonwood district is, as a rule, rather low (about 30°) eastward or northeastward, but just northwest of Alta and also near the American Fork divide it is locally steepened and contorted along two reverse faults, the more prominent of which extends along Superior Gulch. Just south of Alta, around Mount Baldy, the dip is unusually flat, owing to local warping along the west end of the Clayton Peak stock. South of the American Fork divide the dip is at a uniform low angle (15° to 20°) to the east-southeast.

The Cambrian quartzite as a whole is of very light gray color on fresh surfaces and yellowish on weathered surfaces. Its lower part contains many beds of fine conglomerate. Its upper part is thinner bedded than the average and grades upward into a dark sandy shale, which contains thin intercalated beds of quartzite and which in turn grades upward into the argillaceous limestone that forms the basal beds of the great limestone series.

In Big Cottonwood Canyon at two horizons in the shale Walcott[1] found Lower and Middle Cambrian fossils. In Little Cottonwood Canyon fossils were collected by the writers from the shale exposures a little south and east of the Flagstaff mine. On this collection L. D. Burling made the following report: "Contains Zacanthoides cf. *Z. spinosus* and *Obolus* (*Westonia*) *ella* and is almost certainly to be correlated with the Spence shale of the lower portion of the Middle Cambrian." Another collection was made at a horizon about 100 feet higher, of which Mr. Burling says, "Contains *Micromita* (*Iphidella*) *pennula* and is probably to be referred to the lower part of the Middle Cambrian." A collection was also made from the shale on the divide between Little Cottonwood and American Fork canyons. Of this Mr. Burling says, "Contains *Obolus* (*Westonia*) *ella* and is probably to be referred to the lower part of the Middle Cambrian, though this species is not very diagnostic."

The thickness of the Cambrian quartzite is given by Hintze[2] as 700 feet, and that of the overlying shale as 150 to 200 feet.

Cambrian limestone.—The limestone overlying the Lower and Middle Cambrian shale and having the same geographic extent

[1] Walcott, C. D., Correlation papers—Cambrian: U. S. Geol. Survey Bull. 81, p. 319, 1891.
[2] Hintze, F. F., jr., op. cit., pp. 103–104.

consists for the most part of shaly and dolomitic beds, the latter occurring mostly in the upper middle part. The following section of this limestone was measured by Hintze:[1]

Section of Cambrian limestone on Mill D South Fork.

	Feet.
Alternating blue shale and limestone conglomerate in beds 1 inch to 6 inches thick	10
Alternating shale and limestone, passing into shale	20
Thin fissile blue shale	6
Dark-blue thin-bedded limestones, partings exceedingly irregular	55
Dark-blue heavy-bedded limestone, with a wormy appearance, holes far apart	45
White limestone, thin bedded	10
Dark-blue wormy-looking limestone, greatly resembling typical bird's-eye limestone of the East	85
Thin-bedded brown shale, strongly jointed toward the top	60
Finely intercalated lime and shale	10
Light-blue streaky limestone; weathers white	15
Blue heavy-bedded limestone, with wormy appearance toward top	60
Brown shale; blocky appearance from extreme jointing	75
Blue limestone intercalated with seams of clay, giving a banded appearance	30
	481
Subformation: Alta shale	200

Hintze tentatively assigned this limestone to the Ordovician, but Burling,[2] in a more recent paper, states that he and F. B. Weeks found Middle Cambrian fossils in the type section of the limestone, at the south end of Reade and Benson Ridge. The limestone has a character typical of the Middle Cambrian in other parts of Utah, but its thickness, less than 500 feet, is much less than the thicknesses of other Middle Cambrian sections that have been measured in the State.

Unconformity at top of Middle Cambrian.—The oldest strata recognized in the Little Cottonwood district above the Middle Cambrian limestone, and resting in apparent conformity upon it, are of Lower Devonian age. The Upper Cambrian, Ordovician, and Silurian are therefore not present in this district and may be absent from the entire Cottonwood-American Fork region. The general uniformity of strike and dip and the lithologic similarity of beds at different horizons throughout the great limestone series prevent a

[1] Hintze, F. F., jr., op. cit., pp. 105–106.

[2] Burling, L. D., Early Cambrian stratigraphy in the North American Cordillera, with discussion of the Albertella and related faunas: Canada Geol. Survey Mus. Bull. 2, p. 101, 1914.

more positive statement until the series has been studied in great detail throughout the region.

Devonian limestone.—Devonian fossils in the region were first found by Tenney[1] in 1873. In 1912 fossils of this age were also found by Hintze[2] on Montreal Hill, a small area not traversed by either of the writers. Hintze's section is as follows:

Section of Devonian (Benson limestone) found on Mill D South Fork.

	Feet.
Hard dark-blue cherty coralline limestone	100
Massive dark-blue limestone	300
Fossiliferous blue limestone	3
Thick-bedded blue limestone	100
Dark-blue cherty and brecciated limestone	200
Dark-blue limestone	100
Dark porous limestone, very fossiliferous	21
Thick-bedded blue limestone, extensively bored	120
Thick-bedded light-blue limestone	43
Thin-bedded blue limestone	45
	1,032

The Devonian limestone is stated by Hintze to rest unconformably upon the Middle Cambrian limestone. Its base "is marked by a limestone conglomerate which rests upon a thin bed of yellowish-green shale, which in turn rests on a thick limestone member. This condition is best shown on the Reade and Benson Ridge, just above the old mine workings of the same name. It is also exposed on the ridge between Days Fork and Little Cottonwood Canyon, just west of Flagstaff Mountain." Hintze proposes the name Benson limestone to designate the Devonian strata.

These exposures suffice to show that the Devonian limestone is continuous to the northwest of Alta. It may well be present south of Alta also, but its extent in this part of the region is not known. In American Fork Canyon south of the Pacific (Blue Rock) mine, limestone of probable Mississippian age lies only a few hundred feet above the Middle Cambrian shale, and if any Devonian limestone is present at this place it will doubtless prove to be much thinner than the exposures northwest of Alta.

Mississippian limestone.—The Mississippian limestone is the most extensive limestone in the region, and stretches in a continuous broad belt from the hills north of Big Cottonwood Canyon to the southern limits of the region and several miles beyond. It forms a continuous eastward-dipping belt, except at Alta, where it is interrupted by the quartz diorite stock. Mississippian beds also form the uppermost part of the "lower limestone" at the head of Mill D South Fork.

[1] Tenney, Sanborn, On Devonian fossils in the Wasatch Mountains: Am. Jour. Sci., 3d ser., vol. 5, pp. 139–140, 1873.

[2] Hintze, F. F., jr., op. cit., pp. 108–113.

The lower beds consist of massive dark-blue limestone containing abundant fossils. The upper part is also of dark color and fossiliferous and is, in addition, characterized by prominent lenses and nodules of black chert. At or near the top of the cherty horizon is a light yellowish-gray limestone exposed on both sides of Mill D South Fork.

The following lots of fossils were identified by G. H. Girty, of the United States Geological Survey:

South end of "lower limestone" spur, head of Mill D South Fork:

Syringopora sp.	Syringothyris (?) sp.
Zaphrentis sp.	Composita sp.
Amplexus sp.	Cleiothyridina crassicardinalis.
Spirifer centronatus.	Euomphalus sp.

Mr. Girty states that the Madison (lower Mississippian) age of these fossils is highly probable.

West slope of Mill D South Fork, near crest of ridge, about a quarter of a mile north of the Carbonate mine:

Syringopora sp.	Spirifer centronatus.
Zaphrentis sp.	

Northern part of Reade and Benson Ridge, about one-tenth of a mile north of latitude 40° 38′. Bed just above light-gray limestone bed, at approximate base of intercalated limestone and quartzite horizon:

Spirifer centronatus.

These two lots are also stated by Mr. Girty to be of Madison age.

Above this light-gray bed is a considerable thickness of argillaceous limestone with intercalated beds of limy quartzite, which passes upward into the Weber quartzite. These intercalated beds have been noted by the writers along the northern part of Reade and Benson Ridge and along the narrow ridge just north of Ant Knolls, along the Wasatch County-Utah County boundary. The one fossil already listed as found in its lowest beds at the first-named locality determines its basal beds as within or just above the Madison limestone. The following fossils collected from the upper beds, at the small low knob just northwest of Ant Knolls, were determined by Mr. Girty as follows and assigned by him to the upper Mississippian:

Fenestella sp.	Martinia? sp.
Chonetes sp.	Composita sp.
Diaphragmus elegans.	Cliothyridina kirsuta.

According to Hintze,[1] a cream-colored sandstone 250 feet thick and overlain by 35 feet of brown and red shales is present in the middle of the Mississippian limestone section. These beds were not noted on the ground covered by the writers. Hintze states that the Mis-

[1] Hintze, F. F., jr., op. cit., p. 109.

sissippian has a total thickness of 940 feet and is overlain unconformably by the Weber quartzite, of Pennsylvanian age. The writers did not attempt to estimate the thickness of the Mississippian and gave practically no attention to formations of later age, beyond indicating their approximate locations on the map.

Post-Mississippian formations.—The post-Mississippian formations within the Cottonwood-American Fork region include the Weber quartzite, Park City formation, Thaynes formation, Ankareh shale, and Nugget sandstone. The Weber quartzite forms the slopes of Big Cottonwood Canyon and the summit of the ridge east of American Fork canyon. The Park City formation is mostly concealed by glacial drift and therefore is not separated on the map from the Weber quartzite. Its approximate position should be along the floor or lower east slope of Big Cottonwood Canyon from Brighton (Silver Lake) northwestward. The Thaynes formation extends along the northeast slope of Big Cottonwood Canyon, and the overlying Ankareh shale forms the crest of the ridge which marks the boundary between Salt Lake and Summit counties. The Nugget sandstone is exposed only in a small area at the north edge of the area mapped.

These formations are all more extensive and more important commercially in the Park City district, and full descriptions of them will be found in Boutwell's report on that district.[1]

IGNEOUS ROCKS.

The extensive east-west zone of intrusion of the central part of the Wasatch Mountains crosses the area under discussion. Within this area at the west is the Little Cottonwood stock of granodiorite, and at the east, extending from Alta into the Park City area, is the Clayton Peak stock of quartz diorite. These two main intrusive bodies are separated by about a mile of sedimentary rocks. The size and relation of these bodies can be best understood by reference to the accompanying map (Pl. VI). Although there is no surface connection between the two masses, the similarity of the rocks and the presence of numerous dikes of similar rock in the area between the two bodies make it seem very probable that they are of common origin and are connected beneath the surface.

As already mentioned, the sedimentary rocks are cut by numerous dikes of a porphyritic rock similar in composition to the intrusive masses and also by some much more siliceous dikes. A few small pegmatitic dikes were noted, and detailed study of the area may reveal other types of intrusive rocks.

[1] Boutwell, J. M., op. cit.

Little Cottonwood stock of granodiorite.—The Little Cottonwood intrusive body is composed of a rock of rather uniform composition. This stock was designated Archean by the geologists of the Fortieth Parallel Survey, but their interpretation was questioned by Geikie,[1] who pointed out features indicative of the intrusive relations of the rock. Its intrusive character was later verified by Emmons,[2] one of the Fortieth Parallel Survey geologists, who revisited the district in 1903. The interior of the stock has been exposed to a depth of at least 5,000 feet in Little Cottonwood Canyon, and so far as observed there is but little change in the rock from the portion adjacent to the intruded rocks to the deeper exposed portions of the mass. Typically it is a rock of granitic texture, locally porphyritic, with light-gray groundmass containing rather abundant dark minerals. Quartz, feldspar, hornblende, and biotite are readily recognized, and usually small yellowish-brown crystals of sphene can be detected. Under the microscope, in addition to the above-mentioned minerals, magnetite and apatite are seen to be rather abundant accessory minerals and a few crystals of zircon are noted. Both plagioclase and orthoclase feldspar are present, the former being far more abundant than the latter. The plagioclase is mostly oligoclase but scattered crystals as basic as andesine are present. Orthoclase and albite form micropegmatitic intergrowths, but such intergrowths are of small amount in the specimens examined. Biotite and hornblende are present in about equal amounts. Both are the common varieties.

A rather notable feature observed at numerous points is the presence of kidney-shaped portions distinctly darker than the main body of the rock. These range from a fraction of an inch to several inches in length and for the most part show a distinct gradation to the normal rock. In mineral constituents they are identical with the main rock, the difference being due to a relative increase in the amount of certain minerals, notably plagioclase, biotite, hornblende, and apatite and probably titanite and magnetite. The similarity in mineral constituents and the gradation to the main rock type suggest that these darker portions have resulted from a segregation of the more basic minerals during the process of crystallization. It may readily be imagined, however, that portions of the magma which had already crystallized were torn loose as the magma was intruded and disseminated through the mass, and that they were later partly dissolved and recrystallized and thus show now a gradation to the normal rock.

---

[1] Geikie, Archibald, Archean rocks of the Wahsatch Mountains: Am. Jour. Sci., 3d ser., vol. 19, pp. 363–367, 1880.

[2] Emmons, S. F., The Little Cottonwood granite body of the Wasatch Mountains: Am. Jour. Sci., 4th ser., vol. 16, pp. 139–147, 1903.

A chemical analysis of a specimen of the granodiorite collected near the wagon road about one-third of a mile below the power house in Little Cottonwood Canyon shows the following composition:

Analysis of granodiorite one-third of a mile below power house, Little Cottonwood Canyon.

[R. C. Wells, analyst.]

SiO_2	67.02	TiO_2	0.37
Al_2O_3	15.78	ZrO_2	.04
Fe_2O_3	1.56	CO_2	.00
FeO	2.18	P_2O_5	.26
MgO	1.09	S	.03
CaO	3.31	MnO	.02
Na_2O	3.85	BaO	.13
K_2O	3.67		
H_2O-	.29		100.23
H_2O+	.63		

No analyses of the hornblende and biotite of the rock are available, so that it is not possible to calculate the mineral composition accurately. From the chemical analyses and microscopic study it is believed that the following closely represents the mineral composition of the rock:

Approximate mineral composition of granodiorite, Little Cottonwood Canyon.

Quartz	20	Hornblende	7
Orthoclase molecule	20	Magnetite	2
Albite molecule	30	Titanite	1
Anorthite molecule	12	Apatite	½
Biotite	7		

Clayton Peak stock of quartz and diorite.—The Clayton Peak mass of quartz diorite is very similar to the Little Cottonwood stock of granodiorite in its relations to the sedimentary rocks, though more linear in outline. The mineral constituents are the same, but in general quartz is less abundant and plagioclase and the dark minerals form a larger percentage of the rock. This mass extends into the Park City area and has been described by Boutwell and Woolsey.[1] It contains many dark inclusions, especially near the northern contact at the pass between Alta and Brighton (Silver Lake). Along the southern contact, due south of Brighton, a considerable body of darker augite-biotite diorite has separated from the main mass.

Quartz diorite porphyry dikes.—Numerous dikes cut the sedimentary rocks in the area between and around the two main intrusive masses and have been found throughout the area from its northern limit as far south as the Dutchman mine, in American Fork canyon. They vary considerably in appearance and doubtless

[1] Boutwell, J. M., op. cit., p. 75.

in composition. Commonly they are dark rocks with rather abundant phenocrysts of plagioclase, hornblende, and biotite in a groundmass of the same minerals, together with orthoclase and some quartz. In mineral constituents they are similar to both of the large intrusive bodies but for the most part, at least, are more basic than either. Some of the dikes are probably true diorite porphyries; others are of distinctly monzonitic character. Although none of these dikes were found to be directly connected with the main intrusive bodies, it is believed that they are offshoots from these larger bodies and are connected with them below the surface.

Granite porphyry dikes.—Dikes of granite porphyry were noted on the north side of Little Cottonwood Canyon. Such a dike is well exposed a short distance north of the Columbus Consolidated plant, where it can be traced for several hundred feet, striking several degrees north of east and apparently standing nearly vertical. Similar dike rocks were noted farther east in the direction of the strike of this dike.

The dikes are light fine-grained rocks containing scattered phenocrysts of quartz and feldspar and usually iron-stained cavities where some mineral has oxidized and been partly removed in solution. Under the microscope the phenocrysts are seen to be quartz, plagioclase, and orthoclase in a groundmass of quartz and orthoclase, the orthoclase forming a very large percentage of the rock. Sericitic muscovite is rather abundant as an alteration product of the feldspars.

Aplitic and pegmatite dikes.—Aplitic dikes are numerous, and a few of pegmatite were noted. A small vein of pyroxene and quartz is associated with one of the small aplitic dikes on the slope northwest of the pass between Silver Lake and Snake Creek. The pyroxene occurs in dark greenish-black crystals as much as 1 inch in length and is near diopside in character. Some crystals are partly altered to a greenish-gray fibrous amphibole. The aplite also contains similar crystals of fibrous or multiple-twinned amphibole. This vein, though small, is of interest as an indication that the mineralizing agents which developed diopside and associated minerals in the limestone at the contact near by were also active within the granite, where they represented the latest phase of the intrusion.

STRUCTURE.

The structure of the district is complex, and detailed mapping is necessary to work it out with the accuracy desirable for the direction of mining operations. Notes on the general relations are presented below, and it is hoped that they will prove of assistance in working out the detailed structural relations at the individual mines.

FOLDING.

The north-south folds that were apparently one of the earliest structural developments of this general region are not conspicuous in the Cottonwood area; at least their importance has not been recognized in the reconnaissance work. The area has, however, been affected by minor folding, which was a result of faulting.

OVERTHRUST FAULTING.

The earliest important structural disturbance in this part of the range seems to have been overthrust faulting. It is possible that this was contemporaneous with the folding farther east.[1] The main thrust fault extends along an irregular but generally north-northwest course and has been traced from the vicinity of Big Cottonwood Creek to the head of American Fork Canyon, where is disappears among a complex of reverse and normal faults.

South of Little Cottonwood Canyon it is well seen on both the east and west sides of the Mount Baldy mass, where several hundred feet of the great limestone has been overridden by Cambrian quartzite and shale. It is shown similarly north of the canyon, especially just east of Superior Gulch, and has been traced over the divide into Mill D South Fork as far as the north-south ridge south of the Carbonate mine. Its course is marked by the contact between the "lower limestone" and "upper quartzite" as far as Vena Flat, beyond which the "upper quartzite" overlaps on the main or "lower quartzite."

The amount of the overthrust has not been determined, but is considerable. The Cambrian strata are considerably above their normal position in the vicinity of the Alta Consolidated mine. Whether the position of the strata at this locality is due wholly to the overthrust faulting or in part to later faulting and the effects of intrusion has not been determined. The shale beds within the "upper quartzite" and between it and the great limestone series were most complexly folded, crumpled, and faulted during the overthrust movement. This result is especially well shown on the south slope of Flagstaff Mountain above the Columbus Consolidated mine. The movement on the fault was apparently from the east toward the west, and at the time of the faulting the plane probably had a rather gentle eastward dip that was increased by later movements.

Owing to the unknown extent of the overthrust and the irregularity of its contact, the depth and extent of the "lower limestone" east of its outcrop can not be closely calculated, a fact to be borne

[1] Hintze, F. F., jr., op. cit., p. 135.

in mind by companies planning to prospect the "lower limestone" at depth. Whether or not the "lower limestone" exists east and south of its outcrop at the head of the American Fork canyon can not be proved until the complex of faults there has been thoroughly worked out. From the meager evidence at hand it seems probable that the overthrust dies out in this vicinity and that the existence of the "lower limestone" in the American Fork country is improbable. (See section B–B′, Pl. VI.)

STRUCTURES FORMED DURING THE INTRUSION OF THE IGNEOUS BODIES.

Doming.—The igneous material that forms the Little Cottonwood and Clayton Peak masses, on being forced into the sedimentary series, in part broke across the strata and in part raised the overlying beds, forming a broad dome in which the sedimentary beds dip away from the intrusive rock. The doming is especially well shown around the Little Cottonwood mass, where the sedimentary formations crop out in concentric semielliptical form around the north and east boundaries of the intrusive mass. On the south the granodiorite broke completely through both the pre-Cambrian and Cambrian quartzites and is now exposed in contact with the great limestone series, which also dips radially away from the intrusive rock. On the west the dome structure is partly preserved but is mostly cut off by the great Wasatch fault. The small faulted domes along the lower part of American Fork canyon and east of Alpine may have been caused by the upward thrust of minor intrusive bodies connected with the granodiorite mass.

The same relation is true in a general way for the Clayton Peak body of quartz diorite east of Alta. The doming effect of the Little Cottonwood mass of granodiorite, however, was much more pronounced and conceals that of the Clayton Peak body except at the west contact of the latter south of Alta, where the eastward-dipping overthrust plane has been bent upward into a faulted synclinal attitude.

Reverse faulting.—In addition to the general doming of the sedimentary rocks adjacent to the intrusive bodies, the strata in places have been broken and thrust upward and outward from the intrusives, reverse faults being produced. The best exposed of these reverse faults is that in Superior Gulch, where the quartzites have been thrust up in contact with the overlying limestone. (See section A–A′, Pl. VI.) A smaller one is exposed along the quartzite, shale, and limestone contact at the south end of Reade and Benson Ridge. Similar faults were observed to the south, near the American Fork divide, and others are probably present in the

area. Those recognized have a concentric arrangement with respect to the intrusive granodiorite.

Mineralized fissures and faults.—The mineralized and other closely related fissures also appear to have been formed during or just after the intrusion of the main bodies. Those noted in the Mill D South Fork area, in the Cardiff and Branborg mines, strike about N. 35° E. and dip 60°–65° NW. The Silver King fissure zone of the Branborg mine can be followed southwestward through the quartzite and down into the granodiorite of Little Cottonwood canyon. The mineralized fissures in the principal mines around Alta strike N. 60°–70° E., in general parallel to the trend of the quartz diorite body, and dip rather steeply (60°–65°) to the north. Those in the American Fork district, so far as seen, appear to belong to two systems, one of northeasterly and one of about easterly trend. The stopes of the famous Miller mine lie in both directions, though the longest stope extends about N. 85° E. The Live Yankee also has veins in both directions. The Pacific and Dutchman veins belong to the northeasterly system. In the Barry-Coxe mine, on the north slope of the pass between Brighton and Park City, the mineralized fissures strike about north and east. The northerly fissures are the more heavily mineralized. These fissures lie at right angles to and parallel to the north boundary of the Clayton Peak body of quartz diorite.

Prominent barren fissures were noted following both the northeasterly and the easterly direction, and some with northwesterly trends were also seen.

The porphyry dikes follow the same general directions as the mineralized fissures. Those near Alta extend mostly north of east. Those in the Dutchman, Live Yankee, and Miller mines of the American Fork area extend northeasterly, and for a part of their course form one wall to the veins. The dikes, however, were introduced before the veins were formed. The fissures are distinctly later than the overthrust, but the presence of the dikes is proof that some of these fissures were formed before the cessation of igneous intrusion. The presence of veins along some of the dikes is proof that the same fissures, or fissure zones, were reopened shortly after the dike intrusion, and the presence of mineralized fissures within the main intrusive bodies is evidence that some of the fissures were not formed until the intrusive rock had become solid enough to undergo fracturing. There has been movement along at least some of these fissures, but the amount of movement is in most places not readily determined. Here and there it is known to have been slight, and nowhere has it been demonstrated to have been very great.

It is believed that the fissures were formed at the time of intrusion as an effect of the doming of the sedimentary rocks. It should be expected that the strongest fissures would lie parallel and near to the

common major axis of the intrusive bodies. This direction furthermore coincides essentially with the axis of the principal fissures of the Park City district, which are also closely associated with the Clayton Peak stock of quartz diorite. The northeasterly fissures of the Cardiff and Branborg mines and the easterly fissures of the American Fork mines are radial with respect to the granodiorite stock. The northeasterly fissures of the American Fork mines are concentric with respect to the same body. Radial and concentric fissures are the ones most likely to be formed as a result of doming, and also the contraction of the domed area during the cooling of the newly intruded igneous bodies. The observations made, however, are too few and localized to give more than a suggestion of these structural relations. Settling of the area at intervals throughout the cooling stage may account for the displacements noted along these fissures, some displacements preceding and others following the deposition of the vein minerals.

FAULTS DISTINCTLY LATER THAN IGNEOUS INTRUSION AND ORE DEPOSITION.

Faults distinctly later than igneous intrusion and ore deposition may be conveniently classified into two groups—local faults, intimately associated with ore bodies, and those of great extent, associated with the formation of the mountain range. The only proved member of the first group, so far as the writers know, is the normal fault that offsets the vein in the Pacific mine of the American Fork district. This fault trends N. 70° W. and has a horizontal displacement of 18 feet. The abrupt terminations of some of the larger ore bodies of the region, such as the Miller body, in the American Fork district, may be due to faulting, but in none of these places, so far as the writers are aware, has the existence of a fault been proved, nor is it known in places where faulting is supposed to have occurred whether the ore body terminates against the impervious wall of a premineral fault or whether it has been displaced by a postmineral fault. It was stated by the managers that one of the large ore bodies of the Columbus Consolidated (Wasatch) mine gave out against a fault, and recently it has been reported that the ore body has been located on the other side of the fault. This fault was not accessible underground at the time of visit.

Other normal faults of small displacement are present in the region, but as they are not intimately associated with mineralized fissures their age can not be closely determined. Examples of such faults may be seen on the divide north of the Toledo mine and around the head of American Fork canyon. These were evidently of later origin than the overthrust and probably later than the reverse

faults and the concentric and radial fissures that are believed to have been closely associated with the igneous activity of the region. They are possibly to be correlated with the northerly fissuring and faulting in the Park City district and may have been contemporaneous with the great Wasatch fault.

The latest large structural feature of the region is believed to be the great normal fault that extends along the front or west edge of the Wasatch Range. Its vertical displacement is doubtless to be measured in thousands of feet. This displacement probably produced an eastward tilting of the great Wasatch block, so that the eastward dip of the strata was somewhat steepened. The growth of this great fault was gradual and may well have been accompanied by the development of many minor faults in the region, but, as already shown, a definite correlation of most of these minor faults is impossible at present.

Evidence in the Park City region[1] indicates that the igneous intrusions took place in late Cretaceous or early Tertiary time, and evidence in the southern and northern parts of the Wasatch Mountains[2] indicates that the faulting along that range occurred after the depositions of Ecoene sediments and that in some of the "Basin Ranges" faulting had ceased before the deposition of Pliocene sediments. G. K. Gilbert has shown that faulting along the Wasatch Range has occurred in very recent times. The normal faults that preceded and followed ore deposition may well have been in process of formation throughout the period that followed the igneous intrusion, and even the most detailed mapping may not produce evidence on which the normal faults may be classified into distinct groups.

ALTERATION OF THE SEDIMENTARY ROCKS RESULTING FROM THE INTRUSION OF THE GRANODIORITE AND QUARTZ DIORITE.

The reconnaissance work was not extended over sufficient territory or pursued with sufficient detail to establish definitely the types of alteration that were due to regional metamorphism and those that are to be attributed to the influence of the intrusive bodies. Regional metamorphism, however, has been comparatively slight in the great limestone and overlying rocks, and the cause of changes in these rocks can be more certainly determined.

The Little Cottonwood stock of granodiorite in the area examined is in contact with the Cambrian and pre-Cambrian quartzites and schists. Both have undergone considerable regional metamorphism,

[1] Boutwell, J. M., op. cit., p. 43.

[2] Loughlin, G. F., Reconnaissance in the southern Wasatch Mountains, Utah: Jour. Geology, vol. 21, No. 5, p. 451, 1913. (Eocene conglomerate is displaced by "Basin Range" faults.) Mansfield, G. R., unpublished map of the Montpelier quadrangle, U. S. Geol. Survey. (Pliocene lake beds lie undisturbed in the valleys between faulted "Basin Ranges.")

and they were not examined with sufficient care outside of the zone influenced by the intrusive body to determine what the changes have been within that zone. Specimens of schist collected at the contact in a gulch west of Superior Gulch are composed of quartz, orthoclase, some plagioclase, rather abundant zoisite, abundant magnetite, and small amounts of muscovite and biotite. The rocks near the contact appear to contain more magnetite and less mica than those at a greater distance. The effect of the intrusion on the Cambrian quartzite does not appear to have been great but was not closely studied. Its effect on the great limestone series along the southern boundary of the area mapped is expressed by a general bleaching and recrystallizing of the originally dark limestone into white marble and by the development of such typical contact minerals as pyroxene, tremolite, brown garnet, epidote, quartz, and pyrite—the same general effect as those that accompanied the intrusion of the quartz diorite.

The Clayton Peak mass of quartz diorite is almost wholly in contact with the limestone and its metamorphic influence has received more attention, but by no means detailed study. Alteration of the "contact" type associated with the main body of intrusive rock was noted especially in the vicinity of the Alta Consolidated and City Rock mines and associated with lesser intrusive bodies north of Lake Solitude and in the workings of the South Hecla mine. Much of the limestone near the intrusive mass has been recrystallized and bleached, but the development of abundant contact silicates has occurred only at certain points and was apparently associated with certain beds in the limestone. Some of the replaced beds could be traced for several hundred feet from the contact, but other replacement bodies were noted several hundred feet from an observed igneous contact and with no apparent direct connection with an igneous rock. The principal contact minerals noted were diopside, a light yellow and a beautiful green garnet, monticellite, muscovite, ludwigite, green phlogopite, magnetite, hematite, and iron and copper sulphides. Other contact minerals are probably present, such as vesuvianite and spinel, which have been noted farther east in the Park City area.

ORE DEPOSITS.

HISTORY AND PRODUCTION.[1]

LITTLE COTTONWOOD DISTRICT.

Ore was first discovered in the Little Cottonwood district by Gen. Conner's soldiers in 1864, and the Wasatch district was then organized, but it was soon abandoned owing to the great expense of work-

[1] The section on history and production (pp. 183–224) was written by V. C. Heikes.

ing. In 1867 most of the claims were "jumped" and a new district organized, called the Mountain Lake, which included a large area in the Wasatch Range. It was divided in 1869–70 into the Little and Big Cottonwood, American Fork, and Uinta districts. The mining claims recorded in the Little Cottonwood district covered an area about 2½ miles square. Most of the principal mines of the Little Cottonwood district are on the northern slope of the Little Cottonwood Canyon. Alta, the principal camp, is 16 miles east of Sandy, a station on the Denver & Rio Grande and San Pedro, Los Angeles & Salt Lake railroads. A railroad was completed to the district in May, 1873, but was discontinued a few years later. In 1913 the grade was repaired and rails laid as far as Wasatch for the transportation of building stone to Salt Lake City. The mine operators in the district took advantage of this renewed method of transportation, thus saving a wagon haul of 9 miles to the smelters. The most productive period was between 1871 and 1877, and at the time of Huntley's visit[1] (October, 1880) the district was very dull and but two mines—the Vallejo and the City Rock—were working regularly. This idleness of the mines was due to several causes, including legal troubles, the exhaustion of working capital of several large prospecting companies, the giving out of surface bodies, the finding of pyrite and water in the lower levels, and the low price of lead.

Very little metallurgic work was ever done in the district, as most of the ore was sold in the Salt Lake market. In 1866 the owner of the North Star mine built a Scotch hearth furnace and ran out about 3 tons of lead. In the following year he erected a reverberatory furnace and a cupel furnace. The former was a success, but the latter failed. The Jones smelter, about 4½ miles from the mouth of Little Cottonwood Canyon, was operated in 1871, and ran on custom ores for two years. In 1872 or 1873 the Davenport smelter was started at the same place. In addition to the ore from the mine it worked some custom ore, but was shut down in 1875. The Flagstaff Co. also erected three stacks in this vicinity. Several unsuccessful attempts were made to leach ores on a small scale. Concentration works were built for the Emma mine and were financially successful, though the percentage obtained was low.

The history of the Emma mine is given by Huntley,[2] who reported on it and other mines as follows:

> The Emma mine is situated halfway up the southern slope of a high, steep ridge called Emma Hill. It was located in 1868 by Woodman, Chisholm, Woodhull & Reich. Little work was done until the autumn of 1869, when the ore

[1] Huntley, D. B., The mining industries of Utah: Tenth Census U. S., vol. 13, p. 422, 1880.

[2] Idem, p. 423.

body was struck. Some ore was shipped and sold prior to the sale of the mine to the Emma Mining Co., of New York, in 1870. This company worked the mine quite vigorously and shipped a large amount of ore. The following year the property was sold to the Emma Silver Mining Co. of Utah (Ltd.) for $5,000,000 cash; another authority placed the price at $3,500,000. The mine was then worked by English managers, paid $300,000 in dividends (one authority says $1,300,000) until September, 1874, when it was attached by T. W. Park and others for an indebtedness of $300,000. It was then idle until October, 1877, when the American Emma Mining Co. was incorporated and work resumed.[1] The second ore body failed in the autumn of 1873, up to which time most of the ore had been shipped to Swansea, Wales. During the years 1873, 1874, 1878, and 1879 much low-grade ore was concentrated by jigs.

When the American Emma Co. began work it first prospected the old ore bodies and then leased the Bay City tunnel, which was 1,700 feet long and 90 feet below the lowest old workings of the Emma. This tunnel had been run by a St. Louis company at a cost of $75,000 and had been abandoned in 1876. Since making the connection a small ocher-stained seam, in an incline or winze 130 feet below the tunnel level, has been followed. * * * About 3,500 gallons of water per hour is raised. During the census year about 14 men were employed. The property of this company consists of the Emma, 2,400 by 100 feet, and the Cincinnati, 1,200 by 100 feet. One hundred thousand dollars was paid for the latter, but, the claim having been jumped, the title is in dispute. * * * From Mr. Charles Smith, of Salt Lake City, whose accounts included all but the first few hundred tons sold, the writer learned that the sales of ore to June 1, 1880, amounted to 27,451 tons, for which $2,637,727.44 was received. The mine had been developed below the discovery only about 500 feet vertically and 350 feet horizontally. The openings of the old workings were estimated at something less than 4,000 feet, and those of the new workings at about 700 feet.

The Flagstaff mine is situated a quarter of a mile north of Alta, halfway up the southern slope of a high ridge which separates Big from Little Cottonwood Canyon, from 700 to 800 feet above the valley. It was located in 1879 by Groesbeck, Schneider, and others, who worked it under the name of the Salt Lake Mining Co. until February, 1872, when it was bonded to one Davis for $300,000, who sold it to English capitalists for $1,500,000. They organized the Flagstaff Silver Mining Co. of Utah (Ltd.) and worked the mine in a very expensive manner until December, 1873, when the ore bodies in sight gave out. The company was then found to be in debt to Davis for money advanced, some $300,000. Davis took the mine and worked it under agreement with the company until December 24, 1876, when he was dispossessed by the United States marshal under orders from the English directors. Heavy lawsuits with small results followed. Since 1876 the mine has been leased and subleased many times, but has been idle since the summer of 1880. At the time of examination it was owned by Seligman Bros., of New York, who took it for debt. * * * The English company erected the Flagstaff smelter (three stacks) at the mouth of Little Cottonwood Canyon and ran it until November, 1873, when they leased the Last Chance smelter near Sandy. Smelting was not as profitable as selling the ore, which, after April, 1876, was disposed of in the Salt Lake market. The divi-

[1] There has been a great amount of litigation between the English stockholders and T. W. Park and others, but these differences have recently [about 1880] been amicably adjusted.

dends paid to the English company amounted to about $350,000. The property consists of the Flagstaff, South Star and Titus, Virginia, and Nabob. The Flagstaff is 2,200 by 100 feet, but it extends across and not along the belt. In early times, before the suits, the right to "swing their patent" was insisted on, and the workings extended 1,000 feet or more on the belt. * * *

The total product was estimated by the superintendent to be as follows:

	Tons.
Prior to 1872	6,000
1872	8,000
1873	17,000
1874 to 1876	35,000
1877 and 1878	30,000
1879	4,000
	100,000

Of this, 30,000 tons probably assayed $10 gold, 60 ounces silver, and 40 per cent lead and sold for or was worth $80 per ton. The remainder probably assayed $4 gold, 30 ounces silver, and 20 per cent lead and was worth $30 per ton.

The mine is developed by a 530-foot tunnel, from which there is an incline 515 feet in length, at an angle of 49°. From this incline there are six levels, from 700 to 1,400 feet in length. The lower level is about 700 feet vertically below the discovery croppings. The total cuttings, exclusive of stopes, are variously estimated at from 9,000 to 14,000 feet. From the mouth of the tunnel the ore is sent to the foot of the hill on a tramway 2,800 feet in length. * * *

The South Star and Titus, an older location than the Flagstaff, has been constantly harassed by lawsuits. Several hundred thousand dollars' worth of ore has been extracted. It is developed by tunnel and shaft to the extent of several thousand feet. Active work ceased in 1878.

The Nabob was located in 1876. A large body of ore, lying partly in the Virginia ground, was struck in the winter of 1876–77, which yielded about $100,000. Little has been done since. The mine is a part of the mineral belt of Emma Hill. An ore body, 30 by 25 by 4 feet, was found not 50 feet from the surface. The average assay of this ore was $74.76, of which $26 was gold. The developments consist of a 115-foot incline and 300 feet of other cuttings.

The Joab Lawrence Co., the principal actively working company on Emma Hill at the time of the writer's visit, was organized in the spring of 1879. Its property consists of the Vallejo and the North Star, adjacent claims, situated between the Emma and the Flagstaff. The North Star was one of the earliest claims of the district, having been located in 1865, and has yielded largely. There are said to be large bodies of low-grade oxide of iron ore in the lower levels, but little had been done for some time excepting a small amount of "tribute" work. The Vallejo was worked in 1872, 1873, 1874, 1875, and 1877 by several companies, and much ore was extracted. It was being worked on an extensive scale at the time of the writer's visit. * * * It [the ore] was fine and contained from 20 to 45 per cent lead and from 15 to 90 ounces silver, from 20 to 35 per cent iron and from 9 to 14 per cent of moisture. It was in great demand among the smelters owing to the lack of silica and the presence of so much iron. A low grade of ore containing from 40 to 50 per cent of iron, no lead, and a few ounces of silver was also shipped. The following table

shows the price received per ton for some lots of ore in February and March, 1880:

Weight.	Assay value.		Price received per ton.
	Lead.	Silver.	
Pounds.	*Per cent.*	*Ounces.*	
111,855	5	5	$10.00
76,225	41	48	66.50
56,877	42	65	85.10
54,376	35	39	52.25
74,011	12	15	17.50
130,304	43	54	73.75
140,525	6	9	12.00

The ore was transported from the mine to the tramway of the Wasatch & Jordan Valley Railway by a wire-rope tramway.

The Toledo-Utah Silver Mining & Smelting Co. bought the Toledo mine shortly after its discovery in 1872 and worked it quite extensively until April, 1880. The property consists of the Toledo and the Fuller claims. On the latter most of the ore has been found and most of the work done. * * * The mine is operated through a shaft 455 feet deep, vertical for part of its length. The horizontal development of the vein is 350 feet, and the total cuttings are estimated at 2,000 feet. * * * The total product of the mine and its output during the census year were large. The exact figures can not be given, owing to the confidential character of the information furnished.

The Emily mine is situated in a small ravine between the Toledo and Emma Hill. It was discovered in 1870. It is owned by the Emily Mining Co., of Pittsburgh, Pa. They ceased regular work in 1874, and the mine has been leased since at one-fifth royalty. It is a bedded vein of clay slate in quartzite, dipping about 60° E. The ore is from 1 to 6 inches wide and consists of quartz containing pyrite, sphalerite, galena, and tetrahedrite. When sorted it assays from $80 to $100. Mine is opened by three tunnels on the vein. The total length of cuttings is 800 feet. The mine is very wet and has no machinery. The total yield has been $15,000 or $20,000.

City Rock and Utah group is situated at the head of Little Cottonwood Canyon and comprises the Utah, 100 by 1,000 feet; City Rock, 100 by 1,000 feet; West Wind, 100 by 495 feet; King of the West, Utah No. 2, Utah No. 3, and Freeland. The first three are on the Utah vein, and the others are on the parallel King of the West vein, 200 feet distant, and have but little development. Most of these claims were located in 1870. In 1872 much work was done. Between 1872 and 1876 the mines were involved in litigation. Twelve men were employed during the census year. * * * The mine was being thoroughly opened at intervals of 100 feet by levels and winzes through the ore bodies. Very little stoping has been done. The developments consisted of two inclines and three tunnels on the vein. The lower one, which was to be the main working tunnel, is 5 by 7 feet, well timbered, has an iron rail track, and is 600 feet long. The middle tunnel, 490 feet vertically above the lower one, is 1,300 feet long. One hundred feet below this is the water level. The upper tunnel is 600 feet long and 201 feet above the middle one. These tunnels have a grade of half an inch in 12 feet. The total cuttings amount to 4,800 feet. During the census year 385 tons of ore were sold for $25,480.67. The previous product was estimated at $50,000.

The other mines of the Little Cottonwood district are:

Mine.	Total length of openings.	Total product.	Condition at close of the census year.	Remarks.
	Feet.			
Cincinnati group	1,500	$10,000	Worked irregularly	Ore, a sulphuret containing considerable zinc.
Enterprise	500		Idle	One ore body yielded $10,000 or more.
Dexter Consolidated	300	Small.	do	
Brian lode		(a)	do	
Marion group	1,800		Worked irregularly	
Manitoba	630		Idle	Vein not well defined.
Emily	800	18,000	Worked on lease	Ore assays $80 to $100 per ton.
Caledonia	700		do	Several thousand dollars have been extracted.
Highland Chief	1,100		Idle	Ore assays 20 ounces silver and 25 per cent lead. Many hundred tons have been shipped.
Ohio River group	500	60,000	Little work done	
Savage and Montezuma group.	3,000	200,000	Idle	Ore 35 per cent lead and 35 to 150 ounces silver.
Stoker	450	Small.	do	Ore medium grade.
McKay and Revolution	1,000		Tunnel being run	A few hundred tons have been extracted.
Grizzly and Lavinia	3,000	Large.	Idle	Contains large bodies of low-grade ore.
Darlington	500	Small.	do	
Davenport	4,800	600,000	do	
Island	1,000		do	Do.
Siskiyou	500	Small.	do	
Alpha	500	37,000		Average assays: 200 ounces silver, 10 per cent lead, $10 gold.
Evergreen			Worked irregularly	
North Pole	300			Ore, galena in small seams in limestone.
Albion and Rising Sun	1,800	100,000	Idle	
Oxford and Geneva	1,910	20,000	Worked on lease	Ore assays 30 to 90 ounces silver, 40 to 60 per cent lead, $3 gold.
Louisa	600	8,000	Idle	Ore, 10 to 12 ounces ochery carbonate and 40 to 50 ounces galena.
Sedan	300	Small.		Ore, cerusite, galena, and pyrites, containing 16 to 60 ounces silver.
Fritz	460	Small.		Vein, 20 feet; soft, low-grade ocher.
Peruvian	700	Small.		A few tons shipped, assaying 40 to 60 ounces silver, 40 to 70 per cent lead, and $6 gold.
Kenosha	500	Small.		
Highland Boy	500	None.		Small stringers of carbonate ore in limestone.

a A few thousand dollars.

TUNNEL SITES.

The topography of this district is very favorable for the location of tunnel sites. Accordingly, in early times, work was begun upon a great many. They have cost fortunes, but have rarely been successful in finding ore; and though all are still claimed, few are worked more than is sufficient for assessment work. These tunnel sites, in a legal way, are a great drawback to the district. They were located before many of the present claims; they ran in all directions, and, in case large and rich ore bodies should be found, some of them might be used to make serious legal difficulties. The following are the principal tunnel sites in the order of their situation, beginning at the west, on the north side of Little Cottonwood, and continuing in a semicircle around the head of the canyon:

The Frederick tunnel.—This was driven to develop the Frederick and Crown Point claims. These are parallel veins, 70 feet apart, 3 and 4½ feet wide, dip-

ping 54° N. in limestone and between limestone and quartzite. The ore is a carbonate, 18 inches wide, and averages 60 ounces silver and 35 per cent lead. The claims were located in 1870 and were worked until 1873, when water and galena were encountered at a depth of 337 feet. The value of the ore sold was estimated at $35,000. The mines were leased until May, 1876, when the tunnel was begun. It is 1,300 feet long and has to be driven several hundred feet farther before cutting the veins, which are expected to be reached at 980 feet below the croppings. Its size is 6 feet 6 inches by 4 feet 4 inches. Timbering is unnecessary. * * *

The Howland tunnel.—Work was begun on this several years ago. It has been relocated several times and was, at the period under review, known as the Solitary. Its length is 600 feet. Only assessment work is being done.

The Geneva tunnel.—Abandoned. Length unknown.

The Lady Emma tunnel.—Length, 370 feet. Relocated and called the Prince of the Hills. Only assessment work is being done.

The Chicago tunnel.—Length, 600 feet. Relocated and called the Fitzgerald tunnel.

The Vallejo tunnel.—Used in the early development of the Vallejo mine.

The Utah tunnel.—Relocated as the Burgess and used to work the Vallejo mine.

The Gladiator tunnel.—Length, about 1,000 feet. Used to work the North Star mine.

The Great Salt Lake Tunnel & Mining Co.—This is better known as the Buffalo tunnel. It was located in 1871, is 600 feet in length, and is regularly worked, 275 feet having been run the preceding year. This company has located two claims, the Buffalo and another, having 9-inch veins, containing galena and pyrites. Three small bodies were found. The ore sold for about $80 per ton and yielded a few thousand dollars. The Allegan mine, operated through this tunnel, has about 550 feet of cuttings and yielded a few thousand dollars some years ago.

The Bay City tunnel.—Length, 1,700 feet. * * *

The Illinois tunnel.—Length, 800 feet. * * *

The Equitable Tunnel & Mining Co.—This company's tunnel is about 1,500 feet in length, with side drifts and winzes amounting to 900 feet, and is situated above the Bay City. Three small claims, Bolles & Collins, Equitable, and Equitable No. 2, as well as the Phoenix and the Lady Esten tunnel site, in other parts of the district, are owned by this company. * * *

The Little Cottonwood tunnel.—Relocated and called the Buckland. It is 600 feet long and was run to tap the Savage and Montezuma group.

The Reliance tunnel.—Abandoned. Little work done.

The Manhattan tunnel.—Abandoned and relocated as the McKay and Revolution. Length, 500 feet.

The Ely tunnel.—Abandoned.

The Phoenix tunnel.—Owned by the Equitable Tunnel & Mining Co. Length, 700 feet.

The Herman tunnel, known as the Tilden.—Length, 500 feet.

The Emma Hill tunnel.—Length, 900 feet.

The Victoria tunnel.—Length, 900 feet. Used to work the Victoria, Imperial, Emma May, and Alice mines. These have a large amount of cuttings, have shipped considerable ore, and are being worked upon lease.

The Christiana tunnel, known as the Oneida.—Length, 250 feet.

The Brewer & Lapham tunnel.—Length, 150 feet. Located to develop the Darlington mine.

The Lady Esten tunnel.—Length, 300 feet. Owned by the Equitable Tunnel & Mining Co.

The Iris Tunnel Co.—This was a San Francisco company which began work in the spring of 1872 and failed in the autumn of 1877 having spent about $100,000. The tunnel was taken by one of the creditors for debt. The property consists of eight locations and two tunnel sites on Emerald Hill. The upper tunnel is 1,165 feet in length and has 600 feet of drifts. Two veins, from 6 inches to 2 feet and from 2 to 4 feet wide, were cut. Some galena and pyrite ore was extracted. Water is very plentiful, and the lower tunnel, 300 feet below, was run to drain the ledges. The lower tunnel is 635 feet long and has to be run 300 feet farther before cutting the first vein. The tunnels are large and straight and are ventilated by means of a water blast driven by the waste water.

The Etna, St. Joseph, Wasatch, Silver Belt, and Rothschild tunnel sites are of varying lengths and have all been abandoned.

Besides the tunnels above mentioned, there are many others having more or less development.

In recent years (1901–1913) the most important producers in the Little Cottonwood district, named in the order of greatest output, have been the Columbus Consolidated group; the Continental-Alta, reorganized as the Unity and later as the Michigan-Utah Mining Co. (this included the early producing claims known as the Darlington, Grizzly, Regulator, and Lavinia); the City Rocks, now part of the Michigan-Utah group (this included the Utah, an early producer); and the South Hecla (includes the Alta Hecla, South Columbus, and Wedge). The Flagstaff and the Columbus Consolidated are now owned by the Wasatch Mines Co. For several years the Columbus Consolidated operated a concentration mill, but it was destroyed by fire in September, 1914.

The Little Cottonwood district has yielded a regular production of metal annually since 1867 and may be expected to continue productive for many years to come. Unfortunately, no complete records were kept of the annual production in the early period of operation, but enough data are available to make very close estimates possible. Such data are found in the statistical reports on mines and mining in the States and Territories west of the Rocky Mountains for the years 1867 to 1876. Between 1875 and 1880 statistics were not compiled by the Government, and for these years the mining journals and the Salt Lake Tribune furnish statistics. The operations and statistics of many of the most prominent producers from 1870 to 1880 were ably reviewed by D. B. Huntley in volume 13 of the Tenth Census report. During the succeeding years the reports of the Director of the Mint give fragmentary figures until the year 1901, and the statistics from that year to the end of 1913 have been compiled by the United States Geological Survey. In the tables of production (pp. 193–194) the statistics are combined with those for the Big Cottonwood district.

BIG COTTONWOOD DISTRICT.

The Big Cottonwood district, organized July 11, 1870, is in Cottonwood Canyon, in Salt Lake County, north and east of the Little Cottonwood district, its boundaries being the summits of the ridges on each side of the canyon. Most of the mines are on the southern ridge. Most of the ore, from the earliest days, has been hauled by wagon down the canyon to Sandy, at present a station of the Denver & Rio Grande and San Pedro, Los Angeles & Salt Lake railroads, or directly to the smelters and samplers in that vicinity.

The Maxfield mine, on the north side of Cottonwood Canyon, is 14 miles east of Sandy. Argenta, in the seventies the principal mining camp of the district, is but a quarter of a mile from the Maxfield mine. This property, up to the year 1880, was mostly patented and only slightly developed. During 1880, according to Huntley,[1] it produced about 90 tons of lead ore, containing 30 to 100 ounces of silver, which was sold for $4,518. The value of the product prior to 1880 was roughly estimated at $20,000. Transportation costs in 1880 to Sandy were $4 to $4.50 a ton. The shipments made in 1880 averaged 60 ounces of silver to the ton and 35 per cent of lead. The most productive period of the mine was in 1892 and 1893. No records are available of the total quantity of silver and lead produced from the mine, but it is reported[2] that $1,053,000 would cover the total yield of the property from 1875 to the end of 1906. Since 1906 lessees have produced some lead ore each year. The total dividends paid by the Maxfield Co. amounted to $118,000. The mine was pumped out early in 1915, with a view to further development.

On the south side of Cottonwood Canyon there are several side ravines or forks, including Mill, South, Honeycomb, Silver, Days, Mill D South, and Mineral. Between Honeycomb and Silver forks, 2½ miles northeast of Alta, is the Prince of Wales group, consisting of the Antelope, Prince of Wales, Wandering Boy, Highland Chief, Wellington, and Warrior claims. All were discovered about 1870. Very important lawsuits were pending between 1871 and 1875, in which the owners of the Highland Chief were defeated and a compromise was effected with the owners of the Wellington. The Prince of Wales group is credited with a production of 10,121 tons of ore[3] to the end of 1890. Since that time a very little has been produced by lessees, who in 1909, 1910, and 1911 made shipments of ore containing 0.01 ounce of gold and 90 to 144 ounces of silver to the ton, 1.25 to 3.75 per cent of copper, and 12 to 21 per cent of lead. Assays made on shipments in 1879 show the lead to have averaged between 25 and 48 per cent and the silver between 61 and 224 ounces. Mining

[1] Huntley, D. B., op. cit., p. 428.
[2] Personal statement of A. L. Thomas, jr., Salt Lake City.
[3] Compiled from reports of Director of Mint and commissioners, 1870–1890.

by lessees was discontinued because of the large amount of water present in the lower workings, to which the ore is said to extend. The total value of the ore produced from the Prince of Wales group between 1870 and 1890, including a few shipments since, is variously estimated from $1,012,000 to $2,000,000. According to Huntley,[1] about 30 men were employed in 1880, many of them working under contracts or leases. He says:

> The mine is opened by several tunnels, the main one being 2,200 feet long and running on the vein entirely through the ridge, and an 1,100-foot incline, on which there are hoisting works, on the crest of the ridge. The cuttings are said to be 1,300 feet in extent.

The Richmond and Theresa claims, south of the Prince of Wales, had about 1,400 feet of openings and produced lead-silver ore valued at $150,000 to the end of 1880. The Reade and Benson claims are often mentioned in early reviews as producers of rich ore. Subsequently these and other claims in the vicinity were incorporated into the Kennebec group, whose record as a producer was not important. Huntley[2] estimates the total product to 1880 at $600,000.

The Ophir, discovered in 1870, according to Huntley, had produced about $30,000 worth of ore to 1880.

The mines of the Kessler Mining Co., later purchased by the Carbonate Co., are estimated by Huntley to have produced ore valued at about $380,000 previous to 1880.

Other mines active in the district previous to 1880 are mentioned by Huntley as follows:

Mine.	Total length of openings.	Total product.	Condition at close of the census year (1880).	Remarks.
	Feet.			
Silver Mountain Mining Co.	500	$10,000	Active	Ore assays 50 ounces silver, 35 per cent lead, and $3 gold.
Thor and Bright Point	500	2,000	do	Ore assays 60 to 100 ounces silver and 40 to 60 per cent lead.
Elgin Mining Co.	700	Small.	Prospected irregularly.	Veins small.
Puterbaugh	300	[a] 840		
Imperial Mining, Milling & Smelting Co.		Small.		A few hundred feet of cuttings. Worked irregularly for two other years.
Dolly Varden	1,400	25,000		Property in litigation.

[a] During 1880.

In recent years very few properties in the Big Cottonwood district have produced any ore. The more productive have been the Black Bess group of the Michigan-Utah Mining Co., the Maxfield, and the Cardiff. It is impossible to segregate the production of the district from that generally credited to the Little Cottonwood district; therefore, all the statistics available for the Big Cottonwood district have been combined in the table with those of the Little Cottonwood district in the table below.

[1] Huntley, D. B., op. cit., p. 428. [2] Idem, p. 429.

Production of metals in Big and Little Cottonwood mining districts, 1901–1913, by years.

Year.	Ore mined.	Gold.		Silver.		Copper.		Lead.		Total value.
		Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	
	Short tons.	*Fine oz.*		*Fine oz.*		*Pounds.*		*Pounds.*		
1901	935	161.19	$3,332	37,532	$22,519	.....	.....	300,298	$12,913	$38,764
1902	850	146.53	3,029	34,120	18,084	58,490	$7,136	272,999	11,193	39,442
1903	1,977	85.24	1,762	69,336	37,441	102,260	14,010	552,483	23,204	76,417
1904	4,878	306.36	6,333	106,249	60,828	235,832	29,479	1,190,005	52,063	148,703
1905	26,003	949.99	19,638	371,683	224,496	811,639	126,616	1,702,258	80,006	450,756
1906	20,801	762.05	15,753	345,102	231,218	1,193,743	230,392	1,922,276	109,570	586,933
1907	19,896	976.93	20,195	399,417	263,615	1,074,238	214,848	2,337,924	123,910	622,568
1908	5,866	321.36	6,643	63,246	33,520	269,212	35,536	603,840	25,362	101,061
1909	13,208	335.72	6,940	158,867	82,611	1,842,711	239,553	332,475	14,296	343,400
1910	14,203	381.87	7,894	202,010	109,085	804,018	102,110	1,102,907	48,528	267,617
1911	6,040	139.17	2,877	158,448	83,978	407,719	50,965	1,043,608	46,963	184,783
1912	6,566	142.46	2,945	186,183	114,503	386,963	63,849	1,135,191	51,084	232,381
1913	5,167	112.08	2,317	93,821	56,668	136,901	21,219	1,091,617	48,031	128,235
	[a] 126,390	4,820.95	99,658	2,226,014	1,338,566	7,323,726	1,135,713	13,587,881	647,123	3,221,060

[a] Within the period covered by this total the Columbus Consolidated Co. operated its concentration mill from 1904 to 1912, inclusive, producing 15,172 tons of copper-lead concentrates. In 1905 the Continental Alta produced lead concentrates, and in 1910 some copper-lead concentrates were recovered from Columbus Extension ores.

Production of metals in Big and Little Cottonwood mining districts, 1867–1913, by periods.

Period.	Ore mined.	Gold.		Silver.		Copper.		Lead.		Total value.
		Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	
	Short tons.	*Fine ounces.*		*Fine ounces.*		*Pounds.*		*Pounds.*		
1867–1870 [a]	5,573	59.99	$1,240	703,138	$933,667	.....	.....	6,444,800	$387,048	$1,321,955
1871–1880 [b]	133,796	3,585.02	74,109	6,259,000	7,876,458	.....	.....	95,201,998	5,450,541	13,401,008
1881–1890 [c]	22,515	5,426.90	112,184	883,034	927,886	.....	.....	14,784,900	662,998	1,703,068
1891–1900 [d]	13,885	7,581.38	156,721	707,731	525,144	.....	.....	8,457,869	323,954	1,005,819
1901–1913 [e]	126,390	4,820.95	99,658	2,226,014	1,338,566	7,323,726	$1,135,713	13,587,881	647,123	3,221,060
	302,159	21,474,24	443,912	10,778,917	11,601,621	7,323,726	1,135,713	138,477,448	7,471,664	20,652,910

[a] J. R. Browne (Mineral resources of the States and Territories west of the Rocky Mountains, 1868, p. 486) refers to the operation (in 1867) of two small furnaces in Cottonwood Canyon. These furnaces were under construction in 1866, according to the Daily Union Vedette of Aug. 25, 1866, and in September they began producing lead, which evidently was lost in slag and cinders (Vedette, Oct. 26, 1867) and recovered in 1867 by a German metallurgist named Reese under the supervision of A. A. Hirst, who had reconstructed the works for treatment of North Star ores. According to R. W. Raymond (Statistics of mines and mining in the States and Territories west of the Rocky Mountains, 1870, p. 223), the first efficient smelter (a cupola), erected by Woodhull Bros., 7 miles south of Salt Lake City, began to operate in June, 1870, producing 5,000 pounds of bullion in 36 hours. Most of the ore was from the Monitor and Magnet claims (idem, p. 222). Shipments of ore from the Emma mine (located August, 1868) began in June, 1870, and up to Dec. 31, 1870, Walker Bros. had shipped 4,200 tons of ore (mostly Emma, with an average assay of 35 per cent of lead and $182 in silver to the ton). Lead bullion shipments, mostly from Cottonwood ores, were 2 tons to England and 6½ tons to San Francisco (Raymond, R. W., idem., 1872, p. 319). In the fall of 1870 mining locations in the Big Cottonwood district (the Davenport, Theresa, Wandering Boy, Maxfield, and Prince of Wales) had each yielded some ore for shipment (idem, p. 321). On the Little Cottonwood side the Emma mine had produced up to August, 1871, 10,000 to 12,000 tons of ore, which assayed 100 to 216 ounces of silver to the ton and from 30 to 66 per cent of lead, averaging 160 ounces of silver and from 45 to 50 per cent of lead. The total value of the ore, at the cash price paid for it, a large part of it at Liverpool, was about $2,000,000 (idem, p. 323). The Flagstaff mine, up to April, 1871, had yielded over 80 tons of shipping ore.

[b] Between 1871 and 1880 the largest producers were the Emma (largely depleted by 1873), Flagstaff, North Star, Vallejo, Joab Lawrence Co., City Rock, Grizzly and Lavinia, Davenport, Savage and Montezuma, Reade & Benson, and Prince of Wales. According to Huntley (op. cit., pp. 423, 424), the Emma mine had yielded to June 1, 1880, ore aggregating 27,451 tons, for which $2,637,727 was received. The rich ore bodies of the Flagstaff mine gave out in December, 1873, having produced about 31,000 tons, which probably assayed $10 in gold and 60 ounces of silver to the ton and 40 per cent of lead and which sold for $80 a ton. Between 1874 and 1879 about 69,000 tons was produced from the Flagstaff, probably assaying $4 in gold and 30 ounces of silver to the ton and 20 per cent of lead, and was sold for $30 a ton, aggregating from the beginning about $4,550,000 (idem, p. 428). The Prince of Wales and Antelope groups of claims were discovered about 1870 and had a record of producing over $1,000,000 to the end of 1882 (U. S. Mint Rept., 1884, p. 421). Subsequent records of the Prince of Wales in the Mint reports to 1890 show not over 10,121 tons of ore shipped, averaging probably 105 ounces of silver to the ton and 30 per cent of lead.

[c] Between 1881 and 1890 the Flagstaff produced in 1881, the Joab Lawrence or Vallejo and City Rocks almost continuously to 1891, and the Maxfield was the heaviest shipper in the years 1884, 1887, 1888, and 1890.

[d] In 1891 and 1892 the Maxfield and Flagstaff were the principal producers. Between 1891 and 1900 very little or no mention of these districts was made in the reports of the Director of the Mint. The figures given are differences between the known output of the other districts in Salt Lake County and the total for the county as given by the Director of the Mint in the reports for each year.

[e] Compiled from producers' reports to the United States Geological Survey.

AMERICAN FORK DISTRICT.

The American Fork district, at the head of American Fork canyon, is separated from the Little Cottonwood district by a sharp divide. It was organized July 21, 1870, and has an area of 6 square miles. The mining town, called Forest City, was 18 miles from the town of American Fork. In later years, since the decline of the Miller mine, the district has yielded only a small production.

Huntley[1] reviews the conditions as they existed in 1880 as follows:

The Miller mine, formerly the principal mine of the district, was discovered in September, 1870, and was sold the following year for $120,000 or over. The Sultana smelter (three stacks) was erected in 1871–72, and ran irregularly until the spring of 1875. In 1871–72 a narrow-gage railroad was built up the canyon to within 4 miles of the smelter, costing $240,000, if report is correct. At the same time 25 stone charcoal kilns, 15 at the smelter and 10 at the end of the railroad, were constructed. Everything was done on a grand scale. At times 200 men were employed. The ore bodies gave out, and the company shut down the mine in December, 1876, since which time it has only been worked on lease. The charcoal kilns, which were of the beehive pattern and held about 25 cords each, ran almost continuously from 1872 to 1877, making coal for the Salt Lake smelters. The track was taken up in 1878 and the iron sold. The bottoms of the old furnaces were torn up to get the large amount of lead contained in them, and the old slag dumps were profitably picked over four times to find scraps of lead, unreduced ore, and matte. * * * Various estimates are given of the total product and the average grade of the ore of the Miller mine. The range of these is between 13,000 and 15,000 tons, assaying from 40 to 54 per cent lead, from 30 to 47 ounces of silver, and from $2 to $10 gold. * * *

The Wild Dutchman mine is a quarter of a mile east of Forest City. It was discovered in 1872 and sold to the Omaha Smelting & Refining Co. of Nebraska, who worked it until September, 1876, when it was leased. * * * Five large bodies [of ore] have been found, one 20 feet from the surface, one 300 feet from the surface, and others between these. The ore is the usual ochery carbonate of lead found in a lime formation and contains small amounts of heavy spar. * * * The mine is opened by seven working tunnels from the hillsides at various levels. * * * The total product of the mine to 1880 was estimated at 7,900 tons, averaging 45 ounces of silver and 40 per cent lead.

The other mines of American Fork district are:

[1] Huntley, D. B., op. cit., pp. 444–445.

Mine.	Total length of openings.	Total product.	Condition at close of the census year.	Remarks.
	Feet.			
Pittsburg	1,185	2,000 tons.	Active	Ore assays 13 ounces silver, 44 per cent lead, and $2 gold.
Sunday	300	$17,000	5 men tunneling	
Silver Bell	[a] 120	130 tons of 100-ounce ore.	Active	
Excelsior Silver Mining Co.			do	Developments limited; ore argentiferous galena, assaying 60 ounces silver and 50 per cent lead and a trace of gold.
Utah Consolidated Mining Co.				Seven claims. Several hundred feet of developments.
Queen of the West	1,000		Idle	In 1874 $28,000 taken from one pocket.
Orphan		250 tons	Active	Ore assays 60 ounces silver and 40 per cent lead.
Live Yankee and Mary Ellen		600 tons	Idle	Ore formerly assayed 18 ounces silver, 7 per cent lead, and $4 gold.
Treasurer	475	A few tons.		Ore assayed 85 ounces silver and some lead.
Silver Dipper	600			Ore assays 10 to 20 ounces and 40 per cent lead.
Whirlwind	1,000	$3,000		
Noncompromise	400	$15,000		Ore assayed 40 ounces silver.
Hudson		None	Some prospecting done.	An extension of the Pittsburg.

[a] Incline; also some tunneling work.

After the closing of the Miller mine in 1876 assessment work was performed yearly and some ore produced and shipped. In 1904 a body of ore was found in the Miller mine, which during the next few years yielded metals to the value of several hundred thousand dollars, but since 1907 there has been a decline in the output.

The following tables show the tonnage and yield of ore produced in the district from 1901 to 1913, and by periods from 1870 to 1913:

Production of metals in American Fork district, 1870-1913, by periods.

Period.	Gold.		Silver.		Copper.		Lead.		Zinc (spelter).		Total value.
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	
	Fine ounces.		*Fine ounces.*		*Pounds.*		*Pounds.*		*Pounds.*		
1870–1880 [a]	3,116.10	$64,415	1,377,600	$1,683,542			14,868,000	$882,744			$2,630,701
1881–1890 [b]	526.80	10,890	32,475	34,071			693,000	30,405			75,366
1891–1900 [c]	200.00	4,134	22,000	15,876			510,000	17,655			37,665
1901–1913 [d]	9,026.70	186,597	359,912	214,088	104,663	$16,956	11,257,628	554,493	2,712	$152	972,286
	12,869.60	266,036	1,791,987	1,947,577	104,663	16,956	27,328,628	1,485,297	2,712	152	[e] 3,716,018

[a] The American Fork district was organized July 21, 1870. Work was not commenced to any extent on the mining claims until the fall of that year. The Miller mine, discovered in September, 1870, was the principal producer. In 1871–72 the Sultana smelter was built for the reduction of Miller ore and ran irregularly until the spring of 1875. The Miller ore bodies gave out and the mine was closed in December, 1876. It was in the hands of lessees at different periods to the end of 1880. D. B. Huntley (op. cit., p. 444) estimates the production of ore from the Miller mine to the end of 1880 between 13,000 and 15,000 tons, assaying from 40 to 54 per cent of lead and 30 to 47 ounces of silver and $2 to $10 in gold to the ton. In 1872 the Wild Dutchman mine was discovered and worked by the company until September, 1876, when it was leased. Its total production to 1880 was estimated at 7,900 tons of ore, averaging 45 ounces of silver to the ton and 40 per cent of lead. The Pittsburgh, Sunday, Silver Bell, Orphan, Queen of the West, Live Yankee, Whirlwind, Non-compromise, and, in the Silver Lake section, the Milkmaid and Wasatch King, were producers prior to 1880.

[b] During the period 1881–1890 development work was done, but very little ore was shipped, probably not averaging over 100 tons a year. The Director of the Mint (Rept., 1886, p. 224) shows that the aggregate shipments of the Bellerophon, Live Yankee, Milkmaid, Miller, Silver Bell, Sultana, and Wild Dutchman in 1886 amounted to 80½ tons.

[c] In 1891 the Wild Dutchman, North Star, Kalamazoo, and Live Yankee properties yielded an aggregate of 100 tons of ore, according to the Director of the Mint (Rept., 1891, p. 224). Estimates were made for the remaining years of this decade, and it is presumed that the average ore yield was not greater than in 1891.

[d] For the period 1902 to 1913, inclusive, the figures of production were collected by the Survey; those for the year 1901 are estimated from the best records available.

[e] The total ore mined between 1870 and 1880 is estimated at 39,950 tons; 1881–1890, 990 tons; 1891–1900, 1,000 tons; and 1901 to 1913, 17,162 tons, making the total output of ore 59,102 tons. This figure, used in seeking the average of the ore produced, gave $4.50 in gold and 30.32 ounces of silver to the ton and 23.12 per cent of lead, and, in value, including small quantities of copper and zinc, $62.87 to the ton.

Production of metals in American Fork district, 1901-1913, by years.

Year.	Ore.	Gold.		Silver.		Copper.		Lead.		Zinc (spelter).		Total value.
		Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	
	Tons.	*Fine ounces.*		*Fine ounces.*		*Pounds.*		*Pounds.*		*Pounds.*		
1901	128	35.40	$732	3,508	$2,111	.....	.....	76,800	$3,302	.....	.....	$6,145
1902	39	3.53	73	663	351	.....	.....	23,666	970	.....	.....	1,394
1903	64	21.28	440	1,872	1,011	.....	.....	11,214	471	.....	.....	1,922
1904	922	800.00	16,537	18,880	10,809	.....	.....	617,280	27,006	.....	.....	54,352
1905	2,479	1,301.00	26,894	27,740	16,755	88	$14	1,374,660	64,609	.....	.....	108,272
1906	2,914	2,096.82	43,345	47,611	31,899	.....	.....	1,959,784	111,708	.....	.....	186,952
1907	4,706	3,483.80	72,017	93,551	61,744	45,098	9,020	3,612,785	191,478	.....	.....	334,259
1908	2,356	745.52	15,411	64,840	34,365	26,073	3,442	1,386,596	58,237	.....	.....	111,455
1909	1,025	125.13	2,587	39,821	20,707	10,670	1,387	628,148	27,011	.....	.....	51,692
1910	965	183.12	3,785	34,204	18,470	12,227	1,553	519,749	22,869	.....	.....	46,677
1911	494	79.05	1,634	9,441	5,004	4,092	511	386,544	17,394	.....	.....	24,543
1912	659	121.44	2,510	11,172	6,871	3,466	572	380,630	17,128	.....	.....	27,081
1913	411	30.61	632	6,609	3,991	2,949	457	279,772	12,310	2,712	$152	17,542
	17,162	9,026.70	186,597	359,912	214,088	104,663	16,956	11,257,628	554,493	2,712	152	972,286

DIVIDENDS.

Dividends aggregating several million dollars are reported to have been paid to stockholders by mining companies operating in the Little Cottonwood and Big Cottonwood districts. Some of the published statements follow, but many of the facts are discredited by old residents, who say that the managements of early mine operations were very expensive. Raymond[1] reviews a statement in which dividends are mentioned, furnished by N. M. Maxwell, superintendent of the Flagstaff mine, as follows:

The product of the Flagstaff furnaces during 1872 was 3,000 tons of metal, containing—

Silver	$390,000; average per ton,	$130
Gold	120,000; average per ton,	40
Lead	240,000; average per ton,	80
Total	750,000	

The capital of the company is £300,000, on which 30 per cent in dividends have been paid during the last three months and 24 per cent during those preceding, the total amount of dividends paid being £76,000.

In a later report[2] it is stated:

This splendid mine has produced during 1873, according to the directors' report, 15,000 tons of ore of an average value of $54 per ton in the ore market. The same report says the expenses for mining ought to have been $5, hauling $8, establishment charges $4, total $17, leaving $37 profit per ton. Yet there was not only no profit made, but in the fall the company was very heavily in debt and the value of shares depreciated rapidly in London.

According to Huntley,[3] who reviews conditions in the district up to October, 1880, the Emma mine, worked by English managers, paid $300,000 in dividends (one authority says $1,300,000) until September, 1874, when it was attached for an indebtedness of $300,000. It was then idle until October, 1877. The Flagstaff mine, when owned by the English company, paid dividends that amounted to about $350,000.

From all available data, the dividends paid by the mining companies in the Little and Big Cottonwood districts to the end of 1913 are as follows: Emma, $300,000; Flagstaff, $350,000; Columbus Consolidated, $212,623; Vallejo and Titus (Joab Lawrence), $180,000; Maxfield, $117,000. If $700,000 is estimated to cover the dividends realized from other properties, including the Prince of Wales, it gives a total dividend record of over $1,850,000.

[1] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1872, p. 247, 1873.
[2] Idem for 1873, p. 260, 1874.
[3] Huntley, D. B., op. cit., p. 423.

DEVELOPMENT.

As in most other mining districts, the earliest development work on the ore bodies consisted in following them down with shafts or inclines. In this region, however, large flows of water were frequently encountered at relatively shallow depth. The heavy cost of pumping and the strong relief of the region early led to the driving of tunnels for the double purpose of draining and developing the deposits. These tunnels have been carried to increasing depths, and in recent years there has been a general tendency toward the consolidation of properties into large groups and the development of these groups by deep drainage tunnels. Such tunnels have been and are being driven from both sides of the ridge between Little Cottonwood and Cottonwood canyons.

The strong relief of the region makes it especially adapted to exploration by tunnel, and there can be no question that this is the most practical method of development. The great abundance of "fine tunnel sites" has apparently been a temptation that was hard to resist, as is shown by the scores of such works that have been started. That more than a "fine site" is necessary to the financial success of such a project, however, is indicated by the large percentage of failures that have resulted.

CLASSIFICATION OF THE ORE DEPOSITS.

GENERAL TYPES.

All the deposits of commercial importance that have been developed to the present time occur in the sedimentary rocks. Some small veins in the intrusive rocks have been prospected to a slight extent, but so far as known they have yielded no metal.[1] The deposits in the sedimentary rocks can be referred to three general types, but the separation of these types in the mines is not always readily accomplished, as they show transitions from one to another. The three main types recognized are contact deposits, fissure deposits, and bedded deposits.

At the time of visit some of the mines that have made the district famous were idle, and only meager notes concerning the occurrence of the ores in them were obtained, but the data from the active mines give a good idea of the character and relations of the different types of deposits. Data on several of the old mines have been taken from reports made by engineers at the time the mines were active.

CONTACT DEPOSITS.

Under contact deposits are included replacement deposits in limestone closely associated with intrusive rocks and containing the min-

[1] Since this was written it has been reported that several tons of molybdenum ore has been produced by the Alta-Gladstone Co. from a quartz-pyrite-molybdenite vein in the granodiorite of the Little Cottonwood stock about 2 miles west of Alta.

erals commonly known as "contact minerals," such as magnetite, garnet, and diopside. Deposits of this character are present along the north border of the Clayton Peak stock, where it is in contact with the limestone, and are also associated with smaller bodies of intrusive rock in the limestone. Certain strata in the limestone have been most susceptible to the action of the mineralizing solutions and have in some localities been partly replaced for several hundred feet from the contact.

At several places in the limestone north of the Clayton Peak stock, several hundred feet from any exposure of igneous rock, were noted deposits that are mineralogically similar to the contact deposits and are classed with them. It is possible that they are not far distant from intrusive rock which is not exposed at the surface. Deposits of this character occur along the southern border of the Clayton Peak stock and are associated with dikes in the sediments between the Clayton Peak and Little Cottonwood stocks.

Mineralogically the deposits contain, in addition to unreplaced carbonate, diopside, garnet, monticellite, muscovite, phlogopite, magnetite, hematite, and iron and copper sulphides. Two species of garnet were noted—a light-yellow variety, probably an iron-lime garnet, and a beautiful green variety, probably containing chromium. The latter was noted especially northwest of Lake Solitude. Ludwigite occurs in contact-altered limestone northeast of the City Rocks mine.

At several localities along the north border of the Clayton Peak stock the deposits contain abundant magnetite and specularite, and have a high content of iron. The copper content varies considerably. Bodies of the material are said to average above 2 per cent of copper and selected portions to average above 5 per cent. The deposits all contain small amounts of gold and silver. Owing to the high cost of transportation in the district it has not been possible to market this material at a profit, and consequently the deposits of this type have been but little developed, and have yielded little metal. In other localities in the State, where transportation is cheaper, it has been found possible to work deposits of this character, the high content of iron serving to pay part of the expense of mining and transportation.

FISSURE DEPOSITS.

GENERAL CHARACTER.

Under fissure deposits are included those in which the minerals occur mainly as a filling of fissures. In nearly all of them there is some replacement of the wall rock, and this replacement may become so extensive at certain points that the deposit approaches the

bedded type. On the other hand, contact minerals may be present in the replaced wall rocks, and such deposits approach the contact type. The fissure deposits are present at different stratigraphic horizons in the district, but where the adjacent rock is especially susceptible to replacement, either on account of chemical composition or of physical character, they give place to bedded deposits. The fissure deposits are mostly in northeasterly and east-northeasterly fissures, which usually have steep northwesterly or northerly dips, but a few have been noted in fissures trending nearly due north. They occur in rocks of very different character and composition, including the Cambrian quartzites and shales, in which the Toledo, Branborg, Cardiff (upper tunnel), Pacific, and one of the Live Yankee veins occur; the Carboniferous limestone, which is the predominant wall rock of the City Rocks vein; and even the Thaynes formation (Triassic), in which the veinlike body of the Barry-Coxe mine is located. The Dutchman, Bay State, and two of the Live Yankee veins are in early Paleozoic, probably Cambrian limestone.

VEINS IN BIG AND LITTLE COTTONWOOD DISTRICTS.

The Toledo vein was not being worked at the time of the writer's visit, though an effort was being made by the Columbus Exposition Co. to locate the vein below the old workings. The following description of the vein is given by Huntley:[1]

> The ore occurs in a fissure vein, from 1 to 3 feet wide, cutting diagonally across a quartzite formation, dipping NNW. 80°, and is found in several chimneys 50 feet long on the strike and about 50 feet apart. They dip with the strike toward the east. The ore is a hard, porous brown siliceous oxide of iron of very high grade. It was said to have averaged from 80 to 109 ounces to the ton. Water was found 200 feet from the surface, but the character of the ore did not change. Where the vein passed from the quartzite into a belt of schist there was much pyrite. The mine is operated through a shaft 455 feet deep, vertical for part of its length. The horizontal development of the vein is 350 feet, and the total cuttings are estimated at 2,000 feet.

The City Rocks fissure (now Michigan-Utah mine), as developed near the surface, is thus described by Huntley:[1]

> The Utah is a fissure vein, from 1 foot to 20 feet wide, dipping 70° or more NW. through strata of blue and white siliceous limestone or dolomite, which dip about 30° NE. It had outcrops in places and is known to extend 4,000 feet in length and 700 feet in depth. The gangue of the vein is oxide of iron and a sand, apparently the result of the decomposition of the siliceous country rock. The ore is from 1 foot to 10 feet (averaging from 2 to 3 feet) wide, immediately in contact with the walls, but not confined to either. Three chimneys have been found 200 feet long and about 300 feet apart. One came to the surface, and the others to within 100 feet of it. They dip with the strike about 65° NE. The

[1] Huntley, D. B., op. cit., p. 425.

positions of these chimneys appear to be determined by the strata of white limestone. The ore makes where the vein crosses the white limestone but pinches where the harder blue limestone is encountered. It is a soft red, sometimes rather sandy oxide of iron containing carbonate of lead and galena and in places stains of malachite. The first class assays 30 per cent lead, 30 ounces and upward of silver, and a trace of gold. There is also much low-grade jigging ore in the mine. On the south side a dike of porphyry appears, running nearly parallel with the vein. Near the porphyry the ore has not been so rich.

The vein has been prospected at greater depth by the Lake Solitude tunnel, which opens it 300 feet below the City Rocks tunnel. In 1912 the vein had been developed for several hundred feet by this tunnel and a winze had been sunk 200 feet below the tunnel level to the ninth and tenth levels. A raise connects this tunnel with the City Rocks tunnel, and levels have been opened between the two. In the lower levels the vein ranges from a few inches to 3 or 4 feet in width, and where the fissure crosses certain of the limestone bedding planes replacement has extended several feet from the fissure.

The ore is oxidized to the Lake Solitude tunnel level and is said to be oxidized to the tenth level, 200 feet below the tunnel. The ore contains abundant limonite and in places rather abundant manganese oxide and notable amounts of wulfenite.[1]

The commercially important metals are lead, silver, and copper, with small amounts of gold.

Raymond[2] describes the mineralization in the Savage and Montezuma claims as follows:

Savage: This claim comprises 1,400 feet and is located high up on the hillside, about 1,500 feet above the Emma and a few hundred feet east of the Flagstaff. It is opened to a depth of over 230 feet by a single inclined prospecting shaft following the vein and without any side drifts. The ore shows near the entrance of the incline as a rusty, gossan-like mass or vein, cutting the beds of limestone vertically. A few feet below the surface, within the incline, the thickness of the vein overhead is about 3 feet. It pinches up at a point lower down and toward the bottom of the incline opens out again to a vein from 2 to 3 feet wide of rich ore, yellowish and rusty in color and in places streaked with green stains of copper. Quartz vein stone is found at the bottom of the mine, and it is hoped that this will prove to be a continuous, regular vein formation. The ore is soft and earthy, much like that from the Emma and other claims. It is rich in silver and lead. The mineral wulfenite is found disseminated in small, thin crystals throughout the vein.

The Montezuma is about 90 feet west of the dump of the Savage. The vein is vertical, or nearly so, like the Savage, and extends apparently from 3° to 5° west of north (magnetic). The croppings are rusty and rather hard, but below the ore is softer and richer in silver and lead. The country rock is a hard black limestone. This vein, like the Savage, is opened by an incline to a depth of 240 feet. This incline follows the ore, and its direction is about

[1] Hess, F. L., Wulfenite at Alta, Utah: U. S. Geol. Survey Bull. 340, p. 238, 1908.

[2] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1871, p. 324, 1872.

N. 40° W. The vein may be said to average, where opened, 2½ feet in thickness. Some 200 tons of ore had been shipped up to July and about the same quantity remained upon the dump.

The deposits in the Columbus Consolidated mines (part of the Wasatch group) are in part fissure veins, though the larger deposits may better be classed as bedded deposits.

Huntley[1] describes the mines on Honeycomb Fork as follows:

The Butte mine, at the head of Honeycomb Fork, 2½ miles northeast of Alta, was discovered in 1869 and has been worked irregularly since. It is said to be a fissure vein in limestone, from 6 inches to 4 feet wide, dipping 55° N., and is supposed to be an extension of the Utah and City Rock of Little Cottonwood district. It outcropped for several hundred feet on the hillside in the form of a soft ocher-stained limestone. Ore occurs on the footwall in 8 or 10 lenticular bodies, from 1 inch to 3 feet wide, at considerable distance below the surface. It is a high-grade ocher and carbonate. Sometimes much black oxide of manganese is found. The mine is dry (excepting surface water) and is worked through a 200-foot tunnel. The total cuttings, including two old inclines, are 2,300 feet Nine men were employed during the census year. The total product to June 1, 1880, was estimated at $27,000.

The Oregon is an extension of the Butte. The property [is held by a Canadian corporation and] also includes four patented prospects on which very little work has been done—the Columbus, the Taylor, the Abbey, and the Black Bess. It is a fissure vein, from 1 to 15 feet (average, 3 feet) wide, dipping 60° NNE. in limestone. Only one body of ore has been found. This came to the surface and was 120 feet long, from 3 inches to 3 feet wide, and extended to a depth of 300 feet. It assayed about 50 ounces silver and 30 per cent lead. The mine contains 1,600 feet of cuttings and has been opened 350 feet on the dip and 480 feet horizontally (by means of an 8-horsepower vertical engine). Water was found at 100 feet, but no change occurred in the oxidized character of the ore. During the census year eight men were employed, and a small amount of ore was extracted. It was idle at the time of the writer's visit, owing to the loss of the lawsuit between it and the Butte. The total product to 1880 was estimated at $10,000.

The main output of the South Hecla mine has been derived from fissure deposits, though contact deposits associated with dikes are also present. The principal metals obtained in the lower workings have been copper and lead, though it is said that near the surface ores with a high lead content were mined.

Fissure deposits are said to be present in the sedimentary rocks between the Little Cottonwood and Clayton Peak stocks in the Albion and other mines, but were not examined.

The vein of the Cardiff mine, exposed in the upper tunnel, follows a fissure that strikes N. 35° E. and dips 65° NW. The wall rock is the "upper quartzite." The ore exposed in 1912 consisted of pyrite and tetrahedrite and a minor amount of galena in a quartz gangue. No zinc blende was noted. A qualitative test proved the presence of a little zinc in the tetrahedrite. No inclusions of zinc blende were

[1] Huntley, D. B., op. cit., p. 428.

detected by microscopic study of the polished mineral, but small amounts of a secondary mineral resembling covellite were noted surrounding pyrite grains in the tetrahedrite and filling minute fractures. Tetrahedrite containing a notable amount of zinc has been reported from the Park City district.[1] The ore minerals formed apparently pure bands or lenses 1 to 3 or 4 feet thick. The greatest thickness ever found was said to be 6 feet. The lenses were separated by bands of white quartz and unreplaced quartzite. The ore then mined was said to contain about 12 per cent of copper, a good proportion of silver, and $1 to $2 in gold to the ton. The proportion of galena was said to increase above the upper tunnel, and, locally at least, to mark the upward termination of pay ore. The ore was practically free from oxidation at and below the level of the upper tunnel. At higher levels, in a vein on which the old Cardiff shaft was sunk, lead carbonate ore was found down to a depth of 150 feet below the shaft collar. The large ore body which was found since the writers' visit and which has attracted much attention, belongs to the bedded type of deposits and will be mentioned later.

The Branborg property contains three fissures—the Garfield, Silver King, and Gustavus Adolphus—all striking N. 35°–40° E. and dipping about 60° NW. Another fissure, probably a branch of the Garfield, strikes N. 10° E. and dips about 60° W. The Garfield fissure and its branch carry ore containing pyrite, blende, and galena in a quartz gangue. They have been cut by a long adit, and the Garfield fissure has been followed by drifts to the southwest and northeast. Northeastward it pinches at the quartzite and shale contact. No prospecting for a continuation of the fissure in the limestone above the shale has been undertaken. Shallow pits in the limestone, however, have struck small quantities of lead carbonate, with a high silver content, which may be connected with northeasterly fissures.

The Silver King fissure had not been reached by the tunnel in 1912. It has been traced a long distance on the surface, from the vicinity of the tunnel southwestward across the divide into Little Cottonwood Canyon, and is in line with one of the fissures that extend downward into the granodiorite. Its mineralization is of the same type as that of the Garfield fissure.

The Gustavus Adolphus fissure also has the same type of mineralization, but its ore, so far as mined, contains less zinc and gives higher assay values than that from the Garfield fissure. The mixed sulphide ore from the fissures as a whole will probably require concentration and the separation of blende from galena to yield the best results. It appears well suited for concentration. Small amounts of oxidized ore mined from shallow workings are said to have yielded as

[1] Boutwell, J. M., op. cit., p. 109.

high as 1,000 ounces of silver to the ton, but the oxidized ores are very superficial and constitute almost negligible fractions of the entire veins.

The ore deposits seen in the Barry-Coxe mine, on the southwest slope of Scott Hill, represent a transition in character between the contact and fissure types of deposits, also between the fissure and bedded replacement types. The ore, so far as developed by shallow workings in 1912, occurs as pockets in partly metamorphosed limestone along fissures trending N. 13° W., north and east. The pay ore is found between layers of lean silicate rock and replaces the walls for a few feet from the fissure. The most pronounced replacement exposed at the time of examinaton extended 10 feet from the N. 13° W. fissure. The ore seen was a mixture of pyrite, blende, and galena in a gangue consisting essentially of garnet, diopside, sericite, and quartz. One of the easterly fissures, along a fault plane against which the ore along a northerly fissure stopped, contained green copper stains. The garnet and diopside were formed before the ore and other gangue minerals, but there was no evidence to determine whether the country rock was first partly replaced by contact-metamorphic minerals and at a distinctly later period replaced further by the ore, or whether all the minerals were deposited in definite sequence during one period. Absence of fracturing in the metamorphic minerals favors the latter view.

VEINS IN THE AMERICAN FORK DISTRICT.

The Silver Dipper vein follows a fissure that strikes N. 65° E. and dips 60°–65° NW., in Cambrian quartzite. The vein, which was worked in the seventies, is said to have consisted of pyrite and quartz with some good shoots of galena.

The Waterfall vein lies along a fault trending nearly due north between shale and quartzite. It is marked by pinches and swells, and the swells are about 4 feet thick. The ore minerals are galena, pyrite, tetrahedrite, and a little zinc blende in a gangue of quartz. It has been opened by two tunnels that extend northward and southward from the creek bed where it crosses the vein. The south tunnel in 1912 was 300 feet long, and the north tunnel about 50 feet.

Three veins have been worked or prospected on the Live Yankee property, near the head of Mary Ellen Gulch, but only one was accessible in 1912. This vein lies between a footwall of quartzite and a hanging wall of pyritized porphyry and has a N. 85° W. trend. Its ore minerals are pyrite, chalcopyrite, zinc blende, and galena, and its gangue minerals quartz and barite. One of the other veins lies along an east-west fault zone and is said to have contained the "big stope," mined in early days. The ore of the "big stope" is said to have lain

between walls of shale at the base of the limestone. Its ore minerals, to judge from specimens on the dump, were chiefly pyrite and chalcopyrite in a gangue of quartz and barite. The gold content is said to have been unusually high, ranging from $20 to $80 or more to the ton. The third vein strikes N. 40° E. in Cambrian limestone, but is said to pinch on reaching and following a porphyry dike. Specimens of its ore consist of pyrite, a little chalcopyrite, zinc blende, galena, and jamesonite in a gangue of quartz, barite, and a little ferruginous dolomite. A fourth vein, too small at its outcrop to be of much promise, strikes N. 45° E. in Cambrian limestone and consists mostly of galena in a gangue of dolomite spar. This group of veins differs from those already described in the prominence of chalcopyrite and in a corresponding high gold content. Their mineral and chemical composition, however, show them to be closely related to the other ore bodies of the region, and there is every reason to believe that they were formed at the same time.

Another source of ore on the Live Yankee property has been the glacial drift in the gulch, from which bowlders of galena ore have been washed. It is said that in some of the bowlders quartzite was attached to the ore, and this may indicate a westward continuation of the N. 85° W. vein, or possibly another vein concealed a short distance up the gulch.

A strong vein is being worked in the Pacific (Blue Rock) mine, just south of the southward bend in the American Fork canyon. The vein strikes N. 45° E. in Cambrian quartzite and at one place has a horizontal offset of 18 feet along a N. 70° W. fault. It is 4 to 8 feet in width and has been followed horizontally for about 450 feet, being worked through the lower tunnel of the mine. Below the tunnel its dip is 60° NW. Above the tunnel the dip flattens and the vein narrows upward until it coincides with a bedding plane at or near the shale contact. In the southern part of the mine the ore is continuous from the shale contact, 130 feet up the dip from the tunnel, to and beyond the lowest workings, 70 feet down the dip from the tunnel. The pay ore pinches northward as well as upward. The ore consists of galena and pyrite in a gangue of quartz and barite. The galena diminishes upward, and near the shale contact granular pyrite is the only ore mineral. The barite tends to be localized in lenticular shoots. The ore is in part milling ore and in part of shipping grade. The other workings of the Pacific mine have found showings of ore but were inaccessible in 1912.

The main vein of the Utah Centennial property, southeast of Pittsburg Lake, trends about east and shows some lead ore at the outcrop. In 1912 two tunnels were being driven to reach this vein. The eastern tunnel starts in quartzite at the upper road in a north-northeast direction and follows a narrow vein of white quartz with

some pyrite and a few small pockets of galena. The tunnel had penetrated the shale, in which the quartz of the vein has largely disappeared and dolomite and barite have become conspicuous.

Huntley[1] describes the Wild Dutchman mine as follows:

> The Wild Dutchman mine is a quarter of a mile east of Forest City. It was discovered in 1872 and sold to the Omaha Smelting & Refining Co. of Nebraska, who worked it until September, 1876, when it was leased. * * * The ore-bearing formation is a bedded vein, from 3 to 40 feet (average, 20 feet) wide, in dolomite, dipping 40° SE. This has been worked 300 feet in length and 450 feet in depth. The gangue in general consists of from 2 to 3 feet of shale upon the footwall and a soft clay containing fragments of silica, and strongly stained by oxide of iron, locally known as "lime porphyry." The ore occurs in scattered egg-shaped bunches of from a few pounds to 600 tons. Five large bodies have been found, one 20 feet from the surface, one 300 feet from the surface, and the others between these. The ore is the usual ochery carbonate of lead found in a lime formation and contains small amounts of heavy spar. At the water line, in the 450-foot tunnel level, a large body of base ore was found. This consisted of iron and copper pyrites, galena, and a very large percentage of zinc blende. A porphyry dike is said to cut through the footwall into the vein near the large bodies of ore. The mine is opened by seven working tunnels from the hillsides at various levels. The total cuttings are 3,500 feet. The lessees obtained 2,880 tons by work similar to that which was being carried on at the Miller. The total product of the mine is estimated at 7,900 tons, averaging 45 ounces silver and 40 per cent lead.

The principal vein of the Dutchman mine, seen in 1912, is in Cambrian limestone. It strikes N. 40° E. and dips vertically or steeply southeastward. Its width ranges from a mere streak up to 6 or 8 feet. Its greatest width is attained in a dark-blue limestone which overlies the lowest argillaceous limestone member of the Cambrian limestone. The vein, for most of its course, lies along the contact of a narrow porphyry dike. It ends abruptly on the northeast against a dense, blocky argillaceous limestone, which probably marks a northwesterly fault, but could not be studied closely.

A minor vein parallels the main vein. Both have been followed up to the cemented talus which caps the bedrock, and several masses of ore are said to have been found in the talus. The ore mined from both veins is mostly a sandy mixed lead and zinc carbonate. That mined by lessees in recent years is said to average about 30 per cent of lead, 9 to 17 per cent of zinc, and 50 ounces of silver to the ton. Remnants of primary ore are composed of galena and blende in a barite and carbonate gangue. Quartz is inconspicuous.

The best showings of ore recently reported in the Bay State mine, about midway between the Dutchman and Pacific mines, but on the east side of the canyon, had not been found in 1912. In that year a few small prospect tunnels showed small amounts of galena and barite impregnating a rather light gray limestone, and one showed an

[1] Huntley, D. B., op. cit., pp. 444–445.

interesting occurrence of stibnite. The stibnite, accompanied by barite and a little dolomite, forms small seams or stringers cutting both the limestone and a porphyry dike. Both the limestone and the dike are altered and have a sericitized appearance. The stibnite is partly altered to kermesite, the oxysulphide of antimony ($2Sb_2S_3.Sb_2O_3$), which occurs in tufts of minute red prismatic crystals and probably accounts for all the red staining along the stibnite seams.

BEDDED DEPOSITS.

LITTLE COTTONWOOD DISTRICT.

The bedded deposits have been the most productive of all the types in the Little Cottonwood district, and most of the "bonanza" deposits that made the district famous in the early days were of this type. Typically these deposits occur as replacements of certain beds of the sedimentary rocks adjacent to crosscutting fissures. The deposits are thus more or less tabular in form, are as a whole parallel with the bedding of the sedimentary rocks, and pitch with the intersection of the replaced bedding and the fissures commonly to the northeast. Where the replacement has extended but a short distance from the fissures the deposits have more nearly the form of "chimneys" than of tabular deposits. In some places similar deposits have formed adjacent to faults whose dip and strike do not differ greatly from those of the sedimentary rocks. Such deposits occur notably next to the overthrust fault in the western part of the district. Like the true bedded deposits, they are associated with the northeasterly fissures and have the same general form. The location of the deposits, however, is probably due in part at least to the character of the rocks that has resulted from the movement along the overthrust fault plane.

Most of the deposits are oxidized to the depth to which they have been mined, and it is not possible to determine the original replacement minerals except by scattered remnants of unaltered material. Some deposits that consist largely of sulphide have been developed, notably in the Columbus Consolidated mine. The original minerals recognized are pyrite, galena, sphalerite, and tetrahedrite in a gangue of quartz and unreplaced carbonate. Sericitic muscovite also is a common gangue mineral in the bedded as well as in the fissure deposits and is prominent both in limestone and shaly beds and in "porphyry."

From a bed in the shale series near the Columbus Consolidated mine, specimens were collected on the surface that showed green amphibole, epidote, and quartz, together with pyrite apparently replacing a dolomitic member in the shale series, but similar replacement by

the silicates was not noted underground. A specimen of tetrahedrite from the Columbus Consolidated mine was examined by R. C. Wells in the chemical laboratory of the Geological Survey and found to contain 6.24 per cent of lead, together with arsenic, as well as antimony. In the material examined no lead mineral other than the tetrahedrite was recognized, and it is believed that the lead is contained in that mineral. Whether or not the tetrahedrite of the district carries lead generally or only at certain localities has not been determined. Specimens of supposed tetrahedrite from the neighboring Park City district have been shown by F. R. Van Horn[1] to contain notable amounts of lead. It has already been noted that tetrahedrite from the Cardiff mine and from the Park City district contains zinc in notable amounts. Probably other minerals are present in the primary ores, but they were not recognized in the small number of specimens collected.

As already noted, most of the deposits have been oxidized to the depth to which they have been developed. In numerous places oxidation has extended far below the level of ground water, though it has not been demonstrated to have gone below the zone of surface drainage, as the deep canyons permit circulation to great depth in many of the veins that crop out at the higher elevations. The typical oxidized ore consists of hydrous iron oxides, with the carbonate and sulphate of lead, cerusite and anglesite, and the carbonates of copper in varying amounts, and usually contains manganese oxide.

At the time of visit oxidized ore that was being mined from the "white limestone" in the Alta Consolidated mine contained a large percentage of an undetermined ferric sulphate of lead and copper. This is a yellow earthy mineral that can usually be crushed in the fingers, though some of it forms rather hard lumps. Such lumps may have a core of galena. The mineral has not been quantitatively analyzed, but in appearance and constituents it resembles beaverite and may prove to be that mineral. One of the massive pieces of this ore was sectioned and found to have a core of galena. Surrounding the galena and extending inward along cleavage planes is a narrow zone of anglesite which gives place outward to the yellow mineral with specks of green, possibly malachite. It is evident that in this specimen the mineral has not resulted from the oxidation of a mixture of iron, lead, and copper sulphides, but that the galena has first altered to sulphate and this has subsequently combined with iron and possibly copper that has been brought to it in solution. To what extent minerals of this character were present in the large oxidized bodies of this district is not known, but it does not seem probable that they were confined to this one deposit.

[1] Geol. Soc. America Bull., vol. 25, p. 47, 1914.

Wulfenite, the molybdate of lead, is rather abundant in the City Rocks vein and in some of the ores from the Alta Consolidated mine and is reported from other mines. It is also reported that the ores contain vanadium,[1] but no vanadium-bearing mineral was recognized. Carbonate and silicate of zinc have been recognized in the oxidized ores of the district, but nowhere in abundance. Sphalerite is rather plentiful in some of the sulphide ores, and it is to be expected that the oxidized ores of zinc will be found, but whether they are anywhere present in commercial quantities is as yet unknown.

The ore body of the Emma mine was one of the earliest discoveries, and the mine has been one of the largest producers in the district. It was located in 1868. From 1870 to 1875 it was a large producer of lead and silver, and until the early eighties it continued to produce intermittently, but for many years little work has been done on the property. The mine is in the "great limestone" series and the deposits are supposed to be in the same strata as the Flagstaff and other important deposits of the district. This limestone is cut by a strong easterly fissure and the ores are said to occur as bedded deposits adjacent to this fissure. No examination of the underground workings was made, but the following description of the ore bodies by Huntley[2] is believed to be essentially correct:

The ore-bearing formation is a belt of siliceous limestone, between a limestone hanging and a dolomite foot wall, the belt being about 200 feet wide, dipping 45° NE., parallel to the stratification of the country rock. The ore did not come to the surface, but was found by following a small seam of ocher 50 feet in a tunnel. Two large bodies were found somewhat nearer to the hanging than to the foot wall, following the general dip and strike of the belt. One began near the surface and was 100 feet deep, 300 feet long, and from 1 to 30 feet wide; and the other, a few feet below the first, was 200 feet long, 150 feet deep, and from 1 to 20 feet wide. The ore was a soft brownish-red ocher, containing cerusite, anglesite, galena, and some manganese oxide.

In 1872 Raymond[3] described the Emma mine as follows:

The Emma mine is one of the most remarkable deposits of argentiferous ore ever opened. Without any well-marked outcroppings, there was nothing upon the surface to indicate the presence of such a mass of ore except a slight discoloration of the limestone and a few ferruginous streaks visible in the face of a cut made for starting the shaft. Some of the earliest locators in the canyon assert, however, that in the little ravines below this shaft large masses of galena, some weighing over 100 pounds, were found upon the surface and in the soil. After the discovery of the deposit by means of the shaft a tunnel was run in so as to intersect it in depth. This tunnel extends in a northwesterly direction and is 365 feet long. It intersects the ore mass where it was about 60 feet long and 40 feet wide, measured horizontally. From this level, called the

[1] Hess, F. L., Wulfenite at Alta, Utah: U. S. Geol. Survey Bull. 340, p. 240, 1908.
[2] Huntley, D. B., op. cit., p. 423.
[3] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1871, p. 321, 1872.

first floor, ore has been mined above and below until an excavation or chamber has been formed, varying from 20 to 50 feet in width and from 50 to 70 in length and 77 in height above the tunnel level and 50 in depth below.

In August last a portion of the ore below the tunnel level was still standing, but the mine had produced from 10,000 to 12,000 tons of ore, assaying from 100 to 216 ounces of silver per ton of 2,000 pounds and from 30 to 66 per cent of lead, averaging about 160 ounces of silver and from 45 to 50 per cent of lead. The total value of this ore, at the cash price paid for a large part of it in Liverpool, £36, or $175 in round numbers, was about $2,000,000.

This ore was extracted at comparatively little cost. Most of it was stoped from below upward and was delivered by chutes into the cars upon the tramway laid in the tunnel. In general the ore was soft and easily excavated by picks and shovels, without the aid of gunpowder. It consisted chiefly of ferruginous and earthy-looking mixtures of carbonate and oxide of lead, oxide of iron, and of antimony, mixed with nodules of galena. It appears to have resulted from the decomposition of argentiferous galena and other sulphureted and antimonial minerals containing silver. The ore may be said to be without gangue and does not require hand sorting or separating by mechanical means from worthless vein stone. This ore was shoveled up and put into sacks for shipment without any other delay or expense. The larger part was shipped overland by railroad to New York, and thence by steamer to Liverpool.

The walls of the excavation are very irregular but consist of a hard, white, dolomitic limestone. The ore mass appears to conform to the stratification and to have a general northwesterly direction, dipping to the northeast. The extent of the ore mass in the direction of its length had not been fully ascertained at some of the levels when I visited the mine in July, though in most of the floors it had all been taken out, and the form of the excavation may be taken as marking in a general way the limits of the main body. A peculiar brecciated mass of dolomitic limestone accompanies the ore and may be regarded as vein matter, for nodules of galena are found isolated in its midst, as well as small patches of soft earthy ore disconnected with the main body. The limits of this ore-bearing breccia are not yet ascertained, and prospecting drifts to the northwest along its course may reach other bodies of rich ore.

Raymond[1] quotes from a description of the ores by Silliman, as follows:

Prof. B. Silliman, of New Haven, has made some interesting investigations to determine the composition of the ores occurring in the Wasatch Range, and more particularly of those in the Emma. With his permission, I insert here his remarks on the subject:

"The ores of the mines thus far opened in the Wasatch Mountains are largely composed of species resulting from the oxidation of sulphides, especially galenite and antimonial galena, with some salts of zinc and copper, all containing silver and rarely a little gold. Iron and manganese ochers occur in considerable quantity in some of them, but the process of oxidation has prevailed very extensively, so that the ochraceous character of the ores is the striking feature of most of the mines in this range.

"The great chamber of the Emma mine * * * was found to be filled almost exclusively with epigene species, the product of oxidation of sulphides, and capable of removal without the aid of gunpowder for the most part. The study of this mass reveals the interesting fact that it is very largely composed of metallic oxides, with but comparatively small proportions of carbonates and

[1] Raymond, R. W., op. cit., p. 325.

sulphates. Fortunately I am able to present an analysis of an average sample of 82 tons (183,080 pounds) of first-class ore from the Emma mine, made by James P. Merry, of Swansea, April, 1871, which is as follows, viz:

Silica	40.90
Lead	34.14
Sulphur	2.37
Antimony	2.27
Copper	.83
Zinc	2.92
Manganese	.15
Iron	3.54
Silver	.48
Alumina	.35
Magnesia	.25
Lime	.72
Carbonic acid	1.50
	90.42
Oxygen and water by difference	9.58
	100.00

"The quantity of silver obtained from this lot of ore was 156 troy ounces to the gross ton of 2,240 pounds.

"This analysis sheds important light on the chemical history of this remarkable metallic deposit and will aid us in the study of the paragenesis of the derived species. It is pretty certain that all the heavy metals have existed originally as sulphides, and we may, therefore, state the analysis thus, allowing 8.52 sulphur to convert the heavy metals to this state:

Silica	40.90
Metallic sulphides	52.60
Al, .35; $\dot{M}g$, .25; $\dot{C}a$, 72; $\ddot{M}n_2$; $\ddot{M}n$, .20	1.52
	95.02
Water, carbonic acid, and loss	4.95

"This calculation assumes that the sulphides are as follows, viz:

Galenite	38.69
Stibnite	3.30
Bornite	1.03
Sphalerite (blende)	3.62
Pyrite	5.42
Argentite	.54
	52.60

"This statement excludes the presence of any other gangue than silica, and considering that the ores exist in limestone, the almost total absence of lime in the composition of the average mass is certainly remarkable. The amount of silica found is noticeable, since quartz is not seen as such in this great ore chamber nor, so far as I could find, in other parts of the mine. The silica can have existed in chemical combination only in the most inconsiderable quantity, since the bases with which it could have combined are present to the extent of less than 1½ per cent; nor do we find in the mine any noticeable quantity

of kaolin or lithomarge, resulting from the decomposition of silicates, nor are there any feldspathic minerals. It is most probable that the silica existed in a state of minute subdivision diffused in the sulphides, as I have seen it in some of the unchanged silver ores of Lion Hill, in the Oquirrh Range.

"The absence of chlorine and of phosphoric acid in the analysis corresponds well with absence of the species cerargyrite and pyromorphite, of which no trace could be found by the most careful search among the contents of the mine. The miners speak of the 'chlorides,' and the unscientific observers have repeated the statement that silver chloride is found in the Emma mine, but the ores indicated to me as such are chiefly antimonic ochers.[1]

"The general (perhaps total) absence of the phosphates of lead in the Wasatch and Oquirrh mountains, so far as explored, is a striking peculiarity of the mineralogy of these ranges. On the other hand, the absence of chlorine in the mines of the two Cottonwoods and the American Fork is in striking contrast with the constant occurrence of cerargyrite (horn silver) in the Oquirrh and also in the southern extension of the Wasatch. I have sought in vain for a trace of this species in the districts of the Wasatch just named, and the occurrence of pyromorphite is extremely doubtful.

"Molybdic acid, however, exists pretty uniformly disseminated in the mines of the Wasatch in the form of wulfenite. Although it occurs in minute quantity, it is rarely absent, and may be regarded as a mineralogical characteristic of the districts of the two Cottonwoods and of the American Fork. For this reason a few particulars will be in place here.

"Wulfenite is found associated with calamine (smithsonite), cerusite, malachite, azurite, and more rarely alone in little cavities in the ochraceous ores. In the Emma mine vugs or geodes are occasionally found lined with botryoidal apple-green calamine, rarely crystallized, often brownish and sometimes colorless, but invariably associated with wulfenite. The calamine incloses and covers the crystals of wulfenite, which form a lining of considerable thickness. The wulfenite is in thin tabular crystals of a yellow color, resembling the Carinthian variety of this species. The crystals are very brilliant and perfect, but quite minute, rarely 2 or 3 millimeters in width and not over 1 millimeter in thickness, often less. They are quite abundant in this association, no piece of the calamine which I have seen being without them. They sometimes but rarely penetrate through the globules of the calamine so as to show themselves on the upper surface of that species. But the calamine has obviously formed botryoidal masses around the wulfenite, a crystal of this species being often seen forming the nucleus of the calamine globules.

"These facts are of interest in the paragenesis of these epigene species. The order of production has obviously been, first, the cerusite resting on ochraceous iron, manganese, and other metallic oxides; next, the wulfenite crystals were deposited upon and among the crystals of cerusite; and lastly came the calamine, crystalline at first and as it accumulated becoming fibrous and amorphous, completely inclosing and capping the other species.

"Wulfenite occurs also in this mine, as likewise in the Flagstaff, the Savage, and Robert Emmet, without the calamine, but never, as far as observed, without cerusite and other carbonates. In the Savage masses of cerusite, with various oxides, are interpenetrated by the tabular crystals of wulfenite.

[1] There exists generally among the mining population of the central Territories of the United States a distinction between horn silver and chloride of silver—an error arising, as I am persuaded, from supposing the ochraceous ores to be chlorides not so perfectly developed as to be sectile.

"Although wulfenite forms a very minute factor of the entire ore mass in these mines, by the law of mineral association it may be considered as the characteristic species of the ores of these districts, occurring in the magnesian limestones. So far as I am informed or have observed, wulfenite has not been hitherto found in any of the other mining districts of Utah; but by the same law it may be reasonably looked for whenever deposits of epigene minerals are explored in the same geological and mineralogical relations in the Wasatch Range of mountains.

"The oxidizing and desulphurizing agency which has acted upon the great ore mass of the Emma mine, whatever it was, has performed its work with remarkable thoroughness. A careful study of its action discloses some other facts of interest in the paragenesis of species. From the appearance of numerous large blocks of ore, forming solid bowlders in the general mass, a concentric arrangement is easily recognized. On breaking these masses across, the fresh fractures disclose a dark center which consists almost entirely of decomposed sulphides, composed chiefly of cerusite blackened by argentite and metallic silver in a pulverulent form. This dark center, chiefly of cerusite, is often pseudomorph of galenite in its fracture. Next is usually a zone of yellowish and orange-yellow antimonial ocher, cervantite, often quite pulverulent, at times only staining the cerusite; then follows a narrow zone of green and blue copper salts, malachite, azurite, cupreous anglesite, with, rarely, wulfenite; then follows cerusite, sometimes stained with antimony ocher, and not unfrequently associated with wulfenite; outside all are the iron and manganese ochers. This concentric arrangement I have observed in a great number of cases; and the above order of species, while not invariable, is believed to reflect accurately the general arrangement. Well-crystallized species, as mineralogical specimens, are rare in this great mass; but the following may be recognized as its chief components: *Galenite*, sphalerite, pyrite, jamesonite (?), argentite, stephanite, boulangerite (?), *antimonial galenite*, *cervantite*, mimetite (?), limonite, wad, kaolin, lithomarge, *cerusite*, anglesite, linarite, *wulfenite*, *azurite*, *malachite*, *smithsonite*. Those most abundant or best crystallized are in italics. This list can no doubt be extended as opportunity occurs for the more careful study of the ores, the great mass of which, amounting to many thousand tons, have gone into commerce without passing under any mineralogical eye."

After the exhaustion of the main ore bodies extensive prospecting was carried on, but with unsatisfactory results.

The Flagstaff mine was located and worked about the same time as the Emma and, like that, has long been idle. Huntley[1] gives the following description of the deposit:

The formation is the same mineral belt as the Emma. Ore came to the surface in one spot, and, following this indication a short distance, the discoverers came to the first and largest body. It was 400 feet long and 500 feet deep, extreme dimensions, and 3 feet wide. Some 20 or 30 other large-sized bodies were found, in all shapes and positions, usually near the hanging wall and invariably connected with one another by a small seam of ore or ocher. One body upon the footwall was joined to another near the hanging wall by a pipe of galena the size of a lead pencil.

The Vallejo and North Star claims are between the Flagstaff and Emma mines, but the occurrence of the ores seems to be somewhat

[1] Huntley, D. B., op. cit., p. 423.

different. Huntley[1] gives the following description of the ore bodies:

> The ore is found in irregular shoots or pipes near the hanging wall. Three bodies began near the grass roots, and others were found as depth was attained. At the period under review there were 10 shoots having a triangular or lenticular cross section and a uniform dip SE. 80°. These were from 20 to 100 feet apart and lay almost at right angles to the strike of the belt. The largest was 150 feet long, extreme dimensions from 6 inches to 10 feet wide, and had been followed 300 feet deep.

The rock formations in the Columbus Consolidated ground (now Wasatch mines) consist of the quartzite, the "lower white limestone," the Cambrian shale series, and some of the upper limestone series, together with granite prophyry dikes. The great overthrust fault of the district passes through the area and has cut off the lower portion of the great limestone series and formed the "lower limestone," while the Cambrian shale and quartzite have overridden this faulted portion. The rocks are also cut by several easterly fissures, one of the most prominent being the Braine fissure, which is connected with some of the largest bodies of ore thus far developed in the mine. The ore occurs both in fissure deposits and in bedded deposits, the latter being the more abundant. The bedded deposits occur where the easterly fissures cut certain sedimentary beds that appear to be especially susceptible to replacement. The trend of the deposits roughly follows the intersection of the bedding and the fissure, replacement extending to variable distances from the fissures.

Some of the larger deposits have been found near the contact of the "white limestone" with the underlying beds. There have also been important deposits in the shale series, apparently formed by replacement of a mottled blue and white calcareous member of the series. Other deposits occur at the contact of the "white limestone" with the overlying shale. The rocks have been broken and brecciated adjacent to the overthrust fault, and this has probably been a factor in rendering them especially susceptible to replacement.

In the lower levels the deposits are mainly sulphides, but it is reported that large bodies of oxidized ores were mined from the upper levels. The principal metallic minerals are pyrite, galena, sphalerite, and tetrahedrite, and the ores carry varying amounts of gold and silver. A specimen of tetrahedrite from this mine, as already noted, was found to contain several per cent of lead. Sphalerite is present in most of the ore but usually is not abundant. In the Garfield fissure a body relatively rich in sphalerite has been found but has not been extensively developed. At the time of visit, in 1912,

[1] Huntley, D. B., op. cit., p. 424.

most of the ore taken out from the lower levels was sulphide of milling grade, though the mine has yielded much shipping ore.

Bedded deposits have also been developed in the Columbus Extension mine, though as yet they have not been as important as the fissure deposits connected with the Toledo fissure, which is now included in that property.

The Alta Consolidated mine is near the head of Little Cottonwood Canyon, a short distance west of the City Rock mine. The sedimentary rocks consist of the Cambrian shale and the overlying limestone, and the Clayton Peak stock of quartz diorite is but a few hundred feet to the south. The Cambrian shale at this point is considerably above the position that is indicated by its dip at the outcrop to the west, on the north side of the canyon, and has apparently been elevated by the entrance of the intrusive material and possibly by later faulting. The sedimentary series is cut by a strong easterly fissure having the prevailing strike and dip for the district.

The ore occurs both in fissure and bedded deposits, but the latter have thus far been the more productive. Deposits have been developed in the shale series (black lime) and near the contact of the shale and overlying limestone. In the shale the ore is largely sulphides—pyrite, galena, tetrahedrite, and some sphalerite. Quartz and muscovite (sericite) are the important gangue minerals. In the limestone the ores are largely oxidized, oxides of iron and manganese are abundant, and the principal valuable metals are lead, silver, and some copper. At the time of visit ore was being mined that contained a large percentage of a yellow earthy sulphate of iron and lead with some copper resembling beaverite.

BIG COTTONWOOD DISTRICT.

The Prince of Wales and other mines are just north of the Little Cottonwood divide on Silver Fork, a branch of Big Cottonwood Canyon. Like many of the other mines of the district they have long been idle. The Prince of Wales mine is apparently several hundred feet higher in the limestone series than the Flagstaff and Emma, and probably at about the horizon of the City Rocks mine. Huntley[1] gives the following description of the Prince of Wales deposits:

> The ore-bearing formation is said to be a bedded vein, dipping about 45° NW. in blue and white limestone. Four distinct chimneys or shoots of ore, 130 feet, 200 feet, and 260 feet apart, have been found. They occur where the limestone is white, metamorphic, and soft, while the barren spaces between

[1] Huntley, D. B., op. cit., p. 428.

these shoots contain the vein only as a narrow seam in hard blue limestone. These shoots outcropped at the surface, or were covered by a few feet of drift, as low-grade, ocher-stained seams of limestone and clay. Good ore was found by sinking a few feet. The Antelope and Prince of Wales shoot is from 2 inches to 4 feet (average, 12 inches) wide, 120 feet long, and has been followed on the dip 1,200 feet. The Highland Chief shoot is from 2 inches to 3 feet (average, 8 inches) wide, 75 feet long, and 800 feet deep. The Wellington shoots are each about from 2½ to 7 feet (average, 3 feet) wide, from 10 to 30 feet long, and 700 feet deep. The ore from the first assays about 140 ounces silver and 45 per cent lead; that from the second, 100 ounces silver and 40 per cent lead; and that from the third and fourth, 60 ounces silver and 50 per cent lead. The ore is a soft brownish-yellow ocher, containing argentiferous cerusite and galena and occasional stains of oxides of manganese and copper. The mine is opened by several tunnels, the main one being 2,200 feet long and running on the vein entirely through the ridge, and a 1,100-foot incline, on which there are hoisting works, on the crest of the ridge. The cuttings are said to be 1,300 feet in extent.

The large ore body of the Cardiff mine, opened by the lower tunnel in October, 1914, doubtless belongs to the bedded type of ore bodies. It lies in the "lower limestone" below the overthrust and is said to be connected with a mineralized fissure, but it is not known whether or not this fissure corresponds to the vein worked through the upper tunnel, 300 feet above the lower. (See p. 204.) According to the latest information, the large ore body has been opened 250 feet along the strike and crosscuts show a width reaching 100 feet along the dip. Ore has been followed more than 200 feet above the tunnel by raising, while a winze has been sunk 90 feet below it. Shipments of about 90 tons daily are being made. Hauling costs about $4 a ton. Up to about August 1, 1915, shipments amounted to 3,420 tons, valued at $145,350.[1] The ore contains silver and lead, with some copper.

Other bedded deposits in the Big Cottonwood district, such as those in the Maxfield, Reade and Benson, and Carbonate (Kessler) mines, were not accessible in 1912, but an idea of their character may be gained from the following descriptions quoted from Huntley:[2]

The Maxfield is situated a quarter of a mile northwest of Argenta and 14 miles east of Sandy, in a side ravine, and near the bed of the main canyon. It is owned by the Maxfield Mining Co., of Salt Lake City, incorporated in March, 1879. This company also owns the extensions or parallel claims Vinnie, Amanda, Red Pine, Tyler, and Fairview. These are mostly patented but only slightly developed. The Maxfield is a bedded vein, from 1 to 8 feet wide, dipping 45° NE., between strata of a compact bluish-white limestone. The ore occurs usually upon the footwall, in one chimney 200 feet long and 2 feet wide. It is a soft brown ochery carbonate and galena, assaying from 30 to 100 ounces. On the hanging wall there was a band of quartz, from 3 to 8 inches wide, containing galena and pyrites. When carefully sorted this yields good ore.

[1] Eng. and Min. Jour., July 24, 1915, p. 167; Aug. 14, 1915, p. 291.
[2] Huntley, D. B., op. cit., pp. 427–430.

The mine is dry and has been developed 75 feet vertically and 212 feet horizontally by a tunnel on the vein from the bed of the ravine. The total openings aggregate 800 feet.

The Maxfield mine was worked up to 1905, but to what extent is not known. In 1905 it became flooded with water, and extensive operations ceased. Since then lessees have produced some lead ore each year.

The Reed and Benson mine is situated on a spur of the Cottonwood divide, between Day's and South forks, 11,000 feet above sea level and 2½ miles northwest of Alta. It was located in 1870 and was worked vigorously from September, 1871, until April, 1878. Since then it has been idle or leased to a very limited extent. This mine is supposed to be upon the same mineral belt as the Flagstaff and the Emma. The belt at this point is about 200 feet wide. The ore occurs in a vein or chimney on the hanging-wall side and in about 20 irregular lenticular bodies, which branch at all angles from the chimney, on its footwall side. These do not, as a rule, extend more than 75 feet from the main chimney and vary from 6 inches to several feet in width. One outcropped as a low-grade ocher. The largest is about 170 feet from the surface. The ore is of the kind usually found in this limestone formation, namely, a yellow and red oxide of iron carrying argentiferous cerusite and galena. It is claimed that the total shipments have averaged 120 ounces silver and 35 per cent lead per ton. The mine is developed by a 380-foot tunnel, in which there is a whim on a 400-foot incline, dipping 35° NNE. Below this there are four windlasses, which carry the incline down 400 or 500 feet deeper. In general the mine may be said to have been opened from the surface 1,100 feet on the dip (35°) by an irregular incline following the chimney. Near the surface the ore extended 100 feet and the workings 200 feet horizontally; but in the bottom of the incline not over 40 feet of drifting have been done. The openings have a total length of 1,950 feet.

The Ophir is a few hundred feet southwest of the Reed and Benson. * * * It was discovered in 1870, purchased by Reed & Goodspeed in 1871, leased until May, 1878, and worked steadily since by about 10 men. Ore is found in three bodies in a 30-foot stratum of compact dark-blue limestone. A stratum of white limestone above carries no ore. The outcrop was a pipe 2½ feet in diameter of low-grade ocher. The shape of the bodies is that of a flattened or an elongated ball, the largest being 50 by 20 by 15 feet. They are 4 and 10 feet apart and not over 50 feet from the surface. At the period under review drifting was being carried on upon a seam of ocher in the expectation of finding another body. The total cuttings did not exceed 700 feet. During the census year 173 tons of ore similar to that of the Reed and Benson, excepting that it was of lower grade, assaying only about 45 per cent lead, 42 ounces silver, with 3 per cent moisture, were sold for $8,581. The previous product was estimated at $22,000.

The mine of the Kessler Mining Co. covers part of the ground of the old Provo claim. It was worked by a New York company in 1872, 1873, and 1874. Little ore was obtained, and it was abandoned. About 1875 a prospector discovered the carbonate ore body while overhauling the old dump, so says tradition. The mine was bought by the Carbonate Co., of Salt Lake City, which extracted large quantities of ore. In January, 1879, after the large discovery ore body had been nearly all extracted, the mine was sold to the Kessler Mining Co., of New York City. This company took out considerable ore and did much

prospecting but ceased work some months previous to the writer's visit, at which time the mine was worked by a few lessees. The property consists of the following overlapping unpatented claims: Carbonate (1,500 by 200 feet), Little Giant, Sailor Jack, Alturas, Baker, and Defiance. These are situated on the summit of the ridge of Silver Mountain, about 11,000 feet above sea level, 3 miles south of Argenta, and about 6 miles northwest of Alta. * * * The ore is found in several bodies near the surface on the hanging-wall side of a stratum or belt of limestone. The largest body was just below the surface and was lenticular in shape, its dimensions being 200 by 100 by 50 feet. It was timbered by 365 square sets but had caved in. The gangue, if such it may be called, which surrounds the bodies and also serves as a connecting link between them, consists of a valueless ocher or limonite. It is very abundant, sometimes fine and soft; at other points hard and siliceous. Occasionally heavy spar, oxide of manganese, and stains of malachite are found. The ore is an ocher, containing cerusite and galena, and assays from 30 to 50 per cent lead and from 30 to 100 ounces silver. A fissure vein, called the "Sailor Jack," connects with this body and has been the cause of much litigation. There is also a vertical fault of 500 feet. The mine is opened 950 feet horizontally and 300 feet vertically below the croppings by six tunnels and one incline shaft. Four of the tunnels and the shaft are upon the fissure vein. The cuttings are 5,500 feet in length. The mine is dry, excepting from surface water from melting snows in the spring. * * * During the census year 692 tons were produced, which sold for $16,554.74. The total product of the mine prior to October, 1877, is estimated at $120,000. Between the above date and the beginning of the census year 4,549 gross tons, averaging about 8 per cent moisture, were sold for $261,044.41.

Bedded deposits are also reported from other localities which were not examined and of which no description has been found.

AMERICAN FORK DISTRICT.

The only bedded deposits in the American Fork district are those of the famous old Miller mine, on Miller Hill, just east of the divide between the head of American Fork canyon and Mary Ellen Gulch. This mine was the cause of great activity in the early seventies. According to Huntley,[1] it "was discovered in 1870 and was sold the following year for $120,000 or over." The mine was examined by J. P. Kimball in 1872 and the following data are abstracted from his published report, lent to the writers by W. A. Wilson, of Salt Lake City, the present manager:

The earliest working, as early as 1872, were inaccessible. The "vein" then worked followed the bedding, which dips 15°–25° SE. It lies near the base of the limestone series. The ore cropped out on the southwest side of the hill and was followed along the footwall for about 120 feet, when it "rolled" downward for a short distance and again followed the bedding. Below the roll (at the Car tunnel) the "vein" was 17 feet thick. The footwall was clearly defined, but the

[1] Huntley, D. B., op. cit., pp. 444–445.

top of the ore body graded into the limestone. The footwall was a bed of "tight lime" with a streak of clay selvage marking the contact with the ore. The hanging wall was shaly, much fractured, and partly altered to "ocherous matter." Fragments of the hanging-wall rock were found throughout the vein. The east side of the old incline showed either a steep pitch, a horse of loosened rock, or a fault causing the abrupt disappearance of the vein material on this side. Not enough work had been done at the time to determine the structure.

Quartz and calcite were generally absent, except as "a residue of country rock." The ore minerals were galena, cerusite, and "plumbic ocher," all carrying silver. Considerable hydrous ferric oxide was present, presumably an alteration product of pyrite, and the green and blue stains of copper carbonate were found in drusy cavities in the hanging wall. Black manganese stains were commonly present with the iron oxide.

Cerusite was the most abundant of the three lead minerals. It included two varieties, black and white. The black variety, in contrast to the white, probably owed its color, in Kimball's opinion, to finely divided silver sulphide and was the rich ore of the mine, "containing 83 per cent lead along with some 76 ounces of silver to the ton." This black variety must have been largely galena, for pure cerusite contains only 76 per cent of lead, whereas galena contains 86 per cent. It occurred in granular masses in the lower and middle parts of the "vein." Some of the masses were 1 to 6 feet in diameter and comprised from 10 to 16 per cent of the total ore shipped. The white variety, carrying about 60 ounces of silver to the ton, was the predominant ore and in a concentrated form occupied the lower half of the ore body. It was arranged in lenticular layers, separated by thin seams of clay and "plumbic ocher." "Perfectly pure lenses" of it were present, from 3 to 5 feet thick and having the consistency of quicksand. The "plumbic ocher" occurred in irregularly distributed masses or lenses in the lower part of the vein and carried as much as 36 ounces of silver and 2.45 ounces of gold to the ton. Some gold was also present in the ferric oxide. The upper part of the "vein" consisted of brecciated limestone and ferric oxide, the former more or less impregnated with copper salts and partly oxidized galena. The ore body, according to Kimball's report, was said to be the largest deposit of lead carbonate then known, but much larger bodies have since been developed in other districts.

The following table of assays, taken from Kimball's report, represents the western ore bodies of the mine, worked up to 1872:

Assays of ore from Miller mine.

Kind of ore.	Lead.	Silver.	Gold.
	Per cent.	*Oz. to the ton.*	*Oz. to the ton.*
Galena	56	25.51	0.30
Do	70	38.88	.60
Do	64	125.97	None.
Do	62	45.20	.43
Gray [white?] carbonate and galena	75	34.62	.75
Gray [white?] carbonate	60	30.37	.60
Black carbonate	68	38.45	Trace.
Do	72	36.57	Trace.
Carbonate	75	35.07	2.34
Do	83	31.49	2.77
Oxide of lead	(a)	25.8	(b)
Third-class vein matter	40	16.96	None.
Run of mine	58	29.16	.50
Do	53	27.32	.60
Do	60	30.37	.60
Do	57	33.41	.60
Do	55	36.00	(b)

a Not determined. b Included in silver.

The average value per ton of base bullion produced from these ores at the old Sultan smelter in American Fork Canyon for 60 working days was as follows: Lead, $140.70; silver (60.36 ounces), $86.47; gold (0.97 ounce), $22.27; total, $249.44.

According to Huntley,[1] there were in 1880 ten tunnels, four shafts, and 10,000 feet of openings, exclusive of stopes, in the Miller mine. The deepest workings were 600 feet below the hilltop and extended horizontally 900 feet. Ore was found in six or eight large bodies which began within 70 feet of the surface in a belt of dolomite. About 4,800 tons was extracted from the largest body. In addition to the minerals mentioned by Kimball, wulfenite was present in the oxidized ore and a little zinc blende and pyrite were found below water level (500 feet). The total production of the old workings was estimated to have been between 13,000 and 15,000 tons, assaying 40 to 54 per cent of lead and 30 to 47 ounces of silver and $2 to $10 in gold to the ton. These figures do not range as high as some of those given by Kimball.

The old ore bodies gave out and the company ceased operations in December, 1876, and since that time the mine has been worked by lessees. No great amount of ore was produced until 1905, when the Tyng Bros., then leasing, opened another large body, which replaced the limestone along a nearly due east fissure for a total distance of over 400 feet and was 10 to 40 feet wide. The increased production from 1905 to 1908 was due to this deposit. The rock replaced was a gray dolomite (?), overlain and underlain by shaly limestone. Two other

[1] Huntley, D. B., op. cit., pp. 444–445.

bodies, smaller and less regular, were found about 100 feet north of the main body, one on each side of a porphyry dike, whose strike is about N. 70° E. The main ore body ended abruptly on the east, possibly against a fault, and a search has recently been made for its eastward continuation, but up to 1913 only relatively low grade oxidized ore had been found. The ore was principally rusted "sand carbonate" containing residual bowlders of galena. It also contained copper stains, but assayed less than 2 per cent copper. The average content of the ore shipped from the Tyng lease was 0.98 ounce of gold and 21.72 ounces of silver to the ton, 39.29 per cent of lead, 4.90 per cent of zinc, 20.17 per cent of iron, 2.61 per cent of sulphur, and 3.56 per cent of insoluble. These figures show that the ore was mostly oxidized and contained very little quartz or barite gangue.

DEPOSITS IN THE ALPINE DISTRICT.

The Alpine mining district is in the foothills of the Wasatch Range, north and east of the town of Alpine, which is about 5 miles north of the town of American Fork. It includes the southwestern part of the granodiorite stock of the Cottonwood region and a considerable part of the great limestone series. Cambrian quartzite is also present but not closely related to either of the two properties examined.

The only fissure deposit in igneous rock examined in the region covered by this report is that of the Lucky Chance mine, about 3 miles north of Alpine. Here the country rock is typical granodiorite of the Little Cottonwood stock. The ore occurs in shear zones along which the rock has developed a highly schistose structure. The shear zones strike N. 60° E. and N. 80° W., with northward dips of 30° to 60°, and appear to be grouped in a belt of north-northeastward trend, 100 feet or more wide and of unknown length.

The mineralized rock consists principally of quartz that fills openings and more or less completely replaces the sheared rock, which is colored dark green by micaceous alteration minerals. The ore minerals are pyrite and galena. The deposits range from thin sprinklings along a fracture to well-defined lenticular veins as much as 1 foot wide and 20 feet long.

In thin section the moderately mineralized rock consists mostly of much shattered feldspar and quartz. The feldspars are traversed by veinlets of sericite and calcite, and the quartz areas by veinlets of minutely granular quartz. Chlorite is present in small drawn-out aggregates, representing the original biotite of the rock. Pyrite is present in small grains closely associated with the sericite and quartz veinlets. The absence of magnetite suggests that its iron, with prob-

ably some from the biotite, has gone to form the pyrite. The sericite (if it is all of the potash variety) implies an introduction of some potash to replace the soda and lime of plagioclase, but the principal materials introduced appear to have been water, carbon dioxide, and a little sulphur.

The more completely mineralized rock in thin section shows the same character, but the feldspar and chlorite are nearly all replaced and the quartz is nearly all recrystallized. Secondary quartz is abundant and sericite subordinate. Galena is present with the pyrite. Both ore minerals form aggregates, confined principally to the network of veinlets but also sending short branches into the inclosing minerals. The quantity of replacing minerals in this rock shows that silica, iron, and lead, as well as sulphur, water, and carbon dioxide, were introduced. Sericitization, characteristic of the less intense alteration, is here overshadowed by silicification.

A small shipment of ore was made from this mine a few years ago. It ran well in silver and comparatively well in gold.

The only deposit in the limestone of the Alpine district visited by the writers is on the Alpine-Galena property, near the mouth of Boxelder Canyon, northeast of Alpine. The country rock is near the base of the great limestone series and is probably of Cambrian age. The only ore found up to 1912 was in small masses of silver-bearing galena and lead carbonate along a bedding plane. The bedding plane had been followed down about 50 feet to a small body of leached replacement quartz, originally pyritic.

The mineralization in the Alpine district, so far as disclosed both in the Lucky Chance and in the Alpine-Galena ground, was of the same character as that in the productive mines of the Cottonwood-American Fork region, but the amount was decidedly small.

GENESIS OF THE ORES.

A detailed discussion of the genesis of the ores of the region will not be given in this place, but certain facts bearing on this subject will be pointed out and the general conclusions reached will be stated.

As has been shown in the discussion of the main types of deposits—contact, fissure, and bedded deposits—there is no doubt that they are of common origin, showing complete mineralogical gradation. At several places contact deposits pass into fissure deposits, and as a rule the classification into fissure and bedded deposits is based on form rather than on any inherent difference in the character of the mineralization.

The deposits in the igneous rocks, so far as shown by present developments, are of little importance in this region, and their relation

to the deposits in the adjacent sedimentary rocks is not as clearly shown as in other districts of the State. The mineralization in the igneous rocks, however, is such as might have been effected by the same solutions that produced the deposits in the sedimentary rocks.

The source of the metal-bearing solutions is believed to have been the igneous material that forms the stocks in the region. This is indicated by the location of the deposits and also by the character of the mineralization. A glance at the geologic map (Pl. VI) will show that the principal mineralized areas of both the Cottonwood-American Fork and the Park City regions are grouped around the Clayton Peak stock. They are associated with fissures that were apparently formed at the time of the intrusion of the stocks. This grouping in itself suggests that the ore-bearing solutions were derived from the intrusive material. Moreover, the aplitic and pegmatitic dikes or veins which were evidently late phases of the igneous activity, contain sulphides and locally diopside in notable amount, and this naturally suggests that the solutions which escaped from the igneous bodies carried ore-forming materials. The association of diopside and pyrite, both in the aplitic veins and in the contact deposits, is especially suggestive. The deposits, notably the contact deposits, are similar in character to those of other districts where their origin from solutions given off from igneous material is pretty definitely established. Of particular significance in this connection is the boron mineral ludwigite, as the boron minerals are commonly regarded as indicative of igneous origin.

The deposits in this region are in many respects similar to those of the Park City district, which have been carefully studied by Boutwell and which he concludes are genetically related to the intrusive rocks.[1] There are, however, differences between the deposits of the two areas that should not be overlooked. It is commonly stated in newspaper and other descriptions of the Cottonwood region that the ore deposits occur in the same formations as those of the Park City district, a statement with no basis in fact, for the deposits of the Park City district are all in the Weber quartzite and higher formations, while the known deposits of the Cottonwood area are, with few exceptions, in formations below the Weber quartzite. A comparison of the deposits at different horizons in the stratigraphic series gives this fact added significance. Around and closely associated with the Little Cottonwood stock of granodiorite, intruded into the pre-Cambrian and early Cambrian rocks, few, if any, deposits of commercial importance have been developed, while most of the important deposits of the belt are associated with the Clayton Peak stock of quartz diorite, intruded into

[1] Boutwell, J. M., op. cit., p. 128.

Paleozoic and Mesozoic rocks. Moreover, viewed in a general way, with due regard for structural features and differences in character of rock which have been important factors in the deposition of the ores, there is a general increase in mineralization from the lower to the higher formations, the ore bodies in the late Paleozoic and early Mesozoic rocks of the Park City district being far more valuable than any known in the earlier rocks of the Cottonwood area.

It is needless to say that this statement does not imply that valuable deposits do not exist in the Cottonwood-American Fork region, for several such deposits have been developed; but, so far as known, they are neither so large nor so continuous as in the Park City district.

A study of the ore deposits of the State [1] indicates that as a general rule the greatest mineralization occurs toward the top of intrusive stocks or in the adjacent sedimentary formations at a corresponding horizon, and therefore it is not probable that the mineralization in the Cottonwood-American Fork area was as extensive as that in the Park City district.

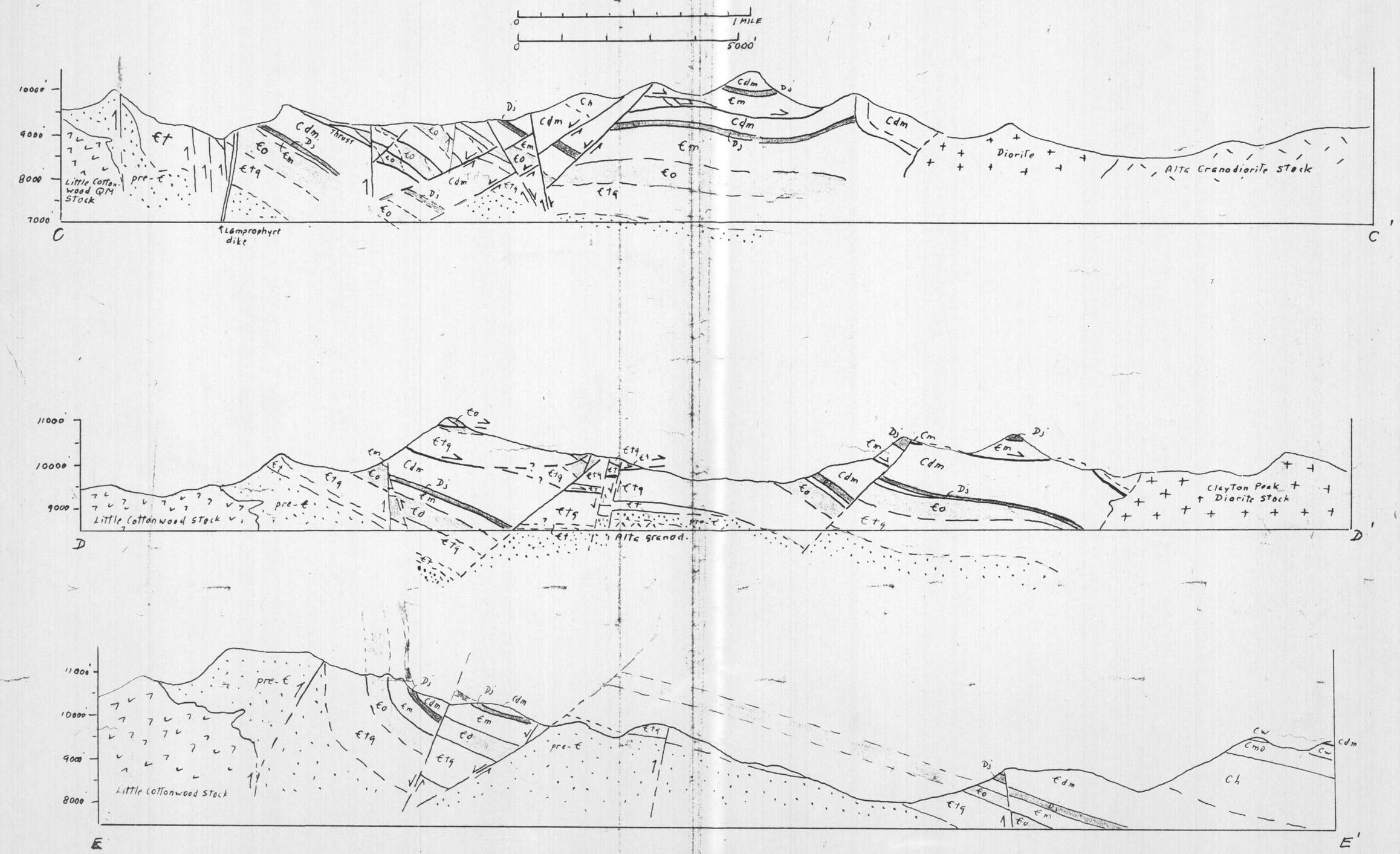
---

[1] Butler, B. S., Relation of ore deposits to different types of intrusive bodies in Utah: Econ. Geology, vol. 10, p. 101, 1915.

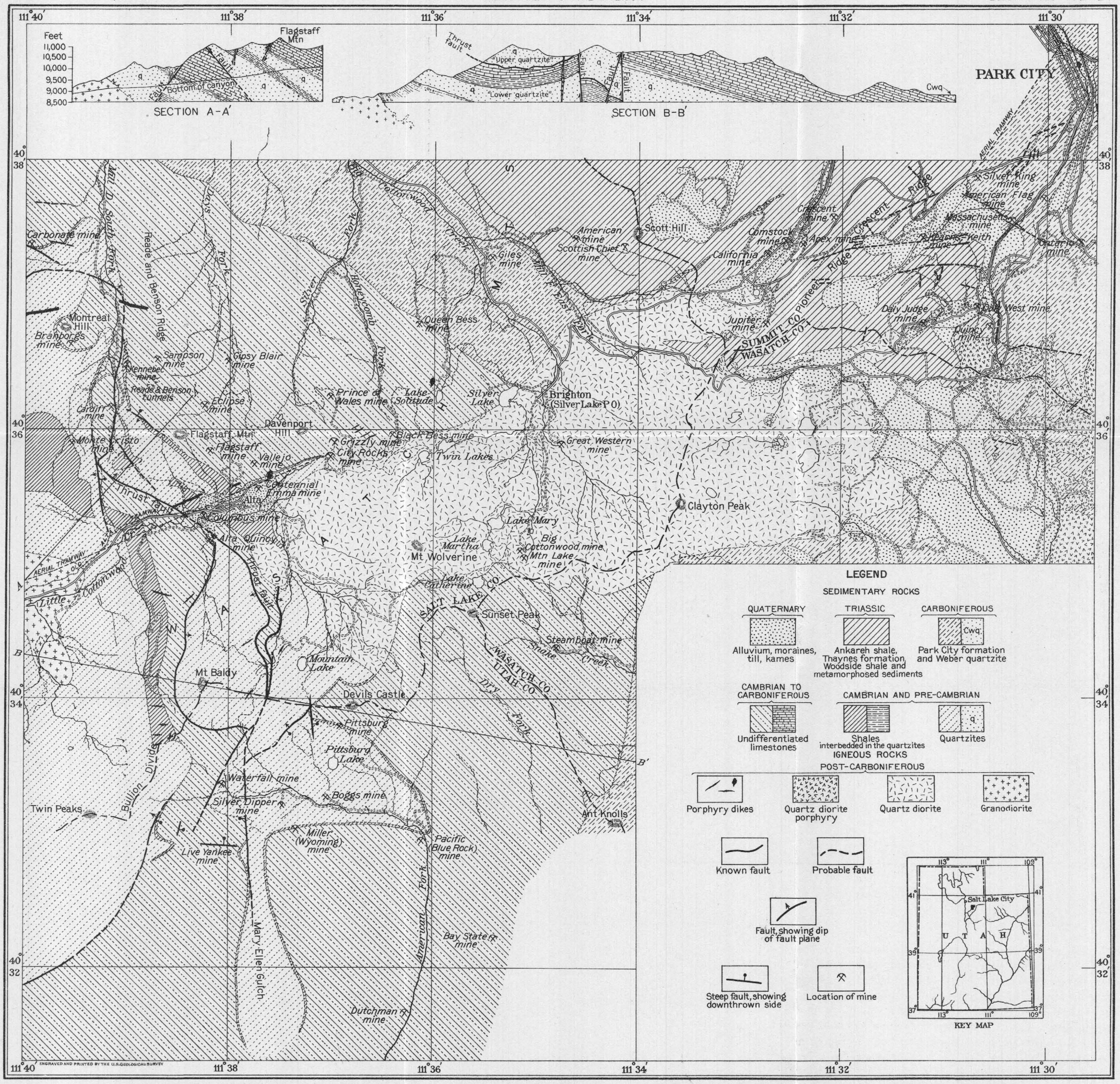
COTTONWOOD DISTRICT, UTAH

GEOLOGIC SECTIONS

After Calkins + Butler, U.S.G.S. P.P. 201-G (Plate 4).



E. Wisser 12/49



GEOLOGIC RECONNAISSANCE MAP OF THE COTTONWOOD-AMERICAN FORK MINING REGION, UTAH

INCLUDING A PORTION OF THE PARK CITY REGION

Base map from U.S. Geological Survey topographic atlas sheets

Scale $\frac{1}{50,000}$

1 ½ 0 1 2 Miles

1 ½ 0 1 2 Kilometers

1915

Geology of Little Cottonwood-American Fork region by B.S. Butler and G.F. Loughlin
Park City region by J.M. Boutwell, J.D. Irving, and L.H. Woolsey

MINING
U. OF C.
ASSOCIATION