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51. The Main Tintic Mining District, Utah*

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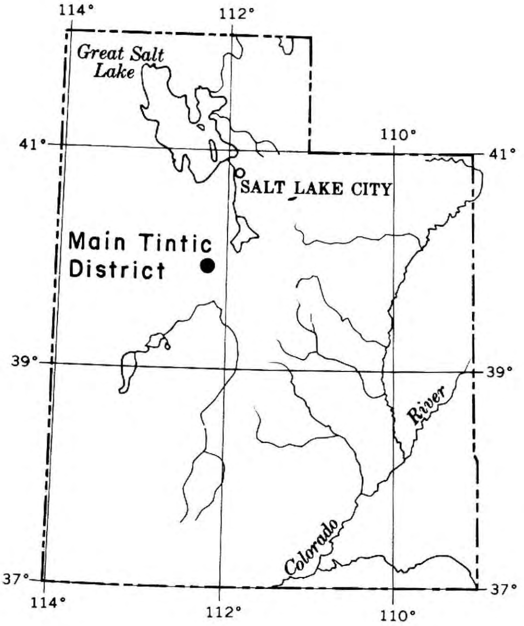


ABSTRACT

The main Tintic mining district in central Utah has produced approximately 13,500,000 tons of ore, containing silver, lead, gold, copper, zinc, and other metals, valued at more than $315,000,000. More than 90 per cent of this ore has come from large, irregular ore bodies that have replaced folded and faulted limestone and dolomite strata. Of lesser importance are replacement veins that chiefly cut contact-pyrometasomatized carbonate rocks and fissure veins that cut altered intrusive bodies and volcanic rocks. The district is in the west-central part of the East Tintic Mountains, a north-trending fault-block range near the eastern margin of the Great Basin. The consolidated sedimentary rocks exposed at the surface and in mine workings are miogeosynclinal deposits more than 10,000 feet thick that range in age from late Precambrian to Late Mississippian. They are folded and strongly faulted and are partly overlain by volcanic tuffs and agglomerates and by extensive flows of porphyritic and vitrophyric quartz latite, latite, and trachyandesite of Eocene age. All of these rocks are locally concealed beneath thick alluvial deposits of Pliocene and Quaternary age. The Eocene and older rocks are cut by dikes, sills, and small stocks of porphyritic quartz monzonite, monzonite, and latite, which are genetically related to the ore deposits. The district is inactive except for the production of halloysite clay and for minor leasing activity and exploration ventures. Several exploration targets remain untested.

INTRODUCTION

The Tintic district is the third-ranking mining district in Utah, having produced about 13,500,000 tons of silver, lead, copper, and zinc ores, chiefly from extensive limestone-replacement deposits. The district is in the central East Tintic Mountains about 55 miles airline south-southwest of Salt Lake City, lying approximately between Meridians 112° and 112°12′W and Parallels 39°45′ and 40°N. By informal but general usage, the northeastern part of the district, an area that is approximately bounded by Meridians 112° and 112°5′W and Parallels 39°55′ and 40°N, is considered to be the "East Tintic" district and is treated in a separate report in this Volume. The remainder of the area is generally known as the main Tintic district and is the subject of this report. The main Tintic district also should not be confused with the West Tintic mining district, which is an entirely unrelated mining camp in the southern Sheeprock Mountains about 20 miles southwest of the central East Tintic Mountains. As officially constituted, the Tintic district includes 150 square miles, but essentially all of the ores produced from the main district have come from a 6-square-mile area extending southward from Eureka through the declining or abandoned towns of Mammoth, Silver City, and Diamond.

The Tintic district is served by U.S. Highway 6-50 and Utah Highway 36 and by branch lines of the Union Pacific and Denver and Rio Grande Western Railroads. The nearest major commercial airport is Salt Lake City, although an airfield at Provo, Utah, 30 miles to the northeast, is suitable for light- and medium-duty aircraft.

The steady decline in the population of Eureka and other communities in the district since 1935, largely resulting from exhaustion of the metalliferous ore bodies and the closing of the last major silver-lead-zinc producing mine in 1957, has been slowed during the last decade or so by the successful development of the Dragon halloysite clay mine and by sporadic exploration efforts throughout the district.

HISTORY AND PRODUCTION

The Tintic district was fortuitously discovered in December 1869 by George Rust, who was returning to Payson, Utah, from a prospecting venture in the southern Sheeprock Mountains. Within a few months after Rust and his associates had located their "Sunbeam" claim, most of the outcropping ore bodies had been staked, and the district had been organized and named in honor of Chief Tintic, the leader of a local tribe of Goshute Indians, for whom Tintic Valley and its adjacent mountain ranges also had been named.

The growth of the district was steady, but the early development was greatly hampered by the lack of adequate transportation facilities. During the first 5 years, only the richest ores could pay for the high freighting costs to Reno, Nevada, and to San Francisco, California, from which some ores were transshipped to Baltimore, Maryland, and even to Swansea, Wales. In 1878, the extension of the Utah Southern Railroad to Ironton, 8 miles southwest of Eureka, resulted in the near doubling of output. Production was further increased during the late 1870's and early 1880's by the establishment of mills and small furnaces in the district, most of which were only doubtfully successful and were soon abandoned. The most successful of the early reduction plants were large pan-amalgamation stamp mills erected during 1893 to 1894 by the Mammoth, the Eureka Hill, and the Bullion Beck mining companies. Even these mills eventually succumbed to the competition provided by larger mills and smelters in the Salt Lake and Tooele areas, which needed the siliceous Tintic ores to balance the excessive iron in the ores from Bingham.

As shown in Table I, the quantity of base and precious metals produced from the ores of the main Tintic district at times has abruptly increased, due in part to the discovery of concealed ore bodies and ore zones. One of the earliest discoveries of concealed ore was made in 1882 by John Beck, who correctly surmised that the ore bodies of the Centennial Eureka and Eureka Hill mines continued along the strike of near vertical limestone host rocks that were partly concealed beneath the alluvium of Eureka Gulch. He probably did not realize, however, that in the Gulch area the north-striking ore zone intersects a great northeasterly trending fault zone, resulting in the formation of ore bodies larger than any known in the adjacent Eureka Hill property.

Shortly after Beck's success, another major discovery of concealed ore in the Tintic district was made in 1896 by Jesse Knight, who stubbornly drove an adit through 450 feet of barren limestone before breaking into the "Humbug" ore shoot, one of the richest lead-silver ore bodies ever discovered in the district. Encouraged by this find, Knight undertook other exploration ventures, resulting in the discovery in 1905 of the extensive Iron Blossom ore zone, which eventually was mined as a continuous horizontal pipelike ore body for 5200 feet; beyond the pipe, the ore continued southward as a series of ore shoots along steep fissures for an additional 2500 feet or more.

TABLE I. Production of Ore and Metals from Main Tintic Mining District, 1869–1965, by 10-year Periods[1]

Period	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1869–1880	3,666,671	36,149	1,605,545	3,179,628	10,353,378	—
1881–1890		61,786	11,692,031	9,692,031	54,318,428	—
1891–1900		332,518	31,366,185	21,441,370	187,524,539	—
1901–1910		731,312	31,856,168	76,565,474	279,893,533	—
1911–1920	3,358,073	496,927	54,227,364	71,086,437	289,143,135	16,914,973
1921–1930	2,674,335	218,712	45,621,103	23,994,912	300,264,767	12,927,818
1931–1940	1,099,913	187,375	8,176,028	8,535,664	20,261,646	2,774,092
1941–1950	1,761,943	64,177	8,689,849	4,838,969	86,444,873	67,339,058
1951–1960	825,605	21,019	4,131,117	1,415,653	58,398,642	38,046,531
1961–1965	50,599	408	31,794	44,300	101,600	42,531
Totals	13,437,139	2,150,383	197,397,184	220,794,438	1,286,704,541	138,045,003

[1] Statistics derived by subtracting the production from mines in East Tintic district from data presented in the following reports: (1) U.S. Geol. Prof. Paper 107; (2) U.S. Geol. Survey Mineral Resources of the United States 1917–1923; (3) U.S. Bureau of Mines Mineral Resources of the United States 1924–1931 and U.S. Bureau of Mines Minerals Yearbook, 1932–1965; (4) Utah Geological and Mineralogical Survey Guidebook to the Geology of Utah, No. 12; and (5) private sources.

This ore zone, named from Knight's Iron Blossom mine, immediately became the principal center of production of the district and raised the annual yield from $5 million to over $8 million.

Rivaling the discovery and development of the Humbug-Iron Blossom ore bodies was the discovery of the Chief Consolidated mine in 1909. This great northerly extension of the Mammoth ore zone say hidden beneath thick lava flows in the northern part of the district until Walter Fitch, Sr., and his consulting engineer and geologist, J. R. Finlay, deepened the Little Chief shaft and, by crosscutting the nearly vertical carbonate formation on several levels, encountered ore on the 1400-foot level. This ore was eventually followed southward to connect with the ore bodies of the Eagle and Bluebell mine and northward to the great fault zone in the Paleozoic rocks underlying the lavas filling Eureka Gulch where, as in the Bullion Beck mine, extensive replacement ore bodies had formed in massive fault breccias. The Chief mine remained in continuous operation from 1909 to 1957, producing nearly 3.5 million tons of ore valued at close to $50 million (net from smelters), making it the most productive mine in the district.

The most recent major discovery in the Tintic district was made in 1923 when the Plutus ore zone, lying between the Mammoth and Godiva zones, was cut in an exploration crosscut driven easterly from the deep workings of the Victoria mine, then under lease to the Plutus Mining Company, an affiliate of the Chief Consolidated Mining Company. The greater part of this ore body was mined by the Plutus Company, which produced 225,480 tons of ore with a net value of nearly $4 million.

The suspension of underground mining in the Chief No. 1 mine on June 15, 1957, essentially terminated the production of base and precious metal ores from the Tintic district. Major mining districts traditionally die hard, however, and this is no less true of Tintic. The profitable production of catalytic clay from the Dragon halloysite mine, which began operations in 1949, the continued exploration efforts throughout the district, and minor leasing activities all indicate life and, therefore, hope for a revival of this famous district.

ACKNOWLEDGMENTS

The data and concepts upon which this report is based have gradually accumulated over a period of nearly 100 years. This accumulation of knowledge began with the observations of the earliest prospectors in the Tintic district and has been increased, modified, and extended by miners, engineers, geologists and others, some of whom have spent their entire lives in the district. Of the many individuals who have cordially provided assistance to the members of the U.S. Geological Survey in their studies in the Tintic district, particular mention should be made of the contributions of C.

A. Fitch, Sr., and Harry J. Pitts, both now deceased, James Quigley, C. A. Fitch, Jr., William G. Stevenson, Max T. Evans, Hollis Peacock, R. C. Gebhardt, J. Steele McIntyre, Brennan Hannifin, and Robert C. Thomas. Many others who were helpful during the field studies are listed, with grateful acknowledgment of their assistance, in other reports.

Of the many published scientific papers, articles, and histories concerning the Tintic district and similar areas, free use has been made of reports by Tower and Smith (1), Crane (4), Lindgren and Loughlin (5), Prescott (7), Billingsley and Crane (8), Kildale (10), Cook (19), and Kildale and Thomas (20). Unpublished private reports and maps by R. C. Gebhardt, R. N. Hunt, Paul Billingsley, G. W. Crane, R. T. Walker, Louis Cramer, and others were also used in the preparation of this report. The name of T. S. Lovering is also indelibly imprinted on the Tintic area. Although his studies were principally focused on the East Tintic district, he has been a perceptive observer and source of new concepts, a constructive critic, and a close friend during the past 20 years in central Utah.

I am also indebted to John D. Ridge, William P. Hewitt, Donald W. Peterson, and Edwin W. Tooker, who read preliminary drafts of this paper and offered suggestions that have been incorporated into the present version.

GENERAL GEOLOGY

The Tintic district occupies the crestal area and western slopes of the East Tintic Mountains, one of the easternmost desert ranges of the Basin and Range province. This north-trending fault-block mountain range has moderate but pronounced topographic relief, rising within the district to peaks that stand more than 2500 feet above the alluvium-filled Tintic Valley at its western base. The rocks in the district consist of more than 10,000 feet of limestone, dolomite, quartzite, shale, and argillite that were deposited in great miogeosynclinal downwarps in early and middle Paleozoic time. These marine sedimentary rocks are exposed across the west limb of the Tintic syncline, which dominates the structure of the district, and are cut by several systems of faults, overlain by extensive deposits of lava and pyroclastic debris, and intruded by stocks, plugs, dikes, and sills of porphyritic monzonite, quartz monzonite, and diabase (Figure 1). The ore deposits of the district are of two types: (1) massive, columnar, irregular, and blanket-like replacement bodies and (2) veins that cut the larger intrusive masses and the adjacent aureoles of pyrometasomatized sedimentary rocks. Ninety per cent of the ore produced in the district has come from deposits of type (1).

Sedimentary Rocks

The prevolcanic sedimentary rocks of the Tintic district range in age from late Precambrian to Eocene(?), but, with the exception of some scattered deposits of conglomerate filling sublava depressions, all are pre-Pennsylvanian in age. (Table II) The Precambrian rocks, consisting of quartzite, phyllitic shale, and minor dolomite, are correlated with the Big Cottonwood Formation extensively exposed in the adjacent Wasatch Range, and the Sheeprock Group of Harris (22) exposed in the Sheeprock Mountains. These rocks are separated from the overlying Tintic Quartzite by a profound unconformity that indicates the removal of many thousand feet of beds, probably including the Mutual Formation and the Mineral Fork Tillite (17, p. 3–6) or equivalent beds.

The Tintic Quartzite generally is considered by the miners to be the basement rock of the district because of its great thickness and the rather small number of ore bodies that it contains. Unlike the Tintic Quartzite in the adjacent East Tintic district, the only ore deposits in this great sequence of conglomerate, quartzite, and minor siliceous phyllite in the main Tintic district are short, narrow veins that did not sustain profitable mining operations. Much of the Tintic Quartzite near Eureka, however, contains more than 90 per cent of silica and in past years has been quarried as a source of ganister for the production of silica brick.

The Paleozoic rocks stratigraphically overlying the Tintic Quartzite are chiefly limestone and dolomite typical of the miogeosynclinal deposits of this age that are common throughout western Utah and eastern Nevada. The Ophir Formation immediately above the Tintic Quartzite consists largely of limy shale, but also includes one or more thick beds of limestone that are important host rocks for ore in the East Tintic district but which are nonproductive in the main Tintic area. Above the Ophir Formation, sandstone and shale are distinctly subordinate to carbonate rocks, although arenaceous rocks are present in the Opex, Victoria, and Humbug Formations, and shale beds are also present in the Herkimer and Opex Formations. An important disconformity is recognized between the Opohonga

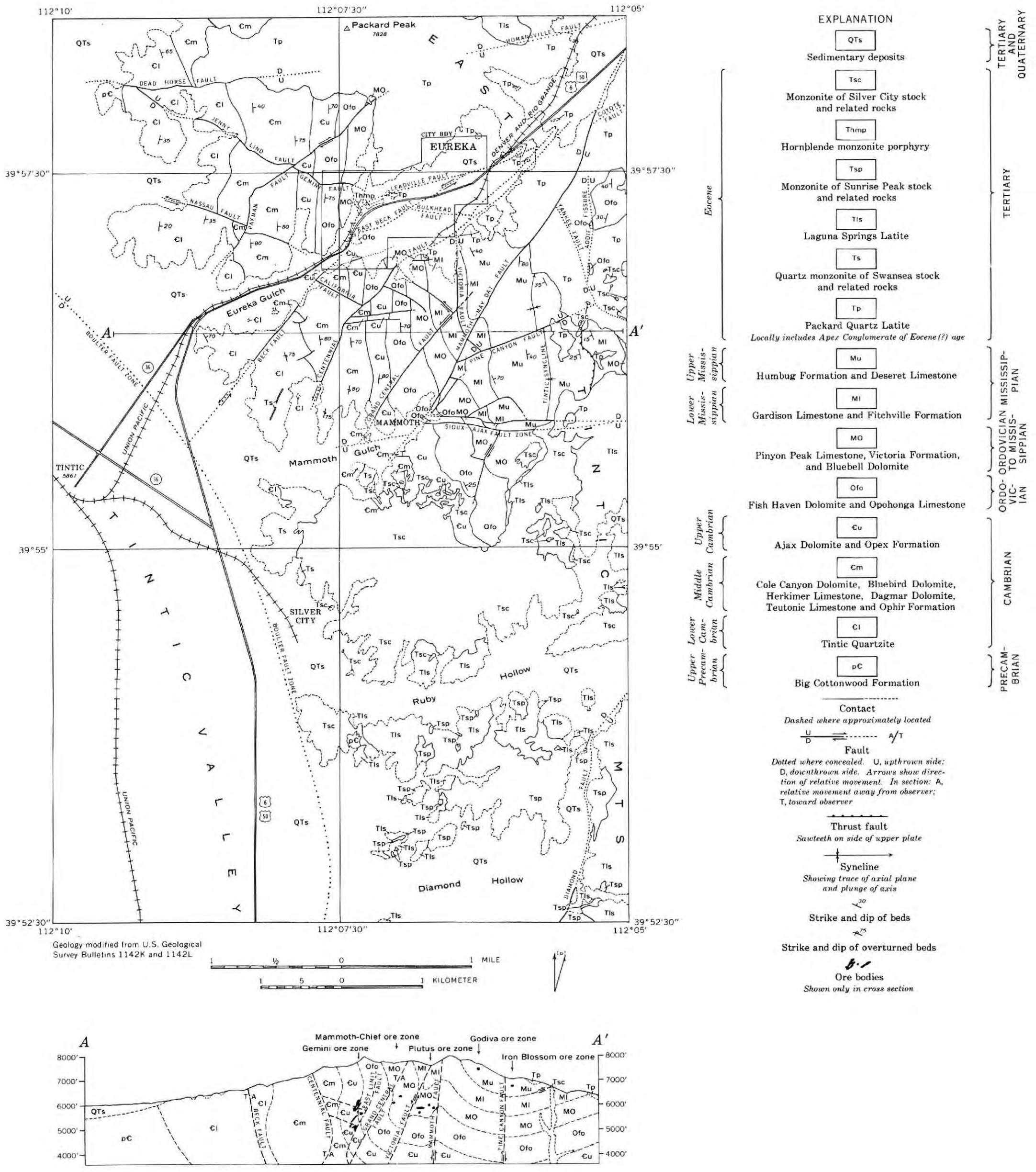


FIG. 1. *Generalized Geologic Map and Section of Main Tintic Mining District.*

Limestone and the Fish Haven Dolomite and possibly also between the Victoria Formation and the Pinyon Peak Limestone. Extensive but subtle nonconformities are also present within the Bluebell Dolomite, but they are not easily recognized because of the lack of structural discordance, the relatively uniform character of the formation, and the dearth of fossils.

The postvolcanic sedimentary deposits in the Tintic district are thickest and most varied in Tintic Valley. The most important of these deposits is a sequence of bentonitic tuff, marly limestone, semiconsolidated conglomerate, and gravel-streaked silt that is provisionally correlated with the Salt Lake Formation of Pliocene age. These beds are exposed extensively in the northern and western parts of the Valley.

Overlying and completely concealing the Salt Lake(?) Formation in the Tintic district are Pleistocene fanglomerates that extend out-

TABLE II. Stratigraphic Column, Main Tintic District, Utah

System	Series	Formation or Unit	Lithology and Average Thickness
Quaternary	Recent	Younger alluvium	Fanglomerate, gravel sand, and silt; 0–100 ft.
	Pleistocene	Older alluvium	Fanglomerate, colluvium, and stream gravels. Overlain by Lake Bonneville deposits in adjacent areas.
		—Unconformity—	
Tertiary	Pliocene	Salt Lake(?) Formation	Marly limestone, bentonitic tuff, sandy silt, and gravel; base concealed.
		—Unconformity—	
	Eocene	Andesite or latite dikes and related intrusion breccias	Purple porphyritic dikes, locally altered to kaolinite; probably contemporaneous with ore deposition.
		Quartz monzonite porphyry	Greenish-gray coarsely porphyritic dikes and plugs. Commonly included with monzonite of the Silver City stock.
		Monzonite of Silver City stock and associated biotite monzonite porphyry	Greenish-gray, granitic to coarsely porphyritic monzonite; altered near veins.
		Monzonite porphyry of Sunrise Peak stock and associated hornblende monzonite porphyry	Medium- to dark-gray coarsely porphyritic monzonite; altered near veins.
		Laguna Springs Latite	Reddish-gray flows, tuffs and agglomerate; 0–2500+ ft.
		Swansea Quartz Monzonite	Granitic intrusive rock chiefly altered and bleached.
		Packard Quartz Latite	Purplish-gray contorted flows and white tuff; 0–2700+ ft.
Tertiary(?)	Eocene(?)	Apex Conglomerate	Brick-red conglomerate and sandy shale; 0–500+ ft. Mapped as part of Packard Quartz Latite.
		—Unconformity—	
Carboniferous Mississippian	Upper	Humbug Formation	Blue limestone and buff sandstone; 250+ ft., top eroded.
		Deseret Limestone	Blue-gray cherty and coquinoid limestone; about 1000 ft.
	Lower	Gardison Limestone	Blue-gray distinctly bedded cherty limestone; 500 ft.
		Fitchville Formation	Seven distinctive units of limestone and cherty dolomite; curly laminated bed near top; 280 ft.
Devonian	Upper	Pinyon Peak Limestone	Blue-gray shaly limestone, sandy at base; 75 ft.
		—Disconformity(?)—	
		Victoria Formation	Gray dolomite and buff quartzite; locally some lenses of penecontemporaneous breccia; 280 ft.
Ordovician, Silurian, and Devonian		Bluebell Dolomite	Dusky gray coarse-grained dolomite with some beds of sublithographic creamy white dolomite. Curly laminated marker beds near middle; 350–600 ft.

TABLE II. Stratigraphic Column, Main Tinctic District, Utah (Continued)

System	Series	Formation or Unit	Lithology and Average Thickness
Ordovician	Upper	Fish Haven Dolomite	Mottled gray cherty dolomite; 265–290 ft.
		—Disconformity—	
	Lower	Opohonga Limestone	Blue-gray thin-bedded shaly limestone; 700–850 ft.
Cambrian	Upper	Ajax Dolomite	Dusky-gray cherty dolomite; 560 ft.
		Opex Formation	Thin-bedded sandy limestone and shale; 245 ft.
	Middle	Cole Canyon Dolomite	Dusky gray and creamy white dolomite; 850 ft.
		Bluebird Dolomite	Dusky gray dolomite with white markings; 200 ft.
		Herkimer Limestone	Blue shaly limestone and green shale; 425 ft.
		Dagmar Dolomite	Creamy-white laminated dolomite; 80 ft.
		Teutonic Limestone	Blue shaly limestone with pisolitic zones; 400 ft.
		Ophir Formation	Gray-green shale and blue oolitic limestone; 400 ft.
	Lower	Tintic Quartzite	Buff quartzite; gray-green phyllite beds near top, conglomerate zone near base; 2800–3200 ft.
		—Unconformity—	
Precambrian	Upper	Big Cottonwood Formation	Gray-green phyllitic shale, greenish-brown quartzite, and brownish-gray dolomite: +1673 ft.; base concealed.

ward from the major gulches and coalesce at the western margin of the range to form an extensive linear bajada. In the northern and eastern parts of the East Tintic Mountains, these alluvial fans are partly veneered by embankment and lake-bottom sediments that were deposited in Pleistocene Lake Bonneville, which stood at an elevation of approximately 5150 feet. The fans diminish substantially in thickness westward in Tintic Valley.

The youngest sedimentary deposits consist of gravel, sand, and silt found in the washes and gulches that cut all of the older rock units. None of these deposits is known to contain placer ores.

Igneous Rocks

The extrusive igneous rocks of the Tintic district are the deeply eroded remnants of a large composite volcano that essentially buried a topographically mature, structurally complex mountain range. The core of this volcano was invaded by the Silver City stock and associated plugs, sills, and dikes, some of which were the eruptive conduits of the lavas, tuffs, and pyroclastic deposits. The age of the volcanic rocks has been firmly established at Long Ridge, 30 miles southeast of the Tintic district, where Muessig (16) has shown that the agglomerates and tuffs at the edge of the Tintic volcanic field interfinger with limestones, shales, and bentonitic tuffs in the upper part of the Green River Formation of early and middle Eocene age. In this locality, the upper unit of the Laguna Springs Latite also includes a lens of limestone that contains plant fossils identified by Roland W. Brown (written communication, June 6, 1950) as middle Eocene on the basis of *Koelreuteria nigricans, Aralia wyomingensis,* and other forms.

The paleontologic and stratigraphic evidence for the middle Eocene age of the igneous rocks of the Tintic area is supported by the radiometric age of zircons from the North Lily and Silver City stocks, which were determined to be 38 and 46.5 million years old, respectively, by the lead-alpha or Larsen method (21, p. 30).

The succession of igneous intrusions is not precisely known because of the absence of definitive crosscutting relationships. The Swansea stock is chemically and mineralogically similar to the Packard Quartz Latite and may be its intrusive equivalent; therefore, it is presumed to be older than the Sunrise Peak and Silver City stocks. The Silver City stock also shows a chilled margin against the Swansea stock north of the Swansea mine. The Sunrise Peak and Silver City plutons are comparably similar in chemical and mineralogical composition to the Laguna Springs Latite. The Sunrise Peak body is somewhat more porphyritic than the granitic-textured Silver City stock and locally exhibits other features that are characteristic of a hypabyssal intrusion. This suggests that it may have invaded the latite volcanic pile during the eruptive phase of volcanism and, therefore, is somewhat older than the more deeply emplaced and slower cooled Silver City stock.

The northern and eastern boundaries of the Silver City stock show unmistakable evidence of the invasion of its country rocks by stoping. In detail, the monzonite penetrates the host rocks along faults, bedding planes, and joints, locally surrounding blocks of large and small size. Some of these xenolithic blocks are frozen in the monzonite and are little changed from their original composition; others show all degrees of reaction from slight contact-pyrometasomatism to essentially complete digestion. The least resistant xenoliths apparently are the blocks of dolomite and limestone; the most resistant are composed of shale, quartzite, and latite tuff.

Stoping is much less evident at the contacts of the Silver City and Sunrise Peak stocks with the Laguna Springs Latite than at the contact of the Silver City stock with the Paleozoic sedimentary rocks. In some areas, "soaking" and reaction have obliterated the contacts of the intrusive and volcanic rocks, and the margins of the intrusive bodies can be established only where porphyroblastic phenocrysts of feldspar and biotite become as numerous as the phenocrysts of nearby crosscutting rocks of undoubted magmatic origin.

Structure

REGIONAL SETTING The Tintic district is located approximately in the center of the Sevier orogenic belt, a north-northeast-trending, 100-mile-wide linear welt characterized by overlapping, internally deformed thrust fault plates that extend from California to Montana (24; 30, p. 1944–1951). The structural deformation of the Sevier orogeny began in Late Jurassic and Early Cretaceous time in the western part of the orogenic belt and continued eastward during Cretaceous time, culminating in the eastward transport of great plates of rock across the area of the Tintic district during the Late Cretaceous (12, p. 149–156; 27, p. K8; and 30, p. 1944). By middle Eocene time in the Tintic area, the orogeny had subsided, and the deformed and faulted sedimentary rocks were invaded by igneous intrusions; later, but before earliest Miocene time, all of the rocks were broken and disrupted by the block faults of the Basin and Range system.

FOLDS The dominant structural feature of the Tintic district is the asymmetric Tintic syncline, which occupies nearly all of the area of the main district and part of the adjacent East Tintic district. This syncline is cut by three or more sets of transverse faults, and is downdropped on its western side by a north- to northwest-trending zone of Basin and Range faults (28, p. L18). The axis of the fold is particularly well exposed for about a mile northward from the Sioux-Ajax fault; beyond this exposure both to the north and south the axis is obscured by igneous rocks (Figure 3). The plunge of the Tintic syncline is about 20°N, but ranges from nearly horizontal to 30° or more, partly because of differential tilting of individual fault blocks. North of Eureka Gulch, the west limb dips steeply eastward; to the south, the dip progressively increases until some beds are slightly overturned (Figure 1). As shown in mine workings, this reversed dip continues downward for more than 2500 feet below the ridge crest (5, p. 76). In the axial area of the fold, the steep beds of the western limb abruptly flatten and then curve upward at an angle of 20° to 30° to form the moderately inclined east limb of the fold. All of the prelava sedimentary rocks of the district from the Precambrian Big Cottonwood Formation to the Mississippian Humbug Formation are exposed across the western limb and axial area of the fold, indicating a minimum amplitude of nearly 12,000 feet.

An obscure but structurally important disharmonic anticline lies between the Centennial and Sioux-Ajax faults a short distance west of the axis of the Tintic syncline. This fold apparently developed in response to the shortening and compression of part of the stratigraphic section in the trough of the syncline and possibly may be related also in origin to the adjacent Victoria strike fault. This disharmonic fold is penetrated by only a few mine workings, and consequently is not well known; it is possible that it deforms only those beds between the shaly Opohonga Limestone and the highly incompetent basal phosphatic shale member of the Deseret Limestone.

FAULTS The faults that cut the Tintic syncline and the younger igneous rocks are broadly classified into four groups: (1) shear faults formed during folding; (2) normal faults formed after folding but prior to volcanic activity; (3) mineralized fissures and faults related to the volcanic episode; and (4) late normal faults of the Basin and Range system. None of the major thrust faults of the Sevier orogenic belt is exposed in the Tintic district although the Midas fault zone undoubtedly underlies the East Tintic Mountains, probably near the base of the Big Cottonwood Formation (30, p. 1952–1953). A tear fault, which apparently delimits the Midas thrust plate on the south, is inferred to underlie the lavas of the East Tintic district and may also have guided the emplacement of the near surface part of the Silver City stock (29, p. C20).

Shear Faults The earliest high-angle faults form a conjugate system of northeast- and northwest-trending shear faults that developed in response to the east-west compressive forces that produced the folds. The shear faults in the Tintic district cut the north-trending beds of the Tintic syncline at angles ranging from 30° to 60°; most of them have steep dips and some are surprisingly sinuous in cross section. The dominant displacement on most of the shear faults is horizontal or nearly so, which is indicated by deep horizontal mullion structures that groove the sinuous fault planes, and by the great contrast in the apparent throw of steep and flat beds. In general, the northeastward-trending set of faults, including the Paxman, Beck, Centennial, Grand Central, and Mammoth-May Day faults, are more throughgoing than the northwest-trending faults and are more important as ore-localizing structures.

Normal Faults The faults that were formed after the period of compressive deformation but before the volcanic eruptions include the Dead Horse-Homansville fault and the Sioux-Ajax fault. These faults cut the north-trending beds of the major folds nearly at right angles and dip steeply to the north. The rocks on the north side of the Dead Horse-Homansville fault are downdropped relative to those on the south, and the displacement increases from 1300 feet or less in the western part of the district to more than 1700 feet in the eastern part. Prior to the eruption of the Packard Quartz Latite, the trace of the Dead Horse segment of the fault was the site of a deep, eastward-sloping, alluvium-floored valley that later became filled with lava. The Sioux-Ajax fault zone consists of several braided fault strands that drop the steeply dipping beds of the west limb of the Tintic syncline north of the fault against gently dipping beds in the trough of the syncline south of the fault, indicating a vertical displacement of approximately 1600 feet. Beneath the alluvium in Mammoth Gulch the Sioux-Ajax fault may be deflected to the south along part of the older Mammoth-May Day fault.

Mineralized Faults and Fissures The Silver City stock is cut by veins that define a system of north-northwest-trending fissures and faults of small displacement that dip steeply westward (Figure 2). These faults apparently were active both during and after the volcanic episode and have been mineralized with base metals and silver. The fractures in the northwestern part of this fault system extend into the steeply dipping sedimentary rocks of the west limb of the Tintic syncline, where they are commonly deflected along north-trending bedding-plane faults. The fractures in the southeastern part of the fault system extend into the East Tintic district where they are important localizing features for injected pebble breccias, igneous dikes, and veins.

Basin and Range Faults The truncation of major geological structures at the west edge of the East Tintic Mountains and the presence of erosion-modified fault scarps in alluvium denote a zone of late normal faults between Tintic Valley and the East Tintic Mountains. A gravity survey of this general area by K. L. Cook and J. W. Berg, Jr. (23, p. 85) indicates a total gravity relief of more than 20 milligals across the Boulter fault zone southwest of Eureka Gulch, suggesting a thickness of more than 7200 feet of valley-fill deposits (28, p. L18). More recent studies of the Tintic Valley anomaly by Mabey and Morris (31) confirm the thickness of light density material in Tintic Valley and indicate further that the abrupt thickening of the fill is probably distributed on two or more normal faults with a total displacement of at least 7500 feet.

Age of Mineralization

The close spatial associations and structural relations of the ore bodies and the igneous rocks, as well as the hydrothermal origin of the ores, leave little doubt that ore deposition was the culminating event of igneous activity. As shown earlier, the age of this eruptive episode has been established firmly as middle Eocene by the stratigraphic relations of the Laguna Springs Latite and the Eocene Green River Formation, and by diagnostic assemblages of fossil plants collected from a lacustrine limestone bed interlayered with the uppermost pyroclastic member of this volcanic unit. The close chemical and mineralogic similarity of the youngest flow rocks of the Laguna Springs Latite to the biotite monzonite of the Silver City stock suggests that the monzonite invaded the volcanic pile perhaps even before the latite and older volcanic and intrusive rocks had cooled. Fissuring and faulting accompanied the intrusion of the monzonite body and continued after its consolidation. During this final episode, hydrothermal solutions, presumably from a deep magmatic reservoir, invaded both the igneous and sedimentary rocks through many of the same fractures that were followed earlier by monzonite dikes, plugs, and sills. The total duration of the waning stages of magmatic consolidation, during which the ore solutions were generated, is believed to have been short, as indicated by the steep dispersion fronts of the ore-stage metals in wall rocks adjacent to the ore bodies (18, p. 715–716). These relations therefore suggest that ore deposition was probably complete before the early part of late Eocene time and well before the earliest inception of Basin and Range faulting and the minor volcanic activity associated with it.

ORE DEPOSITS

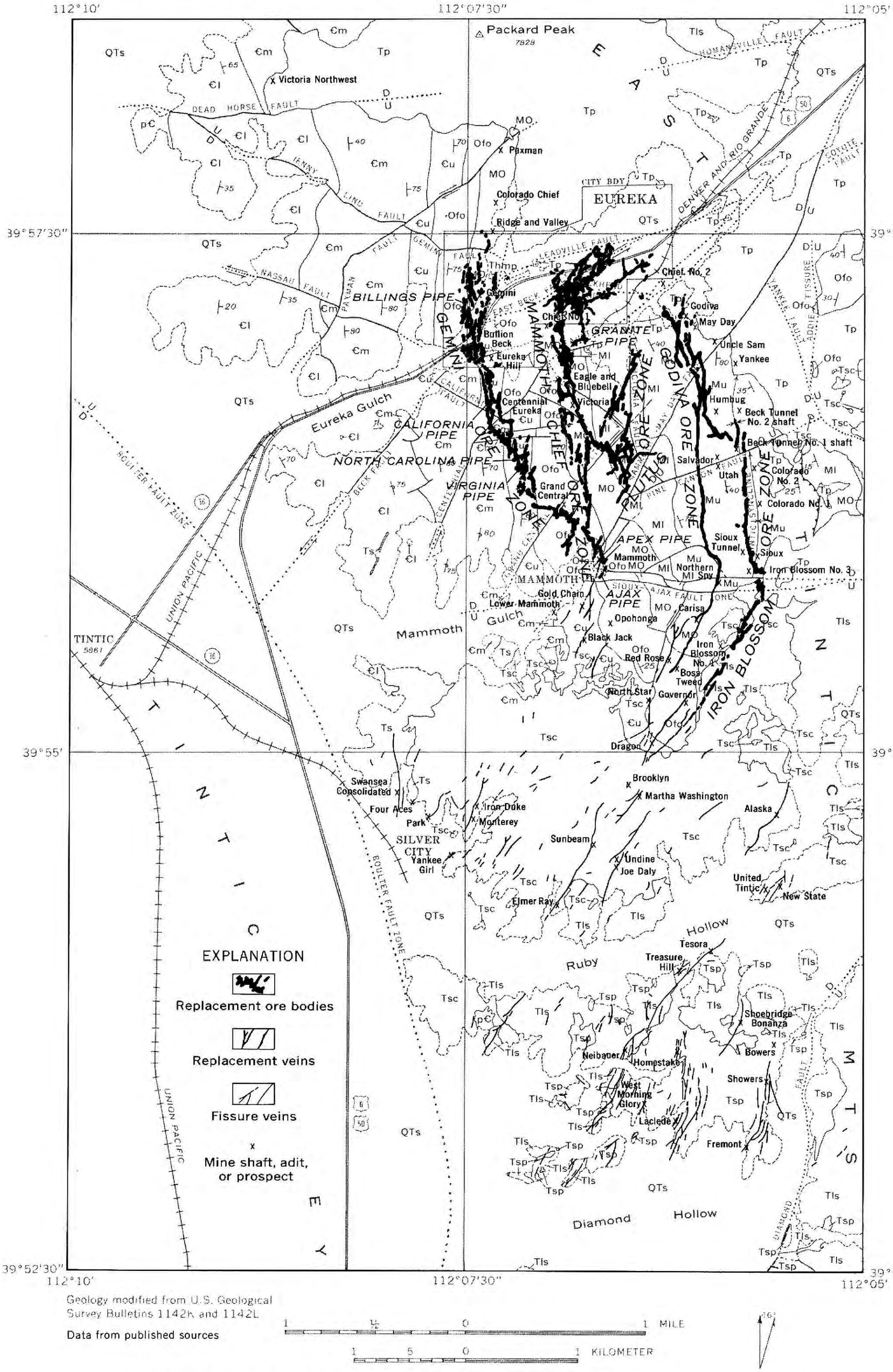
General Features

The metalliferous ore deposits of the Tintic district include both fissure and replacement veins as well as the extensive replacement ore bodies for which the district is so widely known. Together, these ore deposits form persistent linear zones (or ore runs) that extend north-northeasterly across the Silver City stock and adjacent rocks and northerly through the sedimentary rocks north of the Sioux-Ajax fault. (Figure 2) In the carbonate rocks north of the stock, five zones of replacement ore bodies are recognized. For convenience of description these have been named, beginning with the westernmost: (1) the Gemini, which includes, from north to south, the Ridge and Valley, Gemini, Bullion Beck, Eureka Hill, and Centennial Eureka mines; (2) the Mammoth-Chief zone, which includes the Chief No. 1, Eagle and Bluebell, Victoria, Grand Central, Mammoth, Gold Chain (Ajax), Opohonga, Lower Mammoth, and Black Jack mines; (3) the Plutus zone, which was opened in the Plutus and northern part of the Mammoth mines; (4) the Godiva zone, which includes the Godiva, May Day, Yankee, Uncle Sam (Humbug), Salvador, Utah, Sioux, Northern Spy, Carisa, Victor, Red Rose, Boss Tweed, and North Star mines; and (5) the Iron Blossom zone, which includes the Beck Tunnel, Colorado, Sioux, Iron Blossom, Governor, and Dragon mines. Two of these zones, the Gemini and Plutus ore runs do not extend southward as far as the Sioux-Ajax fault but merge with the Mammoth-Chief zone near the Grand Central mine.

The linear character of the three principal ore zones persists through the Silver City stock and beyond it into the altered lavas and tuffs bordering Diamond Hollow. The Mammoth-Chief zone extends across the contact of the stock in the vicinity of the Lower Mammoth mine, where one or more ore shoots were mined without interruption or change in mineralization from the marbleized dolomite into the adjoining argillized and pyritized monzonite. South of the monzonite contact, this ore zone is characterized by many short, locally en echelon veins that have been opened by the Iron Duke, Monterey, Yankee Girl, and other mines near Silver City. The Godiva and Iron Blossom zones similarly are alined with a wide zone of rather productive fissure veins, which have been opened by the Sunbeam, Elmer Ray, Martha Washington, Undine, and Joe Daly mines. Southeast of the Undine and Joe Daly veins, three other zones of north-northeasterly-trending veins cut altered rocks and monzonite. These zones include: the West Morning Glory, Treasure Hill, and adjacent veins; the Laclede, Homestake, and adjacent veins; and the Fremont, Showers, and adjacent veins. The veins in these zones generally are alined with the replacement ore deposits of the East Tintic mining district but are separated from them by an unexplored area covered by volcanic and hypabyssal rocks.

Form and Character of Ore Bodies

The wide range in the form and character of the Tintic ore bodies is caused chiefly by dissimilarities in the physical and chemical characteristics of the host rocks but is also



Geology modified from U.S. Geological Survey Bulletins 1142h and 1142L

Data from published sources

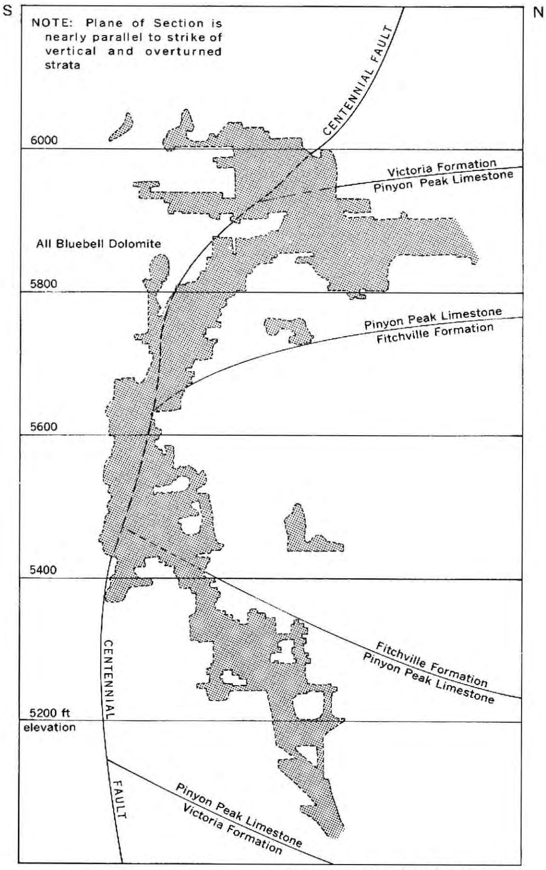
FIG. 2. *Vertical Projection of Ore Bodies, Main Tintic Mining District.*

affected by distance from the Silver City stock and by differences in the properties of the hydrothermal solutions. In the nearly nonreactive siliceous, argillaceous, and certain contact-pyrometasomatized rocks, the ore bodies essentially are restricted between the walls of the enclosing fissures. As these tabular ore bodies extend into zones of weaker contact pyrometasomatism, they become less veinlike and consist of a series of pods or steeply dipping lenses of ore. In the reactive, easily brecciated dolomites and limestones beyond the contact zone, the ore deposits are characteristically diverse in form and unpredictable in habit and assume irregular pipe-like, columnar, or bulbous forms. Unlike the fissure and replacement veins, these replacement ore bodies conform only in a general way to the structures with which they are associated. The gradations from the fissure veins to replacement veins to replacement ore bodies are nearly imperceptible, but each type of ore body is distinct and is believed to represent a particular structural and chemical environment.

Replacement Ore Bodies More than 90 per cent of the ore produced from the Tintic district has come from ore bodies that have replaced folded and faulted carbonate rocks of Paleozoic age. These replacement ore bodies range in size from insignificant stringers and small kernels to great columnar, linear, and bulbous masses, some containing several hundred thousand tons of ore. Several of the columnar and linear ore bodies in the trough of the Tintic syncline resemble the chimney and manto replacement ore deposits of north-central Mexico, but, elsewhere in the Tintic district, the structural complexity and varied lithology of the host rocks preclude such a simple comparison.

The most productive of the replacement ore bodies are the great columnar masses or chimneys, locally termed pipes, that were mined in the Mammoth, Chief, Gemini, Centennial Eureka, Gold Chain, and other mines. The largest of these pipes is the Apex ore body in the Mammoth mine. This remarkable ore column closely follows the hanging wall of the Sioux-Ajax fault, plunging steeply from the surface to the 2400-foot level of the mine where it merges with the Gold Chain fissure. It is roughly elliptical in plan, averaging about 200 feet in breadth and 30 to 100 feet in width. The comparable Granite pipe, near the Centennial fault in the southern part of the Chief No. 1 mine, ranges from 40 to 275 feet in diameter and extends from a point above the 600-foot level to a point below the 1400-foot level, flattening and merging with low-plunging ore runs at both the top and the bottom. (Figure 3) Other steep pipe-shaped ore bodies include the California column, which extends from the 600-foot level to the 1700-foot level of the Centennial Eureka mine, the Virginia and North Carolina columns between the 400- and 1700-foot levels also in the Centennial Eureka mine, the Ajax chimney of the Gold Chain mine, which was mined from the surface to the 1000-foot level, and the Billings pipe of the Bullion Beck mine.

The largest manto-like replacement body in the Tintic district follows a nearly horizontal segment of the axis of the Tintic syncline northward for nearly a mile through the Iron Blossom No. 3, Sioux, Colorado, and Beck Tunnel mines (5, p. 166). In the Colorado


NOTE: Plane of Section is nearly parallel to strike of vertical and overturned strata

Stope outlines from Chief Con. Mining Co.

FIG. 3. *Horizontal Projection of the Columnar Granite Ore Body (shaded) of the Chief No. 1 Mine, showing relation to the Centennial fault.*

mine, this great horizontal pipe of ore ranges from 20 to 60 feet wide and averages 20 feet in height, although cross sections twice these dimensions are not uncommon in parts of the Iron Blossom No. 3 and Beck Tunnel mines. A somewhat smaller manto-like body, which is the deepest known ore in the Tintic district, replaces fractured dolomite beneath a gently north-dipping bedding plane fault on the 2500- to 2900-foot levels of the Chief No. 1 mine. This manto consists of three separate sinuous ore bodies that locally branch and rejoin, surrounding unreplaced masses of the host rock; the individual ore bodies are 15 to 40 feet wide, 3 to 25 feet high, and have been followed downdip for 800 feet where they were abandoned because of high mining and pumping costs.

The replacement ore bodies that may not specifically be termed either pipes or mantos are mostly podlike; however, they are unpredictably irregular in habit and differ widely in size and character. Their relation to the more regular ore bodies is shown by manto-like projections that locally extend along flat-lying beds and veinlike, pipelike, and sinuous extensions that locally follow steep faults, fissures, and bedding planes. One of the largest and most typical of the podlike replacement masses is the 18-316 ore body of the Chief No. 1 mine. This ore body occurs near the intersection of several major faults where extensive breccia zones have been developed in the Victoria, Pinyon Peak, and Fitchville Formations. In plan view, the ore mass may be compared to a large crab, with a bulbous central body and several leglike appendages that extend southward, northward, and northeastward along faults and favorable bedding horizons. The central podlike body is about 300 feet long and 150 feet wide, and extends from the 1700-foot sublevel to the 1950-foot sublevel of the mine. The contacts of this ore body with the brecciated country rock are extremely ragged, and many unreplaced residual blocks of altered dolomite were encountered near the edges of the ore mass.

Essentially all of the replacement ore bodies in the Tintic district are siliceous, consisting of jasperoid, barite, and metallic minerals. The jasperoid gangue of the ore bodies in the northern part of the mineralized area is flinty or cherty in character, and commonly contains only a few plates of barite in addition to various amounts of sphalerite, galena, pyrite, enargite, argentite, and less abundant silver-bearing sulfosalts. In the central part of the area containing the replacement deposits, the jasperoid is somewhat coarser textured, and the plates of barite are larger and more fully developed. In both the central and northern ore bodies, much of the jasperoid is strongly banded, some bands having developed as a result of the dessication of hydrated colloidal silica and others having originated by the rhythmic precipitation of sulfide and other minerals in the original colloidal mass (5, p. 154–158).

The southernmost replacement ore bodies are commonly more coarse grained than the others, locally resembling quartzite or fine grit. In some parts of these ore bodies, barite predominates over quartz, which commonly occurs as well-formed crystals coating as many as three generations of platy barite crystals.

In all of the replacement deposits, there is evidence of two or more phases of silicification and brecciation. Barite is more abundant in the jasperoid of the second phase and the quartz of this phase is typically more nearly transparent and better crystallized, commonly projecting into vugs and fracture cavities. The ore minerals were deposited in volume with the quartz and barite of the second phase, and galena in particular was deposited as large crystals or grains.

The transition between the replacement ore bodies and the altered country rock is typically sharp and distinct and is locally marked by a thin selvage of clay that separates the jasperoid casings of the ore shoots from the unsilicified, but commonly pyritized and sanded, carbonate host rocks. A characteristic feature of the replacement ore bodies and replacement veins above the water table is a halo-like zone of "chocolate rock" in the adjacent limestone and dolomite. This readily identifiable prospecting guide is an outward diminishing zone of weakly sanded, iron-stained rock resulting from the oxidation of disseminated pyrite.

REPLACEMENT VEINS South of the Sioux-Ajax fault in the pyrometasomatized carbonate rocks near the Silver City stock, the ore bodies are less irregular in form than those north of the fault and assume the aspect of typical replacement veins. Essentially all of them are narrow relative to their length and height, but, unlike the fissure veins in the adjacent intrusive rocks, they more completely replace the breccia fillings of the fissure zones and locally expand on cross fractures and bedding breccias. Most of the individual replacement veins are only a few hundred feet long; however, the Dragon vein in the Iron Blossom ore zone has been mined continuously, if not profitably, for more than 2500 feet into the Iron Blossom No. 1 mine, where the ore shoots become true replacement ore bodies.

Although ore minerals are dispersed through most of the vein filling, the mineable concentrations of ore are segregated into shoots that range from columnar bodies that locally expand from a few inches to 50 or 60 feet in diameter to tabular masses several hundred feet long, several hundred feet high and an average of 4 to 5 feet wide. With only a few exceptions, the ore shoots in the replacement veins all lie within 800 feet of the present surface.

The texture of the ores of the replacement veins is similar to the texture of the ores of the southernmost replacement ore bodies. Much of the ore in these veins contains both fine- and coarse-grained barite in excess of the more coarse-grained jasperoid and the granular aggregates of small quartz crystals. The relationship of the sulfide minerals and the gangue of many of these ore shoots is not well known, however, because of the extensive oxidation of the ore bodies.

FISSURE VEINS Many of the ore bodies in the Tintic Quartzite, Opohonga Limestone, and the volcanic rocks, as well as the majority of those that cut the Silver City and Swansea stocks, commonly show little evidence of wall rock replacement and locally are classified as fissure veins. These veins have quite smooth, well-defined contacts with the altered country rock and, unlike the replacement veins and ore bodies, are commonly crustified and banded. These fissure veins range in width from knife-edge seams to about 20 feet, averaging about 2 feet. Most are less than a few hundred feet long, although the Sunbeam vein is nearly continuous for about 4000 feet. The structures occupied by the veins seem to be small normal faults with an average strike of N20°E; the average dip is 75° to 85°W, but some veins are vertical, and others dip east. They are widest and longest where they cut massive intrusive and sedimentary rocks, but they tend to form groups of short, subparallel veins or disappear entirely in altered tuffs and in incompetent argillaceous sedimentary units.

The banded veins that cut the Silver City and Swansea stocks consist of vertical layers of quartz, pyrite, galena, and other minerals that lie parallel to the fissure walls. Some of the bands characteristically contain central vugs that appear to lie along the original fractures; other bands are separated by vertical sheets of altered country rock. Locally, the intervening slabs of rock are progressively replaced by quartz, resulting in wide quartz bands without vugs or the typical crustified appearance.

Owing to heavy inflows of water at depths of 350 to 500 feet, only the Swansea vein was extensively mined below the water table. According to Lindgren and Loughlin (5, p. 255 and pl. 3), the main Swansea ore shoot was stoped continuously from a point within 40 feet of the surface to a maximum depth of about 800 feet and through a maximum horizontal distance of 900 feet. The general shape of the stoped area is that of the letter T, the stem of which rakes 35°N. This ore body has an average width of about 3 feet but ranges from a narrow streak to 10 feet or more in thickness. A cross section of this vein observed on the 500-foot level by Tower and Smith (1, p. 758) showed, from east to west, 18 inches of pyrite and quartz, 18 inches of galena and quartz, 30 inches of pyrite and quartz, 6.5 inches of galena, 3 inches of pyrite, and finally 3 inches of galena. The wall rocks adjacent to the vein are silicified, sericitized, and pyritized quartz monzonite of the Swansea stock. Oxidation of the ore was nearly complete to the 250-foot level; above this horizon, the ores consisted chiefly of cerussite, anglesite, plumbojarosite, jarosite, argentojarosite, and cerargyrite in a matrix of iron-stained honeycombed quartz.

Many fissure veins cutting the igneous rocks undoubtedly contain unmined shoots of ore similar to the deep ore bodies of the Swansea mine. However, the small size of these ore bodies and the rather low-grade of the primary ores may not justify the expense of unitizing the small holdings or disposing of the excessive inflows of mine water.

Stratigraphic and Structural Relations

The preferential occurrence of the more productive Tintic ore bodies with certain stratigraphic units and structural features was recognized by the earliest miners and has continued to be among the principal factors that guide modern prospecting and mine development. Despite the throughgoing character of the persistently north-trending ore zones, it is obvious that most of the replacement ore has been produced from only a few formations, principally the Cole Canyon and Ajax Dolomites, the Fish Haven, Bluebell, and Victoria Formations, the Pinyon Peak, Fitchville, and Gardison Formations, and the upper part of the Deseret Limestone. Ore bodies in the Ajax, Bluebell, Fitchville, and Deseret Formations alone are estimated to have provided more than three-quarters of all of the ore produced from the district. Structural controls are equally obvious for the fissure and replacement veins and for some of the replacement ore bodies, but they are locally obscure for many of the replacement bodies. Of signal importance as sites of deposition of the replacement ore bodies, however, were large areas of tectonic breccia that were in the path of hydrothermal solutions rising along north-northeast-trending fissures, north-trending bedding plane faults, and northeast-trending shear faults.

The general stratigraphic and structural relations of all the major ore zones have many similarities, but they exhibit so many individual characteristics as to warrant individual description.

GEMINI ORE ZONE The Gemini ore zone extends from the Grand Central mine northward to the Gemini and Ridge and Valley mines. The southernmost ore bodies of this ore zone, lying at an elevation of 4850 feet, are localized by north-northeasterly-trending fissures cutting the Ajax Dolomite, which strikes northwesterly and dips moderately to the northeast in the trough of the Tintic syncline near the Mammoth fault. From this point, the ore bodies follow a selected horizon in the Ajax Dolomite westerly to the Grand Central fault and dike zone. West of this fault, the beds abruptly steepen as the strike swings to the north. The ore bodies continue to follow the Ajax along its strike but rake steeply upward toward the north and extend to an elevation of about 6550 feet, chiefly in columnar ore shoots localized by the east-trending, south-dipping Virginia and North Carolina faults that crop out a short distance south and southeast of the Centennial Eureka shaft. Near the Centennial fault, the ore zone turns westerly through the Opex Formation and the upper part of the Cole Canyon Dolomite, crosses the fault, and again enters the Ajax Dolomite north of the fault. In this area, the great California ore column is localized near the northwest-trending California fault. This near-vertical pipe of ore extends from an elevation of about 5000 feet to an elevation of about 6300 feet. From the California pipe, the ore bodies extend northward as a series of separate lenticular pods lying between elevations of 5500 to 6500 feet. These lenticular ore bodies chiefly follow selected stratigraphic beds and nearly vertical bedding-plane faults in the Ajax Dolomite along two principal subzones or channels. At the Bullion Beck shaft, the ore zone crosses the Beck fault, where large, irregular, pipelike and podlike ore bodies have developed in both the footwall and hanging wall rocks of the fault zone. Here again, the ore zone extends through a major shear fault with little deviation, leaving the Ajax and entering the Bluebell Dolomite. Northward from this point, the ore bodies occur as a series of separate lenses and pipelike ore bodies along four subzones or channels that rake downward to the north and west along nearly vertical beds and bedding plane faults. At an elevation of about 4500 feet, midway between the Beck and Paxman faults, the ore bodies were abandoned because of high pumping costs and diminishing size and grade.

MAMMOTH-CHIEF ORE ZONE The highly productive central ore zone of the Tintic district, which chiefly extends between the Mammoth and Chief No. 1 mines, properly may be regarded to begin in a group of discontinuous north-northeast-trending fissure veins in the Silver City stock perhaps best known from exposures in the Iron Duke and Monterey mines. At least one of these veins crosses from the monzonite into the bleached and silicated carbonate rocks in the Lower Mammoth mine. Between the monzonite contact and the Sioux-Ajax fault in the Opohonga and Gold Chain mines, several other replacement veins cut pyrometasomatized limestone and dolomite of Cambrian to Ordovician age. No obvious preference for any specific host formation is noted in these mines, except, perhaps, for the Ajax and Cole Canyon Dolomite, which localize columnar ore shoots of various sizes. At the intersection of the throughgoing fissures and the rocks of the hanging wall of the Sioux-Ajax fault, the remarkable Apex ore chimney of the Mammoth mine is localized in shattered carbonate rocks of Cambrian to Devonian age. This great ore column was mined continuously from the surface to the 2200-foot level of the mine and recently was recognized to join a fissure zone on the 2400- and 2600-foot levels. (J. Steele McIntyre, oral communication, 1965) North of the Apex ore body, the ore-bearing fissures extend at least to the Mammoth fault, where the Silveropolis and other columnar ore bodies were mined.

North of the Mammoth fault, where the tops of the ore bodies reach an elevation of nearly 7200 feet, podlike replacement ore bodies in the ore zone plunge northward along strike faults and favorable horizons in the Fish Haven and Bluebell Dolomites to the 800-foot level of the Grand Central mine, where the zone flattens at an elevation of about 6400 feet. From this point northward for more than 3000 feet, the ore zone essentially is confined between elevations of 5800 to 6500 feet. The ore bodies are virtually continuous, following strike faults, north-northeast-trending fissures, and selected dolomite beds in the vertical to overturned Fish Haven and Bluebell Dolomites. Near the Victoria shaft, the ore zone turns north-northwestward and again plunges downward, forming irregular and pipelike shoots in the Bluebell Dolomite between elevations of 5200 and 6000 feet. At the Centennial fault, the ore plunges through the fault zone and expands upward and downward in the hanging wall to form the Granite chimney. North of the Centennial fault, the ore plunges northward down steep beds of the Fitchville Formation to the Beck fault, where the large, crab-shaped 18-316 ore body is localized. Through this area, the base of the ore zone plunges from an elevation of about 5300 feet to 4600 feet, which is the elevation of the 18-316 ore body. North of this ore body, the ore zone extends below the level of permanent water and continues northward as four separate subzones or channels, the most important of which, the "Beck-Northeaster" channel, rakes northeasterly down the East Beck fault zone. This subsidiary ore run follows the fault zone for a horizontal distance of about 1500 feet, at which point it turns northward on a minor north-northeast-trending fracture linking the East Beck and Leadville faults and plunges through the Leadville fault and dike zone, where the base of the ore zone extends to the lower part of the Fish Haven Dolomite at an elevation of about 4000 feet.

The "C Sump" subzone, which is adjacent to the "Beck-Northeaster" subzone on the west, also leaves the 18-316 ore body on the 1900-foot sublevel of the mine (elevation 4720), plunges through the East Beck fault zone and extends downward through the Bluebell Dolomite along a fracture of small displacement. In the vicinity of the Leadville fault and dike zone, the "C Sump" ore bodies plunge nearly vertically to the base of the Fish Haven Dolomite, forming a pipelike ore body that lies between the 2100- and 2600-foot levels, at elevations of 4500 to 4050 feet.

At an elevation of approximately 4000 feet, both the "C Sump" and "Beck-Northeaster" ore bodies cross directly through the Leadville reverse fault and again enter the upper part of the Bluebell Dolomite, which strikes easterly and dips gently to the north. A short distance beyond the Leadville dike and fault zone, the two ore channels join and extend northward and downward along bedding-plane faults to an elevation of 3700 feet, where mining was terminated because of high pumping costs.

A separate subzone channel of high-grade silver ore bodies southeast of the "Beck-Northeaster" subzone plunges down the Millionaire Row fault, which is about 600 feet southeast and parallel to the Beck fault. These ore bodies merge upward with the ore bodies of the main Mammoth-Chief zone at the 1800-foot level of the Chief No. 1 mine (elevation 4835) in an area where mineralization spreads widely in the trough of the Tintic syncline. The rich silver ores were mined downward only to the 2700-foot level (elevation 3970) where mining was terminated because of high pumping and mining costs and the unpredictable habit of the ore.

PLUTUS ORE ZONE The smallest and most recently discovered ore zone in the main Tintic district is confined essentially to the Plutus claims, which are east of the Grand Central and Victoria mines, and to the adjoining northern part of the Mammoth property. The ore bodies of this zone are localized in the Fish Haven, Bluebell, and Victoria Formations, chiefly near fissures that are also mineralized in the Mammoth and Grand Central mines. The recurrence of the ore-bearing formations east of their exposures in the Grand Central, Victoria, and adjacent mines was not anticipated from the surface geology when the area was first explored in 1925 but was later determined to have been the result of disharmonic folding that produced a subsidiary anticline in the rocks between the Centennial and Sioux-Ajax faults. This subsidiary fold is partly delimited on the west by an unobtrusive strike fault, which is named the Victoria fault from exposures in the lower levels of the Victoria mine.

The ore bodies in the southern part of the Plutus zone replace flat and gently dipping beds in the Fish Haven, Bluebell, and Victoria Formations in the axial area of the disharmonic anticline at elevations of 5600 and 5700 feet. The principal ore bodies, which consist of partly oxidized argentiferous galena and jasperoid, replace selected bedding horizons 10 to 20 feet thick that bridge areas between the essentially unmineralized faults and fissures. Near the West fissure, which extends north-northeasterly from the workings of the Grand Central mine, the ore shoots extend through several fault blocks in the same favorable horizon at the top of the Bluebell Dolomite, erroneously suggesting post-mineral fault displacement.

In the central part of the Plutus zone, the ore bodies preferentially replace horizons in the upper part of the Bluebell Dolomite and in the Victoria Formation at elevations of 5300 to 5600 feet. (Figure 4) In this part of the Plutus zone, the ore bodies are more obviously related to fissures, particularly the north-northeast-trending Plutus fissure zone*; however, many of them also extend outward for many feet on beds that strike northwest and dip northeast at 35°. Much rich siliceous silver ore was produced from shoots in this part of the Plutus mine.

The ore bodies in the northern part of the Plutus zone form gently northeast-plunging, en echelon, ore shoots that cut across the moderately dipping upper Bluebell and Victoria Formations. The southernmost and easternmost of these ore bodies are localized near the obscure Plutus fissure, and the others are similarly localized near noncontinuous en echelon fractures in the same zone. The northernmost shoot has been mined to a depth of 5200 feet. Extensive exploration in the northern part of the Plutus zone, particularly near the Centennial fault zone, was unsuccessful, suggesting that the principal access ways for the hydrothermal solutions were the north-northeasterly mineralized fissures that also localize the roots of the Mammoth, Grand Central, and Centennial Eureka ore bodies.

GODIVA ORE ZONE The closely adjacent Godiva and Iron Blossom ore zones have many similarities and are parallel through the greater part of their length. Both have their beginnings in a wide zone of northeast-trending veins and fissures that extends from Ruby Hollow across the Silver City stock and its aureole of contact-metasomatized sedimentary rocks to the Sioux-Ajax fault. The dominant veins on the western side of the fissure and vein zone in the monzonite were opened by the Sunbeam, Elmer Ray, and other mines. These veins do not cross the contact but are more or less alined with replacement veins exposed in the North Star, Red Rose, Boss Tweed, Victor, Carisa, and Northern Spy mines that cut the Ajax, Opohonga, Fish Haven, Bluebell, and Victoria Formations. The replacement veins in the latter mines range from narrow seams cutting marbleized and silicated carbonate rocks to zones 30 or more feet wide that principally occur near fissure intersections in areas of less bleached and altered dolomite. The vertical range of the ore shoots of the replacement veins is small, extending in the Carisa mine area from the surface at an elevation of 7500 feet to an elevation of 6800 feet and from the surface in the North Star mine area at an elevation of 7000 feet to an elevation of about 6600 feet.

North of the Sioux-Ajax fault, the ore bodies of the Godiva zone consist of tabular and podlike replacement masses that persistently follow a selected horizon of bioclastic limestone in the upper part of the Deseret Limestone for more than 5000 feet to the Humbug mine, where the ore zone is intersected by the northern, or "connecting" ore bodies of the Iron Blossom zone. Between the Northern Spy and Humbug mines, the ore bodies of the Godiva zone are from 2 to 50 feet wide and are essentially confined between elevations of 7000 to 7300 feet in beds that strike north and dip east at 30° to 60° into the trough of the Tintic syncline.

North of the Humbug mine, the ore bodies of the Godiva zone continue northerly along the strike of the favorable horizon to the Yankee mine. In this area, the ore zone is cut by many northeast-trending fractures of small displacement, and the ore bodies become larger and extend through a greater vertical range, chiefly following the dip of the beds. Despite the influence of the Yankee fissure zone, the ore bodies continue north along the ore beds into the Godiva mine, where a series of strong, north-trending fissures and steep strike faults cross the ore zone. Here the ore zone divides, one subzone crossing the fissure and fault zone on northwest-trending beds and extending to the Centennial fault zone. The other subzone, which has been more productive, plunges northward down the fissure zone to an elevation of 6300 feet, where the ore bodies diminish in size and become lower in grade. Extensive exploration for possible continuations of the Godiva ore zone north of the Godiva mine has not been successful.

IRON BLOSSOM ORE ZONE The easternmost of the Tintic ore zones is named from the Iron Blossom mine, workings of which extend both north and south of the Sioux-Ajax fault. The Iron Blossom ore zone originates in the same group of northeast-trending veins and fissures as the Godiva zone and similarly consists of veinlike deposits south of the Sioux-Ajax fault and more or less continuous replacement deposits in the Deseret Limestone north of the Sioux-Ajax fault zone.

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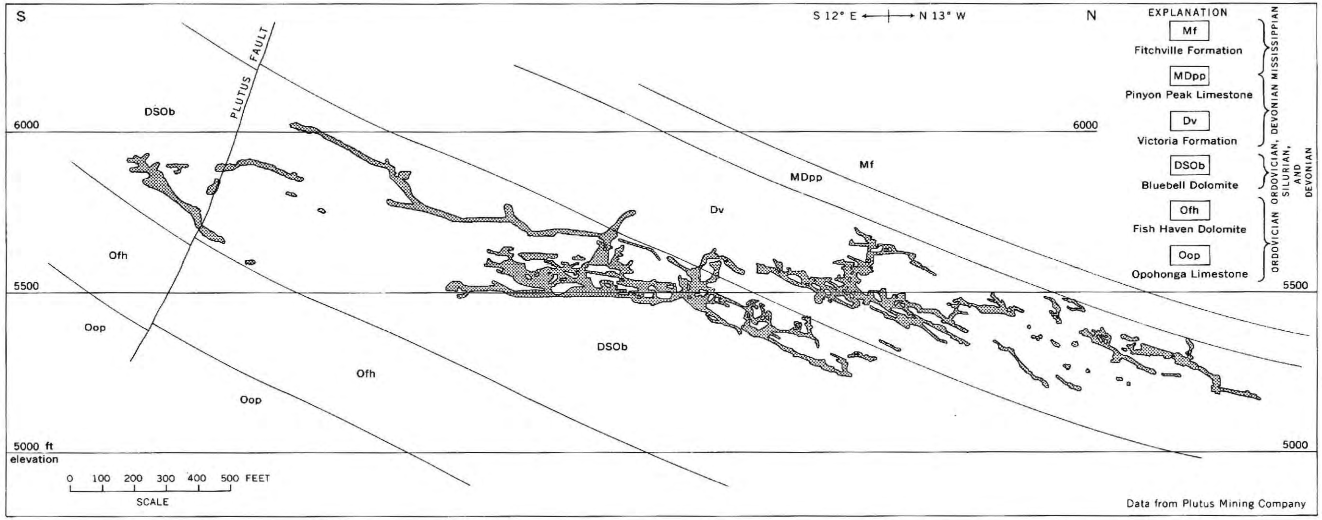
* Not to be confused with the east-striking Plutus fault zone.



Data from Plutus Mining Company

FIG. 4. *Longitudinal Section of the Central and Northern Parts of the Plutus Ore Zone in the Plane of the Plutus Fissure, showing relation of replacement ore bodies (shaded) to stratigraphic units and the Plutus fault.*

The principal veins cutting the Silver City stock that appear to be allied with the Iron Blossom zone are opened by the Undine and Martha Washington mines, now long abandoned. Neither these veins nor others in the same zone cross the contact of the monzonite and sedimentary rocks, but they are closely alined with the Dragon vein which cuts the contact aureole near the Dragon mine. In the general vicinity of this mine, the ore shoots occur in the Ajax and Opohonga Formations and are chiefly valuable for gold; however, they also contain galena and enargite, or their oxidation products, in a gangue of jasperoid and barite.

In the Iron Blossom No. 1 mine, the Dragon vein zone enters the Fish Haven and Bluebell Dolomites, and, in these more hospitable host rocks, the ore shoots show a greater tendency to replace wall rocks, some of them being 10 to 15 feet wide and 100 to 150 feet high. They are chiefly confined to elevations of 6700 to 6900 feet although the roots of some ore bodies have been followed downward to an elevation of 6200 feet. The main ore zone continues northward at this horizon for a third of a mile or more, maintaining the same general dimensions and character. These ore bodies have yielded large amounts of gold, copper, silver, and lead ores.

Near the Iron Blossom No. 3 shaft, the Iron Blossom ore zone crosses the Sioux-Ajax fault zone, which is approximately 300 feet wide and contains fractured and brecciated rocks of the Fitchville, Gardison, and lower Deseret Formations. In this disturbed zone, the continuity of the ore zone is disrupted, but an infaulted segment of the Gardison Limestone localizes the rich Van ore body, which extends for 50 feet above and 60 feet below the 480-foot level.

North of the Sioux-Ajax fault zone, the ore bodies enter the horizon of coarse bioclastic limestones in the upper part of the Deseret Limestone and extend without interruption for nearly a mile straight north, following the nearly flat beds in the axial area of the Tintic syncline. This shoot may be considered to be a horizontal pipe nearly a mile in length, lying at altitudes ranging from 6800 to 6900 feet. Although no vein structures are visible, the ore body appears to have formed at the intersection of vertical tension fissures and the susceptible "ore beds" that are also the host rocks for the replacement ore bodies of the adjacent Godiva zone. The ore pipe is conformable to the stratification and has a width of 20 to 170 feet and a height of 20 to 60 feet. In many places, the high-grade silver and lead ore bodies are adjoined by large masses of dark jasperoid, which has been the source of much siliceous fluxing ore. Oxidation and leaching of the ore body resulted in the development of a shrinkage cavity above the ore body that made it possible for the miners to walk for long distances through an open cave between the top of the oxidized ore body and the limestone country rock during the initial development of the ore body.

Near the northern end of the horizontal pipe, between the Beck Tunnel No. 1 and No. 2 shafts, the ore shoots leave the axis of the syncline at an elevation of about 6800 feet and extend upward to the northwest along the dip of the ore-bearing limestone beds, in part following a system of obscure cross fractures. The ore bodies become more irregular in size and less continuous, but the mineralized zone persists northwesterly until it joins the Humbug ore bodies of the Godiva ore zone, which lie 200 to 500 feet higher in elevation. Extensive exploration on projection of the horizontal pipe in the Beck Tunnel No. 2 mine has failed to disclose any continuation of the Iron Blossom ore body.

Horizontal Persistence of the Ore Zones

The persistent northward course of the principal ore zones through a variety of host rocks and across major structural features is explained less readily than the stratigraphic and structural localization of their constituent ore bodies. A possible interpretation of this relationship may be found in the inferred occurrence of deep, north-trending, structural features that conceivably guided the emplacement of apophyses and cupolas of the invading monzonite body and also provided the initial channelways that were utilized by the ore-depositing solutions. These deep structures possibly occur in the rocks below the Midas thrust fault, which is inferred to underlie the entire district (30, p. 1946).

The general character and distribution of the individual ore bodies in the ore zones, as well as the general characteristics of the zones themselves, suggest that the hydrothermal solutions found access through several principal conduits along each ore zone and migrated upward, outward, and locally downward through many different types of openings. The solutions rising along any one conduit eventually mingled with comparable solutions rising along other conduits that tap the same deep structural zone, producing the apparent linearity of the ore runs.

ORES

General Features

The primary ores of the Tintic district consist chiefly of sulfides and sulfosalts of silver, lead, copper, iron, zinc, and bismuth in association with jasperoid (silicified carbonate rock), barite, aggregates of quartz crystals, calcite, dolomite, and ankerite. In addition, gold is locally abundant in some of the copper ores, in part as the native metal and in part as a telluride; primary native silver is also abundant in some late ore bodies in the Chief No. 1 mine. The mineral assemblage is generally characteristic of mesothermal deposits; however, the general geologic environment and certain mineral textures and associations suggest rather low temperatures and pressures at the time of ore deposition (9, p. 585).

The primary ore bodies were partly to wholly oxidized to depths of 400 feet or more in the fissure veins cutting the igneous rocks and to depths of 1800 to 2300 feet in the sedimentary rocks. This oxidation greatly obscured the original character of some of the ore bodies, which is difficult to interpret, except from minor masses of residual primary minerals or from the gross chemical composition of the secondary ores.

Although the ores intergrade from one type to another, not uncommonly within a single mine, they are generally segregated into the following classes:

(1) *Lead ores* containing from 5 to 50 per cent lead and as much as 50 ounces of silver to the ton. Rarely they also contain small quantities of zinc and copper and a few hundredths of an ounce of gold.

(2) *Siliceous lead ores* containing a few per cent lead with minor amounts of zinc and copper in a siliceous gangue of more than 70 per cent silica. The silver content has a considerable range and is locally high.

(3) *Siliceous silver ores* generally containing 20 ounces or less of silver to the ton and gold worth a few dollars. In many places, these ores contain no identifiable metallic minerals except rare scattered crystals of cerussite and some copper stain.

(4) *Lead-zinc ores* containing 5 to 15 per cent each of lead and zinc and about 8 to 10 ounces of silver to the ton.

(5) *Copper-gold ores* containing a few per cent or more of copper, 10 to 20 ounces of silver to the ton, and commonly a half ounce or more of gold. Some rich ores contain many hundred to several thousand ounces of gold to the ton.

(6) *Siliceous lead-copper ores* occurring where copper ores give way to lead ores, as in the Eureka Hill, Grand Central, Chief, Iron Blossom, and other mines. These ores generally contain only a few per cent each of lead and copper.

In addition, a special class of zinc ore that originated through oxidation and migration was mined in the Godiva, May Day, and adjacent mines (2), and an unusual variety of primary native silver ore was produced from the deep, late ore bodies in the Chief No. 1 mine (27, p. K26).

Primary Ore and Gangue Minerals

The principal primary gold minerals are believed to be sylvanite and native gold, which most commonly occur with enargite. The most important primary silver mineral is argentite, which is ubiquitous in the galena ores. Of lesser importance, but locally occurring in rich shoots, especially in the Chief and Gemini mines, are proustite, pearceite, freibergite, native silver, pyrargyrite, stephanite, and, more rarely, smithite and hessite.

Galena is the predominant primary lead mineral, ranging in texture from fine-grained ("steel") galena to aggregates of coarse crystals displaying cubic faces more than 2 inches square. Small amounts of arsenic and antimony persistently present in some of the galena ores are attributed to near-microscopic grains of gratonite, zinkenite, and jamesonite, which have been identified by X-ray and electron microprobe techniques (A. S. Radtke, oral communication, 1966).

Much of the copper ore in the Tintic district was deeply oxidized, but residual masses of unaltered sulfides and sulfosalts show enargite to be the principal primary copper mineral, occurring in at least small amounts in many of the mines and generally intergrown with famatinite. Tennantite and tetrahedrite, both commonly argentiferous, are less abundant than enargite and famatinite, but locally, as in the Chief No. 1 mine, they are the dominant copper minerals in some rich shoots of silver ore. Curiously, the enargite ores contain far less silver on the average than the tennantite ores but decidedly more gold. Chalcopyrite also has been observed as a primary copper mineral.

The principal primary zinc- and iron-bearing ore minerals are sphalerite and pyrite. Arsenopyrite and marcasite have been reported (5, p. 147), but they are not abundant. The sphalerite ranges in composition from a nearly colorless, iron-free variety to nearly black crystal aggregates (blackjack ore) containing considerable iron. Cadmium is consistently present in the zinc ores, probably within the sphalerite lattice, inasmuch as greenockite or hawleyite have not been observed even in microscopic examinations. The primary bismuth mineral has not been recognized in the Tintic district; it is inferred to be bismuthinite or an unknown sulfarsenide of bismuth and copper, although tetradymite was reported from the adjacent East Tintic district by Lovering, *et al.* (15, p. 18).

The principal nonmetallic minerals in the ores are quartz and barite. The quartz ranges from finely crystalline jasperoid to coarse aggregates of terminated crystals; the barite similarly shows a wide range in crystal size. Calcite, dolomite, and ankerite are abundant only at the periphery of the ore bodies and may represent the redeposition of country-rock constituents that were replaced by the ore and gangue minerals. The ubiquitous jasperoid is most commonly gray or bluish-gray to black; much of it is delicately banded and contains vugs lined with small terminated quartz crystals generally not more than a few millimeters long. Some of the jasperoid resembles fine-grained quartzite, but in the central and northern parts of the district, it more nearly resembles chert or flint. The coarse crystalline quartz is most abundant in the veins cutting monzonite.

Barite is generally subordinate to jasperoid and quartz except in the Centennial Eureka, Grand Central, Carisa, and other copper-producing mines, where it occurs in large masses of coarsely granular or platy aggregates commonly coated by quartz and sulfide minerals. In the finer-grained jasperoids, small prisms or plates of barite embedded in the mosaic of interlocked quartz grains appear to be the earliest product of replacement of the limestone. Other nonmetallic gangue minerals include rhodochrosite and zunyite, but neither is abundant.

PARAGENESIS The associations of the ore minerals in the various types of Tintic ores are complex when considered on a district-wide basis. In general, jasperoid and barite of several generations are early, followed by pyrite, some of which is intimately associated with late quartz that continued to crystallize through a considerable period. Next younger are enargite and famatinite, which deposited more or less simultaneously; these copper-bearing minerals are typically earlier than galena, which in turn is older than sphalerite. Locally, as in the Chief and Gemini mines, shoots of rich silver ore, containing native silver, proustite, argentian tennantite, and pale, reddish-brown sphalerite, are later than the galena, ferroan sphalerite, and tetrahedrite ores of these mines. In some mines, calcite, dolomite, and ankerite, fill vugs and cement fractures in the ore bodies, but these minerals may have been deposited after the principal phase of ore deposition.

Secondary Ore and Gangue Minerals

In all of the mines of the Tintic district, oxidation has penetrated to the water table and locally below it, although in no mine is the oxidation complete. Residual masses of enargite, pyrite, and galena may be found at all levels embedded in the generally soft, crumbling masses of cellular and cavernous, gossan-like oxidized ore. In general, the permanent water table in the sedimentary rocks stands approximately at an altitude of 4800 feet, placing it from 1650 to 2400 feet below the collars of the principal mine shafts. In the igneous rocks, the water table stands much higher, normally from 100 to about 650 feet below the surface.

The oxidized copper ores commonly contain malachite, azurite, copper pitch (impure chrysocolla), copper arsenate minerals, and more rarely, turquoise, cuprite, and native copper. Covellite and chalcocite are widespread throughout the oxidized zone, though nowhere in large masses. They principally form small nodules ranging from walnut-sized kernels to dull sooty or bluish spots in or near partly oxidized enargite. The typical matrix of the oxidized copper ore is fractured and corroded, iron-stained jasperoid, most of which contains barite. Secondary quartz coating limonite or chrysocolla is not uncommon, and alunite, halloysite, and kaolinite are locally abundant. The latest products of oxidation include crystalline and pulverulent calcite, gypsum, and, in damp areas, many different kinds of hydrous copper and iron sulfate minerals. Some rich shoots of oxidized copper ore, particularly in the Mammoth and Iron Blossom No. 1 mines, contained visible native gold as minute wires and grains in iron- and copper-stained jasperoid, as small grains and flakes in secondary argentite, and rarely as ragged plates on joint planes or embedded in limonite.

Oxidation of the argentiferous lead ores has produced anglesite, cerussite, plumbojarosite, pyromorphite, and mimetite. In places where pyrite is abundant, jarosite accompanies the plumbojarosite. Some of the massive lead ore bodies were converted to loose granular aggregates of cerussite, producing the "sand carbonate" ore, so called by the miners. During the replacement of galena by cerussite and anglesite, there has not been much migration of lead although the development of well-formed tabular, pyramidal, and twinned crystals of cerussite on quartz crystals and of secondary galena and sphalerite indicate some solution and movement of this insoluble metal.

The silver in the oxidized zone commonly takes the form of native silver, cerargyrite, and argentojarosite. Some highly siliceous silver ore bodies containing secondary argentite, brown crusts of cerargyrite, and native silver were discovered below masses of cerussite and anglesite, suggesting local downward migration of silver during the oxidation of argentiferous galena ores.

The nearly complete oxidation of mixed sphalerite and galena ore bodies in the May Day, Yankee, Godiva, Chief, and other mines caused zinc to migrate downward, forming residual ore bodies of cerussite and anglesite at the original site of ore deposition and separate zinc ore bodies below them. Loughlin (2) concluded that the readily soluble zinc sulfate apparently moved in descending waters until it reached the carbonate country rock beneath or downdip from the residual lead ore bodies and was precipitated as ferruginous smithsonite, calamine, hydrozincite, aurichalcite, and other minerals. This nearly lead-free zinc ore is accompanied by a gangue of unreplaced limestone, dolomite, chert, jarosite, and the hydrous oxides of iron and manganese, calcite, and gypsum. Most of the ore contained from 20 to 35 per cent of zinc. Zalinski (3) reports that a selected sample of ore free from insoluble gangue material contained essentially no gold or silver.

The incomplete oxidation of mixed lead and copper ores, such as in the Eureka Hill and Grand Central mines, has yielded chiefly chalcocite and covellite, which are intergrown with anglesite or which may surround the residual grains of galena. Covellite, particularly, is found with anglesite in the druses. Locally these mixed ores have provided rare and beautiful specimens of mimetite and linarite.

The local occurrence of siliceous silver ores that contain practically no recognizable metallic minerals suggests either the oxidation of primary silver deposits or the migration of silver during the oxidation of argentiferous lead and copper ores. Most of these "dry" silver ores are of low grade, containing a few hundredths of an ounce of gold and 20 ounces or less of silver to the ton. Their texture is generally drusy or honeycombed although locally they may consist of massive chert-like jasperoid. The richest of these ores are found beneath lead shoots, suggesting that migration of silver during the oxidation process was the dominant factor in their development. A particularly rich specimen from the Eagle and Bluebell mine is described by Lindgren (5, p. 175) as being a jasperoid in part replaced by argentite and cerargyrite and coated by soft yellow crusts containing iron, lead, and bismuth. Small specks of bright yellow gold occur in both the argentite and quartz. This apparently enriched ore may be contrasted with the more typical fine-grained banded and vuggy jasperoid ores that carry from a few ounces to several hundred ounces per ton of silver. Much ore of this latter type in the Grand Central, Victoria, Chief, and other mines is remote from lead or copper ore shoots and suggests the oxidation of siliceous argentite ores with little if any migration of silver.

Supergene Sulfide Enrichment

Although the Tintic district has produced only moderate amounts of secondary sulfide ores, the Chief and Gemini mines, in particular, contained enriched sulfide ores near the permanent water table. These ores were parts of continuous ore bodies that were mined from the zone of oxidation downward into the zone of primary ore. In the Chief mine, primary galena ore bodies near the 1800-foot level are enriched in argentite and also contain druses lined with native silver. Some adjacent ore bodies that were essentially zinc-free above the water table were mined downward into wurtzite and galena ore shoots, providing some of the first important zinc-sulfide ores produced from the Tintic district. Evidence for sulfide enrichment persists to the 2000-foot level of the mine, about 150 feet below the water table, below which only primary sulfide ores were encountered.

Lindgren (5, p. 177–180) has described a shoot of rich silver ore containing from 50 to 3000 ounces of silver to the ton in the Gem "channel" of fthe Gemini mine that may also be the result of secondary enrichment. This ore consisted of fine-grained jasperoid containing disseminated galena, sphalerite, and pyrite that had been brecciated and in part cemented by coarse galena, abundant late sphalerite, a little enargite, marcasite(?), and pearcite. Quartz in small clear crystals was seemingly the last mineral to form. As Lindgren (5, p. 180) observed, however, it is not certain that the pearceite-rich ore bodies were formed by descending solutions, only that they were deposited from late flowing, rather cool solutions, ascending or descending, that were unusually rich in silver.

The secondary sulfide ore bodies in the Chief mine occur in extensive masses of fractured jasperoid containing abundant pyrite. This carbonate-free environment was doubtless a factor in the development and migration of the acidic, ferric sulfate-bearing solutions in which the descending metals were carried. In contrast, the Gem ore bodies of the Gemini mine are small masses of mineralized jasperoid in steeply dipping beds of reactive dolomite.

Hydrothermal Alteration

The monzonite wall rocks of the veins traversing the Silver City stock and other igneous bodies in the Tintic district exhibit a sequence of hydrothermally altered zones that resemble the alteration selvages adjacent to the veins of the Boulder County, Colorado tungsten district (11, p. 234–259), Butte, Montana (13), and many other districts. Proceeding outward from the margins of the ore shoots, the vein filling abruptly adjoins a zone of quartz-sericite-pyrite rock, which locally retains the original texture of the porphyritic igneous rock. This zone gradually merges outward with a wider zone of nearly white argillized rock containing clay minerals, chiefly kaolinite and endellite. In places where it is widely developed, the argillized zone contains dickite on its veinward side and merges with the propylitized country rock through a zone containing decreasing amounts of kaolinite and increasing amounts of montmorillonite, epidote, chlorite-group minerals, and carbonate minerals. Some variations of this sequence are noted, particularly in the southern part of the productive area, where the vein walls locally contain much potassium feldspar in the place of sericite, and zunyite in the argillized parts of the vein zone.

The carbonate host rocks of the replacement ore bodies are closely associated with similar but less obvious altered zones. The quartz-sericite-pyrite zone in the igneous rocks may have its counterpart in the sericitic and pyritic jasperoid that is commonly fractured and recemented by ore minerals, baritic jasperoid, and fine-grained quartz of the ore stage. Surrounding these mineralized jasperoid masses are the irregular zones of pyritized rock that give rise to the halos of "chocolate rock" surrounding the oxidized ore bodies. The argillized zones are represented by irregular masses of sanded limestone and dolomite or by solution breccias, except near shale beds and layers of argillaceous limestone, which locally provided sufficient alumina and silica to produce hydrothermal clay minerals. In the sedimentary rocks, the quartz-sericite-pyrite and the argillic alteration episodes were preceded by pervasive hydrothermal dolomitization. The dolomitizing solutions, which apparently heralded the sequential episode of hydrothermal activity that culminated in ore deposition, preceded the intrusion of the stocks and followed more routes and penetrated farther than those of the later alteration stages.

Dragon Halloysite Deposit

The remarkable deposit of high-grade halloysite clay at the Dragon mine (20) near the north boundary of the Silver City stock originated during the episode of argillic alteration as a replacement of the Ajax Dolomite. The halloysite deposit, a large part of which has been exhausted, originally occurred as two irregular pipelike bodies that were separated by a zone of iron oxide deposits localized by the crosscutting Dragon fissure. The two clay bodies plunge steeply to the 230-foot level, where they essentially join and follow a particular horizon of the Ajax. The purest material as mined consists dominantly of endellite ($Al_2O_3 \cdot 2SiO_2 \cdot 4H_2O$), which resembles lustrous, white porcelain, although less hard. The endellite dehydrates in the dry desert atmosphere to halloysite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$), which is chalky in appearance and reticulated by small fractures. The less pure material contains, in addition to the iron oxides, fine-grained pyrite, manganese oxides, gibbsite, and unreplaced residual kernels of dolomite and chert. The halloysite body orginally contained more than 1.5 million tons of high- and intermediate-grade clay, which is mined and chemically activated for use as a filter catalyst required in the refining of certain crude oils.

The source of the silica and alumina of the halloysite deposit is inferred to be the argillized wall rocks of the veins near the Sunbeam, Undine, and Joe Daly mines, which merge with the Dragon fissures at the monzonite contact. The highly acid, argillizing solutions apparently leached all of the constituents of the monzonite as they rose obliquely up the vein zone and, on entering and reacting with the carbonate rocks, became partly neutralized, depositing endellite, gibbsite, and the manganese and iron oxides. The absence of comparably large metalliferous deposits associated directly with the halloysite body is compelling evidence that the argillizing solutions were barren of metals and that the ore depositing solutions were later and of a different chemical character.

Zonation of Ore Bodies

A general horizontal zonation is evident in the composition and, to a lesser degree, the texture of the ore bodies of the linear ore zones of the Tintic district (Figure 5). The replacement ore bodies and replacement veins closest to the Silver City stock are valuable chiefly for copper and gold. The mines at an intermediate distance from the stock have produced mostly lead and silver ores, including locally rich silver bodies that are lead free; gold is an important constituent of only a few of these deposits. The northernmost ore bodies in the district carry as much zinc as lead and contain significantly smaller quantities of silver than those in the area of predominantly lead deposits. It should be noted, however, that much lead ore and some zinc ore have been mined in the southern, copper-producing area and that the Granite pipe and other vertical pipelike ore bodies in the central, lead-silver zone contained notable amounts of copper and some gold. One or more of the lead-rich ore bodies in the southern zone of the district may have been deposited late in the general sequence of ore deposition. No copper and only insignificant amounts of gold occur with the zinc-rich ores of the northern zone.

Vertical zonation of individual ore bodies is not obvious, except in mines where the oxidation of primary lead-zinc ores has caused the separation and downward migration of zinc into zones of secondary zinc sulfides or into bodies of high-grade zinc carbonate and hydrous zinc silicate. In some mines that dominantly produce copper, lead and copper shoots may be in close proximity, but no systematic relationships have been observed, thus suggesting local telescoping of the ores.

A textural zonation of the gangue minerals outward from the Silver City stock is perhaps as prominent as the chemical zonation, although it is less spectacular and not of direct commercial significance. As noted by Lindgren (5, p. 127), the quartz in the veins cutting the igneous rocks occurs as well-developed crystals, some several inches long. In contrast, the siliceous gangue of the replacement copper ore bodies in the sedimentary rocks near the Silver City stock consists of granular aggregates of small quartz crystals or medium-grained jasperoid, both containing medium to large plates of barite and druses filled with quartz crystals 0.3 inches or so long. The jasperoid associated with the silver and silver-lead ore bodies farther north is still finer grained, resembling chert, and contains small barite plates and tiny quartz crystals filling fractures and shrinkage openings. The fine-grained jasperoid continues into the northern, zinc-rich areas, but barite and crystalline quartz cease to be abundant. In the outermost fringes of the district, small podlike deposits of lead and zinc are characterized by modest amounts of silver and silica and much dolomite and calcite. The dolomite, which is commonly associated with scattered crystals of galena and sphalerite, is abundant as granular aggregates of small curved rhombohedrons. The calcite is largely later than the dolomite and typically forms slender scalenohedrons lining cavities; it appears to be the latest phase of primary mineral deposition.

GENESIS OF THE ORE DEPOSITS

The mineral assemblages, textures, and structural relationships of the ore deposits of the Tintic district all substantiate an origin from hydrothermal processes. The relations of the ore bodies and the selvages of altered country rock leave no reasonable doubt that the primary minerals were the final product of solutions that differed in composition during the various stages of their development. Earlier investigators, including Lindgren and Loughlin (5, p. 128), have suggested that these solutions rose along fissures in the Silver City monzonite stock and penetrated the adjacent sedimentary rocks, spreading and descending northward until they gradually cooled or became depleted in metals and the other elements. More recent studies by Billingsley and Crane (8, p. 113–116), Kildale (10), T. S. Lovering (oral communication, 1949), and the writer have provided evidence that the ore solutions rose from many centers within the district, in the sedimentary rocks as well as in the monzonite. Several of these hydrothermal centers, as indicated by the form and distribution of the ore bodies, resemble the trunk of a tree from which the ore bodies at higher elevations branch and divide, commonly extending for great distances along bedding plane faults and other minor features. It is noteworthy that sev-

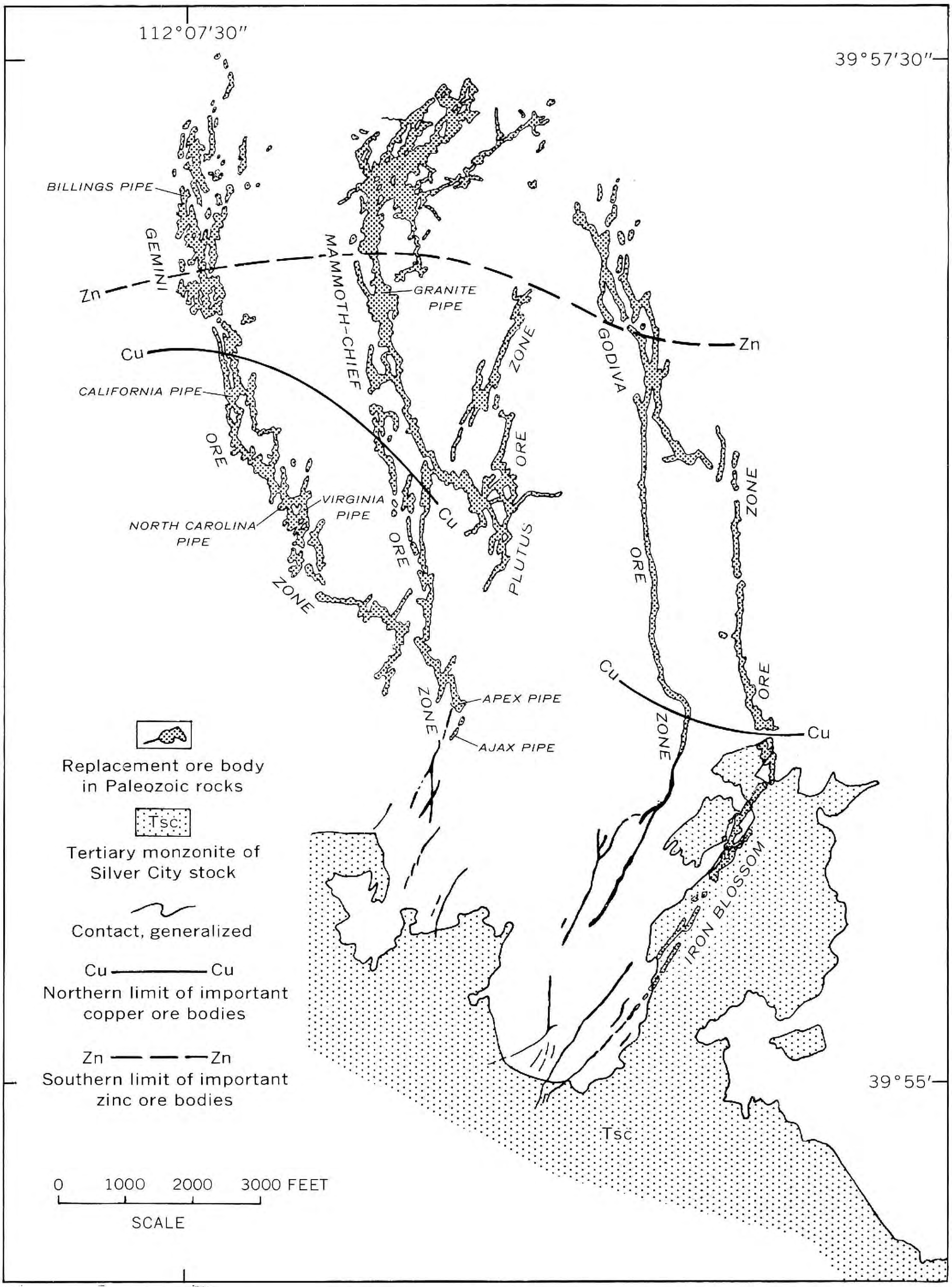


FIG. 5. *Vertical Projection of Replacement Ore Bodies, showing generalized compositional zonation.*

eral of the trunklike ore bodies terminate downward in breccia masses that are also invaded by intrusive plugs, dikes, and injected debris.

The ultimate origin of the hydrothermal solutions is a matter of somewhat greater speculation. Geophysical studies (31) have shown that the Silver City monzonite stock apparently is a satellitic appendage of a much larger mass of intrusive rock that is inferred to underlie the central and southern East Tintic Mountains. This larger body doubtless cuts deep-lying Precambrian rocks of unknown composition and one or more thrust fault plates containing dominantly carbonate rocks (30, p. 1946, 1952–1953). Its composition, the possible composition of the crustal materials from which it was derived, and the inferred composition of its residual solutions are all unknown except from the evidence provided by the ore deposits and their halos of altered rocks.

EXPLORATION AND MINE DEVELOPMENT

During the past three decades, several major programs of exploration and mine development have been undertaken in the main Tintic district. The most successful of these efforts was the redevelopment of the deep ore bodies of the Chief No. 1 mine in 1942. These ore bodies were known to contain lead and zinc ores (bypassed during the earlier operations) that probably were mineable under the quota system and premium price plan offered by the Federal Government during World War II (14, p. 233). These bypassed ores were successfully mined from 1943 to 1945, and this effort, and the techniques of mining and exploration that were newly employed in their development, later led to the discovery and development of new ore bodies extending 600 to 800 feet below the ores that were originally sought. These new ore bodies were the principal source of ore in the Tintic district from 1945 to 1955.

This successful redevelopment of the Chief No. 1 mine, along with other factors, prompted several other major mining companies to undertake additional exploration and development programs, but none of these efforts can be considered to have been even moderately successful. In general, the programs were well conceived and well financed, and although ore was not discovered, they did provide additional geologic data that will be of great value in the future search for undiscovered ore in the Tintic district.

Geologic and Mineralogic Guides to Ore

In their broadest aspects, the ore deposits of the Tintic district are located near the northern edge of a mostly buried body of intrusive rock (31) that is part of an easterly trending zone or belt of granitic and porphyritic intrusions that extends from the Wasatch Mountains westward to the Deep Creek Range (6, pl. 11; 26; 25, p. 29, 30). The ore bodies in the district are clustered near centers of mineralization that are alined along north- or northeast-trending fissures, some of which are masked by older faults and bedding features of diverse strike and altitude (this paper under Structure). These fissures, which may reflect a deep, concealed shear zone, are regarded as the fundamental ore guides. Their recognition, or their inferred occurrence based on known ore trends, the presence of ore minerals, geochemical anomalies, alteration halos, intrusion breccias, and dikes of igneous rock, is of vital importance in establishing the general target area of any exploration effort.

Within the areas that have been entered or traversed by the ore depositing solutions, the principal guides to ore bodies include: (1) specific mineralized fissures and ore channels, some of which may be marked only by insignificant traces of ore minerals; (2) favorable rock units, particularly limestone or dolomite beds that have fractured and brecciated under tectonic stresses; (3) faults that trend across the general zones of mineralized fissures, locally shattering the carbonate host rocks; (4) tight folds of diverse types that have brecciated the more brittle horizons; and (5) zones of intrusion breccia that provided a favorable environment for the cooling, pressure release, and accelerated reaction of the hydrothermal solutions.

It is important to recognize, in any specific area under study, a general vertical zone or interval above or below which ore deposits are not likely to occur. It has been noted that the upper limits of ore deposition are commonly within a hundred feet or so of the base, or the projected base, of the lavas which capped the district. The lower limits are less well defined; some ore bodies near the ore-solution conduits, for example, extend hundreds of feet below the general base of the productive interval.

Exploration Techniques

The irregular shape and unpredictable habit of the replacement ore bodies has resulted in the gradual development of mining and exploration techniques that are peculiar to ore deposits of this type. During past mining operations, commonly less than a few months' supply of ore was ever blocked out in advance of stoping. The downward-plunging ore bodies were carefully mapped, establishing their position relative to each other and their shapes in three dimensions. Winzes or the operating shafts were then deepened and crosscuts driven to the projected intersection of the ore bodies at the new level. Diamond core drills were then used to locate the ore zones, thereby reducing costs by shortening the length of development drifts and raises. Little if any attempt was made to fully delineate the ore bodies or to determine their specific grade.

Exploration from the surface in undeveloped areas is chiefly carried out by drilling. Churn and rotary drills are used to penetrate the largely barren lavas, and the cuttings are examined under the microscope to determine the character and progressive changes in depth of the zones of hydrothermal alteration. The cuttings are also analyzed for traces of ore-stage metals. When the Paleozoic sedimentary rocks are encountered, casing is set and core is taken with a diamond drill. The core is examined under the microscope for significant alteration minerals, analyzed for heavy metals, and stratigraphically identified to aid in determining the subsurface structure. Commonly the Paleozoic rocks are so porous, especially above the water table, that it is not possible to recirculate the drilling water and recover cuttings. Consequently, drilling is done merely to locate concealed ore bodies and not to determine their true size or grade.

UNDERGROUND DISPOSAL OF MINE DISCHARGE WATERS

Mine-dewatering operations in the Tintic district have commanded wide interest in recent years because of the unusual technique of discharging the mine waters into natural caves or underground sinks at or near the water table. Sustained volumes of water exceeding 6600 gallons per minute have been pumped from depths extending to 1300 feet below the original ground-water surface and directed into caverns in the Gemini and Chief No. 1 mines without either filling the caverns or recirculating the waters back into the mine workings. Hall (14) has presented a competent history of these pumping operations from 1909 to 1949 but concluded that the mystery of the water-disposal cavern was yet to be solved. Detailed geologic studies of the deep levels of the Chief and Gemini mines up to the cessation of pumping operations in September of 1955 and much broader geological and geophysical studies of the central East Tintic Mountains completed in 1963 (Morris, in preparation) have offered a possible solution to this intriguing problem.

As Hall (14, p. 233) has described, the Chief Consolidated Mining Company began extensive pumping operations in the Chief No. 1 mine in 1918 to dewater the zone of rich secondary sulfide ores that extended below the water table, which then stood close to the 1830-foot level. During the early part of this pumping effort, it was fortuitously discovered that extensive volumes of water discharged into a cavern about 60 feet in diameter on the 1600-foot level of the mine disappeared and did not seem to return to the workings below. Tests utilizing a quantity of fluorescein dye sufficient to contaminate more than 5 billion gallons of water confirmed that none of the water returned to the mine workings. When operations temporarily ceased in March 1927, the Chief mine had been partly developed to the 2500-foot level and the cavern at the 1600-foot level had continuously discharged an average of 2000 gallons of water per minute for a period of several years and had not filled during surges of 3000 gpm.

During this same interval, a second cavern 1100 feet northwest of the Chief 1600-level cavern and about 200 feet lower in elevation was cut by mine workings at the Gemini 1600-foot level. This new cavern, which is an irregular pipelike opening about 35 feet in diameter generally following an apparent bedding plane fault in fractured limestone, was used to dispose of 300 to 400 gallons of water per minute from the Gemini operations and again no recirculation was evident. An examination of this cavern after pumping was terminated at the Gemini mine in 1925 revealed that it plunged downward at about 45° to a flat-lying horizontal room that was about 200 feet vertically below the Gemini 1600-foot level, or approximately 160 feet below the natural water table. This horizontal cavern was floored with mud, and no openings large enough to allow a man to descend further were found. In a final attempt to explore this cavern, the Chief Consolidated Company sank two small winzes some 100 feet below the mud floor of the cavern, but these openings penetrated only dry vuggy limestone.

After March 1927, no further thought was given to the water-disposal caverns until the early part of World War II, when a decision was made to dewater the lower workings of the Chief mine to recover medium- and low-grade zinc and lead ores that were bypassed during the earlier period of pumping. The Gemini cavern was selected as the disposal point for the mine waters, chiefly because of the possibility that the discharge waters undetectably recirculated into the mine workings, and this cavern was 1100 feet farther from the general mine workings than the Chief 1600-level cavern. Dewatering operations were started in August 1942. Initially, 2400 gpm were discharged into the Genini cavern by lifting the water through pump columns to the Chief 1600-foot level, where it was piped through old workings to the Gemini cavern. In May 1944, however, a drift driven at the Chief 1800-foot level intersected the Gemini cavern; this relieved the pumps of the additional 215-foot head to the Chief 1600-foot level, allowing the volume of water being pumped to increase to approximately 4000 gpm. The water table was lowered rapidly after this date, and by mid-1947 the principal underground shaft of the Chief No. 1 mine, the 18-411 winze, was extended to the 2737 level, and stations cut on the 2400-, 2500-, 2600-, and 2700-foot levels without any evidence of recirculation of discharge waters back into these workings.

When mine development had reached a point between the 2600- and 2700-foot levels, it was discovered that the north-plunging ore bodies are cut by a tabular mass of argillized latite porphyry about 2.5 feet thick. This dike, which was injected along the south-dipping Leadville fault, proved to be an effective dam for underground water, holding the depressed water surface at the 2350-foot level in the footwall block although the hanging-wall block had been dewatered to the 2735-foot level. Attempts to mine the ores north of the dike were thus prevented until the dike was breached at a lower level and the area to the north fully dewatered. Accordingly, the 18-411 winze was deepened to the 3100-foot level and the pumping capacity increased to dewater both blocks of the fault to a point below the 3000-foot level. Because of the high initial cost of supplementing and improving the pumping system of the mine, the Chief Consolidated Company applied to the Defense Minerals Production Administration for assistance in this program of mine development, which was to be followed by a Defense Minerals Exploration Administration program. This application prompted a detailed study of the Chief No. 1 mine by the U.S. Geological Survey and the U.S. Bureau of Mines, which included tests to again determine if water recirculated from the disposal cavern back into the mine. In one test, 8 kg of sodium fluorescein salt was added to the water being discharged into the cavern, and water samples were periodically taken at various points in the mine over a period of several months. These samples were drawn into capillary tubes and were examined under an ultraviolet light against a background of black velvet in a photographic dark room. By this technique one part of fluorescein dye in 10 billion parts of water could be detected. Again, no trace of the fluorescein was found in the mine water although the quantity of sodium fluorescein salt used was sufficient to contaminate detectably all of the water pumped in approximately 9 months at the pumping rate then in effect.

A second test, carried out by the Bureau of Mines, involved the addition of over 100 tons of rock salt to the Gemini cavern, preceded and followed by careful analytical studies to detect any change in the sodium content of the mine waters. No change was recognized.

With these assurances, the new pumping system was installed, and, early in 1951, crosscuts were driven into the area north of the Leadville dike. The flow of water soon increased to 7200 gpm but later diminished to 6600 gpm as the vuggy ore bodies and their brecciated dolomite host rocks were dewatered. This increased water inflow, which included temporary surges exceeding 10,000 gpm, was readily discharged by the water disposal cavern. By May 1955, the 18-411 winze reached the 3100-foot level, which is at an elevation of 3550 feet, approximately 650 feet below the level of Great Salt Lake, the lowest surface elevation within a radius of several hundred miles.

Throughout this interval, water was continuously pumped at an average rate of 6600 gpm without any change in the capacity of the Gemini cavern to discharge the waters pumped into it until the pumping operation was abandoned September 8, 1955. According to Mr. C. A. Fitch, Jr., General Manager of the Chief Consolidated Mining Company, the water level then rose 170 feet in 25 hours, or 6.8 feet per hour. By mid-January 1956, all of the workings at and below the 2200-foot level were under water. Since this time, the water level has risen at a slow and gradually diminishing rate averaging approximately 6 feet per month. When last checked in 1961, the water level was still below the 2000-foot level, which is 160 feet below the water level as of March 1942, just prior to the decision to dewater the mine.

Geologic Factors

The complete removal of the discharged water from the mine area suggests that the water table encountered in the Tintic mines is perched above an impervious unit, presumably the shale members of the Ophir Formation or the phyllitic argillites of the Big Cottonwood Formation, and that a porous unit or structural zone lies somewhere at a lower elevation. As Hall (14, p. 234) points out, this would be analogous to pumping from a full tank of water to an empty one some distance below it; the water, of course, cannot return to the upper tank.

It is significant that both the Chief and Gemini caverns are near faults that are part of the Beck fault system. This large shear fault extends southwesterly from the area of the Chief No. 1 and Gemini mines to the western edge of the East Tintic Mountains, where it is cut by a Basin Range fault and concealed beneath the valley-fill deposits of Tintic Valley. As indicated earlier in this report, gravity and geologic studies of the Tintic Valley area by Mabey and Morris (31) indicate an accumulation of more than 7000 feet of low-density sedimentary and volcanic rocks, which are thickest near the range front. Conceivably, the discharged waters find their way down the zone of the Beck fault system and into porous, waterfree, conglomerate lenses at great depth below the valley surface. The thrust fault zones that deeply underlie the East Tintic Mountains also possibly may provide a deep reservoir for the discharged waters; however, such zones are rarely marked by massive porous breccias.

Economic Factors

The underground disposal of mine waters has effected tremendous savings in power costs and investment in pumping equipment by reducing the static head requirements of the pumping system from the 3100 feet required if the waters were pumped to the surface, to 1300 feet that was required to discharge the water into the Gemini cavern. The cost of future operations in the Chief, Gemini, and other mines might be lowered materially by driving to the Beck fault zone at levels lower than the water disposal caverns to search for porous, dry areas that indicate the natural discharge of ground water into the deep reservoir.

OUTLOOK FOR THE FUTURE

The re-establishment of the Tintic district as an important producer of lead, zinc, and silver ores will depend largely on new exploration. In addition to the geological constraints, exploration in the district also doubtless will require the unitization of many of the private holdings and the continuing refinement of new ore-finding techniques to help overcome the high risks and high costs of modern mine discovery and development.

The known ore bodies on the lowest levels of the Chief and Gemini mines could not, by themselves, pay mounting mining and pumping costs in the face of gradually diminishing size and decreasing tenor of silver and lead and were abandoned in 1955. It is possible that future cost reductions based on a more daring utilization of the underground water-disposal caverns or on the establishment of atomic-powered pumping plants, which conceivably may be called upon to meet the increasing demands for water and thus may dewater the mines at small direct cost to the mine owners. If so, exploration of the northerly extensions of both the Chief and Gemini ore runs in the vicinity of the Paxman fault zone may be justified. Elsewhere in these and other mines, it also seems reasonably certain that individual ore bodies, and even considerable segments of the ore runs, will be discovered, in part as a result of the stubborn persistence and perpetual optimism of self-employed lessees, who have contributed much of the ore produced from the Tintic district. Also of particular interest are the northerly extensions of the Godiva ore zone, and the southerly extension of the Gemini ore zone south of the Grand Central mine, as well as subsidiary ore runs that may lie deeper than the main ore channels.

Disseminated copper ores near Diamond, first explored by the Longyear Drilling Company in association with the Calumet and Hecla and Kennecott Copper Corporations, have been drilled recently by the Bear Creek Mining Company. These deposits are apparently extensive but may be too low grade to be mined in the foreseeable future.

Large areas some distance from the known ore centers of the district have been only slightly explored and perhaps offer potential for the occurrence of new, undiscovered ore centers. Extensive zones of hydrothermal alteration south and southeast of the main producing part of the district in Government and Copperopolis Canyons probably warrant more consideration than they have received. This is also true of the nearly unprospected areas of altered rocks in the upper part of Burriston Canyon east of the Iron Blossom ore zone. Finally, the concealed intrusive body that is inferred from aeromagnetic data to underlie the southern part of the district, may eventually prove to be the parent source of yet undiscovered ore deposits along its eastern, western, and southern borders that conceivably are larger than any yet known in the Tintic area.

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52. Mountain City Copper Mine, Elko County, Nevada

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Contents

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