Oxidized Zinc Deposits of the United States

Part 2. Utah

By ALLEN V. HEYL

GEOLOGICAL SURVEY BULLETIN 1135-B

A detailed study of the supergene zinc deposits of Utah

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

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Washington 25, D.C.

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ABSTRACT

Deposits of oxidized zinc minerals are widely distributed in the western half of Utah, but only a few small ones are known in eastern Utah. The main production and reserves are restricted to relatively few mining regions in western Utah—the Tintic group of districts, Star and San Francisco districts, Dry Canyon and Ophir districts, Big and Little Cottonwood and Park City districts, Promontory district, and the Lucin district—in all of which limestone and dolomite of Paleozoic age are the prevalent host rocks. The oxidized zinc ore is in lead-zinc-silver deposits that have been deeply oxidized. The principal ore minerals are smithsonite and hemimorphite, associated with smaller quantities of hydrozincite, aurichalcite, and many secondary minerals of lead, copper, and silver. Oxidized zinc minerals directly replace primary sulfide minerals in veins, massive replacement bodies, and disseminated masses. The zinc from primary ore bodies may also be leached by acidic solutions of meteoric origin and migrate into the wallrock. Chemical reaction between these solutions and the limestone wallrock has produced deposits of oxidized zinc minerals in sheaths, blankets, pockets, and irregular bodies.

Not much high-grade ore (containing 25 to 50 percent zinc) remains, but large quantities of low-grade material (10 to 25 percent zinc) await better methods of beneficiation and market conditions.

INTRODUCTION

Oxidized zinc deposits were formerly commercially important sources of zinc in Utah and are still mined on a limited scale. They are widely distributed in the western half of Utah. Although most of the known high-grade ore containing 25 to 50 percent zinc has been removed, many low-grade deposits containing 10 to 25 percent zinc remain.

FIELDWORK

This report is compiled from fieldwork and available published data on the oxidized zinc deposits of Utah. Most of the deposits were examined by the author during the autumns of 1952–55 as part of a general study of oxidized zinc deposits of the Western States. In addition, several deposits were visited by geologists of the U.S. Geological Survey as a part of mineral investigation studies since 1940. In the process of obtaining this information many mining companies and individuals have been consulted.

C. N. Bozion and Priestley Toulmin 3d, ably assisted in the field and compilation work. H. T. Morris, T. S. Lovering, A. E. Disbrow, M. D. Crittenden and J. W. Hasler provided much useful information, constructive discussion, and assistance during field examinations of the Tintic, Big and Little Cottonwood, and other districts in central Utah.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the wholehearted cooperation of the many mining companies, mine owners, mine operators, and consulting geologists who supplied valuable information about the deposits. Of these, the author is particularly indebted to Otto Herres, E. H. Snyder, and E. B. Young of the Combined Metals Reduction Co.; J. M. Boutwell, A. W. Pinger, and Mr. and Mrs. J. J. Beeson, consulting geologists; M. B. Kildale and B. L. Sackett of the International Smelting and Refining Co.; B. C. Sharp, geologist for the U.S. Atomic Energy Commission; S. R. Wilson, supervising engineer of the Salt Lake Field Office, U.S. Bureau of Mines; Prof. B. F. Stringham of the University of Utah; S. E. Jerome, geologist, Gulf Minerals; J. W. Wade and George Ryan, consulting engineers; D. C. Arnold, geologist; and M. G. Heitzman of the Park City Consolidated Mining Co.

GEOLOGY

LOCATION OF THE DEPOSITS

Deposits of oxidized zinc ore are widely distributed in the western half of Utah (pl. 1), but only one productive deposit is known in the eastern half of the State. Despite this wide distribution, the principal production and reserves are restricted to relatively few districts in western Utah.

The principal known deposits of oxidized zinc ore are in the following mining regions, given in the order of their importance: (1) Tintic district (pl. 2) and the nearby North Tintic, East Tintic, and West Tintic districts; (2) the Hornsilver and King David mines (pl. 1), San Francisco district; (3) Dry Canyon and Ophir districts; (4) the Lakeview mine, Promontory district (pl. 1); (5) Big and Little Cottonwood districts (pl. 3); the Wasatch Mountains or in ranges of the Basin and Range province to the west, where limestone and dolomite are important host rocks for the lead and zinc deposits, and where oxidation is relatively deep. Many smaller deposits are known in most of the base-metal districts within the same general area; however little or no oxidized zinc ore is known in the largest base-metal district of Utah, the West Mountain or Bingham district.

The largest of the small deposits in eastern and southeastern Utah is at the Redmond Silver mine (pl. 1, no. 121), Redmond, Sevier

County. Several small deposits (pl. 1, nos. 29, 38, 39, 40, 41, 42) occur in the limestones of the Uinta Mountains of Uintah County (Kinney, 1955, p. 161), and an isolated productive deposit (pl. 1, no. 120) is in the north part of the San Rafael Swell.

Descriptions of the geology and ore deposits of the mining districts of Utah may be found in the report by Butler and others (1920).

MINERALOGY

Many of the minerals found in the oxidized zinc deposits of Utah are given in table 1, including the main primary minerals from which the oxidized minerals are derived and with which they may be associated. All the secondary zinc minerals are listed in the relative order of abundance, as well as the principal associated secondary minerals of the other metals deposited with the zinc minerals. At least half of the associated minerals given are commonly found in most oxidized zinc deposits, and the others are abundant in some localities.

TABLE 1.—*Minerals of the supergene zinc deposits of Utah*

Main primary minerals

Ore and sulfide minerals:
- Spalerite [ZnS]
- Galena [PbS]
- Pyrite [FeS_2]
- Chalcopyrite [$Cu_2Fe_2S_4$]
- Enargite [Cu_3AsS_4]
- Tetrahedrite [$(Cu,Fe)_{12}Sb_4S_{13}$]
- Tennantite [$(Cu,Fe)_{12}As_4S_{13}$]
- Argentite [Ag_2S]
- Arsenopyrite [$FeAsS$]

Gangue minerals:
- Quartz [SiO_2]
- Calcite [$CaCO_3$]
- Barite [$BaSO_4$]
- Garnet [$R_3^{+2}R_2^{+3}(SiO_4)_3$]
- Siderite [$FeCO_3$]
- Sericite [$KAl_3Si_3O_{10}(OH)_2$]
- Tremolite [$Ca_2Mg_5Si_8O_{22}(OH)_2$]
- Wollastonite [$CaSiO_3$]
- Idocrase [$Ca_{10}Al_4(Mg,Fe)_2Si_9O_{34}(OH)_4$]
- Epidote [$Ca_2(Al,Fe)_3(SiO_4)_3(OH)$]
- Chlorite [$(Mg,Fe)_5(Al,Fe^{+3})_2Si_3O_{10}(OH)_8$]
- Ankerite [$Ca(Fe,Mg)(CO_3)_2$]
- Alunite [$KAl_3(SO_4)_2(OH)_6$]
- Halloysite [$Al_2Si_2O_5(OH)_4 \cdot H_2O$]
- Dolomite [$CaMg(CO_3)_2$]

Secondary minerals

Secondary zinc minerals:
- Smithsonite [$ZnCO_3$] and monheimite [ferroan smithsonite]
- Hemimorphite (calamine) [$Zn_4Si_2O_7(OH)_2 \cdot H_2O$]
- Hydrozincite [$Zn_5(CO_3)_2(OH)_6$]
- Aurichalcite [$(Zn,Cu)_5(CO_3)_2(OH)_6$]
- Sauconite [$(Zn,Mg,Al,Fe)(Al,Si)O_{10}(OH)_2Ca/2NaK$]
- Goslarite [$ZnSO_4 \cdot 7H_2O$]
- Willemite [Zn_2SiO_4]
- Descloizite [$ZnPb(VO_4)(OH)$]
- Adamite [$Zn_2(AsO_4)(OH)$]
- Nicholsonite [zincian aragonite]
- Austinite [$CaZn(AsO_4)(OH)$]
- Wurtzite [ZnS]

Associated secondary minerals:
- Geothite [$HFeO_2$] and limonite [hydrous iron oxides]
- Cerussite [$PbCO_3$]
- Jarosite [$KFe_3(SO_4)_2(OH)_6$]
- Plumbojarosite [$PbFe_6(SO_4)_4(OH)_{12}$]
- Pyrolusite [MnO_2]
- Calcite, var. travertine [$CaCO_3$]
- Opal [$Sio_2 \cdot nH_2O$]
- Anglesite [$PbSO_4$]
- Bindheimite [$Pb_2Sb_2O_6(O,OH)$]
- Cerargyrite [$AgCl$]
- Conichalcite [$CaCu(AsO_4)(OH)$]
- Wulfenite [$Pb(MO_4)$]
- Stolzite [$Pb(WO_4)$]
- Greenockite [CdS]
- Kaolinite [$Al_2Si_2O_5(OH)_4$]
- Linarite [$PbCu(SO_4)(OH)_2$]
- Malachite [$Cu_2(CO_3)(OH)_2$]
- Azurite [$Cu_3(CO_3)_2(OH)_2$]
- Pyromorphite [$Pb_5(PO_4)_3Cl$]
- Vanadinite [$Pb_5(VO_4)_3Cl$]
- Copper pitch [a massive form of tenorite] and tenorite [CuO]
- Chrysocolla [$CuSiO_3 \cdot 2H_2O$]
- Scorodite [$Fe(AsO_4) \cdot 2H_2O$]
- Gypsum [$CaSO_4 \cdot 2H_2O$]
- Cuprite [Cu_2O]
- Minium [Pb_3O_4]
- Beaverite [$Pb(Cu,Fe,Al)_3(SO_4)_2(OH)_6$]

SECONDARY ZINC MINERALS

Smithsonite and hemimorphite are the main oxidized zinc minerals in Utah. Locally hydrozincite and aurichalcite have been shipped commercially, and at one locality each, willemite adamite, descloizite, and austinite are nearly abundant enough to be sources of ore.

SMITHSONITE

Smithsonite, zinc carbonate, is the most abundant of the oxidized zinc minerals. If pure, it contains 52 percent metallic zinc, but owing to associated impurities such as limonite and quartz, the percentage of zinc in the better grades of zinc carbonate ore is not commonly above 40 percent and is mostly below 30 percent.

In most places, smithsonite shows three successive stages of deposition. The first is a direct replacement of the primary sphalerite and gangue carbonate minerals; the smithsonite occurs as cellular boxworks or massive pseudomorphs of the original minerals. In the second stage, three distinctive types of smithsonite replace limestone and dolomite wallrocks. The first type consists of dense gray, buff, red, or brown masses that commonly contain small crystal-lined or botryoidal cavities or vugs (fig. 1) which have been attributed to shrinkage by Lindgren and Loughlin (1919, p. 170). Less common is a coarse cellular type, in which the smithsonite appears to have

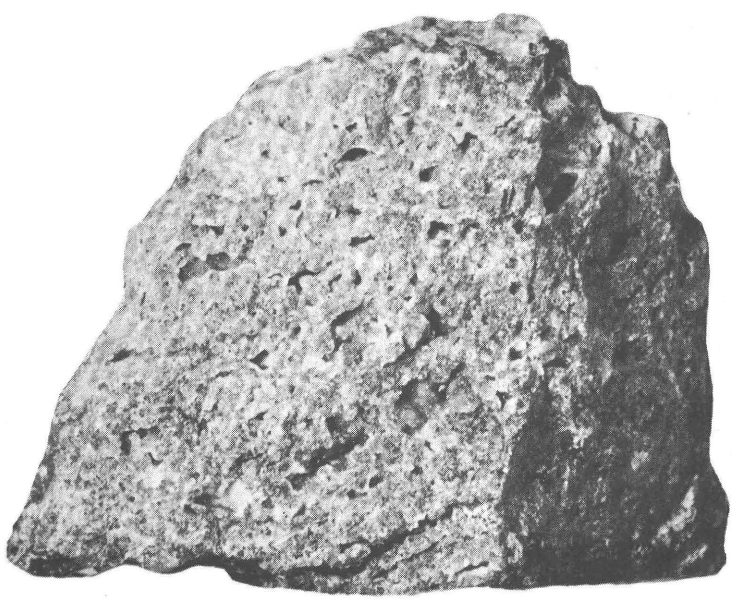

FIGURE 1.—Finely granular replacement smithsonite from May Day mine, Tintic district, Utah; shows many small cavities attributed to shrinkage accompanying replacement. The cavities are partly filled with drusy smithsonite and hemimorphite. Natural size. From Lindgren and Loughlin (1919, pl. 28A).

replaced limestone along certain lamellae and cross fractures, after which the surrounding unreplaced limestone was removed by solution (fig. 2). The third type is fine-grained to microgranular lamellar smithsonite that selectively replaced wallrock in concentrically curved patterns. The lamellae are commonly 1 mm to 1 cm thick and are separated by thinner open(?) spaces lined with films or drusy growths of other zinc, copper, iron, and manganese minerals, or by fibrous and holohedral crystallized smithsonite and calcite (fig. 3). All three types—massive, cellular, and lamellar—are contemporaneous.

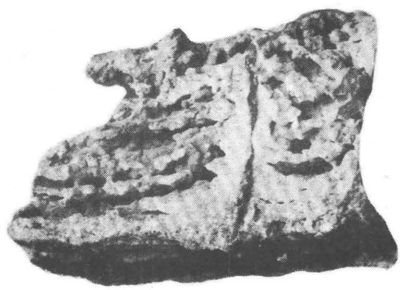

FIGURE 2.—Monheimite (ferroan zinc carbonate) from the Yankee mine, Tintic district, Utah; illustrates partial limestone replacement along closely spaced bedding planes and cross fractures, and subsequent removal of unreplaced limestone by solution. Natural size. From Lindgren and Loughlin (1919, pl. 28*B*).

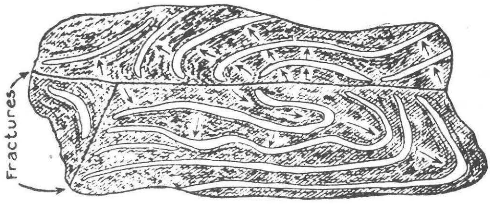

FIGURE 3.—Sketch of a piece of lamellar smithsonite from the Hidden Treasure mine, Dry Canyon district, Utah, showing the curved rhythmic lamellae in fractured and replaced limestone. Arrows indicate directions in which the solutions moved most rapidly according to Loughlin (1917, fig. 4). Broad shaded bands are smithsonite, thin bands are cavities.

In the third and youngest stage, smithsonite commonly lines fractures, fills vugs, and forms coatings on the wallrock and on smithsonite deposited in the two other stages. This youngest smithsonite is in mammillary, drusy, or fibrous masses, and in coarse crystals; it is colorless, white, pale green, or blue where free of ferric oxides (fig. 4) and yellow, red, and brown where stained by ferric oxides. It is commonly coarsely banded and has interlayered calcite, limonite, psilomelane-type manganese oxides, eggshell-like hydrozincite, greenish-blue radiating crystals of aurichalcite, or malachite and azurite.

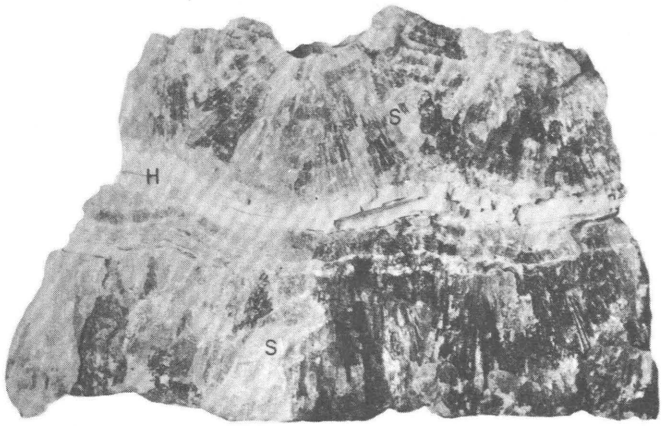

FIGURE 4.—Fibrous smithsonite (S) with chalky white hydrozincite (H), May Day mine, Tintic district, Utah. Natural size. From Lindgren and Loughlin (1919, pl. 28D).

HEMIMORPHITE (CALAMINE)

Hemimorphite, if pure, contains 54.2 percent metallic zinc. It occurs typically in crusts of small colorless, white, or gray bladed and sheaflike crystals (fig. 5), also in dirty-gray or brown masses, which on close inspection prove to be porous aggregates of small radiating crystals that are commonly intimately mixed with manganese oxides, cerussite, and limonite, and in places with small quantities of cerargyrite.

Hemimorphite is nearly as abundant as smithsonite in most oxidized zinc deposits. Two types of replacement by hemimorphite are common. In the first, crystallized crusts of hemimorphite apparently have directly replaced the primary sulfide minerals. This type is most abundant in the oxidized parts of ore bodies which have silica-rich gangue or wallrock. The second type of hemimorphite coats and replaces all three stages of smithsonite; it is commonly in radiating crystals, coarse crystals, or crystalline masses filling fractures and vugs in smithsonite or hydrozincite in wallrock. Where mineral deposits of the first type have been further leached and replaced by limonite, jasperoid, and calcite, the remaining zinc is generally in scattered crystalline masses and coarse crystals of hemimorphite.

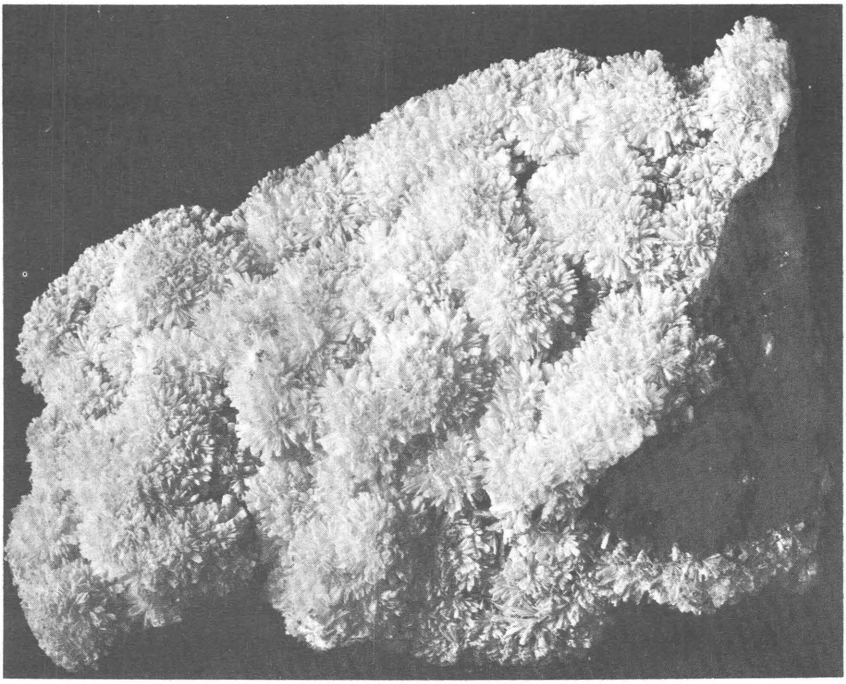

FIGURE 5.—Radiating druses of colorless hemimorphite (calamine) crystals coating smithsonite. Natural size. From Loughlin (1918, pl. 4*B*.)

HYDROZINCITE

The basic zinc carbonate, hydrozincite, is a chalky white mineral which is commonly deposited as eggshell-like, platy masses that replace and coat smithsonite (fig. 4). Locally it is fibrous perpendicular to the curved surfaces of the "eggshells." It is a minor constituent in many of the deposits in the Tintic, Dry Canyon, Fish Springs, Promontory and Mount Nebo districts, but at only one place in Utah—the Redmond silver mine, Redmond district, Sevier County—has the mineral been found in commercial quantities.

AURICHALCITE

Aurichalcite is a basic carbonate of zinc and copper; the metallic zinc content ranges from 50 to 59 percent, and the copper content from 15 to 22 percent. The pure mineral is pale green to sky blue, has a pearly or silky luster, and occurs in radiating drusy surfaces and clusters of small columnar platy or needlelike crystals.

Aurichalcite does not ordinarily occur in commercial quantities, but it was shipped in small tonnages from the Carbonate mine, Big Cottonwood district, Salt Lake County. It occurs as a subordinate constituent of the oxidized zinc ore from the Iron Blossom mine in the Tintic district, Utah County, and from the Hidden Treasure and Queen of the Hills mines in the Dry Canyon district, Tooele County.

WURTZITE

A rare zinc sulfide deposit of yellow wurtzite, which is reported to be an oxidation and supergene enrichment product (Butler, 1913, p. 154), occurs as overgrowths on slightly darker colored sphalerite in the Horn Silver mine, at Frisco, mostly below the 600-foot level. Mineable quantities of wurtzite were deposited in the volcanic rocks of the hanging wall and in the main vein within a broad zone of zinc sulfide enrichment that lies above the primary mixed sulfide ore and below a thin zone of enriched copper sulfide ore. Butler and others (1920, p. 213) state:

> The primary ore consists of sulphides of iron, lead, zinc, copper, and some antimony and arsenic minerals and silver in an undetermined mineral combination * * * A large part of the iron sulphate, and probably much of the zinc sulphate has apparently been carried away in solutions [during oxidization] and dispersed. Part of the zinc, however, was reprecipitated in the sulphide zone as the hexagonal sulphide wurtzite, usually forming in zones of brecciated ore, and frequently surrounding grains of sphalerite. The cause of precipitation is believed to be essentially as follows: The solutions passing from the oxidizing zone contain, in addition to zinc sulphate, sulfuric acid and hydrogen sulphide. As the solutions pass to deeper levels their acidity is reduced by reaction with alkaline solutions from the adjacent rocks or with the alkaline silicates of the gangue minerals. This reduction of acidity causes the precipitation of a part of the zinc as wurtzite. The precipitation apparently takes place slowly and the zone of sulphide enrichment of zinc is deep.

The richest zinc sulfide stopes are those in which secondary wurtzite is relatively abundant. They have yielded a large tonnage of high-grade zinc sulfide and zinc-lead sulfide ore.

OTHER SECONDARY ZINC MINERALS

None of the other oxidized zinc minerals is abundant enough to constitute ore. Zinc-bearing clay, probably sauconite, was recognized by Loughlin (1917, p. 7) at Ophir, Tooele County, as a very minor constituent of the ore. Powdery white goslarite (zine sulfate) is a common mineral in the zone of oxidation of zinc sulfide deposits, but because it is water soluble, it never accumulates in mineable quantities. Small yellow or brown hexagonal crystals of willemite (Zn_2SiO_4) form crusts on other oxidized minerals in the Harrington-Hickory and Cedar Talisman mines in the Star district, Beaver County, also at the Escalante mine near Modena, Iron County. Descloizite was described by Schaller (*in* Butler and others, 1920, p. 568) as a yellow crystalline coating at the Escalante mine, and it has been noted but is uncommon in the Tintic and Gold Hill districts. Adamite and another zinc arsenate, austinite, are locally abundant in masses of colorless or white crystals at the Western Utah mine at Gold Hill, Tooele County, (Nolan, 1935, p. 116; Staples, 1935, p. 112). Zincian aragonite, nicholsonite, was noted in the Tintic district (Lindgren and Loughlin, 1919) and also in the Dry Canyon district near Ophir as a mineralogical curiosity.

ASSOCIATED MINERALS

The most abundant minerals associated with the oxidized zinc ores are limonite, psilomelane, calcite, quartz, jarosite, plumbojarosite, galena, cerussite, and malachite. The limonite and much of the psilomelane form brown and black masses and also stain weathered smithsonite. The psilomelane, however, has in some places distinctly replaced laminae of smithsonite. At many deposits much of the soft brown and yellow material that resembles limonite in general appearance is composed of minute granular hexagonal flakes of jarosite or plumbojarosite.

Calcite is found in many of the ores as bands of smithsonite-like travertine and as small crystals. Chemical or refractive-index tests are needed to tell much of this calcite from smithsonite, although the greater specific gravity of the latter is commonly helpful. Silica commonly in dense forms such as jasperoid, chalcedony, or opalline jasper is a common gangue. In many places the silica is closely associated with hemimorphite and replaces the more massive varieties of smithsonite. Partial silica replacement that lowers the grade of the oxidized zinc ores is common, especially where zinc has been further leached from the ore.

Cerussite, and less commonly anglesite, pyromorphite, wulfenite and stolzite are constituents of some oxidized zinc ore, such as at Alta and near Milford, where the secondary zinc minerals are a direct replacement of the original sulfide deposits. Malachite and azurite are interbanded with and replace smithsonite at Ophir (Loughlin, 1917, p. 7–8), and at the Carbonate mine in Big Cottonwood Canyon north of Alta. Scorodite, the olive-green iron arsenate, is a close associate of the oxidized zinc minerals at Gold Hill. This arsenic ore commonly contains some secondary silver minerals, mainly cerargyrite, and a little free gold.

RELATION OF OXIDIZED ZINC DEPOSITS TO ROCK TYPES

Most of the oxidized zinc deposits of commercial size are formed in base-metal deposits that replaced limestone of Paleozoic age, although a few are in limestone of Mesozoic or Tertiary age. In such deposits the controlling fissures and pipes were sufficiently open to permit rather free circulation of meteoric solutions. The water table is commonly far below the present land surface, and the primary ore has in consequence been extensively oxidized. Most of the larger deposits have at least one side of the ore body in limestone or dolomite, which neutralized the zinc-bearing acidic solutions that were formed during oxidation of the primary zinc sulfide by oxygenated meteoric water, and precipitated the zinc as carbonate. The purer limestones and dolomites are more favorable for the deposition of zinc carbonate ores than the less pure argillaceous and siliceous carbonate rocks (Smirnow, 1954, p. 179); however, marbles and sideritic limestones are favorable host rocks in some places.

Rocks other than limestone and dolomite are very poor hosts for supergene zinc minerals, and no deposits of economic value are known in them in Utah. Noncarbonate sedimentary, igneous, and metamorphic rocks generally form sharply defined barren roofs, walls, or floors where oxidized zinc ore bodies occur in contact with them. In contrast, the volcanic rock of the vein and in the hanging wall of the Horn Silver mine is a good host for secondarily enriched zinc sulfide in the form of wurtzite.

The stratigraphy in areas containing major oxidized zinc deposits is shown in tables 2 and 3. Table 2 shows the geologic section in the part of the Wasatch Mountains at Alta, where the Paleozoic limestone units are relatively thin. These units prevail without notable change along the Wasatch Mountains from the Idaho border south to beyond Nephi, Utah. Table 3, by comparison, shows marked increases in the thickness of the Paleozoic limestone and dolomite strata in the Basin and Range province west of the Wasatch Mountains, as exemplified in the Tintic district (Morris and Lovering, 1961). Gilluly (1932, p. 7) gives a somewhat similar stratigraphy for the Oquirrh Mountains to the north and Nolan (1935, p. 24) compares and correlates these rocks with the notably thicker Paleozoic section in the Gold Hill quadrangle of western Utah. Kinney (1955, pl. 6) describes the mainly clastic Paleozoic and Mesozoic rocks of the Uinta Mountains, where the lower Paleozoic section is thin but includes a few limestone units favorable for oxidized zinc ore deposits.

In the Alta area (pl. 3) the oxidized zinc deposits are mainly in the Ophir, Maxfield, Jefferson, Madison, Deseret, and Humbug formations. At Park City (pl. 5) many are in the purer limestone beds of the Park City and Thaynes formations. To the west, in the Tintic and Ophir-Dry Canyon districts, the ore deposits occur in limestone and dolomite strata of Paleozoic age, but they are most abundant in the purer dolomites and limestones, especially those of Mississippian age.

In the Star, San Francisco, and Beaver Lake districts (pl. 1), the oxidized zinc minerals are in Paleozoic limestones that correlate in a general way with similar limestones to the northeast at Tintic; however, the deposits in the mines on the east side of the Star Range (pl. 4), in the Rocky district, and in the Mineral Range east of Milford, are in the limestone units of the Harrington formation of Triassic age, or rocks of approximately equivalent age (Butler and others, 1920, pl. 40, p. 531).

TABLE 2.—*Stratigraphic section of the sedimentary rocks in the Alta area*

[Adapted from Calkins and Butler (1943, pl. 5)]

System and series		Formation or group	Thickness (feet)	Description
Jurassic		Nugget sandstone	200–500	Light-colored sandstone and interbedded shale.
Triassic(?)		Ankareh shale	1,225	Red shale interbedded with gray sandstone.
Triassic		Thaynes formation	1,180	Limestone containing sandstone and shale.
		Woodside shale	1,175	Shale, mainly red, partly altered to green; fine grained, thin bedded.
Carboniferous	Permian and Pennsylvanian	Park City formation	575	Limestone interbedded with quartzite sandstone, shale and a little phosphate rock.
	Pennsylvanian	Weber quartzite	1,350+	White to pale-gray quartzite interbedded with calcareous sandstone.
		Morgan(?) formation	350±	Limestone, gray, cherty. —Unconformity—
	Mississipian	Brazer group Humbug formation	750±	Limestone, black, cherty, and gray. Black shale locally in middle part.
		Deseret limestone	900	Limestone and dolomite, cherty.
		Madison group	450	Limestone, blue.
Devonian(?)		Jefferson(?) dolomite	150	Dolomite, mostly thick-bedded; sandstone at base. —Unconformity—
Cambrian	Upper Cambrian	Maxfield limestone	570	Dolomite and limestone, buff, gray, and white; lower part oolitic.
	Middle and Lower Cambrian	Ophir shale	420	Shale, greenish-gray, at top; limestone, nodular, mottled, in middle; dark micaceous shale at base.
	Lower Cambrian	Tintic quartzite	800±	Quartzite, light-colored; conglomeratic layers near base. —Unconformity—
Precambrian	Algonkian	Tillite	0–3,000	Tillite interbedded with varved shale; dark colored. —Unconformity—
		Mutual formation	400	Quartzite, light-colored, interbedded with purple shale.
		Big Cottonwood	1,000	Quartzite, white, red, dull-greenish, purple; thick beds of argillite near top. —Unconformity—
	Archean	Undifferentiated older rocks.	------------	Mostly schist and gneiss.

The oxidized zinc-lead ores of the Redmond silver mine, in Sevier County, are unusual because they are in a lenticular fissure vein in a nearly vertical fault that has displaced limestones of the Wasatch formation of Eocene age downward against red shale, sandstone, and salt beds of Jurassic age. Another deposit in which the host rocks are unusual is at the Escalante mine in Iron County, north of Enterprise. Here the oxidized silver, lead, and zinc minerals replace and coat abundant calcite and fluorite in a silicified fissure zone that cuts Tertiary latites, rhyolites, tuffs, and breccias.

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TABLE 3.—*Stratigraphic section of the sedimentary rocks of the Tintic Mountains*

[From data given by Morris and Lovering (1961)]

System and series		Group and formation	Thickness (feet)	Description
Carboniferous	Permian and Pennsylvania	Oquirrh formation	20,000+	Alternating limestone and quartzite.
	Pennsylvanian and Mississippian.	Manning Canyon shale.	700–1,000	Black shale weathering olive green.
	Mississippian	Great Blue formation	2,500–4,000	Silty limestone, shale, quartzite, and sandstone.
		Humbug formation	825	Alternating limestone and sandstone.
		Deseret limestone	700–1,000	Cherty limestone; phosphatic shale at base.
		Gardison limestone	450–525	Cherty blue fossiliferous limestone.
		Fitchville formation	240–270	Limestone and dolomite.
	Mississippian and Devonian.	Pinyon Peak limestone.	70–300	Shaly limestone.
Devonian		Victoria formation	250–275	Dolomite and quartzite.
Devonian, Silurian, and Ordovician.		Bluebell dolomite	545–675	Dolomite.
Ordovician	Upper Ordovician	Fish Haven dolomite	270–350	Cherty dolomite.
	Lower Ordovician	Opohonga limestone	450–1,200	Shaly limestone with basal sandstone.
Cambrian	Upper Cambrian	Ajax dolomite	475–650	Cherty blue and white dolomite.
		Opex formation	230–280	Shale, limestone, sandstone, and dolomite.
	Middle Cambrian	Cole Canyon dolomite	825–850	Light- and dark-gray dolomite.
		Bluebird dolomite	420	Shaly limestone and olive-green shale.
		Dagmar dolomite	60–80	Light-gray laminated dolomite.
		Teutonic limestone	420	Limestone.
		Ophir formation	380–450	Olive-green shale, limestone and shale, sandstone at base.
	Lower Cambrian	Tintic quartzite	2,300–3,200	Quartzite, quartzite conglomerate, and phyllitic shale.

TYPES OF SUPERGENE ZINC DEPOSITS

The supergene zinc deposits of Utah consist of several distinct geologic types, some of which have been described by Loughlin (Lindgren and Loughlin, 1919, p. 171–173, 221, 269–272; Loughlin, 1917). Three methods of formation have been recognized in Utah: direct replacement of primary sulfides, replacement of wallrock after migration of zinc from primary deposits, and sulfide enrichment within the primary mineral deposits. In popular usage the term "oxidized zinc deposits" is applied to aggregates of supergene zinc minerals formed by secondary replacement, whether of wallrock or of primary mineral deposits (1 and 2 below). Only one example of zinc-sulfide enrichment is described.

The supergene zinc deposits of Utah can be classified by origin, shape, and position as follows:

1. Deposits formed by direct secondary replacement of primary sulfides
   - A. Oxidized vein and breccia deposits
     Examples:
     - a. Early progressive oxidation stage,
       - Moon claim at Hyrum, Cache County.
       - New Bullion mine in the North Tintic district, Tooele County.
     - b. Late progressive oxidation stage,
       - Redmond Silver mine (fig. 6) at Redmond, Sevier County.
       - Escalante mine, Iron County, north of Enterprise.
   - B. Oxidized massive replacement deposits
     Examples:
     - a. Early progressive oxidation stage,
       - Miller Hill mine in the American Fork district, Utah County.
       - Emma mine in the Little Cottonwood district, Salt Lake County.
     - b. Late progressive oxidation stage,
       - Western Utah mine at Gold Hill, Tooele County.
   - C. Oxidized disseminated deposits
     Examples:
     - a. Early progressive oxidation stage,
       - Bay State mine in the American Fork district, Utah County.
     - b. Late progressive oxidation stage,
       - Delmonti mine in the North Tintic district, Tooele County.
2. Deposits formed by secondary replacement of wallrock after migration of zinc
   - A. Blanket and pocket ore bodies
     Examples:
     - May Day, Yankee, and Colorado mines (fig. 7) in the Tintic district, Utah County.
     - Magazine tunnel in the North Tintic district, Tooele County.
     - Lakeview mine in the Promontory district, Box Elder County.
     - Eva, Vagabond No. 10, and other mines in the Nebo district, Utah County.

B. Replacement sheaths around pipes and mantos
   Examples:
      Hidden Treasure mine, Ophir Hill mines in the Dry Canyon and Ophir districts, Tooele County.
      Honorine mine in the Rush Valley district, Tooele County.

C. Replacement bodies in walls of veins
   (1) Hanging wall of the vein
   Example:
      Lower Mammoth mine (fig. 8) in the Tintic district, Juab County.
   (2) Footwall of the vein
   Examples:
      Horn Silver mine (fig. 9) San Francisco district, Beaver County.
      Hoosier Boy and Rebel mines in the Star district, Beaver County.
      Tecoma mine in the Lucin district, Box Elder County.
      Carbonate mine in the Big Cottonwood district, Salt Lake County.

3. Deposits formed by secondary sulfide enrichment within the primary sulfides
   Example:
      Horn Silver mine (fig. 9).

DEPOSITS FORMED BY DIRECT REPLACEMENT OF PRIMARY DEPOSITS

Oxidized zinc deposits that were formed by direct replacement of primary sulfide bodies are much more abundant than commonly recognized, but many of them were mined out years ago for their lead and silver content. Direct replacement deposits in (*A*) veins and breccias, (*B*) massive replacements, and (*C*) disseminations, may be in early or late stages of progressive oxidation and leaching.

In all three types of deposits the early stage of progressive oxidation commonly contains some remnants of hypogene sulfides, particularly galena and sphalerite. The secondary smithsonite is mainly in porous brown masses and in cellular, spongy, and crudely triangular boxworks in part pseudomorphic after sphalerite. Crystallized gray or white crusts are uncommon. Hemimorphite is abundant in deposits that contain siliceous gangue or wallrock as drusy crystal crusts or discrete crystals and clusters in vugs of the ore. Boxworks of limonite are common but platy and massive limonite is much less so. Hydrozincite and willemite are uncommon.

An example of such an early-stage vein and breccia deposit is at the Moon claim at Hyrum, where a sphalerite-pyrite deposit is oxidized for 25 to 50 feet to massive smithsonite and coarse vuggy limonite that cement a limestone breccia. No hemimorphite is known and only a little hydrozincite is present. Some concentrically banded smithsonite contains unreplaced cores of blue-gray sphalerite. The New Bullion oxidized lead-zinc deposit in the North Tintic district is a somewhat more oxidized lenticular chimney of cerussite, limonite, galena, hemimorphite, and brown smithsonite at the intersection of fissure zones.

Vein deposits in the late stage of progressive oxidation include the Redmond silver mine and the Escalante mine. The Redmond silver mine (fig. 6) is a zinc-lead sulfide vein that has been deeply oxidized and completely replaced by massive chalklike hydrozincite and smithsonite; the vein shows only insignificant migration of the zinc and no sulfides remain. Deposits where hydrozincite is the principal ore apparently are the result of further oxidation of smithsonite to the basic zinc carbonate. Such greatly oxidized deposits are of the late stage in progressive oxidation typical of deposits in Nevada and southern California. Locally, in the more arid parts of Nevada, California, and New Mexico, willemite becomes the main mineral of the oxidized zinc deposits. Similarly it is a minor but notable

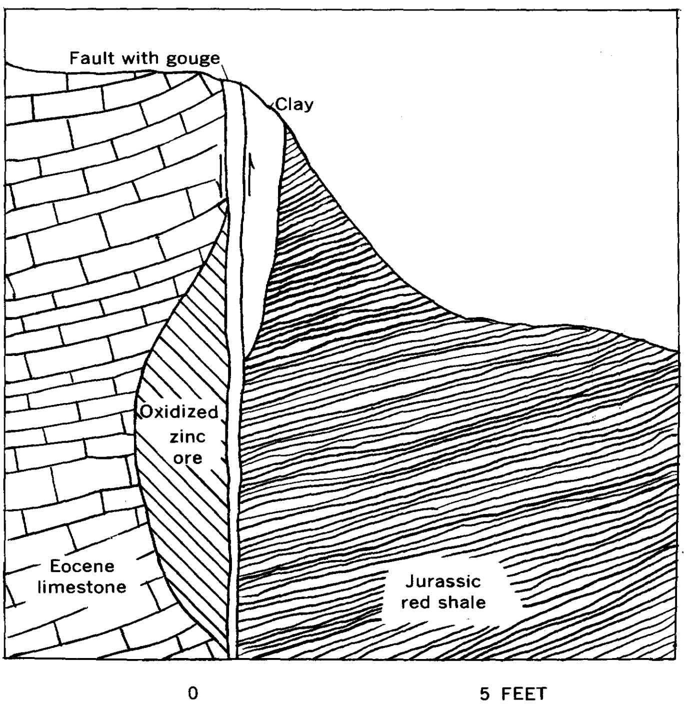

FIGURE 6.—Diagram showing fissure vein of oxidized zinc ore, Redmond silver mine, Redmond, Utah. View towards northeast. Ore directly replaces the original sphalerite in which there was only a little pyrite and galena. Note the lenticular swelling of the vein on the limestone side of the fault.

constituent of some of the deposits in the Star district, Beaver County, near the south edge of the Sevier Desert. The Escalante mine deposit is the only known example in Utah of the vanadium-, arsenic-, and phosphorous-rich oxidized zinc vein deposits that are abundant in Arizona and in southern Nevada; however, small quantities of minerals containing these elements occur as accessories to smithsonite in the Star and Tintic districts.

The Western Utah mine at Gold Hill is a massive replacement deposit in the late stage of progressive oxidation. Scorodite, limonite, quartz, and chonicalcite are the principal minerals in completely oxidized parts of massive ore bodies that contain arsenic, copper, lead, silver, and zinc. Many colorless crystals of austinite and pale-yellow-green crusts of adamite (zinc arsenates) coat vugs and fissures in limonite and scorodite in places, apparently the result of local migration and redeposition within the ore body. The crystals and crusts are without any evidence of a preceding smithsonite stage.

Some of the blanket or pipelike massive replacement bodies of primary silver-lead ore in the early oxidation stage contain much zinc. High-grade oxidized silver-lead ores from some of the better known mines are accordingly rich in oxidized zinc minerals, mostly hemimorphic and smithsonite. In past mning, the zinc may have been removed from the ore by hand-sorting; in the 19th century, when smelter requirements were not as rigid as at present, the ore was smelted without penalties. The following table gives assays of some of these zinc-bearing ores:

Partial analyses of zinc-bearing oxidized lead-silver ore

[Analyst, Deason and Nichols, Salt Lake City, 1954–55. N.d. means not determined; gold and silver in ounces, the rest in weight percent]

Constituent	American Fork district (representative high-grade ore from stope)	Little Cottonwood district (selected sample from mine dump)	Park City district (selected sample from mine dump)
Gold	0.59	0.015	0.08
Silver	23.00	23.80	13.30
Lead	43.8	22.6	7.3
Tungsten	N.d.	.15	N.d.
Zinc	16.4	33.7	15.4
Silica	N.d.	17.4	58.2
Iron	N.d.	N.d.	4.6
Carbonate	13.9	10.5	7.5

The sample from the Little Cottonwood district probably came from near the margin of the ore body. The margin was richer in zinc than the central part, possibly owing to outward migration within the ore body of some of the zinc during oxidation or to a zinc-rich marginal zoning of the primary ore which was rich in pyrite in the more central parts.

The sphalerite and galena in disseminated replacement deposits in limestone may oxidize directly to porous pseudomorphs without much migration of the metals, provided the deposits are lean enough in pyrite to avoid formation of excess acid. Within the disseminated ore body at the Delmonti mine, North Tintic district, considerable local secondary migration of zinc took place.

DEPOSITS FORMED BY REPLACEMENT OF WALLROCK

Many oxidized zinc deposits are secondary replacements of the limestone wallrocks by smithsonite. The zinc was leached from the sulfide ore body during oxidation leaving the relatively insoluble lead behind in the original ore site. The zinc migrated down or to the side of the deposit in sulfuric acid solutions, which reacted with the limestone wallrock to form smithsonite. The reaction is described by Loughlin (1917, p. 12–13; 1914, p. 1–19; Lindgren and Loughlin, 1919, p. 171–173). Such secondary zinc ores are commonly rich in zinc and lean in lead, silver, and gold. Copper carbonates are abundant in places, as well as iron in the form of limonite. (See analysis below of ore from the Big Cottonwood district.) Analyses of four such ores follow:

Partial analyses of oxidized zinc ore from wallrock replacement deposits

Analyst, Deason and Nichols, Salt Lake City, 1954–55. N.d. means not determined; gold and silver in ounces, the rest in weight percent]

Constituent	North Tintic district (channel sample from mine)	Dry Canyon district (Hidden Treasure mine [1])	Tintic district (grab sample from mine dump)	Big Cottonwood district (representative sample of ore pile)
Gold	None	None	0.02	0.005
Silver	0.04	0.75	1.90	.90
Lead	.4	1.75	None	N.d.
Copper	N.d.	1.0	N.d.	9.11
Zinc	28.0	40.2	34.1	14.00
Silica	13.2	N.d.	13.2	N.d.
Iron	17.1	N.d.	10.7	17.4
Carbonate	26.6	N.d.	26.0	25.40

[1] Analyses of carload shipments; gold content is an average (Loughlin, 1918, p. 1); analyst unknown.

Secondary bodies replacing wallrock are most commonly blankets, pockets, veins, or pipes beneath or toward the lower end of the oxidized silver-lead ore bodies or in sheaths around them. They vary widely in position and form (fig. 7) and have supplied much of the oxidized zinc ore that has been produced.

The limestone walls of leached zinc-bearing pipes and mantos have been replaced by thin casings of rich zinc carbonate ore as much as 3 feet thick in the Ophir, Dry Canyon, and Rush Valley districts. The contacts are sharp between the lamellar smithsonite casing and the unreplaced wallrock. In places, a thinner casing of copper carbonates and cuprian smithsonite lies inside the pure zinc carbonate casing, with gradational contact (Loughlin, 1917, p. 2). The sheaths may entirely encircle pipes or mantos but are commonly thickest on the lower side, and in places are restricted to this side. Because the sheaths are thin the known ore bodies are small, but most of the ore is very high grade. (See assay of ore from Hidden Treasure mine, p. 17.)

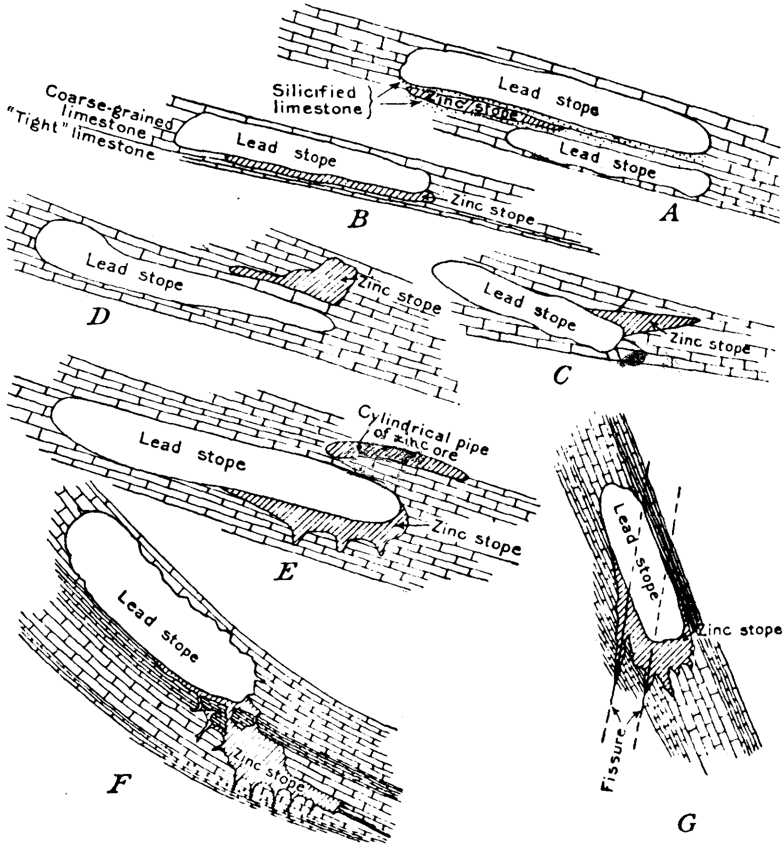

FIGURE 7.—Diagrammatic sections showing relations between stopes of oxidized zinc and lead ores in May Day and Yankee mines, Tintic district, Utah. From Lindgren and Loughlin (1919, fig. 23.)

Many replacement ore bodies of oxidized zinc minerals occur in the wallrocks of veins. They may be in the hanging wall of the vein (fig. 8), but more commonly are in the footwall block (fig. 9). Where the veins are nearly vertical and both walls are limestone, replacement bodies and crusts may be deposited along both vein walls. Much of the oxidized zinc in these deposits is low grade. For example, the deposit in the Lower Mammoth mine was estimated to average 13 percent zinc (Lindgren and Loughlin, 1919, p. 221), and much of the ore in the Horn Silver mine is about the same grade. Several of the deposits are uncommonly large, however, and locally contain pockets of rich ore.

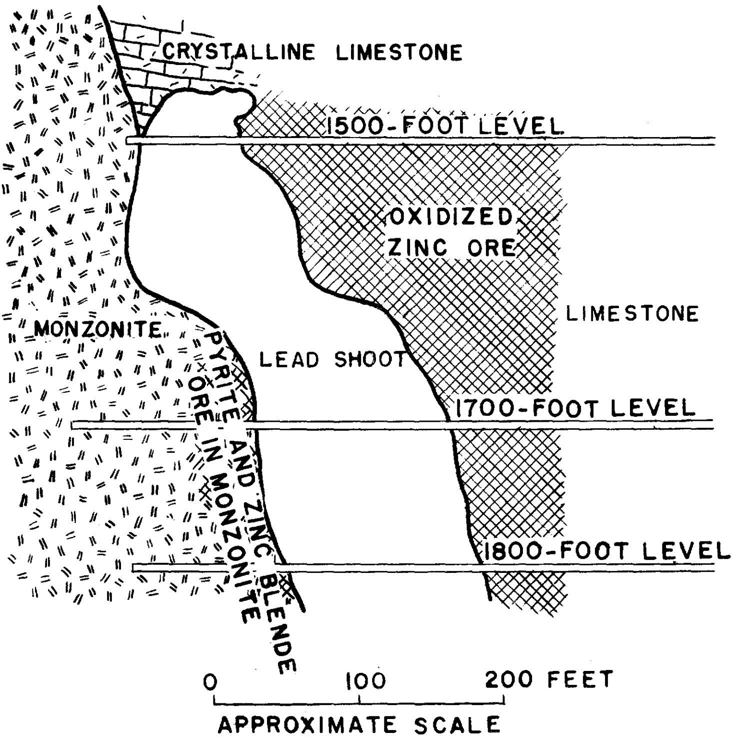

FIGURE 8.—Section of a large low-grade oxidized zinc ore body in the hanging wall of a lead vein, Lower Mammoth mine, Tintic district, Utah. Modified from Lindgren and Loughlin (1919, fig. 34).

The supergene zinc ore bodies of the Horn Silver mine (fig. 9) are among the largest in Utah and are the most complex geologically. Three types of oxidized ore are known in the mine: (*A*) replacement of the primary ore by hemimorphite and smithsonite in parts of the main oxidized lead-silver deposit, especially near the limestone footwall of the vein; (*B*) replacement of the limestone footwall by hemimorphite and smithsonite in the form of a continuous sheath or crust along the west side of the vein for thicknesses of 1 to about 20 feet; and (*C*) low-grade lenticular and irregular replacement of the footwall limestone of the main vein in the form of secondary pipes of iron-rich smithsonite along the intersections of steeply dipping faults. The known pipes are irregularly spaced in a north-south line in the northern part of the mine, where they extend from the west side of the surface cave-in pit vertically downward to below the 1,000-foot level. In addition, the mine contains unique deposits of supergene zinc sulfide, as indicated in the following section.

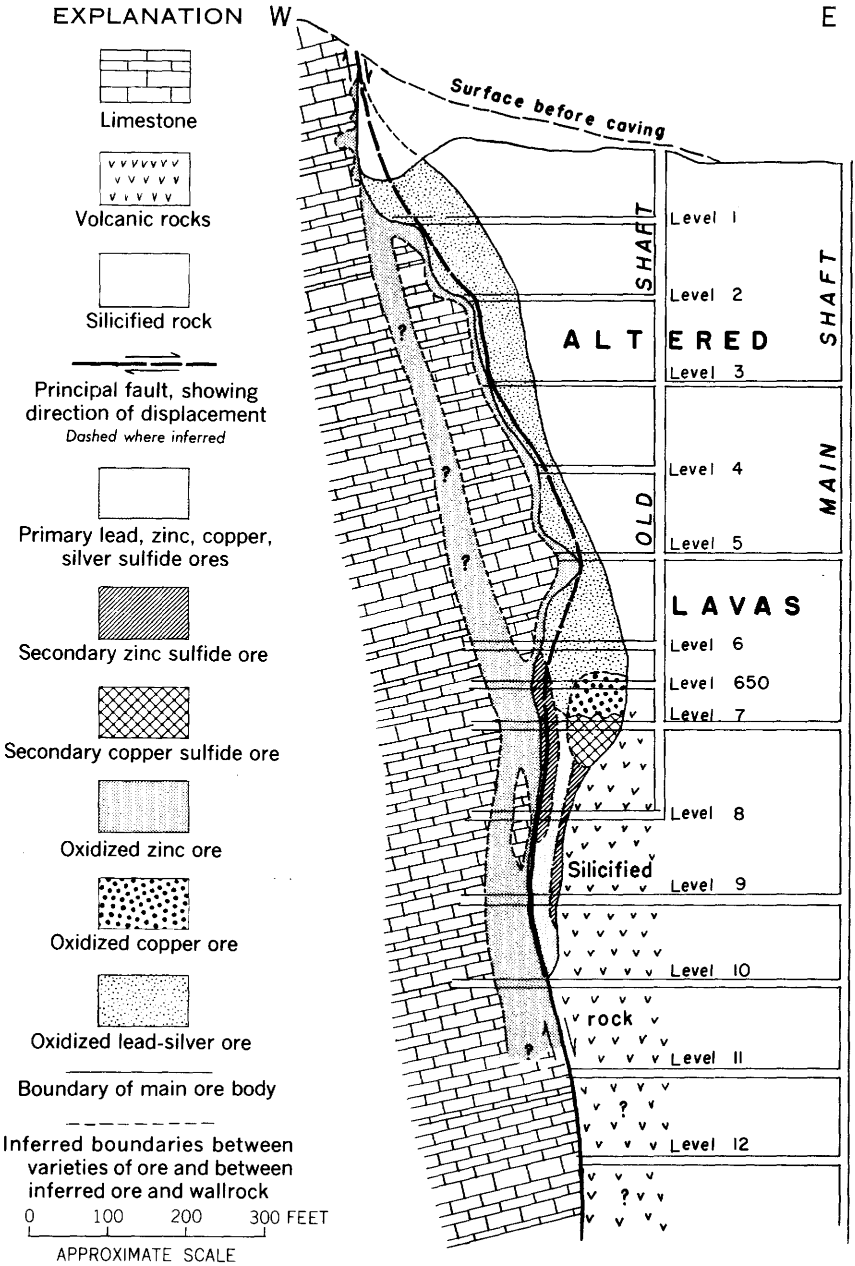

Figure 9.—Diagrammatic section of the Horn Silver ore body, Frisco, Utah, and the oxidized zinc ore bodies in the footwall limestone. Modified after Butler and others (1920, pl. 42).

DEPOSITS FORMED BY SULFIDE ENRICHMENT WITHIN THE PRIMARY ORES

In parts of the Horn Silver mine between the 650- and 900-foot levels, large and rich bodies of zinc sulfide, showing yellow wurtzite deposited as overgrowths on brownish-red sphalerite, were probably formed by secondary sulfide enrichment. These bodies lie partly above and partly below the water table, between the primary ore and overlying copper deposit that was formed by secondary enrichment (fig. 9). They are localized along several east-striking cross fractures within the primary ore body and along the north-trending walls of the main vein.

ORIGIN OF OXIDIZED ZINC DEPOSITS

The term "oxidized" is here used in its traditional geological sense to include that part of the deposit which has been altered by oxygenated surface water, rather than as defined by chemists to indicate an increase in positive valence or a decrease in negative valence. Zinc carbonate is formed by a simple exchange of radicles rather than by a valence change.

The origin of oxidized zinc deposits is summarized by Loughlin (*in* Lindgren and Loughlin, 1919, p. 172) as a result of his detailed study of the deposits, particularly the wallrock deplacement ore bodies (types 2_A, 2_c but not sheath type 2_B 1, p. 13) at Tintic, Utah:

> * * * the oxidized zinc ore bodies were derived from original bodies of mixed lead and zinc sulphides [silver-lead-zinc-copper, or zinc sulfide bodies]. The zinc blende was oxidized to the very soluble zinc sulphate, which was carried downward, whereas the relatively insoluble oxidation products of galena remained in the original ore body. The zinc sulphate solution, moving along fractures and bedding planes, replaced the purer and more permeable beds of limestone with which it came in contact, forming granular smithsonite. The drusy and fibrous smithsonite, the hydrozincite, and other carbonate were formed either by a recrystallization of smithsonite along cavity walls or by precipitation during a later stage of oxidation, after the sulphur necessary to form zinc sulphate had been largely exhausted and the carbon dioxide became an active acid radicle. The silica in the ground water, derived from the siliceous portions of the primary ore or from igneous [or siliceous] rocks that formerly overlay the present surface [or are associated with the ore deposits], also became an active radicle during the late stages of oxidation, reacting with smithsonite along water courses and depositing calamine.

The origin of the sheaths of lamellar zinc carbonates and copper carbonates at Ophir, Utah (type 2_B p. 14), was discussed by Loughlin (1917, p. 12–13) as follows:

> 1. Ferruginous zinc blende was removed by oxidation from mixed sulphide ore bodies, and the resulting zinc sulphate solution migrated downward into the adjacent limestone, which became replaced by smithsonite.
>
> 2. The replacement was accompanied by a considerable shrinkage in volume, expressed by the open lamellar structure of the smithsonite.
>
> 3. The lamellar structure bears a direct relation to fractures or other openings along which the zinc solutions invaded the limestone. The lamellae

tend to parallel these openings or to lie concave to the more open parts of fractures. Where the openings were far apart the lamellae present simple forms, but where there was a network of fractures and the permeability of the limestone was not uniform the forms of the lamellae are very complicated.

4. The expression of shrinkage in lamellae rather than in a honeycomb structure is attributed to a rhythmic order of replacement, similar to the process proposed by Liesegang to account for diffusion banding—a process referred to in the last few years by several investigators to account for banded structure in numerous ore bodies.

5. The contrast between the large amount of shrinkage that accompanied replacement at Ophir and the small amount that took place in other districts studied by the writer is attributed to difference in geologic conditions. In the other districts * * * replacement took place near and even below the general or local ground-water level, where the rock could become thoroughly permeated with the zinc solution. At Ophir the opportunity for descending water to obtain carbon dioxide in considerable quantity before depositing zinc carbonate was relatively small, and there is no evidence that downward circulation of the water was impeded at the level of the smithsonite deposits. Such conditions permitted direct molecular reaction between zinc sulphate and limestone, but they were not favorable to replacement volume for volume.

6. A small amount of ferruginous smithsonite was changed under oxidizing conditions into limonite and drusy smithsonite low or lacking in iron. Psilomelane and associated drusy smithsonite had an analogous origin.

7. The scarcity of calamine and zinc-bearing clay at Ophir is attributed to the fact that no volcanic rock formerly overlay the limestone in the vicinity of the zinc carbonate deposits. It is believed that in districts where calamine is abundant the silica of the calamine was derived from the decomposition or alteration of igneous rocks (or other silicate rocks) above the ore horizons. The fact that in the Ophir district calamine is of later origin than both varieties of smithsonite shows that silica does not combine with zinc to form hydrous silicate until the carbon dioxide in solution has been reduced to a very small quantity.

8. Oxidation of chalcopyrite, or cupriferous pyrite, did not take place extensively until after the smithsonite bodies had been formed. The resulting copper sulphate solution migrated downward and doubtless replaced in part smithsonite and in part limestone * * *.

9. Whether smithsonite is replaced by malachite or azurite is thought to depend on the relative amount of carbon dioxide in the sulphate solution. If little is present, replacement by malachite occurs until the carbon dioxide resulting from this reaction is sufficient to cause the deposition of azurite. If much carbon dioxide is originally present in the attacking solution, the smithsonite is replaced at once by azurite, no malachite being formed. Malachite was the principal mineral that replaced smithsonite at Ophir.

10. Where the copper carbonate minerals were deposited in openings carbon dioxide was also the determining factor. Where it was relatively abundant azurite was deposited first, followed, when the supply decreased beyond a certain undetermined point, by malachite. If zinc was present, derived through the replacement of smithsonite, deposition of malachite would continue only until a certain copper-zinc ratio was reached, beyond which the double basic carbonate aurichalcite would be deposited. This ideal order, represented in several of the Ophir speciments, may vary according to variations in the solutions at different times and to other changes in the zone of oxidation.

Loughlin (Lindgren and Loughlin, 1919, p. 172) more briefly discusses the origin of the oxidized zinc-lead ores that directly replace the primary ores (types 1, especially the disseminated ores) in the North Tintic district:

> The [oxidized] zinc-lead or "combination" ore in the North Tintic district was formed by the same chemical processes as the zinc ores free from lead, but the original lead-zinc sulphide ore was evidently due to impregnation rather than complete replacement of the limestone. When the zinc blende was oxidized, limestone was at hand to react immediately with the zinc sulphate before it could migrate from the lead ore.

Butler (1913, p. 154) has described in detail his views on the supergene origin of the wurtzite in the lower levels of the oxidized zone in the Horn Silver ore body. The wurtzite is probably the result of the transport by, and redeposition from, oxygenated surface water at the water table and thus it is a result of oxidation, although no valence change takes place in the process.

GEOLOGIC FEATURES FAVORABLE FOR PROSPECTING

Supergene zinc ore bodies are closely associated with deeply oxidized lead-silver, lead-zinc, or zinc ore bodies. Limestone wallrocks must be present, at least as the footwall of the ore body, before deposits of commercial size can be expected. Most of the zinc bodies are intimately associated with old lead and lead-silver stopes, but their exact positions, shapes, and sizes depend upon too many variable factors to be determined without actual prospecting. Some general suggestions for prospecting are as follows:

1. New deposits of oxidized zinc ore may be found by field examinations of old deeply oxidized lead-silver or lead deposits from which zinc has not been produced, in districts where limestone is the main wallrock. An example is the Fish Springs district. Some of the little-known base-metal districts in western and southern Utah, such as those of the Newfoundland and Desert Ranges, may contain undiscovered deposits. Unworked oxidized zinc deposits are present in some of the larger silver-lead-zinc districts where the sulfide zinc ores have long been mined but the oxidized zinc ores, although common, are in forms difficult to identify, such as at Park City.
2. Oxidized zinc deposits are common in many places where the primary ores in limestone are lean in silver and lead but rich in zinc; however, they are little worked because of the low market value of such zinc-rich ores and the high cost of mining and shipping from localities far from the smelters. Southern Cache Valley, Cache County, and western Utah contain several of these deposits.
3. New pockets of high-grade oxidized zinc ores or large low-grade deposits may be found, in many of the deposits that formerly produced large quantities of oxidized zinc ore, by further exploration in

the limestone footwalls and in the lower sides of old stopes where fractures, breccias, or limonite-replaced zones can be followed out from the primary ore bodies. Undiscovered pockets most probably remain in deposits that were exploited during the First World War but not thoroughly explored by experienced miners.

4. Old dumps or gob backfills in lead-silver or lead mines may contain considerable tonnages of zinc ore that can be easily recovered by re-sorting and screening.

The influence of local structures was summarized by Loughlin (1918, p. 86):

> Faults and strong fissures, if filled with impervious material or if bringing impervious or nonreplaceable beds opposite replaceable beds, may serve to impound the solutions and impound an ore body of unusual thickness; faults and fissures of similar magnitude, if open and very pervious, may serve to concentrate the flow of solutions along them and give rise to deposits of general veinlike form. If solutions traveling along open fissures pass beyond the limits of the carbonate rocks before effecting much replacement, it is probable that no workable deposits will be formed by them. Impervious rock layers, such as the quartzites and porphyries, may confine replacement to the limestone above them; but the same rocks, if fractured, may allow the solutions to pass into or through them. Where solutions penetrate Cambrian quartzite or thick masses of porphyry [or other igneous rocks] in this manner their zinc contents are not likely to be concentrated into workable deposits. If solutions find their way into a large body of rock which is chemically replaceable, but only slightly permeable, and which is not immediately underlain by some impervious bed, the solutions are likely to become dispersed and to yield an extensive body of low-grade ore or a series of shoots too small for profitable mining.

PRODUCTION AND RESERVES

Production and reserve data for oxidized zinc ore are difficult to obtain and commonly incomplete, for such ore has been produced only sporadically as a byproduct from many of the mines. Little prospecting for it has been done, and extraction since 1919 has generally been unprofitable. As a result many owners and operators have been reluctant to draw attention to the oxidized zinc ores in their mines as these ores have been looked upon with general disfavor by the mining industry for many years.

HISTORY OF PRODUCTION

The following table 4 shows the total production of zinc ores, total metallic zinc recovered from all ores, and the value of all the zinc produced in Utah, compared with the figures for oxidized zinc ores during the same period. The data since 1939 are incomplete because since then most of the production statistics of oxidized zinc, zinc-lead, and lead ores have been included with those of the sulfide ores because of the minor place of oxidized ores in the industry, even though the smelters classify the two kinds of ores separately because their processing is completely different.

TABLE 4.—*Zinc and oxidized zinc produced in Utah, 1905–52*

[Compiled from Butler and others (1920), U.S. Geol. Survey (1905–23), U.S. Bur. Mines (1924–26, 1926–52), and unpublished data]

Years	Mine production from all sources			Mine production from oxidized zinc ores		
	Zinc-bearing concentrates and direct-smelting zinc, zinc-lead, zinc-lead-copper crude ores (short tons)	Total recoverable zinc metal (short tons)	Value of total recoverable zinc	Total oxidized zinc and zinc-lead ores (short tons)	Total recoverable zinc metal in oxidized ores (short tons)	Value of oxidized zinc ores
1905–09	68,361	15,176	$1,736,852	[1] 13,136	[1] 4,157	[1] $458,300
1910–14	140,699	43,061	4,949,845	32,910	9,257	1,040,050
1915–19	161,825	48,991	11,144,030	44,429	11,166	2,900,395
1920–24	60,332	21,620	2,933,333	3,890	732	108,129
1925–29	485,088	221,923	30,009,398	679	146	25,106
1930–34	340,168	169,395	13,809,189	1,295	290	26,427
1935–39	378,672	183,479	19,418,160	738	152	18,314
1940–44	419,395	217,270	39,315,804	[2] 4,000	(3)	(3)
1945–49	727,918	187,755	46,329,514	[2] 8,500	(3)	(3)
1950–52	556,004	98,442	32,426,344	[2] 4,000	(3)	(3)

[1] 1906–09 inclusive, no production of oxidized zinc ores recorded previous to 1906.
[2] Estimated from incomplete data in Minerals Yearbook (U.S. Bur. Mines, 1940–52).
[3] Not given in Minerals Yearbook (U.S. Bur. Mines, 1940–52). U.S. Bur. Mines does not make any distinction between sulfide and oxidized ores.

The total production of oxidized zinc and zinc-lead ores in Utah from 1906 to 1952 is probably about 113,000 short tons, which is estimated to have yielded about 30,000 short tons of zinc metal.

The first notice of oxidized zinc minerals in Utah was by Benjamin Silliman, Jr. (Raymond, 1872, p. 321), who examined the Emma mine at Alta, Utah, about 1870 and noted that smithsonite was a common constituent of the ore. The zinc in the oxidized ore was not recovered from this mine, nor from any of the other lead-silver deposits mined during the 19th century in Utah.

Commercial deposits of oxidized zinc ore in Utah apparently were discovered about 1905 or early in 1906 at the Scranton mines of the North Tintic district, at about the same time that similar ore was first produced independently in Colorado at the Madonna and Eclipse mines in the Monarch district (Crawford, 1913, p. 251). In 1906 over 1,500 tons of rich oxidized zinc ore was produced from the Scranton mines (Butler and others, 1920). In 1907 and 1908 oxidized zinc ore was produced in the Star district from the Cedar Talisman and the Moscow mines. The Dry Canyon district started producing oxidized zinc and zinc-lead ore in 1911 from the Hidden Treasure mine, and in the same year the Eva mine in the Nebo district began production. The Tintic district, which probably has produced more oxidized zinc and zinc-lead ore than any other, did not start mining it until 1912. The first shipments from the Promontory and Lucin districts were in 1915 and 1917, respectively.

The main production of oxidized zinc was from 1910 to 1920, when a ready market was available because of processing plants and smelters that would handle it. The largest annual production of oxidized zinc and lead-zinc ores in Utah was in 1916 when 19,342 tons was produced, valued at $1,337,461 in zinc, lead, silver, and gold. This was roughly 73 percent of the total zinc production from Utah in 1916. About 1917, a zinc oxide plant was erected at Murray, Utah, and for about two years it recovered large quantities of zinc oxide from oxidized ores. The plant was closed permanently in 1919 when the price for zinc dropped abruptly as a result of the sharp depression that followed World War I. Nearly one-fourth of all the zinc produced in Utah during 1910–19 was recovered from oxidized zinc and zinc-lead ores.

Low prices, poor market conditions, and the depletion of high-grade ores were all factors that made production of oxidized zinc ores during the period 1920–40 small and sporadic.

Since 1940 oxidized zinc-bearing ore has been a small to fairly important source of the metal. The grade of the ore shipped to the smelter has decreased from an average of about 35 percent zinc before 1920 to 25 to 30 percent zinc at the present time.

In 1941 the International Smelting and Refining Co. erected a zinc slag-fuming plant at its smelter near Tooele, Utah. Some oxidized zinc ore is purchased annually for this plant, but the grade must exceed 25 percent zinc and meet certain other specifications, such as a relatively low iron content, in order to be successfully fumed. The operation of the Tooele plant and improved market conditions produced a small revival of the oxidized zinc mining industry during the period 1941–55 (see production table, p. 25). Between 2,000 and 4,000 tons of oxidized zinc and zinc-lead ores was produced in Utah in 1950, and smaller quantities since then, from several mines and from reworking of old dumps. Since about 1953 several smelters with fuming plants in the Western States have processed some zinc-lead and mixed lead, zinc, copper, silver, and gold ores in which the zinc content is considerably less than 25 percent. The strict smelter specifications, further depletion of high-grade ores, and the low prices the smelters have been able to pay for these ores (which are not easily smelted, have high losses, and yield an impure zinc oxide that must be shipped to eastern plants for further processing), have prevented any further expansion of the industry or extensive search for new deposits.

The North Tintic district, having a recorded production of more than 41,000 tons, has produced the most oxidized zinc ore in Utah. The Tintic and East Tintic districts combined, the second largest producing unit, have produced almost 32,000 tons. The other important districts in which oxidized zinc ores have been mined are, in the order of decreasing production: Promontory, Ophir-Dry Canyon, Big Cottonwood, Star (North Star), Indian Peak, Lucin, Wah Wah, Nebo, and Rush Valley.

RESERVES

Known reserves of oxidized zinc or zinc-lead ore in Utah that contain more than 25 percent zinc or zinc and lead are small; measured and indicated ore reserves probably do not total more than 30,000–40,000 short tons at the present time (1956). Most of the rest of the ore in Utah is inferred.[1] Some of it contains too much iron or other impurities, is too remote from smelters, or has other special smelting problems that prevent its shipment.

Oxidized zinc-bearing material containing between 10 and 25 percent zinc and zinc-lead-bearing material containing less than 20 percent combined zinc and lead, although too low grade to be profitably recovered at the present time, make up the bulk of the known oxidized zinc reserves in Utah. More than 1 million short tons of such low-grade material is known, mostly in the walls of old mines in the Tintic, Wah Wah, San Francisco, Lucin, and other districts, but also as small tonnages in many dumps. Such dumps were noted in the Tintic, Star, Little Cottonwood, American Fork, Dry Canyon, Lakeside, Fish Springs, Lucin, and North Tintic districts. Under more favorable economic conditions, many of the dumps could be reworked and small tonnages of shipping ore sorted from them. Most of the low-grade material on the dumps will probably be reworked eventually, but experience has shown that the bulk of it is submarginal even under the best market conditions in recent years. It will probably become a profitable source of zinc only after better milling and smelting processes are developed.

PROSPECTS FOR FUTURE DEVELOPMENT OF RESERVES

The outlook for new discoveries of oxidized zinc ore in Utah is good. Field examinations suggest that such ore exists in quantity in several districts where it has previously been either unnoticed or considered to be in negligible amounts. For example: (a) Several mine dumps in the western part of the Park City district contain large quantities of oxidized ore; (b) the deposits of the Lakeside district may still have much low-grade zinc-lead-bearing material and some commerical ore; (c) some mines and dumps in the Fish Spring district contain much silver-bearing zinc-lead oxide ore; (d) oxidized zinc ores are abundant in parts of the West Tintic district; (e) small deposits of high-grade smithsonite ore in the southern parts of the Bear River Range may be indications of larger deposits in the vicinity. If exploration were stimulated by a favorable market, good possibilities would exist for the discovery

[1] Inferred reserves may be poorly or not at all exposed, and are estimated on the basis of geologic data.

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of at least small tonnages of high-grade ore in many of these and other districts such as the Tecoma, Little Cottonwood, American Fork, and Star districts, where oxidized zinc was not sought to any extent in the past. Large tonnages of low-grade material, and perhaps new high-grade bodies, might be developed without too much difficulty in the Promontory, Park City, Star, North Tintic and East Tintic districts. Even the best oxidized zinc ores, however, do not provide much profit at the present time; in fact, there have been few reasons to stimulate mining and exploration since World War I.

The discovery and exploration of oxidized zinc ores have been retarded by the problem of recognizing the common ore forms of oxidized zinc minerals. They are very difficult to identify without a chemical analysis and are easily confused with travertine or iron-rich gossans even by trained miners, geologists, and engineers. The wallrock replacement deposits are commonly overlooked unless sought by men experienced in mining oxidized zinc ores. Much of the knowledge developed from experience by mining men has been lost since the active period of production during World War I.

PROSPECTS FOR FUTURE DEVELOPMENT OF MARKETS AND PROCESSING OF ORES

Little market exists today for oxidized zinc ore that contains less than 25 percent zinc, although ores containing as little as 17 percent zinc were profitably processed during World War I. Also, few smelting companies will purchase small lots of high-grade oxidized ore because of the change in the plants from the old horizontal to the modern vertical retorts that need a uniform large tonnage feed. The efforts of metallurgists to improve the smelting of zinc nationally have been almost entirely focused on the processing of the more abundant sulfide ores to the neglect of oxidized ores. The latter, with which the successful production of zinc started in the Eastern United States in 1852, were long preferred by the smelters because they were much more easily processed in the horizontal retorts than sulfide ores.

A further problem in the mining and smelting of zinc in the Western United States is that the principal markets for the metal are still in the East, and eastern slab zinc can still be produced and shipped to the West Coast by boat more cheaply than zinc mined and smelted in the West. Consequently, most of the zinc produced in the West is a by product of more profitable silver-lead or silver-lead-copper mining. Mining of zinc ores or zinc-lead ores which are lean in silver or gold is uncommon in the West except at a few localities such as Metalline Falls, Wash., and Hanover, N. Mex.

Considerable experimentation has been undertaken in recent years to develop an ore-dressing and concentration method that would successfully concentrate low-grade oxidized zinc ore at low cost and with little loss of metal content. Caustic-leach processes that have worked well in pilot plants and in laboratories have been developed by the U.S. Bureau of Mines and mining companies. (See for example, Wendt, 1953, p. 84–90.) Flotation and acid-leach processes are used successfully on oxidized and mixed oxidized-sulfide ores in large-scale commercial operations in Europe (Ray and others, 1954, p. 416–420; Straniero, 1954, p. 68–72). A similar industry has not started in this country, partly because the zinc ores found in the West are commonly rich in iron and are reported not to be amenable to the European milling techniques. Commercial concentration plants to process oxidized zinc ores have not been erected because of a lack of known reserves of ore sufficient to supply a plant for sufficient time to amortize it, and because of generally unfavorable zinc market conditions in the West.

DESCRIPTION OF OXIDIZED ZINC DISTRICTS AND DEPOSITS

The oxidized zinc and zinc-lead ore deposits in Utah are described by districts and deposits in the following pages. Selected individual deposits are described in some detail to serve as examples. They are arranged by counties from north to south. A list of districts, mines, claims, and prospects is given in table 5. The mines are shown on plates 1, 2, 3, 4, 5. All districts in more than one county are described under the county in which most of the district occurs. For example, the Tintic district is in both Utah and Juab Counties but is described under Juab County which contains the largest part of it.

The term "resources" as used in this report means the total available ore and oxidized zinc-bearing material that might conceivably be utilized in the future, both known or inferred to be present because of favorable geologic conditions, thus:

Oxidized zinc resources = oxidized zinc and zinc-lead ore reserves + known marginal and submarginal oxidized zinc-bearing material + potential (future possibilities of the district).

Ore as used in this section includes all oxidized zinc-bearing material that contains 25 percent zinc or better, or oxidized zinc-lead-bearing material that contains at least a total of 20 percent zinc and lead combined and commonly some silver. In a few places ore includes zinc-rich material containing sufficient copper, silver, or gold to be of commercial value.

TABLE 5.—*List of districts, mines, claims, and prospects of oxidized zinc ore in Utah*

[More than half of the mines are shown on pl. 1; for others, see pls. 2, 3, 4, 5]

No.	Property	District	Township location
	BOX ELDER COUNTY		
	Cedar Ridge mine (see Lake View).		
1.	Copper Mountain mine	Lucin	T. 6 N., R. 19 W.
2.	Lake View, Cedar Ridge, and Lead Hill mines.	Promontory	T. 6 N., R. 6 W.
	Lead Hill mine (see Lake View).		
3.	Newfoundland district		T. 5 N., R. 13 W.
4.	Sierra Madre district		T. 7–8 N., R. 1 W.
5.	Tecoma district		T. 9 N., R. 19 W.
6.	Tecoma mine	Lucin	T. 6 N., R. 19 W.
	CACHE COUNTY		
7.	Amazon mine	Swan Creek	T. 14 N., R. 4 E.
	Hilltop claim (see Tip Top).		
	Lucky Star group of mines (see Tip Top).		
8.	Moon claim	Hyrum or Paradise	T. 10 N., R. 1 E.
9.	Tip Top or Hilltop claim of Lucky Star group of mines.	do	T. 11 N., R. 3 E.
	MORGAN COUNTY		
10.	Carbonate Gem mine (Blacksmith tunnel).	Argentia	T. 5 N., R. 2 E.
11.	Carbonate Hill mine (in 1920 included properties 10 and 12).	do	T. 5 N., R. 2 E.
12.	Morgan Argentine mine (Silver Zone tunnel).	do	T. 5 N., R. 3 E.
	SALT LAKE COUNTY[1]		
13.	Albion shaft (pl. 3)	Little Cottonwood (Alta area).	T. 3 S., R. 3 E.
14.	Alta tunnel (pl. 3)	Big Cottonwood (Alta area).	T. 2 S., R. 3 E.
15.	Carbonate mine (pl. 3)	do	T. 2 S., R. 2 E.
16.	Cardiff mine (pl. 3)	do	T. 2 S., R. 3 E.
17.	Columbus-Rexall mine (pl. 3)	Little Cottonwood (Alta area).	T. 3 S., R. 3 E.
18.	Emma mine (pl. 3)	do	T. 2–3 S., R. 3 E.
19.	Flagstaff mine (pl. 3)	do	T. 2 S., R. 3 E.
20.	Grizzly mine (pl. 3)	do	T. 2 S., R. 3 E.
21.	Kentucky-Utah mine (pl. 3)	Big Cottonwood (Alta area).	T. 2 S., R. 3 E.
22.	Louise mine (pl. 3)	Little Cottonwood (Alta area).	T. 3 S., R. 3 E.
23.	Maxfield mine	Big Cottonwood (Alta area).	T. 2 S., R. 2 E.
24.	Michigan-Utah mine (pl. 3)	Little Cottonwood (Alta area).	T. 2 S., R. 3 E.
25.	Peruvian mine (pl. 3)	do	T. 3 S., R. 3 E.
26.	South Hecla mine (pl. 3)	do	T. 3 S., R. 3 E.
27.	West Toledo mine (pl. 3)	do	T. 2 S., R. 3 E.
28.	Woodlawn mine (pl. 3)	Big Cottonwood (Alta area).	T. 2 S., R. 3 E.

[1] For American Fork district see Utah County.

TABLE 5.—*List of districts, mines, claims, and prospects of oxidized zinc ore in Utah*—Continued

SUMMIT COUNTY

No.	Property	District	Township location
29.	Beaver Creek lead-zinc mine		T. 2 S., R. 7 E.
30.	Cresent Ridge mines (pl. 5)	Park City	T. 2 S., R. 4 E.
31.	Daly Judge mine (pl. 5)	do	T. 2 S., R. 4 E.
32.	Daly No. 1 mine (pl. 5)	do	T. 2 S., R. 4 E.
33.	Daly West mine (pl. 5)	do	T. 2 S., R. 4 E.
34.	Little Bell mine (pl. 5)	do	T. 2 S., R. 4 E.
35.	Quincy mine (pl. 5)	do	T. 2 S., R. 4 E.
36.	Silver King mine (pl. 5)	do	T. 2 S., R. 4 E.
37.	Snyderville prospect	do	T. 2 S., R. 4 E.

DAGGET COUNTY

No.	Property	District	Township location
38.	Basset Prospect	Carbonate	T. 1 S., R. 21–22 E.

UINTAH COUNTY

No.	Property	District	Township location
39.	Dyer lead prospects	Carbonate	T. 1 S., R. 21 E.
40.	Brush Creek Cave prospect	do	T. 1 S., R. 21 E.
41.	Little Brush Creek prospect	do	T. 1 S., R. 21 E.
42.	North Dyer lead prospect	do	T. 1 S., R. 21 E.

TOOELE COUNTY

No.	Property	District	Township location
	Bauer mine (see Honorine).		
	Blaine mine (see Ida).		
43.	Blue Bell mine	Blue Bell	T. 10 S., R. 5 W.
	Bullion Coalition (see Honorine).		
	Chicago mine (see Hidden Treasure).		
44.	Chloride Point mine	Lion Hill	T. 5 S., R. 4 W.
	Cliff mine (see Hidden Treasure).		
	Combined Metals mine (see Honorine).		
	Delmonti mine (see Scranton mines).		
45.	Four Metals and Smelter Canyon mines.	Dugway	T. 9 S., R. 12 W.
46.	Free Coinage district		T. 2 S., R. 7 W.
47.	Galena King mine	Rush Valley	T. 4 S., R. 4 W.
48.	Garrison Monster mine	Gold Hill	T. 7 S., R. 18 W.
	Gold Hill mine (see Western Utah mine).		
49.	Happy Jack mine	Erickson	T. 10 S., R. 8 W.
50.	Hidden Treasure, Cliff, Chicago, and Ophir Hill mines.	Ophir and Dry Canyon.	T. 5 S., R. 4 W.
51.	Honorine, Bullion Coalition, Bauer, or Combined Metals mine.	Rush Valley	T. 4 S., R. 4 W.
52.	Ida or Blaine mine	Erickson	T. 10 S., R. 8 W.
53.	Kearsage mine	Dry Canyon	T. 5 S., R. 4 W.
54.	Lakeside Monarch mine	Lakeside	T. 2 N., R. 9 W.
55.	Last Hope mine	Erickson	T. 10 S., R. 8 W.
	Magazine or Magazine Tunnel mine (see Scranton mines).		
56.	Monoco mine	Gold Hill	T. 8 S., R. 17 W.
57.	New Baltimore mine	do	T. 8 S., R. 17 W.
58.	New Bullion mine	North Tintic	T. 9 S., R. 3 W.
	North Essex mine (see Scranton mines).		
59.	Old Sharp mine	Columbia	T. 9 S., R. 6 W.
	Ophir mine (see Hidden Treasure).		

TABLE 5.—*List of districts, mines, claims, and prospects of oxidized zinc ore in Utah*—Continued

TOOELE COUNTY—continued

No.	Property	District	Township location
60.	Prospect Incline mine	Lakeside	T. 2 N., R. 9 W.
61.	Queen of the Hills and Wandering Jew mines.	Ophir	T. 5 S., R. 4 W.
62.	Sacramento mine	Mercur	T. 6 S., R. 3 W.
63.	Scranton mines (Delmonti, Magazine, North Essex, and South Essex).	North Tintic	T. 9 S., R. 3 W.
	Smelter Canyon mine (see Four Metals).		
	South Essex mine (see Scranton mines).		
64.	Surprise tunnel	Dry Canyon	T. 5 S., R. 4 W.
65.	Tintic Zinc Co. prospects	North Tintic	T. 9 S., R. 3 W.
	Wandering Jew mine (see Queen of the Hills).		
66.	Western Utah (Gold Hill) mine	Gold Hill	T. 7 S., R. 17 W.
67.	Yellow Jacket mine	Dugway	T. 10 S., R. 12 W.

UTAH COUNTY[2]

No.	Property	District	Township location
68.	Alpine prospect	Alpine	T. 4 S., R. 2 E.
69.	Bay State mine (pl. 3)	American Fork (Alta area).	T. 3 S., R. 3 E.
70.	Bog mine (pl. 3)	do	T. 3 S., R. 3 E.
71.	Delsa mine	Santaquin	T. 10 S., R. 1 E.
72.	Dutchman mine (pl. 3)	American Fork (Alta area).	T. 3 S., R. 3 E.
73.	East Tintic Development or Eureka Lilly mine.	East Tintic	T. 10 S., R. 2 W.
74.	Miller Hill mine (pl. 3)	American Fork (Alta area).	T. 3 S., R. 3 E.
75.	Monarch mine	Provo	T. 6 S., R. 3 E.
76.	New Deal mine	Santaquin	T. 10 S., R. 1 E.
77.	Pittsburg mine (pl. 3)	American Fork (Alta area).	T. 3 S., R. 3 E.
78.	Tintic Standard mine	East Tintic	T. 10 S., R. 2 W.
79.	Zinc prospect south of Tintic Standard.	do	T. 10 S., R. 2 W.

JUAB COUNTY

[Includes a few mines in westernmost Utah County in the Tintic district]

No.	Property	District	Township location
80.	Beck Tunnel No. 1 (pl. 2)	Tintic district	T. 10 S., R. 2 W.
81.	Beck Tunnel No. 2 (pl. 2)	do	T. 10 S., R. 2 W.
	Big Nebo mine (see Mount Nebo).		
	Blue Bell mine (see Eagle, pl. 2).		
82.	Boss Tweed or Victor mine (pl. 2).	do	T. 10 S., R. 2 W.
83.	Bullion Beck mine (pl. 2)	Tintic	T. 10 S., R. 3 W.
84.	Carnation or Wilson mine	Fish Springs	T. 11 S., R. 14 W.
85.	Chief Consolidated mine (pl. 2).	Tintic	T. 10 S., R. 2 W.
86.	Colorado No. 1 mine (pl. 2)	do	T. 10 S., R. 2 W.
87.	Colorado No. 2 mine (pl. 2)	do	T. 10 S., R. 2 W.
88.	Eagle and Blue Bell mine (pl. 2).	do	T. 10 S., R. 2 W.
89.	East Vulcan prospect	Fish Springs	T. 11 S., R. 14 W.
90.	Emma mine	do	T. 11 S., R. 14 W.
91.	Eureka Hill mine (pl. 2)	Tintic	T. 10 S., R. 3 W.
92.	Eureka L and M (Vagabond No. 10 mine).	Mount Nebo (Mona).	T. 11 S., R. 1 E.

[2] For Tintic district see Juab County, also plate 2.

TABLE 5.—*List of districts, mines, claims, and prospects of oxidized zinc ore in Utah*—Continued

JUAB COUNTY—continued

No.	*Property*	*District*	*Township location*
93.	Eva, Privateer mine	Mount Nebo	T. 11 S., R. 1 E.
94.	Freddie Lode mine	do	T. 11 S., R. 1 E.
95.	Galena mine	Fish Springs	T. 11 S., R. 14 W.
96.	Gemini mine (pl. 2)	Tintic	T. 10 S., R. 3 W.
97.	Godiva mine (pl. 2)	do	T. 10 S., R. 2 W.
98.	Goshute Canyon district		T. 11 S., R. 19 W.
99.	Grand Central mine (pl. 2)	Tintic	T. 10 S., R. 2 W.
100.	Gunnison and Highland mines	Mount Nebo	T. 11 S., R. 1 E.
	Highland mine (see Gunnison).		
	Humbug mine (see Uncle Sam pl. 2).		
101.	Iris mine	Mount Nebo	T. 11 S., R. 1 E.
102.	Iron Blossom No. 1 mine (pl. 2).	Tintic	T. 10 S., R. 2 W.
103.	Iron Blossom No. 3 mine (pl. 2).	do	T. 10 S., R. 2 W.
104.	Lower Mammoth mine (pl. 2)	do	T. 10 S., R. 2 W.
105.	Mammoth mine (pl. 2)	do	T. 10 S., R. 2 W.
106.	May Day mine (pl. 2)	do	T. 10 S., R. 2 W.
107.	Mt. Nebo or Big Nebo mine	Mount Nebo	T. 11 S., R. 1 E.
108.	Orient, Resurrection mine	West Tintic	T. 11 S., R. 6 W.
	Privateer mine (see Eva).		
	Resurrection (see Orient).		
109.	Ridge and Valley mine (pl. 2)	Tintic	T. 10 S., R. 3 W.
110.	Santaquin Chief mine	Mount Nebo	T. 11 S., R. 1 E.
111.	Scotia mine	West Tintic	T. 11 S., R. 5 W.
112.	Sioux Consolidated mine (pl. 2).	Tintic	T. 10 S., R. 2 W.
113.	Uncle Sam and Humbug mines (pl. 2).	do	T. 10 S., R. 2 W.
114.	Utah mine	Fish Springs	T. 11 S., R. 14 W.
	Vagabond No. 10 mine (see Eureka L and M).		
	Victor mine (see Boss Tweed pl. 2).		
115.	Vulcan mine	Fish Springs	T. 11 S., R. 14 W.
116.	War Eagle No. 3 mine	West Tintic	T. 11 S., R. 6 W.
	Wilson mine (see Carnation).		
117.	Yankee mine (pl. 2)	Tintic	T. 10 S., R. 2 W.
118.	1888 mine (east)	West Tintic	T. 11 S., R. 5 W.
119.	1888 mine (west)	do	T. 11 S., R. 6 W.

EMERY COUNTY

120.	Good Hope mine	Summerville, Emery, or Lost Springs.	T. 18 S., R. 13 E.

SEVIER COUNTY

121.	Redmond Silver or Salina Zinc mine.	Redmond	T. 21 S., R. 1 E.

MILLARD COUNTY

122.	Black Rock area		T. 24 S., R. 11 W.
123.	Blue Bell (or Jelkes?) mine	Gordon	T. 24 S., R. 6 W.
124.	M. and M. mine	Notch Peak	T. 20 S., R. 14 W.

TABLE 5.—*List of districts, mines, claims, and prospects of oxidized zinc ore in Utah*—Continued

BEAVER COUNTY

No.	Property	District	Township location
125.	Beaver View Extension mine	Granite	T. 27 S., R. 8 W.
	Bradshaw mine (see Cave).		
126.	Cave (Bradshaw) mine	Bradshaw	T. 29 S., R. 9 W.
127.	Cedar-Talisman mine (pl. 4)	Star	T. 28 S., R. 12 W.
128.	Creole mine	Lincoln	T. 29–30 S., R. 9 W.
129.	Croff mine	do	T. 29 S., R. 9 W.
	East Moscow mine (see Moscow).		
	Galena mine (see Independent Silver).		
130.	Harrington-Hickory mine (pl. 4).	Star (North Star)	T. 28 S., R. 11 W.
131.	Hoosier Boy mine (pl. 4)	Star	T. 28 S., R. 12 W.
132.	Horn Silver mine	San Francisco	T. 27 S., R. 13 W.
133.	Hub mine (pl. 4)	Star	T. 28 S., R. 12 W.
134.	Independent Silver (Galena mine).	Beaver Lake	T. 26 S., R. 11 W.
135.	King David mine	San Francisco	T. 27 S., R. 13 W.
136.	Lady Bryan (or Lady Potter?) mine (pl. 4).	Star	T. 28 S., R. 12 W.
137.	Lincoln or Rollins mine	Lincoln	T. 29 S., R. 9 W.
138.	Magnolia, Manasa, and Osceola mines (pl. 4).	Star	T. 28 S., R. 12 W.
	Manasa mine (see Magnolia).		
139.	Moscow and East Moscow mines (pl. 4).	Star	T. 28 S., R. 12 W.
140.	Mowitza mine (pl. 4)	do	T. 28 S., R. 12 W.
141.	North Granite, Granite, and J. E. Robinson properties.	Granite	T. 27 S., R. 8 W.
	Osceola mine (see Magnolia).		
142.	Old Hickory mine	Rocky	T. 27 S., R. 11 W.
143.	Prospects southeast of Moscow mine (pl. 4).	Star	T. 28 S., R. 2 W.
144.	Rebel mine (pl. 4)	do	T. 28 S., R. 11 W.
145.	Red Warrior mine (pl. 4)	do	T. 28 S., R. 12 W.
	Rollins mine (see Lincoln)		
146.	Wah Wah mine	Pine Grove	T. 28 S., R. 16 W.
147.	Wild Bill mine (pl. 4)	Star	T. 28 S., R. 12 W.

PIUTE COUNTY

148.	Cascade mine	Ohio	T. 27 S., R. 3 W.

IRON COUNTY

149.	Escalante mine	Escalante	T. 36 S., R. 17 W.
150.	New Arrowhead mine	Indian Peak	T. 31 S., R. 18 W.

WASHINGTON COUNTY

151.	Black Warrior mine	Tutsagabet	T. 42 S., R. 19 W.
152.	Dixie Apex mine	do	T. 43 S., R. 18 W.
153.	Paymaster mine	do	T. 43 S., R. 18 W.

BOX ELDER COUNTY

LUCIN DISTRICT

Plate 1, nos. 1, 6

Location.—West side of Pilot Range near Nevada boundary, about 7 miles south of Lucin, Utah. Reached by 12 miles of dirt road extending southeastward from Lucin-Montello road from intersection about half a mile east of Montello, Nev.

Development and production.—The Lucin district includes a group of opencuts and adits that trend eastward along a canyon up to the crest of the Pilot Range (fig. 10). The Tecoma mine is the main zinc-lead mine; others to the east are the Mineral Mountain mine of the Mountain Mining Co. in the canyon and the lead-zinc workings of the Copper Mountain mine near the crest of the range just north of the copper workings. Most workings in these mines are accessible.

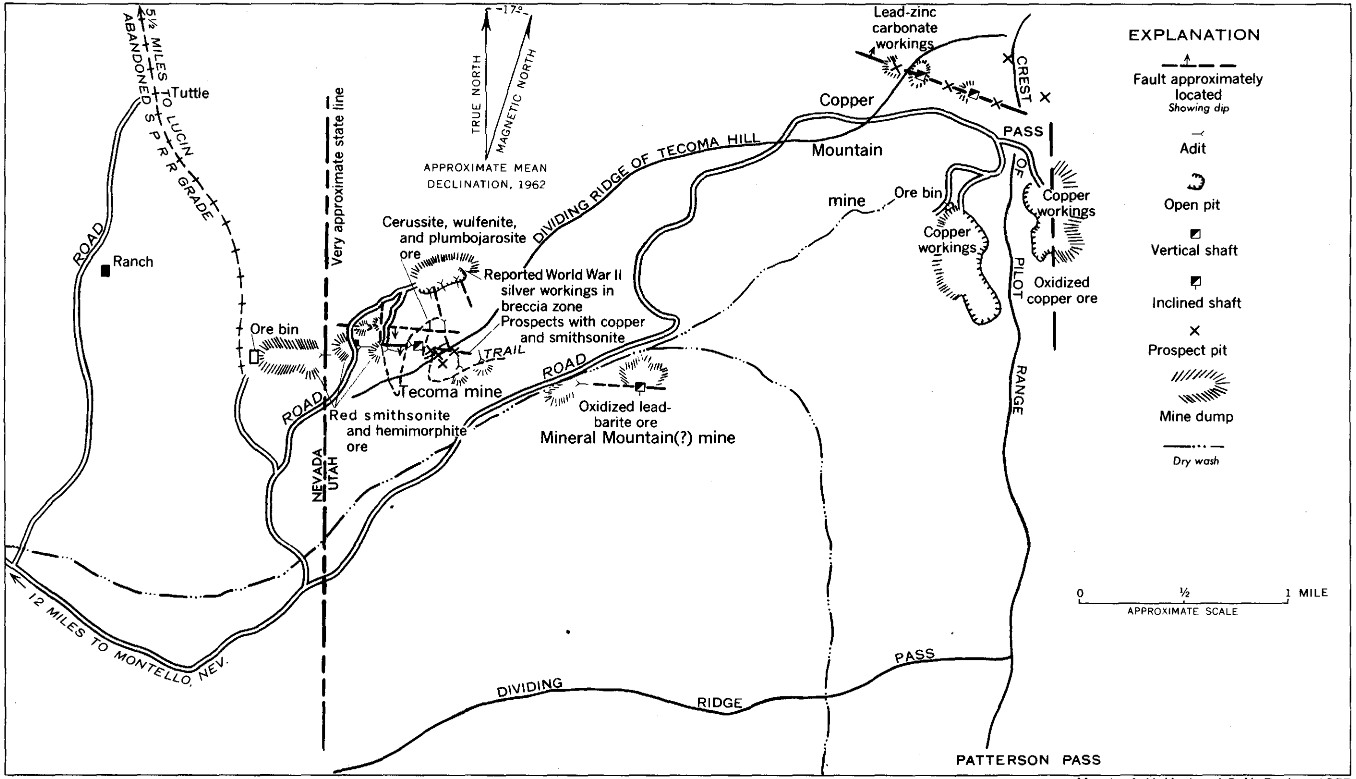
The district was operated for silver-lead and copper in the 19th century starting about 1870, and for copper and oxidized zinc ores during 1916–22. The Tecoma mine produced $1 million worth of all kinds of oxidized ore until 1920 (Weed, 1920, p. 1373). More than 2,000 tons of oxidized zinc ore are estimated to have been stoped out at the mine from 1917 through 1922, yielding between 300 and 400 tons of zinc metal. This zinc was produced by the Tintic Standard Mining Co. and the Tecoma Consolidated Mining Co. Some development for zinc, but little mining, was done by the Tecoma Consolidated Mining Co. at the Tecoma mine in 1943–44. Copper was being mined from the Copper Mountain mine by lessees in 1955.

Geology.—The deposits are veins in fault fissures or vertical pipes at fissure intersections in limestones of reported Pennsylvanian age. South and southeast of the mines in Patterson Pass, a quartz monzonite stock of probable Tertiary age intrudes the limestones (Butler and others, 1920, p. 490). Another, smaller stock lies north of the Tecoma mine.

The main mineralized fissure zone at the Tecoma mine strikes nearly due east and dips steeply southward (fig. 10). It is exposed for a length of about 2,000 feet, a width of 150 feet, and a vertical height of 400 feet. Weaker northward-striking fractures cross it. Oxidized lead-silver-zinc ore is mostly in east-striking veins along this stockwork of fissures and as vertical pipes at the fissure intersections. Red smithsonite ore is deposited in replacement zones and pods in the footwalls of the veins.

The lead-zinc ore at the Copper Mountain mine occurs in a northwest-trending fault fissure north of the main north-striking fissure zone that contains the copper deposit.

Ore.—The oxidized zinc ores consist of red and brown smithsonite, white hemimorphite, and traces of aurichalcite associated with jasper and acicular aragonite. The associated minerals are limonitic anglesite, cerussite, barite, wulfenite, plumbojarosite, malachite, chrysocolla, and copper pitch. The only primary ore mineral seen was galena, which occurred as a few partly oxidized grains.



Map by A. V. Heyl and C. N. Bozion, 1955

FIGURE 10.—Sketch map of Tecoma and Copper Mountain mines, Lucin district, Box Elder County, Utah.

Oxidized zinc ore resources.—The district contains substantial reserves of oxidized zinc ores and zinc-bearing material. Field examination suggests that much mineralized material remains in the stopes and on the dumps. Most of this material is estimated to contain between 5 and 20 percent zinc, but some is ore averaging at least 30 percent zinc.

Reference.—Butler and others (1920, p. 448–494).

PROMONTORY DISTRICT

Plate 1, no. 2

Location.—On west side of Promontory Mountains about 4 miles north of Promontory Point. Reached by fair dirt road west and north from Promontory Point station. The mines are reported to be about 1,000 to 1,500 feet in height above Great Salt Lake.

Development and production.—The district has been prospected and mined for about 4,500 feet in a northward direction and includes several mines—notably the extensive Lakeview group (fig. 11)

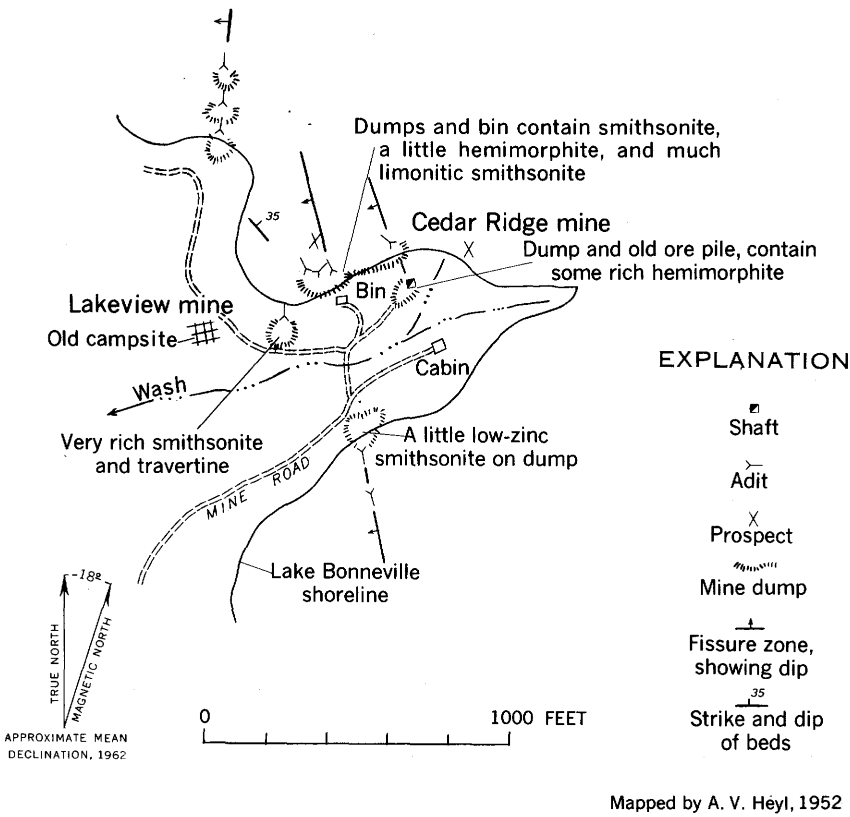


FIGURE 11.—Sketch map of Lakeview group of mines, Promontory district, Box Elder County, Utah.

and the nearby Cedar Ridge and Lead Hill mines. The Lakeview group of mines, in the southern part of the district, has been the principal and most profitable producer. Many accessible adits and shafts are clustered in a westward-draining valley.

Boulders, and then outcrops, of oxidized zinc-lead ores were found in 1914 by placer gold miners on nearby claims. The Lakeview group was opened on the zinc-lead ores in 1915, and large quantities of oxidized zinc and zinc-lead ore were shipped from this group profitably until 1917. Smaller quantities of ore were produced in 1919, from 1942 to 1947, and again in 1952. The entire district, which to date has yielded more than 14,000 tons of oxidized zinc and zinc-lead ores, is the third largest producer in the State.

Most of the ores averaged 32 percent zinc (Weed, 1920, p. 1385) and contained considerable lead. Some oxidized lead ores were shipped separately. The 989 tons of ore produced before August 1, 1915, averaged as follows, according to company data (Arentz, 1915, p. 15):

Average composition of 989 tons of ore produced before August 1, 1915, Promotory district

[Analyst not known, probably an average of smelter returns]

Constituent	*Percent*	*Constituent*	*Percent*
Gold	Trace	Iron	1.1
Silver [1]	0.02	Sulfur	.2
Lead	7.7	Insoluble	16.0
Zinc	32.75		

[1] In ounces per short ton.

Geology.—The deposits are in four thin limestone beds of Cambrian age, interbedded with shale, which strike northwestward and dip 30° to 40° NE. Small dikes are the only known nearby intrusive bodies. The strata are cut by well-defined fissures that trend northward and dip steeply westward (fig. 11). Where these fissures cut the limestone beds, oxidized zinc and lead ores form pods replacing the sheared limestone. Some ore is in all four beds, but most of the ore produced in the past has come from the thicker of the two middle beds. Later mining has been in the thinner limestone beds to the east and west.

Ore.—The ore is mostly porous cellular smithsonite of a dirty brown color, associated with some white reniform smithsonite, crystalline masses of hemimorphite, cerussite, and a little hydrozincite. Locally the ore is rich in limonite, suggesting the former abundance of iron sulfides. Much of the oxidized minerals replaced the sulfides, apparently with some migration within the body, so that now lead carbonate and hemimorphite form the central core, surrounded by smithsonite, which in turn is coated with a thin outer shell of limonite. Gangue minerals are calcite, pink dolomite, and a little quartz and jasperoid. The ore is reported to become richer in lead at depth, and in the deepest parts of the mine some galena has been found. Depth of oxidation is about 1,000 feet.

Oxidized zinc ore resources.—Most of the known high-grade ore has been removed from the district but some of the thinner beds contain a fairly large tonnage of mineralized material in thin veins. The material is estimated to contain 5–8 percent lead and 5–10 percent zinc.

References.—Butler and others (1920, p. 499–502); Arentz (1915, p. 12–13); U.S. Geological Survey (1915–23); U.S. Bureau of Mines (1924–53); Heikes and Butler (1916, p. 1–10).

NEWFOUNDLAND DISTRICT

Plate 1, no. 3

Location.—In the Newfoundland Mountains, a small range in the north-central part of the Great Salt Lake Desert. Can be reached in favorable weather by 24-mile trail, suitable for 4-wheel-drive vehicle, southeast from Knolls, Utah, on U.S. Highway 40. District is shown on central-east side of range on some maps; was not visited by the author.

Development and production.—Little is known about the Newfoundland district. Small mines and many prospects have been reported, including the Mineral Monarch copper mines and the King Extension lead-silver mine.

It was organized in 1872 and until 1880 was the scene of much prospecting for silver-lead ore. Small quantities of copper and lead-copper-silver ores were produced in 1916–19. The area has not often been visited by prospectors in recent years because of its remoteness and difficulty of access.

Geology.—According to Butler and others (1920, p. 488), the rocks include both sedimentary rocks and some porphyry. The silver-lead veins are reported to be narrow—less than 18 inches wide.

Ore.—Samples of high-grade earthy hydrozincite are in the University of Utah collection; their specific location is not given.

Oxidized zinc ore resources.—None are known, but several unsubstantiated reports suggest that the district is worth more prospecting.

SIERRA MADRE DISTRICT

Plate 1, no. 4

Location.—On westslope near crest of Wasatch Range, 10 miles north of Ogden. Reportedly accessible by trials from east side of range north of Liberty, but was not visited by the writer.

Development and production.—The district produced a little copper, silver, and gold from 1901 to 1905. The Eldorado mine and other shallow mines and prospects near the crest of the range have apparently long been inactive, in part owing to the inaccessibility of the district.

Geology.—The rock in the lower slopes of this part of the Wasatch Range is granite of Precambrian age. A sequence of quartzite of Early Cambrian age and dolomite, limestone, and shale of Middle Cambrian age unconformably caps the granite and forms the upper slopes of the range. In part of the range the Cambrian strata are overlain by an overthrust sheet of Precambrian quartzite. Mineralized fissures extend continuously from the Precambrian granite, where they contain copper, through the lower Cambrian quartzite up into the Middle Cambrian limestone and dolomite, where they feather and die out in bedded replacement lead-zinc deposits which are lean in silver. The ore is in replacement bunches in the first dolomite bed above the Cambrian quartzite; the dolomite and ore are capped by shale (Butler and others, 1920, fig. 39).

Ore.—The ore consists of galena, sphalerite, and pyrite in a gangue of quartz, sericite, calcite, dolomite, and traces of fluorite. Locally it is partly oxidized, and small deposits of oxidized zinc ore are reported.

Oxidized zinc ore resources.—Small deposits are reported.

Reference.—Butler and others (1920, p. 223–226, pls. 25 and 26, fig. 39),

TECOMA DISTRICT

Plate 1, no. 5

Location.—In northwest part of Goose Creek Hills, on Nevada-Utah border north-northwest of Lucin, Utah. Mostly in Nevada but easternmost prospects are probably in Utah. Western part of district is 10 miles northeast of Tecoma, Nev., and is reached by a poor dirt road.

Development and production.—The district has several small mines and prospects. The Queen of the West mine in the southeast part, possibly in Utah, has a 120-foot inclined shaft.

The district has been a small but sporadic producer since the 19th century, mostly from the Nevada side. Some of the oxidized silver-lead ores shipped were rich in zinc.

Geology.—Deposits are irregular replacements along northwest-striking fissures near the axis of a gentle northward-trending anticline, in limestone of Devonian age which is overlain by quartzite. For details see Hill (1916, p. 105).

Ore.—The ore bodies are completely oxidized, and those in the southeastern part are reported to contain the most zinc. Some shipments of ore from the Queen of the West mine contained as much as 18 percent zinc and 80 ounces of silver per ton. The ore is cellular cerussite, limonite, and smithsonite.

Oxidized zinc ore resources.—No reserves are known, but the deposits in the southeastern part are rich in zinc and apparently little prospecting has been done for this type of ore.

References.—Hill (1916, p. 10, 105).

SILVER ISLET DISTRICT

The district is 15 miles northeast of Wendover in the Desert Range. Oxidized antimony-rich lead-silver deposits are reported in Ordovician limestones. The deposits are small, difficult of access, and little known or worked. Zinc is reported in one shipment, and the deposits are similar to many others where oxidized zinc ores have been found.

CACHE COUNTY

SWAN CREEK DISTRICT

Plate 1, no. 7

Location.—Crest and east slope of Bear River Range, from west of Garden City, Utah, northward into Idaho. Amazon mine is 8 miles west of Garden City and about a quarter mile south of U.S. Highway 89 at crest of Bear River Range in NW¼ sec. 21, T. 14 N., R. 4 E.

Development and production.—The district contains widely scattered lead, lead-zinc, and copper prospects and small mines. Two of them in Utah are the Victoria No. 1 (Swan Creek) and the Amazon mine (pl. 1, no. 7). The workings at the Amazon consist of several shallow shafts, short adits, pits, and trenches in a general northward line.

The district was apparently discovered about 1900 and prospected until 1920. In 1950–51 the Amazon mine was worked by H. C. Hanson of Logan, Utah, who reports he produced some lead, silver, and copper ore (oral communication, 1953).

Geology.—The geology of the region is described by Richards (1911) and by Mansfield (*in* Boutwell and others, 1933, pl. 18). At the Amazon mine, locally dolomitized limestone of Cambrian age is cut by a weakly mineralized west-northwest-striking fracture, which is intersected by weak southwest-striking fractures and joints and by eastward-trending, southward-dipping breccia zones. Many of these fractures and breccia zones are cemented by coarse-grained vein dolomite that contains bunches, veinlets, and large discrete crystals of galena and light-brown sphalerite. Much of the sphalerite at the surface is directly replaced by cellular cleavage boxworks of buff-colored smithsonite. Most of the ore was produced from pockets of pure galena containing coarse crystals of enargite and as much as 25 ounces of silver per ton. Oxidized minerals do not extend below 10 feet in places, possibly because of the absence of the pyrite necessary to form the acidic solutions.

Oxidized zinc ore resources.—No resources known except a few tons of lean material. The deposits are significant because of the direct replacement of sphalerite by smithsonite, and because they are in a large but little-prospected district that contains other scattered lead-zinc deposits, some of which are known to be much more deeply oxidized.

Other reference.—Butler and others (1920).

HYRUM OR PARADISE DISTRICT

Plate 1, nos. 8, 9

Location.—Western slope of Bear River Range and in westward-draining canyons from Avon northward to Logan.

Development and production.—Many small lead, zinc, silver, iron, and copper mines and prospects are widely scattered in the district, but the two main oxidized zinc deposits are the Tip Top or Hilltop Claim of the Lucky Star group of mines on the left fork of Blacksmith Fork, and the Moon claim near the west base of the Bear River Range, 3½ miles southeast of Hyrum (fig. 12).

Before 1900 small quantities of gold, silver, and lead were produced. From about 1908 to 1920 small shipments of gold, silver, copper, lead, and zinc ores were made from several claims, including about 17 tons of zinc carbonate ore averaging 29.92 percent zinc, 6.3 percent lead, and 0.6 ounce of silver per ton, from the Tip Top claim, and two carloads of zinc carbonate ore containing 22–28 percent zinc, from the Moon claim (Butler Loughlin and others, 1920, p. 218). H. C. Hanson, owner of the Moon claim, shipped a few hundred pounds of zinc carbonate ore to a smelter about 1952 and he reports that it "tested very high grade" (oral communication, 1953).

Geology.—The part of the Bear River Range in the Hyrum or Paradise district is structurally a syncline bounded on the west by a basin-and-range-type normal fault system, and on the east by a low-angle thrust zone. The rocks range in age from Cambrian on the margins of the syncline to Carboniferous, capped by Tertiary lake beds, in the area of the northward-trending axis. The Moon claim is near the west foot of the range, where dolomites or limestones, reported to be Devonian in age, are cut by a mineralized fault (fig. 12)—probably one of several that make up the basin-and-range fault system along the eastern edge of Cache Valley.

Ore.—The primary ore minerals are pyrite and sphalerite in pure blue-gray fine-grained masses in the fault and fault breccia. This ore is oxidized to depths of 50 to 100 feet, forming limonite, direct-replacement smithsonite, and a little hydrozincite. Zinc carbonate ore from the district contained 22–30 percent zinc; the author estimates that ore piles at the Moon claim may average as much as 35 percent zinc.

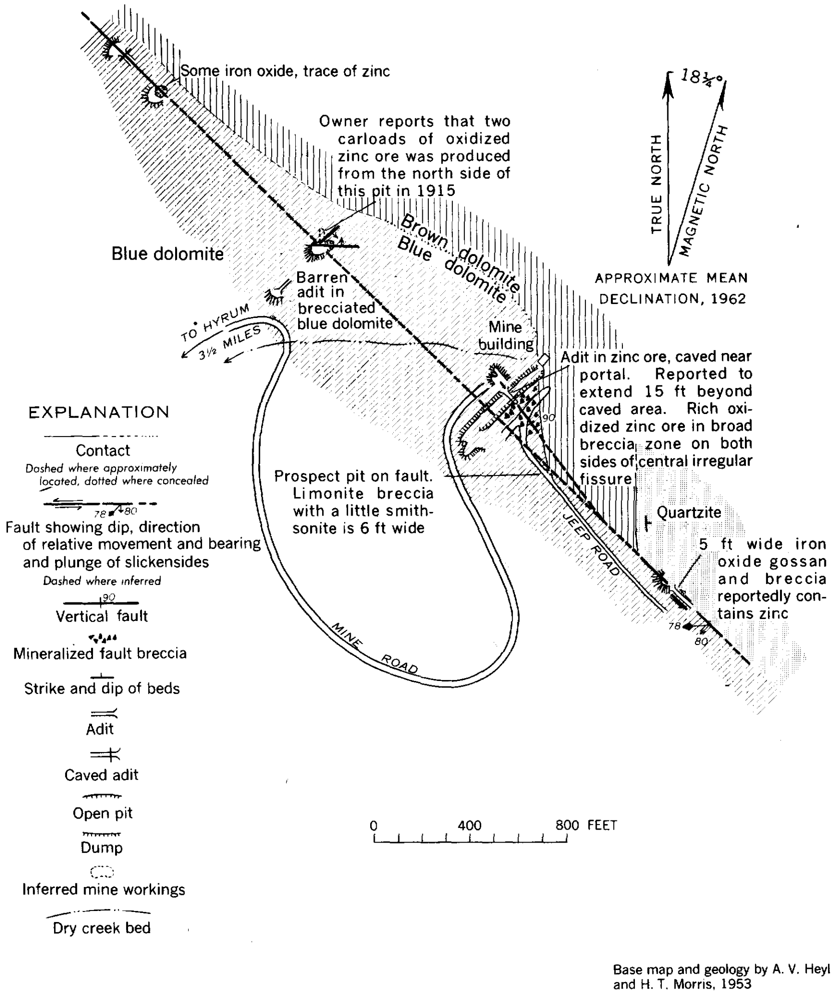


FIGURE 12.—Map of Moon claim, Hyrum district, Cache County, Utah.

Oxidized zinc ore resources.—The district shows promise as an area of small but high-grade oxidized zinc deposits, but it is more promising for zinc sulfide deposits because oxidation is shallow.

Reference.—Butler and others (1920, p. 217–219).

MORGAN COUNTY

ARGENTIA DISTRICT

Plate 1, nos. 10, 11, 12

Location.—Mainly on south side of Cottonwood Creek, 6 miles north of Peterson in sec. 24, T. 5 N., R. 2 E. and sec. 19, T. 5 N., R. 3 E.

Development and production.—Several small mines developed by adits and opencuts are near the crest of the hills about half a mile south of the creek (pl. 1), and many small prospects are in the vicinity. Small shipments of lead-silver ore from the mines began in 1905 and continued until about 1920. The ore shipped before 1918 contained an average of 16.9 percent lead and 2.7 ounces of silver per ton. Ore was again produced during World War II and in 1951. The principal source has been the Carbonate Hill mine.

Geology.—Cambrian quartzite and conglomerate are overlain by quartzite and shale and then by a great thickness of steeply eastward dipping limestone. In lithology, the lower part of the limestone sequence resembles limestones of Middle Cambrian age; the upper (eastern) part contains fossils of Early Mississippian age (Butler and others, 1920, p. 218–219).

At the Morgan Argentine mine the limestone beds, locally dolomitized, strike nearly due north and dip 80° E. Irregular masses of primary lead and zinc ore are in fissures and breccia zones that strike northwest, east, and northeast. Oxidation extends at least 300 feet below the crest of the ridge. At the Morgan Argentine upper adit an east-trending fissure zone that dips 60° N. contains a central band of zinc and lead carbonate 2–3 feet wide within a vein of limonite 11 feet wide.

Ore.—The primary ore and gangue minerals consist of steel galena, pyrite, dark-brown sphalerite, platy barite, calcite, and much jasperoid. The oxidized ores, which apparently directly replaced the primary veins, consist of limonite, cerussite, hemimorphite, brown smithsonite, and possibly a little jarosite and plumbojarosite.

Oxidized zinc ore resources.—Iron-rich oxidized zinc-lead-bearing material is common in the upper workings of the mines, and undoubtedly could be produced commercially, from the district, particularly from the Morgan Argentine, if iron-rich ores were desired.

Other reference.—Weed (1920, p. 1377).

SALT LAKE COUNTY

ALTA AREA—BIG COTTONWOOD DISTRICT

Plate 1, no. 23; plate 3, nos. 14, 15, 16, 21, 28

Location.—All the upper drainage basin of Big Cottonwood Creek in Wasatch Mountains south of Salt Lake City, accessible by Utah Route 152; part of the Alta area (pl. 3).

Development and production.—District includes many large and small mines, which are described by Calkins and Butler (1943). Plate 3 shows the main workings of most of them.

The deposits were discovered in 1870 by prospectors who were encouraged by rich ore finds in the adjacent Little Cottonwood district. From 1870 to 1880 the district was very active and during the

1880's the Maxfield mine was one of the largest producers in the area. The district was again active during World War I, but only the Cardiff mine, discovered in 1910, has produced a substantial tonnage of lead, silver, copper, and zinc ores in recent years.

Several mines in the district, particularly the Carbonate and Cardiff mines, have produced between 2,000 and 5,000 tons of oxidized zinc ores, lead-zinc ores, and lead-zinc-copper ores. From 1913 through 1916, 658 tons of zinc carbonate ore were shipped from the Carbonate mine, most of it averaging 23.59 percent zinc (Calkins and Butler, 1943, p. 105). Incomplete data suggest that the district has been about the fifth largest source of zinc-rich oxidized ores in Utah.

Geology and ore.—The Big Cottonwood district is on the north edge of the Alta stock of granodiorite, and contains a sequence of sedimentary rocks ranging in age from Precambrian to Jurassic (table 2), which are very complexly thrust faulted, folded and block faulted (in that general order). The stocks of the Alta area were intruded after much of the thrust faulting and folding had taken place. Calkins and Butler (1943) describe in detail the complex geology of the district.

The commercially important sulfide minerals were deposited in the Ophir shale, in the overlying Maxfield limestone, and in the upper part of the Jefferson(?) dolomite of probable Devonian age. Replacement deposits along bedding planes have been far more productive than abundant but small fissure deposits and mineralized breccia deposits associated with thrust faults. The original sulfides have been oxidized to depths of several hundred to 1,000 feet below the surface.

At the Carbonate mine (Calkins and Butler, 1943, pl. 32) the ore bodies are mostly along several subsidiary fissures that strike N. 75° W., and dip steeply southward parallel to the Carbonate reverse fault, which is 100 feet to the south. Other mineralized fissures in the western part of the mine strike northward, and some of the largest ore bodies are at the intersections of these two fissure systems. During oxidation the zinc and some of the copper migrated outward and downward from the primary ore bodies and replaced certain beds of mottled Maxfield limestone adjacent to the fissures (Calkins and Butler, 1943, pl. 32, section *B–B′*).

East of the glory hole in the main lead ore body, the northward-striking cross fissures are weak and most of the oxidized lead and zinc ore bodies are in pod-shaped shoots or pipes that pitch 10 or 20° E. along the eastward-striking fissures. Several of these pipes, which are elongate oxidized lead ore bodies having zinc carbonate shells, occur one above the other in the fissures; they apparently join westward into one large pod, which rises gently upward into the eastern base of the glory-hole ore body.

East of the base of the glory hole, beneath the lead stopes, is a large podlike ore body of rich zinc carbonate that has filled and replaced the fissure walls to a width of 2 to 6 feet. This zinc ore body curves sharply downward to the east and grades into leaner zinc carbonate ore with depth. It is still present in the Homeward Bound tunnel below. H. G. Ryan, who operated this mine for the oxidized zinc ores, states that in the deepest part of this main zinc stope the high-grade band of ore in the center was still 2 feet wide and had a marginal shell of low-grade zinc carbonate and copper-zinc carbonate (aurichalcite) material, the latter being outermost (oral communication, 1953). The overall grade of the ore that was shipped from the bottom of this stope was 26 percent zinc. The Carbonate mine is unusual because aurichalcite has been produced as a principal ore.

Oxidized zinc ore is abundant in the upper levels of the Cardiff mine, especially in the western part near the edges of the deposit. This is mostly smithsonite that contains manganese, iron, and copper in such quantities that part of it has been difficult to fume economically using present (1952) methods.

Oxidized zinc ores were also mined in the Alta tunnel, and they occur in the Woodlawn and Maxfield mine. The geology of these mines is described by Calkins and Butler (1943, p. 102–103, 109–111, 114, 115–117, pls. 31, 35, 37). In the Alta tunnel, oxidized ores that contain zinc, lead, and silver were probably mostly in the No. 5 fissure and the Christmas stope. In the Maxfield mine the oxidized ores are mostly smithsonite, cerussite, and galena; they are located in the southeastern part, probably mostly east of the Main tunnel and near the mouth of the Upper tunnel.

Unoxidized primary ores occur below water table in all these mines except the Carbonate, where none were seen. They are most commonly silver-bearing galena, sphalerite, pyrite, tetrahedrite, and some bornite, chalcopyrite, and enargite. Sericite, dolomite, calcite, quartz, and rhodochrosite are the principal gangue minerals.

Oxidized zinc ore resources.—Several of the mines in the district contain partly developed reserves of oxidized zinc ores, some of which contain 25–35 percent zinc. The ores are not all of premium grade because some are difficult to fume by processes now in use. Few attempts have been made in recent years to find and develop oxidized ores, except in the cardiff mine, and very probably other deposits could be found without great difficulty.

Other references.—Butler and others (1920); Beeson (1925); Ledoux (1917).

ALTA AREA—LITTLE COTTONWOOD DISTRICT

Plate 3

Location.—All upper drainage basin of Little Cottonwood Canyon in the Wasatch Mountains southeast of Salt Lake City. Accessible by Utah Route 210 to Alta. The district is in the central part of Alta mineralized area that includes Big Cottonwood district to north and American Fork district to south.

Development and production.—Many large and small mines are included, the best known of which are the Emma, Columbus-Rexall, and South Hecla mines. (See Calkins and Butler, 1934, for details, and Butler and others, 1920, p. 274–275, for some of Sillman's description of the Emma.) Plate 3 shows the main workings of most of the mines; many of the older ones are inaccessible.

The district was discovered about 1864 by soldiers stationed at Camp Douglas in Salt Lake City under the command of General Conner, who encouraged them to prospect. In 1869 J. B. Woodman discovered the Emma lead-silver ore body (which also contained much unrecovered zinc) while digging a shallow prospect shaft in iron-stained limestone. The discovery and great profit from this bonanza ore body gave great impetus to mining in the district and nearby. The ore is reported (Raymond, 1872, p. 321) to have averaged 160 ounces of silver per ton and 45 to 50 percent lead and was sold in Liverpool at $175 per ton. A total of $2 million worth of ore was produced before 1873. Mining in the district was very active until nearly 1880, after which it declined until 1903, when production again began to increase slowly. Mining reached a second peak in 1917, when more than $2 million worth of ore was produced, including small shipments of oxidized zinc and zinc-lead ores. Since then production has declined, and in recent years it has nearly ceased.

Production of oxidized zinc and zinc-lead ores has been very small, mostly from the Albion, Columbus-Rexall, South Hecla, and Wasatch mines. The total ore mined probably has not exceeded more than 200 tons, but 485 tons of mostly oxidized zinc-lead ore was produced from the Michigan-Utah and Flagstaff dumps in 1949. This fact and other information indicates that a notable proportion of the oxidized silver-lead ores mined in the early days contained zinc which was either lost in smelting or culled by hand and thrown on the waste dumps.

Geology.—The geology is similar to that in the Big Cottonwood district to the north and has been described in detail by Calkins and Butler (1943). The ore bodies are in carbonate rocks of Cambrian to Mississippian age (table 2), and they are closely grouped around the northwest and west margins of the Alta granodiorite stock. They have been less productive than those at Park City to the east, apparently because at Alta the stocks and related ore bodies have been more deeply eroded.

Most of the productive deposits are tabular or chimneylike bedded replacement bodies controlled by minor fissures or by breccia zones adjacent to thrust-fault planes. In the Emma mine and the connected Flagstaff mine to the west the deposits are structurally complex (Calkins and Butler, 1943, pl. 41). The known ore bodies are a series of both tabular and chimneylike replacement deposits that pitch northeastward and eastward at about 45°. Near the surface they coalesce into a discontinuous band of ore that trends southeastward. The resulting form is somewhat palmate, with fingers pointing downward. The ore bodies follow northeast-striking fissures in the Jefferson(?) dolomite and the lower part of the Madison group, and many ore bodies are in breccia zones underlain by weak thrust-fault planes. All these features are cut by several northward-striking high-angle faults, of small displacement and postmineral age, that drop segments of the ore bodies successively downward toward the east.

Ore.—The primary ores are relatively low grade. In the Emma mine they consist of pyrite and galena in a gangue of quartz. Associated with the principal minerals are lesser amounts of sphalerite, tetrahedrite, tungstenite (tungsten sulfide), and mangano-siderite. Unoxidized ores are found at depth between 600 and 700 feet; nearer the surface, the ores have been partly or completely oxidized. Many of the sulfide bodies were too low grade to work at depth but became progressively richer upward, and near the surface, where oxidized, they are exceedingly rich, especially in lead and silver.

Benjamin Silliman (1872, p. 195–201; also *in* Raymond, 1872, p. 325), who examined the oxidized ore bodies during the bonanza days, gives the following analysis of an average sample of 183,080 pounds of rich ore:

Analysis of average sample of oxidized ore, Little Cottonwood district

[Analyst, J. P. Merrea, Swansea, 1871. In addition to constituents listed, these ores are known to contain 0.1 to 0.2 percent tungsten in the form of stolzite, and a little gold]

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

Although such oxidized ores are direct replacements of the primary ores, considerable migration and local reconcentration of the elements has taken place during oxidation, and parts of the ore body are reliably reported to contain more than 30 percent zinc. The ore minerals are smithsonite and hemimorphite. Available information suggests that the zinc-rich masses are marginal casings in the ore bodies but that they are separated from the limestone wallrocks by earthy casings of iron and manganese oxides. Silliman (1872) describes also a concentric-banded zoning in the zinc-rich central parts of the ore bodies of boulderlike masses within the partly oxidized lead-zinc-silver ores. The banded masses, which have broken from the solid mass, have dark centers composed either of partly oxidized galena, sphalerite, pyrite, jamesonite(?), argentite, and stephanite, or of cerussite pseudomorphous after galena, darkened by argentite and metallic silver in a pulverulent form. Surrounding the dark center is commonly a band of yellowish and orange-yellow antimonical ochers—probably bindheimite and cervantite—in places as stains on cerussite, and elsewhere as earthy masses. Next is a narrow band of green and blue copper salts such as linarite, azurite, malachite, and cupreous anglesite, and a little "wulfenite" (or more probably stolzite); surrounding it is a band of cerussite stained with antimony-ocher and coated locally with yellow stolzite crystals, which are in turn coated with apple-green hemimorphite. The outermost band consists of iron and manganese ochers, including possibly jarosite and plumbojarosite. Small quantities of smithsonite, hydrozincite, and aurichalcite are associated with the bands containing stolzite.

Similar zinc-rich silver-lead ores, that contain much zinc carbonate and hemimorphite in the Flagstaff mine, and a black silver-bearing cerussite-hemimorphite ore is abundant in parts of the Columbus-Rexall mine. Elsewhere in the district, such as at the Grizzly, Michigan-Utah, West Toledo and South Hecla mines, the ore is commonly relatively pure calamine and smithsonite, which in part may be from wallrock replacement deposits.

Oxidized zinc ore resources.—Oxidized zinc ores are common in the Little Cottonwood district, although little ore of this type has had the zinc recovered from it. Much of the ore is rich in lead and silver and contains recoverable copper and, north of Alta, tungsten in the form of stolzite. Most of this ore was long ago mined and shipped to the smelters for its lead and silver content, and most of the old stopes are reported to be thoroughly cleaned; however, many dumps contain some ore of this type. Zinc-bearing ores undoubtedly remain as casings in some mines, for a search for wallrock pockets of secondary zinc ores has apparently never been made in the district, even though the limestone wallrocks and many fissures make such pockets probable. The oxidized zinc ore reserves are probably not large but are likely to be high grade, and some of the ore still on the dumps contains desirable byproduct lead and silver.

Other references.—Beeson (1925); Boutwell (*in* Boutwell and others, 1933).

SUMMIT COUNTY

BEAVER CREEK LEAD-ZINC MINE

Plate 1, no. 29

Location.—On north side of Beaver Creek in T. 2 S., R. 7 E., about 5 or 6 miles east-southeast of Kamas, in western foothills of the Uinta Mountains.

Available information.—This is a small zinc-lead prospect in limestone of Cambrian age; it has produced a small amount of low-silver ore from an adit and nearby workings. Locally the ore is oxidized, and oxidized zinc minerals are reported to be present.

PARK CITY OR UINTAH DISTRICT

Plate 5; plate 1, no. 37

Location.—Vicinity of Park City, on east side of Wasatch Range (pls. 1, 5).

Development and production.—The district has many large mines, as shown on plate 5, and includes the New Park mines to the east. Most operations were consolidated in recent years into two companies, Park Utah Consolidated Mining Co., and New Park Mining Co. (See Boutwell, 1912, and Boutwell and others, 1933, p. 69–81 for developments.) In 1933 about 60 square miles of ground was opened to a maximum depth of 5,000 feet and levels aggregated about 250 miles in length.

The first claim, the Walker and Webster, was located in 1869, and in 1870 the first shipment of ore was made from this district. Discovery of the famous Ontario silver-lead ledge in 1872 stimulated the development of lode ores. Prospecting of lodes to the west on Crescent Ridge led to the discovery of replacement deposits of rich silver-lead ores in limestones of Treasure Hill, where the Silver King mine was opened in 1892 (Boutwell and others, 1933, p. 70–72). Output from both types of ore bodies increased so greatly that Park City was for 50 years one of the major sources of base and precious metals in the United States. The value of the total output of the district until 1933 was about $300 million. Oxidized zinc-bearing ores, although present in at least the western part of the district, have not been shipped for their zinc content.

Geology.—The mineral deposits lie on the north side of a quartz diorite porphyry stock along a westward extension of the Uinta uplift. Intersection of this uplift with the Wasatch axis farther to the west is marked by the stocks of the Alta area. The Park City stock intrudes about 10,000 feet of siliceous and calcareous strata of from Mississippian to Jurassic age which are extensively folded, fractured, and mineralized. The fractures and fissures commonly trend eastward parallel to the Unita structural axis, but east of Park City, overriding wedges of sedimentary rocks are displaced eastward along westward-dipping thrust faults that trend northward parallel to the Wasatch axis. Hydrothermal solutions, presumably from the quartz diorite porphyry, deposited the ores in the fissures and replacement bodies along certain more favorable calcareous beds of the Park City (Permian) and Thaynes (Triassic) formations. Oxidation has extended to an average depth of 650 feet but locally to 1,700 feet.

Ore.—The primary minerals are silver-bearing galena and tetrahedrite, and also sphalerite, bournonite, jamesonite, pyrite, quartz, calcite, barite, and fluorite. Some of these minerals have been oxidized to cerussite, anglesite, pyromorphite, cerargyrite, mimetite, massicot, bindheimite, electrum, limonite, azurite, malachite, chrysocolla, chalcanthite, chalcocite, olivenite(?), hemimorphite, smithsonite, hydrozincite, aurichalcite, and pyrolusite.

Supergene zinc deposits are abundant in and near the oxidized parts of some of the deposits in the western part of the district, notably at the New Quincy, Daly No. 1, Little Bell, and possibly the upper parts of the Silver King mine. Three types of supergene zinc deposits are common: (a) direct replacement ores composed of cerussite, cerargyrite, and hemimorphite; (b) casings or crusts enclosing the oxidized lead-silver bodies, consisting of cellular gray and reddish smithsonite and hemimorphite; and (c) replacement pockets in the limestone wallrock composed of white hydrozincite, gray to green nodular or reinform smithsonite, and a little aurichalcite. Most of these ores are notably lean in iron (1–5 percent) and rich in silver (7–13 ounces per ton).

Assays of two hand samples of oxidized zinc-bearing specimens selected from dumps are as follows:

Analyses of two hand samples from the Park City or Uintah district

[Analyst, Deason and Nichols, Salt Lake City, 1955]

Constituent	Daly No. 1 mine	Quincy mine
Gold ounces	0. 08	0. 02
Silver do	13. 30	7. 40
Lead percent	7. 3	13. 4
Zinc do	15. 4	37. 8
Silica do	58. 2	36. 1
Iron do	4. 6	1. 3
Carbonate do	7. 5	13. 8
Manganese do	2. 62	. 95

Oxidized zinc ore resources.—Commercial quantities of oxidized zinc ores exist, at least in the western part of the district. These ores have not been recognized heretofore, probably because of their dirty-gray, black, and brown appearance, which makes them very difficult to identify. The dumps of two mines are estimated to contain as much as 5 percent zinc in oxidized material and include an equal quantity of lead, several ounces of silver per ton, and a little copper. Thousands of tons of oxidized zinc ores could be culled from dump material, and a few dumps in the district are rich enough in several metals to be shipped as low-grade lead-zinc-silver ores for fuming without sorting when the market for such ores is favorable.

The abundance of oxidized zinc minerals in the old dumps suggests that reexaminations of the walls and floors of old oxidized stopes would yield appreciable tonnages of rich zinc-bearing ores similar to those found in quantity at Leadville, Colo., about 1910. However, the thinness of the limestone units and the abundance of quartzite at Park City would probably exclude the possibility here of very large ore bodies such as exist at Leadville.

Other references.—Butler and others (1920, p. 285–317); Van Horn (1914).

DAGGET AND UINTAH COUNTIES

CARBONATE DISTRICT

Plate 1, nos. 38–42

Location.—Upper south slopes and crest of Uinta Mountains, 25 to 30 miles north of Vernal, Utah, west of Utah Route 44.

Development and production.—Shallow shafts, adits, and prospect pits are in at least 5 localities, as shown on plate 1. Several of these prospects are described by Kinney (1955, p. 161).

Copper was found at the Dyer mine about 1887, and more than 4,000 short tons of rich copper-silver-gold ore was produced from 1891 to 1904. Lead and zinc were found nearby, but the only known production was a few tons of lead ore from the Kate lode on Grizzly Mountain in 1917 (U.S. Geol. Survey, 1917, p. 201).

Geology.—The oxidized lead and zinc minerals are in small residual deposits in the soil, or in bedded replacement lenses in limestones of Mississippian age. At the Basset prospect on Little Brush Mountain, small quantities of oxidized lead and zinc minerals replace limestone beds mostly on the south side of an open perpendicular fissure zone filled with soil and rock breccia. Kinney (1955) describes the geology of the general area.

Ore and resources.—No commercial quantities of zinc minerals were seen, but smithsonite and hydrozincite are locally present. Oxidation extends downward only a few tens of feet in places although at the Dyer mine it was at least 100 feet deep. Prospecting in the general area might reveal small deposits of oxidized zinc ore in commercial quantities as at the Mantle mine to the east in Colorado.

Other reference.—Butler and others (1920, p. 599–606).

TOOELE COUNTY

BLUE BELL DISTRICT

Plate 1, no. 43

Location.—East side of Sheeprock Mountains, near south boundary of county, accessible by 10-mile road, west and then south from Lofgreen, Utah. District was not visited.

Development and production.—Only a few small mines are reported, including the Morgan, Black Hawk, and Blue Bell. Butler and others (1920, p. 430–432) describe the first two.

Production began in 1891 although the district was not organized until 1896. Most of the ore produced has been from the Morgan and Black Hawk mines and contains silver, lead, and a little gold. In 1922 the Blue Bell mine produced 15 tons of oxidized zinc ore.

Other reference.—U. S. Geological Survey (1922, pt. 1).

DUGWAY DISTRICT

Plate 1, nos. 45, 67

Location.—Northern part of Dugway Mountains, south of Granite Peak, about 50 miles west of Vernon. North of old Calleo emigrant and pony express road. Access roads and some mines are shown on Dugway Range quadrangle. Can be more easily reached from Dugway Proving Ground, if permission to use proving-ground access roads can be obtained. District was not visited.

Development and production.—The largest of several small mines and many prospects in the district is the Four Metals mine, which was 400 feet deep in 1920 (Butler and others, 1920, p. 463). The Four Metals and Smelter Canyon mines have been the main operations for base metals in recent years, but the Francis and Raymond have also produced. The district was discovered in 1869 and organized in 1872. Small shipments of rich silver ore were made at intervals until 1903, and again during World War I. In 1945, 1946, 1950, and 1951, 2,276 tons of zinc-lead and zinc ore containing some silver and a little gold were shipped directly to the smelters from the Four Metals and Smelter Canyon mines (U.S. Bureau of Mines, 1945, 1946, 1951). The ores probably include oxide ore, mixed sulfide and oxide ore, and sulfide ore.

Geology.—The oxidized deposits are in the upper parts of replacement veins in limestones and of fissure veins in quartzites. Both rocks are possibly of Mississippian or Pennsylvanian age; they have been silicified, and bleached along fractures. The southern border of the Granite Mountain intrusives lies north of the district. Dikes of altered quartz monzonite(?) cut the sedimentary rocks. Oxidation is relatively shallow, extending to depths of about 100 feet, below which sulfides remain. The geology of the Dugway Granite Range is described in some detail by Butler and others (1920, p. 458–460).

Ore and oxidized zinc ore resources.—The primary ores are silver-bearing lead and zinc sulfides; copper is present in places. The oxidized zinc and lead-zinc minerals are in large slabby masses (Willard Cleghorn, American Fork, Utah, oral communication, 1954), and are reported to be abundant at several little-worked claims in the district. A sample from an unworked oxidized vein outcrop near the Four Metals mine is reported to have contained 14.3 percent lead and 7.7 percent zinc. Most of the known ore deposits are apparently small.

FREE COINAGE OR TIMPIE CANYON DISTRICT

Plate 1, no. 46

Location.—Small and little-known district at northeast of Stansbury Range about 7 miles west-northwest of Grantsville. District was not visited.

Development and production.—Apparently there are only a few small mines and prospects in the district. About 40 tons of oxidized zinc ore containing between 24 and 42 percent zinc was shipped from the Climax claim. Operators of the Last Chance claim shipped a carload of oxidized lead ore in 1917; 15 tons of possibly oxidized zinc-lead ore containing some silver was produced from the district in 1948.

Geology and ores.—The deposits, in limestone probably of Carboniferous age, contain both zinc and mixed zinc-lead ores; the latter are reported to contain more than 15 percent zinc and 15 percent lead. They are oxidized and probably not rich in silver.

Oxidized ore resources.—Oxidized lead-zinc ores are reported to be still present in mineable quantities.

ERICKSON DISTRICT

Plate 1, nos. 49, 52, 55

Location.—Southwest end of Simpson Mountains, just north of Juab County line in Tooele County about 30 miles due west of Mammoth, Utah. Reached by improved gravel roads west from Vernon or Faust to Indian Springs then southwestward on unimproved roads around west side of Simpson Mountains.

Development and production.—Many scattered lead, zinc, copper, and manganese prospects and several small mines are in the district, notably the Ida or Blaine, Happy Jack, Bar X, Last Hope and Highland Lassie, Silver Reef, Indian Chief, and Utonia mines (Butler and others, 1920, p. 453–456). The district produced some lead carbonate and silver ore in the 1880's and again from 1912 to the end of World War I. In 1945, and from 1949 to 1952, the district produced 3,193 tons of lead-zinc ore, some of which was oxidized. The ore contained a little gold, silver, and copper. The principal producers were the Ida-Desert View, Esther-Bar X, and Tintic Delaware (U.S. Bur. of Mines, 1945, 1949–52).

Geology.—The rocks in the south-central part of the Erickson district are reported (Butler and others, 1920, p. 446–448) to be mostly alternating chloritic quartzite, greenish shale, and conglomerate. In the northern part of the district, these rocks are interbedded with some cherty dolomitic limestone reported to be of Middle Cambrian age. The igneous rocks include a few dikes or sills of granodiorite porphyry and monzonite porphyry and remnants of equivalent extrusive rocks. Many of the fissures and faults have low dips and many strike parallel to bedding. The low-dipping fissures fall into two groups, one striking north to N. 15° W. and the other N. 65°–85° W. Other steeply dipping fractures strike northeastward. Butler and others (1920, figs. 45–51) show details of the fissure systems.

Ore.—The primary ores of lead, zinc, and copper sulfides are mostly in bedded veins and fissure veins or in lenses marginal to fissures. Calcite and quartz are abundant gangue minerals. Oxidation extends in places to depths of about 100 feet, below which the ores are mostly sulfides. Most of the oxidized lead-zinc ores are mixed cerussite, smithsonite, and hemimorphite, and they contain a little silver and copper. Those shipped from the Ida mine are reported to have contained 9 to 19 percent zinc and 7 percent iron.

Oxidized zinc ore resources.—The district has produced an appreciable quantity of oxidized lead-zinc ores and is reported to contain more. Such deposits, however, are most probably of the mixed lead and zinc type, which extend only to the water table at shallow depths before changing to sulfides. The small fissure veins typical of the district probably do not contain large oxidized deposits.

COLUMBIA DISTRICT

Plate 1, no. 59

Location.—Northeast slope of Sheeprock Mountains, 9 miles southwest of Vernon, Utah. District was not visited.

Development and production.—The district was organized in 1871, which was early in the mining history of the region, like many other old districts near the old emigrant-pony express road. According to Huntley (1885, p. 455), there was activity here in 1871 and 1872 and again in 1875. Many small mines and prospects for copper, silver, lead, and zinc are in the higher parts of the mountains, but only one somewhat larger mine, the Old Sharp mine, has been developed. In 1920 it had 1,250 feet of tunnel workings and a considerable volume of stopes. Water was reached at shallow depths in many of the mines and has retarded development.

From 1880 to 1918 most of the production was from the Old Sharp mine. In 1916 and 1917 this mine produced 122 tons of oxidized lead-zinc ore containing a little silver. In more recent years, several small shipments have been made.

Geology.—The formations include chloritic quartzite, shale, and conglomerate of possible Precambrian age, which may correlate with the Big Cottonwood formation, overlain by limestones of Middle Cambrian age. The sedimentary rocks overlie the largest intrusive granite stock in the Sheeprock Mountains. They strike northwest to west and dip northeast to south at 45° near the stock and more gently away from it. A few dikes of rhyolite and quartz monzonite have been noted (Butler and others, 1920, p. 426).

Ore.—Most of the deposits are veins in granite or quartzite. They include quartz veins containing pyrate, sphalerite, and galena, which are oxidized at shallow depths to lead, zinc, and iron oxides. The ores are lean in silver.

Oxidized zinc ore resources.—The district is reported to contain some reserves of oxidized zinc-lead ores although the past production has been small. The lack of limestones near the known deposits and the shallow depths to the water table suggest that such ore deposits are not very large.

References.—Butler and others (1920, p. 423–429); Huntley (1885, p. 455).

LAKESIDE DISTRICT

Plate 1, nos. 54, 60; plate 6

Location.—Most of district is on east slope of Lakeside Mountains west of Great Salt Lake; few mines and prospects are on west slope of range. Mines on east slope reached by fair to very poor desert roads from Timpie, or Delle, Utah. Lakeside Monarch mine is near head of canyon, 3 miles west of old ranch and well that are 18 miles by road north of Delle.

Development and production.—The principal workings are those of the Lakeside Monarch Mining Co., including from north to south the McBride tunnel, Waters tunnel, Plentiful No. 2 mine, and Prospect incline, as shown on plate 6. Other small mines and prospects in the vicinity include the Georgia Lyn to the south. The McBride tunnel is reported to extend 1,200 feet southward and to have a raise to the surface which is continuous with a 200-foot winze on the No. 1 ore shoot according to J. Parker, former Lakeside Monarch Mining Co. secretary (oral communication, 1955). The Waters tunnel is at a little higher altitude than the McBride and extends northward over it to work the No. 2 ore shoot, which lies south of the No. 1 shoot. Large stopes in these shoots are now caved. The Prospect incline extends southeastward on a 20° slope for 225 feet and has very small stopes on the northeast side.

The district was organized in 1871 and was the scene of some mining activity from 1871 to 1874 and later. Several claims, probably those of the Lakeside Monarch mine, are said to have produced a large quantity of lead ore containing silver but production was not profitable. The silver content of some of the highest grade ores was only 10 ounces per ton (Weed, 1920, p. 1398), and some ore contained only 1 ounce of silver per ton (U.S. Geological Survey, 1917, p. 200). About 30,000 tons of ore of all grades has been produced (U.S. Bureau of Mines, 1947–48).

The Georgia Lyn produced 11,400 pounds of zinc in 1942, probably from oxidized zinc ore (U.S. Bureau of Mines, 1942). In 1947–48, the Lakeside Monarch Mining Co. shipped 193 tons of oxidized lead and zinc-lead ores that contained 137 ounces of silver, 200 pounds of copper, 29,300 pounds of lead, and 7,400 pounds of zinc (U.S. Bureau of Mines, 1947–48). A mill built during 1940–50 to process the low-grade oxidized lead ore probably was not successful.

Geology.—The known geology of the district is shown on plate 6. The country rock, limestone and some quartzite and shale, is probably of Cambrian and Ordovician age. The main ore bodies are lenticular shoots as much as 40 feet thick, which occur mainly in the footwalls of the Monarch and other fissures but also in veins along the faults; some small bedded replacement ore bodies are in limestones and secondary dolomites adjacent to the faults. Most of the ore is brecciated. The limestone wallrocks have been altered near the ore bodies to dolomites, which in turn were "sanded" by removal of the cementing material around the dolomite grains and then silicified for the most part to a brown jasperoid.

The geology of the southern part of the Lakeside Mountains has been described by Young (1956), but his study does not extend northward into the mining district.

Ore.—All the ore is oxidized except for small remnant masses of lead sulfide. The main minerals are cerussite, hemimorphite, smithsonite, limonite, and jasperoid in blackish, brown, and reddish masses stained by manganese oxides, and some calcite and acicular aragonite. Much of the ore is lean in silver and too low grade for direct shipping to the smelters, and some is rich in iron oxide.

Apparently the ores directly replaced the original sulfide deposits (as shown by the eyes of galena in many places) without notable migration of the metals during oxidation. Assays of hand samples, selected to show the different types of ore, are as follows:

Analyses of hand samples of ores from the Lakeside district

[Analyst, Deason and Nichols, Salt Lake City, 1955]

Constituent	McBride tunnel		Prospect Incline (oxidized zinc)
	(oxidized siliceous zinc-lead)	(oxidized iron-rich lead)	
Gold..........oz per ton..	0. 02	0. 02	0. 015
Silver..........do....	. 80	1. 40	1. 20
Lead..........percent..	5. 1	18. 9	5. 5
Zinc..........do....	17. 2	5. 9	32. 9
Silica..........do....	34. 2	13. 0	21. 6
Iron..........do....	15. 6	38. 5	3. 2
Carbonate..........do....	23. 9	14. 5	25. 2

Oxidized zinc ore resources.—In 1920 the owners reported that they had 100,000 tons of lead-silver "ore" blocked out (Weed, 1920, p. 1398). Undoubtedly large tonnages of lead- and zinc-bearing material remain in the large caved stopes, but its recovery would be difficult and its reported leanness in silver would probably prevent profitable mining under present conditions. If further exploration should develop larger bodies of the oxidized zinc ores in the Prospect incline, they would be desirable for fuming. Some ore can be sorted from parts of the dumps.

Other reference.—Butler and others (1920, p. 488).

GOLD HILL DISTRICT

Plate 1, nos. 48, 56, 57, 66

Location.—South and north of Gold Hill, Utah, about 43 miles south of Wendover. See Nolan (1935) for details.

Development and production.—Many small and large mines and hundreds of prospects are in the district. The principal mines include the Western Utah (or Gold Hill), U. S., Cane Springs, Garrison Monster, Monoco, Midas, and Alvarado mines. The first mineral discovery is said to have been made in 1858, but the hostility of the Indians retarded development until 1869, when mining operations began and the district was organized. Two furnaces were built and operated during the 1870's. The Cane Springs, Alvarado, Midas, and Gold Hill mines were operated again during the 1890's, when about 19,000 tons of gold ore was produced and milled. From 1916 until 1926 the district was active, the Western Utah and U. S. mines leading in the production of gold, copper, and lead. Some zinc ore, probably sulfide, was produced in 1926–27, and in recent years the district has produced considerable tungsten. Oxidized zinc ore probably has not been produced.

Geology and ore.—The geology of the district, shown on plate 1, has been described by Nolan (1935). The principal mines in which oxidized zinc minerals occur are the Western Utah, Garrison Monster, Success, New Baltimore, Monoco, and U. S. mines. The oxidized zinc minerals occur in two of the largest types of deposits in the district, namely, the arsenic replacement bodies and the copper-lead-silver replacement bodies, both of which contain some sphalerite in the primary ores. Some bodies of the second type are shoots and veins within the large bodies of the first type, as at the Western Utah and U. S. mines, but others are independent ore bodies, as at the Garrison Monster mine.

The zinc-bearing ore bodies are oxidized in places to depths of 100 to over 750 feet and contain the following oxidized zinc minerals, including several unusual ones, in sparse to fair abundance: hemimorphite and smithsonite at the Garrison Monster, the arsenates of zinc—adamite and austinite—at the Western Utah and U. S. mines, and the lead-zinc vanadate—descloizite—at the New Baltimore and other mines.

Crystal-lined veins and vugs of austinite and adamite are common, associated with scorodite and limonite in the deeply oxidized parts of the large ore shoots of the Western Utah mine. In addition to these minerals, arseniosiderite, jarosite, pharmacosiderite, beudantite, clinoclasite, olivenite, and plumbojarosite are present in places in the ore body. The dominant color of the scorodite ore is rust brown to olive green at the surface and gray green at greater depths. It occurs in coarse open vugs and boxworks with drusy masses and milky-white crystals of quartz. Fractures in the intricate mesh of coarse boxworks derived from arsenopyrite have fragile siliceous limonite and scorodite partitions. The fractures are encrusted with calcite, aragonite, grass-green conichalcite, chrysocolla, and more locally with white to pale-yellow-green crystallized and radiating mammillary crusts of adamite and austinite in brilliantly lustrous and limpid orthorhombic crystals of acicular habit. The immediate walls of the ore body are coarse-grained brown or black manganocalcite. Fine-grained siderite that resembles smithsonite occurs in places at deeper levels, as described by Nolan (1935, p. 107, 112).

Oxidized ore resources.—Only small tonnages of oxidized zinc arsenate minerals are known in the district, at the Western Utah mine. A hand sample of limonite, austinite, calcite, and scorodite assayed as follows:

667528 O—63——5

Analysis of a sample from the Western Utah mine

[Analyst, Deason and Nichols, Salt Lake City, 1956]

Constituent	*Percent*	*Constituent*	*Percent*
Gold	None	Silica	4.6
Silver	Trace	Iron	38.8
Lead	0.30	Carbonate	14.3
Copper	0.10	Arsenic	4.38
Zinc	9.4		

This sample is among the richest found in the workings, and shows that even the best material is much too lean in zinc to be a potential ore. Similarly, lean hemimorphite- and smithsonite-bearing material is reported at the Garrison Monster mine.

Other references.—Butler and others (1920, p. 469–484); Kemp and Billingsley (1918).

RUSH VALLEY DISTRICT

Plate 1, nos. 47, 51

Location.—East and northeast of Bauer, and Stockton, Utah. See Gilluly (1932) for exact location of mines.

Development and production.—The district has several large mines and many small ones, some of which have been consolidated by Combined Metals Reduction Co. into a single large operation called the Honorine or Bauer mine, which in recent years has been one of the major lead-zinc-silver mines in Utah. Access to the mines is by a drainage and haulage tunnel several thousand feet long, whose mouth is at Bauer.

The deposits were discovered in April 1864 by soldiers from California who were stationed at Camp Floyd a short distance south of the present town of Stockton. The mining district was developed and several small furnaces were erected to smelt the lead-silver ores. By 1900 the district had produced several million dollars worth of ore, and from 1901 through 1917 an additional $4,561,047 worth was produced. Oxidized zinc and lead-zinc ores, however, have never been important in the district, although more than 1,000 tons of such ore was produced, mostly from the Honorine, Calumet, and Galena King mine dumps, during 1914–21. In addition, some oxidized lead-zinc ores were probably produced from these mines in 1945.

Geology and ore.—The general geology of the district is shown on plate 1, and the detailed geology of the district and its principal mines are described by Gilluly (1932). The ore occurs mainly as pipelike or tabular replacement bodies at the intersections of fissures with limestone beds. The hypogene sulfides are pyrite, galena, sphalerite, and a little chalcopyrite, tetrahedrite, and arsenopyrite. Minerals of the supergene ores are cerussite, plumbojarosite, jarosite, smithsonite, aurichalcite, pyromorphite, malachite, and limonite.

Oxidation of the ores is complete to about 800 feet in depth, but partial oxidation extends as deep as 1,000 feet.

Oxidized zinc ores are reported to occur as casings that replaced the limestone wallrocks surrounding the ore bodies, as previously described in this report (p. 17–18). Oxidized ores produced in 1914 averaged 29.03 percent zinc (U.S. Geol. Survey, 1914). The lead-silver ores contain from 3 to 6 percent zinc as shipped.

Oxidized zinc ore resources.—Small tonnages of oxidized zinc and lead-zinc ore of commercial grade undoubtedly remain in the old caved stopes of the district; some of these ores, however, may be too rich in iron to be desirable for refining under present fuming processes. In addition, material that contains some zinc, lead, and silver probably remains in places on the dumps.

Other references.—Butler and others (1920, p. 362–374); U.S. Geological Survey (1912–23); U.S. Bureau of Mines (1924–31; 1932–53).

DRY CANYON AND OPHIR DISTRICTS

Plate 1, nos. 50, 53, 61, 64

Location.—Near, but mostly north of Ophir, Utah, on west side of Oquirrh Mountains. Dry Canyon district is north part and Ophir district south part of same group of ore deposits. Mine workings connect the two districts. Dry Canyon part is reached by gravel road from Stockton.

Development and production.—Several large mines and many small ones, including the Ophir Hill and Hidden Treasure mines, are owned and operated in part under lease by the U.S. Smelting, Refining and Mining Co. McFarlan and Hullinger operated the Hidden Treasure mine under lease in recent years until August 1953.

The ores were first located by soldiers of General Conner's command in 1865 at the outcrop of the Hidden Treasure mine on the St. Louis claim. Little was done until 1870 when, activity having been stimulated by discoveries at the Little Cottonwood district, the districts were organized and several small mills and smelters were built. Mining was very active during the 1870's and again during the early part of the 20th century. Production of oxidized zinc and lead-zinc ores began in 1911 from the Hidden Treasure mine and continued from that mine and others in the district through 1923, except for 1921 and 1922. A few small shipments have been made since then. A reported total of more than 6,500 tons of oxidized ores has been produced, principally from the Hidden Treasure, Queen of the Hills, Ophir Hill, and Cliff mines, making the two districts together one of the largest sources of zinc-bearing oxidized ores in the State.

Geology and ore.—The general geology of these districts is shown on plate 1, and is described by Gilluly (1932). Copper-bearing lead-silver and zinc ores are oxidized to depths of several hundred feet in the Dry Canyon district but to shallower depths in the Ophir district. Casings of oxidized zinc ore around pipes and mantos of sulfide ore in these districts have been described in detail by Loughlin (1917, p. 1–14), whose findings are summarized on pages 17, 21 and 22 of this report.

Oxidized zinc ore resources.—Large quantities of low-grade oxidized zinc- and copper-bearing material might be recovered by reworking some of the older dumps. Some of the old lead carbonate stopes are reported to have unmined rich oxidized zinc ore casings (Dunham and Gunnell, 1948, p. 8), a few in large quantities. Similar zinc ore shipped in the past averaged 40 percent zinc.

Other references.—Wideman (1947); Butler and others (1920, p. 366–381); U.S. Geological Survey (1911–23); and U.S. Bureau of Mines (1923–31; 1932–53).

LION HILL DISTRICT

Plate 1, no. 44

Location.—On Lion and Silveropolis Hills, 1 mile south of Ophir. Reached by trails or poor roads from Mercur, Ophir, and West Dip. District was not visited.

Development and production.—The district contains several small but rich silver mines. Some of the more important producers are the Chloride Point, Silveropolis, Lion, Monarch group, and Zella group mines. The mines on Lion Hill were discovered about 1870, and yielded silver-lead ore during the next decade. Since that time lessees have worked the mines on a small scale and even this has apparently ceased in recent years.

Geology and ore.—The completely oxidized silver-lead deposits are bedded replacements, mostly within the Great Blue formation of Mississippian age. Gilluly (1932) describes the geology in detail. The silver-lead ore is rich in cerargyrite and plumbojarosite. Small quantities of aurichalcite and other zinc-bearing minerals have been reported.

Oxidized zinc ore resources.—Oxidized zinc minerals are not known to occur in commercial quantities in the district, but available reports suggest that no search has been made for them.

Other references.—Butler and others (1920, p. 366–369, 381–382); Huntley (1885, p. 477).

MERCUR OR CAMP FLOYD DISTRICT

Plate 1, no. 62

Oxidized zinc minerals have been reported at the Sacramento mine (Gilluly, 1932); Butler and others (1920) in this gold district at Mercur on the west slope of the Oquirrh Mountains, but field examinations show that they do not occur in more than hand-sample quantities.

NORTH TINTIC DISTRICT

Plate 1, nos. 58, 63, 65

Location.—Westernmost range of East Tintic Mountains, northwest of Eureka, Utah. Scranton group of mines is in E½ sec. 8, T. 9 S., R. 3 W., in Scranton or Barlow Canyon, northeast of Lofgreen, Utah. New Bullion mine is 8 miles east of Lofgreen on south slope of Miners or Bullion Canyon. Accessible by poor roads from Utah Route 36 near low pass between Rush and Tintic Valleys.

Development and production.—The workings of the Scranton group of mines are shown on plate 7. The mines from north to south, in the general order of size of workings and production, are: Del Monte, Magazine tunnel, South Essex No. 1, and South Essex No. 2. Small mines and prospects are located north of this group, between this group and the New Bullion mine 3 miles to the south including the Tintic Zinc Co. prospects, and also in the eastern part of the mountains. The New Bullion mine consists of a glory hole on a hill and a southward-extending adit 370 feet long, from which there is a 200-foot winze beneath the glory hole.

The North Tintic district is the largest producer of oxidized zinc ores in Utah, exceeding the combined production from the Tintic and East Tintic districts by about 10,000 short tons of ore and concentrates. The district was first called the Oasis district; from 1875 to 1878 it was called the Caledonia district, and in 1879 it became the North Tintic district. Some ore was produced before 1902, including $35,000 worth of lead and silver in about 1897 from the New Bullion, but details of production prior to 1902 are not accurately known. The production of ore from the district during 1902–17 including the zinc from oxidized zinc and lead-zinc ores is given by Butler and others (1920, p. 416).

Oxidized zinc ores were first produced in Utah from the Scranton mines in 1906. Beginning in that year and to 1954, a total of 41,253 short tons of mainly hand-sorted oxidized zinc and lead-zinc ores is reported to have been produced from the district (table 5). Most of this ore was from the Scranton group of mines; the rest was from the New Bullion mine and a few smaller producers such as the Tintic-Humboldt property. The New Bullion mine has produced between 500 to 1,000 tons of oxidized zinc and zinc-lead ores which contained more than 15 tons of recoverable lead, 170 tons of recoverable zinc, and a little gold and silver. In addition, large quantities of oxidized lead, lead-silver, and siliceous silver ore have been produced.

TABLE 6.—*Oxidized zinc, lead-zinc, and zinc-lead ore produced in the North Tintic district* [1]

[Compiled from Butler and others (1920); Lindgren and Loughlin (1919); U.S. Geol. Survey 1906–23; U.S Bur. Mines (1920–26; 1927–53)]

Year	Class of oxidized ore	Ore (short tons)	Gold (troy ounces per ton)	Silver (troy ounces per ton)	Metallic copper (pounds)	Metallic lead (pounds)	Metallic zinc (pounds)	Value of zinc produced
1906	Zinc	1,615					2,176,200	$132,748
1907	do	7,999					4,154,988	245,144
1908		None						
1909	Zinc	3,264					1,817,542	98,147
1910	Lead-zinc	2,069				413,800	827,200	153,524
	Zinc	4,017					2,015,832	
1911	Lead-zinc	6,918				1,472,060	3,574,414	234,750
	Zinc	835					544,000	
1912	Lead-zinc	1,402		613		201,433	754,420	59,355
	Zinc	148					105,802	
1913	Lead-zinc	152		33		26,851	332,770	23,348
	Zinc	547					74,230	
1914	do	36					19,730	1,006
1915		None						
1916	Zinc	3,402					1,730,645	231,906
1917	do	1,143				8,112	654,601	66,769
1918	do	746					455,925	25,488
1919	do	697					327,657	23,119
1920	do	1,787					729,912	59,138
1921–22		None						
1923	Zinc	38					19,031	(2)
1924		None						
1925	Lead-zinc [3]	106				11,500	31,903	2,455
1926	do	24				2,389	8,399	(2)
1927 1936		None						
1937	Zinc	173				2,500	84,000	4,200
1938	do	83					40,979	(2)
1939–40		None						
1941	Zinc [4,5]	300±		(2)		(2)	(2)	(2)
1942	Zinc [5] and lead ores undifferentiated	109		59		12,600	8,700	(2)
1943	Zinc-lead [6]	35	1	62		3,600	5,500	(2)
1944	Zinc [5]	30		(2)		1,200	5,500	(2)
1945	do [5]	45		45		1,500	9,200	(2)
1946	do [5]	2,900	10	1,464	2,500	210,000	366,000	(2)
1947	do [5]	633	1	390	400	40,000	86,000	(2)
1948–53		None						
Total		41,253	12	[7] 2,666	2,900	[7] 1,407,545	[7] 20,961,080	1,354,442
Total copper, lead, and zinc produced (short tons)					1	707	1,481	

[1] Does not include the quantity of ore and the lead, copper, silver, and gold from other classes of ore produced, such as siliceous silver and oxidized lead ores. These data can be obtained for 1902–17 in Butler and others (1920, p. 416). All data in terms of recoverable metals.
[2] Data not available.
[3] Production from the New Bullion mine alone. In 1925 the average grade of the ore was 6.26 percent lead and 16.22 percent zinc; valued at $35.68 per short ton.
[4] Estimated, from available data in Minerals Yearbook.
[5] Scranton group of mines only.
[6] New Bullion group of mines only. Same class of ore given as "lead-zinc," but zinc is now listed before lead.
[7] Available data only.

Geology and ore.—The geology is well summarized by Butler and others (1920, p. 417) as follows:

Ore deposits in the western range have been successfully worked at two places, the Scranton mines in Barlow Canyon, about 9 miles northwest of Eureka, and the New Bullion (Bal Hinch) mine in Miners Canyon, about 3 miles farther south. The ore bodies of the Scranton are in coarse-grained limestone of probable upper Mississippian age, identical in character with that of the Colorado Channel or north half of the Iron Blossom zone in the Tintic district. Those of the New Bullion are at a somewhat lower horizon, probably near the boundary between the Pine Canyon limestone and the underlying Gardner dolomite, but the stratigraphy in this vicinity has not been determined with certainty.

These ore bodies, which have yielded oxidized lead, lead-zinc, and zinc ores, are all formed along the intersection of single fissures or branching and crossing fissures with specially replaceable limestone beds. Most of them vary from small bunches to bedded replacement or blanket bodies of considerable extent. Those of the Scranton mines lie in a nearly north-south zone, strongly indicating that the mineralizing solutions migrated along a pronounced fissure zone and spread more or less where intersecting fissures or permeable beds gave opportunity. Fractures in that zone show premineral displacements of a few feet.

The ore and gangue are generally similar in character to those formed in the Tintic district by the cooler parts of the mineralizing solutions. The principal gangue along the trunk fissures is mostly dark cherty quartz, and away from the trunk fissures dolomite and calcite. Only small remnants of sulphide ore remain in the oxidized ore, which consists chiefly of cerussite, smithsonite, and calamine, and which contains galena and zinc blende but very little pyrite. The abundance of iron oxide in the ore, however, shows either that considerable pyrite was present or that the blende contained considerable iron.

The metal content of the oxidized ore depends largely on the thoroughness of replacement of the limestone by primary sulphides and on the amount of zinc that migrated during oxidation. Where replacement was complete the zinc was mostly removed from the lead ore during oxidation and was more or less concentrated into separate bodies or bunches. This process was especially pronounced in the southern part of the Scranton property, especially in the Magazine tunnel, where a large body of oxidized zinc ore was mined at the down dip end of a large lead stope. Where the primary ore only impregnated the limestone and did not wholly replace it the unreplaced part precipitated the oxidized zinc as carbonate and produced the lead-zinc or 'combination' ore prominent in the northern part of the Scranton property and in part at least of the New Bullion mine.

The lead ores shipped have assayed 0.5 to 3 ounces of silver to the ton, 21 to 33 per cent lead, 2 to 3 per cent zinc, 22 to 32 per cent iron, and 8 to 24 per cent insoluble; the zinc ores 0.5 ounce of silver to the ton, 0 to 2.5 per cent lead, 32 to 52 per cent zinc, 6 per cent or less iron; and 14 per cent or less insoluble; the combination ores 0.5 to 7 ounces of silver, 8 to 40 per cent lead, 14 to 33 per cent zinc, 5 to 14 per cent iron, and 7 to 15 per cent insoluble. The low silver content, averaging about 1 ounce to the ton in the Scranton mines and about 5 ounces in the New Bullion mine, is characteristic.

Other properties, prospecting in mineralized ground of the same type as that described, are the North Scranton and the Tintic Zinc Co., which is located between the Scranton and New Bullion mines.

The relations of ore bodies are shown on plate 7, and a new study of the geology has been completed (Disbrow, 1961).

Oxidized zinc ore resources.—The mines of the North Tintic district have long been Utah's largest source of oxidized zinc and lead-zinc ores. Many thousands of tons of mineralized material remain on the dumps and in the mines, much of which is relatively rich in iron and silica (3–20 percent). The known zinc-bearing ore bodies in the district are reported to have limits without too large a potential for extension. The district, however, is relatively unprospected compared to the nearby Tintic district of somewhat similar geology, because the zinc-rich silver-lean ores have not proven to be as profitable as the Tintic ores. For this reason, further careful prospecting on the Scranton fissure and related fractures for new ore bodies and extensions of known channels probably would be worthwhile, not only for oxidized zinc-bearing ores but also for unoxidized lead and zinc sulfide ores, which might be found deeper in the thick limestone section beneath the present surface.

Other reference.—Lindgren and Loughlin (1919, p. 265–274); Disbrow and Morris (1957); and Morris (1957).

UTAH COUNTY

AMERICAN FORK DISTRICT (ALTA AREA)

Plate 3, nos. 69, 70, 72, 74, 77

Location.—Upper drainage basin of American Fork in Wasatch Mountains northeast of Lehi, Utah County.

Development and production.—The district contains several small and intermediate-sized mines and many prospects; plate 3 shows the main workings of most of them. Most of the older workings are caved and inaccessible.

The district was discovered before 1870 but little work was done until September of that year, when the rich lead-silver-gold-zinc Miller Hill mine was discovered and quickly became the main producer. Huntley (1885, p. 444) estimates that before 1881 the Miller Hill mine produced 13,000–15,000 tons of ore, some of which yielded about $250 per ton in lead, silver, and gold. In 1872 the Wild Dutchman or Dutchman was discovered, and most of the other large producers were in operation during the same decade. Between 1880 and about 1905 much development work was completed but little ore was shipped. In 1905 the Tyng brothers, who had a lease on the Miller Hill mine, found a large new oxidized ore body in a downfaulted block east of the old workings, and a gradual revival of production in the district began. Mining continued sporadically through World War II but has almost ceased in recent years. Small shipments aggregating about 150 tons of oxidized zinc were made during World War I. Some of this ore came from the Miller Hill mine and is reported to have contained 36 percent zinc.

Geology.—The district is in an area of complexly folded and faulted quartzites and carbonate rocks of Paleozoic age that lies between the Alta and Clayton Peak stocks to the north and the Little Cottonwood stock to the west (Calkins and Butler, 1943).

Most of the ore deposits are in fissure veins or in adjacent limestone wallrock as replacements; most of them are adjacent to eastward-trending faults of considerable magnitude. The primary replacement ore was deposited in several ways in the district; (a) as massive bedded replacements, (b) as lean disseminated replacements near fissures, and (c) as chimneys at fissure intersections.

Ore.—Several types of oxidized zinc deposits are known in the district. Most of the ore at the Miller Hill mine is a zinc-bearing lead-silver-gold ore consisting of cerussite, lead ochers, smithsonite, wulfenite, and limonite, but containing small nodules of unreplaced galena. The average content per short ton of this ore that was shipped about 1908 by the Tyng brothers was 0.98 ounce of gold, 21.72 ounces of silver, 39.29 percent lead, 4.90 percent zinc, 20.17 percent iron, 2.61 percent sulfur, and 3.56 percent of insoluble matter (Butler and Loughlin, 1915, p. 220). Some of this ore is reported to have contained less lead but as much as 15 to 20 percent zinc. Oxidized zinc ore shipped during World War I averaged 36 percent zinc, and was probably wallrock replacement ore.

The secondary ore at the Dutchman mine is in fissure veins and consists of cerussite, smithsonite, a little hydrozincite, and some barite that directly replaced the primary vein ores, but with some redistribution of the constituents during oxidation. This ore is reported to average about 30 percent lead, 9 to 17 percent zinc, and 50 ounces of silver per short ton (Calkins and Butler, 1943, p. 208). Some of the zinc-rich ore contains as much as 34 percent zinc and only 2 to 3 percent lead.

In contrast, the ore at the Bay State mine is a disseminated bedded replacement deposit in brecciated, dolomitized, and silicified Deseret limestone of Mississippian age. The ore is reported to contain 5 to 8 percent lead, 8 to 10 ounces of silver per short ton, and 15 to 20 percent zinc (Weed, 1920, p. 1387), in the form of cerussite, smithsonite, and hemimorphite which directly replace the sulfides. A little unaltered galena and sphalerite still remain in some of this ore.

Oxidized zinc ore resources.—Past production of oxidized zinc ores has been small, except where zinc-bearing lead-silver ores were mined but the zinc was not recovered, as at the Miller Hill and Dutchman mines. Low-grade lead-zinc-silver ores remain in several mines, especially the Bay State, and wallrock pockets of rich oxidized zinc ore may remain undiscovered in places. The upper workings of the Dutchman mine are one of the few places where unmined fissures of high-grade oxidized zinc ore may be examined.

References.—Calkins and Butler (1943); Butler and others (1920, p. 227–280); Raymond (1872); Weed (1920, p. 1387); and Butler and Loughlin (1915).

ALPINE DISTRICT

Plate 1, no. 68

Location.—In western foothills of Wasatch Range, north and east of Alpine, Utah, about midway between Provo and Salt Lake City.

Development and production.—The district contains, in addition to several prospects, at least 2 small shallow mines, the Lucky Chance and Alpine Galena; small shipments of silver and lead-silver ore were made from both mines between 1910 and 1920. No oxidized zinc ores have been produced.

Geology.—The district includes the southwestern part of the Little Cottonwood granodiorite stock, an area of quartzites and slates of Precambrian age, quartzite of Cambrian age, and a great thickness of limestones of Paleozoic age, all locally complexly folded and faulted with thrusts and high-angle shear, normal, and reverse faults. The geology has been briefly described by Butler and others (1920, p. 283–284) and Baker and Crittenden (1961); the area was studied in detail recently by Crittenden and Calkins.

Ore and resources.—Smithsonite is reported by Crittenden (oral communication, 1955) at one of the prospects in the foothills of the Wasatch Range northeast of Alpine near the Alpine galena mine. The deposits in this area are small bedded replacements of galena and sphalerite, partly oxidized to cerussite and smithsonite. All the known deposits are very small.

PROVO DISTRICT

Plate 1, no. 75

Location.—Western edge of Wasatch Range east of Provo and south of Provo River. Monarch mine is about 1 mile northeast of Brigham Young University in Provo, on north side of Rock Creek Canyon about halfway up Squaw Mountain, at an altitude of 6,600 feet. It is accessible only by a narrow steep footpath not usable at times owing to landslides.

Development and production.—Considerable prospecting has been done in the district since it was organized in 1871, but only the Monarch mine, which opened about 1902 has been productive. Although the mine includes upper and lower tunnels about 130 feet vertically apart, and several hundred feet of drifts, crosscuts, inclines, and small stopes, only 8 to 50 tons of lead-silver ore per year was shipped during 1902–13 and in 1917, a small amount of ore is known to have been shipped. No oxidized zinc ores have been shipped.

Geology.—The mineral deposits are in veins, chimneys, and breccias in and adjacent to fissures and at fissure intersections in limestones of Mississippian age that overlie quartzite and shale of Cambrian age. The strata strike norhtward. To the west of the mine they dip gently eastward but the dip steepens markedly at the mine. The upper workings follow a northeastward-striking vertical fissure to where it intersects a fissure that trends N. 25° W., and they continue 400 feet along the second fissure, which contained most of the ore shipped (Butler and others, 1920, p. 321). The lower workings prospected these fissures at greater depths.

Ore.—The primary deposits are in the wallrock of the fissures where a mixture of white dolomite, calcite, galena, and presumably pyrite and sphalerite has replaced limestone selectively. These deposits are nearly completely oxidized to cerussite which contains several ounces of silver, brown limonite, and a little smithsonite.

Oxidized zinc ore resources.—Loughlin (*in* Butler and others, 1920, p. 322) states, "Examination of the lower walls of the floors and stopes may prove the presence of oxidized zinc ore." Such an examination may never have been made as there has apparently been little or no activity in the nearly inaccessible Monarch mine since 1920. Only very lean samples of smithsonite-bearing material were noted by the writer, although only a small part of the workings were accessible and could be examined.

SANTAQUIN DISTRICT

Plate 1, nos. 71, 76

Location.—In front range of Wasatch Mountains mostly in Utah County, south and east of Santaquin. Contiguous to Mount Nebo district (p. 81) mostly in Juab County to south. Boundaries between the two districts ill-defined. Most mines and prospects reached by roads and trails in Pole and Santaquin Canyons, which extend southward from town of Santaquin. District was not visited.

Development and production.—The district was organized in 1871 and some lead-silver and zinc ore was produced between 1910 and 1917, but the district has not been notably productive. The main mines and prospects for lead, silver, and zinc are the Union Chief, Delsa, New Deal or Blue Eagle, and White Dragon, most of which are on the slopes of Santaquin Mountain.

Geology and ore.—The geology and ore bodies are described in considerable detail by Loughlin (*in* Butler and others, 1920, p. 322–333, fig. 40). The principal rock types include granite gneisses of Precambrian age on the east side of Santaquin Canyon, overlain by gently eastward-dipping quartzite of Cambrian age, which in turn is overlain by limestones of Cambrian through Mississippian age. A few lamprophyre dikes of probable Tertiary age are known. Several major normal and possible thrust faults which trend north and a series of eastward-striking faults divide the district into square and rectangular blocks, but the minor fractures have diverse trends.

The ore deposits are in small fissure veins and bedded replacement bodies. They contain nearly completely oxidized lead, zinc, copper, and silver minerals. Selected samples of the ore at the New Deal or Blue Eagle mine are reported to contain 2 to 13 percent zinc, 2 percent lead, and about 1.2 ounces of silver per ton. Some of the lead ore contains vanadium.

Oxidized zinc resources.—The known deposits are all very small. Those at the New Deal mine may be secondary replacement bodies that during oxidation were redeposited from now-eroded sulfide bodies above; thus they may not extend below the known small pockets.

EAST TINTIC DISTRICT

Plate 1, nos. 73, 78, 79

Location.—In eastern foothill area of East Tintic Mountains, near Dividend, Utah. North boundary generally considered to be Eureka branch line of Denver and Rio Grande Western Railroad and western boundary the meridian 112° 5′.

Development and production.—In addition to many prospects and small mines, this district contains a few mines which were developed in the 20th century into some of the largest and most productive in Utah. They are the Tintic Standard, North Lilly, Eureka Standard, and Eureka Lilly (East Tintic Development) mines. The district was the last part of the Tintic mining area to be developed into major production. Although much prospecting had been done previously in the small patches of limestone and altered rhyolites of the district, it was not until 1916 that development beneath the volcanic rocks in the Tintic Standard mine broke into the first of the great ore bodies. This mine has since produced more than $75 million worth of lead-silver-zinc ore. The North Lilly deposit was found in 1927, the Eureka Lilly and the Eureka Standard in 1928. These deposits are now exhausted, but following recent work by the U.S. Geological Survey, the Bear Creek Mining Co. and associated companies in 1956 started major development, prospecting, and mining in oxidized ore in the district.

Before 1912, oxidized zinc ore was thrown on the dump at the East Tintic Development (later part of the Eureka Lilly) mine, but in 1912 and 1913 the lessees worked the dump and lead stopes for zinc ore (Lindgren and Loughlin, 1919, p. 247). From 1912 through 1916 the East Tintic Development mine and the Tintic Standard mine are reported to have produced nearly 1,600 short tons of oxidized zinc and lead-zinc ores. T. S. Lovering (oral communication, 1952) reports that, in addition, a carload of zinc carbonate ore was produced from the Zinc Prospect in Silver Canyon (pl. 1, no. 79) south of the Tintic Standard mine. Oxidized ores from the district are reported to have yielded about 83,000 pounds of metallic lead and 722,000 pounds of metallic zinc. Much of the ore from the East Tintic Development mine averaged 27 percent zinc (Lindgren and Loughlin, 1919, p. 113), while that from the Tintic Standard mine averaged 20 percent zinc and 13 percent lead.

Geology and ore.—The geology of the East Tintic district has been described by Lovering (1949; 1951), Lovering and others (1948), Morris and Lovering (1961) and in older reports by Billingsley (*in* Boutwell and others, 1933, p. 19–24), and Lindgren and Loughlin (1919, p. 246–254, pl. 1).

The rocks of the district consist of complexly folded and block-faulted limestones and dolomites of Paleozoic age which are intruded by a few small felsic pipes, stocks, and dikes, probably of Tertiary age and capped by locally altered rhyolites and latites of Tertiary age. The ore bodies are mostly in complex structural troughs, and are mainly in the Middle Cambrian limestones, especially the Ophir formation and Teutonic limestone.

The primary silver-rich ore bodies replaced the limestone in large rich veins, pipes, and funnel-shaped bodies, consisting of barite, pyrite, enargite, tetrahedrite, marcasite, galena, quartz, and sphalerite. Hydrothermal alteration of the rocks near the ore bodies is conspicuous and has produced dolomite, chlorite, kaolinite, montmorillonite, halloysite, jasperoid, and manganese and iron oxides (Lovering, 1949).

Oxidation has been almost complete down to the 900 level and incomplete to the 1,250 level. The principal minerals of the oxidized parts of the ore bodies are anglesite, cerussite, plumbojarosite, argentojarosite, jarosite, native silver, smithsonite, hemimorphite, and iron and manganese oxides. Chalcophanite is reported in the eastern part of the district by T. S. Lovering (oral communication, 1956).

Lindgren and Loughlin (1919, p. 247–248) state that at the East Tintic Development (Eureka Lilly) mine,

> The main bodies of oxidized zinc ore were mined along the walls of the lead stope between the 230- and 300-foot levels, and in the bottom of the stope and on the crossbreak. The ore was evidently concentrated by leaching from the upper levels, downward migration and replacement of the limestone walls.

A smaller ore body in the Tintic Standard mine is also described (Lindgren and Loughlin, 1919, p. 250):

> At the "1,200-foot" level the [inclined] winze [from the 1,000-foot level] entered a small shoot of oxidized zinc ore which had a maximum thickness of 6 feet, thinning both to the east and to the west, and which yielded a carload shipment. The ore still shown in the east face of the stope is brown fine-grained smithsonite that contains drusy vugs and is similar to the "brown zinc" ore of the May Day, Yankee, and Gemini mines. It is said to contain an average of 33 percent zinc. So far as can be determined in the iron-stained walls of the stope, the smithsonite had been formed by the replacement of a small lens of limestone just above the quartzite.

Manganese oxides are abundant constituents of oxidized parts of the East Tintic ore bodies. Some of these contain between 0.5 and 3 percent zinc, probably as a partial substitution for the manganese. For example, the nodular manganese ores of the Tip Top tunnel manganese mine (Crittenden, 1951, p. 49–50) contain 0.5 to 1 percent zinc (Lovering, T. S., oral communication, 1952). Bodies of similar manganese oxides in the upper levels of the Tintic Standard mine (Crittenden, 1951, p. 51) contain from 0.6 to 2.85 percent zinc. In 1953, J. W. Wade (oral communication) reported that this ore was being mined and sent to the Combined Metals Co. mill at Pioche, Nev., for its manganese content by Ralph Hopes, lessee, and that it averaged 2 percent zinc as shipped.

The Bear Creek Mining Co. and associates have recently (1957) encountered an iron and manganese "shield" containing zinc, during drilling and drifting from their 1,050-foot deep exploration shaft in the eastern part of the district (Anonymous, 1957, no. 11, p. 192; no. 12, p. 196). The zinc mineral is reported to be chalcophanite Morris, H. T., written communication, 1958); it is associated with other manganese and iron oxides in large bodies and is regarded by the company as important, as, according to Morris, "most major [oxidized] lead-silver-zinc occurrences in the district are associated with iron-manganese [oxides]."

Oxidized zinc ore resources.—Available reports suggest strongly that all the known deposits of oxidized zinc ores in the principal mines of the district have been completely mined out. A small tonnage of commercial ore might be obtained by further prospecting at the Zinc Prospect in Silver Canyon. The zinc-bearing manganiferous material may be valuable as a future source of zinc.

Careful search of the walls of the later and deeper stopes of the main mines might locate other wallrock replacement pockets of brown oxidized zinc ore similar to the one in the Tintic Standard mine described above, and the oxidized parts of the new ore bodies that have been found in the district will probably contain pockets of high-grade ores similar to those mined in the past.

JUAB COUNTY

TINTIC DISTRICT

Plate 2

Location.—In East Tintic Mountains, extending southward from vicinity of Eureka to south and east of Silver City. Bounded on the east by East Tintic district at long 112° 5′, on the north by North Tintic district, and less closely on the west by West Tintic district in West Tintic Mountains. Part of district east of East Tintic Mountains crest is in Utah County, remainder in Juab County.

Development and production.—The mines for silver, lead, copper, gold, and zinc in the Tintic district are among the largest in Utah. Those that have produced or are known to contain oxidized zinc ores are numbered and shown on plate 2. The district, named for a chief of the Ute tribe, is among the oldest mining camps in Utah. Ore was discovered first in veins in the quartz monzonite about 1 mile east of Silver City and Diamond on the Sunbeam claim, located

December 13, 1869 (Crane, 1917, p. 343). The Black Dragon claim was located in January 1870. These earliest discoveries were followed in quick succession by locations in February 1870 in the limestone toward the north, first on the Mammoth ledge near the middle of the district, and shortly afterwards on the Eureka Hill ledge in the northern part. Mining operations began at once in the vein deposits in the southern part of the district, but the much larger replacement deposits were not very productive until 1872 or later.

Production increased steadily with minor fluctuations until about 1926, when a peak of about $16 million worth of ore annually was reached. This has never since been exceeded, owing to depletion of the mines. In recent years, metal production declined from nearly $5 million worth in 1949 to a little over $2 million worth in 1953. A further decline occurred in 1956 when the Chief Consolidated Mining Co. ceased operations in the deeper levels of the mine owing to rising mining costs and low market prices. The total value of mine production in the district during 1869–1953 was $421,591,472 (U.S. Bureau of Mines, 1953, p. 1019). Details of the history of mining and production are given by Butler and others (1920, p. 403–410), Lindgren and Loughlin (1919, p. 105–117), Billingsley and Crane (*in* Boutwell and others, 1933, p. 101–104), and Crane (1917).

Oxidized zinc ores were probably first discovered in 1911 in the May Day mine. Production began in 1912 when ores were discovered and mined in the Gemini (1912–13, 1915–17), Godiva (1912–13, 1915–17, 1924–25), Lower Mammoth (1912–16), May Day (1912–17), Ridge and Valley (1912–13, 1915–17), Uncle Sam (1912–16), and Yankee (1912–18) mines. Other producers in later years were the Bullion Beck (1915–18), Beck Tunnel (1915–16), Chief Consolidated (1914–18), and 1922), Colorado (1914–17, and 1926), Eagle and Blue Bell (1916), Empire (1917), Eureka Hill (1916), Iron Blossom (1915, 1917, 1923), Mammoth (1942), and Sioux Consolidated (1915–16). The production is given in table 7.

The data show that production of oxidized zinc ore was large from 1912 to 1917, but dropped rapidly when the price for the ore declined in the latter part of 1916 and has never been large since then. Unlike most other sources of this ore in Utah, the Tintic district has produced very little oxidized zinc ore since 1930, probably in part because the easily found pockets of ore were exhausted during the early productive period. In this brief early period of a little more than 5 years, however, the district produced more than 30,000 tons of ore, which to date exceeds the production from any other district in Utah except the North Tintic district.

Geology.—The complex geology of the Tintic district has been described in detail by Morris (1957); Lindgren and Loughlin (1919);

TABLE 7.—*Oxidized zinc and lead-zinc ore produced in the Tintic and East Tintic districts, 1912–53*

[Compiled from Butler and others (1920), Lindgren and Loughlin (1919), U.S. Geol. Survey (1912–23), and U.S. Bur. Mines (1924–26, 1940–53)]

Year	Class of oxidized ore	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Copper (recoverable pounds)	Lead		Zinc		Average gross value per ton	Value of recoverable zinc
						Recoverable pounds	Percent	Recoverable pounds	Percent [1]		
1912	Zinc	6,306	100.06	8,548		190,392	1.91	3,709,737	29.41	$43.47	$255,972
1913	do	6,265						3,596,544	27.91	31.26	201,406
	Lead-zinc	192				32,278	9.45	89,437	23.29	34.40	
1914	Zinc	1,064						586,633	27.57	28.12	
	Lead-zinc	393	6.98	2,041	401	89,098	11.3	171,584	21.8	46.29	38,669
1915	Zinc	7,029	.82	4,798	1,250	47,597	.34	3,845,058	27.35	68.53	476,787
1916	do	7,318				31,322	.21	3,635,604	24.84	66.87	
	Lead-zinc	227				82,216	18.1	75,552	16.6	69.72	497,295
1917	Zinc	1,883						1,096,807	29.12	59.41	120,661
	Lead-zinc	258				73,172	[2] 14.84	86,134	[2] 20.29	([3])	
1918	Zinc	205						137,223	([3])	([3])	12,487
1919–21	None recorded										
1922	Zinc	43						24,022	([3])	([3])	1,369
1923	do	15						8,298	([3])	([3])	254
1924	do	45						23,984	26.65	([3])	2,308
	Lead-zinc	36				7,000	9.72	11,520	16.00	([3])	
1925	Zinc	219				18,400	([3])	86,206	([3])	([3])	6,551
1926	Lead-zinc	100				8,400	([3])	34,200	([3])	([3])	2,574
1927–41	None recorded										
1942	Zinc	Some				([3])	([3])	([3])	([3])	([3])	([3])
1942–56	None recorded										
Total		[4] 31,598	107.86	15,387	1,651	[4] 579,875		[4] 17,218,663			[4] 1,706,994

[1] Most of the oxidized zinc ores for which records are available contained between 30 and 40 percent zinc as shipped from the mine. The much lower zinc content hown here is the result of the low rate of recovery in processing these ores.

[2] For 223 tons from the Chief Consolidated mine only.

[3] Information not available.

[4] Does not include the small production from 1 mine in 1942.

Butler and others (1920, p. 396–415); Billingsley and Crane (*in* Boutwell and others, 1933, p. 101–124); Crane (1917); and Tower and Smith (1899, p. 601–767).

The main rock units of the district are shown on plate 1. The uncolored areas are mostly valley fill that caps felsic volcanic rocks of Tertiary age. Table 3 shows the sedimentary rocks of the Tintic Mountains, including the thick limestone units of Paleozoic age which are the principal hosts for the oxidized zinc deposits.

The position, extent, and form of the primary gold-copper-lead-silver-zinc ore bodies are shown in plate 2. Four main ore-bearing pipes or channels extend from veinlike roots in or near the Silver City quartz monzonite stock northward across the district to the vicinity of Eureka, where they tend to split and funnel out into smaller branches. Zoning of the primary ores is notable. Near the Silver City stock the ores are rich in gold, copper, and silver. Farther north, beneath Eureka Peak, are lead-silver ores. Lead-zinc-silver ores occur near Eureka and Knightville, and the northernmost ore bodies, northeast and north of Eureka, are rich in zinc and contain some lead and silver. Most of the oxidized zinc ore bodies are in the two northernmost zinc-rich zones, although a few are found in nearly all the main ore bodies that replace limestones, and the largest (a low-grade ore body) is in the Lower Mammoth mine adjacent to the stock.

All the known zinc ore bodies in the district were formed by secondary replacement of the limestone wallrocks after migration of the zinc. Most are small blankets and pockets near the base of or in the footwall of, blanket ore bodies (fig. 7); one is a large body in the hanging wall of a vein. The geology of the oxidized zinc deposits is described in detail by Loughlin (1914) and Lindgren and Loughlin (1919, p. 170–173, 191–192, 221–222, 225–226, 229–237). Their views on the origin of the ores are quoted on page 21, and their views on influences of local structures features given on page 17.

Ore.—The main oxidized zinc ore minerals are smithsonite and hemimorphite. Small amounts of hydrozincite and aurichalcite are associated, but they are insignificant in themselves; malachite, as well as cerussite are present in some of the ores. The main gangue minerals are the hydrous oxides of iron and manganese, and calcite, aragonite, and gypsum. Figures 1, 2, and 4 show the characteristic ores. Most of the oxidized zinc ores for which records are available contained between 30 and 40 percent zinc as shipped from the mine.

Oxidized zinc ore resources.—The consensus of opinion is that the known oxidized zinc ore pockets in the Tintic district are largely mined out, and this is supported by the absence of oxidized zinc ore production from the district in recent years. Other ore bodies probably exist and could be found by careful exploration in the floor and walls of the old stopes, but the chances are not good of finding large numbers of such bodies.

The only known reserve of oxidized zinc material is the large body in the hanging wall of the lead vein in the Lower Mammoth mine (fig. 8), from which only some of the pockets of 30-percent zinc ore within the mass have been mined (U.S. Geol. Survey, 1916, p. 442). The amount of ore remaining in high-grade pockets is not known but probably is not large. This body of "low-grade zinc ore" was estimated by the company to contain 100,000 tons of 12-percent zinc just after the last ore was produced from it (Anonymous, 1917). Although submarginal, this ore body is one of the largest known in the State and is potentially valuable if new concentrating and refining methods can be developed to process such material profitably. In addition to the zinc this material is reported to contain 1.5 ounces of silver and 20 to 30 cents worth of gold per ton, and 0.5 to 1 percent lead, about 10 percent iron, 10 to 15 percent silica, and 25 percent carbonate (Zalinski, 1913, p. 1227–1228).

WEST TINTIC DISTRICT

Plate 1, nos. 108, 111, 116, 118, 119

Location.—Southern low part of Sheeprock mountains ,west of West Tintic mountains, in north-central Juab County. Accessible by dirt roads from Tintic Junction and Jericho, Utah.

Development and production.—Several small to fairly large mines are in the district, the most active of which in recent years have been tungsten mines in the western part. Figure 47 of Butler and others (1920) and plate 1 of Stringham (1942) show the mine locations and some of the access roads. A longitudinal section of the Scotia mine, the largest in the district, is shown in figure 5 of Stringham's report.

The mineral deposits in the district were discovered apparently about 1869. The first production was of high-grade gold-silver-lead ore from the surface opencut of the Scotia mine in the northeastern part of the district. This pocket of rich ore stimulated prospecting for some years and several mines were developed, only a few of which have been productive. A large quantity of oxidized lead ore containing silver, gold, and a little copper was produced from the Scotia mine from 1914 to 1916 by the Chief Consolidated Mining Co. under an option (U.S. Geol. Survey, 1916, p. 443), but mining was discontinued because of the disadvantage of operating the property at a distance from their main properties at that time and because of relatively small ore bodies.

The only known production in which zinc is recorded, probably from oxidized ore, was in 1950–51 from the 1888 mine (probably the westernmost of the two 1888 mines) which produced 55 tons of ore yielding 1 ounce of gold, 74 ounces of silver, 100 pounds of copper, 13,645 pounds of lead, and 5,175 pounds of zinc (U.S. Bureau of Mines, 1950, p. 1598; 1951).

Geology.—Quartzites and slates of Precambrian age have been thrust over limestones and dolomite of Paleozoic age (in part Ordovician), and the sequence has been intruded by several stocks and related dikes of silicic to intermediate composition. The limestones and dolomites have been metamorphosed next to stocks into broad zones of marble and silicate minerals. Most of the zinc is in the epithermal and mesothermal deposits, and it is most abundant at the Scotia, War Eagle No. 3, and 1888 mine (west). The epithermal zinc-bearing deposits are scattered along the northern boundary of the district just south of the central east-trending part of the major thrust zone that bounds the district on three sides. The geology of the Scotia mine is best known (Stringham, 1942, p. 282–284). The ore here is in small to large brecciated zones and podlike replacement bodies that are nearly flatlying and have a general eastward elongation. The podlike ore bodies lie along low-angle thrust faults which underlie the main overthrust; many small irregular pipes of ore branch from the pods. The pods are connected by thin vertical fissure veins, presumably the feeding fissures, that strike eastward.

Ore.—The ore is nearly completely oxidized and only a little galena remains in places; quartz. calcite, barite, and fluorite are gangue minerals. Obviously derived from very complex primary ores, it consists of anglesite, cerussite, scorodite, hemimorphite, conichalcite, limonite, olivinite, malachite, chrysocolla, azurite, linarite, aragonite, bindheimite, plumbojarosite, smithsonite, and a little hydrozincite and aurichalcite. Mixed ores containing some or all of these minerals are typical of the Scotia mine, and they resemble the ores of the Tintic district to the east. Most of the smithsonite is brown and earthy or in colorless to white rhombohedral crystals and masses. Hemimorphite is in grayish reniform crusts and colorless masses of minutely radiating crystals. A partial analysis of a sample from the mine showed the following:

Analysis of selected typical hand sample of oxidized zinc ore from the Scotia mine

[Analyst, Deason and Nichols, Salt Lake City, 1955]

Constituent	Percent	Constituent	Percent
Gold[1]	0.02	Copper	1.45
Silver[1]	.90	Silica	17.6
Lead	2.7	Carbonate	19.0
Zinc	31.1		

[1] In ounces per short ton.

Gray massive smithsonite is abundant at the 1888 mine (west), from which small shipments of ore containing probable oxidized zinc have been made in recent years. White hemimorphite, a little fine-grained smithsonite, and bright-blue aurichalcite are present at the three War Eagle mines, especially War Eagle No. 3. Hand samples of oxidized zinc minerals were found at most of the other base-metal mines and prospects.

The oxidized zinc minerals directly replace parts of the primary ore bodies in all the deposits seen, and no large secondary wallrock replacement pockets of these minerals have been found as yet.

Oxidized zinc ore resources.—The quantity of oxidized zinc ore that could be hand-sorted from the Scotia mine dump is substantial, and some mineable reserves are reported to be still in the mine. The author knows of no other reserves in the district, but other small bodies similar to that mined recently at the 1888 mine (west) might be found. The district has many possibilities for prospecting, especially beneath the main overthrust zone. The geologic potential is good for the discovery of new oxidized complex zinc-bearing ore bodies.

Reference.—Butler and others (1920, p. 432–444); and Stringham (1942, p. 267–290).

FISH SPRINGS DISTRICT

Plate 1, nos. 84, 89, 90, 95, 114, 115

Location.—On west slope of north part of Fish Springs Range, at the ghost town of Fish Springs, in northwestern part of Juab County just south of Great Salt Lake Desert. Accessible by about 16 miles of graded road east from Calleo, or 85 miles by a similar road (the old emigrant and pony express trail) which runs west from Vernon through the "Dugway," and curves around north end of Fish Springs Range to junction with short access road to the mines.

Development and production.—The principal mines of the district are shown on plate 8. The Utah mine on the north side of the district is by far the largest; it is at least 800 feet deep and has many east-southeast trending stopes and drifts. The next largest mine is the Galena, which adjoins the Utah mine on the west; and next in size is the Emma mine in the south-central part of the district. Other producers include the Vulcan, Utah No. 2, Cactus, Spanish, Ada, Carnation (probably formerly the Wild Cat), Early Harvest and Last Chance claims. Most of the mines are accessible, open, and dry, as water level is at a depth of 800 feet in the Utah mine.

The district is reported to have been discovered in 1890 and was organized the following year. The original discovery was made on the fissure zone developed by the Utah and Galena mines and they became the main producers. The district produced $2,316,464 worth of gold-silver-lead ore during 1891–1917. Since 1917 production has been intermittent and mostly from the Utah mine. In 1950 this mine produced 43 tons of oxidized zinc-lead ore containing 1 ounce gold, 2,570 ounces silver, 36,000 pounds of lead, and 2,500 pounds of zinc.

Geology.—Most of the rocks are limestone and dolomite interspersed with some shale and quartzite and are reported to be of Cambrian(?), Ordovician, and Silurian age (Butler and others, 1920, p. 464–468). The strata strike generally northward and dip gently westward as much as 30°. The rocks have been block faulted by southeastward-striking northeastward-dipping faults whose collective displacement is large. Several of these faults are concentrated in Fish Springs Pass, a short distance east of the area shown on plate 8. Some of the smaller fractures such as those in the Carnation mine strike northeastward and dip at relatively low angles southeastward.

Rhyolite and granite porphyry dikes occupy fissures which have also furnished channels for the circulation of the ore-bearing solutions. The largest of these dikes, composed of granite porphyry, is about 50 feet wide, and is north of and parallel to the Utah-Galena fissure (pl. 8). A small intrusive stock may underlie an alluvium-filled amphitheatre in the northwest foothills of the district north of the Joseph tunnel. The amphitheatre walls are coarse-grained marbles and calcium silicates, which suggests that they represent the contact zone around a small deeply eroded stock or plug of felsite composition such as are common elsewhere in this part of Utah. Similar marbles occur locally near the dikes.

The ore deposits in the district are pipes, veins, and irregular bedded replacements of limestone closely associated with fissures and their intersections. Most of the productive fissures strike southeastward. Much of the limestone near the ore bodies has been altered to fine-grained dolomite similar to that in the East Tintic district (Lovering, 1949). Later this dolomite was fractured to a crackle breccia and recemented with white coarse dolomite. Some jasperoid deposited near the veins was later partly redissolved or desilicated, and much of the dolomite near the veins was also partly redissolved and "sanded" by later solutions.

Ores.—The primary ores are completely oxidized in place to white and gray cerussite, anglesite, orange to yellow microflaky plumbojarosite, limonite, reddish-black ruby-silver minerals, finely crystalline red-brown calamine, coarse white smithsonite, and a little hydrozincite, aurichalcite, hexagonal barrellike prisms of willemite(?), and bright-yellow lustrous crusts of minutely crystalline wulfenite or vanadinite. For details about the ore at individual mines see the notations on plate 8, and the following partial of oxidized zinc-bearing ores:

Partial analyses of oxidized zinc-bearing ores of the Fish Springs district

[Analyst, Deason and Nichols, Salt Lake City, 1955. N.d. means not determined]

Constituent	Emma mine		Galena mine (selected sample from dump of oxidized zinc-silver ore)	Utah mine (selected high-grade sample of oxidized zinc-silver ore from dump)	Carnation mine (selected hand sample of oxidized zinc ore)
	Selected sample of oxidized zinc ore (from dump)	Channel sample across 1-ft vein of oxidized lead-zinc-silver ore (in opencut)			
Gold...ounce per ton..	0.025	0.01	0.05	0.007	0.02
Silver............do....	5.90	31.40	22.70	16.50	4.50
Lead.........percent..	7.2	5.5	6.20	7.50	2.2
Zinc...............do....	24.3	4.2	16.8	38.6	27.6
Copper...........do....	N.d.	N.d.	N.d.	0.53	N.d.
Silica..............do....	21.0	40.2	10.4	14.3	7.2
Carbonate.......do....	26.5	26.4	29.8	19.89	32.0
Iron...............do....	7.7	17.2	1.5	1.6	N.d.

The analyses above, except for the one channel sample, show the range in grade of oxidized zinc-bearing ores that were culled in former operations and thrown on the dumps or left in the mines; they do not represent the average grade. The samples all contain silver, and three are rich in this metal. All contain sufficient lead to be recoverable and to make them worth shipping as zinc-lead-silver ores under favorable conditions. Three contain sufficient zinc to be commercially valuable as oxidized zinc ores alone, especially as they are lean enough in both silica and iron to make them desirable for fuming. The discarding of such silver-zinc ores is probably a result of the high penalties charged by lead-silver smelters.

Oxidized zinc ore resources.—The mines and dumps of the Fish Springs district contain recoverable tonnages of silver-rich oxidized zinc-lead ores. Appreciable tonnages of "low-grade" ores are reported to remain in the main fissure zones, and smaller tonnages of similar material can be culled from the several mine dumps. The total tonnage of zinc-bearing ore of all classes in the district, both in the mines and on the dumps, may be substantial; the grade will fall within the range of the several analyses given.

If a market develops for silver-rich oxidized zinc ore containing some lead, then this district may produce large quantities of such ores, although the shipping costs will be high owing to the distance from the smelter. The generally low iron content of the ores is favorable for beneficiation by flotation or fuming. Much ore of this type has been shipped since 1950 from Nevada.

SPRING CREEK DISTRICT

Location.—In southwest corner of Juab County on west side of Deep Creek Range, about 15–20 miles south of Ibapah, and probably in Goshute Canyon near Goshute Indian Reservation. District was not visited.

Development and production.—The only known productive property is the Queen of Sheba, but several other mines and prospects are in the range and its foothills to the southwest. The district was organized in 1891, and the Queen of Sheba produced gold ore intermittently until at least 1920, a total of $40,000 worth. Thirty-one tons of lead-silver-copper ore were produced from the Silver Prince mine, but no oxidized zinc ore production is known.

Geology.—The known geology of the district is included in a description of the Deep Creek Range by Butler and others (1920, p. 469–475). The mines lie south of the large Ibapah stock of granodiorite or sodic granite of Tertiary age, which intrudes rocks of Paleozoic age. South of the stock on the west side of the range most of the rocks are quartzite and schist of possible Cambrian age, but the foothills farther west and southwest are composed of thick-bedded limestones of Ordovician age. The reported lead and zinc deposits are probably in these limestones in the southwestern foothills of the range.

Oxidized zinc ore resources.—Reports indicate that potentially valuable deposits of lead-rich oxidized zinc ores exist in this little-known district.

MOUNT NEBO AND MONA DISTRICTS

Plate 1, nos. 92–94, 100, 101, 107, 110

Location.—In Wasatch Range in vicinity of Mount Nebo, south from approximately Utah County line to Nephi. A small western part near base of range near Mona is known as Mona district. Mount Nebo district is adjoining and continuous with Santaquin district to the north, mostly in Utah County.

Development and production.—The many small mines and prospects are mostly near the crest of the range or near the western base. The Eva, Nebo Star, Highland, and Eureka L and M (Vagabond) are among the more productive properties. The Mount Nebo district was organized in 1870, and many small mines have produced gold, silver, copper, lead, and zinc worth more than $200,000. A total of more than 1,553 tons of oxidized zinc and lead-zinc ores came mostly from the Eva mine but also from other properties, including the Bald Eagle, Eureka L and M (Vagabond), Freddie Lode, Gunnison, Highland, Mount Nebo, and Iris. Table 8 gives the recorded production of oxidized zinc and lead-zinc ores.

Geology and ores.—The geology of the Mount Nebo district is described by Butler and others (1920, p. 322–333) and has been summarized previously under the Santaquin district (p. 69). The Eva and Eureka L and M (Vagabond) mines illustrate well the two main types of oxidized ore bodies in the district. That in the Eva mine, near the crest of Mount Nebo ridge, is a small bedded

TABLE 8.—*Oxidized zinc, lead-zinc, and zinc-lead ore produced in the Mount Nebo and Mona districts*

[Compiled from Butler and others (1920, p. 334), U.S. Geol. Survey (1911-23), and U.S. Bur. of Mines (1924-53)]

Year	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead (pounds)	Zinc (pounds)	Value of zinc
1911	19			5,956	11,359	$647
1912	372	2	3,742	172,233	233,668	16,123
1913	215			69,253	131,749	7,378
1914	34			10,719	16,283	830
1915	322			14,683	206,229	25,573
1916	291		1,353	35,199	163,350	21,889
1917	50			3,618	26,041	2,656
1918	95	2	215	6,090	50,882	(1)
1919-22	None					
1923	56		300	8,877	19,468	(1)
1924-48	None					
1949	41		42	11,067	800	(1)
1950	23		74	5,400	6,000	(1)
1951	35		84	4,000	6,400	(1)
1952-53	None					
Total	1,553	4	5,810	347,095	872,229	[2] $75,096

[1] Data not given.
[2] Total for 1911-17 only.

replacement manto in limestone, plunging about 30° E. It is crossed by north- to northeast-striking fissures and faults that are vertical or nearly so, and the east sides are displaced downward relative to the west sides. Figure 13 shows the geology of the upper main workings of the mine. Much of the oxidized zinc minerals directly replaces the primary lead-rich ores, but a smaller part is reconcentrated as secondary carbonates along the bottom of the blanket. The ores, similar to most others in the Mount Nebo district, contain some silver but are not notably rich in this metal.

The Eureka L and M or Vagabond No. 10 mine in the Mona district has opened several small to medium-sized pockets of oxidized lead-zinc ores, mostly in flat oval bedded replacements near fissures or as veins along fissures that strike northward and dip westward at about 45° W. (fig. 14). Near the portal of the mine a thin lamprophyre dike is exposed. In the innermost drift the limestones apparently are thrust eastward at a low angle over black brecciated shales. Similar shales, mineralized with disseminated galena and sphalerite, were mined in the nearby Freddie Lode of the northeast. The only primary ore seen is a little pale-yellow sphalerite from workings beneath thick rock cover. Most of the ore is intermixed cerussite and gray smithsonite, some of which is reported to contain nearly 40 percent zinc and a little silver. In places in the central parts of the ore bodies, pods of lead carbonate ores containing a few ounces of silver and a little zinc carbonate remain unmined.

Oxidized zinc ore resources.—Most of the known oxidized zinc-lead ore bodies have been worked out, but some ore remains or is reported to remain in several of the mines and their dumps, for example at

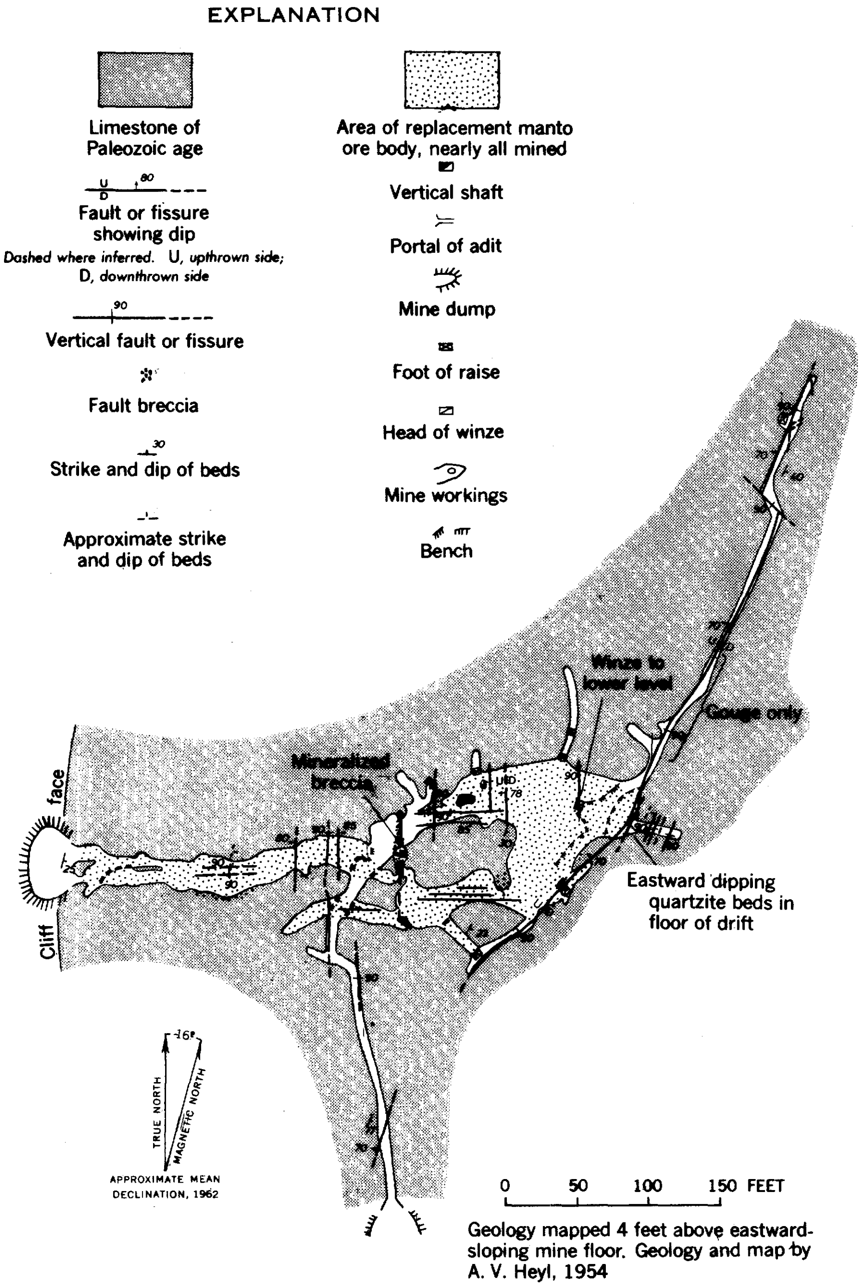


FIGURE 13.—Map of the Eva mine, Mount Nebo district, Juab County, Utah, showing replacement manto of oxidized lead-zinc ore.

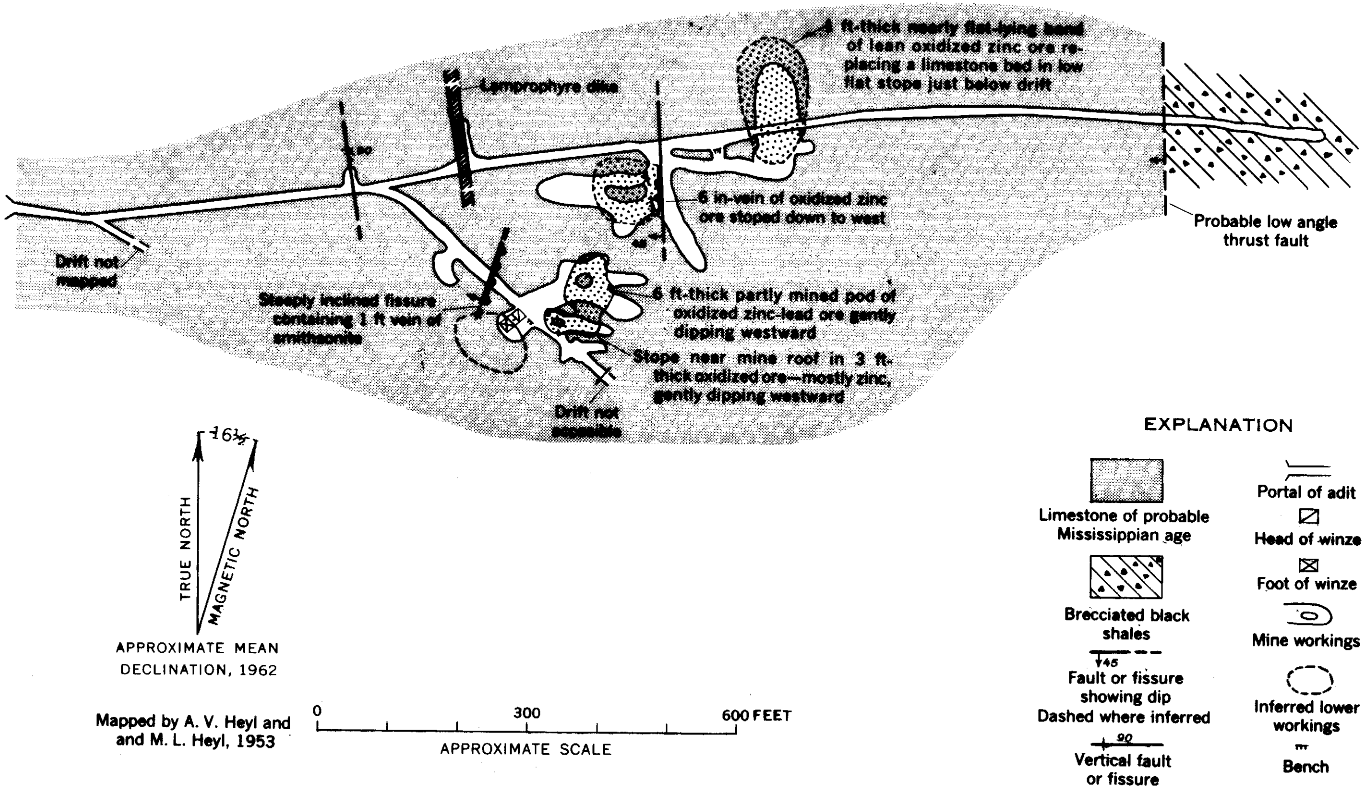


FIGURE 14.—Map of part of Eureka L and M (Vagabond No. 10) mine, Mount Nebo (Mona) district, showing fissure veins and oxidized zinc ore replacement bodies.

the Eureka L and M mine. One of the possibilities for finding additional ore in the district is to explore further for an ore body in the downfaulted block of the Eva mine.

EMERY COUNTY

SUMMERVILLE, EMERY, OR LOST SPRINGS DISTRICT

Plate 1, no. 120

Location.—In southeastern foothills of Red Plateau, northeastern part of San Rafael swell. The site of Summerville is in T. 18 S., R. 13 E., about 10 miles southwest of Woodside in eastern Emery County and north of old Spanish road to Castle Dale, Utah. Good Hope claims were not found.

Development and production.—The only known oxidized zinc ore produciton was in 1915 from the Good Hope claims (U.S. Geological Survey, 1915, p. 401). Oxidized zinc ore was hand-sorted from crude ore and the operators shipped 139 tons, which averaged 25 percent zinc and contained some lead and silver to an eastern smelter. Some copper was produced from this district in 1915 and 1917.

Geology and ore.—The deposit is reported to be in a shale bed about 5 feet thick between limestone and sandstone strata. It is probably in the Moenkopi formation of Early and Middle(?) Triassic age, or less probably in the Kaibab limestone of Permian age. An average sample of the ore face is reported to contain 1.5 to 8 percent zinc, and 1.5 to 7.5 ounces of silver per ton (U.S. Geological Survey, 1915, p. 401). A sample of the best ore exposed is reported to assay 13.5 ounces of silver per ton, 4 percent lead and 27.45 percent zinc. The minerals of the ore are not described.

Reference.—Varley and others (1921, map shows district location).

SEVIER COUNTY

REDMOND DISTRICT

Plate 1, no. 121

Location.—Western foothills of Cedar Mountains (subdivision of Wasatch Plateau) 1 to 3 miles east of Redmond, Utah. Oxidized zinc deposits are in a small hill 2 miles east of Redmond, on north side of dirt road past Redmond railroad station.

Development and production.—The main metal mine is the Redmond silver mine, whose surface workings are shown on plate 9. The main shaft is reported to be between 100 and 200 feet deep; drifting was to the northeast and southwest along the vein as several levels. Stoping has been done on the vein from the upper levels at depths of about 36 and 60 feet and some ore mined in the opencuts.

The mine is reported to have produced oxidized zinc ores about the time of World War I. The shaft was deepened from 60 feet to its present depth about 1929, and development work was done; the deeper levels, however, are reported to have too little ore to be productive. Some oxidized zinc and lead-zinc ore containing between 25 and 33 percent zinc was produced in 1929 and 1930, probably from the shallower workings, and similar ore was again produced in 1947 and 1950. Since 1928 the mine has produced a total of 206 tons of oxidized zinc and zinc-lead ore, some of which contained a little recoverable copper and silver (U.S. Bur. Mines, 1929, 1930, 1947, 1950).

Geology and ore.—Lenticular veins of hydrozincite, some smithsonite, calcite, and a little cerussite and limonite are in or along several steeply dipping normal faults or branching fissures. The largest of these faults strikes northeastward and brings white marly limestone of Eocene age on the northwest side down against red shales of Jurassic age on the southeast side. North-striking cross faults displace the largest fissure, and at the acute intersection of one of these cross faults with the older, larger one is a small pocket or pipe of oxidized zinc minerals. The original sulfide-bearing vein material presumably has been directly replaced by the oxidized material for many small cavities occur in the calcite of the veins which formerly were occupied by disseminated sphalerite and galena crystals. Limonite is not abundant, and the oxidized zinc veins contain only 1 to 5 percent iron.

Oxidized zinc ore resources.—Only some of the richest parts of the oxidized zinc ores have been mined, particularly those parts richest in lead, silver, and zinc. Some lower grade ore and zinc-bearing material remain that probably would be amenable to flotation methods that are now successfully used on iron-poor oxidized zinc ores in Europe. The reported scarcity of ore in deeper parts of the main workings and the possible low-angle plunge of the mineralized shoots are geologic features of the deposit which should be considered in further exploration.

Reference.—For general regional relations to the south, see Butler and others (1920, p. 559–561).

MILLARD COUNTY

BLACK ROCK AREA

Plate 1, no. 122

Oxidized zinc minerals are reported in prospects in limestones of Paleozoic age along the Union Pacific Railroad on the eastern flanks of the Beaver Mountains west of Black Rock, in southern Millard County.

GORDON (KANOSH) DISTRICT

Plate 1, no. 123

Location.—In and near Dog Valley on west slope of Pavant Range 10–15 miles northeast of Cove Fort, and about 10 to 15 miles south of Kanosh. District was not visited.

Development and production.—The district apparently first produced in the 1920's but its exact discovery date is not known. The main productive mine is the Blue Bell, which produced lead, lead-zinc, and oxidized zinc ores at intervals from 1925 to 1951. The total oxidized zinc ore production was 591 tons of ore from which were recovered 7 ounces of silver, 1,200 pounds of lead, and 227,715 pounds of zinc (U.S. Bureau of Mines, 1925; 1942, 1943).

Geology and ore.—Little is known except that most of the ores produced were oxidized and not notably rich in silver, and most of the oxidized zinc ore can be mined separately from the lead ore.

NOTCH PEAK DISTRICT

Plate 1, no. 124

Location.—On west slope of House Range a few miles south of Notch Peak, near U.S. Highway 6. District was not visited.

Development and production.—In 1944 the M. and M. mine produced 112 tons of oxidized zinc ore that yielded 7 ounces of silver, 1,800 pounds of lead, and 43,500 pounds of zinc (U.S. Bur. Mines, 1944). The ore averaged more than 25 percent zinc. The rocks in the district are of probable Cambrian age.

BEAVER COUNTY

GRANITE DISTRICT

Plate 1, nos. 125, 141

Location.—East-central Beaver County on eastern lower slopes of Mineral Range. Mines and prospects reached by gravel roads from Beaver, about 10 miles to southeast, and from Adamsville, about 8 miles to south.

Development and production.—The Granite district was organized 1863 and has shipped some tungsten, copper, lead, bismuth, and oxidized zinc ores. At times ores from the adjacent Antelope and Bradshaw districts have been listed as from the Granite district. The known production of oxidized ores that contain zinc includes 100 tons of lead-zinc ores produced from several mines in 1916 by J. E. Robinson (U.S. Geol. Survey, 1916), and more than 600 tons of zinc-lead ore containing some gold, silver, and copper from the Beaver View Extension mine in 1947–50 (U.S. Bur. Mines, 1947–50). The Granite and North Granite mines are also reported to have oxidized zinc ores.

Geology and ore.—Limestones and clastic rocks of probable Carboniferous age are intruded by the large Mineral Range granitic stock. Most of the mineral deposits are bedded replacements of the limestones in contact-metamorphic zones along the stock (Butler and others, 1920, p. 529–535). The deposits at the Beaver View Extension are reported to be as much as 12 feet thick. Much of the oxidized zinc-bearing ore has directly replaced primary sulfides accompanied by only partial migration within the original deposits. The owner reports that tungsten is present (Morgan Evans, written communication, 1942).

Oxidized zinc ore resources.—Most of the base metal deposits in the district have been small producers of sulfide and oxidized ores in the past. Ores containing zinc are reported to occur in some quantity, but at least one past producer has experienced difficulties in finding a ready market for them.

BRADSHAW DISTRICT

Plate 1, no. 126

Location.—On western slope of Mineral Range, about halfway between Minersville and Milford. Accessible by roads (if 4 wheel-drive vehicles are used) and trails from Utah Route 21.

Development and production.—The cave in which mineral deposits were first discovered was known as early as 1859, but the Cave claim was not located until 1871, and the district was organized officially in 1875 (Huntley, 1885, p. 474–475). Huntley estimates that prior to 1880 $270,000 worth of limonitic gold-silver-lead ore was produced from the Cave mine. In 1940 a carload of oxidized zinc-lead ore was shipped from this mine—the only reported production of this class of ore from the district. The workings of the Cave mine are fairly extensive; they are described by Butler (Butler and others, 1920, p. 535). In 1953 they were largely inaccessible because of caved portals. Several other smaller mines and prospects are in the district.

Geology.—The district is geologically similar to the Granite district, except that it lies southwest of the Mineral Range stock in limestone reentrants between the granitic stock and a large westward-trending granitic dike (Butler and others, 1920, p. 531–535).

Ore.—The ores replace limestone adjacent to fissures. They are completely oxidized, very limonitic, and have been mined mostly for their lead, gold, silver, and iron-flux content. The grade of the rich ore is given by Huntley (1885, p. 474–475), but that of the oxidized zinc-lead ore is not known. The ores occur mostly in cave clays in the floors of at least 20 caves along the main north-striking fissures and in bedded replacements that extend for considerable distances from the fissures. The oxidized zinc minerals noted are brown smithsonite and aurichalcite that are commonly closely associated with limonite, cerussite, and small quantities of copper carbonates.

Oxidized zinc ore resources.—Ore of the type shipped is reported to remain but the quality is probably small. As far as is known, no search has been made beneath the floors of the caves for pockets of oxidized zinc ores that may have replaced limestones beneath the limonitic ores.

LINCOLN DISTRICT

Plate 1, nos. 128, 129, 137

Location.—South end of the Mineral Range. Accessible by gravel road 2–3 mines north from Minersville.

Development and production.—The first mining recorded in Utah was in this district in 1854, when Brigham Young sent a man named Grundy to mine lead for bullets at the old Spanish mine, now called the Lincoln or Rollins mine. The several mines of the district were in operation much of the time until the 1870's and have been worked intermittently since then for lead and copper ore. The only ore containing oxidized zinc that is known to have been produced from the district is 66 tons of zinc-lead ore from the Croff mine in 1923. This ore contained 4.10 ounces of gold, 310 ounces of silver, 14,300 pounds of lead, and 24,436 pounds of zinc.

Geology and ore.—The district lies south of the main Mineral Range granitic stock in an area where many small stocks and dikes intrude limestones and quartzites of late Carboniferous age. The ore deposit at the Lincoln mine is a small steeply plunging chimney of lead and zinc sulfides in silicated limestone, possibly related to a fissure zone (Butler and others, 1920, p. 534).

Oxidized zinc ores are reported in the shallow workings of the Lincoln, Croff, and Creole mines.

Oxidized zinc ore resources.—The relatively shallow depth of oxidation and the small size of the reported ore bodies suggest that the district will not be a major source of these ores.

References.—Butler and others (1920, p. 529–535); Huntley (1885, p. 475); and Weed (1920, p. 1349).

BEAVER LAKE DISTRICT

Plate 1, no. 134

Location.—In Beaver Lake Mountains about 7 miles west of Read Siding on Union Pacific Railroad; about 15 miles west-northwest of Milford by gravel and unimproved roads. District was not visited.

Development and production.—The district was organized in 1871. It contains several small mines and prospects, including the O.K., San Francisco, Beaver Lake, and Independent Silver (Galena) mines. Production has been small, comprising copper, lead, and iron ores.

Geology and ore.—The lead and zinc deposits are in limestones of probable Paleozoic age north of a large stock of quartz monzonite (Butler, 1913). Bedded replacement deposits of oxidized zinc minerals at the Independent Silver mine are reported to extend through at least 25 feet of strata.

Oxidized zinc ore resources.—Sizable oxidized zinc deposits are reported in the district, particularly at the Independent Silver mine.

ROCKY DISTRICT

Plate 1, no. 142

Location.—In south part of low Rocky Range, about 10 miles northwest of Milford in T. 27 S., R. 11 W. The main mine, Old Hickory, is visible from Utah Route 21 and is accessible by dirt road extending north from that highway.

Development and production.—Most of the fairly large production of the district was from the Old Hickory mine (Butler, 1913) and consisted of siliceous silver, copper, and some lead ores.

Geology and ore.—The Old Hickory deposit is in an irregular contact-metamorphic zone of magnetite-bearing limestone at the south edge of a quartz monzonite stock. In addition to magnetite, the ore contains copper sulfides and some lead and zinc minerals. Oxidized zinc ores are reported to be present in places in the mine.

Other reference.—Butler and others (1920, pl. XL, p. 505–512, 515, 518).

STAR DISTRICT

Plate 4

Location.—In Star Range, 5–10 miles west and southwest of Milford, in T. 28 S., R. 11 and 12 W. Reached from several sides by fair to poor dirt roads and roads traversable by 4-wheel-drive vehicles.

Development and production.—The district was divided during the first few years into the Star and North Star districts. The Star district was organized in 1870 and its most productive years were before 1880 (Huntley, 1885, p. 471–474). Production gradually revived from 1904 to 1918 but decreased markedly thereafter. The Moscow mine, probably the largest and most productive in the district, includes a group of workings, some of which are called East Moscow, Old Moscow, and presumably Burning Moscow.

Production of oxidized zinc began in 1907, when the Cedar-Talisman shipped several carloads of high-grade oxidized zinc ores, and continued until 1918 from several mines. The oxidized zinc, lead-zinc, and zinc-lead ores came from the Cedar-Talisman, Moscow, Harrington-Hickory (or New Majestic), Osceola, Rebel, Wild Bill, and Leonora mines. Production of oxidized zinc-bearing ores was resumed at intervals after 1939 from the Harrington-Hickory, Lady

Potter, and Burning Moscow mines but ceased again before 1950. In 1944–47 the Harrington-Hickory mine was probably the largest single producer of oxidized zinc-lead ores in Utah, contributing 3,721.65 short tons.[2] The production figures in table 9 show that the Star district has been one of the largest sources of oxidized zinc-lead and zinc ores in Utah.

TABLE 9.—*Oxidized zinc and zinc-lead ore produced in the Star district, 1907–53*

[Compiled from U.S. Geol. Survey (1907–17), U.S. Bur. Mines (1938–53), and data published with permission of the Harrington Mines Co.]

Year	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Recoverable lead (pounds)	Recoverable zinc (pounds)
1907	159		323		106,008
1908	99	0.99	1,044	11,536	54,902
1909	None				
1910	87		186	1,264	61,854
1911–12	None				
1913	37				25,262
1914	None				
1915	329		1,491	35,000	160,528
1916	923			68,224	440,322
1917	1,120			886	588,106
1920–38	None				
1939	(1)				
1940	(1)				
1941–43	None				
1944	[2] 256				
1945	[2] 899				
1946	[2] 2,244				
1947	[2] 962				
1948–53	None				
Total or sum	7,115	0.99	3,044	116,910	1,436,982

[1] Probably a small quantity of oxidized zinc-lead ore was produced.
[2] Zinc-lead ore containing recoverable silver, lead, and zinc.

The average zinc content of ore from the Moscow mine in 1908 was 27.73 percent; from the Cedar-Talisman mine in 1913, 40.16 percent; and from the Harrington-Hickory mine in 1944–47, 12.29 percent. Both lead and silver were recovered from much of the ore; that from the Harrington-Hickory mine averaged 11.38 percent lead and 7.74 ounces of silver per ton.[3]

Geology.—The geology and ore deposits of the Star district have been described by Butler (1913). The Star Range exposes northward-striking eastward-dipping sedimentary rocks, mostly limestones and quartzites, that range from Silurian to Triassic in age; most of the strata on the west side and crest of the range are of Paleozoic age and those on the east side are of Mesozoic age. Many small stocks, plugs, and dikes of quartz monzonite and granodiorite intrude the strata, and much of the limestone is metamorphosed to marble near its contacts with these intrusions. The western foothill area is largely capped by latite flows of Tertiary age.

The ore deposits are in igneous contact zones, replacement-fissure veins, replacement chimneys at the intersections of fissures with fa-

[2] Published with permission of the Harrington Mines Co.
[3] Published with permission of the Harrington Mines Co.

vorable beds, and in beds selectively replaced, mostly limestone, as for example in the Harrington-Hickory mine. In most massive limestones, however, replacement along fissures is rather uniform in the different beds producing a tabular deposit parallel with the fissure. The ore bodies in the Mammoth, Hoosier Boy, and Rebel mines are of this type. Some replacement-fissure deposits merge into contact deposits, such as those of the Wild Bill and Hub mines.

Ores.—Secondary replacement pockets of oxidized zinc ores in the limestone wallrocks were noted in the Cedar-Talisman and Hoosier Boy and are probably present in the Moscow, but most of the oxidized zinc-bearing deposits in the district directly replaced the primary ores in conjunction with some internal migration of zinc and silver within the ore bodies. Oxidation commonly extends to more than 500 feet in depth.

The oxidized zinc-bearing ores are varied and complex. The oxidized zinc minerals are hemimorphite, smithsonite, willemite, and aurichalcite; hydrozincite is notably absent. Supergene willemite, common at the Cedar-Talisman mine, is also locally abundant in several districts in the Basin and Range province of Nevada, California, Arizona, and New Mexico. Silver and lead are present in recoverable quantities in nearly all the direct-replacement ores. In some of the ores small quantities of molybdenum, vanadium, arsenic, antimony, phosphorous, and cadmium are present in wulfenite, vanadinite, mimetite, pyromorphite, greenockite, and lead-antimony ochers. Iron is abundant in most ores, but the assay of wallrock-replacement ore from the Cedar-Talisman mine showed no iron at all. The following partial analyses illustrate some of this variation in composition:

Analyses of ores from the Star district

[Analyst, Deason and Nichols, Salt Lake City, 1954, 1956, except as otherwise noted. N.d. means not determined]

Constituent	Hoosier Boy mine (grab sample from dump and vein walls)	Harrington-Hickory mine		Rebel mine (grab sample of hemimorphite ore from open-cut and dumps)	Cedar-Talisman mine (willemite-hemimorphite-smithsonite ore)	Moscow mine (grab sample of smithsonite ore from dumps)
		Selected hemimorphite ore (from dumps) [1]	Oxidized zinc ore (from raise No. 3) [2]			
Gold oz. per ton	N.d.	None	N.d.	0.005	0.015	0.01
Silver do	N.d.	0.40	10.10	.070	4.10	1.50
Lead percent	N.d.	4.8	12.00	9.4	5.6	2.2
Zinc do	34	24.9	12.27	41.4	40.1	37.8
Silica do	8	64.0	N.d.	N.d.	22.4	N.d.
Iron do	N.d.	N.d.	N.d.	N.d.	None	N.d.
Carbonate do	26.8	8.3	N.d.	8.0	8.50	30.0
Phosphorus do	N.d.	N.d.	N.d.	N.d.	.196	N.d.
Molybdenum do	N.d.	.11	N.d.	N.d.	N.d.	N.d.

[1] Cadmium and vanadium looked for but not found.
[2] Analysis published with permission of Harrington Mines Co. Analyst not known, probably smelter returns from a smelter near Salt Lake City.

Oxidized zinc ore resources.—The district is one of the more promising in Utah as a potential source of high-grade oxidized zinc and lead-zinc ores. Among the mines that still contain or are reported to contain oxidized zinc and zinc-lead ores are the Moscow, Cedar-Talisman, Rebel, Lady Byran (or Lady Potter), and Wild Bill. The Cedar-Talisman Co. estimated in 1920 that the mine and dump contained 40,000 to 50,000 tons of blocked-out ore that averaged 8 percent lead, 14 percent zinc, and 7 ounces of silver per ton (Weed, 1920, p. 1346). Ore from the Cedar-Talisman mine might be amenable to milling by flotation owing to its low iron content; also, some of the richest ore might bring premium prices at eastern zinc oxide plants, as have similar ores from Ely and Eureka, Nev., in recent years.

Other references.—Butler and others (1920, p. 505–527); Weed (1920, p. 1346, 1373); and Clark (1916, p. 89–91).

SAN FRANCISCO DISTRICT

Plate 1, nos. 132, 135

Location.—In southern part of San Francisco Mountains between the former towns of Frisco and Newhouse, on Utah Route 21 about 15 miles west of Milford, in T. 27 S., R. 13 W.

Development and production.—The district was organized in 1871 but was not important until 1875 when the deposit at the Horn Silver mine was discovered. This deposit, one of the richest and largest high-grade silver-lead-copper-zinc ore bodies in Utah, was opened in 1876 and operated continuously until about 1952, although it has not been a major producer since the 1920's. By the 1920's tthe mine had produced at least $25 million worth of ore (Butler and others, 1920).

Very little zinc carbonate and silicate ores have been produced from the district. In 1929 the Horn Silver mine shipped 35 tons of oxidized zinc-lead ore that yielded over 7 tons of metallic lead and 6½ tons of metallic zinc. In 1940 some zinc ore, probably oxidized, was shipped from the King David mine direct to the Tooele smelter.

Geology and ore.—In the Horn Silver deposit the ore and gangue minerals have partly filled open fissures and partly replaced the brecciated rocks adjacent to the fissures in and along the major northward-striking Horn Silver fault which lies along the eastern base of the San Francisco Mountains. The volcanic rocks on the east side of the fault are downthrown more than 1,600 feet against limestones of Cambrian(?) and Ordovician age. The geology of the main vein deposit has been described at length by Butler (1913); and Butler and others (1920, p. 519–527). The supergene zinc ore bodies, which are large and complex, are described on page 19 of this report. Hemimorphite and smithsonite are the ore minerals. Zinc sulfide bodies in parts of the mine contain wurtzite, which Butler (1913) interpreted as a product of oxidation and secondary enrichment (p. 20).

The ores in the King David mine (connected by drifts to the Horn Silver) are reported to be oxidized zinc and lead ores containing some silver. They are bedded replacement deposits in limestone.

Oxidized zinc ore resources.—The San Francisco district contains some of the largest deposits of oxidized zinc minerals in Utah. If a commercial milling process can be perfected to concentrate these low-grade deposits, the district, and especially the Horn Silver mine, is potentially a major source of ores. Some high-grade shipping ore is present with the low-grade material, but it is widely scattered and not amenable to selective mining without great cost and waste, except perhaps for a small tonnage in the surface cave-in and openpit of the Horn Silver mine (fig. 9).

Other references.—Becker (1880, p. 37–47); Butler (1914, p. 413–434, 529–558); and Emmons (1902, p. 658–683).

PINE GROVE DISTRICT

Plate 1, no. 146

Location.—West slope of Wah Wah Mountains in Pine Grove Canyon, about 33 miles west of Milford. Best access road is Utah Route 21 over Wah Wah Pass then south down Pine Valley to Pine Grove Canyon. Wah Wah mine is up the canyon high in the mountains, at an altitude of 7,500 feet.

Development and production.—The district was organized in 1873 but no work was done until it was reorganized in 1879. Before 1918 the Pine Grove Consolidated Mining Co. opened up the Wah Wah mine, and it was further developed by the Revenue Mining Co. In the early 1940's the district consisted of several prospects and only three productive lead-silver and gold mines, the Wah Wah on the Tasso Claim, the Revenue about 3,000 feet west-northwest of the Wah Wah, and a shaft on the Keystone no. 2 claim about 1,800 feet east-southeast of the Wah Wah (Goddard, E. N., written communication, 1943). The Wah Wah mine consists of the Tasso shaft, which has levels at 15, 80, and 125 feet below the collar, and drifts and stopes that in 1940 aggregated about 1,300 feet. The only known oxidized-zinc ore production was in 1943–45, when 1,439 tons of ore was produced that yielded 274,500 pounds of metallic zinc (U.S. Bureau of Mines, 1943–45).

Geology.—Most of the range is composed of a thick sequence of quartzite, shale, and massive limestone, in part of Middle Cambrian age. The beds trend northward and dip from a few degrees to 40° E.

(Arthur Richards and A. L. Brokaw, written communication, 1943). A large eastward-trending dike of rhyolite is exposed in Pine Grove Canyon just east of the Wah Wah mine. The dike is about 1½ miles long and 1,000 feet wide. The mine is on a major fault that strikes N. 75° W. and in the mine dips about 65° N. Goddard reports (written communication, 1943) that the fault has a large horizontal component of displacement of about 900 feet. In the Wah Wah mine workings the fault zone is 60 to 120 feet wide and consists of gouge, sheared shale and limestone, and some breccia, but in the Revenue mine to the west the fault is entirely within quartzite and is composed of two zones of sheeted and sheared quartzite, each 15 feet wide.

Ore.—The sulfide ore body at the Wah Wah mine is completely oxidized to a depth of 125 feet and consists of porous brown, red, and yellow masses of limonitic oxidized material containing lead, silver, gold, copper, and zinc. A few unoxidized pockets on the 125-foot level are composed of silver-bearing galena with small quantities of sphalerite and sheared pyrite; some of the pyrite is coated with covellite. Rhodochrosite, ankerite, and galena were noted in the deepest workings at about 200 feet.

Most of the zinc-bearing material is apparently low-grade smithsonite rock and smithsonite-bearing breccia which is lean in other metals except zinc. The smithsonite rock is a large lenticular replacement body in the wallrock beneath and east of a partly oxidized base- and precious-metal ore body. The zinc wallrock body is exposed in the 125-foot level and extends to at least 20 feet below the 200-foot level. The oxidized zinc body trends northwest and is about 170 feet long and 5 to 50 feet thick; it dips for over 100 feet downward from the 125-foot level at about 50° NE.

Oxidized zinc ore resources.—The Wah Wah mine contains a large body of low-grade oxidized zinc-bearing material. Probably only a small part of this material can be selectively mined and sorted as shipping-grade zinc ore. Production records show that some of this ore was mined during World War II. The U.S. Bureau of Mines developed the oxidized zinc body as part of their strategic minerals program according to Jones and Dunham (1946), and they state (U.S. Bureau of Mines, 1943, p. 472):

> * * * the Bureau of Mines did considerable development on the property, including 145 feet of drifting and 200 feet of diamond drilling.
>
> As a net result of the aid received, the company reports ore reserves exposed include 38,500 tons of oxide zinc ore, 8,000 tons of sulfide zinc-lead ore, and 20,000 tons of oxidized silver-lead ore.

Most of these reserves are still unmined.

Reference.—Butler and others (1920, p. 527–529).

PIUTE COUNTY

OHIO DISTRICT

Plate 1, no. 148

The Ohio district is a gold, silver, lead, copper district on the east side of the Tushar Range, about 6 miles southwest of Marysvale on the Sevier River. Some of the ore deposits are in quartzites, and others are in limestones and oxidized in the upper part. Oxidized zinc minerals are reported from the Cascade mine in quartzite and might be expected in some of the nearby mines in limestone. The district was not visited.

IRON COUNTY

ESCALANTE DISTRICT

Plate 1, no. 149

Location.—In low hills that bound Escalante Desert on the southwest, about 10–20 miles southeast of Modena. Escalante mine is 15 miles north of Enterprise on west side of Modena-Enterprise road, T. 36 S., R. 17 W.

Development.—The Escalante mine is one of the largest of several prospects and has a 150-foot shaft, a small dump, and an old mill foundation on the property. No production is recorded from the property.

Geology.—The widely scattered prospects are on vein and fissure zones. The Escalante deposit is in a fissure zone that trends north-northeast and dips east-southeast in rhyolite of Tertiary age. Although the rhyolite is sheared and silicified over a width of 100 feet, only 4 to 10 feet has been mineralized. The fissure zone can be traced from about 1,000 feet along its strike. The vein contains many thin crusts of cerussite, traces of galena, yellow descloizite, gray to bright-green pyromorphite, annabergite(?), orange-red wulfenite, and green arsenates of copper, associated with calcite, fluorite, quartz, adularia, iron oxides, and possibly cerargyrite. Colloform structures are common in the calcite and fluorite.

The deposit is the northeasternmost representative of a vanadium-, phosphorous-, and molybdenum-rich type of direct-replacement deposit that is common in southern New Mexico, Arizona (for example, near Yuma), Southern California, and southern Nevada. Vanadinite, pyromorphite, descloizite, cuprodesclozite, and wulfenite are common and characteristic of such deposits.

Oxidized zinc ore resources.—No oxidized zinc-bearing material approaching commercial grade is present here, although it might be a byproduct of the silver- and lead-bearing material.

Reference.—Butler and others (1920, p. 567–568).

INDIAN PEAK DISTRICT

Plate 1, no. 150

Location.—Southern part of Needle Range at and south of Indian Peak. New Arrowhead mine is in northernmost part of Iron County just south of Beaver County line, about 7 miles south of Indian Peak; reached by 28 to 35 miles of dirt roads north and west from Zane or Lund. District was not visited.

Development and production.—The district has been prospected for many years and produced a little lead and silver prior to World War II. In 1943 the New Arrowhead Mining Co. of Cedar City, Utah, opened and operated the New Arrowhead mine. From 1943 through 1946 the company produced, among other classes of ore, about 2,000 tons of oxidized zinc and zinc-lead ores that contained about 10 ounces of gold, 950 ounces of silver, 6,500 pounds of copper, 270,000 pounds of lead, and 570,000 pounds of zinc (U.S. Bureau of Mines, 1943–46).

Geology and ore.—The lead-zinc deposit is reported to be in a contact-metamorphic zone in dolomite which is intruded by porphyry. Zinc carbonate ore is in the dolomite hanging wall and has directly replaced the primary ore minerals. The oxidized zinc deposit is reported to contain about 15 percent zinc before sorting.

WASHINGTON COUNTY

TUTSAGABET DISTRICT

Plate 1, nos. 151, 152, 153

Location.—West of St. George, Utah, on northwest slope of Beaver Dam Mountains. Accessible by dirt road south from U.S. Highway 91 about 15 miles west of St. George, near pass.

Description.—Oxidized zinc minerals occur at the Black Warrior, Paymaster, and Dixie-Apex mines, and a very large body of iron-rich material that contains some zinc remains in the upper workings of both the Dixie-Apex and Paymaster. In 1947 the Dixie-Apex mine produced 773 tons of oxidized lead ore, probably selectively mined from this large body; the ore yielded 4 ounces of gold, 1,255 pounds of copper, 278,322 pounds of lead, and 9,275 pounds of zinc. (U.S. Bur. Mines, 1947). The mineralized material probably is an ore body that oxidized in place, as it contains small patches of galena.

No oxidized zinc ore of commercial grade is known in this district, and, according to A. R. Kinkel, Jr. (written communication, 1943), it is doubtful if the gossans contain enough zinc to warrant consideration as a potential zinc source.

SELECTED REFERENCES

Arentz, S. S., 1915, *in* Higgins, W. C., Wonderful showing being made by the Lakeview Mining Company on Promontory Point: Salt Lake Mining Review, v. 17, no. 11, p. 11–15.

Baker, A. A., and Crittenden, M. D., 1961, Geology of the Timpanogos Cave quadrangle, Utah: U.S. Geol. Survey Quad. Map GQ–132.

Becker G. F., 1880, Reconnaissance of the San Francisco, Eureka, and Bodie districts [Utah]: U.S. Geol. Survey First Ann. Rept., p. 37–47.

Beeson, J. J., 1925, Mining districts and their relations to structural geology: Am. Inst. Mining Metall. Eng. Trans. [reprint] no. 1500, 36 p.

Billingsley, P. R., 1933, The utilization of geology in Tintic, Utah, *in* Ore deposits of the Western States (Lindgren volume): New York, Am. Inst. Mining Metall Eng., pl. 12.

Boutwell, J. M., 1912, Geology and ore deposits of the Park City district, Utah: U.S. Geol. Survey Prof. Paper 77, 231 p.

Boutwell, J. M., and others, 1933, The Salt Lake region [Utah]: Internat. Geol. Cong., 16th, United States, 1933, Guidebook 17, Excursion C-1, 149 p.

Butler, B. S., 1913, Geology and ore deposits of the San Francisco and adjacent districts, Utah: U.S. Geol. Survey Prof. Paper 80, 212 p.

———1914, Geology and ore deposits of the San Francisco and adjacent districts, Utah: Econ. Geology, v. 9, p. 413–434, 529–558.

Butler, B. S., and Loughlin, G. F., 1915, A reconnaissance of the Cottonwood–American Fork mining region, Utah: U.S. Geol. Survey Bull. 620, p. 165–226.

Butler, B. S., and others, 1920, The ore deposits of Utah: U.S. Geol. Survey Prof. Paper 111, 672 p.

Calkins, F. C., and Butler, B. S., 1943, Geology and ore deposits of the Cottonwood-American Fork area, Utah: U.S. Geol. Survey Prof. Paper 201, 152 p.

Clark, R. W., 1916, A new occurrence of crystallized willemite, Star district, Beaver County, Utah: Am. Mineralogist, v. 1, no. 6, p. 89–91.

Crane, G. W., 1917, Geology of the ore deposits of the Tintic mining district [Utah]: Am. Inst. Mining Eng. Trans., v. 54, p. 342–355.

Crawford, R. D., 1913, Geology and ore deposits of the Monarch and Tomichi districts: Colo. Geol. Survey Bull. 4, p. 250, 251.

Crittenden, M. D., 1951, Manganese deposits of western Utah: U.S. Geol. Survey Bull. 979–A, p. 49–51.

Disbrow, A. E., 1961, Geology of the Boulter Peak quadrangle, Utah: U.S. Geol. Survey Quad. Map GQ–141.

Disbrow, A. E., and Morris, H. T., 1957, Ore deposits of the North Tintic mining district, *in* Guidebook to the geology of Utah, no. 12: Utah Geol. Soc., 15 p.

Dunham, W. C., and Gunnell, F. H., 1948, Lead and zinc deposits of the Treasure Hill mines, Ophir mining district, Tooele County, Utah: U.S. Bur. Mines Rept. Inv. 4181, 25 p.

Emmons, S. F., 1902, The Delamar and Horn-Silver mines; two types of ore deposits in the deserts of Nevada and Utah: Am. Inst. Mining Eng. Trans., v. 31, p. 658–683.

Gilluly, James, 1932, Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U.S. Geol. Survey Prof. Paper 173, 171 p.

Heikes, V. C., and Butler, B. S., 1916, Notes on the Promontory district, Utah: U.S. Geol. Survey Bull. 640, p. 1–10.

Hill, J. M., 1916, Notes on some mining districts in eastern Nevada: U.S. Geol. Survey Bull. 648, 214 p.

Huntley, D. B., 1885, The mining industries of Utah: U.S. 10th Census [1880] v. 13, p. 405–489.

Jones, R. L., and Dunham, W. C., 1946, Examination of the Wah Wah lead-zinc mine, Beaver County, Utah: U.S. Bur. Mines Rept. Inv. 3853, 14 p.

Kemp, J. F., and Billingsley, Paul, 1918, Notes on Gold Hill and vicinity, Tooele County, western Utah: Econ. Geology, v. 13, p. 247–274.

Kinney, D. M., 1955, Geology of the Uinta River-Brush Creek area, Duchesne and Uintah Counties, Utah: U.S. Geol. Survey Bull. 1007, p. 159–161.

Ledoux, Auguste, 1917, Aurichalcite from Big Cottonwood Canyon, Salt Lake County, Utah: Wash. Acad. Sci. Jour., v. 7, no. 12, p. 361–365.

Lindgren, Waldemar, and Loughlin, G. F., 1919, Geology and ore deposits of the Tintic mining district, Utah: U.S. Geol. Survey Prof. Paper 107, 282 p.

Loughlin, G. F., 1914, The oxidized zinc ores of the Tintic district, Utah: Econ. Geology, v. 9, p. 1–19.

——— 1917, Zinc carbonate and related copper carbonate ores at Ophir, Utah: U.S. Geol. Survey Bull. 690-A, p. 1–14.

——— 1918, The oxidized zinc ores of Leadville, Colo.: U.S. Geol. Survey Bull. 681.

Lovering, T. S., 1949, Rock alteration as a guide to ore—East Tintic district, Utah: Econ. Geology Mon. 1, 65 p.

——— 1951, Structure of East Tintic district modified, *in* Hawkes, H. E., Jr., Geochemistry, a symposium on the prospector's newest tool: Mining Cong. Jour., v. 37, no. 9.

Lovering, T. S., Sokoloff, V. P., and Morris, H. T., 1948, Heavy metals in altered rock over blind ore bodies, East Tintic district, Utah: Econ. Geology, v. 43, no. 5, p. 384–399.

Morris, H. T., 1957, General geology of the East Tintic Mountains; Utah; *in* Guidebook to the geology of Utah, no. 12: Utah Geol. Soc., 56 p.

Morris, H. T., and Lovering, T. S., 1961, Stratigraphy of the East Tintic Mountains [Utah]: U.S. Geol. Survey Prof. Paper 361, 145 p.

Nolan, T. B., 1935, The Gold Hill mining district, Utah: U.S. Geol. Survey Prof. Paper 177, 172 p.

Raymond, R. W., 1872, Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1871, U.S. Treasury Dept., Washington, esp. p. 321, 325.

Rey, M., Sitia, G., Raffinot, P., Formanek, V., 1954, Flotation of oxidized zinc ores: Mining Eng., v. 6, no. 4, p. 416–420.

Richards, R. W., 1911, Notes on lead and copper deposits in the Bear River Range, Idaho and Utah: U.S. Geol. Survey Bull. 470.

Silliman, Benjamin, Jr., 1872, Geological and mineralogical notes on some of the mining districts of Utah Territory and especially those of the Wasatch and Oquirrh ranges of mountains: Am. Jour. Sci., 3d ser., v. 3, p. 195–201.

Smirnow, S. S., 1954, Die oxydationszone sulfidischer lagerstätten: Berlin, Akademie-Verlag, p. 179.

Spurr, J. E., 1895, Economic geology of the Mercur mining district [Utah]: U.S. Geol. Survey 16th Ann. Rept., 1894–95, pt. 2, p. 395–455.

Staples, L. W., 1935, Austinite, a new arsenate mineral from Gold Hill, Utah: Am. Mineralogist, v. 20, no. 2, p. 112–119.

Stranierio, Diego, 1954, Nossa's unique electrolytic plant extracts zinc from calamine ores: Eng. Mining Jour., v. 155, no. 5, p. 68-72.

Stringham, B. F., 1942, Mineralization in the West Tintic mining district, Utah: Geol. Soc. America Bull., v. 53, no. 2, p. 267–290.

Tower, G. W., Jr., and Smith, G. O., 1899, Geology and mining industry of the Tintic district, Utah: U.S. Geol. Survey 19th Ann. Rept., pt. 3, p. 601–767.

U.S. Bureau of Mines, 1924–31, Mineral Resources of the United States [annual volumes for the years indicated].

——— 1932–53, Minerals Yearbook [annual volumes for the years indicated].

U.S. Geological Survey, 1883–1923, Mineral Resources of the United States [annual volumes for the years indicated].

Van Horn, F. R., 1914, The occurrence of bournonite, jamesonite, and calamine at Park City, Utah: Am. Inst. Mining Eng. Bull. 92, p. 2223–2230.

Varley, Thomas, Stevenson, C. C., Ried, W. S., 1921, Utah's mineral wealth: Salt Lake City, The Commercial Club-Chamber of Commerce, 32 p.

Weed, W. H., 1920, The mines handbook: New York, V. 14, Hill Publishing Co.

Wendt, W. J., 1953, Ammonia—Ammonium carbonate leaching of low-grade zinc ores: Eng. Mining Jour., v. 154, no. 9, p. 84–90.

Wideman, F. L., 1947, Ophir Hill Consolidated lead-zinc mine, Tooele County, Utah: U.S. Bur. Mines Rept. Inv. 4072, 13 p.

Young, J. C., 1956, Geology of the southern Lakeside Mountains, Utah: Utah Geol. and Mineralog. Survey Bull. 56, 116 p.

Zalinski, E. R., 1913, Occurrence of oxidized zinc ores at Tintic: Eng. Mining Jour., v. 95, p. 1227–1228.

Anonymous, 1917, Annual report for the year ending Dec. 31, 1916: Eureka, Utah, Lower Mammoth Mining Company.

——— 1957, Utah: Eng. Mining Jour., v. 158, no. 11, p. 192; no. 12, p. 196.

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U.S. GOVERNMENT PRINTING OFFICE : 1963 O—667528