Oxidized Zinc Deposits of the United States

GEOLOGICAL SURVEY BULLETIN 1135

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STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

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Part 1. General Geology

By ALLEN V. HEYL *and* C. N. BOZION

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Descriptions of the many varieties of oxidized zinc deposits of supergene and hypogene origin

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OXIDIZED ZINC DEPOSITS OF THE UNITED STATES

PART 1. GENERAL GEOLOGY

By ALLEN V. HEYL and C. N. BOZION

ABSTRACT

Deposits of oxidized zinc-bearing ores are widely distributed throughout the United States and have yielded about 4½ million tons of metallic zinc and zinc oxide, most of which was produced prior to 1920. The deposits contain carbonates, silicates, or oxides of zinc, and most are of supergene origin. Smithsonite and hemimorphite are the main oxidized zinc minerals in supergene deposits; hydrozincite, willemite, aurichalcite, descloizite, chalcophanite, and sauconite are also important. Hypogene deposits of oxidized zinc minerals are uncommon; nevertheless, the unique metamorphic deposits of franklinite, willemite, and zincite at Franklin Furnace and Sterling Hill, N.J., have been by far the most important source of oxidized zinc ores.

Commercial oxidized zinc ores have a wide range in mineralogy, and commonly zinc is not the only recoverable metal. Lead, vanadium, copper, silver, gold and, in places, molybdenum, antimony, tungsten, and bismuth have been recovered. Manganese and iron are byproducts of the New Jersey and Leadville deposits. Commercial ores commonly contain at least 25 percent zinc and may contain as much as 50 percent. Ores containing 20 percent lead and zinc combined are sold as zinc-lead ores.

Although most of the deposits are in carbonate rocks, commercial deposits in noncarbonate rocks are not uncommon in the Western States. Most oxidized zinc deposits of supergene origin can be classified as direct-replacement deposits, wallrock-replacement deposits, or saprolitic accumulations. More than half of the known ore bodies directly replace hypogene sulfide deposits; such direct-replacement deposits are very complex mineralogically if the replaced sulfide deposits were also complex. Deposits that have replaced wallrocks after leaching of hypogene sulfides are commonly less complex and richer in zinc than direct-replacement deposits. Wallrock-replacement deposits are confined to carbonate rocks and are rare east of the Rocky Mountains. Saprolitic accumulations of smithsonite and hemimorphite in solution pockets of decomposed limestone are known only in the Valley and Ridge province of the Eastern United States.

INTRODUCTION

Deposits of oxidized zinc minerals are widely distributed throughout the United States and have yielded about 4½ million tons of metallic zinc (table 1). Zinc, zinc-lead, zinc-lead-silver, and zinc-copper ores are included. Most of the ore was produced before 1920; since then, only the geologically unique deposits of Franklin and Sterling Hill, N.J., have been a major source, although recently production has been increasing in Utah and Nevada.

The term "oxidized zinc deposits" is used in this report in its geological sense to describe deposits or parts of deposits that contain oxides, carbonates, or silicates of zinc that result from weathering processes (supergene deposits) or from processes other than weathering (hypogene deposits). Although most of the oxidized zinc deposits in the United States are of supergene origin, the greatest quantity of oxidized zinc ore has been produced from the hypogene franklinite and willemite deposits at Franklin and Sterling Hill, N.J. Chemists, unlike geologists, define "oxidized" as denoting an increase in positive valence or a decrease in negative valence.

TABLE 1.—*Oxidized zinc ore produced in the United States*

[Compiled from annual volumes of "Mineral Resources of the United States," U.S. Geol. Survey, and "Minerals Yearbook of the United States," U.S. Bur. Mines, 1900–54]

	Ore, in short tons (mostly in hand-sorted concentrates)	Metal[1] (short tons)
Supergene ore:		
New Jersey[2]	100,000	30,000
Pennsylvania[2]	754,000	123,000
Maryland	700	200
Virginia[2]	266,000	93,000
Tennessee[2]	400,000	120,000
Kentucky	25,000	7,400
Southeastern Missouri (including Valle mines)	100,000	30,000
Central Missouri	10,000	3,000
Western Missouri, Kansas, and Oklahoma[2]	[3] 500,000	190,000
Wisconsin, Iowa, N. Illinois[4]	175,000	46,000
Arkansas[4]	60,000	24,000
Texas[4]	260	150
Colorado	900,000	150,000
New Mexico[2]	242,000	80,000
Arizona[4]	53,000	10,800
Utah	113,000	30,000
Nevada[2]	540,000	65,000
California	393,000	27,500
Idaho[2]	14,000	2,000
Montana[2]	280,000	40,000
Washington[2]	11,000	700
Total	4,936,900	1,072,750
Hypogene ore:		
New Jersey	30,000,000	3,500,000
Grand total	34,936,000	4,572,750

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[1] Some of this zinc listed as metal was processed from the ore into zinc oxide and then sold and never refined into metal.

[2] Estimated from incomplete published production data, plus information based on history and size of mines. Eastern states include 19th-century production. No known production of metal from Alaska.

[3] Includes 550 tons from Davis, Murray County, Okla.

[4] Production to 1934 only.

Notable works on the oxidation of zinc deposits are by Smirnow (1954, p. 167–189), Loughlin (1916; 1918), Kelley (1958), Boswell and Blanchard (1927, p. 419–453), Hewett (1931), Mason (1947), Palache (1935), and Watson (1905). The complex origins of the several varieties of oxidized zinc ores have been adequately described by Loughlin (1914, 1916, 1918), Boswell and Blanchard (1927), Butler (1913), Hewett (1931), Smirnow (1954), and Kelley (1958), and interested readers are referred to these works.

This report is intended as a descriptive summary. The fieldwork on which it is based was completed in the central Western States in 1952–56, and additional studies were made in the Central and Eastern States before and after the western studies. Research and compilation were completed in 1956–59. Other reports will describe in detail the geology and origin of the oxidized zinc deposits in Colorado, Utah, Nevada, and California. (See also Heyl and Bozion, 1960.)

DISTRIBUTION

Deposits of oxidized zinc ores are widely distributed throughout the United States (pl. 1), especially in Precambrian rocks of the Adirondack uplift and the New Jersey Highlands of the New England province, the Ridge and Valley province, the principal Mississippi Valley zinc and lead districts, and the general region of the Rocky Mountains and Basin and Range province. They are uncommon elsewhere in the country.

All the oxidized zinc districts are shown on plate 1, but of these the following have been the most important producing areas:

- New England province:
  - Franklin-Sterling Hill, N.J.
- Ridge and Valley province:
  - Friedensville, Pa.
  - Austinville, Va.
  - Mascot-Jefferson City, Tenn.
  - Embreeville, Tenn.
- Interior and Ozark Plateaus and Central Lowland provinces:
  - Kentucky-Illinois fluorspar-zinc district
  - Upper Mississippi Valley zinc-lead district
  - Valle Mines, Mo.
  - Tri-State zinc district
  - Arkansas zinc districts
- Southern Rocky Mountains province:
  - Leadville, Colo.
  - Aspen district, Colo.
  - Spring Creek district, Colo.
  - Monarch-Tomichi districts, Colo.
- Middle Rocky Mountains province:
  - Big Cottonwood district, Utah
- Northern Rocky Mountains province:
  - Mineral Hill (Hailey) district, Idaho
  - Alder Creek or Mackay district, Idaho
  - Texas (Gilmore) district, Idaho
  - Warm Springs (Ketchum) district, Idaho
  - Clayton area, Bayhorse district, Idaho

  - Nicholia (Birch Creek) district, Idaho
  - Hecla or Bryant district, Mont.
  - Colorado district, Mont.
  - Elkhorn district, Mont.
  - Radersburg district, Mont.
  - Northport district, Wash.
- Basin and Range province:
  - Magdalena district, N.Mex.
  - Central-Hanover districts, N.Mex.
  - North Tintic and Tintic districts, Utah
  - Promontory district, Utah
  - Ophir-Dry Canyon districts, Utah
  - Star and other districts near Frisco, Utah
  - Pioche-Bristol districts, Nev.
  - Comet district, Nev.
  - Goodsprings, Nev.
  - Ely or Robinson district, Nev.
  - Lone Mountain district near Eureka, Nev.
  - Aurum, Nev.
  - Bagdad, Ariz.
  - Pima (Twin Buttes) district, Ariz.
  - Tombstone and other districts in Dragoon Mountains, Ariz.
  - Globe-Miami districts, Ariz.
  - Cerro Gordo district, Calif.
  - Coso-Argus districts, Calif.
  - Resting Springs (Tecopa)-Kingston Range districts, Calif.
  - Ivanpah district, Calif.

Minerals found in deposits in the United States are listed below in the relative order of their abundance. Most of the less common minerals at Franklin Furnace and Sterling Hill, N.J., are omitted; for these minerals the reader is referred to Palache (1935). At least half of the associated minerals listed are common in most oxidized zinc deposits; the others are abundant in some localities.

Minerals found in oxidized zinc deposits in the United States

Main zinc minerals	*Main associated minerals*
Smithsonite and monheimite	Goethite or limonite
Hemimorphite (calamine)	Cerussite
Hydrozincite	Jarosite
Willemite	Plumbojarosite
Franklinite	Pyrolusite
Zincite	Psilomelane or cryptomelane
Aurichalcite	Calcite
Sauconite	Anglesite
Descloizite and mottramite	Cerargyrite
Chalcophanite	Wulfenite
Hetaerolite	Stolzite
Hydrohetaerolite	Vanadinite
Gahnite	Kaolinite
Wurtzite	Malachite
Adamite	Azurite
Goslarite	Gold
Zincian aragonite (or nicholsonite)	Chrysocolla
Serpierite	Chalcocite
Helvite	Tenorite or copper pitch
Danalite	Pyromorphite
Austinite	Hematite
Zincian siderite	Aragonite

MINERALOGY

Oxidized zinc deposits have a much wider range in mineralogy than is commonly described; nevertheless, sphalerite, the isometric zinc sulfide, is the hypogene source mineral for nearly all the oxidized zinc deposits in the country except for the important but geologically unique deposits of Franklin and Sterling Hill, N.J. Wurtzite, the hexagonal zinc sulfide, is an uncommon hypogene mineral in the United States.

Of the oxidized zinc minerals derived from sphalerite in deposits of supergene origin, smithsonite, the carbonate of zinc, and hemimorphite, a hydrous silicate of zinc, are the most important. Smithsonite is the more common and widespread of the two, but hemimorphite occurs in most deposits, at least in small quantities, and is the principal ore mineral in many districts. Other zinc minerals are major ore minerals in places or form special varieties of ore—particularly hydrozincite, the basic zinc carbonate, which is a major constituent of many of the oxidized zinc deposits of California and Nevada.

Hemimorphite occurs typically in clusters of small colorless, white, or gray bladed and sheaflike crystals, also in dirty-gray or brown porous masses or aggregates of small radiating needles. Botryoidal masses resembling smithsonite are found in Kentucky. Hemimorphite is commonly mixed with remnants of galena, limonite, jasperoid, cerussite, manganese oxides, and in places, cerargyrite.

Hydrozincite, a chalky white mineral, is common in the form of eggshell-like, platy masses that replace and coat smithsonite. The mineral is rich in zinc, containing 74 percent zinc oxide.

In the metamorphic deposits of Franklin Furnace and Sterling Hill, N.J., franklinite and much less abundant gahnite (the zincian spinels), willemite (the anhydrous zinc silicate), and zincite (zinc oxide) are major constituents (Palache, 1935). Zincite is restricted in its occurrence almost entirely to these two deposits. These deposits have been by far the most important commercial source of oxidized zinc ores (table 1). In addition, in the central part of the Sterling Hill deposit, two bodies of supergene hemimorphite, chalcophanite, hetaerolite, and zincian clays were mined near the surface many years ago.

Willemite, a major hypogene ore mineral at Franklin and Sterling Hill, N.J., also is a major ore mineral in some supergene deposits where oxidation took place under unusual arid conditions. Willemite in such deposits is in fine-grained red and brown crystalline masses or clusters of small barrel-shaped crystals, commonly not more than 5 mm long.

Aurichalcite, the blue basic carbonate of zinc and copper, is a common minor constituent of many western oxidized zinc deposits, and in places occurs in minable quantities.

Sauconite, the zinc clay mineral, occurs locally in large quantities at a number of districts throughout the country. The pure zinc clays contain between 20 and 25 percent zinc. As far as is known, recovery of zinc from sauconite is too difficult to yield a profit. The reader is referred to Ross (1946, p. 411–424) for descriptions of sauconite and its composition and origin.

Descloizite, the zinc-lead vanadate, and its copper-bearing analog, mottramite, are notably abundant in many deposits in the Southwestern States, and in a few localities in Montana. Many of these deposits are only mined for the zinc; others have been mined along with associated vanadinite for their vanadium and lead.

Minable quantities of the zincian manganese oxides, chalcophanite, hetaerolite, and hydrohetaerolite, have been found at Sterling Hill, N.J., Leadville, Colo., Tintic, Utah, and possibly at Pioche, Nev. Chalcophanite is a common supergene mineral at all these districts. Hetaerolite is known at Sterling Hill, N.J., and with hydrohetaerolite at Leadville, Colo., where it was described by Loughlin (1918, p. 21–23) as "hetaerolite" or "wolftonite." Hetaerolite is also abundant at the Contact mine, Grant County, N. Mex., where it is associated with chalcophanite (Hewett and Fleischer, 1960, p. 12). Hypogene gahnite occurs in the New Jersey deposits. It is also fairly common as green crystals and grains in the sphalerite and galena veins and garnet-schist gangue at Cotopaxi, Colo.

Supergene wurtzite is reported by Butler (1913) as a secondary-enrichment ore mineral at the Hornsilver mine, San Francisco district, Utah.

Similarly adamite and the rare mineral austinite are locally abundant zinc arsenates in the gossans at Gold Hill, Utah (Nolan, 1935).

None of the other oxidized zinc minerals are abundant enough to constitute ores. The zinc sulfate goslarite is common in small quantities as an efflorescence in many oxidizing zinc deposits, but because it is water soluble, it never accumulates in minable quantities. Zincian aragonite is a minor constituent at Friedensville, Pa., and Leadville, Colo. Serpierite, a rare copper-zinc sulfate is reported from near Salida, Colo., and Audubon, Pa. (Mary Mrose, oral communication, 1958). Helvite, an uncommon contact-metamorphic mineral containing beryllium, manganese, iron, and zinc, is locally abundant in New Mexico (Glass and others, 1944.) The zincian analog of helvite, danalite, is a very rare mineral in the southern part of the Sangre de Cristo Mountains of Colorado. Zincian siderite is found only at the F.M.D. mine at Evergreen, Colo. Zinc phosphate minerals from a cave at Island Fort between Covington and Clifton Forge, Va., are under study by Charles Milton (oral communication, 1959).

COMMERCIAL ORES

VARIETIES

Commercial oxidized zinc ores have a wide range in mineralogy, and commonly zinc is not the only recoverable metal. Smithsonite, with or without hemimorphite, is the main mineral in most of the deposits; hemimorphite predominates in many. Other zinc minerals, such as hydrozincite, in places form the main ores. Vanadium, which is very widespread in many western deposits, has been recovered from some descloizite-, cuprodescloizite-, and mottramite-bearing ores. Manganese and iron are byproducts of the Franklin and Sterling Hill deposits and have been produced from Leadville, Colo., Tintic, Utah, and Pioche, Nev. Aurichalcite ores have been mined in Utah and Nevada for their copper content alone.

Silver and gold are notably rich in some supergene ores that have directly replaced hypogene ores, and they are in recoverable quantities in many others (table 2), in places associated with recoverable copper and lead. In places molybdenum, antimony, tungsten, and bismuth are other constituents. In the past, one or more of these metals were not recovered during smelting, but some of the present processes recover most of them. Supergene ores that have replaced the wallrocks of hypogene deposits are, on the average, richer in zinc than the ores listed in table 2, but they are commonly leaner in silver,

TABLE 2.—*Some silver- and gold-bearing oxidized zinc and zinc-lead ores in Colorado, Utah, Nevada, and California*

[All are grab samples; N.d., not determined. Analyst, Deason, and Nichols, Salt Lake City, Utah, 1953-56]

	Locality	Silver (ounces per ton)	Gold (ounces per ton)	Lead (percent)	Zinc (percent)	Copper (percent)
1	Ward district, Nev	35.10	0.05	6.8	8.1	1.35
2	Mine 1, Ely, Nev	2.10	.26	1.7	23.9	.66
3	Mine 2, willemite ore, Ely, Nev	Tr.	.10	.9	46.6	.45
4	Bristol district, Nev	7.50	.02	5.8	14.0	5.65
5	Alpine district, Nev	8.10	.005	7.5	17.0	N.d.
6	Downeyville district, Nev	4.60	.11	5.1	24.2	.10
7	Montezuma group, Big Pine, Calif	10.80	.35	10.4	28.7	N.d.
8	Carbonate King Zinc mine, Ivanpah, Calif	5.60	.01	.8	36.6	N.d.
9	Nopah district, Calif	22.40	.01	25.6	24.8	N.d.
10	Mine 1, Lone Mountain district, Nev	8.65	2.17	5.8	14.1	N.d.
11	Lida district, Nev	26.30	.28	1.35	7.4	1.25
12	Hiko district, Nev	15.40	.015	4.5	12.0	N.d.
13	Jean Stockpile, Goodsprings, Nev	7.10	.015	15.6	28.0	N.d.
14	Soda Mountain district, Calif	20.80	.10	2.9	42.2	3.28
15	Emma mine, Little Cottonwood district, Utah	23.80	.015	22.6	33.7	N.d.
16	Mine 1, American Fork, Utah	22.10	.015	6.2	7.8	N.d.
17	Mine, western part of Park City, Utah	7.40	.02	13.4	37.8	N.d.
18	Fish Springs district, Utah	16.50	.007	7.5	38.6	.53
19	Mine 1, Tin Cup, Colo	28.50	.04	6.6	37.9	N.d.
20	Massadona-Youghall, Colo	.50	.12	2.2	36.5	.66
21	Fryer Hill, Leadville, Colo	4.00	.03	1.85	11.9	N.d.
22	Mine 2, Tin Cup, Colo	50.10	.18	11.4	39.7	N.d.
23	Mine 1, Star district, Utah	13.80	.01	7.2	17.4	N.d.
24	Mine 2, American Fork, Utah	23.00	.59	43.8	16.4	N.d.
25	North Tintic district, Utah	4.10	.01	8.1	35.1	N.d.

gold, and lead; nevertheless, many such ores contain marketable quantities of all three metals. A few wallrock ores are notably rich in copper or manganese.

Some of the main varieties and commercial classes of oxidized ores are as follows:

Mineral content	*Class*
HYPOGENE ORES	
Franklinite, willemite, zincite	Zinc; manganese and iron byproducts.
Cerussite, phosgenite, smithsonite	Lead (zinc is lost).
Descloizite, wulfenite, vanadinite	Vanadium-lead, in places molybdenum and silver (zinc is lost).
SUPERGENE ORES	
Wurtzite (mixed with hypogene sphalerite).	Zinc.
DIRECT-REPLACEMENT ORES	
Smithsonite, hemimorphite, a little cerussite.	Zinc.
Smithsonite, hemimorphite, and lead; silver, gold, and copper minerals in places.	Zinc-lead; with byproducts silver, gold, and copper.
Smithsonite, hemimorphite, aurichalcite; copper oxides and carbonates.	Zinc-copper.
Descloizite, wulfenite, vanadinite	Vanadium-lead, in places molybdenum (zinc is lost).
Oxidized lead, silver, and manganese minerals; zinc carbonates and silicates.	Lead-silver, manganese; zinc rarely recovered.
Willemite, hemimorphite, hydrozincite	Zinc.
Hemimorphite, hydrozincite, smithsonite.	Do.
Porous brown or gray smithsonite; in places galena.	Zinc, zinc-lead drybone.
WALLROCK-REPLACEMENT ORES	
Gray massive smithsonite	Zinc, gray carbonate ore.
Brown porous smithsonite, a little hemimorphite, limonite.	Zinc, brown zinc carbonate ore.
Red massive or spongy smithsonite, a little hemimorphite or hydrozincite.	Zinc, zincite ore.
Smithsonite, hemimorphite, chalcophanite, hydrohetaerolite, hetaerolite, manganese oxide minerals.	Zinc-manganese, black zinc oxide ore.
Sauconite, hemimorphite	Zinc tallow clay or talcy zinc ore.
Aurichalcite, limonite, malachite	Copper (zinc is lost).
Hydrozincite, smithsonite, hemimorphite.	Zinc, white zinc ore.

GRADES

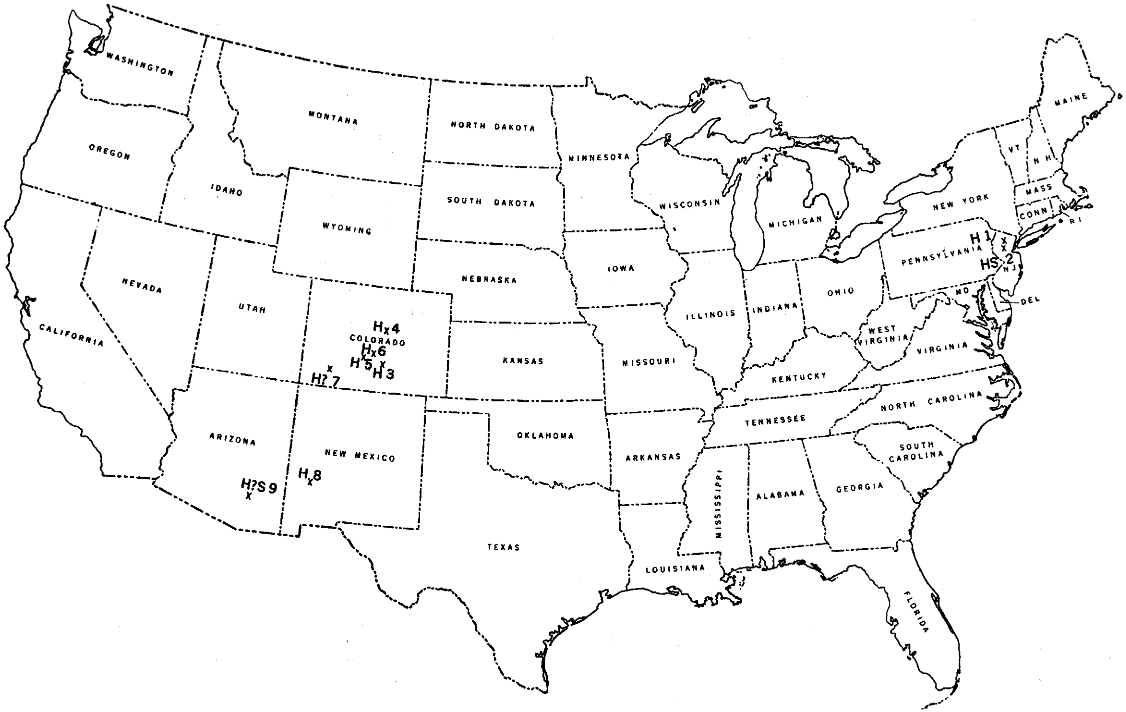
Oxidized zinc ores sold to smelters or zinc pigment plants commonly contain at least 25 percent and often as much as 50 percent zinc. Preferred ores are lean in iron and other impurities, except lead in some cases. High-grade smithsonite, willemite, and hydrozincite ores containing at least 35 percent zinc may be purchased at a premium. Ores containing 20 percent combined zinc and lead, and usually some silver, are generally sold as zinc-lead ores. At times, fuming plants will accept much lower grade zinc and zinc-lead ores, especially if the ores are rich in silver, gold, and copper, all of which can be recovered, and lean in iron.

GENERAL GEOLOGY

Most of the oxidized zinc deposits are in carbonate rocks such as limestone, dolomite, and marble, or in rocks with considerable quantities of carbonate minerals. A fairly large number of commercial deposits in the Western United States, however, are in host rocks other than limestone or marble. Nearly all the deposits are of supergene origin and are the result of oxidation of sulfide deposits containing zinc and, in places, lead, silver, copper, molybdenum, manganese, and vanadium. A few deposits are largely of hypogene origin, and their minerals were formed by metamorphism or were deposited by hydrothermal solutions of unusual composition.

HYPOGENE DEPOSITS

Oxidized zinc deposits of hypogene origin are uncommon. The locations of known hypogene or partly hypogene deposits and the main features of their geology and mineralogy are given in figure 1. Included are veins, lodes, and replacements of widely different geology, but mostly in Precambrian rocks. The metamorphic suite of minerals in marble at the very large Franklin and Sterling Hill deposits is almost unbelievably complex, whereas the cerussite and phosgenite lodes at Ilse, Colo., that contain smithsonite are unusually simple. Late hydrothermal deposits are represented by the zincian siderite and pyrite veins that cut a massive sulfide ore body at Evergreen, Colo., and by the descloizite, vanadinite, and wulfenite veins and incrustations in previously weathered lead-zinc deposits of the Mammoth–St. Anthony district of Arizona (Creasey, 1950, p. 63–84; Peterson, 1938, p. 43–50). Massive sulfide deposits at the Bon Ton and Cotopaxi mines near Salida, Colo., contain hypogene gahnite.



Oxidized zinc data compiled by A. V. Heyl and C. N. Bozion, 1959

FIGURE 1.—Oxidized zinc or lead-zinc deposits reported to be partly or wholly of hypogene origin.

EXPLANATION

H_x

Deposits of hypogene origin

$H?_x$

Deposits of possibly hypogene origin

HS_x

Deposits of hypogene and supergene origin

$H?S_x$

Deposits of supergene origin and, in part, possibly of hypogene origin

GENERALIZED GEOLOGY AND MINERALOGY

Mine or district	*Geology*	*Main minerals*
1. Franklin Furnace, N.J.	Metamorphic replacement deposits of zinc, manganese, and iron; Precambrian in age.	Franklinite, willemite, zincite.
2. Sterling Hill, N.J.	Metamorphic replacement deposits; further altered to supergene direct-replacement ores in places where sphalerite was probably originally present. Metamorphic deposits are Precambrian in age.	Franklinite, willemite, and zincite; supergene hemimorphite, chalcophanite, zincian clays, hetaerolite.
3. Ilse, Colo.	Large lodes of lead carbonate and lead chlorocarbonate in major fault. Deposit is in Precambrian rocks.	Cerussite, phosgenite, smithsenite.
4. F. D. M. mine, Evergreen, Colo.	Late veins of zincian siderite in a massive sulfide deposit.	Zincian siderite, a little smithsonite.
5. Bon Ton mine, Monarch, Colo.	Zinc spinel (gahnite) is a common mineral in vein sulfide deposits of Precambrian age.	Gahnite, sphalerite.
6. Cotopaxi mine, Cotopaxi, Colo.	Zinc spinel is a common mineral in massive sulfide deposits of Precambrian age.	Gahnite, sphalerite, chalcopyrite.

GENERALIZED GEOLOGY AND MINERALOGY—continued

Mine or district—Continued	*Geology*—Continued	*Main minerals*—Continued
7. Lark mine, Red Mountain district, Colo.	Lead carbonate pipes cutting altered felsic volcanic rocks of Tertiary age surrounding a central sulfide pipe.	Cerussite, sericite, a little smithsonite, quartz.
8. Iron Mountain district, N. Mex---	Contact-metamorphic deposit in limestone of Paleozoic age.	Helvite, scheelite, fluorite, willemite.
9. Mammoth–St. Anthony district, Ariz.	Direct supergene replacement of primary vein deposit; partly in rocks of Tertiary age, modified by late hydrothermal vanadium- and molybdenum-bearing solutions.	Cerussite, smithsonite, calamine, willemite, malachite, descloizite, vanadinite, wulfenite.

The deposits of zinc oxides and silicates at Franklin (the northern deposit) and at Sterling Hill (the southern deposit), N.J., are similar geologically in many respects, but they have enough major differences not commonly explained in textbooks that a brief summary of the deposits and their differences may be helpful.

The two deposits are 3 miles apart in a northeastward-trending belt of coarse-grained white marble of Precambrian age. Coarse-grained gneisses lie toward the northwest of the marble belt (Palache, 1935; Pinger, 1950). They dip southeastward and physically underlie the marble. Westward-dipping quarzite and limestone of Cambrian and Ordovician age unconformably overlie the Precambrian rocks and zinc deposits, and this erosion surface cuts off the northern end of the Franklin deposit. The same limestones lie in a fault block southeast of the marble. Alkaline mafic dikes (minettes) and granite pegmatites cut ore, marble, and gneiss at Franklin, but the age of the pegmatites relative to the ore is still not certain. Dikes are rare or absent at Sterling Hill.

The Franklin and Sterling deposits have many features in common, such as similar marble host rocks and broadly similar structures; both deposits are synclinal-shaped and the axes plunge northeastward in synclinal-shaped folds. The main minerals franklinite, willemite, and zincite are common to both deposits and are fairly uniformly distributed throughout each one. Marked mineralogic variations are present in the structurally more complex Sterling Hill ore body (Metsger and others, 1958), which has two northward-plunging keels. Many of the rare and unusual minerals at Franklin, including the sulfides, fluorite, and borosilicates, occur in the metamorphic-contact zones along the pegmatite dikes. Pegmatites and their associated rare minerals are almost entirely lacking at Sterling Hill. Supergene minerals such as hemimorphite, chalcophanite, hetaerolite, and zincian clays form two large bodies in the central part of the Sterling Hill deposit, and these bodies near the surface were mined in large tonnages for zinc many years ago. These typical supergene minerals are rare or absent at Franklin.

At Sterling Hill the main primary ore bands are composed of brown, red, or black willemite, each in distinct bands or bodies mixed with franklinite and more locally zincite (Metsger and others, 1958, fig. 1). Franklinite, tephroite, pyroxene, and biotite are the main constituents of lean mineralized areas. Sphalerite is abundant in the graphitic marbles of the central keel areas of the northeastward-plunging synclines (Pinger, 1950, p. 86).

Metsger and others (1958, p. 775) describe the paragenesis of the primary ores as follows:

> Paragenetically, it appears that of the ore minerals, willemite formed first in the sequence, with tephroite, zincite and franklinite following in undetermined order; tephroite and zincite may have been emplaced at the same time. There is abundant evidence of later generations of willemite, franklinite and zincite. Primary [oldest generation] zincite has been observed only in the presence of tephroite. There is evidence that tephroite has replaced willemite. Manganese solutions possibly replaced the zinc in willemite to form tephroite and may have resulted in the formation of zincite.

There is at least one later generation of willemite, zincite, and franklinite formed by a much later reworking of the deposits by relatively low-temperature magnesian-rich solutions, which serpentinized the older generations of minerals and dolomitized the marbles, according to Metsger and others (1958, p. 787–788).

The supergene hemimorphite bodies at Sterling Hill are large when compared to similar deposits elsewhere, although they form only two central cores within the still larger franklinite-willemite-zincite deposits. Along the keels of the ore bodies the graphitic-marble cores containing sphalerite in places have been altered to hemimorphite and to zincian clays of kaolinite, sericite, and nontronite types to a depth of 680 feet. Near the surface, at least, these minerals are associated with manganese-zinc minerals, chalcophanite, hetaerolite, hydrohetaerolite, and also with calcite and limonite. Pinger (1950, p. 86) states:

> These deposits * * * show an interesting segregation of iron, zinc and manganese into a limonitic gossan, an iron-manganese gossan, and an underlying deposit of calamine [hemimorphite] of low iron and manganese content.

Pinger (1950, p. 86) concludes that the hemimorphite bodies are mainly the result of deep weathering and oxidation of the sphalerite-bearing cores of the deposits; Metsger and others (1958) disagree but present no alternate hypothesis.

Zinc-bearing tactites of contact-metamorphic origin occur in the Iron Mountain district, in northwestern Sierra County and southwestern Socorro County, N. Mex. (Jahns, 1944b, p. 45–79). They are irregular bodies of iron-rich silicate rock formed by replacement of Paleozoic limestone and calcareous shale at or near contacts with small intrusive masses of felsic rocks, probably of middle Tertiary age. Some of the zinc is in the complex silicate mineral helvite, a selected sample of which contained 5.61 percent zinc oxide (Glass and others, 1944, table 1); some is in willemite, which is locally abundant in massive iron-rich tactite and is associated with magnetite, andradite garnet, hedenbergite, specular hematite, fluorite, apatite, and many other minerals. Massive tactites containing fluorite, specularite, and willemite in the Scheelemite and North End areas are reported to have assayed 8 to 21 percent zinc (Jahns, 1944b, p. 60) in places, but most of the tactites contain much less zinc. In the Goat Canyon area, prospects in willemite-bearing tactites exposed small bodies partly weathered to smithsonite, hemimorphite, wulfenite, anglesite, cerussite, and the oxides and carbonates of copper.

At the Lark mine, Red Mountain district, Colorado, lead carbonate pipes containing some zinc carbonate cut altered felsic volcanic rocks of Tertiary age which surround a central sulfide pipe. The sulfide pipe and the adjacent carbonate pipes have been exposed by mining to a depth of several hundred feet (W. S. Burbank, oral communication, 1954). The peculiar geologic relations suggest to Burbank that the carbonate pipes are of hypogene origin and formed by hydrothermal solutions.

Deposits of descloizite, vanadinite, and wulfenite at Mammoth-St. Anthony, Ariz., are suggested by Peterson (1938) and Creasey (1950) to have been formed by late hydrothermal vanadium- and molybdenum-bearing solutions reworking a sulfide deposit that had been previously oxidized to cerussite, smithsonite, hemimorphite, willemite, and malachite. If this interpretation is correct, other descloizite, vanadinite, and wulfenite deposits in the Southwest may have similar origins.

SUPERGENE DEPOSITS

WALLROCKS

The deposits of supergene origin are commonly in carbonate-rich rocks, especially in the purer limestones and dolomites. The greatest number are in limestones and dolomites of Paleozoic age, particularly those from Cambrian through Mississippian, which are the principal carbonate-rock units throughout most of the nation. Some deposits, however, are in limestones, dolomites, or marbles of other ages, especially Precambrian, Pennsylvanian, and Mesozoic.

Although such an occurrence is considered by many to be rare or nonexistent, a considerable number of deposits of commercial size are in a wide variety of noncarbonate rocks. Twenty-four such districts are shown in figure 2, all in the Western United States. Some deposits are notably large and rich, such as those in the Warm Springs district, Idaho; Bagdad, Clifton-Morenci, Globe-Miami, and Silver-Eureka districts, Arizona; and the Sedalia mine, Salida, Colo. The often-stated rule (Lindgren, 1933, p. 851) that zinc is usually dispersed in solutions when veins are oxidized in noncarbonate rocks is not universally true. The wallrocks include many ages, and lithologies such as granitic rocks, gneiss, schist, greenstone, clastic sedimentary rocks,

Oxidized zinc data compiled by A. V. Heyl and C. N. Bozion, 1959

FIGURE 2.—Oxidized zinc-bearing ores in commercial quantities in rocks other than limestone, dolomite, and marble.

District—Continued	*Principal host rocks*—Continued
1. Los Cerillos, N. Mex	Quartz monzonite in shales.
2. North Magdalena, N. Mex	Volcanic rock.
3. Sedalia mine, Salida, Colo	Precambrian biotite schist, gneiss, and pegmatite.
4. Silver Cliff, Colo	Tertiary felsic volcanic rock.
5. Creede, Colo	Do.
6. Escalante, Utah	Tertiary volcanic rocks; manganiferous calcite gangue.
7. Searchlight, Nev	Precambrian gneiss; local rich areas of descloizite.
8. Galena, Nev	Metamorphosed sediment in felsic Tertiary volcanic rocks.
9. Antelope (Cedar), Pershing County, Nev	Triassic slate intruded by dike of rhyolite porphyry.
10. Bagdad, Ariz	Precambrian amphibole-mica schist derived from lava flows, tuffs, sandstone, and shale. Widespread granite intrusions. Tertiary rhyolite, quartz monzonite, and Pleistocene or Recent basalts.
11. Chloride-Wallapai, Ariz	Precambrian granites, gneisses, schist, and amphibolites intruded by two younger granites, one of which is Precambrian(?) in age and the other possibly Mesozoic or Tertiary.
12. Clifton-Morenci, Ariz	Carbonate-free oxidized skarn.
13. Globe-Miami, Ariz	Quartzites of Precambrian and Cambrian age and diabase.
14. Silver-Eureka, Ariz	Schist, granite, and Tertiary volcanic rocks.
15. Castle Dome, Ariz	Schist, gneiss, and granite of Precambrian age, some Cretaceous clastic sedimentary rocks intruded by diorite porphyry, and a thick section of volcanic rocks, probably of Tertiary age; carbonate gangue.
16. Mammoth-St. Anthony, Ariz	Granite intrusive rocks, rhyolite and rhyolite breccia, basaltic volcanic rocks and late Tertiary and Pleistocene Gila conglomerate.
17. Signal Hill, Calif	Granite.
18. Grapevine, Calif	Felsic volcanic rocks.
18a. Black Hawke mine, Agua Caliente, Calif	Quartzite, hornfels, and a little marble.
19. Hondo, Calif	Probably in noncarbonate rocks.

District—Continued	*Principal host rocks*—Continued
20. Copperopolis (Foot Hills copper belt), Calif	Volcanic and argillaceous rocks of probable Jurassic age metamorphosed to schists, slates, and greenstone and intruded by granodiorite, diorite, hornblendite, gabbro, and serpentine.
21. Warm Springs (Ketchum), Idaho	Calcareous sandstone, some shale, a little limestone.
22. Lava Creek and Era, Idaho	Lavas and tuffs.
23. Coeur d'Alene (Hypotheek), Idaho	Calcareous quartzite (ore may be in large quantities).
24. Butte, Mont	Quartz monzonite.

mafic and felsic volcanic rocks, and calcareous quartzite. Most of the districts have long histories of deep and intense oxidation. The oxidized zinc ores directly replace, or are concentrated in the same position as, the parent hypogene ore bodies.

CLASSIFICATION OF DEPOSITS

Most deposits of supergene origin can be classified into three main types: (1) direct replacements, (2) wallrock replacements, and (3) saprolitic accumulations. These are shown diagrammatically in figure 3. A few supergene sulfide-enrichment deposits are known, and a few residual, alluvial, and colluvial placer, bog, and cave accumulations. Many deposits are combinations of one or more types.

Direct-replacement deposits are formed by oxidation of primary zinc ores essentially in place, without major migration of the zinc in solution. They are by far the most abundant type in both the East and the West, notwithstanding statements to the contrary in the literature. All the known oxidized zinc deposits in noncarbonate rocks are of this type. Direct-replacement deposits are quite simple if the primary ores are mineralogically simple, as in deposits of the Mississippi Valley type, or in zinc and iron sulfide veins such as those at the Moon Claim, in the Hyrum district, Utah, but they are much more complex than the other types if the primary ores contained such elements as copper, lead, silver, gold, vanadium, and antimony as well as zinc. Direct-replacement deposits are typically less rich in zinc than wallrock-replacement deposits, but the total accumulation of zinc in them throughout the country is far greater.

Wallrock-replacement deposits are the result of leaching of primary ores, migration of zinc in solution, and redeposition of zinc by replacement of nearby carbonate wallrocks. Such deposits are rare east of the Rocky Mountains, but many of the richest large zinc deposits in the West are of this type; examples are deposits at Leadville, Colo.; Magdalena, N. Mex.; Goodsprings, Nev.; and Cerro Gordo, Calif.

Saprolitic accumulations are found only in the Valley and Ridge province of the Eastern United States. They are typically a mixture of (1) thoroughly decomposed earthy but untransported rock and oxidized zinc minerals, (2) residual masses of clay, smithsonite, and hemimorphite that have slumped vertically and collected in solution pockets of decomposed limestone between buried pinnacles of unweathered limestone, and (3) zinc carbonates and silicates that were deposited near the limestone walls in the bottoms of the solution pockets by reaction of descending zinc-bearing solutions that formed from the weathering of the mineralized pinnacles and leaching of the

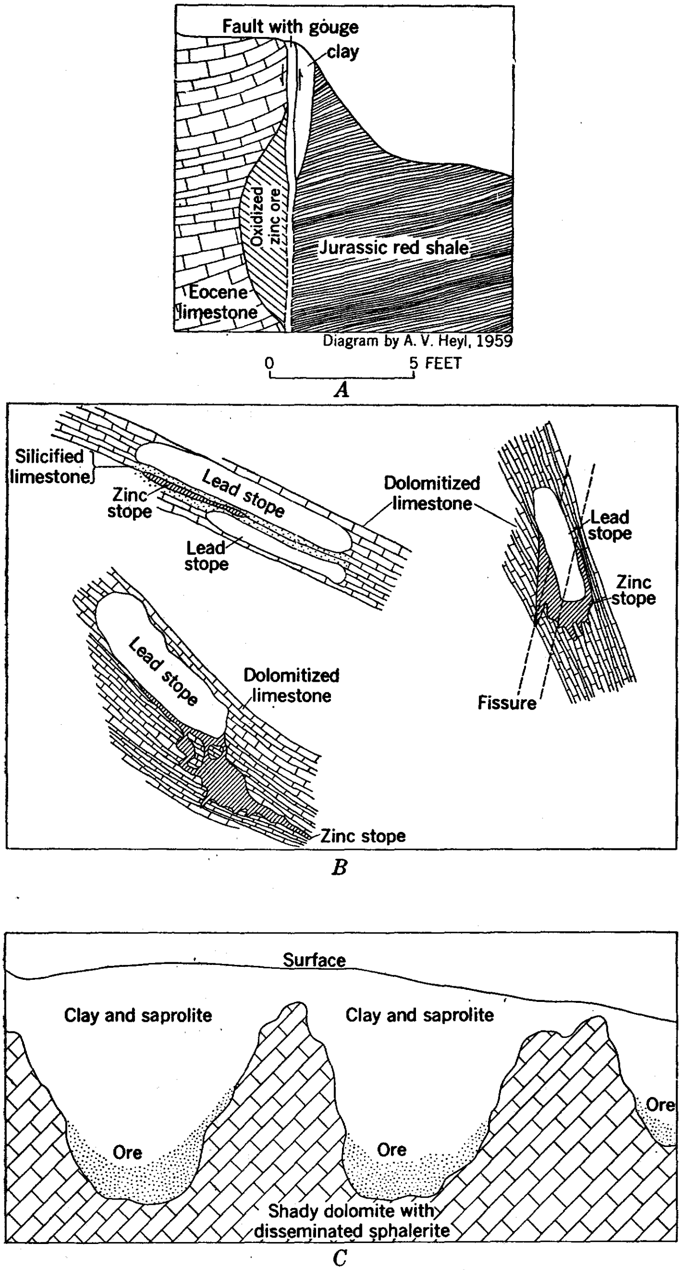


FIGURE 3.—Diagrammatic sections of main types of oxidized zinc deposits. *A*, Direct replacement of zinc sulfide vein by oxidized zinc minerals, Redmond, Utah. *B*, Wallrock-replacement deposits (after Loughlin, 1914, fig. 2), Tintic district, Utah. *C*, Saprolitic accumulation (after Watson, 1905, fig. 16), Bertha, Va.

saprolites above. The source of the zinc is sphalerite, which may occur either in lean disseminations or commercial deposits in the unweathered limestones. The oxidized zinc deposits at Austinville and Bertha, Va., are characteristic examples of saprolitic deposits (Watson, 1905, p. 78–92).

Large supergene zinc sulfide deposits are uncommon, but a supergene wurtzite enrichment zone in the San Francisco district of Utah has been described by Butler (1913). Supergene concentrations of zinc, including zinc sulfide in peat bogs near Manning, Orleans County, N.Y., have been described by Cannon (1955), but few other bog zinc deposits have been described as yet. Cannon's study indicates that the zinc in the bog is derived from the slow accumulation of zinc-bearing waters that were produced by the gradual weathering of sphalerite-bearing dolomites of Silurian age which surround the peat bogs.

The known simple residual deposits form thin blankets of smithsonite and hemimorphite in soils that were derived by weathering from underlying sphalerite deposits in carbonate rocks. They are locally common in the Tri-State district of Missouri, the Upper Mississippi Valley district, and the Kentucky-Illinois fluorspar-zinc district, but most of them are small. Similarly, small hillside colluvial blankets and valley-fill alluvial and placer smithsonite deposits have been prospected in the Upper Mississippi Valley zinc-lead district. In that district, fragments of massive smithsonite and galena have been mined locally in the clay deposits in small caves near Dubuque, Iowa. The smithsonite replaced hypogene sphalerite-galena veins and disseminations that formerly filled parts of the dolomite wallrock in which the caves formed. When the dolomite was dissolved, the ores settled to the cave floors and were redeposited in mud, clay, and rock fragments.

Table 3 classifies deposits of the three major types in the Eastern and Central States and in Colorado and Utah, and summarizes the type of ore body and principal minerals at each locality. The table shows that direct-replacement deposits are much more abundant than all the other types combined. If the rest of the Western States and Alaska were included, the ratio of about 2 direct-replacement deposits to 1 wallrock-replacement deposit typified by Colorado and Utah would probably not change substantially.

Table 3 also shows that most of the supergene oxidized zinc deposits of the Western States (exemplified by Colorado and Utah) are mineralogically more complex and richer in precious metals than those in the Eastern and Central States. Direct-replacement deposits in the West are especially complex, particularly in such areas as the Star district, Utah, and the Creede district, Colo. A few of the

TABLE 3.—*Types of supergene oxidized zinc deposits in the Eastern and Central States, and in Colorado and Utah*

Location or district	Classification			Type of ore body	Principal zinc minerals								Other zinc minerals and associated minerals
	Saprolitic accumulations	Wallrock replacements	Direct replacements		Hemimorphite	Smithsonite	Hydrozincite	Willemite	Aurichalcite	Sauconite	Chalcophanite, and others	Descloizite	
Eastern and Central States													
New York:													
Manning Bog				Supergene bog accumulations from nearby disseminated sulfides.									Zinc sulfides and zincy peats.
Balmat		×		Large pocket in footwall				×					
New Jersey:													
Sterling Hill			×	Hemimorphite and other minerals replace sphalerite core in metamorphic deposit.	×			×		×	×		Hetaerolite, limonite.
German Valley	×		×	Veins and saprolitic pockets	×	×							Cerussite.
Pennsylvania:													
Friedensville	×		×	Veins, bedded veins, and saprolitic pockets; supergene sphalerite reported.	×	×				×			Limonite, greenockite.
Bamford			×	Bedded veins	×								
Sinking Valley			×	Veins and breccia pipes	×	×							Cerussite.
Pequea			×	Veins	×								Silver, cerussite.
Phoenixville			×	do	×	×							Wulfenite, silver, anglesite.
Doughty mine			×	Veins and primary pods	×								Cerussite.
Maryland:													
Unionville			×	Breccia	×	×							Copper carbonates.
Virginia:													
Austinville	×			Saprolitic pockets and residual accumulations.	×	×				×			Limonite, cerussite; locally hydrozincite.
Timberville			×	Bedded veins		×							Dolomite.
Tennessee:													
Mascot-Jefferson City	×			Saprolitic pockets	×	×							Locally hydrozincite, sauconite.
New Prospect			×	Veins and breccias		×							Galena.
Goin prospect	×?		×	Breccia and pockets(?)		×							Cerussite.
Straight Creek			×	Vein and breccia		×							Galena.
Copper Ridge			×	Bedded breccia		×							
Falls Branch	×			Bedded breccia, in part residual	×	×							Residual barite.
Friendsville			×	Bedded breccia		×?							Galena.

Eve Mills	×			Saprolitic pockets		×							
Charleston			×	Bedded replacement	×	×							Galena, barite.
Embreeville	×			Saprolitic pockets	×	×				×			Cerussite, limonite, hydrozincite.
Felknor			×	Breccia	×	×							Cerussite.
Kentucky-Illinois fluorspar			×	Veins, residual deposits	×	×							Galena, greenockite, pyromorphite, limonite.
Upper Mississippi Valley, Wisc.-Ill.-Iowa.			×	Veins and disseminated replacements; local residual, colluvial, cave, and placer deposits.		×							Galena.
Tri-State, Mo.-Kans.-Okla			×	Replacements	×	×							Greenockite.
Southeast Missouri			×	Bedded replacements	×	×							Lead ores.
Arkansas:													
Main Northern Arkansas district (Yelville).			×	do	×	×							Greenockite, cerussite.
Eastern part of Northern Arkansas district (Lawrence and Sharp Counties district).			×	do	×	×							Do.
Oklahoma:													
Davis district			×	do		×							Do.
Total, Eastern and Central States.	8	1	24		19	25		2		4	1		

TABLE 3.—*Types of supergene oxidized zinc deposits in the Eastern and Central States, and in Colorado and Utah*—Continued

Location or district	Classification			Type of ore body	Principal zinc minerals								Other zinc minerals and associated minerals
	Saprolitic accumulations	Wallrock replacements	Direct replacements		Hemimorphite	Smithsonite	Hydrozincite	Willemite	Aurichalcite	Sauconite	Chalcophanite, and others	Descloizite	
				Colorado and Utah									
Colorado:													
Massadona			×	Veins	×		×						
Carbonate			×	do	×	×							Cerussite.
Rifle Creek			×	Veins and breccias		×	×						Selenite.
Red Cliff		×		Replacement pockets	×	×							Manganosiderite.
Lenado			×	Veins		×							Silver, cerussite.
Aspen			×	Veins and massive replacements		×							Do.
Leadville		×		Replacement pockets	×	×				×	×		Hydrohetaerolite, hetaerolite.
Mosquito Range		×		do	×	×				×	×		Hydrohetaerolite.
Horseshoe		×	×	Wallrock casing and veins	×	×	×?						
Weston Pass			×	Bedded replacements	×								Cerussite.
Tomichi			×	Veins and pipes		×							Do.
Tincup			×	Bedded veins, pipes	×	×							Gold, silver, cerussite.
Gold Brick			×	Veins	×								
Spring Creek		×	×	Great breccia pipe, local replacement pockets.	×	×							Cerussite, silver.
Monarch		×	×	Veins and mantos and footwall blankets.	×	×							Limonite, jarosite, cerussite.
Sedalia mine, Salida			×	Weathered massive sulfide deposit.	×	×	×	×	×				Sulfates, rosasite(?).
Silver Cliff			×	Breccia pipes, veins		×							Silver, cerussite.
Rico			×	Bedded veins		×							Cerussite.
Creede			×	Veins		×				×?			Goslarite, cerussite, anglesite, silver.
Sunnyside		×		Replacements of calcareous tufa.		×							
Spar			×	Disseminated smithsonite in veins.		×							Cerussite, barite.
Utah:													
Moon Claim, Hyrum			×	Vein and breccia		×							Limonite.
New Bullion mine, North Tintic.		×	×	Secondary veins, weathered primary chimney.	×	×	×						Cerussite, limonite.
Redmond			×	Vein		×	×						
Escalante			×	do								×	Pyromorphite, manganocalcite.

Gold Hill			×	Massive replacements									Adamite, austinite, scorodite.
Star			×	Veins, pipes, and bedded replacements.	×	×		×					Descloizite, mimetite.
American Fork			×	Bedded replacements and disseminations.		×							Cerargyrite, cerussite.
Little Cottonwood			×	Pipes and bedded replacements.	×	×							Stolzite. silver, cerussite.
Park City			×	Bedded replacements	×	×							Silver, cerussite.
Carbonate mine, Big Cottonwood.		×		Secondary veins and casings	×	×			×				
Mono		×		Secondary replacement pockets		×							
Dry Canyon		×		Casings	×	×			×				
Tintic		×		Replacement pockets	×	×				×	×		Plumbojarosite, lead-copper arsenates, silver.
Ophir		×		Casings	×	×			×				
Rush Valley		×		Replacements and casings		×							
San Francisco		×	×	Secondary pipes and casings and giant oxidized vein; supergene sulfide enrichments.	×	×							Wurtzite enrichment zone.
Scranton mines, North Tintic		×	×	Replacement pockets and oxidized veins.	×	×							Plumbojarosite and jarosite.
Lucin		×	×	Replacements and oxidized veins	×	×							Wulfenite, anglesite, aragonite.
Promontory		×	×	Pockets and casings and oxidized veins and replacements.	×	×							Cerussite.
Tecoma			×	Veins and replacements		×							
Swan Creek			×	Disseminations		×							
Argenta			×	Veins	×	×							Cerussite, limonite.
Erickson			×	Veins and bedded veins	×?	×?							
Lakeside			×	Veins	×	×							Cerussite.
Bradshaw		×		Replacement pockets, ore shoots along fissures and in caves.	×				×				
Fish Springs			×	Veins	×	×							Cerussite, silver, jarosite.
Total, Colorado and Utah		19	36		30	42	6	2	5	4	3	1	
Grand total	8	20	60		49	67	6	4	5	8	4	1	

western wallrock-replacement deposits, such as those at Leadville, Colo., and Tintic, Utah, have a great variety of oxidized zinc minerals, greater even than most of the direct-replacement deposits, but few other minerals are associated with them.

The most complex deposits in the East are the previously described (p. 13) hemimorphite, zincian clays, and zinc-manganese oxide deposits in the centers of the franklinite, willemite, and zincite deposits at Sterling Hill, N.J.; a few of the silver, lead, and zinc veins in the Piedmont province are also complex.

SHAPES OF DEPOSITS

Oxidized zinc deposits have many shapes and forms, which are mainly determined by structural and wallrock controls. Direct-replacement deposits assume the forms of the hypogene bodies from which they are derived; modifications are internal and involve redistribution of the metals in the deposit during oxidation and leaching. For example, lead and silver tend to remain in the center and zinc, copper, and iron tend to migrate and reconcentrate as shells of secondary zinc and copper minerals that have limonite in the margins, or as local kidney-shaped masses within the original ore bodies. The outcrop of the deposit is commonly leached to a porous gossan, and the metals thus leached are redeposited farther downward as oxidized minerals and still deeper as supergene sulfides. The wallrock-replacement bodies have distinct new forms closely dependent on the shape, size, and position of the nearby hypogene ore bodies from which they are derived, and upon the relative solubility of the wallrocks and available solution channelways or impermeable zones.

Saprolitic accumulations are concentrated in solution pockets between the limestone pinnacles, and the richest ore occurs in the bowl-shaped accumulations that line the bottoms of the pockets. Pieces of smithsonite and hemimorphite are scattered in the soft saprolite near the pinnacle walls and in the central areas of slumped residual clay. These scattered pieces are not shown on Watson's (1905) diagram (fig. 3 of this report).

The main forms of ore bodies are listed below in their approximate order of abundance and in terms of whether they are derived from hypogene deposits, secondary wallrock bodies, or are of diverse origin.

- Direct supergene replacement of hypogene ore bodies:
  - Veins and lodes
  - Breccias and stockworks
  - Massive replacement bodies
  - Bedded replacement bodies
  - Pipes
  - Blankets or mantos
  - Disseminations
  - Irregular contact zones
  - Secondary sulfide enrichment zones
- Supergene replacement of wallrock:
  - Pockets
  - Casings
  - Blankets
  - Bedded replacements
  - Pockets in saprolites
  - Secondary veins
  - Secondary pipes
  - Massive replacements
  - Disseminations
  - Cave fillings
- Diverse origin:
  - Residual pockets
  - Residual blankets
  - Bogs and soils
  - Placers

The distribution of the main forms listed above in relation to oxidized zinc districts is given on table 3.

STAGES OF PROGRESSIVE OXIDATION

Oxidized zinc deposits of supergene origin undergo a series of changes during oxidation and leaching to the ultimate limonite-quartz gossan. The usual paragenetic sequences for direct-replacement and wallrock-replacement deposits in progressive stages from sulfide deposits to gossans are tabulated below:

Paragenetic sequence from sulfide deposits to gossans

Direct-replacement deposits (complex sulfide ore bodies)	*Wallrock-replacement deposits*
Unoxidized sulfides----------------------	Unoxidized sulfides.
Partly leached vuggy sulfides, partly replaced by spongy smithsonite, hemimorphite, and locally goslarite and zinc clays; also copper, lead, and silver minerals. Commonly much galena, some sphalerite, and pyrite remain.	Complete or nearly complete leaching of sphalerite, and later of pyrite, from hypogene deposits; zinc, copper, and iron migrate into carbonate wallrocks.
Smithsonite and hemimorphite; copper and lead carbonates, argentite, and ruby-silver minerals fairly evenly distributed. Partly replaced grains of galena and chalcopyrite common. Under special arid conditions, willemite is also formed as an early mineral. Many secondary copper sulfides and oxides in places.	Massive or concentrically banded gray smithsonite or maganosiderite halos deposited, which replace limestone wallrocks; smithsonite commonly ferroan.
Smithsonite leached to hemimorphite; hydrozincite and possibly aurichalcite formed. Minerals are partly redistributed. Zinc and copper migrate toward ore-body walls. Lead sulfate and lead carbonate remain in center, with wulfenite and ruby-silver minerals.	Gray smithsonite is leached to spongy porous brown or red smithsonite, hemimorphite, and chalcophanite in vugs.

Zinc minerals now leached mostly to hemimorphite and hydrozincite; no galena remains, only oxidized lead minerals ("sand carbonate") and copper oxides and carbonates. Much limonite and secondary jasperoids. In places descloizite, vanadinite, and wulfenite in crusts and vugs.	Hemimorphite, aurichalcite, sauconite, as well as limonite and secondary jasperoid, formed by further leaching of brown smithsonite. Local areas, veins, and vugs filled with coarse white crystalline smithsonite. In casings, limonite is nearest the source ore body, copper-zinc carbonates next, crystalline zinc carbonate on outside.
Vuggy jasperiod and limonite leached vein with local crystals and crusts of cerussite, plumbojarosite, hemimorphite, malachite, azurite, or complex arsenides or antimonides; in places much cerargyrite.	All zinc carbonates are leached to concentric shells of limonite, calcite, jasperoid or equivalent spongy porous masses. A few vugs with clear hemimorphite crystals.
Siliceous limonitic gossans	Siliceous limonitic gossans.

Where oxidation is deep and replacement is direct, single ore bodies may show all seven progressive stages, starting with the gossan at the surface, and continuing, in the reverse of the order given, down to unoxidized sulfides.

REGIONAL VARIATIONS BECAUSE OF CLIMATE

Oxidized zinc deposits of supergene origin differ greatly in depth of oxidization and in geology from region to region across the nation. In cool humid climates that have been stable throughout most of the Recent period, as in the Northeast, the Northwest, and the northern Central Lowland, oxidation is not far advanced, and its effects are confined to shallow depths, commonly less than 100 feet below the surface. In the warm humid climates of the Ridge and Valley and Piedmont provinces south of New York, oxidation is deeper, and in the warm but more arid parts of the West, especially the Basin and Range and Colorado Plateaus provinces, oxidation is commonly very deep and irregular.

In the Central Lowland, where the close correspondence between depths of oxidation and present water tables indicates a stability of these levels throughout much of the Recent period, ground water below the water table in limestone areas is nearly uniformly neutral. In the Upper Mississippi Valley district, for example, the pH of such water below the water table ranges from 7 to 7.5 whether the water is collected from rich deposits of marcasite, pyrite, galena, and sphalerite or from barren rock (Kennedy, 1956, pl. 17). Surface water and vadose water in the zone of oxidation of the same district are more variable, having pH values that range from 7.0 to 8.4—the lower values commonly in water that contains metals derived partly from oxidizing ore bodies. The water within oxidizing ore bodies is locally very acidic, but it is quickly neutralized by the wallrock and calcite gangue so that nearly all the oxidized zinc minerals directly replace the primary sulfides and little zinc is lost. Pseudomorphs of smithsonite after sphalerite veins and crystals are common.

In the Ridge and Valley and Piedmont provinces, where climate is warm and rainfall heavy, limestones commonly underlie valleys or basins and are deeply altered and dissolved by vadose water to soft clayey saprolites and residual clays. As the water descends from ground level it dissolves the limestone in deep pockets between pinnacles of undissolved limestone. In places the limestone is mineralized with sphalerite; where weathered, the limestones dissolves irregularly; some of the sphalerite is directly replaced by oxidized zinc minerals, but the remainder is dissolved, and moves down into the pockets. Zinc carbonates and silicates accumulate by slumping and redeposition in these peculiar clay- and saprolite-filled pockets. The main minerals are hemimorphite and smithsonite, but hydrozincite and zinc clays are deposited locally from zinc-bearing ground water. Beneath some of the saprolitic accumulations and in other limestone deposits where the pockets are not formed, sphalerite is directly replaced as hemimorphite and smithsonite. The ground water in these deposits is rich in humic acids and ranges in pH from 7.0 to as low as 4 or 5 in eastern Tennessee (Kelley and others, 1958, p. 1596). Oxidation commonly extends at least 100 to 200 feet below the present water table. This may be simply the result of oxygenated phreatic water currents set up by the descent of large quantities of vadose water that is rich in humic acids, carbon dioxide, and oxygen, or it may reflect a formerly more humid, tropical climate.

In the warm arid West the present water table is generally far below the surface. It may be below or above—commonly far above—the deepest oxidation. In many places water tables are locally perched, preserving bodies of sulfides within the oxidized ore bodies. Such sulfide bodies are present in the Darwin and Argus districts, Inyo County, Calif. Surface water is very alkaline (pH 8 to 12 in many places), but mine water is commonly very acidic. Limestones and dolomites are very resistant to weathering and make ridges that form the crests of some of the highest mountains. In oxidizing sulfide deposits, even those in carbonate rocks, the zinc is much more mobile than lead or silver and commonly migrates in vadose water from the sulfide with some of the copper, where present. The zinc is in part lost, and in part redeposited as wallrock-replacement deposits of smithsonite, hydrozincite, and aurichalcite. Such wallrock-replacement deposits are also found in the high humid mountain areas, where they remain from former periods of greater aridity during the Cenozoic era. Leadville, Colo., and the deposits in Montana are examples.

REGIONAL MINERALOGIC VARIATIONS

Regional mineralogic variations in the oxidized zinc deposits are notable, particularly in the West. They are partly a reflection of marked climatic changes in certain areas, but they probably also reflect metallogenetic differences in the hypogene deposits from which the oxidized deposits are derived. Several regional variations have been noted and plotted on a series of distribution maps, but no detailed study has been made of the relations that may be involved.

Of the silicates of zinc, hemimorphite is the most abundant, and it is widespread as a major ore mineral. Kelley and others (1958, p. 1596) proposed that hemimorphite is more abundant in warm humid climates of much rainfall and groundwater of low pH. No such simple relation is apparent to the writers. Hemimorphite is more common than smithsonite (1) where the deposits and wallrocks are rich in silica, (2) where the oxidized ores directly replace the hypogene ores, especially if quartz is present as a gangue, and (3) where progressive oxidation has reached the later stages, approaching the final stage of limonitic and siliceous gossan. Smithsonite and hydrozincite are most abundant elsewhere.

Willemite (fig. 4), the anhydrous silicate of zinc, is much more abundant in the West as an ore than is commonly reported. It is nearly restricted to certain deeply oxidized districts in the Basin and Range province and, for reasons not yet clear, to certain deposits within those districts. The only other supergene willemite known is at two deposits in the Precambrian of Colorado and one in New York, all of which show evidence of late progressive oxidation, perhaps in Precambrian times. Hypogene willemite is restricted to three deposits in New Jersey—Franklin, Sterling Hill, and Andover—and is also present at Huachuca Mountain, Ariz. (fig. 4).

Zinc-manganese oxides and silcates (fig. 5) are widely distributed throughout the country without evidence of any restrictive association other than an abundance of zinc and manganese in the hypogene ores, deep oxidation, and carbonate wallrocks. Helvite, troostite, and franklinite are hypogene minerals.

Sauconite and other zincian clays (fig. 6) are locally abundant throughout the United States south of the 41st parallel; north of this line they are known only in southwest Wisconsin as uncommon minerals (Heyl and others, 1959). No regional relation other than this is apparent.

Small deposits of vanadium-bearing oxidized zinc-lead minerals are common throughout the southern part of the Basin and Range province of the United States (fig. 7) and also far southward into Mexico. In this part of the United States the minerals descloizite, mottramite, and vanadinite have been mined in places for their vanadium. They are less common in the northeastern part of the Basin and Range province and are absent in the northwestern part. Elsewhere in the country, they are found sporadically in Idaho and Montana and in the metamorphic rocks of the Northeast. The source of the vanadium has been attributed by many to the adjacent limestones, although limestones as a group are lean in vanadium (Kelley and others, 1958, p. 1596). Newhouse (1934, p. 209–219) attributed the vanadium in oxidized zinc deposits to trace quantities in the hypogene deposits.

The study by the writers shows that the vanadium minerals are restricted to limited areas within geomorphic provinces, where they occur under a great variety of geologic conditions and in wallrocks that include granitic rocks, felsic and mafic volcanic rocks, gneisses, amphibolites, limestones, and clastic rocks of many ages. Only one of the several oxidized zinc deposits in the Colorado Plateaus province contains vanadium minerals, although vanadium-bearing rocks are widespread. This information throws considerable doubt on the theory that the vanadium was derived from the wallrocks. The presence of vanadium in deposits of the Northern Rocky Mountains and the Northeastern States, and its absence in most of Nevada and eastern California, does not support the concept that vanadium is concentrated only in areas of deep and intense oxidation. Most probably the descloizite ores are derived from small amounts of vanadium that occur in one or more of the hypogene ore or gangue minerals which are found in the deposits.

One hypogene deposit of vanadium minerals is shown in figure 7: the deposit at St. Anthony, Ariz. The hypothesis of Peterson (1938) and Creasey (1950), that late hydrothermal vanadium-bearing solutions reworked the already-oxidized base-metal ores at St. Anthony and added vanadium to them, seems to the writers to have merit and possibly warrants wider application.

Hydrozincite (fig. 8) is abundant and a major ore in the northern part of the Basin and Range province and locally in the semiarid Colorado Plateaus province, but it is sparce in the southern part of the Basin and Range province. Thus it is most abundant where vanadium minerals are rare or absent. It is a mineral typical of the late-progressive oxidation stages of zinc deposits—particularly in arid areas, as proposed by Kelley, and others (1958, p. 1596)—but the reasons for its relative sparsity in the southern Basin and Range province

Oxidized zinc data compiled by A. V. Heyl and C. N. Bozion, 1959

FIGURE 4.—Known occurrences of willemite in oxidized zinc deposits.

HYPOGENE DEPOSITS

1. Franklin-Sterling Hill, N.J.
2. Andover, N.J.
6a. Iron Mountain, N. Mex.
11. Huachuca Mountain, Ariz.

SUPERGENE DEPOSITS

3. Balmat, N.Y.
4. Evergreen, Colo.
5. Sedalia mine, Salida, Colo.
6. Magdalena, N. Mex.
7. Hillsboro-Kingston, N. Mex.
8. Tres Hermanas, N. Mex.
9. Clifton-Morenci, Ariz.
10. California (Hilltop-Chiricahua), Ariz.
12. St. Anthony, Mammoth, Ariz.
13. Dripping Springs, Ariz.
14. Globe-Miami, Ariz.
15. Silver-Eureka, Ariz.
16. Star district, Utah.
16a. Fish Springs district, Utah.
17. Ely, Nev.
18. Mina, Nev.
18a. Pioche, Nev.
19. Lemoigne, Calif.
20. Cerro Gordo, Calif.
21. Goodsprings, Nev.

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FIGURE 5.—Localities for zinc-manganese oxides and silicates: chalcophanite, hetaerolite, hydrohetaerolite, helvite, willemite variety troostite, and franklinite.

District or deposit	Minerals
1. Franklin, N.J	Franklinite, willemite variety troostite, chalcophanite.
2. Sterling Hill, N.J	Franklinite, willemite variety troostite, chalcophanite, hetaerolite.
3. Leadville, Colo	Chalcophanite, hydrohetaerolite, hetaerolite.
4. Mosquito Range, Colo	Chalcophanite, hydrohetaerolite.
5. Monarch, Colo	Chalcophanite?
6. Aspen, Colo	Do.
7. East Tintic, Utah	Do.
8. Magdalena, N. Mex	Chalcophanite.
9. Superior, Ariz	Chalcophanite? and coronadite.
10. Gold Bottom mine, Slate Range district, California.	Chalcophanite?
11. Pioche, Nev	Zincian manganese oxides.
12. Antelope (Baldwin), Nev	Chalcophanite.
13. Iron Mountain, N. Mex	Helvite.
14. Lake Valley, N. Mex	Chalcophanite.
15. Contact and Copper Flat mines, Grant County, N. Mex.	Chalcophanite, hetaerolite.
16. Lucky Cuss mine, Tombstone, Ariz	Hetaerolite.

EXPLANATION

○

Sauconite and (or) other zinc-bearing clay mineral present in oxidized zinc deposits of district

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FIGURE 6.—Localities for sauconite and other zinc-bearing clays. See list of localities on facing page.

and its occurrence in inverse proportion to the vanadium minerals is not apparent. Perhaps the late hydrothermal solutions, proposed by Peterson (1938) and Creasey (1950) as sources of the vanadium at St. Anthony, Ariz., were widespread and leached the easily soluble hydrozincite to provide zinc for descloizite. Hydrozincite is absent throughout the Northern Rocky Mountains even though its analog aurichalcite is present. Although widespread as a minor mineral in deposits south of the 45th parallel, it is notably absent in the United States in the colder climates north of the 45th parallel (except for a single occurrence in Alaska).

Aurichalcite, the copper analog of hydrozincite, and rosasite(?), a not completely established rare analog of malachite, are found in many places throughout the country (fig. 9). Aurichalcite is much more abundant than commonly described. It is most common in the arid Basin and Range province where, unlike hydrozincite, it is distributed throughout the province fairly uniformly. Locally in the Southwest it is a major or contributing ore mineral that has been mined mostly for its copper content. A new occurrence of rosasite(?) was recently found at the Sedalia mine, Salida, Colo.

Zinc arsenates are rare minerals in this country and are restricted to a few occurrences in the northern Basin and Range province, in deposits whose primary ores are rich in arsenic (fig. 10). Adamite, however, is present also in deposits in Mexico. At Gold Hill, Utah, adamite and the rare mineral austinite are deposited in local abundance as crystal crusts in the oxidized ores, together with scorodite and copper arsenides.

Zinc sulfides as supergene ores are rare (fig. 10). The best known occurrence is the yellow wurtzite associated with hypogene sphalerite and supergene copper sulfides in the Hornsilver mine, San Francisco district, Utah (Butler, 1913). Sphalerite that is possibly supergene is present in the oxidized zone at Aspen, Colo., and sphalerite of supergene origin is reported by Brown (1936) in quantity at Balmat, N.Y.

LOCALITIES

1. Sterling Hill, N.J.
2. Friedensville, Pa.
3. Austinville-Bertha, Va.
4. Embreeville, Tenn.
5. East Tennessee zinc (including Mascot-Jefferson City) district
6. Upper Mississippi Valley district
7. Tri-State zinc-lead district
8. Northern Arkansas district
9. Leadville, Colo.
10. Mosquito Range, Colo.
11. Dry Canyon, Utah
12. Tintic, Utah
13. Alpine (Lone Mountain), Nev.
14. Goodsprings, Nev.
15. Magdalena, N. Mex.
16. Superior, Ariz.
17. Cerro Gordo, Calif.
18. Lee district, Calif.

Oxidized zinc data compiled by A. V. Heyl and C. N. Bozion, 1959

Figure 7.—Known occurrences of vanadium minerals in oxidized zinc deposits.

Location	*Main lithology and age of host rock*
1. Southampton, Mass	Red shales of Triassic age.
2. Sing Sing Prison, N.Y	Marble of Paleozoic(?) age.
3. Franklin, N.J	Marble of late Precambrian age.
4. Sterling Hill, N.J	Do.
5. Phoenixville, Pa	Granodiorite and paragneiss of Precambrian age and red shales of Triassic age.
6. North Magdalena, N. Mex	Veins in volcanic rocks of Tertiary age.
7. Central (Georgetown, Santa Rita, Vanadium), N. Mex	Quartz diorite porphyry and sandstone and shale of Cretaceous age.
8. Lone Mountain, N. Mex	Limestones of Silurian age.
9. Organ Mountains, N. Mex	Limestones of Mississippian and Pennsylvanian age.
10. Palomas Gap, Caballo Mountains district, N. Mex	Limestone of Carboniferous age.
11. Lake Valley district, N. Mex	Lake Valley limestone of Mississippian age.
12. Hillsboro district, N. Mex	Limestone of Paleozoic age capped by lavas of Tertiary age.
13. Hansonburg district, N. Mex	Limestones of Mississippian and Pennsylvanian age.
14. Sacramento district, N. Mex	Strata of Paleozoic age.
15. Hachita, N. Mex	Limestone lenses and clastic rocks of Paleozoic and Cretaceous age.
16. Leadville, Colo	Leadville limestone of Mississippian age.
17. Tintic, Utah	Limestone and sandstone of Paleozoic age and volcanic rocks of Tertiary age.
18. Escalante, Utah	Volcanic rocks of Tertiary age.
19. Star district, Utah	Limestones of Paleozoic and Triassic age.
20. Gold Hill, Utah	Limestones of Paleozoic age.
21. Pioche, Nev	Limestone and sandstone of Paleozoic age and dikes of Tertiary age.
22. Goodsprings, Nev	Limestones of Mississippian age.
23. Searchlight, Nev	Gneisses of Precambrian age.
24. Tombstone, Ariz	Limestones of Devonian and Mississippian age.
25. Bisbee, Ariz	Do.
26. Nogales, Ariz	Information not available.
27. San Cayenta (Grove mine), Ariz	Do.
28. Old Yuma, Ariz	Do.

Location—Continued	*Main lithology and age of host rocks*—Continued
29. Saint Anthony (Mammoth, Tiger, Old Hat), Ariz.	Rhyolite, rhyolite breccias, basaltic volcanic rocks, Gila conglomerate of late Tertiary age and intrusive granite.
30. Bunker Hill (Copper Creek), Ariz.	Granodiorite.
31. Ray, Ariz.	Information not available.
32. Banner, Ariz.	Limestones of Pennsylvanian age.
33. Dripping Springs, Ariz.	Do.
34. Globe-Miami, Ariz.	Quartzites of Precambrian and Cambrian age.
35. Vulture (and Phoenix mine to northeast), Ariz.	Information not available.
36. Castle Dome, Ariz.	Schist, gneiss, and granite of Precambrian age, some clastic sedimentary rocks of Cretaceous age intruded by diorite porphyry; also, a thick section of volcanic rocks, probably of Tertiary age.
37. Silver-Eureka, Ariz.	Schist, granite, and volcanic rocks of Tertiary age.
38. Chloride (Wallapai), Ariz.	Granites, gneisses, schist, and amphibolites of Precambrian age intruded by two younger granites, one of which is of Precambrian(?) age and the other possibly of Mesozoic or Tertiary age.
39. Havasu district, Ariz.	Limestone, shales, and sandstones of Cretaceous age in Colorado Plateau.
40. Ivanpah district, Calif.	Granite gneiss of Precambrian age and quartzites and limestone of Cambrian age.
41. Signal Hill district, Calif.	Granite, probably of Precambrian age.
42. Slate Range district, Calif.	Limestone of Paleozoic age. (Vanadium-mineral identification not certain.)
43. Mineral Hill (Hailey), Idaho	Limestones and other sedimentary rocks of Devonian, Mississippian, and Pennsylvanian age.
44. Teas (Gilmore) district, Idaho	Dolomites of Devonian age.
45. Bald Mountain district, Mont.	Limestones.
46. Silver Star district, Mont.	Information not available.

Oxidized zinc data compiled by A. V. Heyl and C. N. Bozion, 1959

FIGURE 8.—Known occurrences of hydrozincite in oxidized zinc deposits. See list of localities on next page.

LIST OF LOCALITIES

1. Sterling Hill, N.J.
2. Friedensville, Pa.
3. Austinville (and Bertha), Va.
4. Embreeville, Tenn.
5. Kentucky-Illinois fluorite district
6. Granby, Mo.
7. Northern Arkansas
8. Leadville, Colo.
9. Horseshoe, Colo.
10. Rifle Creek, Colo.
11. Massadona-Youghall, Colo.
12. Tintic, Utah
12a. North Tintic, Utah
13. Dry Canyon, Utah
13a. Park City, Utah
14. Fish Springs, Utah
14a. Newfoundland, Utah
15. Promontory, Utah
16. Redmond, Utah
17. Nebo, Utah
18. Ohio, Utah
19. Central (Hanover), N. Mex.
19a. Lone Mountain, N. Mex.
20. Magdalena, N. Mex.
21. Tres Hermanas, N. Mex.
22. Castle Dome, Ariz.
23. Superior, Ariz.
24. Havasu, Ariz.
25. Spruce Mountain, Nev.
26. Ruby Valley, Nev.
27. Aurum, Nev.
28. Ely, Nev.
29. Lone Mountain, Nev.
30. Pioche, Nev.
31. Viola (Carp), Nev.
32. Bristol, Nev.
33. Gass Peak, Nev.
34. Goodsprings, Nev.
35. Dillon (Johnnie), Nev.
36. Hornsilver, Nev.
37. Alpine (Lone Mountain), Nev.
38. Downeyville, Nev.
39. Pilot Mountain, Nev.
40. Silver Star, Nev.
41. Adelanto, Calif.
42. Ivanpah, Calif.
43. Grapevine, Calif.
44. Holcomb, Calif.
45. Kingston Range, Calif.
46. Soda Lake, Calif.
47. Agua Caliente, Calif.
48. Argus (Zinc Hill), Calif.
49. Ballarat, Calif.
50. Carbonate, Calif.
51. Cerro Gordo, Calif.
52. Darwin, Calif.
53. Coso, Calif.
54. Lee, Calif.
55. Modoc, Calif.
56. Resting Springs (Tecopa), Calif.

57. Slate Range, Calif.
58. South Park, Calif.
59. Tibbets, Calif.
60. Ubehebe, Calif.
61. Wild Rose, Calif.
62. Copper Center (Willow Mountain), Alaska
(No. 62 is not shown on fig. 8, but is shown on pl. 1 as Alaska No. 1)

Oxidized zinc data compiled by A. V. Heyl and C. N. Bozion, 1959

FIGURE 9.—Known occurrences of aurichalcite and rosasite(?) in oxidized zinc deposits.

AURICHALCITE

1. Franklin-Sterling Hill, N.J.
2. Moores Station, N.J.
3. Phoenixville, Pa.
4. Bamford district and York area, Pa.
5. Linganore, Md.
6. Upper Mississippi Valley, Wis.
7. Tri-State, Mo.-Okla.-Kans.
8. Alma, Colo.
9. Horseshoe, Colo.
10. Leadville, Colo.
11. Sedalia mine, Salida, Colo.
12. Spring Creek, Colo.
13. Massadona-Youghall, Colo.
14. Park City, Utah
15. Carbonate mine, Big Cottonwood, Utah
16. Rush Valley, Utah
17. Dry Canyon, Utah
18. Lion Hill, Utah
19. Iron Blossom mine, Tintic, Utah
20. West Tintic, Utah
21. Fish Springs, Utah
22. Lucin, Utah-Nev.
23. Cave mine, Bradshaw, Utah
24. Star, Utah

24a. Tutsagabet, Utah

25. Magdalena, N. Mex.
26. Clifton-Morenci, Ariz.
27. Globe-Miami, Ariz.

27a. Silver King mine, Superior, Ariz.

28. Bisbee, Ariz.
29. Turquoise, Ariz.

29a. Empire, Ariz.

30. Aurum, Nev.
31. Ely, Nev.
32. Ward, Nev.
33. Gold Butte, Nev.
34. Yellow Pine mine, Goodsprings, Nev.
35. Downeyville, Nev.
36. General Thomas group (Lone Mountain district), Nev.
37. Alpine group (Lone Mountain district), Nev.
38. Silver Star (Luning), Nev.
39. Cortez, Nev.
40. Old Ivanpah, Calif.
41. Kingston Range, Calif.
42. Darwin, Calif.
43. Cerro Gordo, Calif.
44. Alder Creek (Mackay), Idaho
45. Beaverhead, Mont.
46. Elkhorn mine, Elkhorn, Mont.

ROSASITE (?)

1. Sedalia mine, Salida, Colo.
2. Magdalena (Kelly), N. Mex.
3. Tombstone, Ariz.
4. Majuba Hill, Nev.
5. Wellington, Nev.

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FIGURE 10.—Localities for zinc arsenates and supergene zinc sulfides.

ZINC ARSENATES: ADAMITE, AUSTINITE

District	*Minerals*
1. Gold Hill, Utah	Adamite, austinite.
2. Tintic, Utah	Adamite.
3. Chloride Cliff, Calif	Do.
4. Mina, Nev	Do.
5. Bell, Nev	Do.

SUPERGENE ZINC SULFIDES: WURTZITE OR SUPERGENE SPHALERITE

[Only a few well-established examples shown]

1. San Francisco, Utah	Wurtzite.
2. Aspen, Colo	Sphalerite.
3. Balmat, N.Y	Do.
4. Manning Bog, N.Y	Part of zinc in bog is sulfide; mineral identity not known.
5. Butte, Mont	Wurtzite.

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