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Mineralogy and Trace Element Study of the Manganese Oxide Deposits in the Burgin Mine, East Tintic Mining Distric, Utah County, Utah*

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ABSTRACT.—Manganese oxide ore deposits in the Burgin mine occur as limestone replacements surrounding the southeast portion of the main lead-zinc-silver replacement ore body. Replacement has been in the Middle Herkiner and Lower Cambrian Ophir Formations along the East Tintic thrust fault near its intersection with the Eureka Standard and Apex Standard faults.

The original manganese ore was deposited as rhodochrosite (manganese carbonate) early in the productive stage of mineralization, probably followed by the first surge of galena deposition. The zonal distribution of lead-zinc-silver ore surrounded by manganese carbonate was accomplished by hydrothermal solutions. Alteration of the manganese carbonate to various manganese oxide minerals was a supergene process accomplished by oxygenated ground waters.

Based on mineralogy and geochemistry, three concentric zones are recognized in the manganese oxide ores: (1) pyrolusite-quenselite zone located nearest the lead-zinc-silver ore body, (2) nsutite-hetaerolite zone intermediate from the lead-zinc-silver ore body, and (3) nsutite-birnessite zone farthest away from the lead-zinc-silver ore body. These concentric zones surround the main lead-zinc-silver ore body on all sides and show decreasing concentrations of lead and silver outward from the main ore body. Concentrations of zinc and cadmium are high in the nsutite-hetaerolite zone and low in the other zones. The mineralogy and chemistry in the manganese ores demonstrate a migration of metallic ions outward from the main ore body.

Manganese deposits in the Burgin mine are structurally controlled along the East Tintic Thrust Fault near its intersection with northeast striking tear faults.

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ILLUSTRATIONS

*A thesis submitted to the faculty of the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science.

INTRODUCTION

Purpose and Scope

The Burgin ore body is a large replacement deposit in the middle member of the Ophir Formation and has a large halo of manganese oxide around the southeast portion of the main lead-zinc-silver ore body. Manganese oxide deposits are also associated with other lead-zinc-silver deposits in the district. If the mineralogical and chemical characteristics of the manganese oxides are known they can be used as an exploration guide in search for other lead-zinc-silver deposits. This study was undertaken, at the suggestion of Kennecott Copper Corporation Tintic Division geologist, Paul Mogensen, with the idea that manganese oxide may become useful in future exploration.

Samples were collected from all of the accessible drifts and stopes and from available diamond drill core. This provided representative sampling of the entire deposit. A portion of each sample was sent for wet chemical analysis for thirteen different elements, a second portion was retained for mineralogical studies by polished sections and X-ray diffraction techniques.

Location and Accessibility

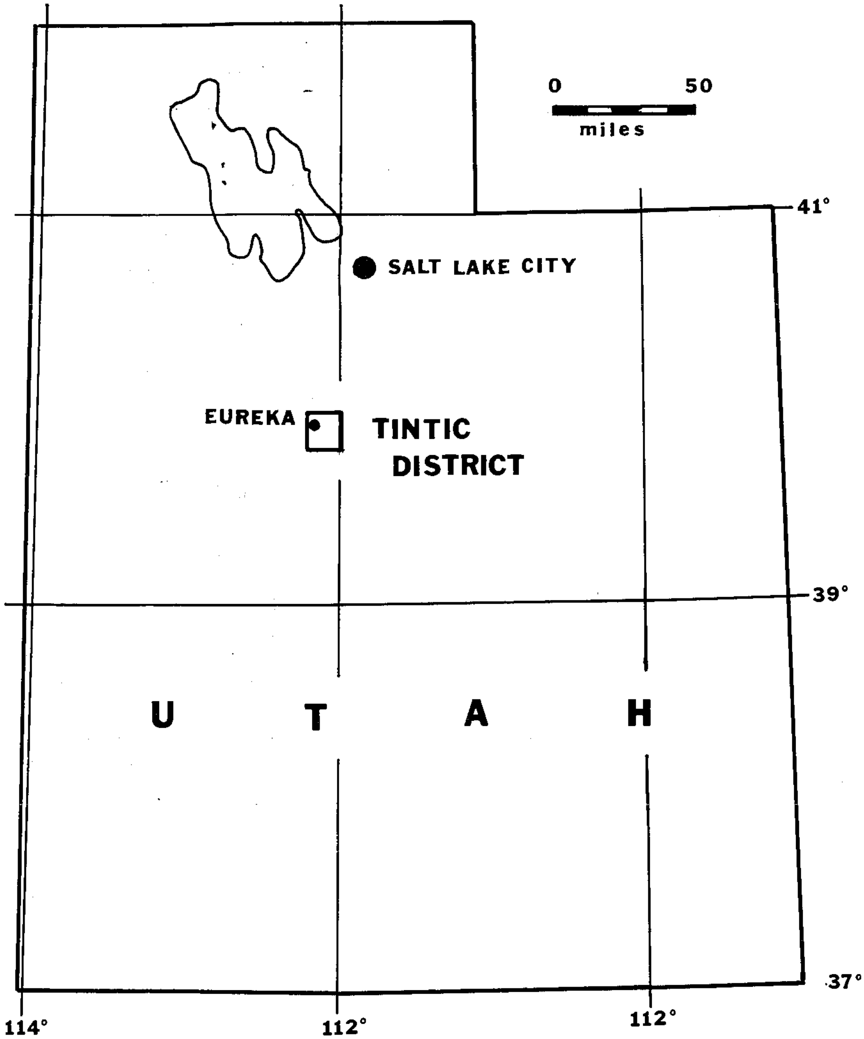
The East Tintic Mining district (Text-figure 1) is located in the southwest corner of Utah County in central Utah, about sixty miles south-southwest of Salt Lake City, Utah. The area is accessible via U.S. Highway 6 and 50 which passes through the north-central portion of the district. Approximate east and west boundaries are meridians 112° and 112°30′ West Longitude, north and south boundaries are parallels 39°55′ and 40° North Latitude.

Physical Features

The East Tintic Mountains are part of a long linear series of mountain ranges that include the Gilson Mountains and Canyon Range to the south and the Oquirrh Mountains, Antelope Island, and Promotory Mountains to the north. This series is considered to be the easternmost of the typical basin- and range-type fault block mountains. The East Tintic Mountains are approximately forty-two miles long and trend almost due north. Along the main divide are ten peaks that range from 7,700 feet to 8,300 feet in elevation. The two highest peaks, Tintic Mountain and Boulter Peak, are 8,218 feet and 8,306 feet, respectively.

The topography is only moderately rugged, but sharp bluffs and steep slopes are not uncommon. Drainage on the west side is to Tintic Valley, elevation 5,300 feet. The east side drains into Goshen Valley, elevation 4,500 feet.

All the gulches contain only intermittent streams (perennial streams are limited to short stretches below springs) that lead to extensive bajadas and compound alluvial fans. The alluvial fans that mark the edges of the range are steep in their upper parts, but gradients decrease down slope towards the valley floor where they coalesce with other fans (Morris and Lovering, 1961, p. 4).



TEXT-FIGURE 1.—Index Map.

Previous Work

Manganese oxides in the Tintic district are described in only one paper (James Anderson, 1964). In this paper, four separate classes of manganese oxides are described.

Owen Bricker (1965) studied the system $Mn\text{-}O_2\text{-}H_2O$ at 25 degrees centigrade and one atmosphere of pressure. Although his work does not relate directly to the high temperatures that existed in the Burgin mineralization, it was helpful in this study.

Present Work

Sampling of drifts, stopes, and drill core began January 1970 and continued throughout the following summer as areas became accessible. The author collected 182 samples from all accessible drifts and stopes to represent the manganese halo.

The samples were divided into three portions: one for wet chemical analysis, a second for X-ray diffraction work, and a third for study by polished sections. All of the 182 samples were assayed by atomic absorption for manganese, iron, lead, zinc, copper, and silver and 123 for cobalt, nickel, cadmium, magnesium, potassium, sodium, and calcium. Sulphur was assayed by reduction methods. Approximately 400 additional samples, collected by the author and Tintic Division personnel, were assayed for manganese, iron, lead, zinc, and silver by the Tintic Division laboratory using atomic absorption. Numerous assay maps prepared by Tintic Division personnel were used in determining zoning patterns.

Acknowledgments

The author is grateful to Dr. Kenneth C. Bullock for his help throughout this project and for serving as thesis committee chairman, to the staff of the Tintic Division of Kennecott Copper Corporation, particularly to D. Donald O. Rausch, general manager of the Tintic Division, for his support in this study, Mr. Paul Mogensen for suggesting the project and for giving many helpful ideas and suggestions, and to Lee Perry for his assistance in collecting samples and mapping work. The author is also grateful to Dennis Norton of Kennecott Exploration Services for the chemical analysis and Steve Cone, also of Kennecott Exploration Services, for his assistance in mineral identification by X-ray diffraction. Many benefits have been derived by stimulating discussions and written communications with Messrs. D. Foster Hewett and Hal T. Morris.

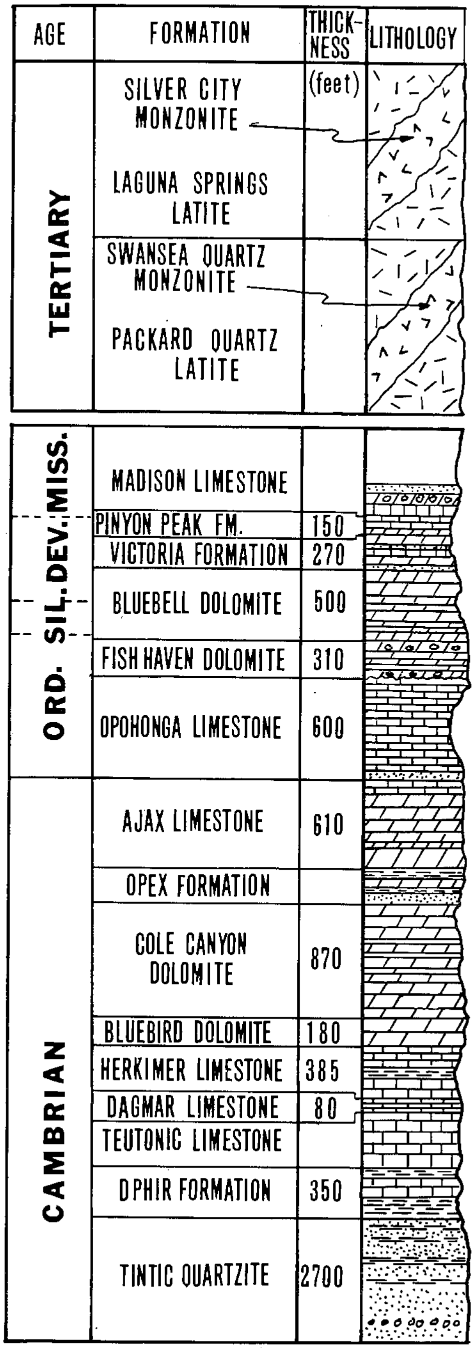
GEOLOGICAL SETTING OF THE DISTRICT

Stratigraphy

Sedimentary rocks exposed at the surface and those penetrated by drill holes and mine workings include approximately 25,000 feet of rocks ranging in age from Precambrian to Recent. Precambrian rocks are only in the western part of the East Tintic Range and are assigned to the Big Cottonwood Series. Because of the limited exposures, the Precambrian rocks are unimportant in the district as ore producing formations. The most productive part of the stratigraphic section in the East Tintic district has been the Middle and Lower Cambrian, principally the Tintic Quartzite and Ophir Formation.

Except for the Tintic Quartzite and the shale in the Ophir and Herkimer Formations, the Paleozoic section is composed of limestone and dolomite (Text-figure 2). In the general area of ore deposits, many of the limestones have been altered to dolomite. Much of this dolomite is in breccia zones adjacent to faults, but some formations, principally the Cole Canyon and Bluebird, are dolomite from base to top in the vicinity of ore deposits; though in areas remote from ore they are mainly limestone. These formations are considered to have been altered to dolomite by hydrothermal activity (Morris, 1964, p. 3), thus the name "hydrothermal dolomite."

A brief description is given only for the Tintic Quartzite, Ophir, and Herkimer Formations since the ore is confined to these stratigraphic horizons.



TEXT-FIGURE 2.—Stratigraphic Column of the East Tintic Mountains.

Tintic Quartzite.—The Tintic Quartzite unconformably overlies the Precambrian Big Cottonwood series. Its total thickness ranges from 2,300 to 3,200 feet (Morris, 1964, p. 7). It is almost wholly quartzite, coarse grained to conglomeratic at the base, medium-grained and cross bedded in the center, and interlayered quartzite and shale at the top. A basalt flow occurs approximately 1,000 feet from the base, providing an excellent marker bed (Morris and Lovering, 1961, p. 14-17).

Ophir Formation.—The Ophir Formation conformably overlies the Tintic Quartzite. It is divided into three members: (1) the Lower Ophir Shale, (2) Middle Ophir Limestone and (3) the Upper Ophir Shale. The Lower Ophir Shale grades from interlayered shale and quartzite at the base to mostly shale in the center and interlayered shale and limestone units in the upper part. The total thickness of the Lower Ophir is 160 to 180 feet. The middle member is wholly limestone and ranges from 100 to 160 feet in thickness. The upper shale unit is interlayered shale and limestone becoming more shale than limestone toward the central portion. Total thickness of the Upper Ophir Shale is 35 to 90 feet (Morris and Lovering, 1961, p. 19-22).

Herkimer Formation.—The Herkimer Formation is distinctive from other formations in the district in that it contains an easily identified marker bed, a 20 foot shale bed. The lower member of the Herkimer is principally blue gray limestone, thin- to medium-bedded and commonly contains lighter color argillaceous layers. Near the base it contains a few pisolite beds and flat pebble conglomerate. The middle member is composed chiefly of green fissile shale. The upper limestone member is dominantly a thin bedded mottled blue gray limestone with beds of flat pebble conglomerate, a few beds of oolite and shale partings becoming common in the upper parts. The total thickness is approximately 425 feet (Morris and Lovering, 1961, p. 32-33).

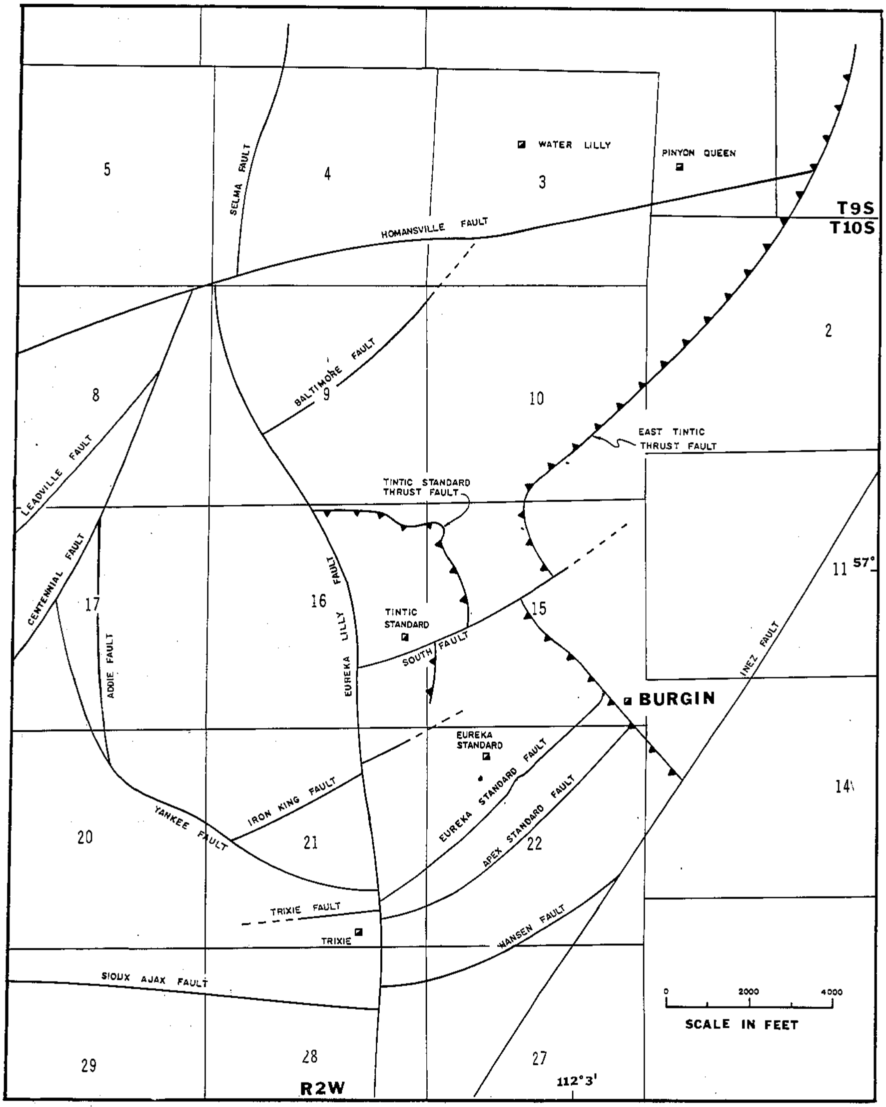
Detailed description of these and other formations in the East Tintic district can be found in reports by Morris and Lovering (1961), Lindgren and Loughlin (1919), Crane (1907), and others.

Structure

Major compressional forces have folded the thick Paleozoic rocks into broad north-trending folds which have been cut by many faults, including normal faults, low-angle thrust faults, and high-angle tear faults. The main Tintic district has a broad major syncline with a steep to overturned west limb and a gently dipping east limb. The adjacent anticline is in the East Tintic district. These folds plunge gently to the north and have a minimum amplitude of approximately 10,000 feet (Morris, 1964, p. 8-9).

Four major sets of faults are recognized throughout the district: (1) north-south trending faults, (2) east-west faults, (3) thrust faults, and (4) northeast tear faults (Text-figure 3). North-south trending faults are characterized by the Eureka Lily fault which dips approximately 45 degrees to the west. These faults have a long complex history of movement (both pre-ore and post-ore). The east-west faults are steep to vertical dipping faults. At the intersections of these two fault systems occur rich pipelike ore bodies.

Three major thrust faults are recognized in the district: (1) the Pinyon Peak thrust fault, (2) the Tintic Standard thrust fault and (3) the East Tintic thrust fault (Morris, 1964, p. 10-12). No ore has been found along



TEXT-FIGURE 3.—Major Faults of the East Tintic district.

the Pinyon Peak thrust which is not as well known. The Tintic Standard thrust is the locus of the large Tintic Standard "pot hole" ore body. Movement of the Tintic Standard thrust sheet has been from the west, and displacement is probably thousands of feet. The East Tintic thrust fault has an average dip of approximately 30 degrees to the southwest in the Burgin mine area but becomes flat north of the Burgin. Displacement ranges from one to two miles, and Early Paleozoic rocks were thrust over Middle and Late Paleozoic rocks.

Associated with this fault are several right-lateral, strike-slip faults. In the Burgin area, two right-lateral, strike-slip faults, the Apex Standard and Eureka Standard, in conjunction with the thrust fault, play an important part in ground preparation and provide channelways for the mineralizing solutions.

Igneous Rocks

General Statement.—Igneous rocks are the most abundant rocks exposed on the surface in the East Tintic district. They represent part of a large deeply eroded volcanic complex, the center of which is near the site of the abandoned town of Silver City, southeast of Eureka (Morris and Lovering, 1961, p. 124).

Extrusive Rocks.—Extrusive rocks consist of two groups: (1) Packard Quartz Latite and (2) Laguna Springs Latite. Both of these contain flow rocks, nonwelded tuffs, welded tuffs, and agglomerates. In general, the Packard Quartz Latite is chiefly fine textured with phenocrysts of sanidine, plagioclase, quartz and minor amounts of biotite. The Laguna Springs Latite contains phenocrysts of sanidine, plagioclase hornblende, and biotite in glassy matrix (Morris and Lovering, 1961, p. 124-125).

Intrusive Rocks.—Intrusive rocks include rocks of three stocks and rocks of many dikes, sills, and plugs. The quartz monzonite of the Swansea stock is considered the intrusive counterpart of the Packard Quartz Latite. It is located in the southwestern part of the district. The Silver City and Sunrise Peak stocks are monzonite and have been correlated with the Laguna Springs Latite. Many of the monzonite dikes, plugs, and sills are believed to have been intruded at the same time as the Silver City and Sunrise Peak stocks (Morris and Lovering, 1961, p. 124-125).

Small linear intrusive breccias called "pebble dikes" are of special interest. They occupy northeast trending fissures which are nearly vertical. They are composed of small pebbles of quartzite, limestone, dolomite, igneous rocks, and shale in a matrix of groundup rock. Some of them are associated with base metal mineralization (Shepard et al., 1968, p. 945).

Ore Deposits

Ore production from the East Tintic district has come from large replacement deposits and fissure deposits which have yielded approximately 3.6 million tons of ore valued at $120 million. The majority of production came from the Tintic Standard mine which produced approximately two-thirds of the district total.

Ore deposits in the East Tintic district are controlled primarily by major structural features. The larger deposits, such as the Burgin and Tintic Standard, are localized along thrust faults near the intersection of northeast striking faults. Smaller deposits are found along normal faults and tear faults. Stratigraphy is also an important control in the localization of ore deposits. The middle limestone member of the Ophir Formation is the largest producer in the district; more than 75 percent of the ore mined has come from this formation. Stratigraphy is also important in determining the size and the type of deposits. Ore deposits in the Tintic Quartzite are small fissure deposits, generally of small tonnage, and often containing areas very rich in gold and silver. The Eureka Standard ore body is a fissure deposit in the Tintic

Quartzite along a footwall strand of the Eureka Standard fault. The Eureka Standard mine produced 373,000 tons of ore with an average grade of 0.7 ounces gold, 9.3 ounces silver, 4 percent copper, 1.5 percent lead, and 0.4 percent zinc. The principal minerals were gold tellurides, enargite, tetrahedrite, galena, and sphalerite (Bush, 1957, p. 120-121). Deposits in the Middle Ophir Limestone are generally larger than the fissure deposits. The Tintic Standard ore body, a replacement deposit in the Middle Ophir, yielded approximately 2 million tons of ore with an average metal content of 0.04 ounces gold, 24 ounces silver, 12 percent lead, and 0.4 percent copper (Kildale, 1957, p. 104-105). The principal hypogene ore minerals were argentiferous galena, sphalerite, enargite, and argentiferous tennantite, and tetrahedrite. The important secondary ore minerals include cerussite, anglesite, and argentojarosite. Although ore deposits have been discovered in other formations, the most favorable site for ore deposition is in the Middle Ophir Limestone in fault contact with the Tintic Quartzite.

GEOLOGY OF THE BURGIN MINE

General Statement

The Burgin mine of Kennecott Copper Corporation is the most recent of the mines in the East Tintic district. It was discovered by the U.S. Geological Survey and Bear Creek Mining Company in 1956 as a result of exploration along the East Tintic thrust.

Diamond drill hole located near the Burgin No. 1 shaft was drilled by the U.S. Geological Survey in 1956. The hole penetrated Mississippian rocks. This was the first indication of a major thrust fault east of the Tintic Standard mine. On this information, Bear Creek Mining Company sank the Burgin No. 1 shaft and drifted to the west to explore this thrust. Subsequent drifting and diamond drilling led to the discovery of the main Burgin ore body.

Stratigraphy

Rocks of the Footwall.—Footwall rocks of the East Tintic thrust are known to include rocks from the Upper Cambrian Ajax Formation to the Lower Mississippian Fitchville Formation; however, the Opohonga Formation lies directly below the East Tintic thrust in the Burgin area and has been highly altered by hydrothermal solutions. The attitudes of these rocks range from gently east dipping to nearly recumbent positions (Shepard et al., 1969, p. 956).

Rocks of the Hanging Wall.—The Lower Cambrian Tintic Quartzite and Ophir Formation form the hanging wall in the northwest part of the mine, but in the southeast portions of the mine, southeast of the Apex Standard fault, Middle Cambrian rocks, probably the Herkimer Formation, form the hanging wall.

Structure

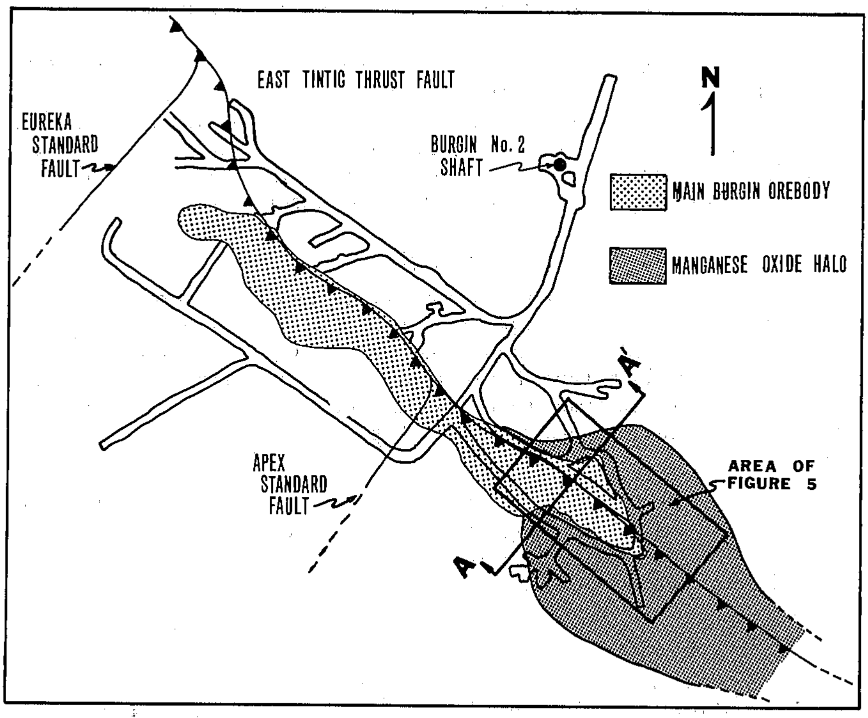
The major structural feature of the Burgin mine is the northwest striking East Tintic thrust fault that cuts the crest of the East Tintic anticline. The thrust fault has steepened the east limb of the East Tintic anticline to where it is completely overturned and nearly flat lying. Associated with the thrust fault are northeast striking right lateral strike-slip faults (Text-figure 4). The Eureka Standard and Apex Standard are faults of this type. Dips are generally 50° to 70° to the west on both of these faults.

Igneous Rocks

In the Burgin mine area the sedimentary rocks are covered by approximately 1,000 feet of Packard Quartz Latite. Pyritic and argillic alteration in the Packard Quartz Latite is strong. Dikes of monzonite have intruded both the sedimentary rocks and the overlying tuffs and flows of the Packard Quartz Latite.

Hydrothermal Alterations

The most extensive study of alteration in the East Tintic district was carried out by the U.S. Geological Survey under the direction of T. S. Lovering et al. (1949) from 1943-1955. Evidence was found of five stages of hydrothermal alterations: (1) early barren—dolomitization of limestones and chloritization of volcanics; (2) mid-barren—argillizaton; (3) late barren—jasperoid, barite, and pyrite of cubic habit; (4) early productive—sericite, quartz, and pyrite of pyritohedral habit; (5) productive—ore minerals. All of these stages are present in the Burgin area and were used as guides during the exploration.



TEXT-FIGURE 4.—General Geology of the Burgin 1200 Level showing major faults and relation of ore to manganese oxide.

Ore Deposits

The ore deposits of the Burgin mine are structurally and stratgraphically controlled. The principal ore body is along the East Tintic thrust. It is a limestone replacement in the Middle Ophir Limestone and the Herkimer Formation. The unoxidized ore is an intimate mixture of argentiferous galena and sphalerite with varying amounts of quartz, barite, jasperoid, and rhodochrosite. The oxide ore bodies contain cerussite, anglesite, smithsonite, and unoxidized masses of primary minerals. The oxide portions of the ore body are unique in that most of them lie below the permanent water table. Development of the ore body, at present, shows its northwest portion to lie directly on the altered footwall rocks of the thrust fault. The southeast portion is marked by manganese oxide deposits and, in some areas, sanded dolomite.

MANGANESE DEPOSITS IN THE BURGIN MINE

General Statement

Manganese deposits of the Burgin mine occur as limestone replacements closely associated with lead, zinc, and silver replacement ores. Manganese oxides surround the southeast portion of the main ore body extending several hundred feet southeast along the East Tintic thrust fault. The contact zone between manganese oxides and the footwall carbonate rocks is narrow, ranging from 0 to 25 percent Mn in two feet. Along the sides of the ore body the manganese oxide ranges in thickness from approximately 20 to 30 feet up to three or four times that width (Text-figure 4). The updip extension of the East Tintic thrust as seen on the 1050 Level shows the manganese to pinch out; but the down dip extension has not been determined. On the 1300 Level the manganese oxide surrounds pods and lenses of lead and zinc sulfides and silver ore. Also in the hanging wall of the thrust fault unreplaced pods of sanded dolomite were found in some areas. The southeast extension of the manganese oxide zone is unknown, but has been traced by diamond drilling for a considerable distance.

A small deposit of manganese oxide occurs on the 1050 Level along the Apex Standard fault. Present exploration shows only small amounts of lead-zinc-silver ore associated with this deposit.

Stratigraphic Controls

Manganese deposits in the Burgin mine are found in portions of two formations, the Middle Ophir Limestone and the Herkimer Limestone. Reactive limestone formations control the deposition of the manganese deposits. The shale units of the Ophir Formation that are in mutual contact show no evidence of replacement.

Structural Controls

The most important control in the localization of manganese oxides is structure. Major controlling structures in the Burgin mine are the East Tintic thrust near its intersection with the Apex Standard fault. Manganese deposits occur on all three levels of the Burgin mine along the East Tintic thrust.

Geochemistry

Trace elements associated with the manganese oxides show the existence of significant composition zones around the main lead-zinc-silver ore body.

Elements in the manganese oxides that show strong zoning are lead and zinc; silver, cadmium, and copper show subordinate zoning patterns. Zoning surrounds the ore body on the top, southeast end on both sides, and possibly on the bottom.

Three zones have been established based on mineralogy and geochemistry: (1) pyrolusite-quenselite zones located nearest the lead-zinc-silver ore body, (2) nsutite-hetaerolite zones intermediate from the lead-zinc-silver ore body, and (3) nsutite-birnessite zone farthest away from the lead-zinc-silver ore body (Text-figure 5 and 6).

Pyrolusite-quenselite zone ranges from a few feet to twenty feet in width and surrounds the main lead-zinc-silver ore body (Text-figure 5). The concentrations of lead, zinc, and silver are 5-15 percent, 1-4 percent, and 5-12 oz/ton, respectively. In this zone the lead is found in the lead manganese mineral, quenselite ($PbMnO_2(OH)$).

Nsutite-hetaerolite zone surrounds and is concentric with the pyrolusite-quenselite zone and is characterized by high zinc (4-10 percent) and low lead (1-4 percent). The principal zinc mineral is hetaerolite ($Zn\ Mn_2O_3$). Chalcophanite (Zn, Mn Fe) Mn_2O_5. ($2H_2O$), not as common as hetaerolite, is a late zinc mineral and forms veinlets in this zone and accounts for a portion of the zinc. Silver in this zone ranges from 0.3-3.0 oz/ton.

Nsutite-birnessite zone lies beyond and is concentric around the nsutite-hetaerolite zone. This zone contains low lead (1-4 percent) and low zinc (1-4 percent).

Silver and copper follow lead and their zoning pattern is the same, increasing from a background of approximately 0.2 ounces of silver per ton and a trace of copper to 1 or 2 ounces per ton silver and approximately 0.01 percent copper. Silver shows distinct and consistent zoning; copper however is erratic and shows only a general trend towards zoning.

Cadmium follows the zinc and its zoning pattern is the same as zinc. The background is approximately 0.02 percent, and values in cadmium range to 0.10 percent.

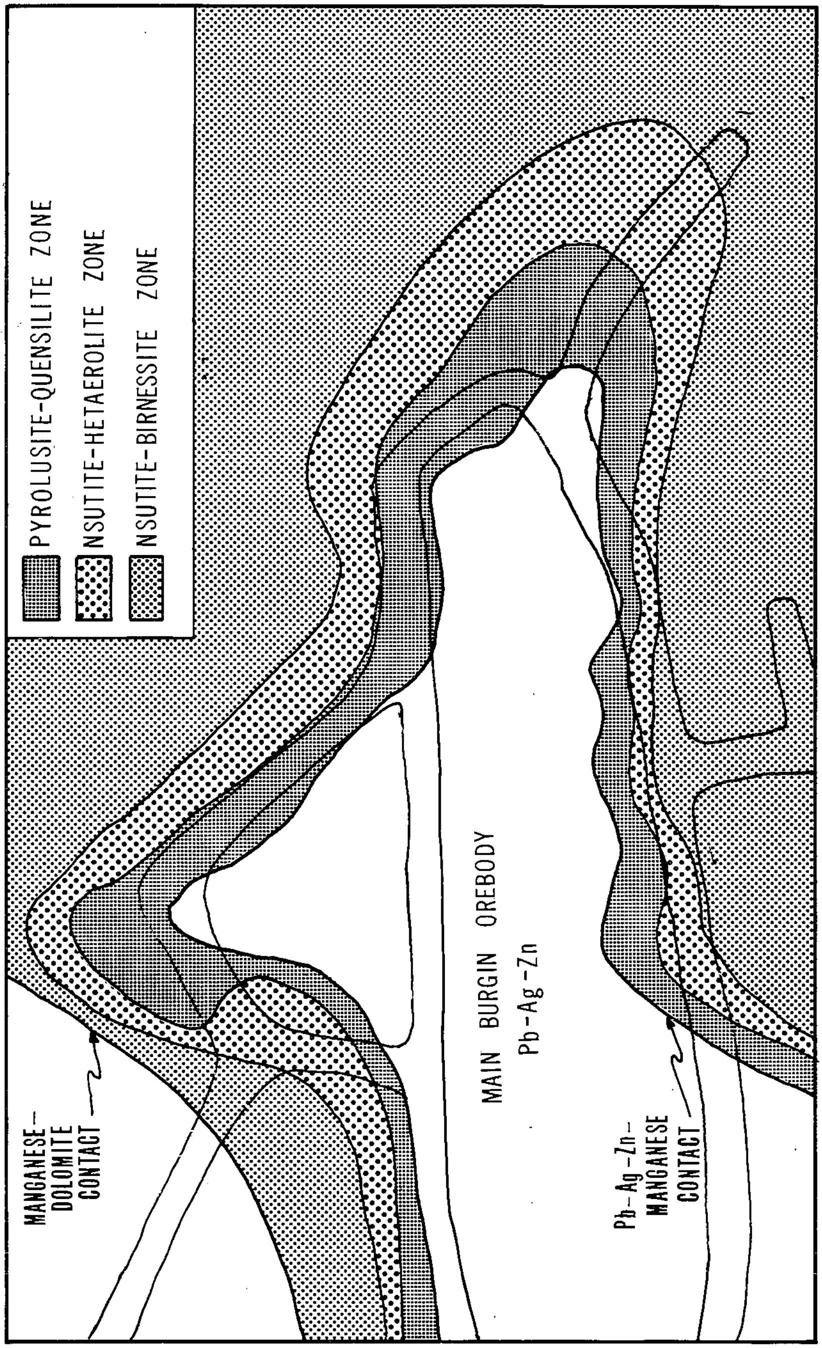
Manganese and iron show no discernible zoning patterns. A plot of manganese versus iron shows a strong correlation. As manganese increases up to 26 percent, iron also increases. As manganese increases above 26 percent, iron begins to decrease.

The other elements analyzed did not show any significant zoning (Table 1). Cobalt and nickel were generally present in amounts less than ten parts per million which is the detection limit of the atomic absorption method used.

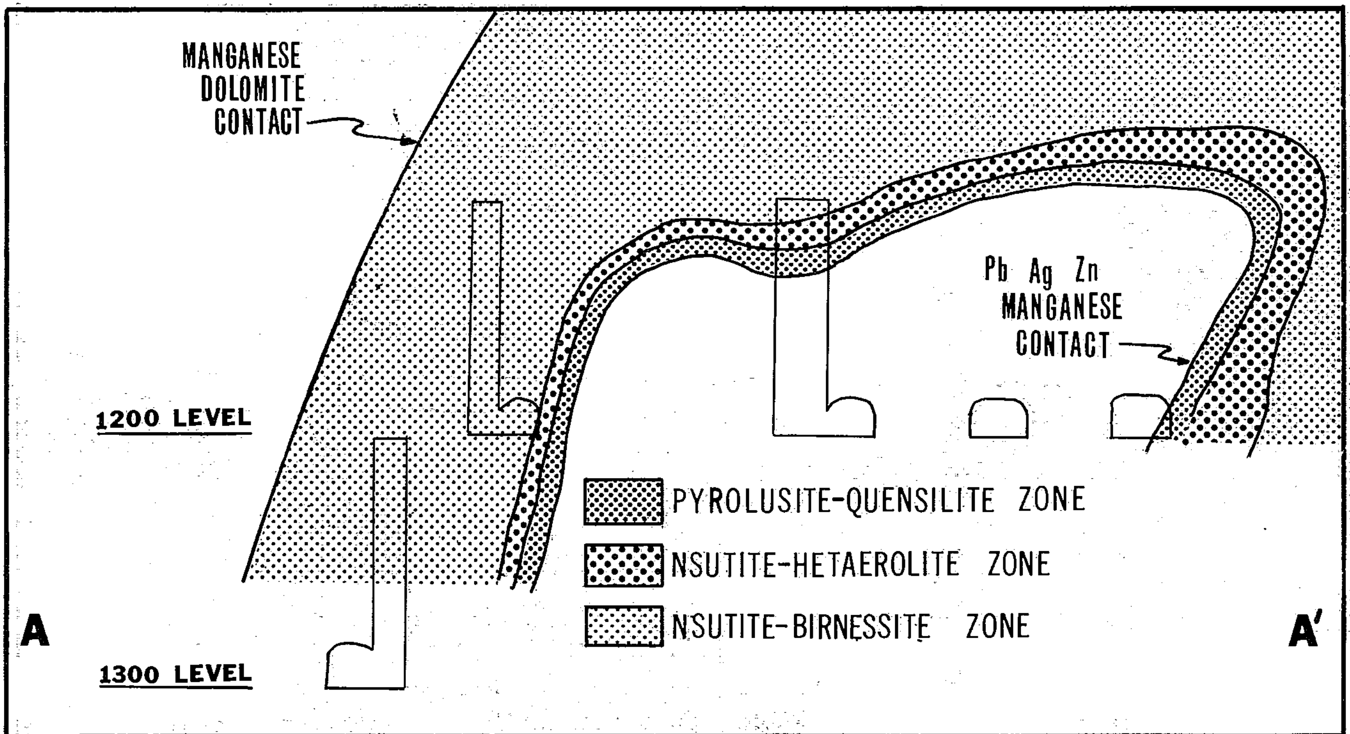
TABLE 1
AVERAGE GRADES OF SAMPLES

Samples From	Mn	Fe	Pb	Zn	Ag ppm	Cd ppm	Co ppm	Ni	Cu	Mg%	K%	Na%	Ca%	S%
1050 Level	23.3	14.9	2.2	4.8	14	306	32	34	42	.14	.27	.08	.33	2.44
1200 Level	18.0	11.2	6.3	7.5	192	807	24	13	647	1.03	.29	.23	1.64	1.21
1300 Level	24.1	10.4	8.1	3.4	126	222	18	16	135	.41	.37	.37	.28	.10
Drill Core	20.6	11.6	2.8	6.9	51	667	25	19	246	.22	.47	.13	.37	1.53
						Pb%	Zn%	Ag			Cu%	Mn%		Fe%
1200 Level						6.7	11.1	2.0			.01	18.2		17.0

(Assayed by Tintic Division Laboratory)



TEXT-FIGURE 5.—Zoning in the Manganese Oxide on the Burgin 1200 Level. Area of figure shown in Text-figure 4.



TEXT-FIGURE 6.—Section A-A′ Zoning in the Manganese Oxide around the main Burgin ore body. Line of section shown in Text-figure 4.

A few samples contained up to sixty parts per million. Sodium and potassium content is approximately 0.25 and 0.10 percent, respectively. Calcium and magnesium content average 0.35 and 0.01 percent, respectively. Sulphur content is about 0.045 percent in the manganese oxide zone.

Mineralogy

Mineralogy of the manganese oxides is very complex because of the wide variety of possible minerals, the intimate mixture of minerals, the large amount of ionic substitution, and the small, almost submicroscopic, size of individual grains. Mineral identification was accomplished by X-ray diffraction, reflecting ore microscope and binocular microscope. X-ray diffraction was the most important tool used. The minor peaks were absent, but identification was considered positive if the major peaks were present.

Birnessite, hetaerolite, nsutite, pyrolusite, and quenselite are the most abundant and show a distinct zoning pattern around the main ore body. Three zones appear and are identical with chemical zoning. The inner ore zone closest to the main ore body is called the pyrolusite-quenselite zone and is the zone of high lead (See Text-figure 5 and 6). The second zone is nsutite-hetaerolite zone and is the zone of high zinc in Text-figures 5 and 6. The third is nsutite-birnessite zone and is outside the high zinc zone. The following manganese minerals were identified:

Mineral Name	Chemical Composition	Crystal System
Birnessite	(Na, Ca) Mn_7 O_{14} 2-8 H_2O	Unknown
Chalcophanite	(Zn, Mn, Fe) Mn_2O_5 $2H_2O$	Monoclinic
Cryptomolene	K Mn_8 Mn_8 O_{16}	Tetragonal
Hetaerolite	Zn Mn_2 O_3	Tetragonal
Hollandite	Mn Ba Mn_6 O_{14}	Tetragonal
Nsutite	Mn O_2	Unknown
Pyrolusite	Mn O_2	Orthorhombic
Quenselite	Pb Mn O_2 (OH)	Monoclinic

X-ray data are included for these minerals in Tables 2 and 3.

Birnessite was first described by McMurdie (1944) as an artificial manganese dioxide. He believed it to be a distinct species and proposed the name delta-MnO_2 for this compound. Buser et al. (1954) investigated the substances described as delta-MnO_2 and manganous manganite. They observed X-ray pattern corresponding to McMurdie's (1944) delta-MnO_2 and manganese manganite described by Feitknecht and Mosti, and they concluded that manganese manganite and delta-MnO_2 are of the same phase.

Buser and Grutter (1956) found that delta-MnO_2 was one of the primary manganese compounds in deep sea manganese nodules. Jones and Milne (1956) described a new manganese mineral found in fluvioglacial gravel deposits near Birness, Scotland. It gave an X-ray pattern identical to delta-MnO_2. They named this mineral birnessite. Frondel et al. (1960) described birnessite from Cummington, Massachusetts, where it occurs as a product of the weathering and oxidation of manganese-rich rocks. Zwicker et al. (1962) reports that birnessite is the first oxide form in the oxidation of manganese carbonate at Nsuta, Ghana. Fleischer (1957) reports that birnessite loses the two inner peaks when heated to above 110°C.

TABLE 2

X-RAY DATA FOR NSUTITE

Zwicker et al. (1962) Nsuta, Ghana				Dubois (1963)		This Work (1971)	
Nsutite		Manganoan Nsutite					
d (Å)	I	d (Å)	I	d (Å)	I	d (Å)	I
4.36	VW	4.46	VW	4.	S	4.12	S
3.96	VS	4.10	VS	2.35	M	2.42	M
2.59	VW	2.66	M	2.06	M	2.12	M
2.43	S	2.45	M	1.58	M	1.61	M
2.34	M	2.39	VW	1.40	W	1.42	W
2.22	VVW	2.16	S	1.38	W		
2.13	S	2.13	M				
2.07	VW	1.92	VW				
1.892	VVW	1.88	VVW				
1.638	S	1.67	S				
1.615	W	1.52	W				
1.488	VVW	1.43	W				
1.425	W	1.39	M				
1.362	VW	1.37	VW				
1.306	VVW	1.33	W				
1.067	VW	1.29	VVW				
		1.26	VW				
		1.23	VVW				
		1.19	VW				
		1.14	VVW				
		1.08	W				

Symbols are as follows: S=Strong, M=Medium, W=Weak, VW=Very Weak, VVW=Very Very Weak.

Modified from Bricker (1965).

Birnessite is intimately associated with nsutite in the nsutite-birnessite zone. In hand specimen, the mineral is soft, has a brown to cinnamon brown color, and is massive. In polished section, it is medium gray in color and cryptocrystalline.

X-ray diffraction patterns generally include lines which are assignable to quartz and nsutite. D-spacings and intensity data are given in Table 2.

Identification of nsutite and birnessite is very difficult for several reasons. First, the patterns obtained from this mineral vary from specimen to specimen in completeness of pattern and interplanar spacing. Second, the nomenclature developed by various workers for similar material is based upon the study of artificial products as well as naturally occurring minerals, most of which give somewhat different X-ray patterns. Third, patterns made by different apparatus, such as the diffractometer and the powder camera, and patterns of materials of unknown purity add apparent discrepancies to the numerous differences in X-ray patterns. X-ray patterns from several workers are included in Table 3.

TABLE 3

X-RAY DATA FOR BIRNESSITE

Jones & Milne Birnessite from Birness, Scotland		Yo Hariya Birnessite from Todoroki Mine Hokkaido, Japan		Owen Bricker Synthetic Birnessite		Buser et al. Manganous Manganite (Birnessite)		This work Birnessite	
d (A)	I	d (A)	I	d (A)	I	d (A)	I	d (A)	I
7.27	S	7.37	37	7.2	8	2.43	S	7.2	S
3.60	W	4.69	11	4.75	9	1.42	S	3.63	M
2.44	M	3.69	9	2.44	10			2.43	S
1.412	M	3.32	5	2.12	4 broad			1.42	S
		3.27	4	1.67	1 broad				
		2.45	5	1.42	8 broad				
		2.37	7	1.27	1 broad				
		2.09	5						
		1.41	8						

Symbols are as follows: S = Strong, M = Moderate, W = Weak.
Modified from Bricker (1965).

Genesis of Manganese Oxide

Through the author's studies and work in the Burgin mine a general hydrothermal paragenetic sequence appears to be as follows: galena was deposited first, then a sphalerite phase followed by a second galena stage, a second sphalerite stage followed by pyrite, quartz, and barite. Manganese was deposited early in the hydrothermal sequence as carbonates. Alteration of manganese carbonates to manganese oxides was subsequently accomplished at temperatures above 65°C by oxygenated ground waters probably mixed with hydrothermal solutions. The elevated temperatures are indicated by the high temperature polymorph of birnessite. The manganese deposits lie along the East Tintic thrust fault in an area where both the footwall and hanging wall rocks are carbonates. These rocks are highly fractured, and around the manganese deposits they are sanded, thereby increasing porosity and allowing the circulation of ground water.

The paragenetic sequence of the manganese ozide minerals is not determinable. No definite conclusions were reached except for chalcophanite which is a late zinc manganese mineral found in small veins and filling small vugs.

Exploration and Ore Potential

Manganese oxide from the Burgin mine cannot be used for metallurgical purposes in the steel industry, battery industry, or chemical industry because of the high lead and zinc content. Small quantities have been mined and shipped to Bunker Hill Company where it is used as an oxidant in the electrolytic zinc cells at the zinc refinery. Total tonnages shipped to date amount to 3,160 tons. Future development of manganese may come from the nsutite and birnessite in the fringe areas, and hetaerolite, quenselite, nsutite, and pyrolusite close to lead-zinc-silver ore bodies. The discovery of manganese ores in new areas of exploration may be an excellent guide to lead-zinc-silver ores.

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