

Chap 47

Ore Deposits of the
United States 1933-1967

John d Ridge Editor Vol. 1

47. Geology and Ore Deposits of the East Tintic Mining District, Utah*

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* Publication authorized by Kennecott Copper Corp. and the Director, U.S. Geological Survey.
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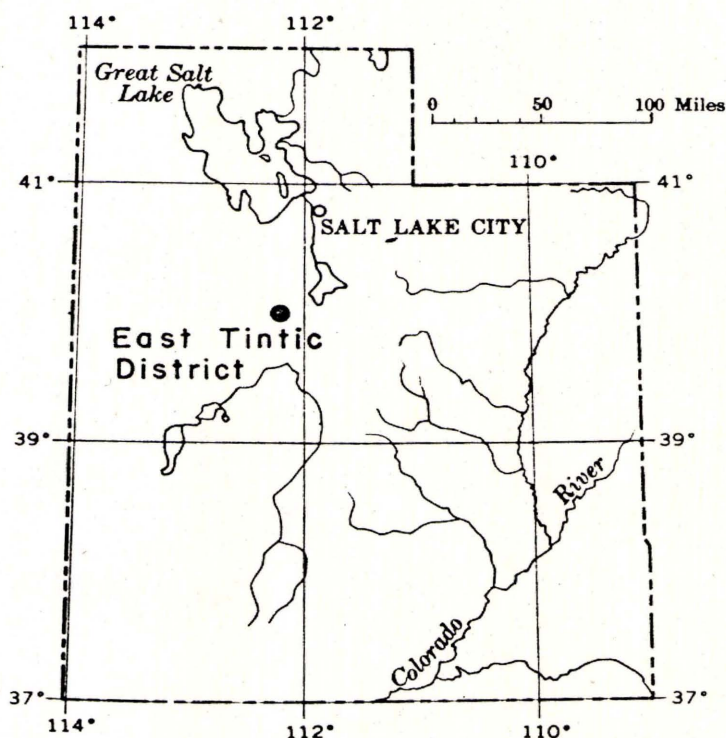
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ABSTRACT

The East Tintic district in central Utah has produced ores of gold, silver, copper, lead, and zinc valued at more than \$120,000,000. All of this ore has been produced from blind ore bodies in Paleozoic sedimentary rocks that are concealed beneath hydrothermally altered volcanic rocks and cut by intrusive bodies of Eocene age. The Paleozoic rocks, which range in age from Early Cambrian to Mississippian,

form the core and limbs of a large, north-trending asymmetric anticline that is cut by low-angle thrust faults, high-angle transcurrent faults, mineralized fissures and faults, and normal faults that are both older and younger than the mineralized fissures. The ore bodies generally may be grouped into two classes: (1) massive replacement bodies that are rich in silver, lead, zinc and manganese and (2) fissure veins that are valuable primarily for their content of gold, copper, and silver. The replacement ore bodies are localized chiefly in the Middle Limestone Member of the Ophir Formation of Middle Cambrian age where it has been thrust-faulted against older or younger rocks and cut by northeast-trending mineralized fissure zones. The fissure veins primarily are productive only in the Lower Cambrian Tintic Quartzite. Extensive low-grade deposits of lead-zinc-silver ore recently have been discovered in Devonian carbonate rocks in the Lower plate of the East Tintic thrust fault but as yet are unevaluated. The principal guides to ore include: (1) intersections of northeast-trending fissures and cross-breaking faults that brecciate the carbonate rocks; (2) zones of late-stage pyritic, calcitic, and sericitic alteration in the lavas; (3) primary geochemical anomalies in the altered rocks; and (4) mineral zoning patterns of the known ore bodies. The present development of the Burgin mine would seem to assure the continued productivity of the district for at least a decade.

INTRODUCTION

The East Tintic mining district in central Utah has achieved world prominence from its production of rich silver and lead ores from blind ore bodies. The recent development of the Burgin mine and the discovery of mineralized areas nearby, all concealed by thick flows of barren lava, give promise of the discovery of new ore bodies by the continued application of geological, geochemical, and geophysical techniques.

The district is in the east-central part of the East Tintic Mountains, a north-trending fault-block mountain range near the east-central margin of the Great Basin. It is approximately bounded by Meridians 112° and 112°5' west and Parallels 39°55' and 40° north and covers about 20 square miles. Officially, it constitutes the northeastern part of the Tintic mining district, but it has been popularly regarded as a separate district since the turn of the century. Although the ores of the two districts are mineralogically similar, the ore bodies of the East Tintic district are localized more obviously by structural features and generally do not form the extensive linear ore zones that characterize the replacement ore bodies of the Main Tintic district.

The topography in the area of the East Tintic district is rolling to moderately rugged,

ranging in elevation from about 5100 feet to 8100 feet. The steepest slopes are found on inliers of sedimentary rocks that project through the extensive lava flows and pyroclastic deposits that cover the greater part of the district. These steep slopes largely represent an ancient topography that is being exhumed through the erosional stripping of the less resistant, commonly altered volcanic rocks.

PRODUCTION

The mines of the East Tintic district have yielded about 3.6 million tons of ore valued at \$120,000,000 (21, p. 97). As shown in Table I, more than two-thirds of this ore was produced from the Tintic Standard mine and the balance from only eight other operating properties. Silver and base metal ores were first produced from the district in 1909, following the discovery of narrow replacement veins by shallow workings driven from the Eureka Lilly shaft. The discovery of these blind ore bodies stimulated exploration and development of adjacent properties, and the district rocketed into prominence with the discovery of the rich, totally concealed Tintic Standard ore bodies in 1916. By 1924, these deposits were yielding 150,000 tons of argentiferous lead ore per year, making the Tintic Standard the most productive silver mine in the United States, if

TABLE I. Mine Production—East Tintic District, Utah, 1909–1966

Mine	Interval	Tons	Gold (Ounces)	Silver (Ounces)	Copper (Pounds)	Lead (Pounds)	Zinc (Pounds)
Apex Standard ¹	1928–1937	13,728	1,373	188,074	109,824	741,312	—
Burgin ²	1955–1966	150,600	22	2,137,400	—	52,551,700	19,699,800
Eureka Lilly	1909–1952	227,610	53,254	1,227,754	3,747,328	21,750,597	18,950
Eureka Standard	1928–1952	362,375	242,903	3,430,277	2,715,748	11,209,798	3,496,852
Iron King ¹		14,000	1,400	19,601	28,000	—	—
North Lily Group ³ (Includes: North Lily, Baltimore, Tintic Bullion, Eureka Bullion, Hannibal, Provo, and other properties operated through North Lily shaft)	1927–1949	375,000	148,000	3,554,000	2,482,000	101,682,000	4,270,000
Tintic Standard (Includes ore from Harold Mill dump 1943–1952)	1913–1952	2,469,722	90,005	52,239,832	18,502,917	554,689,732	954,748
20th Century	1943–1947	1,419	40	7,320	59,716	1,338	—
Lumas ¹	1928–1944	2,208	442	3,754	8,832	343,608	—
Totals		3,616,662	537,439	62,808,012	27,654,365	742,970,085	28,440,350

¹ Data modified from Cook, D. R., editor, 1957, pl. 3.

² This report.

³ Data modified from Kildale, M. B., in Cook, D. R., editor, 1957, p. 105.

All other data from U.S. Bureau of Mines.

not in the world (5, p. 645). Discovery and development of other blind ore bodies in 1927 and 1928 increased the output of the district briefly to more than 200,000 tons of ore per year. By 1933, the effects of the great economic recession had cut back ore production to 70,000 tons during that year, but recovery was rapid, and, in 1937, more than 140,000 tons of ore were produced from five operating mines. After 1937, production steadily declined despite the stimulus of increased demand for metals occasioned by World War II; by 1952, the exhaustion of the known ore bodies had closed all of the mines.

A dramatic revival of the district has been underway since 1958, beginning with the discovery and subsequent development of the Burgin ore bodies (26). This discovery, and the new insights into the geology of the sublava sedimentary rocks revealed by the exploration and development of this mine, in turn, has stimulated the search for other concealed ore deposits. This activity gives promise of a long additional period of productivity for the district.

GRADE OF ORE

The ores produced from the East Tintic district from 1909 to 1952 were classified on the basis of composition and content of recoverable metals as: (1) silver ore, (2) silver-lead ore, (3) siliceous silver ore, (4) lead-silver ore (5) lead-zinc ore, (6) gold-silver-copper ore, and (7) zinc ore. According to data presented by Kildale (24, p. 104-106), 80 per cent or more of all the ore produced during this interval was either: (1) silver-lead ore with an average content of recoverable metals of about 0.035 ounce per ton of gold, 28 ounces per ton of silver, 20 per cent of lead, and 0.3 per cent of copper or (2) siliceous silver ore with an average recoverable metal content of 0.045 ounce per ton of gold, 20 ounces per ton of silver, 4 per cent of lead and 0.5 per cent of copper. Locally, both of these types of ore contained several hundred to as much as several thousand ounces of silver per ton and were sold separately as silver ore.

Next in importance are the siliceous gold-silver-copper ores, typified by the 375,000 tons of ore produced from the Eureka Standard mine containing an overall average of 0.7 ounce per ton of gold, 9.3 ounces per ton of silver, 4 per cent of copper, 1.5 per cent of lead, and 0.4 per cent of zinc (22, p. 121). Some ores of this type were exceptionally rich in gold, as indicated by 65,000 tons of gold-silver-copper ore from the Endline Dike fissure

zone in the North Lily mine that had an average content of 1.326 ounces per ton of gold, 4.75 ounces per ton of silver, and 1.37 per cent of copper. Some small lots of gold-silver-copper ore shipped from deposits in the Endline Dike fissure zone returned over \$10,000 per ton, and cut samples contained over 2000 ounces per ton of gold (24, p. 105).

Of lesser importance are the lead-silver, lead-zinc, and zinc ores. The lead-silver ores are typified by 194,000 tons produced from the North Lily mine that contained an average of 0.116 ounce per ton of gold, 12.6 ounces per ton of silver, and 24 per cent of lead. Much of the lead-zinc ore was similar to 35,000 tons also produced from the North Lily mine from which the average recovery was 0.087 ounce per ton of gold, 10 ounces per ton of silver, 7.1 per cent of lead, and 6.1 per cent of zinc (24, p. 105). The zinc ores provided only small tonnages of secondary ores derived from the oxidation of primary lead-zinc bodies chiefly in the Eureka Lilly mine (3, p. 247).

The partly developed ore bodies of the Burgin mine doubtless include small tonnages of each of the classes of ore listed above, but, in gross aspect, they appear to contain somewhat less silver and considerably more zinc than the ores produced from the East Tintic district prior to 1952. Some of the Burgin ore is further characterized by a gangue containing a large percentage of rhodochrosite and manganosiderite. Preliminary estimates based on diamond drilling and limited development of the Burgin mine indicate a minimum of 1,250,000 tons of high-grade ore with an overall average content of 10 ounces per ton of silver, 15 per cent of lead, and 12 per cent of zinc (28). This high-grade ore is, in turn, surrounded by great masses of mineralized breccia containing an average of approximately 0.5 ounce per ton of silver, 2.1 per cent of lead, 6.3 per cent of zinc, and 15.6 per cent of manganese (26, p. 1537). Incomplete exploration of areas adjacent to the Burgin mine indicates additional large quantities of similar mineralized breccia.

ACKNOWLEDGMENTS

So many geologists and other scientists have contributed to the present understanding of the geology and ore deposits of the East Tintic mining district that it is feasible to acknowledge in this paper only those investigators who have prepared comprehensive reports. The significant publications of Tower and Smith

(1899), Crane (1917), Lindgren and Loughlin (1919), Billingsley (1933), Billingsley and Crane (1933), Farmin (1934), Walker (1928), and Lovering and his co-workers (1949, 1960) are well known. Less well known, but no less significant, are private reports by Paul Billingsley, M. B. Kildale, G. W. Crane, J. B. Bush, J. A. Anderson, F. H. Howd, and many others. These sources have been drawn upon freely in preparing this report. Acknowledgment should also be made of the less tangible sources of data and concepts garnered from innumerable discussions in stopes, field camps, and bars—wherever the subject of East Tintic geology has been discussed throughout the world.

Especial indebtedness is due to the officers and staffs of the Kennecott Copper Corporation, the Chief Consolidated Mining Company, the Tintic Standard Mining Company and affiliated organizations, and the International Smelting and Refining Company for the many courtesies that have been extended during the writers' investigations and employment in the East Tintic district.

The present report is the result of essentially independent effort on the part of the three writers. Cook prepared the sections on exploration and development; Morris prepared the introductory material and the sections on general geology; Shepard prepared the sections on the ore deposits and assembled and coordinated the three parts of the report. All of the writers, however, must bear equal responsibility for the statements and concepts that are presented.

GENERAL GEOLOGY

Sedimentary and Igneous Rocks

The rocks exposed at the surface and penetrated by mine workings and drill holes in the East Tintic district include approximately 10,000 feet of Paleozoic miogeosynclinal deposits and as much as 5000 feet or more of middle-Eocene latite and quartz latite lavas, tuffs, and agglomerates, all of which have been intruded by stocks, plugs, dikes, and sills of monzonite and quartz-monzonite porphyry. These rocks and their stratigraphic relations are summarized in Table II; more complete descriptions may be found in the reports of Morris and Lovering (29), Lindgren and Loughlin (3), and others. The best known of the stratified rocks are the Ophir Formation and adjacent units, which are the principal

host rocks of the major ore bodies and thus are extensively exposed in most of the mines.

The igneous rocks are the deeply eroded remnants of a composite volcano of middle-Eocene age. The core of this volcano, located a few miles southwest of the East Tintic district, was intruded by small stocks of monzonite and quartz monzonite that are the parent rocks of the numerous dikes, sills, and plugs forming the north-northeasterly-trending belt of intrusive rocks that cuts the central part of the district.

Of special interest in the East Tintic district are tabular bodies of intrusion breccia—locally termed “pebble dikes”—that contain abrasion-rounded fragments of quartzite together with less abundant disk-shaped pieces of shale and limestone in a matrix of pulverized rock. These breccias, which occupy the same north-northeasterly-trending fissures that also localize dikes of monzonite porphyry and veins of ore, are believed to have been emplaced explosively by rapidly expanding gases, perhaps chiefly steam, that were generated when invading monzonite bodies encountered zones of underground water. Some pebble dikes may also have been emplaced by upwelling viscous monzonite magmas and by gases suddenly expelled from them.

At depth and in unexplored areas beneath the lavas, the Lower Cambrian Tintic Quartzite, which is considered to be the “basement rock” of the district, is believed to overlie an undetermined thickness of quartzite and argillite of the Upper Precambrian Big Cottonwood Formation, which is exposed in the west central part of the East Tintic Mountains. The youngest of the Paleozoic rocks known in the district, the Humbug Formation of Late Mississippian age, is overlain by more than 17,500 feet of rocks of Pennsylvanian and Permian age that crop out in the northern and southern parts of the range.

The post-volcanic deposits of Pleistocene and Recent age are devoid of placer accumulations and residual ores and thus are economically unimportant except as they conceal possible ore-bearing formations. The Alpine and Bonneville Formations are clastic lacustrine deposits that were laid down during the highest and oldest stages of Lake Bonneville, a glacial lake of Wisconsin age. These units overlie Eocene volcanic rocks, Pleistocene fanglomerates, and alluvium near the eastern edge of the East Tintic district, and they conceal Pliocene fanglomerate and lacustrine marls and bentonite tuffs of the Salt Lake(?) Formation beneath Goshen Valley.

TABLE II. Stratigraphic column, East Tintic District, Utah

System	Series	Formation or Unit	Lithology and Average Thickness	
Quaternary	Recent	Younger Alluvium	Fanglomerate, gravel, sand, and silt; 0-100 ft.	
	Pleistocene	Bonneville Formation	Lacustrine gravel and sand; 20 ft.	
		Alpine Formation	Lacustrine sand and silt; 25 ft.	
		Older alluvium	Fanglomerate, colluvium, and stream gravels.	
<i>Unconformity</i>				
Tertiary	Eocene	Andesite or latite dikes and related intrusion breccias	Purple porphyritic dikes, locally altered to kaolinite; probably contemporaneous with ore deposition.	
		<i>Intrusive contact</i>		
		Quartz monzonite porphyry	Greenish-gray, coarsely porphyritic dikes and plugs.	
		<i>Intrusive contacts</i>		
		Pebble dikes	Narrow dikes of intrusion breccia.	
		Monzonite of Silver City stock and associated biotite monzonite porphyry	Greenish-gray, granitic to coarsely porphyritic monzonite; altered near veins.	
		Monzonite porphyry of Sunrise Peak stock and associated hornblende monzonite porphyry	Medium- to dark-gray coarsely porphyritic monzonite; altered near veins.	
		<i>Intrusive contacts</i>		
		Laguna Springs Latite	Reddish-gray flows, tuffs and agglomerate; 0-2500 ft.	
<i>Intrusive contact</i>				
Swansea Quartz Monzonite	Granitic intrusive rock chiefly altered and bleached.			
<i>Intrusive contact</i>				
Packard Quartz Latite	Purplish-gray contorted flows and white tuff; 0-2700 ft.			
Tertiary (?)	Eocene (?)	Apex Conglomerate	Brick-red conglomerate and sandy shale; 0-500 ft.	
<i>Unconformity</i>				
Carboniferous Mississippian	Upper	Humbug Formation	Alternating blue limestone and buff sandstone; 650 ft.	
		Deseret Limestone	Blue-gray cherty and coquinoïd limestone; 1000 ft.	
	Lower	Gardison Limestone	Blue-gray distinctly bedded cherty limestone; 500 ft.	
		Fitchville Formation	Seven distinctive units of limestone and cherty dolomite; curly laminated bed near top; 300 ft.	
Devonian and Mississippian		Pinyon Peak Limestone	Blue-gray shaly limestone, sandy at base 80 ft.	
<i>Disconformity (?)</i>				
Devonian	Upper	Victoria Formation	Gray dolomite and buff quartzite; locally some lenses of penecontemporaneous breccia; 280 ft.	

TABLE II. Stratigraphic column, East Tintic District, Utah (Continued)

System	Series	Formation or Unit	Lithology and Average Thickness
Devonian, Silurian and Ordovician		Bluebell Dolomite	Dusky-gray coarse-grained dolomite with some beds of sublithographic creamy white dolomite. Curly laminated marker beds near middle; 350-600 ft.
	Upper	Fish Haven Dolomite	Mottled gray cherty dolomite; 300 ft.
Ordovician		<i>Disconformity</i>	
	Lower	Opohonga Limestone	Blue-gray thin-bedded shaly limestone; 300-850 ft.
Cambrian	Upper	Ajax Dolomite	Dusky-gray cherty dolomite; 650 ft.
		Opex Formation	Thin-bedded sandy limestone and shale; 250 ft.
	Middle	Cole Canyon Dolomite	Dusky-gray and creamy white dolomite; 850 ft.
		Bluebird Dolomite	Dusky-gray dolomite with white markings; 190 ft.
		Herkimer Limestone	Blue shaly limestone and green shale; 400 ft.
		Dagmar Dolomite	Creamy-white laminated dolomite; 80 ft.
		Teutonic Limestone	Blue shaly limestone with pisolitic zones; 420 ft.
		Ophir Formation	Gray-green shale and blue oolitic limestone; 410 ft.
	Lower	Tintic Quartzite	Buff quartzite; gray-green phyllite beds near top, conglomerate zone near base; 3000 ft.

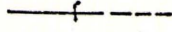
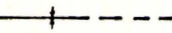
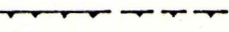
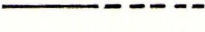
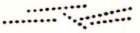




Structure

The thick section of Paleozoic rocks of the East Tintic Mountains is compressed into broad, north-trending folds and is cut by many faults including low-angle thrust faults, high-angle transcurrent faults, post-compressive normal faults, and, locally near the centers of intrusion, by moderately persistent mineralized fissures (Figure 1). The compressive structural features are all pre-lava in age and apparently resulted from the regional deformation of one of a series of large thrust sheets that moved eastward across central Utah in Cretaceous time (11, p. 377-400; 34, p. 1944-1951).

The dominant structures in the district are the north-trending, asymmetric East Tintic anticline and the East Tintic thrust fault that

cuts its eastern limb. These structures are concealed largely beneath the lavas and are known chiefly from exposures in mine workings and from drill hole data. The anticline is one of the folds of the Tintic-Oquirrh fold system, which apparently is limited to the upper plate of the Midas thrust fault (34, p. 1948). A minimum amplitude of 10,000 feet is estimated for this fold on the basis of detailed measurements of the stratigraphic units that are exposed from the core of the anticline to the trough of the adjacent Tintic syncline.

Cross-sections prepared from subsurface data and limited surface exposures show the west limb of the East Tintic anticline dipping more or less uniformly to the west about 30° and the east limb overturned and sharply crumpled above the East Tintic thrust zone.

- EXPLANATION**
-  Anticline
Showing trace of axial plane and direction of plunge of axis. Dashed where concealed or approximately located
 -  Syncline
Showing trace of axial plane. Dashed where concealed or approximately located
 -  Thrust fault
Sawteeth on side of upper plate. Dashed where concealed or approximately located
 -  Steep Fault
Dashed where concealed or approximately located. U, up-thrown side; D, downthrown side
 -  Fissure zone
Dike-and breccia-filled fractures; walls commonly altered. Locally ore bearing at depth
 -  Mined ore
 -  Unmined ore
 -  Drill hole in mineralized rock
 -  Shafts and prospect
- 1 North Standard
 - 2 Water Lillie
 - 3 Central Standard
 - 4 Copper Leaf
 - 5 Independence
 - 6 North Lily
 - 7 Tintic Standard No. 2
 - 8 Eureka Lilly
 - 9 Apex Standard No. 2
 - 10 Iron King (No. 2)
 - 11 Eureka Standard
 - 12 Apex Standard No. 1
 - 13 Zuma
 - 14 Trixie prospect
 - 15 Burgin No. 1
 - 16 Burgin No. 2
 - 17 Tintic Standard No. 1
 - 18 South Standard

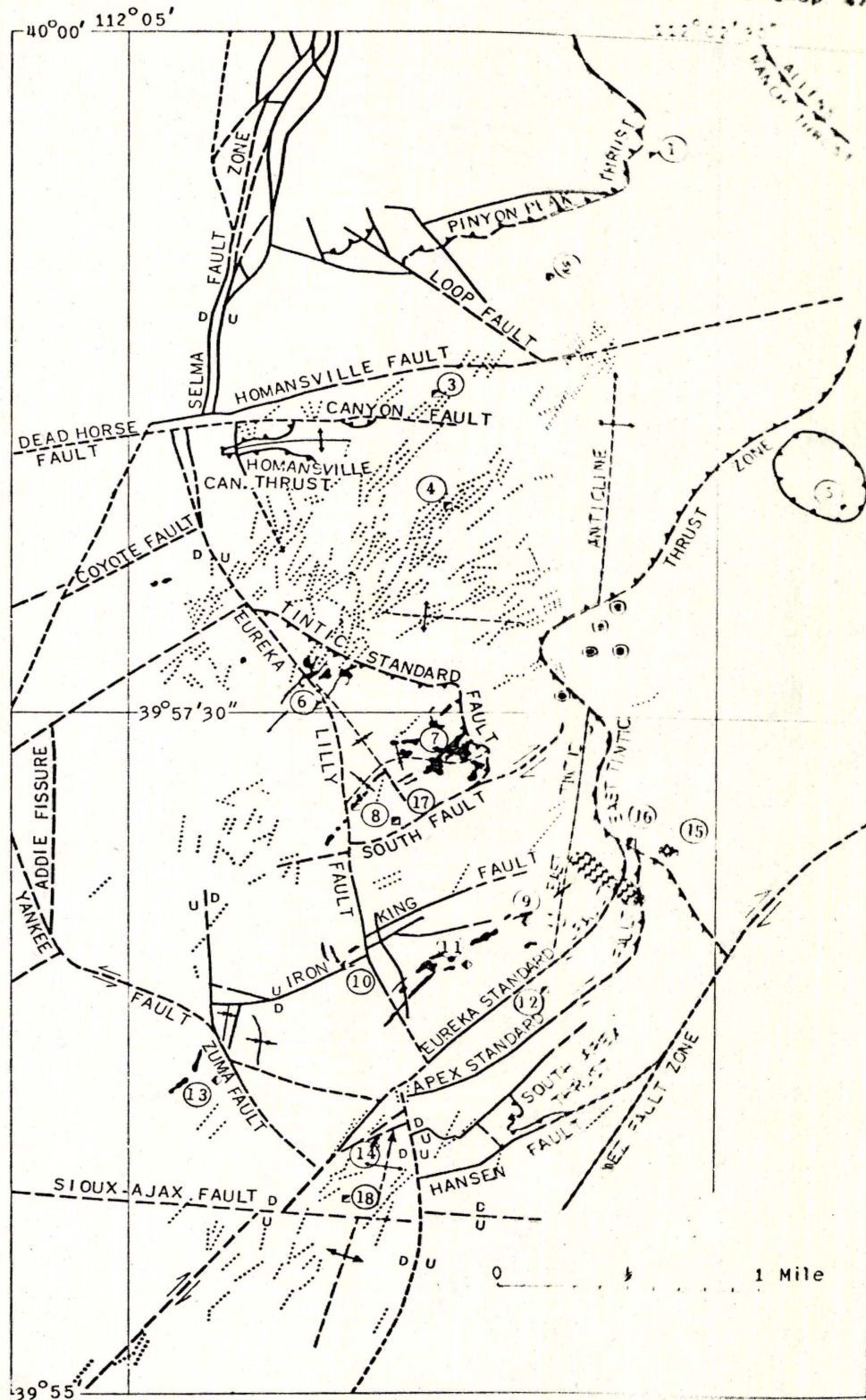


FIG. 1. Subsurface Structure Map of East Tintic District, Utah, showing mined and unmined ore bodies.

The crest of the fold, which plunges gently to the north and south from a point a few hundred feet east of the Tintic Standard mine, is cut by several transverse faults, some of which developed concurrently with the fold and thrust fault during the compressive stages of orogenic activity.

The East Tintic thrust fault, which localizes the principal ore bodies of the Burgin mine, cuts the concealed east limb of the anticline, displacing it 5000 feet or more along a plane dipping moderately to the west. In the Burgin mine, the rocks of the upper plate, which moved relatively eastward, include brecciated

and deformed beds of the Ophir Formation that have been overturned and dragged under a wedge of Tintic Quartzite that rides above one or more subsidiary thrust strands. The rocks of the footwall plate of the main East Tintic thrust fault in the most fully developed parts of the mine are sheared and contorted beds extending from the lower part of the Opohonga Limestone to the Pinyon Peak and Fitchville Formations. The sublava position of the thrust zone has been traced by drill holes from the Burgin mine generally northward for about 2 miles and southward for approximately half a mile, where the thrust zone apparently terminates against the inferred Inez fault, which is believed to be a concealed tear fault of large displacement (31).

Other thrust faults, with somewhat less displacement than the East Tintic thrust but with the same general strike, dip, and sense of displacement, also are recognized in the East Tintic district. The best known minor thrust is a decollement near the contact of the Tintic Quartzite and the Ophir Formation in the upper plate of the East Tintic thrust. It is exposed only in the workings of the Tintic Standard and North Lily mines and has been named the Tintic Standard thrust fault by Lovering and his co-workers (15, p. 14). According to Lovering (15), the late asymmetric development of the East Tintic anticline crumpled the upper and lower plates of a zone of low-angle faults near the top of the Tintic Quartzite into a complex, northwest-trending asymmetric trough that concurrently was cross-folded near its southern end, producing a curving northeasterly- to easterly-striking cross-trough marked by much broken and highly mineralized ground that is known locally as the Tintic Standard "pot hole." A re-evaluation of this structure, based on observations of the Eureka Standard and Apex Standard faults in the Burgin mine, suggests that the Tintic Standard thrust fault may terminate against a northeast-striking tear fault, which Lovering and his co-workers (15) had assumed to be part of the thrust plane. This tear fault, locally termed the South fault, appears to have formed a buttress against which the rocks of the upper plate were crumpled and drag folded, producing the irregular, northeast-striking cross-trough or pot hole. The great size and richness of the Tintic Standard ore body is due in large part to the unique structural form of the pot hole and to the large volume of brecciated limestone—prepared ground—that was contained within it.

The northwestern end of the main trough

of the folded Tintic Standard thrust fault narrows rapidly at the fissure zone that passes near the North Lily mine, where the western side is vertical or overturned. In this part of the folded thrust, the formations in the constricted trough of the fold also are highly broken producing the so-called North Lily pot hole, which localizes the North Lily and Eureka Lilly replacement ore bodies.

The Pinyon Peak thrust, which is exposed near the North Standard shaft, is similar to the East Tintic thrust but has a stratigraphic throw ranging from only a few hundred to about 1500 feet. It is not known to be an ore-bearing structure. The displacement on this thrust is greatest on the lower east slopes of Pinyon Peak where the Middle Cambrian Cole Canyon Dolomite is thrust over the base of the Upper Ordovician Fish Haven Dolomite.

The transcurrent faults are part of a conjugate system of northeast- and northwest-trending fractures that cut the axes of the major folds at angles of 25° to 55°. In the East Tintic district, the best-known faults of this group are the Apex Standard and Eureka Standard faults, both of which are right-lateral tear faults that develop a progressively lower dip and more northerly strike as they approach and merge with the East Tintic thrust. The combined displacement on these two tear faults is 3000 to 4000 feet, as indicated by the horizontal separation of the axis of the East Tintic anticline. Small bodies of high-grade gold-telluride and argentiferous enargite ores, as well as somewhat larger but less profitable replacement deposits of copper, lead, and zinc ores, were mined in the Eureka Standard fault zone in the Eureka Standard and Apex Standard mines. The Apex Standard fault zone, in contrast, contains only small ore shoots in the Apex Standard mine, but it has not been explored fully below the 900-foot level in that mine or southwest of the Apex Standard No. 1 shaft. The intersection of both of these faults with the East Tintic thrust may be one of the principal localizing features of the Burgin ore bodies.

The inferred Inez fault is believed to be a right-lateral, strike-slip fault similar to the Eureka Standard and Apex Standard faults; however it has much greater displacement. Regional studies (34) suggest that it may be the delimiting tear fault marking the southern edge of the Midas thrust fault, which extends northward to the Bingham district. The Inez fault has been bracketed by drill holes, but it is entirely unexplored and as yet cannot be evaluated as a possible ore-bearing structure.

The Yankee fault, which is poorly exposed and consequently is not well known, is believed to be a northwest-trending transcurrent fault. Unlike the northeast-trending shear faults, it apparently did not localize ore.

The post-compressive normal faults may be subdivided into two groups: (1) an east-trending set that is entirely pre-lava in age and (2) a north-trending set that has some post-lava displacement. The east-trending normal faults in the East Tintic district include the Homansville and Sioux-Ajax faults. Both of these faults seem to cut the transcurrent and thrust faults, but many of the critical intersections of these structures are concealed by the volcanic rocks in areas not exposed in mine openings. The Sioux-Ajax fault localizes ore bodies in several mines in the Tintic district.

The only north-trending normal fault recognized in the East Tintic district is the Eureka Lilly-Selma fault zone. This fault has a complex history including: (1) important displacement prior to the eruption of the lavas; (2) reactivation of the fault during the eruptive episode but prior to the deposition of ore; and (3) probable reactivation of the Selma fault segment of this fault zone as a Basin Range fault during the Pliocene and Pleistocene Epochs. The Eureka Lilly segment of the fault localizes small ore shoots in the North Lily mine, and ore also occurs along related fractures close to it in the Iron King No. 2 mine.

The youngest structures recognized in the area of ore deposition are the short, north-northeast-trending fissures that cut the lavas and intrusive rocks as well as the underlying sedimentary rocks. Most of these fissures dip steeply west and range from a few feet to 200 or 300 feet in displacement. They are the principal structures that localize monzonite plugs and dikes and the associated pebble dikes, and many of them provided channels followed by the ore solutions. They are most readily recognized in the lavas and the larger monzonite intrusives by linear zones of hydrothermal alteration that extend outward from the fissure selvages. At depth, particularly where these fissures cut the Tintic Quartzite below the major lead-silver replacement ore bodies, they contain zones of breccia several feet wide that localize the shoots of pyritic auriferous and argentiferous copper ores.

Basin and Range faults are not known with certainty in the near vicinity of the East Tintic district, although, as stated above, the Selma fault may have been reactivated during the Late Tertiary and Quaternary Periods. The general straightness of the eastern edge of the

East Tintic Mountains is suggestive of a Basin and Range fault zone, but geophysical studies do not indicate faulting of large displacement (25, p. 53).

AGE OF MINERALIZATION

As noted by Lindgren and Loughlin (3, p. 104), the ore deposits of the East Tintic Mountains were formed shortly after the intrusion and consolidation of the Silver City monzonite stock and the associated bodies of biotite-monzonite porphyry. The dating of zircons from these intrusions by the lead-alpha method indicates an apparent absolute age of 38 to 46.5 million years (25, p. 30). The general accuracy of these numerical ages is confirmed by the intertonguing of agglomerate members of the Laguna Springs Latite and units equivalent to the Eocene Green River Formation in the southern part of the East Tintic volcanic field, 25 miles south-southeast of the East Tintic district. In this locality, the agglomerate also includes a lens of limestone that contains plant fossils of middle Eocene age (17, p. 234).

ORE DEPOSITS—GENERAL STRATIGRAPHIC AND STRUCTURAL RELATIONS

In a private report written by Paul Billingsley in 1956, in which he analyzed a compilation of field notes taken in the North Lily and Eureka Lilly mines 30 years before, he stated:

"The immediate impression made by these maps and sections is one of extraordinary complexity of geology. This is in fact the case, and in the development of the two mines we were constantly taken by surprise and driven to purely empirical procedures in following the ore. A coherent pattern emerged only with time."

This statement succinctly summarizes the problem of East Tintic mine geology. This is an area of extreme geologic complexity with a masking blanket of Tertiary volcanic rocks covering the larger part of the area. Therefore, this complexity can be seen and studied only in mine workings and from the commonly incomplete or often frustrating data obtained from drill holes.

The ore bodies of the district generally may be divided into two categories: (1) the massive replacement bodies of the Tintic Standard, North Lily, Eureka Lilly, and Burgin mines

that are rich in silver, lead, zinc, and manganese and (2) the fissure ores of the Eureka Standard, Eureka Lilly, and Apex Standard mines that are valuable primarily for their content of gold, copper, and silver.

Most of the ore discovered to date has been found in the lower part of the stratigraphic section, primarily in the Tintic Quartzite and the limy members of the Ophir Formation. This may be attributed, at least in part, to the concentration of exploration in certain parts of the district prior to the past 10 years and to the complex structural setting of the ore bodies. Before the postulation of the East Tintic thrust fault by Lovering and his co-workers in 1950 (16), it was generally believed that the subvolcanic structure at East Tintic was dominated by the East Tintic anticline and that the Tintic Quartzite and successively younger formations would be encountered in the core and east flank of this fold east of the area of the Tintic Standard and Eureka Standard mines. The small amount of exploration accomplished in drill holes from the surface and in the workings of the Apex Standard mine seemed to substantiate this premise. Only in the workings from the Independence shaft of the Silver Shield Mining and Milling Company in the northeast part of the district were much younger rocks encountered beneath the Tintic Quartzite; these later proved to be in the footwall of the East Tintic thrust fault. These younger—Mississippian—rocks were recognized and identified only by a few geologists during the short time this mine was in operation, and their significance was not generally appreciated. Consequently, after the major ore discoveries in the Tintic Standard mine and the subsequent interpretation of the complex structure by Billingsley and others, exploration was directed towards finding the Middle Ophir Limestone Member in structural situations similar to that at the Tintic Standard mine. This work was rewarded by the discovery of the North Lily and the Eureka Lilly mines and the largely accidental discovery of the small, though rich, gold ore shoots of the Eureka Standard mine. Exploration along the East Tintic thrust fault during the past 10 years, however, has brought to light mineralized areas in the rocks much younger than the Ophir in the footwall block of the thrust fault. Thus far, these mineralized areas seem to be concentrated in the Devonian Victoria Formation, a host rock that has not been notably productive in the Main Tintic district.

In the overall picture, structural features are more important than specific host rocks

in the localization of ore at East Tintic, and, in suitable structural environments, it seems probable that ore will be found in many formations that have not been deemed favorable to ore deposition in the district.

The principal productive area of the East Tintic district is divided into structural blocks with by far the largest share of the production having come from an area bounded on the east by the East Tintic thrust fault, on the west by the Eureka Lilly fault, on the north by the Tintic Standard fault and the East Tintic barrier, and on the south by the northeast-striking Apex Standard fault (Figure 1). Within this block, northeast-striking faults break the main block into a series of horsts and grabens. Ore is intimately related to minor folds and crenulations within these larger grossly deformed structural units.

The ore-bearing Ophir Formation is subdivided into three members: the Lower Shale Member, the Middle Limestone Member, and the Upper Shale Member. The average thickness of the Lower Shale Member in the East Tintic district is about 175 feet; this member contains a single carbonate bed about 10 feet thick that forms an excellent marker 70 to 90 feet above the base. The Middle Limestone Member, which averages about 145 feet in thickness, consists of several limestone beds interlayered with lenses and beds of green to light bluish-green shale. These limestone beds are the host rocks for the massive replacement ore bodies of the Tintic Standard, North Lily, and Eureka Lilly mines and probably also for the larger share of the ore developed to date in the Burgin mine. The Upper Shale Member of the Ophir, ranging in thickness from 70 to 90 feet, is a light greenish-gray fissile shale.

The stratigraphic position of the Ophir Formation, between the massive, underlying Tintic Quartzite and the massive limestone and dolomite section above it, has made the Ophir a locus of deformation in the East Tintic district. During the folding and subsequent faulting, deformation commonly was localized in the Ophir, and in those areas in which the Lower Shale Member was squeezed or faulted out, the limestone beds of the Middle Member were converted to ore where they were cut locally by ore-feeding fissures.

Ore occurring in limestone beds in stratigraphic units other than the Ophir Formation doubtless has been mined in the district, but the highly altered character of the rocks adjacent to ore as well as the general lack of diagnostic characteristics in the carbonate rocks of the Middle Cambrian section of the Tintic

area makes positive identification of many of the ore-bearing rocks virtually impossible.

FORM AND CHARACTER OF THE ORE BODIES

As previously stated, the ore deposits of the East Tintic district are notable for their complex structural environments. The ore bodies exploited in the five most important producing mines of the district will be discussed briefly in the light of their complex structural settings, noting particularly the stratigraphic relations of each deposit.

Tintic Standard Mine

The Tintic Standard mine is the largest of the mines in the district, having a recorded production of over 2 million tons of high-grade silver-lead ore. The Tintic Standard "pot hole" is a unique structural node that localized massive replacement ore bodies (Figure 2). The deposits of this mine are associated with the low-angle Tintic Standard thrust fault located on the west side and near the crest of the East Tintic anticline. Movement on this minor thrust fault was localized in the shales and shaly limestone of the Ophir Formation between the underlying Tintic Quartzite and the overlying section of massive Cambrian and younger limestones. This movement served to slice out the Lower Shale Member of the Ophir in some areas, placing the limestone beds of the Middle Member directly against the quartzite footwall (Figure 3). At the places where through-breaking, north-northeast fissures in the quartzite fed directly into the overlying Middle Ophir limestones, large replacement bodies of silver-lead ore were formed, some of which lie directly against the quartzite footwall rocks.

The Tintic Standard structure has been interpreted as: (1) a folded thrust fault; (2) a downfaulted structure, bounded by a series of normal faults curving to form the pot-hole structure; and (3) a thrust fault folded into the complex structure by a tear fault along its southeast side. Regardless of origin, the pot hole structure has created a large volume of prepared ground that was highly amenable to replacement.

In the great Central ore body at the elevation of the 1100-foot level, the limestone beds of the Middle Ophir Member were replaced by ore nearly continuously from the South fault to the Tintic Standard thrust fault, a distance of nearly 600 feet. These beds dip gently

to the east in this sector of the mine, into the narrowing pot-hole structure. Down-dip, the beds are intersected by the main northeast-striking Tintic Standard fissure zone through which the ore-forming solutions moved. These solutions spread upward and outward through the limy beds, and, in this part of the mine, a mass of limestone as much as 200 feet in thickness was altered and mineralized between the 1100-foot and 1400-foot levels. Within this great mass, a large part of the limestone was replaced sufficiently to form ore, the gently-dipping beds locally being replaced by alternating bands of high-grade, silver-lead ore and low-grade, siliceous silver ore.

Above the 1200-foot level, the ore was largely oxidized, consisting of an earthy mixture of altered sanded dolomite, iron oxides, vuggy quartz and jasperoid, cerussite, argentojarosite, and other oxidized silver and lead minerals. The sanded dolomite above the ore bodies is iron-stained, leached, and locally brecciated owing to oxidation of disseminated pyrite and slumping of the altered rocks that lie above the leached and oxidized ore bodies. Heavy timbering was necessary throughout the ore body, and rock temperatures were exceptionally high.

Extending outward and upward from the Central ore body were other replacement ore bodies that occurred in fault blocks in, and adjacent to, the brecciated pot-hole structure. These ore bodies were similar in character to the Central ore body and form narrow pipe-like bodies that Billingsley and Crane (10) described as the fingertip extensions of the ore cluster.

On the lower levels of the Tintic Standard mine, the larger pebble-dike fissure veins were mined for their gold-copper-silver content where they attained sufficient grade and width to constitute ore.

North Lily Mine

The North Lily mine was discovered in 1926 by drifting to the northwest on the Tintic Standard 700-foot level toward a target recommended by Paul Billingsley (6). This ore center is localized within a zone of northeast-striking monzonite porphyry dikes and persistent northeast-trending fissures that cut this and the adjacent Eureka Lily ground. In a structural situation somewhat similar to that at Tintic Standard, the limestone beds of the Middle Ophir Member had been faulted against Tintic Quartzite of the East Tintic Barrier by the Tintic Standard thrust fault. These beds

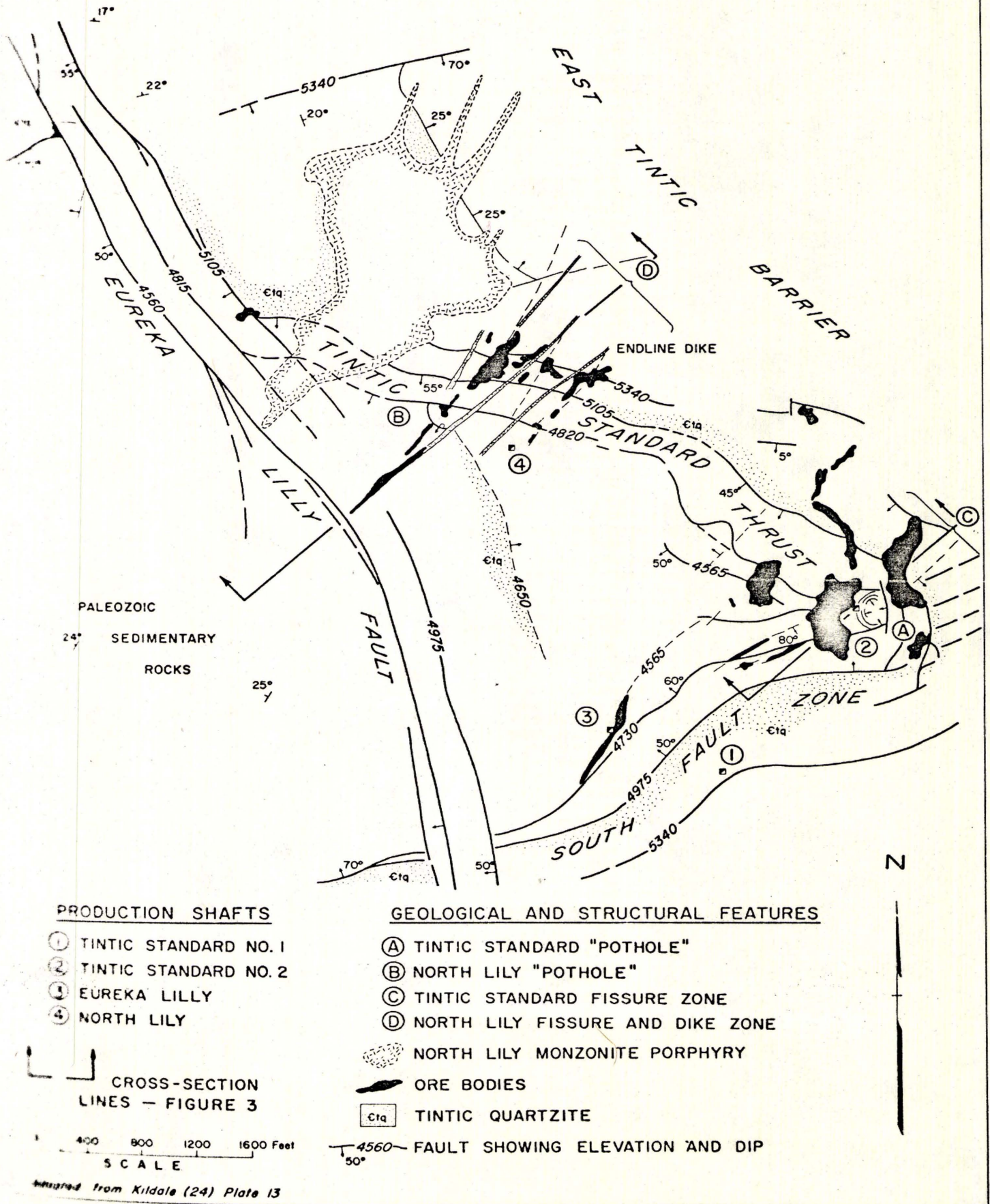
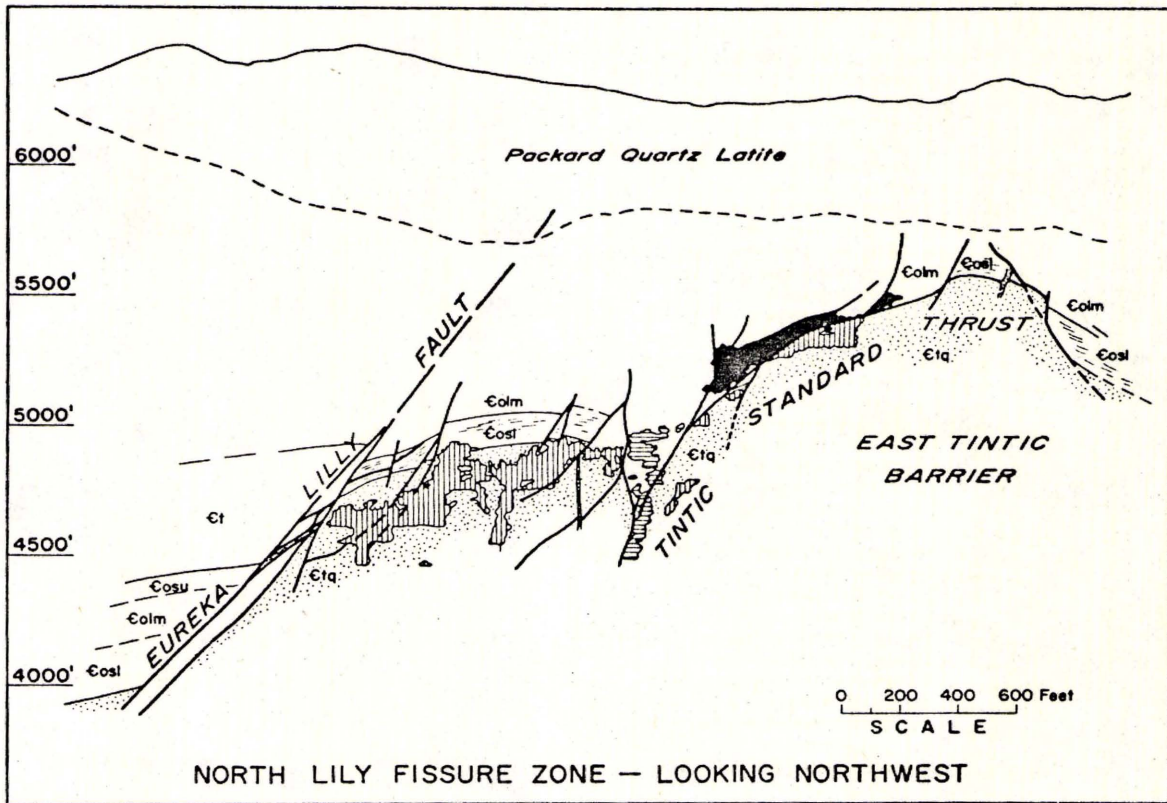
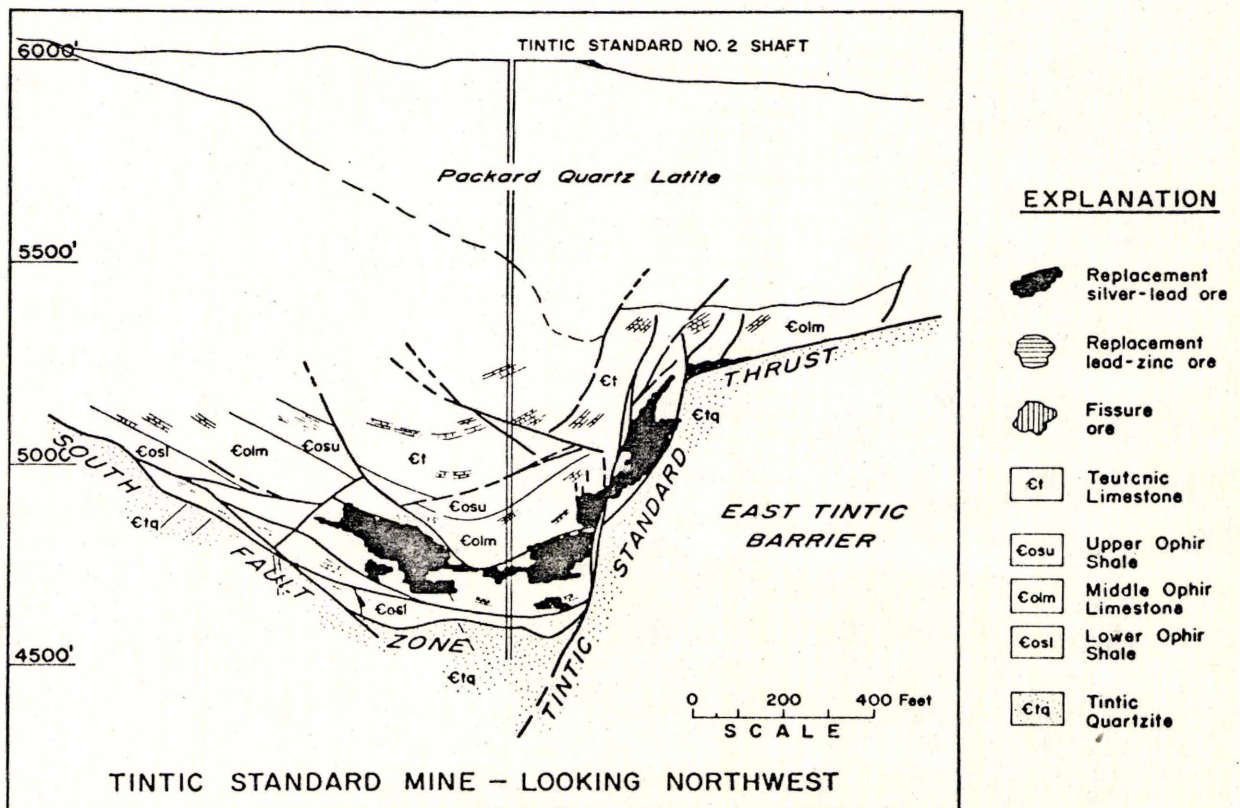


Fig. 2. Composite Plan of Structure and Ore Bodies, Tintic Standard and North Lily Mine Area.



Adapted from Kildale (24) Plate 14



Adapted from Kildale (24) Plate 15

EXPLANATION

- Replacement silver-lead ore
- Replacement lead-zinc ore
- Fissure ore
- Ct Teutonic Limestone
- Cosu Upper Ophir Shale
- Colm Middle Ophir Limestone
- Cosl Lower Ophir Shale
- Ctq Tintic Quartzite

FIG. 3. Generalized Cross-Sections through North Lily and Tintic Standard Mines.

were then mineralized by solutions moving through fissures that cut the quartzite of the East Tintic Barrier as well as the quartzite beds southwest of the mine (Figure 2).

The main lead ore body of the North Lily mine was mined continuously from the 900-foot to the 600-foot level. A "keel" of pyritic gold ore extends down into the Tintic Quartzite along fissures below the upper part of the ore body, and lead ore also spreads easterly along the Tintic Standard thrust fault to the Endline Dike fissure zone. A replacement ore shoot in the Ophir Formation also was mined along the east side of the Endline Dike in the Eureka Lilly mine. Between the 1000-foot and 1200-foot levels along the North Lily fissure zone, the limestone beds of the Middle Ophir Member were down-faulted or down-folded in the hanging-wall block of the Tintic Standard thrust fault to form a large lead-zinc ore body above the North Lily "pot hole" area (Figure 3). This ore consisted of an incomplete replacement of the beds by galena, sphalerite, and pyrite. Below this ore body, in the pot hole itself, low-grade, lead-zinc-gold mineralization occurred in a mass of brecciated Lower Ophir Shale and monzonite.

At the south end of the North Lily mine, high-grade gold and gold-copper ore shoots occur along both the North Lily and Endline Dike fissures within the block of Tintic Quartzite south of the pot-hole area. These fissures converge toward the south and probably are not recognizable as two distinct zones at a distance of half a mile southwest of the North Lily mine. In both of these fissure zones, the ore occurs in part as fissure filling along strong steep fissures but also in part as cementing material enclosing fragments of quartzite or monzonite that make up rubbly breccias between the fissure walls. The richer parts of the ore shoots locally are controlled by small cross-fractures, and the southerly rake of the ore body as a whole indicates some localization by the bedding of the quartzite. This southerly rake also is indicative of deep conduits for ore-forming solutions that rose along the intersection of the northeast fissuring and the Eureka Lilly fault. The high-grade native gold-enargite ore becomes low grade and pyritic on the lower levels.

Eureka Lilly Mine

The Eureka Lilly mine includes the area between the Tintic Standard and North Lily mines and also the property to the south and west of these two great mines. The ore from

the Eureka Lilly has been produced from several different areas and geologic environments. Approximately 60 per cent of the ore came from lead-silver replacement ore bodies and siliceous precious-metal veins along the east side of the Endline Dike and the area immediately southeast of the North Lily mine. Including the production from the North Lily mine, the total tonnage of ore from the combined mines slightly exceeds 0.5 million tons.

Of somewhat lesser importance were siliceous gold-silver-copper ores from fissures along the South fault southwest of the Tintic Standard No. 1 shaft. These ores occurred both as massive fissure fillings and as cementing material for breccias within the fissure zones. The ore solutions appear to have been most strongly concentrated in local zones of open fissuring or unusually strong brecciation, and, in the Eureka Lilly mine fissure, ore of commercial grade is limited to a distance of a few 100 feet vertically below the intersection of the fissures with the South fault.

A small additional tonnage of oxidized lead-zinc replacement ore along fissures was mined from the area immediately northeast of the Eureka Lilly shaft from the 70-foot to 300-foot levels. This was the first production from the East Tintic district and was reported in considerable detail by Lindgren and Loughlin (3, p. 247-248).

Eureka Standard Mine

The Eureka Standard mine was discovered in the late 1920's following the geologic recommendations of Paul Billingsley. The original premise was to explore for a structure similar to that of the great Tintic Standard pot hole in the graben-like block between the steep Iron King fault on the north, and the Eureka Standard fault on the south. However, in 1928, gold mineralization was discovered fortuitously in steep northeast-trending fissures on the foot-wall side of the strands of the Eureka Standard fault.

The valuable metals in this mine were primarily the gold, silver, and copper contained in narrow veins bearing pyrite, quartz, barite, tetrahedrite, enargite, and gold tellurides that cut the Tintic Quartzite. A small amount of silver-lead mineralization was discovered in the limestones of the Ophir Formation early in the exploration of the mine, but these discoveries were not developed further after the discovery of the gold-bearing ores.

The Eureka Standard mine was developed by a 1400-foot vertical shaft and six main

levels driven along the strike of the Eureka Standard fault. Three ore shoots were mined, the southwest, main, and northeast shoots, each plunging at about 20° to the southwest and each having a plunge length of some 600 feet. Gold content diminished down dip in the individual fissures, and the fissures terminated upward against strands of the flatter Eureka Standard fault.

Burgin Mine

The Burgin mine of Kennecott Copper Corporation is the newest addition to the ranks of the producing mines of the East Tintic district. This ore body was discovered as a result of exploration initiated by the Bear Creek Mining Company in 1956 along the East Tintic thrust fault. The studies leading up to the sinking of the exploration shaft and the subsequent underground work have been documented ably by Bush, Cook, Lovering, and Morris (26).

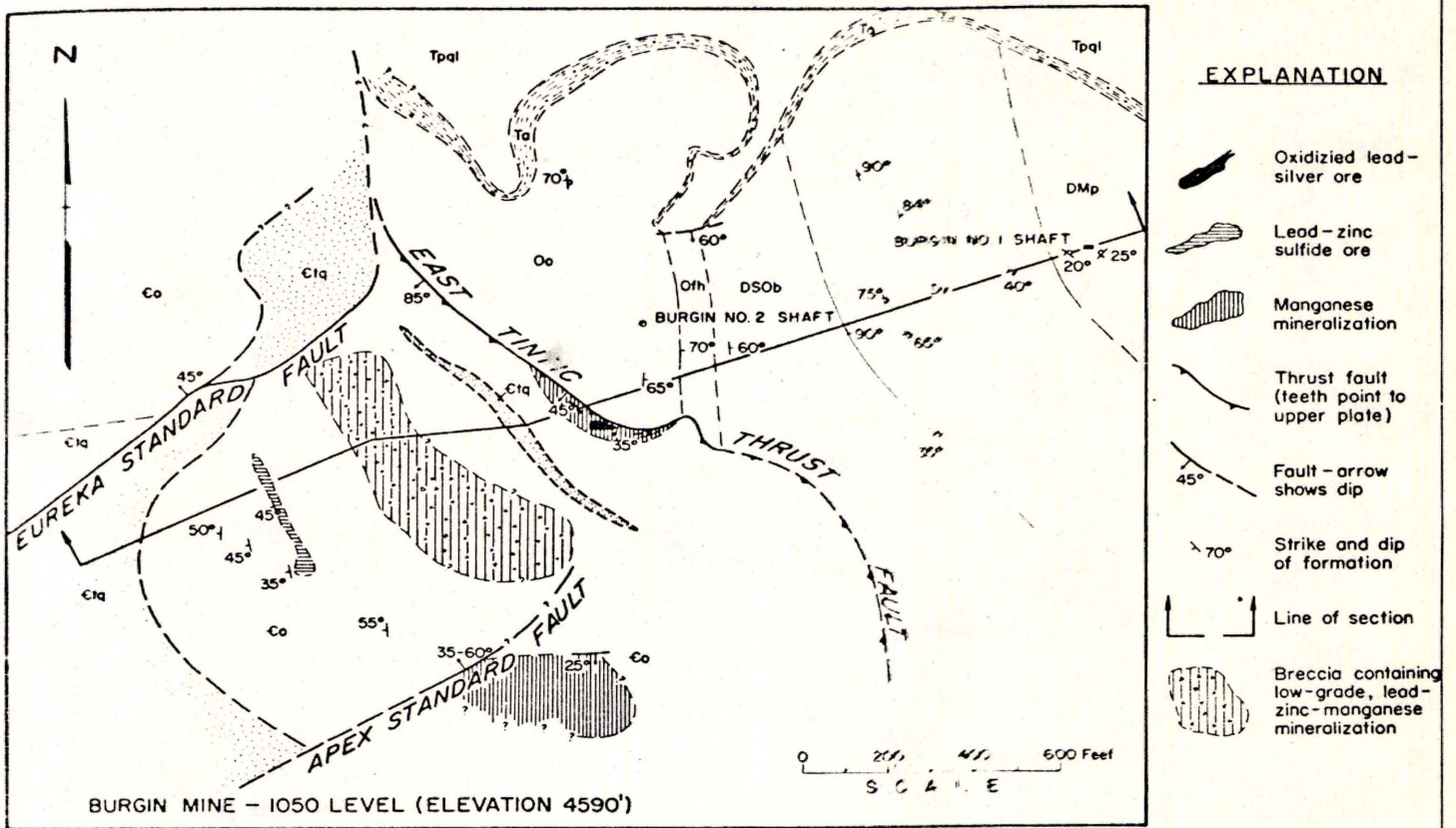
The principal ore body discovered to date is a complex replacement deposit that is localized in the hanging wall of the East Tintic thrust fault where it is intersected by the northeast-striking Eureka Standard and Apex Standard faults (Figure 4). Movement on the thrust fault has placed rocks of the Ophir Formation in contact with beds in the middle and lower parts of the Opohonga Formation in the area of the mine workings. The stratigraphic displacement across the fault is about 3000 to 3500 feet, with total displacement along the structure believed to be approximately 1 mile. In the mine workings, rocks in the footwall of the thrust fault range from the Opohonga Formation of early Ordovician age to the Pinyon Peak Formation of Devonian and Mississippian age. The attitudes of these rocks range from gently dipping to the east to completely overturned, nearly flat-lying beds that are exposed on the 1050-foot level near the No. 1 shaft. The rocks of the hanging wall are broken completely by faults, and the major mineralization discovered to date is in these brecciated hanging wall rocks lying directly on the footwall of the East Tintic thrust fault.

The unoxidized ore is an intimate mixture of lead and zinc sulfides with various amounts of argentite, rhodochrosite, barite, jasperoid, and quartz. The oxidized portions of the ore body contain cerussite, anglesite, smithsonite, cerargyrite, pyrolusite, chalcophanite, and unreplaced masses of the primary minerals. On the 1050-foot, or exploration, level of the mine, lenses of manganese oxides containing

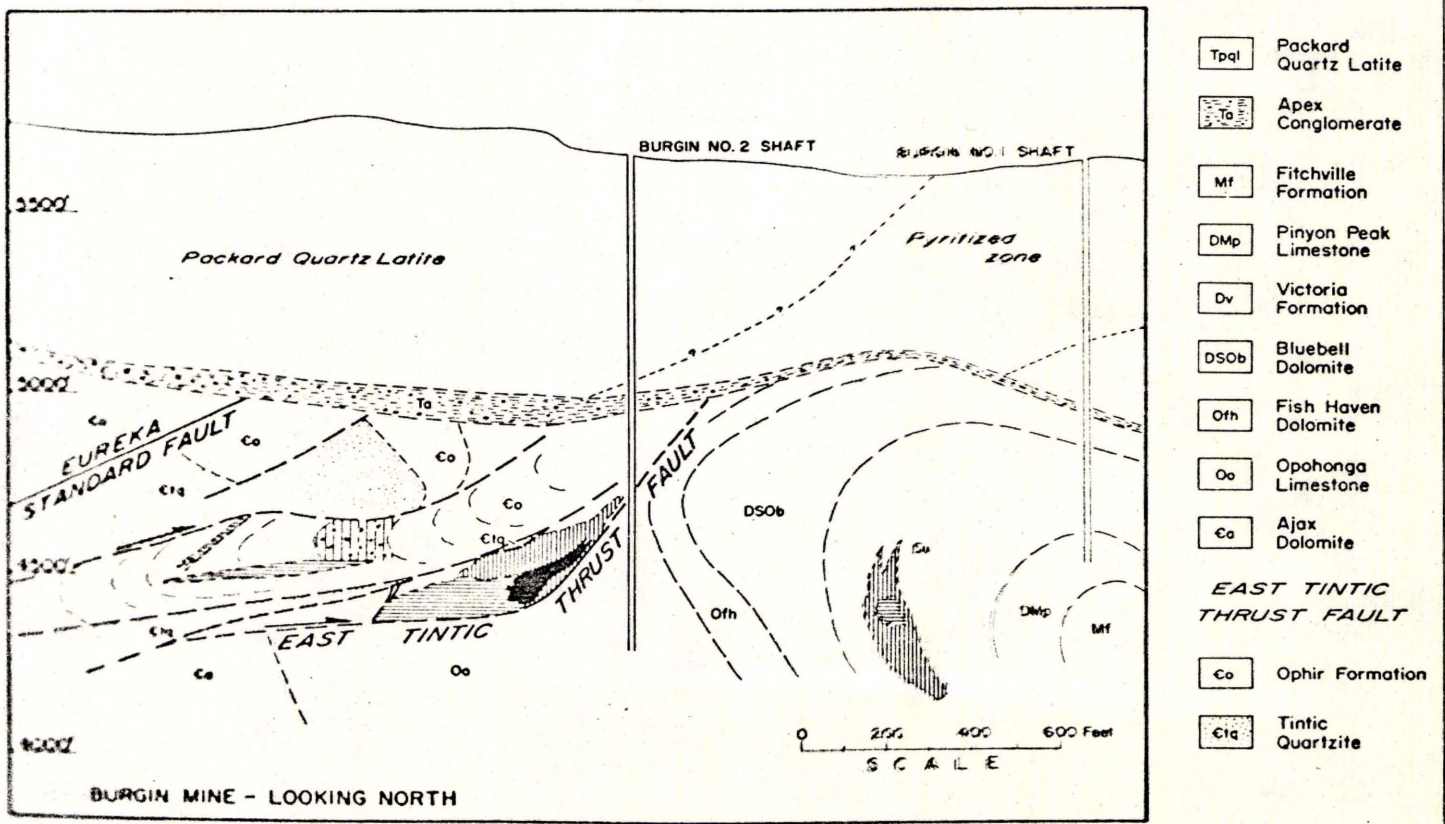
narrow lenses and stringers of oxidized base-metal ores are the only expression of the ore zone below. Development of the ore body, through 1966, has shown that its northeastern edge lies directly against the footwall rocks of the thrust fault, but its southwest edge is a complex steep fault contact with sanded dolomite. This contact is marked in some areas by jasperoid and manganese oxides and in other areas by a thin selvage of galena-sphalerite-rhodochrosite ore. At the present stage of development of the mine, the relationships of the various ore types are not understood fully and a more complete understanding doubtless will be achieved only as development and mining continue.

An ore body of particular interest currently is being mined above the 1050-foot level of the mine. This body has provided a major share of the ore produced during the period of de-watering and development of the lower levels of the mine. It occurs as a replacement of a highly brecciated limestone bed of the Middle Ophir Limestone Member that became the locus of pre-mineral caverns of considerable size. Prior to ore deposition, these caverns were filled with fine-bedded sediment, which also sifted into the interstices of the brecciated rocks below, and adjacent to, the cavern floors. During the mineralizing epoch, the entire mass of cave rubble and breccia was replaced by ore. The cave-fill portions of this ore body have yielded some ores of excellent grade: overall, the zone has averaged about 8 ounces per ton of silver, 10 per cent of lead, and 5.5 per cent of zinc. Surprisingly, this ore, which is located well above the permanent water table, is only slightly oxidized, averaging about 0.25 per cent of non-sulfide lead and zinc. An explanation for this phenomenon may be found in the comparative "tightness" of the entire ore zone caused by the enclosing shale beds.

The larger share of the ore discovered in the Burgin mine to date apparently occurs as replacements of the highly brecciated Ophir Formation immediately above the East Tintic thrust fault. This structure has been prospected for a distance of approximately 1500 feet along the strike in the mine and by drill holes for short distances north and south of the mine. In the ore-bearing interval of the thrust fault in the Burgin mine, the mineralizing solutions apparently rose along the Eureka Standard and other northeast-bearing faults parallel to it, as well as upward along the thrust fault zone, and spread laterally in the brecciated rocks of the hanging-wall block. Exploration



- EXPLANATION**
- Oxidized lead-silver ore
 - Lead-zinc sulfide ore
 - Manganese mineralization
 - Thrust fault (teeth point to upper plate)
 - Fault - arrow shows dip
 - Strike and dip of formation
 - Line of section
 - Breccia containing low-grade, lead-zinc-manganese mineralization



- Packard Quartz Latite
 - Apex Conglomerate
 - Fitchville Formation
 - Pinyon Peak Limestone
 - Victoria Formation
 - Bluebell Dolomite
 - Fish Haven Dolomite
 - Ophonga Limestone
 - Ajax Dolomite
 - Ophir Formation
 - Tintic Quartzite
- EAST TINTIC THRUST FAULT**

FIG. 4. Plan and Generalized Cross-Section of Burgin Mine.

drill holes and mine workings to date have not penetrated the thrust fault north of the Eureka Standard fault in the mine workings, although widespread surface drilling has bracketed this structure over a broad area.

It is noteworthy that the Burgin operation is the first to attempt the extraction of large tonnages of ore from beneath the water table at East Tintic. While workings of limited extent were opened below the water table in both the Tintic Standard and Eureka Standard mines, the present operation constitutes the first attempt to handle large quantities of the hot, corrosive water that is characteristic of the district.

PRIMARY ORE AND GANGUE MINERALS

Composition

The primary ore minerals of the replacement deposits are argentiferous galena and sphalerite with some of the silver probably present in blebs of argentite and tennantite in the galena and in small amounts of other silver minerals such as proustite, pearceite, and polybasite. Barite, rhodochrosite, manganosiderite, calcite, and the ubiquitous quartz, jasperoid,* and pyrite are the principal gangue minerals. Native gold, enargite (including the variety luzonite), and tetrahedrite are the principal ore minerals of the auriferous copper veins in Tintic Quartzite; and various gold and silver tellurides and tetrahedrite are the chief ore minerals in the gold-telluride veins in Tintic Quartzite. Quartz, pyrite, barite, and clay minerals are the main gangue minerals of the vein deposits.

Other primary minerals reported from the East Tintic mines, which generally are found in very small amounts, include: altaite, bismuthinite, bornite, chalcopryrite, chalcocite, jamesonite, marcasite, and tetradymite.

Textures

The replacement silver, lead, and zinc ores generally are composed of fine-grained to coarsely crystalline, massive, galena and sphalerite. Some vugs are present, but good crystalline ore mineral specimens are not common.

* A rock consisting essentially of cryptocrystalline, chalcedonic, or phenocrystalline silica, which has formed by the replacement of some other material, ordinarily calcite or dolomite (Spurr, U.S. Geol. Survey Mon. 31, p. 219).

In some parts of the North Lily and Burgin mines, specimens of well-banded, fine-grained galena formed by metasomatic replacement of thin-bedded limy or shaly sediments have been found. As noted above, some of this material in the Burgin mine is a replacement of a stratified cave fill. Development of octahedral faces on galena crystals from the Burgin mine is quite common. Barite commonly occurs as thin platy crystals and as aggregates of platy crystals in the ores. In the sulfide ore of the Burgin mine, galena and sphalerite are closely intergrown, and some sphalerite is overgrown by rims of galena about 10 μ thick.

Paragenesis

The sequence of hydrothermal alteration at East Tintic has been extensively studied by Lovering and his co-workers (15), and the paragenesis of the alteration has been painstakingly worked out. The minerals of the alteration sequence, which are of principal interest in the study of the ore deposits, are the hydrothermal dolomite of the early barren stage, the clay minerals and the "sanded" dolomite of the mid barren stage, and the quartz or jasperoid of the late barren stage. These were followed by pyrite of the early productive and productive stages that was commonly deposited in open spaces in the fractured and vuggy jasperoid. Lovering's (15, p. 17) general paragenetic sequence for the ore minerals shows an early deposition of minor amounts of gold, enargite, sphalerite, and galena during the early productive stage with later major deposition of sphalerite, galena, enargite, tetrahedrite, proustite, hessite, gold, and both primary and secondary chalcopryrite, and secondary chalcocite during the productive stage and subsequent weathering cycles. Recent work in the Burgin mine indicates at least two major stages of galena deposition, with an intervening episode of sphalerite. The relationship of the manganese and iron carbonates to the sulfides in the Burgin ores has not yet been studied in detail, but several stages of manganese carbonate, with intervening galena deposition seem to be indicated.

SECONDARY ORE AND GANGUE MINERALS

Composition

Oxidation extends to considerable depths in the East Tintic district, the present permanent

water table ranging in depth from less than 1100 to more than 1400 feet in the major producing mines. This has led to the formation of a great variety of secondary minerals, a few of which have been important as ores.

Important secondary minerals of the replacement deposits are cerussite and anglesite with the rare mineral argentojarosite occurring in sufficient quantity to constitute ore in the Tintic Standard mine. Secondary gangue minerals include oxides of iron, and, in the Burgin mine, various complex oxides of manganese including pyrolusite, chalcophanite, hetaerolite, crednerite, and quenselite.

A great variety of secondary minerals has been identified from the East Tintic mines including: antlerite, bindheimite, brochantite, copiapite, halloysite, epsomite, hydrocerussite, jarosite, lanarkite, malachite, massicot, zincian melanterite, mimetite, minium, native silver, plumbojarosite, smithsonite, and szomolnokite.

Oxidation and Enrichment Phenomena

Oxidation and enrichment of silver ores have been important economically in several of the East Tintic mines with some small tonnages of extremely rich secondary silver ore having been mined, particularly in the Tintic Standard mine. Some secondary enrichment in silver has been encountered at or below the present water table and at the boundaries of different types of ore in the Burgin mine.

EXPLORATION AND DEVELOPMENT

The East Tintic district long has been considered by prospectors and mining geologists alike to be an intriguing and baffling area for exploration. The presence of possible ore centers in carbonate rocks beneath a rather thin, nonproductive lava cap provides excellent exploration opportunities adjacent to the known mineralized areas.

The work of Crane (2), Lindgren and Loughlin (3) and later studies by Billingsley (9,10) and Kildale (14) established the basic stratigraphic and structural framework of the district. An understanding of the subsurface structure in the Paleozoic sedimentary rocks resulted in the recognition of favorable areas for ore deposition by many eminent geologists working in the district. More recently, the detailed stratigraphic and structural studies of the U.S. Geological Survey under the direction of Lovering and Morris (15,27,29) provided the basis for predicting a major thrust fault beneath the lavas. This interpretation led to

a new concept for ore localization and resulted in successful exploration for base-metal replacement deposits.

Concealed mineralization is suggested by various "ore guides" in the overlying volcanic rocks including: hydrothermal alteration, weakly mineralized fissures, and pebble dike intrusion breccias. Generalized relationships between hydrothermal alteration and mineralization in the district were established by the work of Lindgren (3) and Billingsley and Smith (7). Later, more specific alteration guides were developed by the U.S. Geological Survey (15), and Bear Creek Mining Company (23).

Historic Sequence of Exploration Activities

Prior to 1907, a number of shallow shafts and prospect pits were sunk on surface indications of fissure vein mineralization in the East Tintic district, but no important discoveries of ore resulted from this activity. A small amount of oxidized replacement ore was shipped in 1909 from the Provo shaft, which is located on a small fault zone in carbonate rocks. The first significant discovery in the district was made in 1913 by the persistent efforts of E. J. Raddatz who sank the original Tintic Standard shaft and drifted beneath outcrops of jasperoidized limestone. These efforts resulted in the discovery of a northeasterly-trending mineralized fissure that led him to explore along strike into an area covered by lava. Fortunately for Raddatz, this lava concealed the Tintic Standard "pot hole," the host structure for the high-grade replacement mineralization of the famous Tintic Standard ore body. This exploration effort was the first success in a number of important blind ore-body discoveries. During its nearly 40 years of operations, the Tintic Standard mine produced more than 2,400,000 tons of high-grade, lead-silver ore from an area of a few acres; approximately \$20,000,000 was paid in dividends from ore that averaged 24 ounces per ton of silver and 12 per cent of lead. The successful discovery and development of the Tintic Standard is attributed to Raddatz's dogged persistence, his uncanny "nose for ore," and good fortune. His subsequent exploration efforts in other areas of the Tintic districts were, unfortunately, not so rewarding.

The discovery of the Tintic Standard bonanza beneath pyritized volcanic rocks stimulated exploration activity in the district where similar relationships were thought to be present. A large number of shafts were sunk

in areas of altered volcanic rocks during the period from 1916 to 1924; the more important included the Copper Leaf, Water Lillie, Eureka Bullion, Iron King, Zuma, Apex Standard, and Central Standard. Each of these shafts penetrated mineralized areas beneath altered volcanic rocks, but little ore was found except for small ore bodies in the Apex Standard and Iron King mines. The lack of success in this period can be attributed to the incomplete understanding of the ore controls, particularly, the failure to recognize the profound effect of structure and stratigraphy on the localization of ore in carbonate rocks, and the effect of the underlying structure on the distribution of hydrothermal alteration in the volcanic rocks. The exploration efforts in this period possess some similarities in conception to "wildcat" drilling early in the history of the petroleum industry.

The interval from 1927 to 1938 was a successful period for ore discovery; this success may be attributed in large measure to the insight of Paul Billingsley, who established a working hypothesis for an understanding of the complex pre-volcanic structure and effectively used alteration of the volcanic rocks as a general ore guide. Ore bodies were discovered and exploited in the North Lily, Eureka Lilly, and Eureka Standard mines during this period. The combined production from these discoveries amounted to almost 1,000,000 tons of ore with an average grade of 0.48 ounces per ton of gold, 8.5 ounces per ton of silver, 6.6 per cent of lead, and 1.8 per cent of copper. Important quantities of gold and copper produced from these mines provided new interest in the search for gold-silver-copper fissure veins in Tintic Quartzite.

The next period of exploration can be attributed to the intensive geologic and alteration studies of the U.S. Geological Survey from 1943 to 1956; intermittent research activities of this organization have continued to the present time. The results of the Geological Survey's work from 1945 to 1955 were a major factor in the instigation of exploration by the following companies: Tintic Standard Mining Company in the Greyhound Area in 1946; Newmont Mining Company in the Apex Standard mine in 1947; Chief Consolidated Mining Company in the Karren Area in 1950; E. J. Longyear Company in the Homansville Area in 1954; and finally Bear Creek Mining Company in the Chief Oxide and Trixie Areas beginning in 1956. Significant discoveries resulted from Bear Creek's exploration. An analysis of the exploration projects conducted during

this period shows that the majority of the unsuccessful work resulted from an inability of the companies to carry the exploration to a logical conclusion rather than to selection of areas with poor potential or to the use of inadequate techniques. Some of this work was terminated prematurely by excessively high drilling costs and poor core recovery. Bear Creek had the full advantage of the drilling, geochemical, and geological data obtained by the U.S. Geological Survey as well as information obtained from many of the previous exploration ventures in the district. Of great significance was a new regional structural concept of the district by the U.S. Geological Survey that, when proved valid, had a dramatic effect on the potential for the search for concealed ore bodies. Of particular importance for the discovery of the Burgin ore bodies was the selection of the Chief Oxide area by the Geological Survey as a target area for testing new exploration techniques. The Chief Consolidated Mining Company first showed interest in the intensely pyritized volcanic rocks in the Chief Oxide area. It was subsequently demonstrated by the Geological Survey geologists that this alteration patch lay on the projection of the northeast-trending Eureka Standard and Apex Standard faults. Both of these faults localize shoots of base and precious metal ores in mines a short distance southwest of the Chief Oxide area. Alteration studies, geochemical surveys, and drilling in this altered area by Newmont Mining Company and the U.S. Geological Survey disclosed late barren, early productive, and productive stage alteration minerals as well as highly anomalous concentrations of ore-stage heavy metals in the volcanic and underlying sedimentary rocks. The possibility of a major thrust fault beneath the lavas was indicated to the Geological Survey geologists by data obtained from underground openings and drill holes and by geologic projections from mapping in the Allens Ranch quadrangle (20). These data were made available to all interested mining companies, but the interpretation of a major concealed thrust fault generally was regarded by the industry with skepticism. Following a careful evaluation of all available geologic data, Bear Creek Mining Company combined the land holdings of the five principal land owners into a Unit Lease. The company then gambled the cost of an exploration shaft to locate the thrust fault and search for possible ore bodies associated with this structure. A major zone of thrusting was subsequently penetrated by drifting on the 1050-foot level westward from the

Burgin shaft. Underground exploration to the south along the footwall of the thrust encountered the upper oxidized tips of a major ore body. Diamond drill holes from this drill platform tested the thrust structure beneath the 150-foot level and discovered sulfide ores (26). These ores currently are being mined by Kennecott Copper Corporation. The development and production to date indicates important quantities of high-grade lead-zinc-silver ore, most of which is a few 100 feet below the water table and is at least partially oxidized. Interesting mineralization also has been intercepted in surface drill holes in other areas of the Unit Tract. These areas are now being explored, but additional data are required before the significance of these other mineralized areas can be evaluated. Bear Creek's recent success doubtless will result in substantial addition to the areal extent of the productive portion of the East Tintic district. This exploration success illustrates the effectiveness of fundamental geological studies of an old mining district by a government agency combined with new exploration techniques and coordinated efforts by private industry.

Ore Guides

The following ore guides and exploration techniques are discussed because they played an important part in the discovery of blind ore bodies at East Tintic and may well be applicable in the search for ore deposits in other mining districts.

MINERALOGICAL AND STRUCTURAL GUIDES The presence of favorable carbonate beds to which ore-bearing fluids had access from structural conduits is a basic requirement for replacement ore in the East Tintic district. The Ophir Limestone is the first carbonate unit in the stratigraphic sequence above the local "basement" of Tintic Quartzite. It is particularly favorable for replacement by ore minerals where cut by mineralizing fissures, especially where the Tintic Shale has been cut-out by faulting. Many of the important mineralized fissures that have been feeders for ore in the sedimentary rocks are mineralized only weakly in the overlying volcanic rocks. Fortunately, many of these fissures can be detected beneath the volcanic rocks by the occurrence of pebble-like material, which was injected into the fissures, and by linear zones of pyritic alteration that occur along the otherwise inconspicuous fissures.

Structural features are important both as regional and as local ore controls. Masses of permeable breccia related to thrust zones are favorable for ore localization in both the Tintic Standard and Burgin mines. Thrust-fault zones also channeled ore fluids effectively into favorable environments for ore deposition because of the development of impermeable barriers of gouge and mylonite along them. Deeply penetrating northeast shear faults are significant because they evidently acted as deep conduits for ore fluids. Fracturing and brecciation of silicified (jasperoidized) limestone or dolomite commonly produced a receptive host for the ore sulfides. Minor structures, such as crease folds, are important to ore localization in developing the necessary brecciation to raise porosity and permeability and increase the area of reactive surfaces.

MINERAL ZONING GUIDES A crude mineral-zoning pattern is discernable around local centers of intrusive activity; this pattern is broadly useful in selecting areas of maximum permissibility for specific types of ore deposits. Intrusive rocks and their immediate surroundings generally are barren of economic mineralization. Zonation of metals in carbonate rocks proceeds outwards from a lead-silver zone to lead-zinc-silver and lead-zinc-silver-manganese zones. Copper-gold ores are confined chiefly to tabular deposits in quartzite, some of which are located in near proximity to base-metal deposits in carbonate rocks.

MINERALOGICAL GUIDES The work of the U.S. Geological Survey has distinguished various assemblages of alteration minerals in sedimentary and volcanic rocks that are believed to have resulted from separate surges of hydrothermal solutions, each with a distinctly different chemical composition. An alternative viewpoint suggests that a continuously flowing solution changed in composition with time. This activity culminated in a metal-rich solution from which the primary ore minerals were deposited.

Hydrothermal dolomitization of the limestones and chloritization (magnesian alteration) of the basal part of the volcanic series is indicative of early, barren solutions, but these alteration zones outline virtually the entire rock volume through which the sequence of hydrothermal solutions moved but only a small part of which was traversed by the ore-stage solutions. Early barren type of alteration can thus be used in a broad sense to establish the general areas of hydrothermal activity, but

other criteria are needed to locate target areas for exploration.

Argillic alteration characterizes the mid barren stage. It is most extensive in igneous rocks, but it is also locally prominent in carbonate rocks near hydrothermal conduits. Argillization is concentrated around centers of intrusion, and, in many of the resulting alteration halos, a zonation within the altered rocks is recognized. In dolomite, the "argillized" zone is generally represented by "sanded" areas that have been leached severely and converted locally to solution breccia. High porosity induced by acid leaching also is characteristic of the argillized igneous rocks; this porosity doubtless facilitated the movement of successive altering and ore depositing solutions.

Later barren-stage alteration zones containing pyrite, calcite, and barite are localized chiefly near major channels of mineralization. Cubic pyrite is disseminated widely in the lava more or less up-dip from fractures that have guided pre-ore altering solutions in the underlying Paleozoic rocks. Calcite of replacement origin may be present in the lavas for hundreds of feet laterally beyond the pyritic zone; the calcite is commonly up-rake from fissures in underlying Paleozoic rocks and spreads out on the footwall side of the projection of the fissure. This may be calcite displaced during silicification of nearby dolomite underlying the lava, and, although spread through a quite large volume of rock, such calcite suggests jasperoid in concealed carbonate rocks and, therefore, is an important guide to concealed ore bodies.

The areas altered during the early productive stage contain sericite, minor clear quartz, and some pyritohedral pyrite. Although this stage was somewhat earlier than the ore stage, pyritohedral pyrite is in large part contemporaneous with ore. Early productive stage alteration may follow fissures above an ore body for several hundred feet, but it does not extend laterally into the wall rocks for more than a short distance.

The productive stage is distinguished by the deposition of sulfides of the base metals, of sulfantimonides and sulfarsenides of copper and silver, and of gold and gold-silver tellurides, all accompanied by minor amounts of barite and terminated clear quartz crystals.

Weathering has masked the hydrothermal alteration effects in many areas. The zones of weathered pyritic alteration are indicated generally by brown, iron-stained areas surrounded by slightly argillized rock that has been bleached by the small volumes of sulfuric

acid generated by the oxidation of the disseminated pyrite. In many places, a band of manganese oxides separates the limonite-stained cap rock and the supergene bleached zone, where the outward moving acids were neutralized beyond the pyritized zone.

The most favorable combination of alteration zones in the lava is a large pyritized zone (marked by heavy limonite stain to a depth of 30 to 100 feet) with calcitized lava on one side (which suggests that the footwall side of a mineralized fracture is present at depth) and weakly argillized lava on the other side of the pyritized zone. Alteration halos of this type generally are up-rake from pre-volcanic, ore-bearing structures, and, therefore, are not necessarily directly above ore. A structural interpretation of sub-volcanic structure and stratigraphy is thus of prime importance in the evaluation of alteration halos in volcanic rocks. A good correlation seems to exist between jasperoidized dolomite or limestone at depth and calcitized lava at the surface. Calcitic alteration does not appear to have as great a vertical range in the lava cap as does pyritic alteration. The transition from altered to completely unaltered lava has been noted to occur above well-mineralized intercepts in drill holes, indicating rather thin alteration halos in some of the areas tested.

The occurrence of manganese oxides in altered sediments is an important ore guide because of the intimate association of manganese mineralization with some of the ore bodies. Anderson (30) has recognized mineralogical and trace-element criteria to distinguish the manganese oxides derived from manganese minerals associated with base-metal ores and those manganese minerals derived from other sources.

GEOCHEMICAL GUIDES Trace concentrations of ore stage heavy metals—geochemical halos—in the altered rocks provide a valuable guide to the location of ore-bearing structures. A technique to select the iron oxides from fractures in the lavas is a necessary sampling method for geochemical work. It is believed the residual ore fluids used the permeability of the fractured lavas for their final deposition of the ore metals. Geological control is needed in the interpretation of geochemical anomalies because the distribution of metals in the volcanic rocks has been found to be highly dependent on the geological structures in the underlying sedimentary rocks.

The identification of "productive jasperoid" on the 1050-foot level of the Burgin mine

by megascopic and geochemical criteria was a critical guide to the discovery of the Burgin ore bodies.

GEOPHYSICAL GUIDES Several geophysical techniques have been attempted during the last 20 years in the East Tintic district but generally with disappointing results. However, gravity measurements taken underground in the Burgin mine have shown considerable promise in the search for nearby massive sulfides. Aeromagnetic surveys have been found to be only of questionable value in the direct detection of small intrusives related to ore centers; however, these surveys may be found more effective in the interpretation of broad features of the subsurface geology. To the present time, electromagnetic and induced polarization techniques have been found ineffective in penetrating the volcanic cover or the high-resistivity limestone units.

An extensive geothermal investigation has been conducted by the U.S. Geological Survey (35), and infrared measurements have been made by various private and government organizations. No practical ore guide has yet resulted from this work, although useful information has been obtained on the distribution of abnormal temperature gradients in the subsurface rocks.

DRILLING Reliable exploration information from drilling has been particularly difficult to obtain at East Tintic because of poor core recovery and unusual drilling difficulties. However, the employment of rotary drilling in the volcanic rocks; wireline equipment in the fractured, altered, and mineralized sedimentary rocks; and the use of special drilling muds and lost circulation materials have resulted in a dramatic improvement in core recovery and a lowering of drilling costs.

Water and Ground Support Problems

Several unusual problems with geologic implications are recognized in the East Tintic district and at least brief mention should be made of these in any discussion of the district.

First of these problems is the presence of extremely hot water in the mines of the district. East of the Eureka Lilly fault, each of the mines that has reached the water table has encountered flows of thermal waters, and rock temperatures that are correspondingly high. These temperatures previously were thought to be due to heat generated by the oxidation of sulfides, however, work during the past

five years, primarily with water samples collected from the Burgin mine, revealed the striking similarity in trace-element content and isotopic ratios with waters from hot springs in western Utah. This similarity has led to the present hypothesis that this water is fed into the groundwater system from hot springs that discharge at the water table and nowhere reach the surface. Water temperatures as high as 147°F have been measured in the Burgin mine. This water contains a high percentage of dissolved material, principally as sulfates and carbonates, as well as a high concentration of sodium chloride. Although the pH of the water is near neutral, it is a strongly corrosive brine that requires stainless steel or suitably protected pumping and water transmission equipment. Lovering and Morris (35) present a detailed discussion of the hot water and its relationship to geothermal gradients in the district.

Second of the geologic-related problems to be considered here is the presence of "sanded dolomite" surrounding many of the silicified ore bodies of the district. This rock type consists of hydrothermal dolomite that was partly leached during the mid barren (argillic) stage of alteration, leaving an unconsolidated mesh of dolomite crystals that crumble and cave readily into underground openings. The tendency of this material to sluff is especially evident in areas where the sanded dolomite is wet, and it essentially flows as a slurry into mine workings or in chutes and bins. This slurry readily works its way into and through the narrowest of openings, and, once flowing, it is extremely difficult to control.

SUMMARY—OUTLOOK FOR THE FUTURE

For more than 50 years, the East Tintic district has been a major producer of silver, lead, gold, copper, and zinc. The discovery of the Tintic Standard mine ushered in a new era in the exploration for blind ore bodies in the district. Continued exploration has led to the discovery of other mines, the most recent being the Burgin mine of Kennecott Copper Corporation. The search for blind ore bodies also has led to studies of alteration, trace element halos, and structure, all of which have added to the understanding of the district and to the body of knowledge concerning the utilization of these criteria as exploration tools.

The most significant development in the district in recent years has been the discovery of the East Tintic thrust fault and the subse-

quent re-interpretation of the geology of the district. This development has opened a large area in the eastern part of the district for exploration, an area that was previously believed to be underlain chiefly by Tintic Quartzite beneath the lava capping, an environment that was inhospitable to the deposition of large replacement ore bodies. Present knowledge leads to the belief that a large area along the strike of the thrust fault presents the best target for prospecting in the district, both in the massive breccia zones along the thrust structure and in the favorable rocks of the footwall block of the thrust fault. The present development of the Burgin mine would seem to assure the continued life of the district for at least a decade.

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