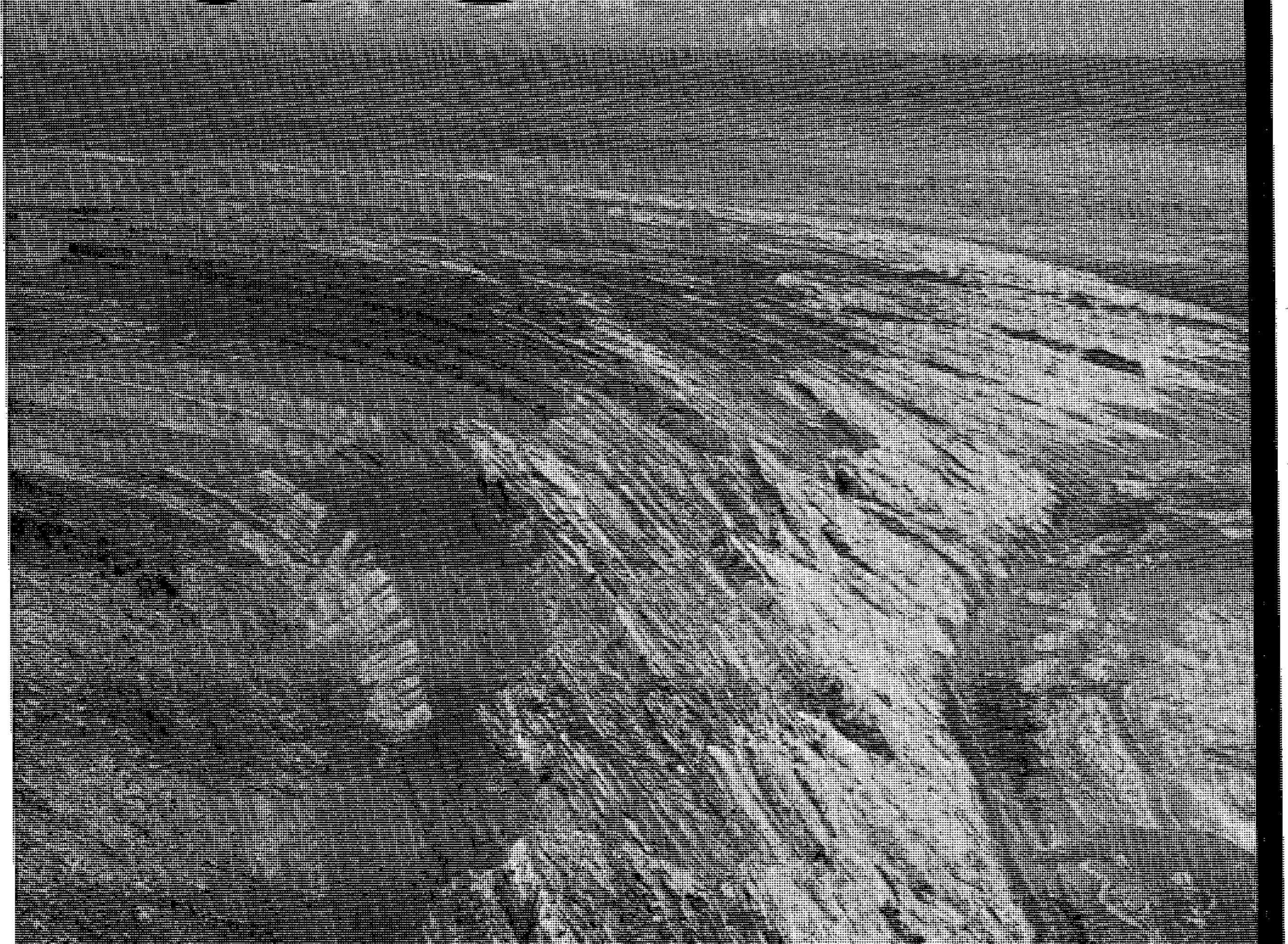
BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES



VOL. 25, PART 1

APRIL 1978

BRIGHAM YOUNG UNIVERSITY GEOLOGY STUDIES

Volume 25, Part 1

Papers reviewing geology of field trip areas, 31st annual meeting, Rocky Mountain Section, Geological Society of America, April 28-29, 1978, at Brigham Young University, Provo, Utah.

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THE GLORY OF GOD IS INTELLIGENCE

Cover: East flank of San Rafael Swell, Emery County, Utah; looking north. Photo by W. K. Hamblin.

A publication of the
Department of Geology
Brigham Young University
Provo, Utah 84602

Brigham Young University Geology Studies is published semiannually by the department. *Geology Studies* consists of graduate-student and staff research in the department and occasional papers from other contributors. *Studies for Students* supplements the regular issues and is intended as a series of short papers of general interest which may serve as guides to the geology of Utah for beginning students and laymen.

ISSN 0068-1016
Distributed April 1978
Price $5.00
(Subject to change without notice)
4-78 800 31295

Tintic Mining District, Utah

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ABSTRACT.– The Tintic mining district, which includes the Main Tintic and East Tintic subdistricts, is in central Utah about 50 km airline southwest of Provo and 95 km south-southwest of Salt Lake City. From its discovery in 1869 to 1976 the district produced 16,654,327 tonnes of ore valued at $568,620,003. More than 90 percent of this ore has come from large, irregular ore bodies that have replaced folded and faulted limestone and dolomite strata of Paleozoic age. Of lesser importance are replacement veins, which chiefly cut pyrometasomatized carbonate rocks, and fissure veins, which cut quartzite, volcanic rocks, and intrusive bodies. The district is in the central part of the East Tintic Mountains, a north-trending fault-block range near the eastern margin of the Great Basin. The consolidated rocks exposed at the surface and in mine workings are miogeosynclinal deposits more than 4,800 m thick. They range in age from late Precambrian to Late Mississippian, and are part of a sedimentary rock sequence that originally may have been 18,000 m thick. The sedimentary strata are folded and strongly faulted, partly overlain by a variety of volcanic rocks chiefly of intermediate composition, and cut by latite, quartz latite, monzonite, and quartz monzonite porphyry intrusions of Oligocene and Miocene ages. All these rocks are locally covered by thick alluvial deposits of Pliocene and Quaternary ages. In some areas, both the Oligocene and pre-Oligocene rocks have been altered by pre-ore solutions, and the resulting alteration zones, with geologic studies and geochemical exploration techniques, have been used to prospect for deeply buried blind ore bodies, which have been the source of most of the ore produced from the district during the last 60 years.

INTRODUCTION

The Tintic district is the second most productive base- and precious-metal mining district in Utah. It is approximately 95 km[1] south-southwest of Salt Lake City and 50 km southwest of Provo (fig. 1). It is traversed by a major highway, U.S. 6-50, and served by the Union Pacific and Denver and Rio Grande Western railroads. The principal communities in the district are Eureka and Mammoth; other former communities, such as Dividend, Silver City, and Diamond, among others, have been mostly obliterated but are still important place names.

Officially the Tintic district includes an area of about 388 km^2 in the central part of the East Tintic Mountains. Traditionally, however, the district is divided into the Main Tintic subdistrict, which is west of 112°05′ W. Long. and centered on the townsites of Eureka, Mammoth, and Silver City; and the East Tintic subdistrict, which is east of 112°05′ W. Long. and centered on the townsite of Dividend about 5 km east of Eureka. Many of the earlier geologic studies of the area have been directed separately to either the East Tintic or Main Tintic "districts." It is important, however, *not* to confuse the Main Tintic subdistrict with the West Tintic mining district, which is an unrelated ore-producing area in the Sheeprock Mountains 30 km southwest of Eureka.

ACKNOWLEDGMENTS

The data and concepts upon which this report is based have gradually accumulated over a period of more than 100 years. This accumulation of knowledge began with the observations of the earliest prospectors in the Tintic district and has been increased, modified, and extended by miners, engineers, geologists, and others, some of whom have spent their entire lives in the district. Of the many individuals who have cordially provided assistance to the U.S. Geological Survey and Kennecott Copper Corporation in their Tintic district studies, particular mention should be made of the contributions of C. A. Fitch, Sr., and Harry J. Pitts, both now deceased; James Quigley; C. A. Fitch, Jr.; William G. Stevenson; Max T. Evans; Hollis Peacock; R. C. Gebhardt (deceased); J. Steele McIntyre; Brennan Hannifin; Robert C. Thomas; Douglas R. Cook; John B. Bush; William M. Shepard; and James Anderson. Many others, listed in other reports, are gratefully acknowledged for their assistance during the field studies.

The name of T. S. Lovering is also indelibly imprinted on the Tintic area. Although his studies were chiefly limited to the East Tintic district, he has been a perceptive observer and source of new concepts concerning the geology of all the East Tintic Mountains and adjacent parts of central Utah.

HISTORY AND PRODUCTION

Ore was first discovered in the Main Tintic district near the present site of the Sunbeam shaft in December 1869 by a prospector returning to Payson, Utah, from an unsuccessful ore search in the West Tintic mining district. By the following spring most of the outcropping ore bodies in the range had been discovered, and several mines had stockpiles of ore ready for shipment. The lack of nearby markets and efficient transportation facilities hampered the early production, but some of the rich oxide ores were freighted by wagon to Salt Lake City and then carried by rail to Reno, Nevada; San Francisco, California; and Baltimore, Maryland. Some ores were even shipped to Swansea, Wales, for reduction. In 1878 the Utah Southern Railroad reached Ironton, 8 km southwest of Eureka, and the ores were then transported to newly constructed smelters in the Salt Lake Valley. With access to low-cost transportation by rail, production from the Main Tintic subdistrict increased substantially and climbed erratically to 1912 when 384,490 tonnes of base- and precious-metal ores were produced. Production declined from the Main Tintic subdistrict after that date, and virtually no ore has been produced from there since 1960.

Ore was first discovered in the East Tintic subdistrict in 1899 near the present Eureka Lilly shaft, but production was insignificant until 1918 when ores were mined in quantity from the newly discovered concealed bonanza of the Tintic Standard mine. Production from East Tintic shows two peaks, 199,579 tonnes in 1929, and 227,848 tonnes in 1976, the latter chiefly from the Burgin mine of Kennecott Copper Corp. An additional 49,380 tonnes of dump ores were produced in 1976.

[1]Metric system is used throughout this report. For conversion table see end of article.

Total production from the Tintic district 1869–1976 is estimated to be 16,654,327 tonnes of base- and precious-metal ores valued at $568,620,003 at the time of production. Production of ores and contained metals by periods is shown in table 1. In addition to the metals listed in this table, the Tintic district has been the source of important quantities of cadmium, bismuth, arsenic, antimony, and manganese ores and coproducts halloysite clay, quartzite ganister, and high-calcium limestone.

GEOLOGY

Regional Setting

The Tintic district is in the East Tintic Mountains, a north-trending fault-block mountain range in the east central part of the Basin and Range province. During the long period of time extending from the late Precambrian, through all of Paleozoic time, and continuing into the Mesozoic, this area was the site of a number of epicratonic basins in which more than 18,000 m of sedimentary rocks accumulated (Morris and Lovering 1961). In the Late Cretaceous this general region was uplifted and cut by three or more superimposed thrust faults of large throw and great regional persistence. Movement on these thrusts, which form part of the central portion of the Sevier orogenic belt (Armstrong 1968), carried large plates of rock eastward for as much as 160 km from eastern Nevada and western Utah over Mesozoic and older strata in central Utah. One of these thrusts is correlated with the Midas thrust fault of the Oquirrh Mountains. It is believed to extend southward from the area of Bingham Canyon into the north half of the East Tintic Mountains and was crumpled into a series of asymmetric anticlines and synclines with amplitudes of 5,000–7,000 m. These folds, which are cut by many transcurrent and normal faults and by subsidiary thrusts (figs. 2 and 3), apparently terminate in the lava-covered and pluton-injected central part of the East Tintic Mountains.

By the end of the Cretaceous, all activity had ceased in the Sevier orogenic belt in central Utah, and during the Paleocene and Eocene, a mature topography with more than 1,600 m of relief was carved into the folded and faulted Precambrian and Paleozoic strata. In middle Oligocene time volcanism began abruptly, and the area of the Tintic district was the site of a large eruptive center. The volcanic episode terminated in ore deposition and was followed by regional tensional faulting in latest Oligocene and Miocene time, producing the fault-block mountains that dominate the present landscape.

Sedimentary Rocks

As shown in table 2, the sedimentary rocks exposed in the Tintic district range in age fom Precambrian to Holocene. The Precambrian rocks, which consist of quartzite, phyllite, and minor dolomite, are correlated with the Big Cottonwood Formation of the Wasatch Range, although a more accurate correlation may be with the Sheeprock Series

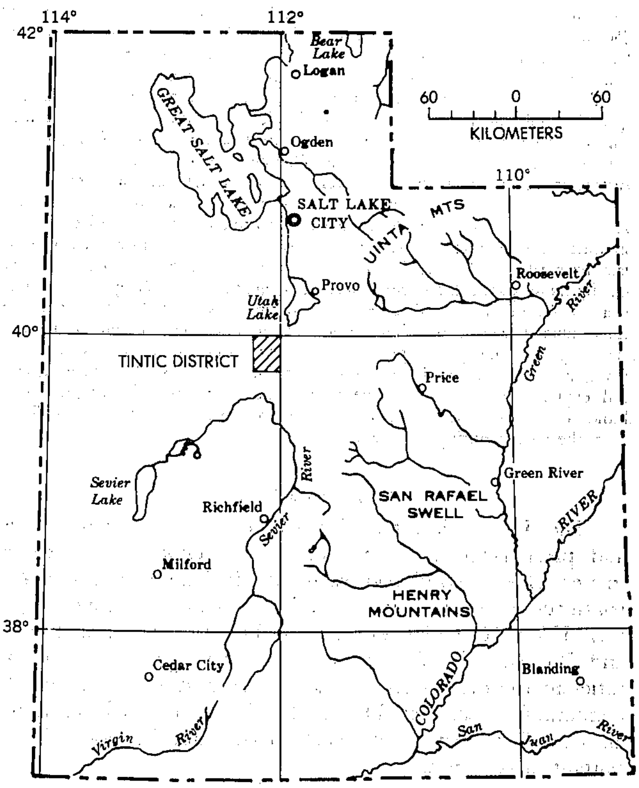

FIGURE 1.– Index map of Utah showing location of Tintic mining district.

TABLE 1
PRODUCTION OF ORE AND METALS FROM TINTIC MINING DISTRICT, 1869-1976, BY PERIODS[1]

Period	Ore (tonnes)	Gold (kilograms)	Silver (kilograms)	Copper (kilograms)	Lead (kilograms)	Zinc (kilograms)	Value[2] (dollars)
1869–1880	(Not known)	1,124	49,938	1,442,279	4,696,292	0	$4,190,594
1881–1890	(Not known)	1,922	363,663	4,495,741	24,638,839	0	16,884,489
1891–1900	(Not known)	10,342	975,598	9,725,805	85,061,131	0	38,749,351
1901–1910	(Incomplete)	22,746	991,072	34,730,099	127,866,907	0	64,029,151
1911–1920	3,172,213	15,587	1,818,739	33,212,173	142,478,161	7,866,779	89,743,231
1921–1930	3,860,639	11,442	2,381,881	14,558,148	342,113,997	6,189,295	118,410,234
1931–1940	2,000,255	13,832	886,956	8,358,345	80,078,245	3,703,157	40,380,101
1941–1950	1,956,651	4,628	408,744	4,914,166	61,398,389	31,423,004	39,557,946
1951–1960	840,244	793	145,021	879,893	27,784,043	17,314,139	20,095,505
1961–1970	601,696	202	188,355	180,306	69,587,275	45,167,991	46,664,229
1971–1976	1,085,600	981	170,015	568,621	62,176,509	76,101,961	89,915,172
Totals	16,654,327[3]	83,599	8,379,982	113,065,576	1,027,879,788	187,766,326	$568,620,003

[1]Table computed from data furnished by U.S. Bureau of Mines.

[2]Dollar value calculated from gross metal content and average yearly price of metals.

[3]Includes estimates for production in years prior to 1910.

of Cohenour (1959), which is extensively exposed in the Sheeprock Mountains. The Precambrian rocks are separated from the overlying Lower Cambrian Quartzite by a profound unconformity that indicates the removal of many thousand feet of beds, probably including the Mutual Formation and the Mineral Fork Tillite (Crittenden et al. 1952) or the equivalent Dutch Peak Formation of Cohenour (1959).

The Tintic Quartzite generally is considered by the miners to be the basement rock of the district because of its great thickness and its lack of susceptibility to the formation of large replacement ore bodies. It is the host rock, however, for a considerable number of veins and fault-breccia ore bodies, particularly in the East Tintic subdistrict. Near Eureka it contains more than 90 percent silica and in past years has been quarried as a source of ganister for the production of silica brick.

The Paleozoic rocks stratigraphically overlying the Tintic Quartzite are chiefly limestone and dolomite typical of the miogeosynclinal deposits of this age that are common throughout western Utah and eastern Nevada. The Ophir Formation, immediately above the Tintic Quartzite, consists mostly of limy shale, but also includes one or more thick beds of limestone that are important host rocks for ore in the East Tintic subdistrict but that are nonproductive in the Main Tintic area. Above the Ophir Formation, sandstone and shale are distinctly subordinate to carbonate rocks, although arenaceous rocks are present in the Opex, Victoria, and Humbug formations, and shale beds are also present in the Herkimer and Opex formations. All the Paleozoic formational units from the Cambrian Ophir Formation to the Mississippian Great Blue Formation contain replacement ore bodies of at least small size. The five most important ore host formations, in order of estimated gross value of ore bodies contained within them are: Ophir Formation ($200,000,000), Bluebell Dolomite ($135,000,000), Ajax Dolomite ($60,000,000), Deseret Formation ($47,000,000), and Tintic Quartzite ($35,000,000).

Igneous Rocks

The volcanic rocks of the Tintic district are the deeply eroded remnants of a large composite volcano that essentially buried a topographically mature, structurally complex mountain range. The volcanic activity took place in three pulses, each characterized by a period of eruption and terminated by a period of igneous intrusion.

The oldest volcanic sequence is the Packard Quartz Latite. It was erupted from unknown centers in the central part of the East Tintic Mountains. The eruption produced a lower tuff, generally about 30 m thick, an overlying lower vitrophyre of about the same thickness, a massive porphyritic biotite quartz latite unit that locally may exceed 900 m in thickness, and an upper vitrophyre and an air-fall tuff each 30–50 m thick. Beyond the northern and southern boundaries of the district the volcanic units that are equivalent to the Packard Quartz Latite contain compacted shards, collapsed pumice fragments, and other features indicative of a welded tuff. In earlier reports the Packard was reported to be of Eocene age on the basis of lead-alpha dating methods and geologic considerations, but recent potassium-argon dating procedures indicate the age of biotite and sanidine from the Packard to be 32.8 ± 1.0 and 32.7 ± 1.0 m.y., respectively (Laughlin et al. 1969, p. 917), and therefore the Packard is now assigned to the Oligocene.

After the eruption of the Packard Quartz Latite, a caldera estimated to be 13.6 km in diameter and more than 1,000 m

TABLE 2
ROCK SEQUENCE, TINTIC MINING DISTRICT, UTAH

SYSTEM	SERIES	FORMATION OR UNIT	MAP SYMBOLS		LITHOLOGY AND APPROXIMATE THICKNESS
QUATERNARY	Holocene	Younger alluvium	QTs		Fanglomerate, gravel, sand, silt; 0-30 m.
	Pleistocene	Lake Bonneville deposits			Embankment gravel, sand, silt; 0-15 m.
		Older alluvium			Fanglomerate, gravel, sand, silt; 0-300 m.
TERTIARY	Pliocene	Salt Lake(?) Formation			Marly limestone, bentonitic tuff, fanglomerate, gravel, sand, and silt; 0-1,500 m.
		UNCONFORMITY			
	Miocene	Silver Shield Quartz Latite	Tss		Dike and flow unit of coarse-grained, dark-gray quartz latite porphyry; 50 m.
		Pinyon Creek Conglomerate	Tpc		Coarse-grained, poorly sorted conglomerate and sandstone; 0-160 m.
		UNCONFORMITY			
	Oligocene	Breccia pipes	Tbp		Pipelike bodies consisting of blocks of limestone and quartzite in a matrix of quartz and feldspar phenocrysts and other volcanic material.
		Andesite or latite dikes and related intrusion breccias	(Not shown)		Purple porphyritic dikes commonly altered to hematitic kaolinite; essentially contemporaneous with ore deposition.
		Monzonite porphyry of Silver City stock and related plutons	Tsc		Greenish-gray, granitic to coarsely porphyritic biotite hornblende augite monzonite porphyry.
		Intrusive contact			
		Pebble dikes and associated dikes of monzonite porphyry	Tpd		Pebble dikes are narrow tabular bodies of intrusion breccia commonly associated with dikes of greenish-gray monzonite porphyry.
		Intrusive contact			
		Laguna Springs Volcanic Group	Tls		Tintic Delmar Latite: dark-gray, coarse-grained latite porphyry flow unit with fine-grained airfall tuff unit at base; 30 m.
					Pinyon Queen Latite: dark-gray, coarse-grained latite porphyry flow unit with fine-grained airfall tuff unit at base; 30 m.
					North Standard Latite: brownish-gray, fine-grained latite porphyry flow unit with heterogeneous boulder tuff at base; 90-300m.
		Sunrise Peak Monzonite Porphyry	Tsp Tsps		Medium- to dark-gray, coarsely porphyritic monzonite porphyry; Tsp: stocks, plugs, dikes; Tsps: extensive sills.
		Latite Intrusive rocks	Tli		Small plugs and dikes of dark-gray, fine- to coarse-grained latite.
		Tintic Mountain Volcanic Group	Ttm		Big Canyon Latite: dark-gray to black, fine-grained latite porphyry with white tuff at base; 0-70 m.
					Latite Ridge Latite: reddish-brown, fine-grained welded tuff with white airfall tuff at base; 0-600 m.
					Copperopolis Latite: sequence of volcanic rocks including white fine-grained tuff at base and overlying units of red, black, and brown, fine-grained latite porphyry and boulder agglomerate; more than 125 m.
		Swansea Quartz Monzonite	Ts		White to gray, fine- to medium-grained quartz monzonite porphyry.
		Packard Quartz Latite	Tp		Purplish-gray, fine- to medium-grained, contorted quartz latite lavas with white tuff and black to dark-green vitrophyre at base and top; more than 900 m.
		Packard Quartz Latite	Tp		Purplish-gray, fine- to medium-grained, contorted quartz latite lavas with white tuff and black to dark-green vitrophyre at base and top; more than 900 m.
		Apex Conglomerate	Tap		Brick red conglomerate and sandy shale; 0-200+ m.
		UNCONFORMITY			
MISSISSIPPIAN	Upper	Great Blue Formation	Mu	Mgb	Blue-gray cherty limestone with thick units of black shale and brown quartzite near middle; 760 m.
		Humbug Formation		Mh	Blue limestone and buff sandstone; 200 m.
		Deseret Limestone		Md	Blue-gray, cherty, fine-grained and coarse bioclastic limestone; 300 m.
	Lower	Gardison Limestone	Ml	Mg	Blue-gray, prominantly bedded, cherty limestone; 160 m.
		Fitchville Formation		MDf	Eight distinctive units of limestone and cherty dolomite; 100 m.
DEVONIAN	Upper	Pinyon Peak Limestone	DO	Dp	Blue-gray silty limestone; sandy at base; 25 m.
		DISCONFORMITY(?)			
		Victoria Formation		Dv	Gray dolomite and buff quartzite; locally some lenses of penecontemporaneous breccia; 75-90 m.
DEVONIAN, SILURIAN, AND ORDOVICIAN		Bluebell Dolomite		DSOb	Dusky-gray, coarse-grained dolomite with some beds of sublithographic creamy white dolomite. Curly laminated marker beds near middle; 100-185 m.
ORDOVICIAN	Upper	Fish Haven Dolomite	Ofo	Ofh	Mottled dusky-gray cherty dolomite; 60-100 m.
		DISCONFORMITY			
	Lower	Opohonga Limestone		Oop	Blue-gray, thin-bedded, silty and shaly limestone; 100-300 m.
CAMBRIAN	Upper	Ajax Dolomite	Єu	Єaj	Dusky-gray, coarse-grained, cherty dolomite; 180-200 m.
		Opex Formation		Єop	Thin-bedded sandy limestone and shale; 40-100 m.
	Middle	Cole Canyon Dolomite	Єm	Єcc	Coarse-grained dusky-gray dolomite; and fine-grained creamy white laminated dolomite; 275 m.
		Bluebird Dolomite		Єb	Coarse-grained dusky-gray dolomite with white, rod-shaped markings; 55 m.
		Herkimer Limestone		Єh	Blue-gray shaly and silty limestone with some green shale; 130 m.
		Dagmar Dolomite		Єd	Fine-grained, creamy-white, laminated dolomite; locally sand-streaked; 25 m.
		Teutonic Limestone		Єte	Blue-gray silty limestone with zones of pisolites; 120 m.
		Ophir Formation		Єo	Gray-green shale and blue oolitic limestone; 130 m.
	Lower	Tintic Quartzite	Єl	Єtq	Fine-grained, locally pebble-streaked buff quartzite; gray-green phyllite beds in upper part; conglomeratic in lower part; 700-1,000 m.
		UNCONFORMITY			
PRECAMBRIAN Y(?)	Upper	Big Cottonwood Formation	pЄ		Gray-green phyllitic shale, greenish-brown quartzite, and some brownish-gray dolomite; more than 560 m.

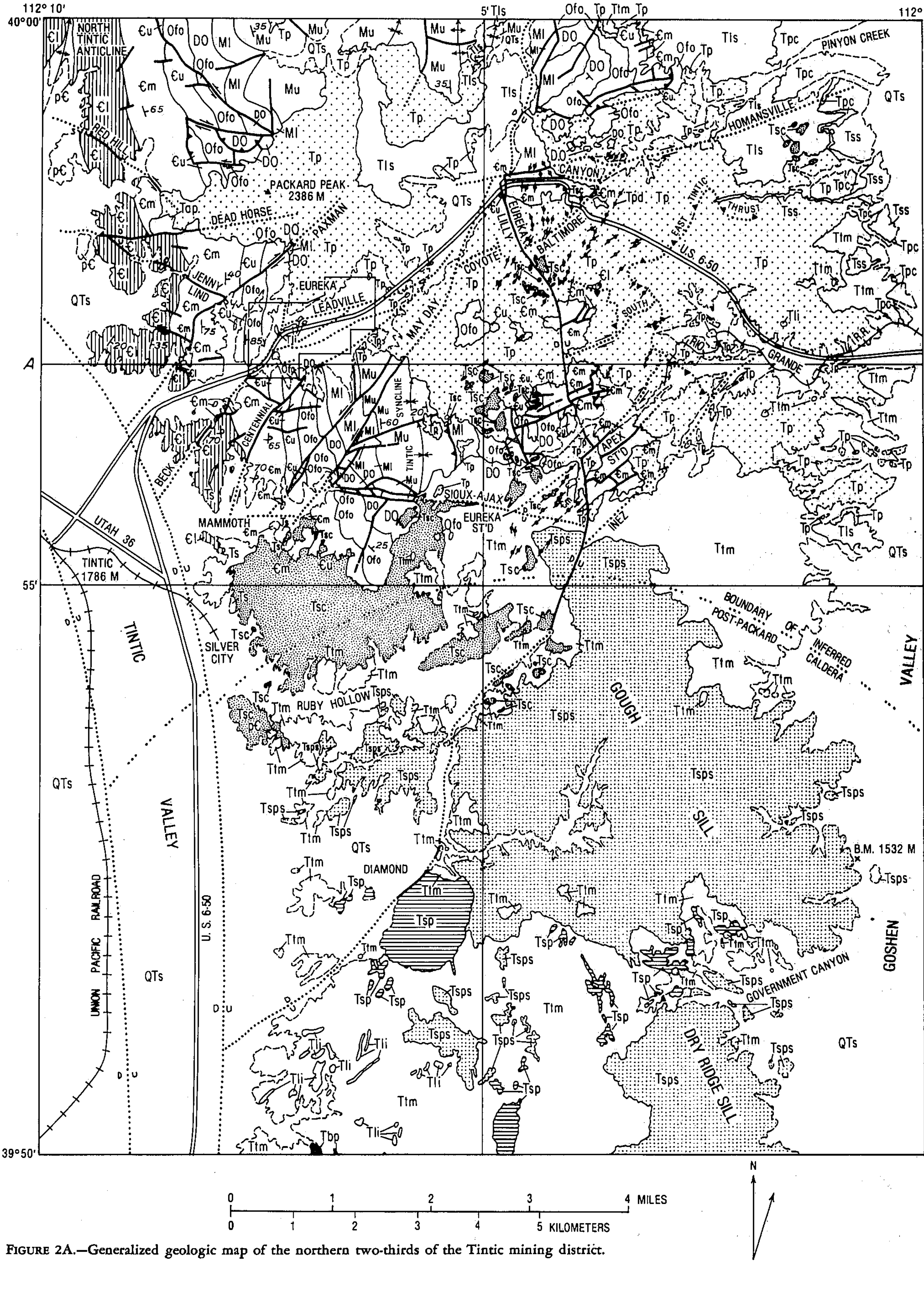

FIGURE 2A.—Generalized geologic map of the northern two-thirds of the Tintic mining district.

EXPLANATION

TERTIARY AND QUATERNARY

QTs
Surficial and valley-fill deposits

TERTIARY

Tss
Silver Shield Quartz Latite and related feeder dike

Tpc
Pinyon Creek Conglomerate

•—Tbp
Breccia pipe

Tsc
Monzonite porphyry of Silver City stock and related plutons

Tpd
Pebble dikes and related dikes of monzonite porphyry

Tls
Laguna Springs Volcanic Group
(Tintic Delmar Latite, Pinyon Queen Latite, and North Standard Latite)

Tsp / Tsps
Sunrise Peak Monzonite Porphyry and related intrusive rocks
Tsp, crosscutting plutons
Tsps, extensive sills

Tli
Latite intrusive rocks

Ttm
Tintic Mountain Volcanic Group
(Big Canyon Latite, Latite Ridge Latite, and Copperopolis Latite)

Ts
Swansea Quartz Monzonite and related intrusive rocks

Tp
Packard Quartz Latite

Tap
Apex Conglomerate

MISSISSIPPIAN

Mu
Upper Mississippian rocks
(Great Blue Formation, Humbug Formation, and Deseret Limestone)

Ml
Mostly Lower Mississippian rocks
(Gardison Limestone and Fitchville Formation; includes some Devonian strata at base)

ORDOVICIAN TO DEVONIAN

DO
Devonian to Ordovician rocks
(Pinyon Peak Limestone, Victoria Formation, and Bluebell Dolomite)

ORDOVICIAN

Ofo
Ordovician rocks
(Fish Haven Dolomite and Opohonga Limestone)

CAMBRIAN

Єu
Upper Cambrian rocks
(Ajax Dolomite and Opex Formation)

Єm
Middle Cambrian rocks
(Cole Canyon Dolomite, Bluebird Dolomite, Herkimer Limestone, Dagmar Dolomite, Teutonic Limestone, and Ophir Formation)

Єl
Lower Cambrian rocks
(Tintic Quartzite)

PRECAMBRIAN

pЄ
Big Cottonwood Formation

Contact
Dashed where approximately located

Fault
(Dotted where concealed; U, upthrown side; D, downthrown side; arrows show direction of relative movement. In section: A, relative movement away from observer; T, toward observer

Thrust fault
(Dotted where concealed; Sawteeth on side of upper plate)

Syncline
(Showing trace of axial plane and plunge of axis)

Anticline
(Showing trace of axial plane and plunge of axis)

50
Strike and dip of beds

70
Strike and dip of overturned beds

Ore bodies
(Shown only in cross section)

FIGURE 2B.—Explanation for map on opposite page.

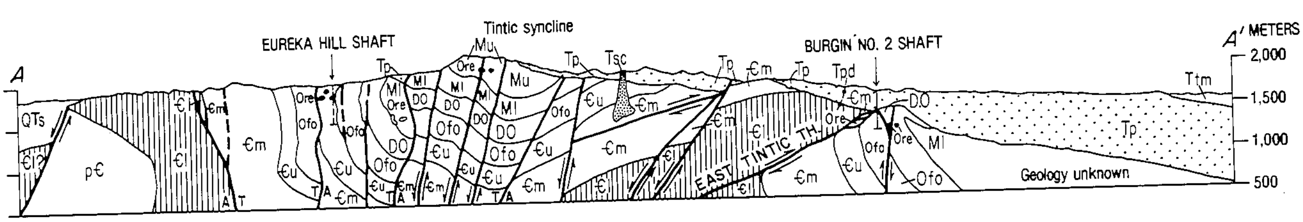

FIGURE 3.—Geologic cross section A-A' extending east-west through the Burgin No. 2 shaft.

deep is believed to have formed near the center of the present East Tintic Mountains (Morris 1974). At approximately the same time, or shortly before, the Swansea Quartz Monzonite stock was intruded a short distance beyond the northwest margin of the caldera. No ores were deposited during this intrusive episode.

Overlying the Packard is a thick and extensive sequence of white tuff and tuff-breccia, dark-brownish-gray latite flows, red-brown welded tuffs, and heterogeneous fine- to coarse-grained agglomerates. These rocks constitute the Tintic Mountain Volcanic Group and have been subdivided into the Copperopolis Latite, the Latite Ridge Latite, and the Big Canyon Latite. The eruptive centers of these rocks were largely within the Packard caldera, and in time the collapsed area was completely filled and overtopped by a large composite volcanic cone, which may have been nearly 50 km in diameter and 4–5 km in height. This second eruptive cycle was terminated with the intrusion of many stocks, plugs, dikes, and sills of biotite augite hypersthene monzonite and latite porphyry, including the Sunrise Peak stock near Diamond, and the thick and extensive Gough and Dry Ridge sills. As in the Swansea intrusive episode, no ores were deposited after the intrusion of the Sunrise Peak stock and related plutons.

Overlying the Tintic Mountain Volcanic Group is the Laguna Springs Volcanic Group, consisting of North Standard Latite, Pinyon Queen Latite, and Tintic Delmar Latite. The volume of the Laguna Springs lavas and tuffs was small in comparison with the Packard and Tintic Mountain volcanic rocks; however, their eruption terminated with the intrusion of the ore-related Silver City stock, a biotite augite hornblende monzonite porphyry, near the northern boundary of the filled Packard caldera. Many monzonite porphyry plugs and dikes were also emplaced in a compound zone extending north–northeastward from the northeastern part of the partly concealed stock. Associated with these plugs and dikes are numerous pebble dikes–tabular bodies of intrusion breccia composed of rounded fragments of quartzite in a matrix of comminuted sedimentary rocks and lava. Many samples of the Silver City stock and related plutons have been dated by K-Ar techniques. The apparent ages of hornblende, biotite, and sanidine range from 38.7 ± 1.9 to 31.5 ± 0.9 m.y., with most samples of biotite from the least altered parts of the main stock yielding ages of about 31.5 m.y. (Laughlin et al. 1969).

Associated with ore bodies in the Chief No. 1, North Lily, and other mines are narrow dikes of biotite augite andesite porphyry. Commonly these dikes are altered to hematite-flecked halloysite or kaolinite, and have been termed "the purple porphyry" by the miners. They are known to crop out at the surface in only two small areas in the East Tintic subdistrict.

The latest manifestations of Oligocene volcanic activity in the Tintic district are breccia pipes in Copperopolis Canyon, mostly south of figure 2. These bodies consist of blocks of limestone and quartzite in a weakly pyritized matrix of broken phenocrysts of quartz, sanidine, and other comminuted igneous minerals. These breccia pipes are similar in most respects to much larger breccia pipes in the West Tintic and southern Sheeprock Mountains (Morris and Kopf 1967).

The youngest volcanic and intrusive rocks in the Tintic district are a wide dike and an associated remnant lava flow named from the Silver Shield shaft which is located south of Pinyon Creek in the northeastern part of figure 2. These rocks are coarse-grained biotite augite hypersthene quartz latite and are similar in general appearance to the older Pinyon Queen and Tintic Delmar latites. Biotite and sanidine from the flow unit and dike yield K-Ar ages ranging from 15.9 ± 2.16 to 18.3 ± 0.5 m.y. indicating a Miocene age for these rocks and the underlying Pinyon Creek Conglomerate (Laughlin et al. 1969, p. 915–16).

The widespread Pliocene Salt Lake(?) Formation, which crops out in Tintic Valley and deeply underlies Goshen Valley, contains a high proportion of fresh and altered rhyolitic tuff, but the source of this igneous material is unknown.

Structure

The dominant structures of the Tintic district are the folds and faults that were formed during the compressive deformation of the Midas thrust plate. Other structures include prevolcanic tensional faults, faults and fractures related to igneous activity and mineralization, and basin-range faults.

Folds

The great folds produced during the Sevier orogeny are the most widely known structural features of the Tintic district. They include the North Tintic anticline, which lies mostly north and northwest of figure 2; the Tintic syncline, which is prominently exposed south of Eureka, and the East Tintic anticline, which is largely concealed beneath lava in the East Tintic subdistrict. These folds have amplitudes ranging from 5,000 to 7,000 m and north-trending, north-plunging axes that are about 3–5 km apart. All three folds are overturned to the east, with the overturning showing a progressive increase eastward. The limbs of the folds contain a number of minor thrust faults, the most important of which is the East Tintic thrust. As shown in figure 3, movement on this thrust carried the low dipping west limb of the East Tintic anticline over the vertical-to-overturned east limb. In the northern part of the Tintic district a number of subsidiary folds have developed in the axial area of the Tintic syncline.

Faults

The faults that cut the folded sedimentary strata and the younger igneous rocks are broadly classified into four groups: (1) shear faults formed during folding; (2) normal faults formed after folding but before volcanic activity; (3) mineralized fissures and faults related to the volcanic episode; and (4) late normal faults of the basin-range system. None of the major thrust faults of the Sevier orogenic belt is exposed in the Tintic district although the Midas fault zone undoubtedly underlies the East Tintic Mountains, probably near the base of the Big Cottonwood Formation (Roberts et al. 1965, p. 1952–53). A tear fault, which apparently delimits the Midas thrust plate on the south, is inferred to underlie the lavas of the East Tintic district and may also have guided the emplacement of the near surface part of the Silver City stock (Morris and Shepard 1964, p. C20).

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

Normal faults. – The faults that were formed after the period of compressive deformation but before the volcanic eruptions include the Dead Horse–Homansville fault and the Sioux–Ajax fault. These faults cut the north-trending beds of the major folds nearly at right angles and dip steeply to the north. The rocks on the north side of Dead Horse–Homansville fault are downdropped relative to those on the south, and the displacement increases from 500 m or less in the western part of the district to more than 1,000 m in the eastern part. Prior to the eruption of the Packard Quartz Latite, the trace of the Dead Horse segment of the fault was the site of a deep eastward-sloping alluvium-floored valley that later became filled with lava. The Sioux–Ajax fault zone consists of several braided fault strands that drop the steeply dipping beds of the west limb of the Tintic syncline north of the fault against gently dipping beds in the trough of the syncline south of the fault, indicating a vertical displacement of approximately 500 m. Beneath the alluvium in Mammoth Gulch the Sioux–Ajax fault may be deflected to the south along part of the older Mammoth–May Day fault.

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

Basin-range faults. – The truncation of major geologic structures at the west edge of the East Tintic Mountains and the presence of erosion-modified fault scarps in alluvium denote a zone of late normal faults between Tintic Valley and the East Tintic Mountains. A gravity survey of this general area by Cook and Berg (1961, p. 85) indicates a total gravity relief of more than 20 milligals across the concealed basin-range fault zone near Tintic station, suggesting a thickness of more than 2,200 m of valley-fill deposits (Morris 1964, p. L18).

Ore Deposits

The metalliferous ore deposits of the Tintic district include fissure veins, replacement veins, and replacement ore bodies. Of these the replacement ore bodies are particularly notable for their great lateral persistence, their richness, and their large size. The principal metals of the deposits, in order of value, are silver, lead, copper, zinc, and gold. Prior to 1916 little if any zinc was recovered from the ores, but since that date it has become increasingly important and in recent years has exceeded both silver and lead as the metal of principal value in the ores from the district. Before the early 1900s the larger ore deposits were discovered by prospecting for outcroppings, however small and seemingly insignificant. Since that time new discoveries of completely concealed ore bodies and ore centers have been made through the application of ore-trend projections, geologic studies and interpretation, studies of hydrothermal alteration, and geochemical investigations of various types. Several large areas of favorably situated and hydrothermally altered rocks, chiefly in the East Tintic subdistrict, remain to be fully explored.

Ore Bodies

Individually the ore bodies of the Tintic district may be described as pods, lenses, pipes, columns, tabular shoots, and a variety of other features that range in size from a few kilograms to 2 million tonnes and more. The wide range in shape and size is related to several factors: geologic structure, dissimilarities in the physical and chemical characteristics of the host rocks, distance from intrusive centers, and differences in the chemical character of parent hydrothermal solution. A vertical projection of the mined and unmined ore bodies that are known in the Tintic district is shown in figure 4.

The tabular ore shoots of the fissure veins are essentially limited to minor fault zones in nearly nonreactive quartzite, monzonite porphyry, and similar rocks. These veins range in width from knife-edge seams to 8–10 m, averaging less than 1 m. Most are less than 100 m in length, although the Sunbeam ore shoot is nearly continuous for over 1,200 m. The pitch lengths of the largest shoots in the intrusive rocks are unknown inasmuch as most of them were mined only to the water table, which stands at depths of 100–150 m in the Silver City and Swansea stocks. The structures occupied by the veins are mostly small normal faults having an average strike of N 20° E and an average dip of 75°–85° W; some, however, are vertical or dip east. They are widest and longest where they cut brittle homogeneous rocks but tend to form groups of short subparallel veins or disappear entirely in altered tuffs and in incompetent shale beds.

The replacement veins are more or less limited to the pyrometasomatized aureoles of the Silver City stock and related satellitic plutons. They are generally alined with the fissure veins and commonly merge with them, but most of them are longer and wider. Unlike the fissure veins they almost completely replace the breccia fillings of the fissure zones and locally expand on cross fractures and bedding breccias. Most of the individual ore shoots in the replacement veins are only a hundred meters or so in length; however the Dragon vein has been mined continuously, if not profitably, for more than 750 m from the edge of the Silver City stock into the Iron Blossom No. 1 mine where the tabular ore shoots become true replacement ore bodies. The ore shoots of the replacement veins range from columnar bodies that locally expand from a few centimeters to 15 to 20 m in diameter, to tabular mass 100 m or so in vertical and horizontal dimensions and 1.5–2 m in thickness.

The great replacement ore bodies of the Tintic district have produced more than 90 percent of the ore credited to the area. These ore bodies, which are limited to the areas of folded and faulted carbonate rocks of Paleozoic age, range in size from insignificant stringers and small kernels to great columnar, pipelike, bulbous, and irregular masses, some containing more than two million tonnes. As shown in figure 4, the replacement ore bodies in the Main Tintic subdistrict occur in five persistent linear zones ("ore runs" in local parlance) that extend northward from the Sioux–Ajax fault zone approximately to the latitude of Eureka townsite. For convenience of description they have been named, beginning with the westernmost: (1) the Gemini ore zone, which ex-

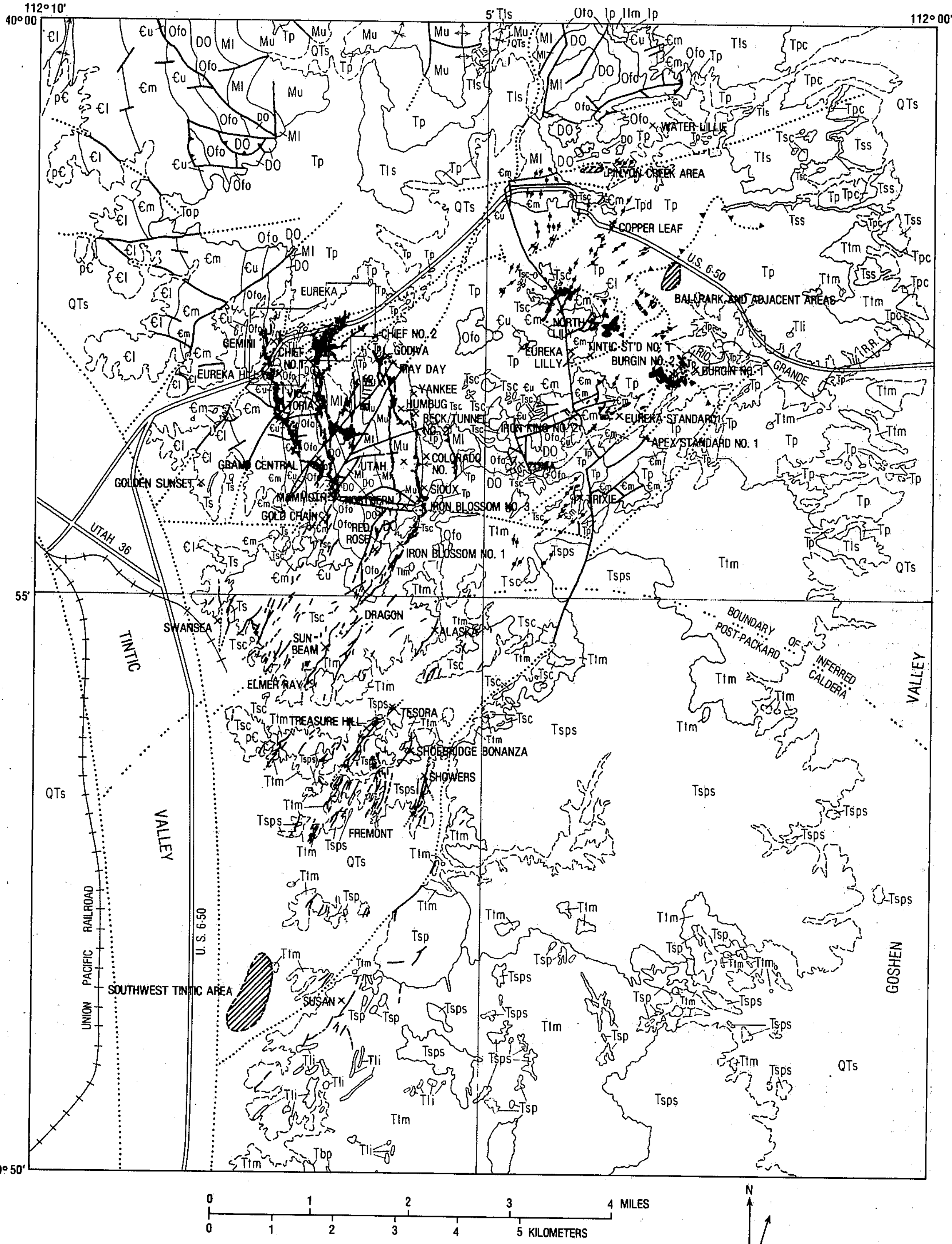

FIGURE 4.– Vertical projection of known ore bodies (solid) and mineralized areas (shaded) in the Tintic district.

tends from the Grand Central to the Gemini mine; (2) the Mammoth-Chief ore zone, which extends between the two named mines; (3) the small Plutus ore zone, which was mined from the Mammoth, Victoria, and other shafts; (4) the Godiva ore zone, which extends from the Northern Spy to the Godiva mine; and (5) the Iron Blossom ore zone, which extends from the Iron Blossom No. 1 mine to the Beck Tunnel No. 2 mine, where the ore zone turns northwestward and joins the Godiva ore zone. A longitudinal section of the Mammoth-Chief ore zone, showing the relations of the ore bodies to stratigraphic units and geologic structure is shown in figure 5. South of the Sioux-Ajax fault the linear character of the Mammoth-Chief, Godiva, and Iron Blossom ore zones persists in a southwestward direction through the pyrometasomatized aureole, the Silver City stock, and beyond it into the altered sills, lavas, and tuffs of Ruby and Diamond hollows.

The replacement ore bodies of the East Tintic subdistrict do not appear to form long linear ore zones, but occur as large irregular masses of ore at or near the intersections of northeast-trending fissures (or tear faults) and generally north-striking thrust faults of small to moderate displacement (fig. 6). The largest East Tintic ore bodies, one of which also contained over two million tonnes of ore, replace limestone beds in the Ophir Formation in the upper plates of thrusts, which have displacements of a few hundred to a few thousand meters. In the Tintic Standard and North Lily mines the Ophir Formation has been displaced over the Tintic Quartzite, and in the Burgin mine over several middle Paleozoic formations. Down-rake to the southwest in the Tintic Standard and North Lily mines, fissure veins in the Tintic Quartzite appear to have been the principal conduits for the ore solutions. In the Burgin mine the ore solutions appear to have moved upward along the East Tintic thrust and through several tear faults into the upper plate. Ore bodies in the 274 area of the Burgin mine lie in the footwall rocks of the thrust and appear to have been deposited from solutions rising on northeast-trending faults in the footwall rocks. These ore bodies show many of the characteristics displayed by the replacement ore zones of the Main Tintic subdistrict.

The ore bodies of the smaller mines of the East Tintic subdistrict are chiefly fissure- and fault-localized veins; however, some of these mines also contained small replacement ore bodies in limestone beds adjacent to or near the veins. As shown in figure 4, the ore bodies of the East Tintic subdistrict, excepting for a highly altered, largely unexplored, 1 x 2 km gap, are also alined with vein zones in the igneous rocks near Ruby Hollow and Diamond. This exploration target is made even more interesting by the north bounding fault of the lava-filled caldera that is inferred to cut through it.

As may be inferred from figures 4, 5, and 6, the replacement ore bodies of the Tintic district are localized by many different types of faults, by fissures, bedding plane openings of various kinds, by certain susceptible limestone beds, and even by unrecognizable features. In the Main Tintic subdistrict, the miners believe that within any one ore zone all the ore is connected, at least by small stringers or undiscovered ore bodies. In contrast, the three main ore centers in the East Tintic subdistrict are more discrete although continued mining and exploration may yet show a greater lateral persistence and interconnected character than is now recognized.

Ores

The primary ores of the Tintic district consist chiefly of sulfides and sulfosalts of silver, lead, copper, iron, zinc, and bismuth in association with jasperoid (silicified carbonate rock), barite, aggregates of quartz crystals, calcite, dolomite, and ankerite. In addition, gold is locally abundant in some of the copper ores, in part as the native metal and in part as a telluride; hypogene native silver is also abundant in some late sulfide ore bodies in the Chief No. 1 mine. The mineral assemblage is generally characteristic of mesothermal deposits; however, the general geologic setting and certain mineral textures and associations suggest temperatures and pressures approaching those of the epithermal environment (Lindgren 1933, p. 585).

The primary ore bodies were partly to wholly oxidized to depths of 120 m or more in the fissure veins cutting the igneous rocks and to depths of 300–700 m in the sedimentary rocks. This oxidation has greatly obscured the original character of some of the ore bodies, which is difficult to interpret except from minor masses of residual primary minerals or from the gross chemical composition of the secondary ores.

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

1. Lead ores containing from 5 to 50 percent lead and as much as 1,700 g of silver per tonne. Rarely they also contain small quantities of zinc and copper and a few grams of gold.
2. Siliceous lead ores containing a few percent lead with minor amounts of zinc and copper in a siliceous gangue of more than 70 percent silica. The silver content has a considerable range and is locally high.
3. Siliceous silver ores generally containing 700 g of silver per tonne and less than 5 g of gold. In many places, these ores contain no identifiable metallic minerals except rare scattered crystals of cerussite and some copper stain.
4. Lead–zinc ores containing 5–15 percent each of lead and zinc and about 275–340 g or less of silver per tonne.
5. Copper–gold ores containing a few percent or more of copper, 340–680 g of silver per tonne, and commonly 15 g or more of gold.
6. Gold telluride ores containing minor tetrahedrite and enargite but containing as much as 100 kg of gold per ton.
7. Siliceous lead–copper ores occurring where copper ores give way to lead ores, as in the Eureka Hill, Grand Central, Chief, Iron Blossom, and other mines. These ores generally contain only a few percent each of lead and copper.

In addition, a special class of zinc carbonate and hydrous silicate ore that originated through oxidation and migration was mined in the Godiva, May Day, and adjacent mines (Loughlin 1914).

The metallic minerals of the primary ores include pyrite, galena, sphalerite, tetrahedrite, tennantite, enargite, argentite, proustite, pearceite, polybasite, freibergite, native silver, pyrargyrite, stephanite, smithite, hessite, sylvanite, and native gold. The high cadmium content of some ores suggests the presence of greenockite or hawleyite, and the occurrence of some oxidized bismuth ores indicates bismuthinite, cuprobismutite, or an unknown mineral containing bismuth, silver, and copper. The principal nonmetallic minerals of the pri-

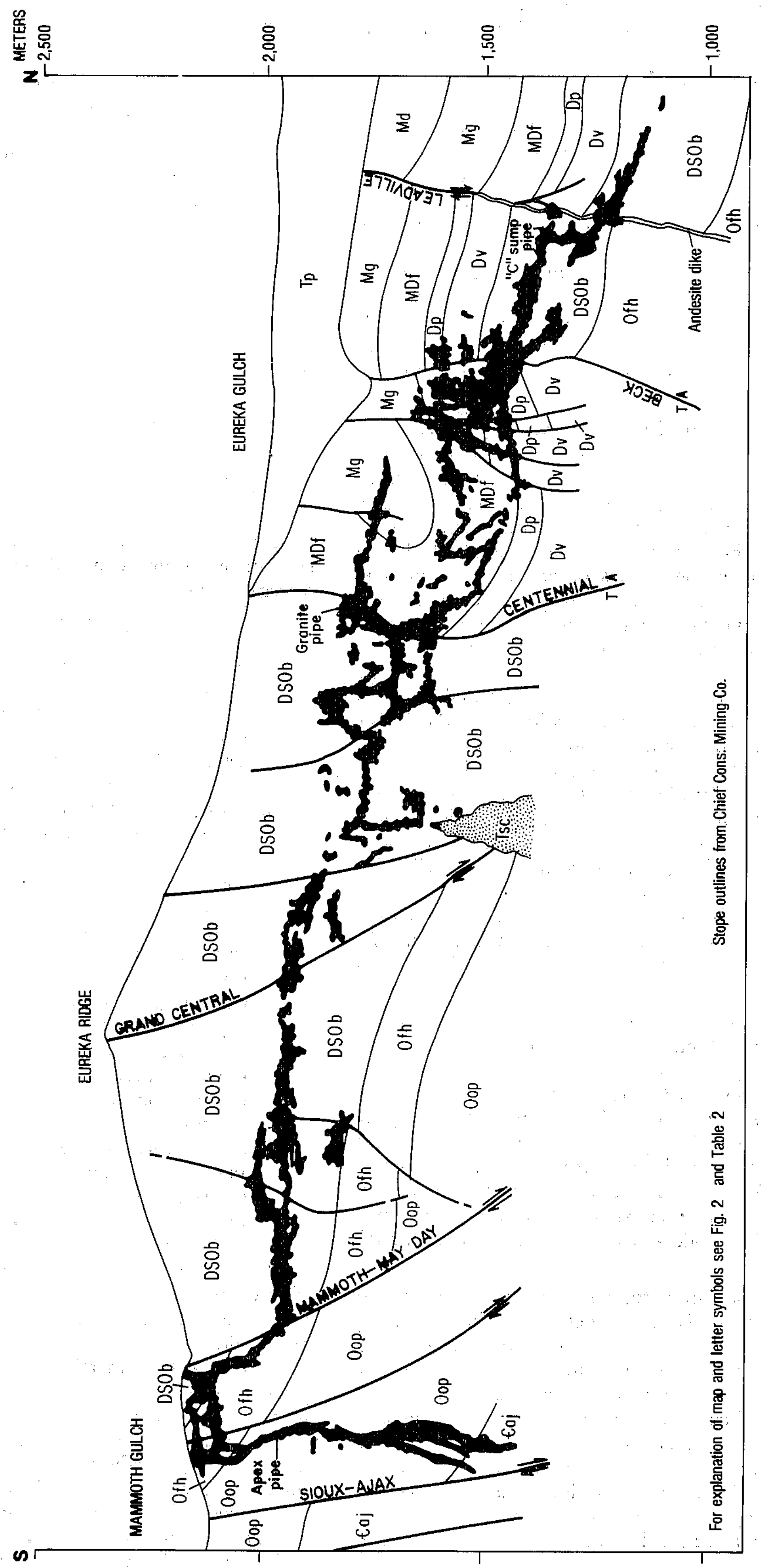

FIGURE 5.—Longitudinal section of the Mammoth-Chief ore zone from the Sioux-Ajax fault to its northern known limits, showing relations of ore bodies to structure and stratigraphic units.

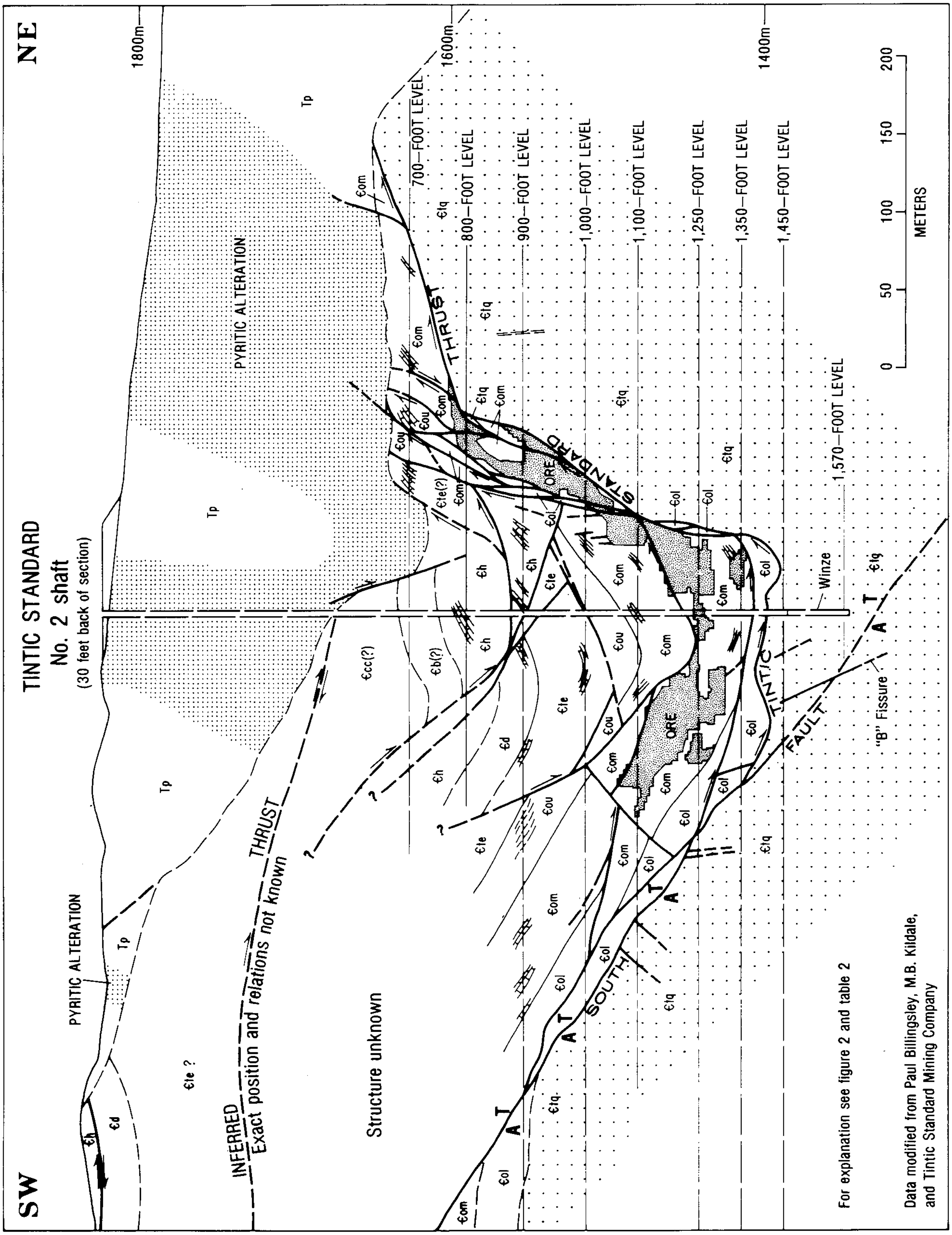

FIGURE 6.—Northeast-trending cross section through Tintic Standard No. 2 shaft area showing relation of ore bodies to South fault and folded Tintic Standard thrust.

mary ores are quartz, which ranges from fine-grained jasperoid to coarse crystal aggregates, barite, rhodochrosite, dolomite, ankerite, and calcite.

The oxidized ores, which were the principal product of the Tintic district prior to 1916, consist of a great variety of minerals, the most important of which are cerussite, anglesite, plumbojarosite, smithsonite, hemimorphite, cerargyrite, native silver, argentojarosite (first described from the East Tintic subdistrict), malachite, azurite, chrysocolla, and many others. In addition to quartz in many forms, the nonmetallic gangue minerals of the oxidized ores include many hydrous iron and manganese oxide minerals, gypsum, calcite, dolomite, and a great variety of hydrous sulfate minerals.

Ore bodies showing secondary sulfide enrichment are not common in the Tintic district and were best observed in extensive masses of pyritic jasperoid near the water table in the Chief No. 1 mine. In this relatively carbonate-free environment, acidic ferric sulfate-bearing solutions facilitated the downward migration of zinc and the deposition of wurtzite-rich ore bodies within 30–50 m below the water table.

Zonation of Ore Bodies

A general horizontal zonation is evident in the composition and—to a lesser degree—the texture of the ore bodies of the linear ore zones of the Main Tintic subdistrict. The replacement ore bodies and replacement veins closest to the Silver City stock are valuable chiefly for copper and gold. The mines at an intermediate distance from the stock have produced mostly lead and silver ores, including locally rich silver bodies that are lead free; gold is an important constituent of only a few of these deposits. The northernmost ore bodies in the subdistrict carry as much zinc as lead and contain significantly smaller quantities of silver than those in the area of predominantly lead deposits. A textural zonation of the gangue minerals outward from the Silver City stock is perhaps as prominent as the chemical zonation although it is less spectacular and not of direct commercial significance. As noted by Lindgren and Loughlin (1919, p. 127), the quartz in the veins cutting the igneous rocks occurs as well-developed crystals, some several inches long. In contrast, the siliceous gangue of the replacement copper ore bodies in the sedimentary rocks near the Silver City stock consists of granular aggregates of small quartz crystals or medium-grained jasperoid, both containing medium to large plates of barite and druses filled with quartz crystals a centimeter or so long. The jasperoid associated with the silver and silver–lead ore bodies farther north is still finer grained, resembling chert, and contains small barite plates and tiny quartz crystals filling fractures and shrinkage openings. The fine-grained jasperoid continues into the northern zinc-rich areas, but barite and crystalline quartz cease to be abundant. In the outermost fringes of the district, small podlike deposits of lead and zinc are characterized by modest amounts of silver and silica and much dolomite and calcite.

In the East Tintic subdistrict zonation of the ore bodies is less apparent and may even be telescoped. In the Tintic Standard mine the deep ores in the southwestern part of the mine are rich in gold and enargite. Upward to the northeast these ores give way to largely oxidized silver-rich tetrahedrite and galena ores, which in turn give way to highly oxidized galena ores. In the uppermost and easternmost part of the main ore body some mostly unmined ores apparently derived from the oxidation of spalerite and rhodochrosite have been explored. In the Burgin mine a somewhat similar zonal pattern is generally apparent although the main Burgin ore body itself contains a high proportion of sphalerite and rhodochrosite. In the footwall ore bodies of the mine, east of the main Burgin ore bodies, the proportion of silver and lead decreases in the ore, zinc increases, and rhodochrosite continues to be the dominant gangue mineral.

Hydrothermal Alteration

The lavas above the concealed ore bodies of the East Tintic subdistrict and the wall rocks of the veins cutting the monzonite and volcanic rocks in the southern part of the Main Tintic subdistrict both exhibit a sequential pattern of hydrothermally altered zones comparable to the alteration selvages adjacent to the veins of the Boulder County, Colorado, tungsten district (Lovering 1941, p. 234–59), and Butte, Montana (Sales and Meyer 1948). The alteration zones in the East Tintic subdistrict have been studied in detail by Lovering (1949) and his coworkers. They recognize five distinct stages of alteration: (1) an Early Barren stage characterized by dolomitization of limestone and chloritic-epidotic alteration of volcanic rocks; (2) a Mid-Barren stage of argillic alteration characterized by the kaolinization and other clay mineral alteration of intrusive and volcanic rocks and shale and the severe leaching and sanding of carbonate rocks; (3) a Late Barren stage characterized by the pyritization of iron-bearing rocks, the silicification of carbonate and other rocks, commonly with the late precipitation of barite and the calcitization of plagioclase feldspar in the volcanic rocks; (4) an Early Productive stage characterized by the local deposition of orthoclase or sericite, other hydrous micas and potassium-rich minerals, pyrite, jasperoid, and quartz; and (5) a Productive stage during which there was continued deposition of baritic and pyritic jasperoid and quartz, and the deposition of the ore minerals. Ore deposition was the terminal phase of the volcanic and alteration sequence in the district.

Geologic relations in the East Tintic subdistrict indicate that the Early Barren stage preceded the intrusion of the plutons of the Silver City monzonite porphyry and that the Mid-Barren stage was contemporaneous with igneous intrusion. The hydrothermal solutions of the Late Barren, Early Productive, and Productive stages apparently became active shortly after the period of argillic alteration, but they did not always utilize the conduits used by the earlier argillizing solutions. They appear to have been essentially a continuously flowing solution that changed in chemical character and composition with time, finally becoming a very dilute solution capable only of precipitating the ore minerals.

It should be noted that the great halloysite deposit of the Dragon mine was deposited during the Mid-Barren stage of hydrothermal alteration of the border areas of the Silver City stock.

Geochemistry

Preliminary and continuing geochemical and isotopic studies by John N. Batchelder, Wayne E. Hall, and the writers indicate that the fluids in inclusions in quartz and barite crystals from a number of fissure veins in both the Tintic and East Tintic subdistricts contain $<$ 0.1–3.1 equivalent weight percent of NaCl. These inclusions do not contain many daughter crystals and have homogenization temperatures ranging from 150°–300°C. The studies, which are chiefly being carried out by Batchelder, indicate that present-day spring waters in the East Tintic district have a δ D of approximately −120 permil and a $\delta^{18}O$ of −15 permil. Water liberated from fluid inclusions in quartz yield δ D values ranging −121 to −118 permil. In sulfide samples water liberated from fluid inclusions have δ D values ranging -114 to -101 and in a sample of coarse-grained galena a value of -84 permil. Calculated $\delta^{18}O$ values for water in equilibrium with quartz range from -5.1 to 0.0 permil. These preliminary data suggest a hydrothermal system that was dominated by meteoric waters in which the oxygen in the waters reequilibrated with oxygen in the sedimentary rocks. In contrast, the data from the sulfides indicate that substantial amounts of magmatic water may have been present during ore deposition.

The isotopic composition of the lead in the ores shows various mixtures of lead from the intrusive rocks and the deep crustal rocks of the Tintic area (Stacey et al. 1968). The $\delta^{34}S$ values of all Tintic sulfide minerals have a very narrow range averaging -1.4 permil, which is typical of many other magmatic hydrothermal ore deposits (Ames 1970).

OUTLOOK FOR THE FUTURE

Except for the year 1962 the Tintic district has been continuously productive since 1870. During this interval of 108 years, the fortunes of the district have waxed and waned, but somehow it has survived and continued to prosper, albeit at a reduced scale from time to time. As shown in figure 3 several areas of mineralized rocks, two of large dimensions, await changes in economic factors that could lead to their development. Other areas in the northern part of the Main Tintic subdistrict, in the Mammoth Gulch area, and in the area between the Trixie and Alaska mines remain essentially unexplored despite the presence of late-state alteration zones or favorable geochemical, structural, and stratigraphic relationships. In view of these factors, it is believed that with continued interest and confidence in the district, new discoveries will continue to be made, and new mines and ore bodies will be developed as the old producers fade away.

Conversion Table

Metric		English	
1 millimeter	=	0.0393701	inch
1 centimeter	=	0.393701	inch
1 meter	=	3.28084	feet
1 kilometer	=	0.621371	mile
1 gram	=	0.032151	ounce (troy)
1 kilogram	=	32.151	ounce (troy)
1 kilogram	=	2.20462	pounds (advp)
1 tonne	=	1.102312	short tons

REFERENCES CITED

Ames, R. L., 1970, Sulfur isotope study of the Tintic mining district: Ph.D. dissertation, Yale Univ., New Haven, Conn., 163 p.
Armstrong, R. L., 1968, Sevier orogenic belt in Nevada and Utah: Geol. Soc. America Bull., v. 79, no. 4, p. 429–58.
Cohenour, R. E., 1959, Sheeprock Mountains, Tooele and Juab Counties, Utah: Utah Geol. and Mineralog. Survey Bull. 63, 201 p.
Cook, K. L., and Berg, J. W., Jr., 1961, Regional gravity survey along the central and southern Wasatch Front, Utah: U.S. Geol. Survey Prof. Paper 316E, p. 75–89.
Crittenden, M. D., Jr., Sharp, B. J., and Calkins, F. C., 1952, Geology of the Wasatch Mountains east of Salt Lake City, Parleys Canyon to Traverse Range: In Geology of the central Wasatch Mountains, Utah: Utah Geol. Soc. Guidebook 8, p. 1–37.
Laughlin, A. W., Lovering, T. S., and Mauger, R. L., 1969, Age of some Tertiary igneous rocks from East Tintic, Utah: Econ. Geology, v. 64, no. 8, p. 915–18.
Lindgren, W., 1933, Mineral deposits, 4th ed.: New York, McGraw-Hill, 930 p.
Lindgren, W., and Loughlin, G. F., 1919, Geology and ore deposits of the Tintic mining district, Utah: U.S. Geol. Survey Prof. Paper 107, 282 p.
Loughlin, G. F., 1914, The oxidized zinc ores of the Tintic district, Utah: Econ. Geology, v. 9, p. 1–19.
Lovering, T. S., 1941, The origin of the tungsten ores of Boulder County, Colorado: Econ. Geology, v. 36, no. 3, p. 229–79.
______, 1949, Rock alteration as a guide to ore–East Tintic district, Utah: Econ. Geology Mon. 1, 65 p.
Morris, H. T., 1964, Geology of the Tintic Junction quadrangle, Tooele, Juab, and Utah counties, Utah: U.S. Geol. Survey Bull. 1142-L, p. L1–L23.
______, 1974, Volcanism and ore deposition in the Tintic mining district–west central United States: In Problems of ore deposition: Internat. Assoc. on the Genesis of Ore Deposits, Varna (Bulgaria), 1974, 4th Symposium, v. 1, p. 265–71.
Morris, H. T., and Kopf, R. W., 1967, Breccia pipes in the West Tintic and Sheeprock Mountains, Utah: In Geological survey research, 1967: U.S. Geol. Survey Prof. Paper 575-C, p. C66–C71.
Morris, H. T., and Lovering, T. S., 1961, Stratigraphy of the East Tintic Mountains, Utah: U.S. Geol. Survey Prof. Paper 361, 154 p.
Morris, H. T., and Shepard, W. M., 1964, Evidence for a concealed tear fault with large displacement in the central East Tintic Mountains, Utah: In Geological survey research, 1964: U.S. Geol. Survey Prof. Paper 501-C, p. C19–C21.
Roberts, R. J., Crittenden, M. D., Jr., Tooker, E. W., Morris, H. T., Hose, R. K., and Cheney, T. M., 1965, Pennsylvanian and Permian basins in northwestern Utah, northeastern Nevada, and south central Idaho: American Assoc. Petroleum Geologists Bull., v. 49, no. 11, p. 1926–56.
Sales, R. H., and Meyer, Charles, 1948, Wall rock alteration, Butte, Montana: American Inst. Mining Engineers Trans., v. 178, p. 9–35.
Stacey, J. S., Zartman, R. E., and Nkomo, I. T., 1968, A lead isotope study of galenas and selected feldspars from mining districts in Utah: Econ. Geology, v. 63, no. 7, p. 796–814.