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Paragenesis and Mineralogy of the Burgin Mine, East Tintic District, Utah County, Utah*

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ABSTRACT.—The Burgin mine is located in the Chief Oxide area in the East Tintic mining district. It is situated on the western limb of a nearly recumbent, north-trending syncline which is overturned to the east and overridden by the East Tintic thrust fault. The rocks beneath the thrust are miogeosynclinal, ranging in age from Lower Ordovician to Lower Mississippian. The upper thrust plate consists mostly of broken and brecciated Middle Cambrian Ophir Formation. The ore deposits of the mine are structurally and stratigraphically controlled. The principal ore body lies along the East Tintic thrust, and is a limestone replacement in the Middle Ophir Limestone.

Five stages of rock alteration are recognized in the Burgin mine. They are (1) the early barren stage, characterized by widespread dolomitization of limestone and chloritization of volcanic rocks; (2) a mid-barren stage, characterized by argillization; (3) the late barren stage, characterized by an extensive jasperoidization with pyrite of cubic habit, and barite; (4) the early productive stage, characterized by the deposition of sericite, quartz, and pyrite of pyritohedral habit; and (5) the productive stage, characterized by the deposition of the ore minerals.

The most common minerals found in the Burgin mine are galena, argentite, sphalerite, chalcopyrite, tetrahedrite, pyrite, rhodochrosite, anglesite, cerussite, cerargyrite, chalcophanite, lead oxide phosphate, mimetite, smithsonite, aurichalcite, hematite, limonite, jarosite, jasperoid, quartz, chalcedony, calcite, dolomite, barite, sericite, hydromuscovite, dickite, and gypsum. Manganese oxides present include birnessite, hetaerolite, nsutite, pyrolusite, and quensilite.

Various periods of silicification and pyritization took place during the late barren, early productive, and productive stages of mineral deposition. Rhodochrosite deposition took place during the early productive and productive stages. Calcite and barite occur in the late barren and productive stages. Two surges of sphalerite, two of galena, one small injection of chalcopyrite, and another of tetrahedrite are discerned in the productive stage of ore deposition.

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*A dissertation submitted to the faculty of the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

ILLUSTRATIONS

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The writer is especially indebted to his adviser Dr. K. C. Bullock for his advice and helpful discussions and critiques during the progress of this work. He wishes to extend his thanks also to Dr. L. F. Hintze and Dr. W. R. Phillips, the other two members of his committee, for their care and support, and to the other professors of the Department of Geology for their encouragement.

He is grateful to the personnel of the Burgin mine, especially to Dr. D. O.

Rausch, Paul Mogenson, and Sam Smith, for having facilitated the writer's field work, and for supplying him with necessary drilling core data and other information for his research. He also wishes to thank James Allen for his help in taking pictures using the electronic microscope.

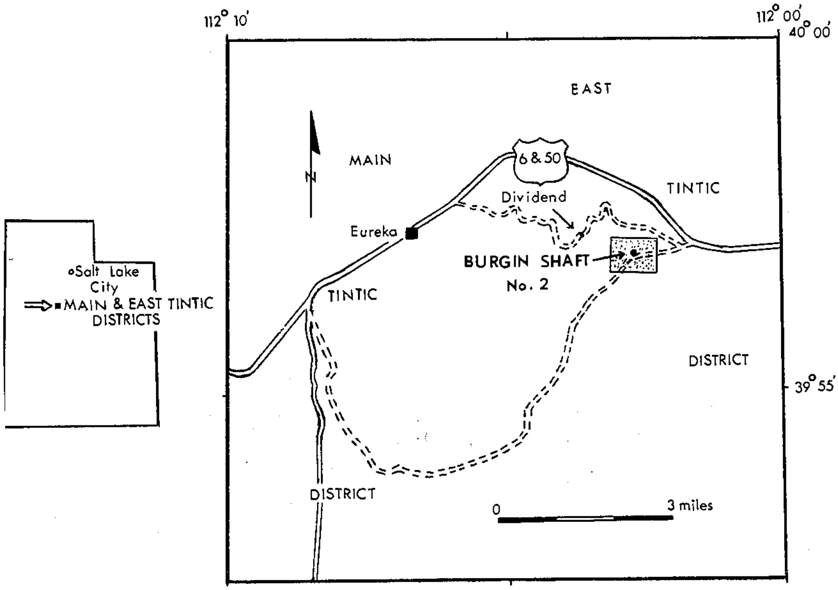
INTRODUCTION

Location and Accessibility

The Burgin mine lies in the East Tintic mining district, in the east central part of the East Tintic Mountains, Utah County, Utah. It is located in the Chief Oxide area, four miles directly east of Eureka, and can be reached by U. S. Highways 50 and 6 (Text-figure 1).

Previous Work

The importance of the Tintic district as a complex ore-yielding district was discovered during the second half of the last century. The first significant geological and mining report, however, did not appear until 1898, when G. W. Tower undertook stratigraphic and economic studies and G. O. Smith investigated the igneous rocks at the request of the U. S. Geological Survey, directed by S. F. Emmons (Tower and Smith, 1899). In 1911, Waldemar Lindgren began an investigation of the ore deposits, and G. F. Loughlin, an examination of the structure, stratigraphy, and igneous rocks of the area (Lindgren and Loughlin, 1919). In 1933, a summary of the major features of the geology was prepared by Paul Billingsley and G. W. Crane to serve as a guide book for a field excursion of members of the Sixteenth International Geological



TEXT-FIGURE 1.—Index map of the Main and East Tintic districts, Utah, showing the Burgin shaft No. 2 inside the Chief Oxide area (Dotted).

Congress (Billingsley and Crane, 1933). In 1938, M. B. Kildale included in his unpublished thesis new data, especially on the East Tintic district, emphasizing the structure and structural control of the ore deposits.

From 1948 to 1968, a large number of publications on the East Tintic district appeared. The most important, however, was the publication on the hydrothermal alteration and its relationship to ore deposits. It included the five stages of alterations from the early barren stage to the productive stage, with a detailed discussion of ore genesis (Lovering et al., 1949). Other important works are those on the Chief Oxide area discoveries (Bush and Cook, 1960; Lovering and Morris, 1960); the detailed publication on the stratigraphy of the East Tintic Mountains (Morris and Lovering, 1961); the geology of the Eureka quadrangle (Morris, 1964); and the most recent one on the geology and ore deposits of the East Tintic mining district (Shepard, Morris, and Cook, 1968). In this latter publication, discussions on the most recent discoveries in the Burgin mine are available.

Scope and Method

The purpose of this investigation is to review the general geology of the Burgin mine and to determine the mineralogy and paragenesis of the ore deposits. The geology is described and summarized from previous publications and from personal observations. A systematic method of sampling was followed in collecting samples for laboratory studies. Wherever the ore was cut by a drift or crosscut, the sampling was carried out on a horizontal plane at about five-foot intervals. Ore occurrences on the three levels of the Burgin mine (1050, 1200, and 1300) were collected to give a three-dimensional control. Additional control was obtained from sampling raises and drill cores. In the case of cavity fillings, the sampling was made across the crustification structure to delineate the successive surges of mineralization.

About 230 polished sections and thin-sections were studied under binocular, ore, and petrographic microscopes to determine the mineralogy and to decipher the paragenesis. Chemical reagents were used wherever it was necessary. Forty fresh ore samples were analyzed spectrographically by the Kennecott Research Division to help interpret mineral zoning and textural relationships. Forty-three drilling logs and their assay results were plotted to give a three-dimensional picture on elemental zoning and the distribution of mineralization. Thirty-five preparations were X-rayed to assist in mineral identification. Finally, 6 carbonate samples from the lower thrust plate were analyzed by atomic absorption to decipher the variations of calcium, magnesium, and silicon.

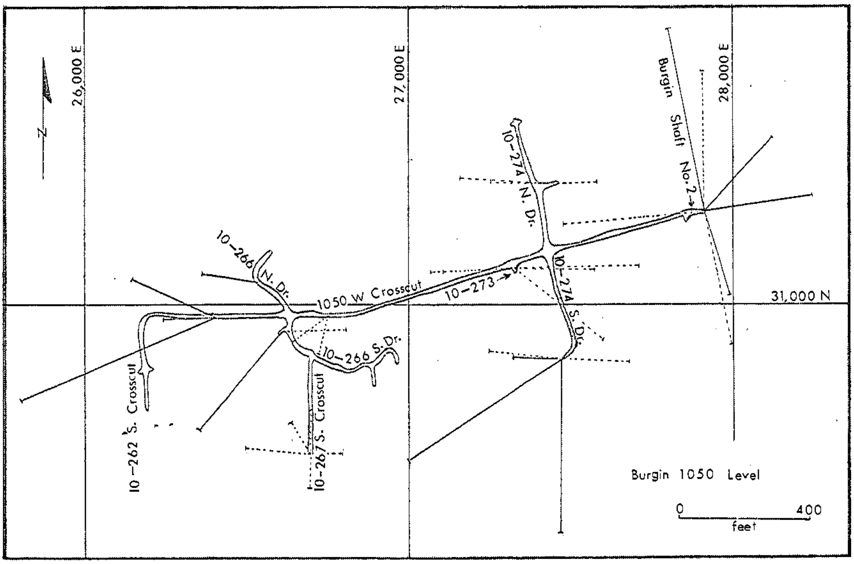
DEVELOPMENT WORK AT THE BURGIN MINE

In 1946, the U. S. Geological Survey, after having conducted geological, geochemical, and geothermal studies, selected the Chief Oxide area as one of the targets for further mineral exploration in the East Tintic district. Drilling was proposed in order to obtain information on the stratigraphy, structure, and mineralization beneath the volcanic cover, and to determine the thickness of the lava flows.

The first two churn drill holes from the surface were drilled in 1948 by Newmont Mining Company. They realized little success, however, since the holes were stopped at the water level, i.e., at depths of 1,145 and 1,100 feet. In 1952, the 1,100-foot-deep hole was diamond drilled and deepened to 1,600 feet by the U. S. Geological Survey. This deepening led to the discovery of a thrust fault, known today as the East Tintic thrust fault, and a weak zinc-lead mineralized zone between 1,310 and 1,445 feet in the footwall. Later, the U. S. Geological Survey drilled a third hole to a depth of 981 feet. In 1956, Bear Creek Mining Company took over drilling and exploration operations. Its first hole was drilled to a depth of 1,185 feet; it was drilled through the volcanic rocks, primarily to locate a shaft site and to determine the stratigraphic units below. This hole showed that the ground was highly fractured, and the locality was categorically rejected as a shaft site. Another hole, some 1,000 feet north of the present Burgin shaft, was drilled in October 1957 to a depth of 2,175 feet. The thickness of the quartz latite flows was found to be 2,000 feet. A pyritized zone 16 feet thick containing anomalous amounts of silver, copper, lead, and zinc was found at the contact of volcanic rocks and Paleozoic carbonate rocks below. Three more holes, which ended in fresh volcanic rock, were drilled some 1,000 to 1,500 feet east-southeast of the Burgin shaft.

Information on subsurface stratigraphy received from drilling by Newmont Mining Company, the U. S. Geological Survey, and Bear Creek Mining Company helped in selecting the "Oxide Hill" as a shaft site. In October 1956, the contract for the shaft was awarded to the Centennial Development Company of Eureka, Utah; and, on 30 January 1957, the shaft-sinking began. By August 1957, the shaft was sunk to 1,100 feet, 700 of which were in volcanics, the bottom 400 feet being in Mississippian-Devonian sediments.

The 1050 level began to be driven westward, and underground diamond drilling started in September on the east side of the shaft (Text-figure 2). After 450 feet, the 1050 west crosscut intersected the narrow north-trending fissures of oxide mineralization of manganese, iron, lead, and zinc. By Novem-



TEXT-FIGURE 2.—Showing the development work in the 1050 level. Dotted lines represent inclined drill holes; and solid lines horizontal drill holes.

ber 1957, at 800 feet west of the shaft, the 1050 west crosscut reached an irregular body of massive manganese and iron oxide, with appreciable amounts of lead and zinc, in the central part of a large brecciated and altered zone. From March through June 1958, extension of the 10-274 south drift was undertaken, and drilling confirmed the southerly extension of an underlying north-trending zone of sulfide mineralization (Text-figure 2). The northern extension of this zone was tested by drilling from the 10-274 north drift. Early in 1958, the East Tintic thrust fault was reached at 1,300 feet. In June, the 10-266 south drift and its southeasterly and easterly extensions were completed in order to explore a substantial body of zincifirous manganese oxides containing lenses of lead carbonate. The 10-266 north drift was unsuccessful; it was stopped in January 1959. In February, the 10-267 south crosscut was advanced through the hanging wall to determine the thickness of the manganese zone. In April 1959, the 1050 west crosscut was again driven westward through the Ophir Shale and dolomite of the upper plate. At 200 feet, it cut a large mylonitized zone with manganese and low-grade lead-zinc mineralization. From this point, the 10-262 south crosscut was turned southward for 290 feet; it thereby appears to have diagonally penetrated the mineralized zone (Text-figure 2).

Systematic hand and core sampling was done as crosscutting, drifting, and drilling proceeded. Samples were analyzed for base metals either by assay methods or by the X-ray fluorescent spectrographic technique. The results obtained indicated that most anomalies occurred in faulted or brecciated zones or where there is a concentration of manganese-iron oxides and jasperoid.

Previous works also include geothermal studies by the U. S. Geological Survey in shallow surface drill holes. The Survey believes that the steep temperature gradients (5-10° F/100 ft. of depth) in the Chief Oxide area is due to the oxidation of sulfides in permeable carbonate rocks beneath lava (Bush and Cook, 1960, p. 1538).

Various geophysical techniques were also tried in the Chief Oxide area by Newmont Mining Company and the U. S. Geological Survey. The results obtained were difficult to interpret in terms of known geology and alteration (Bush and Cook, 1960, p. 1519).

GEOLOGIC SETTING

The subsurface geology of the Burgin mine, first inferred and visualized from surface mapping and drill cores, was confirmed later from Bear Creek's extensive program of shaft-sinking, drifting, and underground diamond drilling. Shaft-sinking penetrated a 700-foot thickness of Tertiary volcanics capping Paleozoic miogeosynclinal sedimentary rocks ranging in age from Ordovician to Mississippian. Westward crosscutting and drifting showed that these rocks form the lower plate of a westerly dipping thrust fault and that the Ordovician Opohonga Limestone is overlain by an upper plate consisting of broken and brecciated Middle Cambrian Ophir Formation and some Lower Cambrian Tintic Quartzite (Morris, 1964, p. K11). Studies of drill cores and geological mapping of the 1050 level indicate that the Burgin mine is situated on the western limb of a nearly recumbent north-trending syncline which is overturned to the east.

SEDIMENTARY ROCKS

By drilling, crosscutting, and drifting, the following formations are found at the Burgin mine: Lower Cambrian Tintic Quartzite; Middle Cambrian

Ophir Formation; Ordovician Opohonga Limestone; Ordovician Fish Haven Dolomite; Ordovician-Silurian-Devonian Bluebell Dolomite; Devonian Victoria Formation; and Devonian-Mississippian Pinyon Peak Limestone (Table 1). Recent stratigraphic studies have been made by Morris (1957 and 1964) and Morris and Lovering (1961).

Tintic Quartzite

The name is given by Smith, Tower, and Emmons (1900, p. 1) for exposures in the Tintic mining district. The quartzite is well bedded, medium grained, and buff colored with quartzite conglomerate beds in the lower half, and shale beds in the upper 500 feet. At 980 feet above the base, a flow of amygdaloidal basalt 2 to 30 feet thick is present. The total thickness is 2,300 to over 3,200 feet (Morris and Lovering, 1961, p. 16).

In the Burgin mine, the Tintic Quartzite encountered by drilling is underlain by sanded and dense dolomite, probably of Opohonga Formation, and overlain by badly broken and brecciated shale and limestone of the Ophir. It is fractured dull gray to whitish, and cut by veinlets of fine yellow green pyrite. No thickness could be measured for Tintic Quartzite at the mine.

Ophir Formation

The name is given by B. S. Butler (Lindgren and Loughlin, 1919, p. 25) for exposures in the Ophir mining district in the Oquirrh Range. Its average thickness in the East Tintic Mountains is about 380 feet (Morris and Lovering, 1961, p. 19), and is subdivided into three members: a lower gray to olive green shale member including a basal bed of sandstone and a fine to medium-grained blue gray bed of limestone or dolomite near the center; a middle fine to medium-grained, blue gray limestone member including lenses and beds of shale, and a basal unit fossilized with trilobites and brachiopods; and an upper greenish gray to buff shale member including lenses of calcareous sandstone.

In the Burgin mine, the Ophir Formation is found in the thrust zone by drilling, drifting, and crosscutting through the three levels. Since the formation is badly broken and brecciated, the above mentioned three members are mixed together, and no thickness could be measured for the Ophir Formation. A breccia, which forms the major part of the upper thrust plate, consists of shale and carbonate fragments. The original limestone of the Ophir Formation is now mostly hydrothermally dolomitized and locally transformed to yellow brown sanded dolomite. The principal lead-zinc-silver ore bodies in the Burgin mine lie in the Ophir Formation.

Opohonga Limestone

Loughlin (Lindgren and Loughlin, 1919, p. 33-34) gave the name for exposures near the Opohonga mine, half a mile or less southeast of Mammoth; he assigned them to Lower Ordovician age on the basis of a few poorly preserved fossils found on the east slope of Eureka Peak. The Lower Ordovician was later confirmed by fossils collected by L. F. Hintze (1951, p. 87-89), from the main Tintic district. The thickness ranges from 400 to 1,000 feet with 850 feet in the East Tintic district (Morris and Lovering, 1961, p. 54). Lithologically, the Opohonga Limestone is a sequence of fine to medium-grained, thin-bedded, light blue gray argillaceous limestone, and flat pebble

TABLE 1.—STRATIGRAPHIC SECTION IN THE BURGIN MINE AND VICINITY.

Age		Formation	Thickness (feet)	Lithologic Description	
TERTIARY	EOCENE	Packard Qtz Latite	700	Volcanic cover consisting of four units: basal gray tuff; thin dark beds of vitrophyre; medium-grained, pinkish to blue gray quartz latite flows, and flow breccia; and an upper vitrophyre unit.	Lower Plate
			Unconformity		
		Apex Formation	25-50	Subangular pebbles, cobbles, and boulders of Paleozoic quartzite, shale, dolomite, and limestone cemented in a brick red calcareous matrix.	
			Unconformity		
DEVONIAN		Pinyon Peak Limestone	160	Fine-grained, gray blue, thin to medium-bedded slightly argillaceous fossiliferous limestone. The uppermost few feet are related to the Lower Mississippian.	
		Victoria Formation	290	Fine-grained, thin-bedded gray dolomite interbedded with quartzite, and locally transformed to yellowish gray sanded dolomite. A three-foot "speckled bed" above the base.	
SILURIAN		Bluebell Dolomite	120	Fine-grained, thin-bedded, dark gray to gray dolomite locally with a minor amount of chert.	
ORDOVICIAN	UPPER	Fish Haven Dolomite	120	Fine-grained, thin-bedded, dark gray to gray locally fossiliferous mottled dolomite with scattered chert nodules near the base. Massive upper part known as the "Leopard Skin" marker.	
			Disconformity		
	LOWER	Opohonga Limestone	>150	Fine to medium-grained, thin-bedded, dark gray to gray brown argillaceous dolomitized limestone with a mottled appearance. Sanded dolomite locally present. Base not exposed, and true thickness unknown. 850 feet thick in the East Tintic district.	
				Segmented line indicates that section is tectonically incomplete.	
CAMBRIAN	MIDDLE	Ophir Formation	?	Lower and upper shale members intermixed with middle limestone member by brecciation. Limestone mostly dolomitized, and locally transformed to sanded dolomite. Found only in the upper thrust plate. 380 feet thick in the East Tintic Mountains.	Upper Plate
	LOWER	Tintic Quartzite	?	Whitish to dull gray, dense but fractured quartzite. Found as rock fragments in the upper thrust plate. 2,300 to 3,200 feet thick in the Tintic mining district.	

conglomerate, with a sandstone bed and cherty layers at the base. By weathering, the surface looks mottled, and the shaly material forms hexagons.

In the Burgin mine, the Opohonga Limestone is dolomitized, thinly bedded, argillaceous in nature with a mottled brown and yellow appearance. It is overlain by the Fish Haven Dolomite of Upper Ordovician age. Its true thickness is unknown since only the upper 150 to 200 feet are penetrated by the horizontal crosscut of the 1050 level before it reaches the thrust fault to the west. Locally, the dolomite is leached and appears yellowish gray brown in color and sandy in structure especially near the thrust zone. The sanding has been interpreted as being the result of preferential leaching of the undolomitized calcium carbonate from the rock by the weak sulfuric acid derived from the oxidation of pyrite (Howd, 1957, p. 134). Atomic absorption and petrographic studies of the fine to medium-grained dense and sanded samples from the Opohonga Limestone, however, do not favor Howd's explanation. Calcium and magnesium have relatively increased in the sanded dolomite, whereas silicon has decreased. The enrichment in calcium and magnesium, and the solution of silica, suggest that the infiltering fluids were alkaline in nature.

Fish Haven Dolomite

In the East Tintic Mountains the Fish Haven Dolomite, disconformably overlying the Opohonga, forms the lower third of the Bluebell Dolomite as originally defined by Lindgren and Loughlin (1919, 34-36). Its thickness ranges from 268 to 345 feet (Morris and Lovering, 1961, p. 59), and consists of thin and massive-bedded, medium to coarse-grained, dark to light gray dolomite with scattered chert nodules near the base and abundant chert nodules in the upper third. The top of this formation is placed above a thick, mottled, massive dolomite known locally as the "Leopard Skin" marker bed. The upper Ordovician age assigned to the Fish Haven is based upon corals and brachiopods.

In the Burgin mine, the formation, which has a thickness of about 120 feet, is penetrated by the 1050 west crosscut, and identified by an Ordovician fossil, its lithology, its stratigraphic position, and by the occurrence of the "Leopard Skin" marker whose chert nodules are replaced now by calcite and dolomite (Bush and Cook, 1960, p. 1531). In the 1200 level, the base of the Fish Haven can be recognized by a higher amount of silica, with respect to that of the upper part of the Opohonga, due to the presence of chert nodules.

Bluebell Dolomite

The Bluebell Dolomite, conformably overlying the Fish Haven Dolomite, forms the upper two-thirds of the original Bluebell as defined by Loughlin (Lindgren and Loughlin, 1919, p. 34-36) from exposures near the Eagle and Bluebell mine, about a half mile south of Eureka. It differs from the Fish Haven by including a little chert and being more banded than mottled. Its thickness ranges from 330 to more than 600 feet (Morris and Lovering, 1961, p. 64). Its late Ordovician-Silurian-Devonian age is based on poorly preserved and fragmented fossils of crinoid columnals, honeycomb and chain corals, and pentameroid brachiopods in some beds.

In the Burgin mine, the Bluebell Dolomite penetrated by the 1050 west crosscut falls between the basal "speckled" bed of the overlying Victoria

Formation, and the top of the "Leopard Skin" marker of the underlying Fish Haven. Along the 1050 west crosscut, the 240-foot combined thickness of both the Bluebell and Fish Haven is much thinner due to faulting, than their normal combined thickness of 620-950 feet in the main Tintic district.

Victoria Formation

The name is given by Loughlin (Lindgren and Loughlin, 1919, p. 38-39) for exposures near the Victoria mine about one mile south-southeast of Eureka. As currently redefined by the U. S. Geological Survey (Morris, 1957, p. 13), the formation includes the original Victoria Quartzite plus the lower 50-75 feet of Loughlin's Gardner Dolomite with combined thickness of 280 feet. A Late Devonian age is based on fossils found on the top of the Bluebell Dolomite and the lower part of the Pinyon Peak Limestone.

In the Burgin mine, the Victoria Formation is cut by the shaft from 800 to 1,030 feet, i. e., 230 feet of interbedded quartzite, dolomite, and sanded dolomite. Poorly preserved fossils related to the younger Pinyon Peak Formation are found between 1,050 and 1,100 feet, i.e., under the older Victoria Formation. This could be the result of an overturned section or an overthrust. Victoria Formation is again penetrated by the 1050 west crosscut, and its three-foot "speckled" bed near the base is cut 500 feet west of the shaft. The thickness of the limb of the recumbent fold is around 280 to 300 feet.

Pinyon Peak Limestone

The name is given by Loughlin (Lindgren and Loughlin, 1919, p. 36) for exposures on the east side of Pinyon Peak with a thickness ranging from 70 to about 300 feet (Morris and Lovering, 1961, p. 75). A basal quartzite or shale bed usually marks the lower contact with the Victoria Formation. Lithologically, the Pinyon Peak Limestones are chiefly fine-grained, gray blue, thin to medium-bedded, resembling those of the Opohonga Formation but with lesser argillaceous material and fewer flat-pebble conglomerate beds. Fossils from the Pinyon Peak assign the Late Devonian age to all except the uppermost few feet of the Pinyon Peak Limestone which contain Lower Mississippian fossils.

In the Burgin mine, the thickness of the Pinyon Peak Limestone is 160 feet. The formation is found in the shaft and below the Victoria Formation, i.e., between 1,050 and 1,100 feet with poorly preserved fossils.

Apex Conglomerate

The Apex Conglomerate, as mentioned by Morris and Lovering (1961, p. 123), is named from exposures in the Apex Standard No. 2 shaft. It unconformably overlies the folded, faulted, and deeply eroded Paleozoic rocks, and is overlain by volcanic rocks of Middle Eocene age. Its thickness is variable and consists of subangular pebbles, cobbles, and boulders of prevolcanic Paleozoic rocks such as quartzite, dolomite, limestone, and shale cemented in a brick red, calcareous matrix. The angularity and poor sorting of the fragments suggest that they are accumulated as colluvium or talus on the structurally deformed pre-Tertiary rocks following the Laramide orogeny.

In the Burgin mine, the shafts No. 1 and 2 penetrated the Apex Conglomerate lying between the underlying Paleozoic rocks and the overlying

Tertiary volcanic cover. The thickness ranges from 0 to 150 feet (Paul Mogenson, oral communication).

IGNEOUS ROCKS

The main igneous rocks found in the Burgin mine area are volcanic rocks forming a cover above older sedimentary rocks. These volcanics, known as the Packard Quartz Latite series, seem to increase in thickness to the north and east and to decrease to the south and west of the Burgin shaft No. 1.

Packard Quartz Latite

The Packard Quartz Latite of Eocene age is the oldest volcanic rock found in the East Tintic Mountains. Tower and Smith (1899, p. 74) gave the name "Packard rhyolite" for extensive exposures at Packard Peak. They also gave the name "Fernow rhyolite" to closely similar exposures found near Fernow Canyon in the southern part of the range south of Tintic Mountain. Recent studies, as mentioned by Morris (1957, p. 30), show that both contain as much plagioclase as orthoclase (sanidine) in addition to quartz and other constituents, and thus have the composition of quartz latite as the title indicates. The Packard Quartz Latite is subdivided into four units (Morris, 1957, p. 30):

1. a basal tuff hydrothermally altered in places;
2. a lower vitrophyre enclosing phenocrysts of biotite, sanidine, and partly resorbed quartz;
3. a massive flow unit; and
4. an upper vitrophyre unit which closely resembles the lower vitrophyre unit.

Where hydrothermally devitrified, the lower vitrophyre resembles a fine-grained biotite-quartz latite. The rocks in the massive flow unit are medium-grained, dense, and ranging in color from pinkish gray to smoky lavender and blue gray. They consist of 20 to 50 percent phenocrysts of sanidine, andesine, quartz and biotite, with a little hornblende being locally present, and magnetite, apatite, and sphene as accessory minerals. The upper vitrophyre is agglomeratic near the top, and contains one or more beds of fine to medium-grained tuff (Morris, 1957, p. 30-31).

The Burgin shaft penetrated about 700 feet of Packard Quartz Latite, and ranges from 500 to 1500 feet thick in the district (Paul Mogenson, oral communication). Tuffaceous beds of the first unit are found at the base, overlain by thin beds of dark, hard vitrophyre representing the second unit. The rocks above, mostly medium-grained, pinkish to blue gray quartz latite flows and flow breccia, are evidently related to the third unit. The fourth unit is found at the top, although the vitrophyre is absent. Core studies show a pyrite-argillic alteration from the surface to a depth of 500 feet. Below this depth, however, the pyrite disappears and the rocks are fresh.

STRUCTURAL GEOLOGY

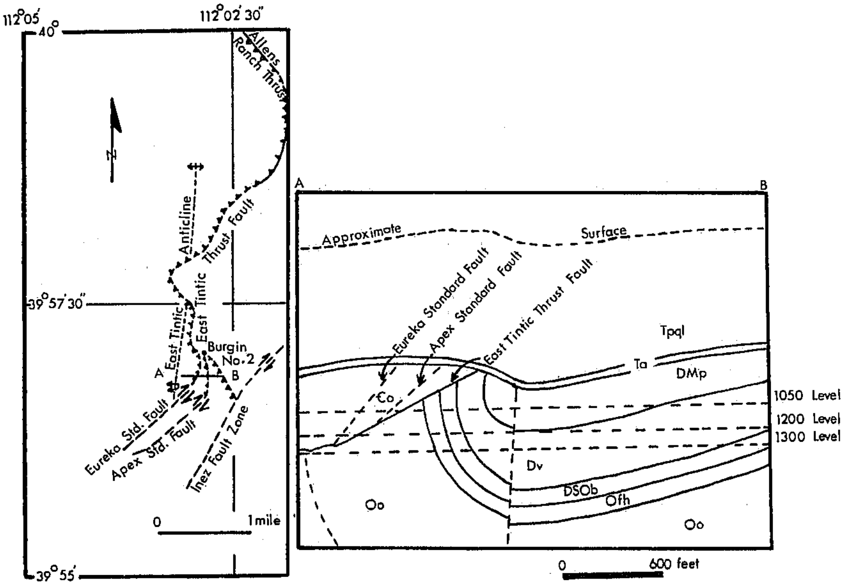
As a part of the East Tintic Mountains, near the eastern border of the Great Basin, the rocks of the East Tintic district in general, and those of the Burgin mine in particular, have passed through a long history of tectonism during Late Mesozoic and Cenozoic times. They have been involved in at least three major tectonic events: the Late Mesozoic Laramide orogeny, Eocene plutonic and volcanic activity, and Cenozoic block-faulting.

Folding

The Burgin mine is situated on the western limb of a north-trending syncline, overturned to the east. This structural feature is in part the result of fault drag in response to a continuous east-west compressional stress during the Laramide orogeny (Bush and Cook, 1960; and Morris, 1964). In other words, this western limb is the overturned eastern limb of the East Tintic anticline which, by the accentuation of compression, was broken to form the East Tintic thrust fault (Text-figure 3).

At the surface, the folded and faulted Paleozoic strata are concealed by an Eocene volcanic cover. Folding and other structural features, however, are deciphered from scattered surficial outcrops, mine openings in the East Tintic district, and underground workings, shaft-sinking, and diamond drilling within the Burgin mine.

Underground mapping shows that the sedimentary strata in the footwall block, west of the shaft, have a fairly constant northerly strike with local trends to the northwest in the 1050 level. The dip, however, varies noticeably from the east, where overturned, to the west. These variations are probably due to differential movements of rocks under the effects of folding, fracturing,



TEXT-FIGURE 3.—Map and cross section showing respectively the surficial courses of thrust and tear faults, and the stratigraphy around the Burgin mine. Tpql = Tertiary Packard Quartz Latite; Ta = Tertiary Apex Conglomerate; DMp = Devonian-Mississippian Pinyon Peak Limestone; Dv = Devonian Victoria Formation; DSOb = Ordovician-Silurian-Devonian Bluebell Dolomite; Ofn = Ordovician Fish Haven Dolomite; Oo = Ordovician Opohonga Limestone; Co = Cambrian Ohpir Formation.

and faulting. Where hydrothermal alteration and brecciation are prominent, the dip becomes confused. Although the bedding is commonly preserved in the hanging wall, its attitude varies because of the displacement, shearing, and contortion that took place by thrusting. In the 1200 level, the dip of the Opohonga beds was measured eastward, and was found to vary from 30° to 57° east.

Faulting

The most important faults discovered so far in the Burgin mine are the East Tintic thrust fault, and its two more or less contemporaneous Eureka Standard and Apex Standard tear faults. All three faults are of premineralization and prevolcanic in age.

East Tintic Thrust Fault.—The East Tintic thrust fault was first discovered by drilling, then confirmed by crosscutting in the 1050 level where it was found about 1300 feet west of the shaft. Its eastward movement placed the Lower Middle Cambrian Ophir Formation and the Lower Cambrian Tintic Quartzite over the younger Lower Ordovician Opohonga Limestone with a stratigraphic displacement of about 3,000 to 3,500 feet (Morris, 1964, p. K11). The total displacement is about one mile along the structure. The lower part of the upper thrust plate is marked by a gouge, stained with limonite and black manganese oxides.

The East Tintic thrust fault strikes generally north with the dip ranging from 15° to 30° west. During its course, however, the strike appears to change sharply between the Inez fault to the south, and the Allen Ranch thrust fault to the north. Starting from Inez fault, the East Tintic thrust fault strikes N 31° W for about half a mile, then it swings to N 57° W for about 1,300 feet, where it intersects both the Apex Standard and the Eureka Standard tear faults, and crosses the Burgin mine before it turns northward for another half a mile. Its trend, thereafter, changes to N 43° W, and intersects the north-northeast-trending axis of the East Tintic anticline after 500-600 feet. About a half mile from this turning point, the East Tintic thrust fault takes a general N 45° E strike for almost two miles.

Inside the Burgin mine, the strike of the East Tintic thrust fault swings first to the southeast along the 10-266 drift (Text-figure 2), then eastward, then to the southeast again. Drilling from the 1050 level showed that the dip varies locally from the southwest to both the southeast and northeast, a fact which suggests an undulatory surface underneath the upper thrust plate.

Eureka Standard Tear Fault.—The Eureka Standard fault, striking northeasterly and averaging 50° in dip to the northwest, is related to a well-known northeasterly trending set of fractures in the Tintic mining district. These fractures are called transcurrent because of the fact that they cut the axes of the major folds of the area at angles ranging from 25° to 55°. The Eureka Standard fault was responsible for the localization of mineralization in the Eureka Standard mine, southwest of the Burgin mine. During its major course, its N 43° E strike progressively deviates to the north until it merges with the East Tintic thrust fault in the Burgin mine. Drilling from the 1050 level confirms what it was believed that the Eureka Standard is a right-lateral tear fault. Core studies showed that two repetitions of the three members of the Ophir Formation in the upper thrust plate are present to the west of the Eureka Standard tear fault. Its displacement combined with that of Apex Standard tear fault directly to the southeast is 3,000 to 4,000 feet, as indicated by the horizontal separation of the East Tintic anticline (Shepard et al., 1968, p. 949).

Apex Standard Tear Fault.—The Apex Standard fault, lying to the southeast of Eureka Standard tear fault, strikes nearly parallel to it and in turn is related to the above mentioned northeast-trending transcurrent set of fractures in the Tintic mining district. Like the Eureka Standard tear fault, the Apex Standard fault swings northward from its major N 50° E trend before it merges with the East Tintic thrust fault to the north. It is one of the major structures responsible for the development of the Apex mine, some half a mile southwest of the Burgin mine. Although it is not fully explored, it is also believed to be like the Eureka Standard, a right-lateral tear fault, and both are related to the development of the East Tintic thrust fault. The combined displacement of these two tear faults is 3,000 to 4,000 feet.

The East Tintic thrust fault and both the Eureka Standard and Apex Standard tear faults are of major importance in ore localization in the Burgin mine.

Other Minor Fractures and Faults.—Besides the three major faults described above, other minor important breaks are also present in the Burgin mine. They include small bedding faults developed during folding; pre-mineralization north-trending fractures; and small faults striking nearly parallel to the East Tintic thrust fault with dips ranging from 45° to 75° W-SW (Sam Smith, oral communication). They include also postfolding postmineralization fractures cutting ore bodies within the thrust zone.

ECONOMIC GEOLOGY

The principal ores mined from the Burgin mine are lead-zinc-silver sulfides, their oxidation products, and manganese oxides. This study is mainly concerned with the mineralogy and paragenesis of the ore deposits, excluding any detailed work on manganese which forms the subject of another project. Stratigraphic, structural, and alteration controls are discussed with an emphasis on the relation of ore deposition and stages of alteration.

Stratigraphic Control of the Ore Body

Drilling, crosscutting, drifting, and assay reports in the Burgin mine show that the Middle Cambrian Ophir Formation, which forms the major part of the exposed upper thrust plate is the host rock. Ore bodies of lead-zinc-silver sulfides and their oxidation products, locally overlapped by manganese oxides, are restricted to this formation. The Ophir Formation consists of a mixture of broken and brecciated shale and hydrothermally dolomitized limestone. Locally, gray blue limestone alters to yellowish gray hues by leaching and has a sandy texture. In places, blocks several feet thick maintain well-preserved bedding, and are cut only by minor fractures despite their displacement by thrusting. In most underground exposures, sedimentary breccia is typical. Small cavities, one to two feet across, occur in the breccia and are filled with thin-bedded brown gray clayey to silty material. The major part of rock fragments belong to the Ophir Formation. They are shaly and carbonate in nature but locally silicified. Other rock fragments belong to the whitish gray lower Cambrian Tintic Quartzite. Along the thrust fault plane a brown to dark gouge, stained with limonite and black manganese oxides, was found to be siliceous in nature and contained only traces of calcium and magnesium.

Field observations and microscopic studies indicate that the ores are associated with highly brecciated limestone. In places, the fragments are wholly replaced by ores; in others, they are only partly replaced with the mineralization usually found at their peripheries. Ore is rarely found in the fine-grained impervious shale fragments. Wherever strong mineralization has taken place, the beds of the Ophir Shale are contorted, broken, hydrothermally altered, and show a confused alternating structure with the ore. Dissemination and fracture-filling types of mineralization are also found in shaly and carbonate fragments.

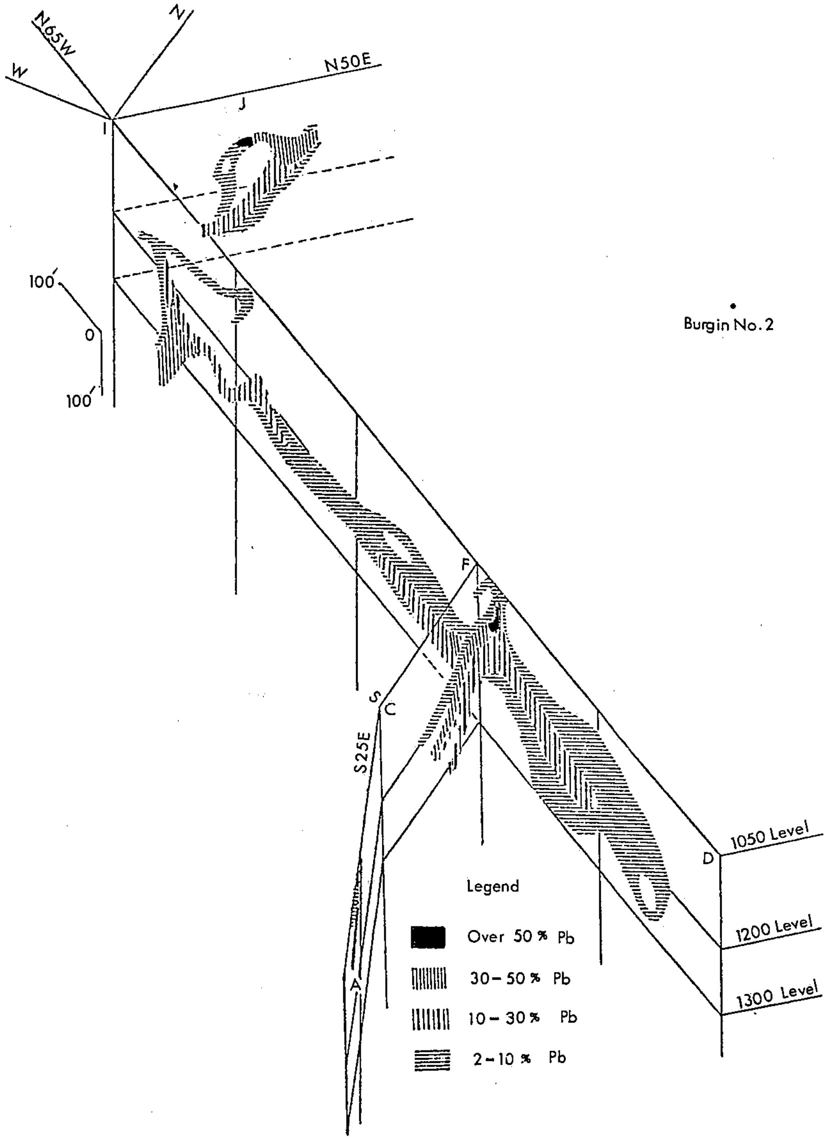
Structural Control of the Ore Body

Rocks of the Burgin mine were subjected to several major tectonic disturbances during Upper Cretaceous and Cenozoic times. The most important events in ground preparation for ore deposition are the premineralization structures which rendered the Paleozoic rocks in general, and those of Ophir Formation in particular, appropriate for hydrothermal alteration and metallization.

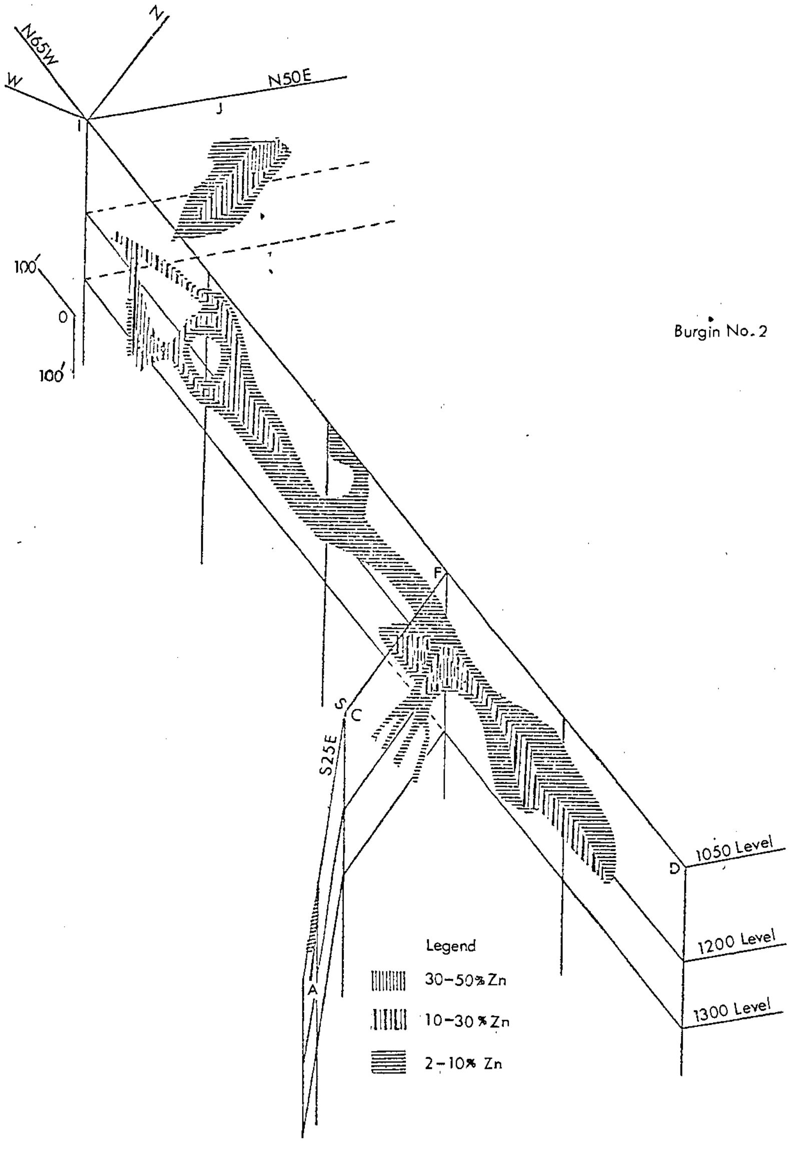
The Laramide orogeny was responsible, first, for folding the Paleozoic rocks and, second, for thrusting the Lower and Middle Cambrian formations over Lower Ordovician rocks, thus creating the generally north-trending and west-dipping East Tintic thrust fault. Although the folding has led to tension and shear fractures, bedding faults, and local brecciation in the rocks of the footwall, the confinement of ore bodies to the upper thrust plate indicates that thrust faulting is responsible for the main control and distribution of ores. The one-mile displacement of the Ophir Formation over the undulatory topography of the footwall has accentuated fracturing of the previously broken and folded rocks, then has crushed and brecciated them under the frictional effect of the thrust movement and load pressure. Along the thrust fault, a dark brown fine siliceous gouge has been formed as a result of crushing. Sections, mainly of shale, several feet in thickness, have survived the thrust movement. They have maintained their bedding and undergone only minor fractures. Their shapes differ from lensoid, one foot to several tens of feet long, to large isolated blocks surrounded by a brecciated loose material. The lithology of the exposed upper thrust plate consists mostly of a mixture of shaly and carbonate fragments ranging in size from pebbles to cobbles to boulders intermixed with a fine matrix. A few scattered fragments from the Tintic Quartzite were also found.

Differential movement of thrusting has led to the creation of two northeast-trending tear faults in the upper thrust plate. These tear faults, the Eureka Standard and Apex Standard, have a right-lateral movement. This kind of faulting has accentuated further the breakage of rocks and proved to form also the major passageways for the hydrothermal and ore-bearing liquids. Although the porosity and permeability of rocks have increased tremendously, the distribution of ores appears to be unequal in the different sections of the thrust zone (Text-figures 4, 5, and 6).

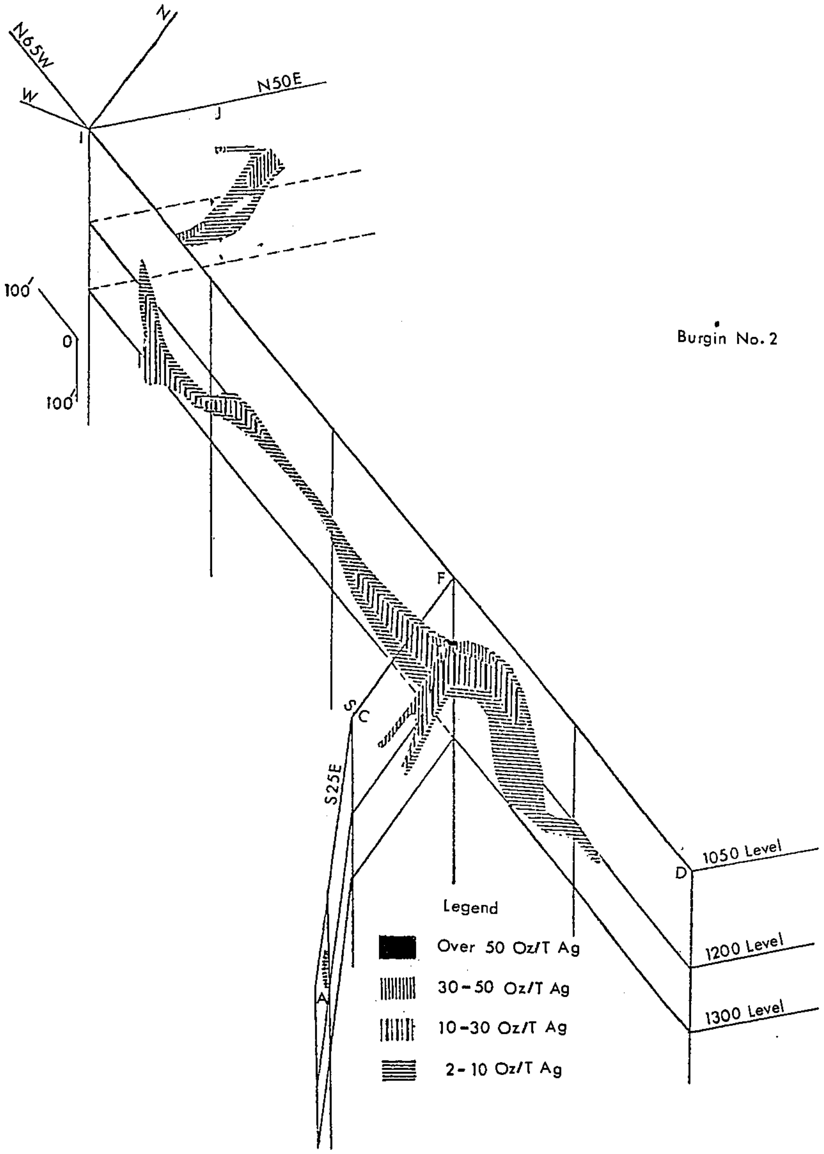
The second major premineralization tectonic event is the volcanic and plutonic activities in the Tintic mining district. Their tectonic contribution, especially that of plutonic stocks, appears to be the creation of the northwest and/or northeast sets of transcurrent fractures, besides the accentuation of



TEXT-FIGURE 4.—A cross section showing the distribution of lead in the Burgin mine. N, S, W=compass directions; A, C, D, F, I, J=drill sites.



TEXT-FIGURE 5.—A cross section showing the distribution of zinc in the Burgin mine. N, S, W=compass directions; A, C, D, F, I, J=drill sites.



TEXT-FIGURE 6.—A cross section showing the distribution of silver in the Burgin mine N, S, W = compass directions; A, C, D, F, I, J = drill sites.

folding, shearing, and brecciation of rocks. The plutonic intrusions in the Tintic district, contemporaneous with or somewhat younger than volcanic rocks, are believed to be the major source which yielded the ore-bearing solutions during their cooling period. The presence of the volcanic cover in the Burgin mine area might have played an important role as an impervious cap during the surges of hydrothermal liquids and ore deposition.

Rock Alteration in the Burgin Mine

Lovering et al. (1949) recognized five stages of alteration in the East Tintic district. These stages are (1) the early barren stage, characterized by a widespread hydrothermal dolomitization and chloritization of volcanic rocks; (2) the mid-barren stage, characterized by an argillic alteration and an abundant development of clay minerals; (3) the late barren stage, characterized by a relatively extensive jasperoidization, followed by the deposition of cubic pyrite and barite; (4) the early productive stage, characterized by a potassic alteration (sericite and hydromica), and the deposition of clear quartz and pyrite of pyritohedral habit; and (5) the productive stage, characterized by the deposition of ore minerals. Based on Lovering's findings, the detailed microscopic studies of polished sections from the Burgin mine, and field observations in the mine show these stages of hydrothermal alterations. A postproductive hydration stage was found along fractures cutting galena and sphalerite where hydromuscovite was detected.

Early Barren Stage.—Hydrothermal dolomite is widespread in the Burgin mine. In the upper thrust plate where the rocks are strongly disturbed by thrusting, the limestone member of the Ophir Formation is highly dolomitized with a prominent dark blue color. This color, however, changes locally to dark gray. A chemical test with dilute hydrochloric acid showed that dark blue rock fragments or patches are more dolomitized than the dark gray ones. The dolomitization appears to be structurally controlled. Lovering concluded that both the chloritization of the lower part of volcanic rocks and the hydrothermal dolomitization are related to the same stage of alteration. This chloritization-dolomitization relationship, well exposed over the Apex Standard fault (Lovering et al., 1949, p. 23), is also present in the nearby Burgin mine.

The association of ore sulfides mostly with the dark blue dolomite of the upper thrust plate, suggests that most ore-bearing hydrothermal fluids followed the same paths through which the intensive hydrothermal dolomitization took place. The dark blue hydrothermally dolomitized limestone may be a good indication, at least in the East Tintic district, for ore explorations.

Mid-Barren Stage.—In the Burgin mine the mid-barren stage is characterized by argillic alteration. The volcanic rocks have a bleached appearance due to clay and mica minerals replacing phenocrysts and groundmass. This alteration is present in the underlying sedimentary rocks but is much less extensive. The *argillic* alteration started in the mid-barren stage and proceeded throughout the younger stages. Dickite was locally found filling vugs in jasperoid, massive galena, and manganese oxides of psilomelane type.

Late Barren Stage.—In the Burgin mine the late barren stage is characterized chiefly by its noticeable amount of jasperoid, accompanied with a minor amount of cubic pyrite, and barite. Within the mine, a close association between jasperoid and ore bodies was observed. Where it occurs alone, the jasperoid was found to be only a few feet away from ores, indicating that the jasperoidization is not as widespread as dolomitization. It suggests also that jasperoid followed the same paths which were followed later by ore-bearing liquids. Jasperoid is mostly restricted to the upper thrust plate. This may reflect the fact that jasperoidizing solutions sought out passageways of greatest permeability. These solutions were found mainly to replace the dark blue hydrothermally dolomitized limestone. It was also found that the jasperoid is, in turn, replaced and/or cut by ore bodies and ore veins. Wherever the fragmented shale is jasperoidized, it becomes locally opalized or chertified. In places, however, the dark gray shale changed to greenish gray or gray and became blotchy under the hydrothermal effects.

The intimate association of jasperoid with sulfide ore bodies in the Burgin mine suggests that this type of silicification is of great importance in exploring for more ore deposits around this mine and in the district.

Late barren stage cubic pyrite was found as small veinlets cutting the dolomitized Opohonga Limestone in the footwall block. A bleaching phenomenon was observed along these veinlets but with no traces of sulfide ores of any kind. This cubic pyrite was also found disseminated within the jasperoid in the upper thrust plate. The late barren stage barite is even more restricted in space; paragenetically it was found to cut both the jasperoid and pyrite.

Early Productive Stage.—In the Burgin mine the early productive stage is only arbitrarily separated from the productive stage. It includes the gangue minerals which have directly preceded the deposition of ores in the upper thrust plate and are intimately associated with them. These minerals, as revealed by the paragenetic study, are translucent quartz, rhodochrosite, and pyrite. Some sericite found at least partly associated with ore sulfides may be related to the early productive stage also and may have been formed prior to the ore deposition.

The early barren stage, late barren stage, and early productive stage have obviously changed the chemical compositions of the host rocks, at least along the passageways of hydrothermal liquids, where chemical reactions between the rocks of these liquids took place. The most impressive, and most important reaction is the expulsion of calcium ions from the original limestone of the Ophir Formation in the upper thrust plate and the introduction of magnesium ions. This exchange was apparently enough to accomplish more or less a complete hydrothermal dolomitization. As a result, a multitude of vugs, now partly filled with dickite, appear in this dark blue dolomite. This increase in porosity indicates a decrease in the bulk volume of limestone. Another important reaction is the replacement of dolomite by jasperoid. This also led to the creation of new vugs and an increase in porosity. Due to these reactions, the physical characteristics of these broken rocks have evidently changed in the upper thrust plate. The increase in porosity and permeability has rendered the rocks more appropriate to react later with the ore-bearing liquids and become metallized.

Productive Stage.—The productive stage is characterized by the metallization of rocks mostly with hypogene lead-zinc-silver sulfides and a minor amount of chalcopyrite and tetrahedrite. The ore bodies are usually accompanied with contemporaneous primary gangue minerals such as pyrite, rhodochrosite, quartz, and barite. Pyrite and rhodochrosite are noticeably abundant.

In the Burgin mine, the ore bodies are found in the upper thrust plate and mined from the brecciated and jasperoidized hydrothermal dark blue vuggy dolomitic limestone of the Ophir Formation.

The brecciated, fragmented, and fractured rocks, where the ore bodies of the Burgin mine are located, are a good evidence for a structural control of ore distribution. Folding, thrust and tear faulting, and igneous intrusions have led to the formation of the major north-trending East Tintic thrust fault and the northeast-trending Eureka Standard and Apex Standard tear faults. These faults were used as channelways for dolomitization, jasperoidization, and metallization in the upper thrust plate. The intimate association of ores with jasperoidized and dolomitized rocks indicates that metallizing liquids followed to a certain extent the same channelways which were used for dolomitization and jasperoidization. It appears that these main channelways are also branching, with some branches being used as transfusion paths which carried the ores to places of deposition some distance into the footwall block. Other branches are only dolomitized. These barren fractures are mostly found in the Opohonga Formation close to the thrust fault plane. Being mainly located in the upper thrust plate, the ores are deposited between an impervious 700-foot volcanic cover acting as a roof and a floor consisting of a gouge and dense footwall rocks.

Mineralogy of the Ore Deposits

A study of the Burgin mine ore deposits by X-ray diffractions, microchemical tests, and microscopic examinations reveal the presence of some twenty-five metal-bearing and gangue minerals, excluding the manganese oxides. The metal-bearing minerals include primary or hypogene and secondary minerals. The hypogene minerals are argentite-bearing galena, sphalerite, chalcopyrite, tetrahedrite, pyrite, and rhodochrosite. Secondary minerals are anglecite, cerussite, lead oxide phosphate and silver plumbate, mimetite,. smithsonite, aurichalcite, hematite, limonite, jarosite, and manganese oxides.

Gangue minerals include primary minerals formed with ores such as jasperoid, quartz, chalcedony, calcite, dolomite, and barite; and secondary minerals which may be subdivided into (1) hydrothermal alteration products such as sericite, hydromuscovite, and dickite, and (2) secondary alteration products such as gypsum.

Galena (PbS).—Galena is the most common lead mineral in the Burgin mine. It was commonly found associated with primary sphalerite, pyrite, rhodochrosite, and jasperoid in a hydrothermally dolomitized host rock and occasionally with chalcopyrite, tetrahedrite, barite, and crystallized quartz. Galena was found partly replaced by cerussite along fractures. It occurs locally as coarse-grained crystalline masses with a lead content of more than 75 percent and more commonly as fine-grained crystalline aggregates which become gradually disseminated inside the host rocks. Individual cubes of galena, although not widespread, are found as isolated grains in vugs and breccia. Fine to medium-grained galena was also found in brecciated rocks and between beds of shale or carbonates. A massive blady form was observed in places. A pyritohedral form, after pyritohedral pyrite, was rarely found under the microscope. At least two generations of galena took place in the productive stage, separated only by the deposition of rhodochrosite and pyrite. They are preceded and followed by sphalerite deposits as the microscope showed. All the galena is argentiferous. The coarse-grained massive type, however, includes the highest amount of silver (about 56 Oz/T) as the spectrographic analysis showed. Silver is derived from included argentite.

Argentite (Ag_2S).—Due to its fine size, argentite could only be detected by the electronic microscope, under which it is found as exsolved small very narrow string-like features in galena up to one hundred microns long and two to thirty microns wide. It also occurs as blebs not more than ten microns in diameter. (Plate 1, Figures 1, 2, and 3). The presence of argentite is also evidenced by the reaction of hydrochloric acid with galena and the development of its characteristic aureole.

Anglesite ($PbSO_4$).—Anglesite is derived from alteration of galena and is locally found as thin white films surrounding the lead sulfide. It was rarely found as colorless cubic pseudomorphs of galena in cavities. Anglesite does not occur in large quantities due to its presence in a carbonate environment.

Cerussite ($PbCO_3$).—Cerussite is an alteration product derived from the exchange of SO_4 in anglesite by CO_3 carried by water in the form of calcium bicarbonate. The mineral is abundant, especially in the southeastern part of the mine where it is mined as an oxidation ore with smithsonite. It commonly occurs as gray massive aggregates replacing galena along fractures. Wherever the replacement is incomplete, remnants of galena were observed as scattered spots inside cerussite. Calcite was locally found with lead carbonate along fractures cutting galena.

Lead Oxide Phosphate [$5PbO.\ Pb_3(PO_4)_2$].—Lead oxide phosphate is considered as an oxidation product. It was found combined with silver plumbate ($Ag_5Pb_2O_6$) as a yellow mineral in only one dry locality consisting of gray brecciated and friable dolomitized limestone between the 1050 and 1200 levels. The phosphorus may have been derived from the limestone of the Ophir Formation. The chemical analysis of the No. 1 limestone in the middle limestone member of the Ophir Formation showed 0.1 percent P_2O_5 in the 1450 level of the nearby Tintic Standard mine (Morris and Lovering, 1961, p. 24).

Mimetite [$Pb_5(AsO_4)_3Cl$].—Mimetite is also an oxidation product and not very common. It was found below the water table as whitish gray, well-crystallized small scattered grains mostly in vugs in brecciated dolomite, locally stained with manganese oxides and limonite. Arsenic may have been derived from galena or from some undiscovered sulfarsenide minerals. Chlorine is derived from the hot water of the Burgin mine. The chemical analysis of two water samples showed 3,590 and 3,670 ppm of chlorine in them.

Sphalerite (ZnS).—Sphalerite is the most common zinc mineral in the Burglin mine. It was commonly associated with primary galena, pyrite, rhodochrosite, and jasperoid and occasionally with chalcopyrite, tetrahedrite, barite, and crystallized quartz. Sphalerite was found also with smithsonite in places. It occurs locally as coarse-grained dark brown resinous aggregates; it occurs also as disseminated imperfectly crystallized grains and as intergrowth with galena and chalcopyrite. Rarely, the zinc sulfide was found as dodecahedral grains in vugs and cavities. Although the brown color is dominant, a greenish yellow variety was found as fine-grained thin beds alternating with fine-grained galena, where both are replacing a cavity-filling fine clayey material. In this locality in the 1050 level, a small amount of blue aurichalcite was found with sphalerite. At least two generations of zinc sulfide took place in the productive stage; the first surge marks the beginning of this stage, and the second succeeds the second surge of galena. The mine, however, seems to be less metallized with sphalerite than with galena.

Smithsonite ($ZnCO_3$).—Smithsonite is the commonest oxidation product of sphalerite and was derived from the reaction of zinc sulfate with CO_3 carried by water. The mineral is abundantly present with cerussite in the southeastern part of the Burgin mine, where they both are mined as an oxidation ore. It occurs mostly as a yellowish brown mineral stained with limonite below and above the water table; the iron oxide is probably the oxidation product of some siderite included inside smithsonite. In the 1300 level, however, a dark brown to black zinc carbonate was found; the darkness may be attributed to the presence of manganese oxides probably derived from oxidation of some included rhodochrosite. The presence of this dark variety below the yellowish brown smithsonite indicates that the more soluble manganese was carried deeper than the less soluble iron by the descending water.

Aurichalcite [$2(Zn,Cu)CO_3 . 3(Zn,Cu)(OH)_2$].—This blue zinc-copper carbonate is very rare in the Burgin mine, due to the scarcity of copper meneralization. It is an oxidation product found only in one place above the water table in the 1050 level, where fine alternating thin beds of galena and sphalerite were found to replace a cavity-filling clayey material. It locally occurs in this bedding type of ore as fine scaly dust between beds. Its formation may be attributed to the oxidation of a very minor amount of copper with zinc.

Chalcopyrite ($CuFeS_2$).—Chalcopyrite is very limited in the Burgin mine. It is primary and belongs to the productive stage and was locally found as small narrow microscopic veinlets cutting galena, sphalerite, and pyrite. It was also found as specks intergrowing with, or exsolved from, sphalerite, galena, and tetrahedrite.

Tetrahedrite ($Cu_8Sb_2S_7$).—Tetrahedrite is very rare in the Burgin mine. It belongs to the last part of the productive stage, preceded by chalcopyrite and succeeded only by gangue minerals. It was locally found as small narrow microscopic veinlets cutting sphalerite and galena and showing an intergrowth with chalcopyrite.

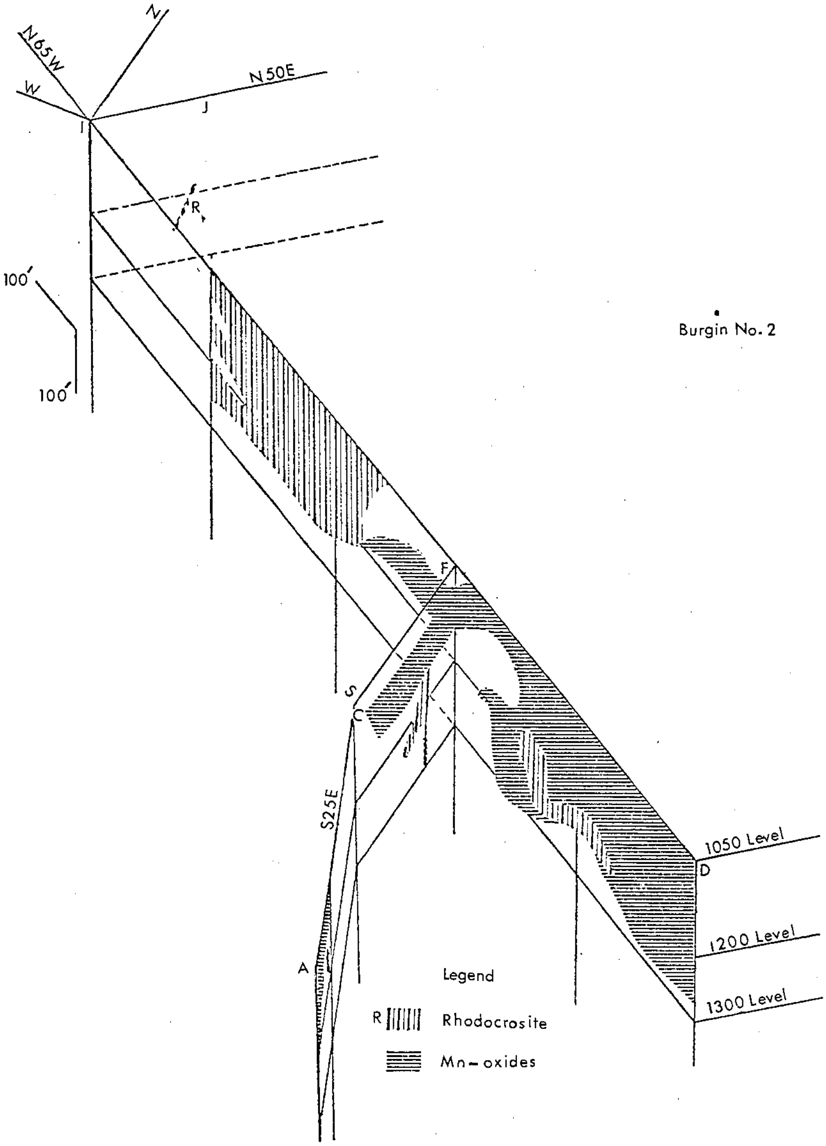
Pyrite (FeS_2).—Pyrite is a primary mineral which belongs to the late barren, early productive, and productive stages. It is widespread in the three levels of the Burgin mine and was found associated with almost every primary mineral such as galena, sphalerite, chalcopyrite, jasperoid, dolomite, rhodochrosite, calcite, barite, and quartz. At least five generations of pyrite took place. It was commonly found oxidized in part to hematite-limonite below and above the water table, wherever the oxidation conditions are available. Texturally, it occurs locally as small disseminated cubes; commonly as disseminated pyritohedrons; and occasionally as massive, fibrous, fracture-filling, and small concentric spherulites. The massive, fibrous, and spherulitis varieties are found to replace rhodochrosite.

Hematite (Fe_2O_3).—Hematite is an oxidation product of pyrite, found below and above the water table as small red earthy spots and patches staining locally the breccia of the upper thrust plate. Hematite is not widespread in the Burgin mine. It is commonly hydrated to limonite.

Limonite ($2Fe_2O_3 . 3H_2O$).—Limonite is very common in the southeastern part of the Burgin mine, where it was found in the three levels, i.e., below and above the water table. It is the hydration product of hematite or an alteration product of pyrite. It occurs as a dark brown to yellow brown earthy matter coloring smithsonite; in this case, limonite is probably derived from oxidation of some included siderite. It occurs also with manganese oxides along the thrust fault plane and fractures; as pure soft earthy and cellular masses probably left over after the removal of zinc carbonate; or as soft brown crusts lining various openings. In this latter case, limonite was probably deposited directly from solution and was derived from the oxidation of pyrite. Brown limonite cubes pseudomorphic after pyrite were also observed in some cavities.

Jarosite ($K_2O. 3Fe_2O_3. 4SO_3. 6H_2O$).—Jarosite is found associated with gypsum in the barren Ophir Shale along the drift in the 1050 level. It is one of the latest minerals to be formed in the Burgin mine. It occurs as a fine soft yellow material with no association with ores. The necessary potassium and iron may have been derived from the shale itself; sulfur, however, may have come either from pyrite, or from the limestone member of the Ophir Formation. The chemical analysis of the No. 1 limestone in the middle limestone member of the Ophir Formation showed 2.52 percent SO_3 in the 1450 level of the nearby Tintic Standard mine (Morris and Lovering, 1961, p. 24).

Rhodochrosite ($MnCO_3$).—Rhodochrosite is very common in the Burgin mine. It was found mostly associated with primary sulfide minerals such as galena, sphalerite, and pyrite where it marks a low-temperature deposit by its botryoidal form. It was also found with jasperoid, quartz, barite, and dolomite. At least three generations of rhodochrosite took place during early productive and productive stages. This manganese carbonate ranges in color from pinkish gray to pink; and its texture changes from rhombohedral to concentric botryoidal and spherulitic. Locally, rhodochrosite is partly replaced by pyrite and/or galena. Commonly, the concentric layers in the botryoidal forms change color; that may be due to a slight variation in their iron and/or other impurity contents during their successive depositions around a nucleus, which usually is a rock fragment. The same observations were seen in spherulites, where the nucleii are small minute grains of rock material. Rhodochrosite appears to be deeply oxidized in places; the oxides were found in the three levels and particularly in the southeastern part of the mine where the oxidation conditions are favorable along the thrust fault plane and fractures. In this locality, only lensoid bodies of manganese carbonate, a few tens of feet long, are enclosed inside the manganese oxides. Rhodochrosite, however, increases toward the northwest then decreases again but with little or no oxidation at all (Text-figure 7). It was found fresh below and above the water table as evidenced by its occurrence in the 1050 level. This occurrence is probably due to the complete isolation of rhodochrosite from the air by an impervious envelope formed by the Ophir Shale and the volcanic cover. In places below the water table, the manganese carbonate was found partly oxidized along fractures and in brecciated localities, i.e., wherever its connection with the oxygen was insured through these openings.



TEXT-FIGURE 7.—A cross section showing the distribution of manganese in the Bergin mine. N, S, W = compass directions; A, C, D, F, I, J = drill sites.

Manganese Oxides.—The manganese oxides are likely oxidation products of rhodochrosite. Their intimate field association favors this derivative relationship (Text-figure 7). Manganese oxides are not present in the northwestern part of the mine. This fact, coupled with the absence of supergene lead-zinc minerals (Sam Smith, oral communication), suggests that the northwestern part is isolated from oxidation. The mineralogy of the manganese oxides is very complex. Sam Smith (oral communication) has determined that the most abundant manganese oxides are birnessite, hetaerolite, nsutite, pyrolusite, and quenselite.

Jasperoid (SiO_2).—Cryptocrystalline jasperoid is the most widespread variety of silica found in the Burgin mine. It is vuggy to dense, and gray to brown to red found to replace partly the dolomitized limestone, as the unreplaced carbonate inclusions indicate. Vugs are locally filled with dickite; and jasperoid is intimately associated with, and partly replaced by, galena, sphalerite, and pyrite. Unreplaced remnants of jasperoid are very common.

Quartz (SiO_2).—Quartz was emplaced at the beginning of the early productive and in the last part of productive stages. In the early productive stage, quartz, locally associated with jasperoid and ores, is dense and translucent. In the productive stage, however, it is crystalline and locally found in fissures and cavities, with a few millimeter-long crystals of quartz showing pyramidal faces. This generation preceded barite of the productive stage; this barite, however, was succeeded by another generation of silica found in cavities of metallized rocks, where over one-centimeter-long crystals of quartz show both prismatic and pyramidal faces. Although most quartz preceded the oxidation period of ores, a postoxidation, well-crystallized generation is found also on oxidation products.

Chalcedony (SiO_2).—Cryptocrystalline chaledony is found locally silicifying shale fragments. It may be related to the jasperoidization generation.

Calcite ($CaCO_3$).—Calcite is found as the last primary gangue mineral to crustify fissures and cavities following a crustifying series of primary ore and gangue minerals. Being deposited after the latest generation of barite, this minor amount of hydrothermal calcite should be considered as one of the latest minerals of the productive stage. Calcite of secondary origin is found associated with cerussite. This type of calcite, dissolved in and carried by the ground water, is responsible for the formation and deposition of lead and zinc carbonates. Small rhombs of calcite are also found in vugs; and fine-grained calcite is deposited as small veinlets with silica.

Dolomite $[Ca,Mg(CO_3)_2]$.—Dolomite rhombs were observed under the microscope; the major aspect of dolomite, however, forms a medium-grained dark blue aggregate in the upper thrust plate. Dolomite is related to the hydrothermal dolomitization of the early barren stage. It is the most widespread mineral in the Burgin mine and is mostly found associated with and/or replaced by jasperoid and sulfide ores. It is vuggy in places, and a large amount of vugs is noticeably filled with dickite.

Barite ($BaSO_4$).—Barite occurs in two primary generations in the Burgin mine: (1) in the late barren stage where it is found to fill cracks in jasperoid; and (2) toward the end of the productive stage preceded by silica and rhodochrosite. In both generations, barite is well crystallized in plate-like aggregates mostly found with jasperoid, crystallized quartz, rhodochrosite, galena, pyrite, and sphalerite. The individual tabular crystals may reach one centimeter in length.

Seritite $[KAl_2(AlSi_3O_{10}(OH_2]$.—Sericite is mainly the hydrothermal alteration product of late barren and early productive stages. It occurs locally as greenish gray fine-grained sericitic aggregates in the Ophir Shale in the upper thrust plate with or without metallization.

Hydromuscovite $[KAl_2(AlSi_3O_{10})\ (OH)_2]$.—Hydromuscovite may be related to a postproductive stage. It is not common in the Burgin mine. It is found as a greenish fine-grained material filling small narrow fractures across galena and sphalerite in the Ophir Shale.

Dickite $(Al_2O_3.\ 2SiO_2.\ 2H_2O)$.—Dickite is commonly found as a fine-grained soft white material filling vugs mostly present in jasperoidized and decalcified rocks. Locally, it is found in vuggy galena and in more or less dense manganese oxides.

Gypsum $(CaSO_4.\ 2H_2O)$.—Gypsum belongs to the secondary alteration phase of the deposits. It occurs as small slender needle-like crystals, usually less than one centimer long, standing on the Ophir Shale, and associated with jarosite along the drift in the 1050 level. This type of occurrence indicates that gypsum is one of the latest minerals to be formed in the paragenetic sequence and is still forming today. Its sulfur and calcium may have been derived from the limestone member of the Ophir Formation, where both elements are sufficiently present as the chemical analysis of this member indicates (Morris and Lovering, 1961, p. 24). Pyrite, which is commonly present in this locality, may have been also the original source for sulfur.

Textures of Ores

The microscopic and megascopic studies of both ore and gangue minerals showed that texturally the ores are more complicated than it was originally thought. About seven textural varieties of ores were discerned. They are (1) massive replacement, (2) bedding replacement, (3) dissemination, (4) fracture-filling, (5) exsolution, (6) breccia, and (7) colloidal types. Although they were all observed, only three types are prominent and economically important. They are the massive replacement, dissemination, and breccia types.

Massive Replacement Types.—Massive replacements are by far the most abundant and important textural types (See Plates 2, 6, 10, 11, and 12). They are subdivided into coarse and fine crystalline ores. The coarsely crystalline ore was spectrographically found to carry the highest amounts of lead and silver and the lowest amount of zinc, with no cadmium and only a trace of copper. It appears favorable for the deposition of lead and silver, and unfavorable for the deposition of zinc and cadmium. The coarse crystalline texture occurs where strong metallization took place.

A fine crystalline texture is commonly present in the ore deposits and is spectrographically found to be highly favorable for the deposition of all kinds of sulfide ores. Wherever the low-temperature minerals, such as rhodochrosite, barite, and crystallized quartz, are absent, the fine ore seems to carry the highest metallizations in zinc and cadmium with high lead and silver values.

EXPLANATION OF PLATE 1

ELECTRONIC PHOTOMICROGRAPHS

Scale Indicated on Photomicrographs

FIG. 1.—Argentite (Ar) exsolved in galena (Ga) and both minerals are related to the productive stage. Black patches probably represent older vugs in the host rock now replaced by galena. Photomicrograph taken from Winze 2 in the 1200 level.

FIG. 2.—Argentite (Ar) exsolved in galena (Ga), and both minerals are related to the productive stage. Straight gray lines represent scratches. Photomicrograph taken from Winze 2 in the 1200 level.

FIG. 3.—Argentite (Ar) exsolved in galena (Ga), and both minerals are related to the productive stage. Note blebs of argentite. Photomicrograph taken from 73-11 stope in the 1300 level.

EXPLANATION OF PLATE 2

PHOTOMICROGRAPHS

All X 5.6, Reflected Light

FIG. 1.—Unsupported residuals of jasperoid (Ja) and dolomite (Do) in pitted galena (Ga) showing pseudomorphs of replaced host rock and exsolved grains of chalcopyrite Ch). Black patches are vugs. Galena and chalcopyrite are related to the productive stage, and jasperoid and dolomite respectively to the late and early barren stages. Photomicrograph taken from 80-51 Timber stope in the 1200 level.

FIG. 2.—Pyrite (Py) disseminated in jasperoid (Ja). Note the alignment of pyrite. Small dark patches are vugs, and the dark wide line is a fracture. Both minerals are related to the late barren stage. Photomicrograph taken from 73-11 stope in the 1300 level.

FIG. 4.—Barite (Ba) cutting jasperoid (Ja) and mineralized with specks of galena and pyrite (Py) along microscopic cracks. Dark patches are vugs. Barite is related to the late barren stage, and galena and pyrite to the productive stage. Photomicrograph taken from 73-11 stope in the 1300 level.

EXPLANATION OF PLATE 3

PHOTOMICROGRAPHS

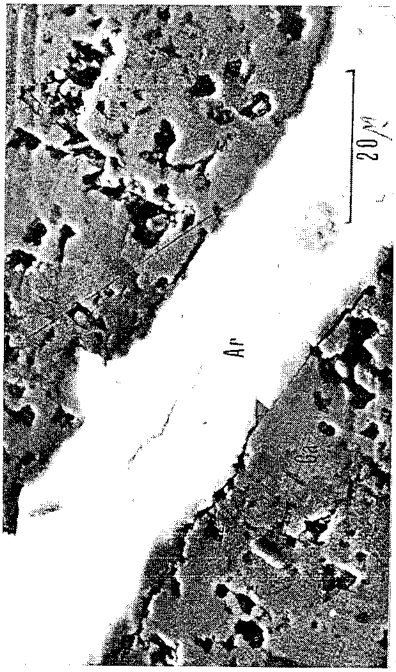
All X 5.6, Reflected Light

FIG. 1.—Jasperoid (Ja) cut by a veinlet of galena (Ga). Quartz (Qz) and jasperoid showing different textures. Note Quartz with its larger vugs. Galena is related to the productive stage. Photomicrograph taken from 73-11 stope in the 1300 level.

FIG. 2.—Veinlets of sphalerite (Sp) and chalcopyrite (Ch) cutting jasperoid (Ja). Dark patches are vugs. Both zinc and copper sulfides are related to the productive stage. Photomicrographs taken from D. D. H. B-24 between 360 and 376 foot depth.

FIG. 3.—Pyrite (Py) cutting and partly replacing rhodochrosite (Rh). Note unreplaced residuals of rhodochrosite inside the veinlet of pyrite. Dark patches are vugs. Both minerals are related to the early productive stage. Photomicrograph taken from 5-8-C1 (2nd floor) in the 1200 level.

FIG. 4.—Pyrite (Py) and sphalerite (Sp) partly replacing rhodochrosite (Rh). Note unsupported residuals of rhodochrosite. Note also the pyritohedral pyrite. Dark patches are vugs. Sphalerite is related to the productive stage. Photomicrograph taken from 40-04 in the 1300 level.



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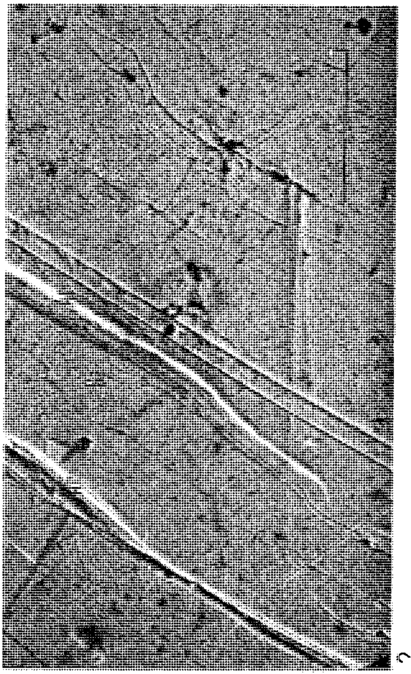

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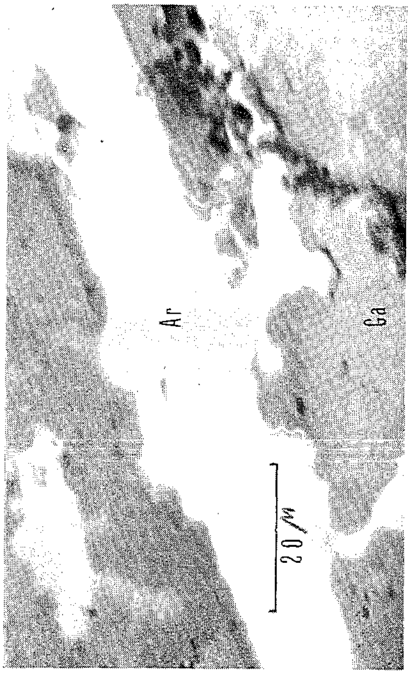

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Plate 1

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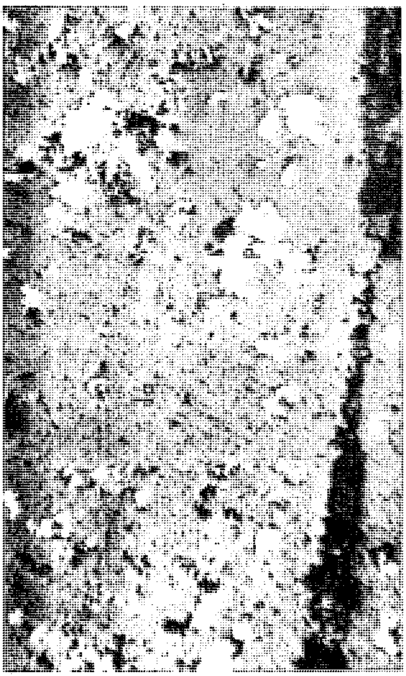

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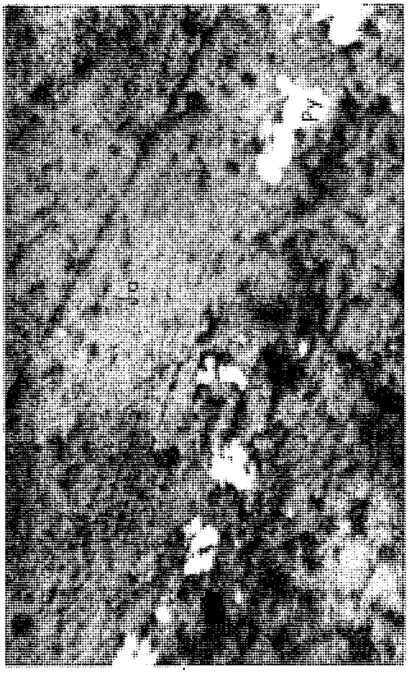

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Plate 2

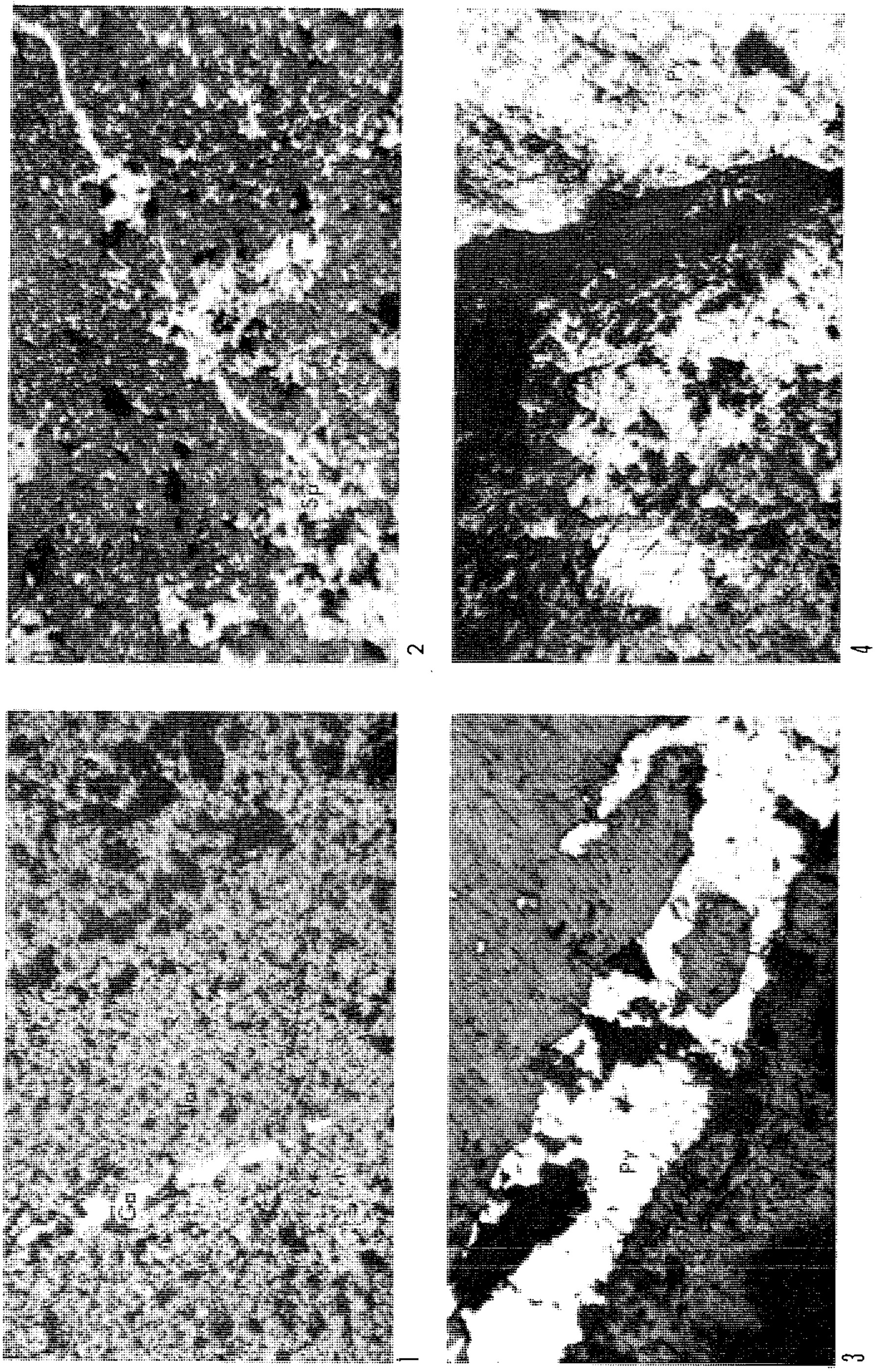


Plate 3

EXPLANATION OF PLATE 4

PHOTOMICROGRAPHS

All X 5.6, Reflected Light

FIG. 1.—Galena (Ga) cutting sphalerite (Sp) and cut in turn and partly replaced by pyrite (Py). Dark patches are vugs. All minerals are related to the productive stage. Photomicrographs taken from 73-11 stope in the 1300 level.

FIG. 2.—Rhodochrosite (Rh) cut by pyrite (Py), and both cut in turn by galena (Ga). Note the abrupt stop of the veinlet of pyrite at the contact with galena to the right. Dark patches are vugs. All minerals are related to the productive stage. Photomicrograph taken from 40-04 in the 1300 level.

FIG. 3—Fibrous pyrite (Py) after botryoidal rhodochrosite (Rh). Both minerals are related to the productive stage. Photomicrograph taken from 302 in the 1050 level.

FIG. 4.—Rhombohedral pyrite (Py) after rhombohedral rhodocrosite (Rh). Note the faint rhombic outlines of rhodochrosite shaped up by pyrite. Dark patches are vugs. Pyrite, rhodochrosite, and galena are related to the productive stage. Photomicrograph taken from 5-8-C1 (2nd floor) in the 1200 level.

EXPLANATION OF PLATE 5

PHOTOMICROGRAPHS

All X 5.6, Reflected Light

FIG. 1.—Spherulitic pyrite (Py). Note sphalerite (Sp) replacing galena (Ga) to the left. Dark patches are vugs. All minerals are related to the productive stage. Photomicrograph taken from 40-04 in the 1300 level.

FIG. 2.—Spherulitic pyrite (Py) rimmed by galena (Ga) and both included in sphalerite (Sp). Note rhodochrosite in the lower part of the picture. All minerals are related to the productive stage. Photomicrograph taken from 302 in the 1050 level.

FIG. 3.—Galena (Ga) cutting rhodochrosite (Rh) disseminated with pyrite (Py). The dark line is a fracture. Dark patches are vugs. All minerals are related to the productive stage Photomicrograph taken from 80-51 Timber stope in the 1200 level.

FIG. 4.—Galena (Ga) cutting pyrite (Py) and rhodochrosite (Rh). Note pyrite cutting rhodochrosite. All minerals are related to the productive stage. Photomicrograph taken from 40-04 in the 1300 level.

EXPLANATION OF PLATE 6

PHOTOMICROGRAPHS

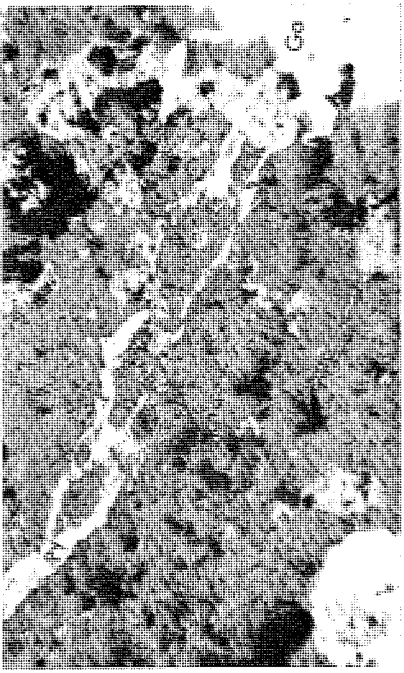
All X 5.6, Reflected Light

FIG. 1.—A fracture cutting sphalerite (Sp) and crustified inward with calcite (Ca), quartz (Qz), and pyrite (Py). The dark patch is a part of the fracture. Note scratched galena inside sphalerite. All minerals are related to the productive stage. Photomicrograph taken from 73-11 stope in the 1300 level.

FIG. 2.—Barite (Ba) cutting quartz (Qz), sphalerite (Sp), and galena (Ga). Note unreplaced residuals of dolomite inside galena. Dark patches are vugs. All minerals are related to the productive stage. Photomicrograph taken from S. crosscut 56-56 raise in the 1300 level.

FIG. 3.—Barite (Ba) partly replacing pitted galena (Ga) and chalcopyrite (Ch). Note remnants of galena inside barite. Dark patches are vugs. All minerals are related to the productive stage. Photomicrograph taken from DDH B-24 between 256 and 322 foot depth.

FIG. 4.—Barite (Ba) partly replacing pitted galena (Ga). Note the cleavage outline of galena replaced by barite. Both minerals are related to the productive stage. Photomicrograph taken from DDH B-24 between 256 and 322 foot depth.



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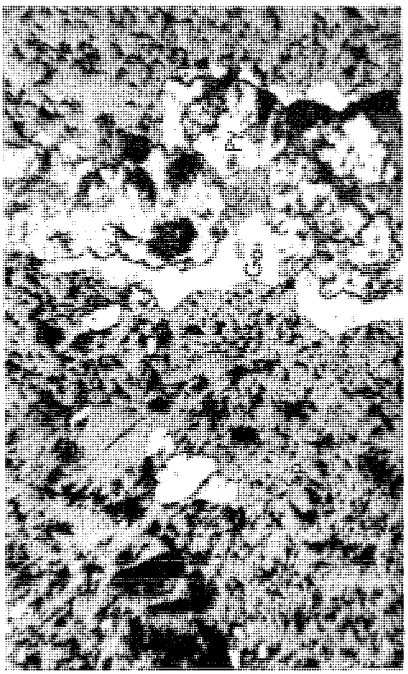

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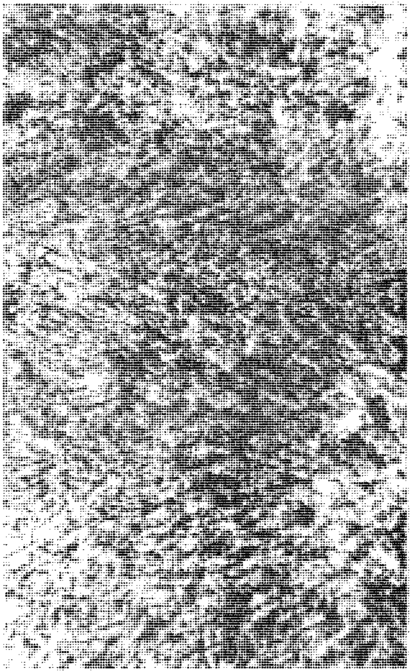

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Plate 4

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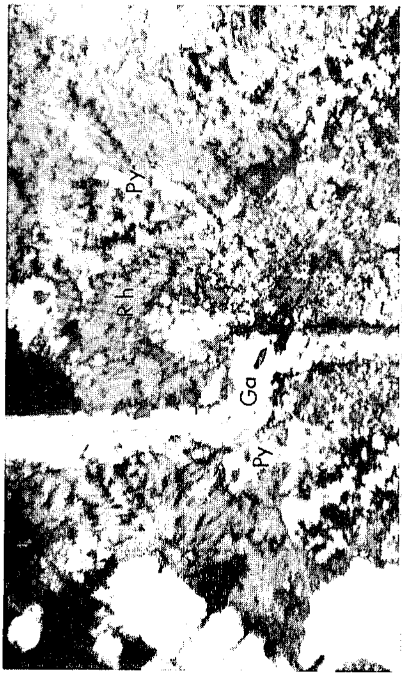

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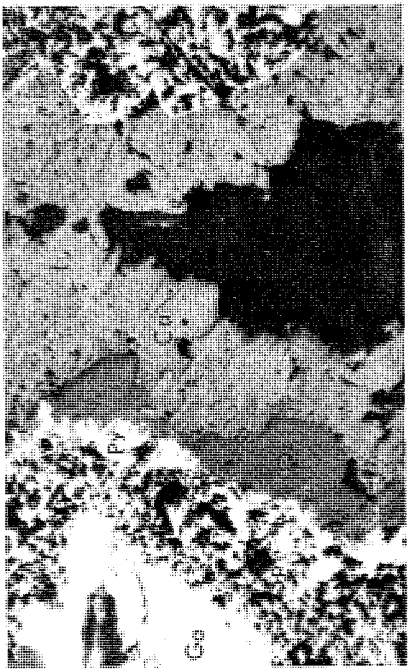
Plate 5



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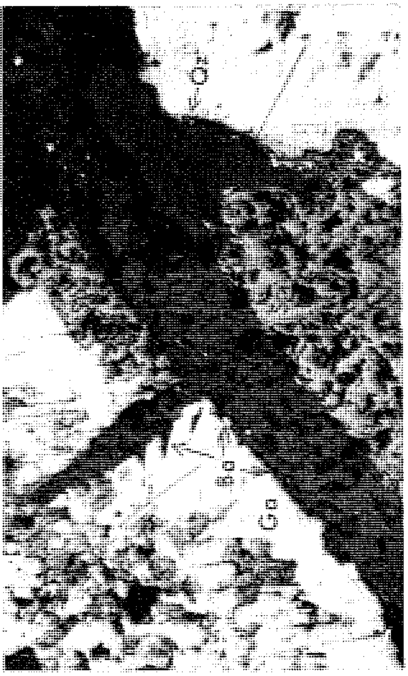

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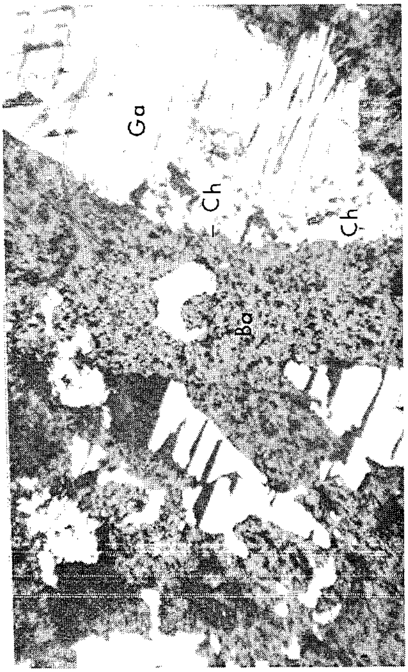

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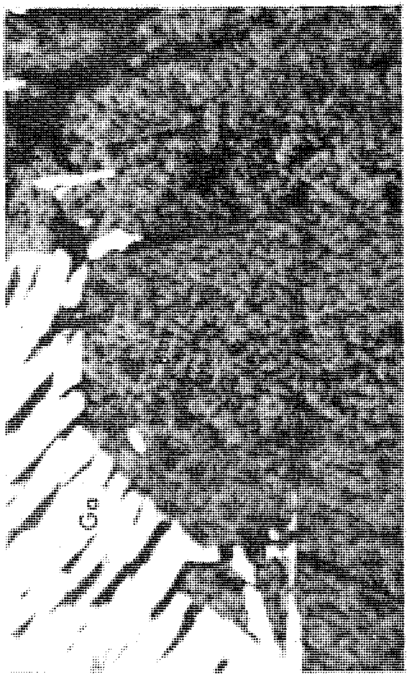

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Plate 6

EXPLANATION OF PLATE 7

PHOTOMICROGRAPHS

All X 5.6, Reflected Light

FIG. 1.—Barite (Ba) butting pitted galena (Ga), and both cut in turn by quartz (Qz). All minerals are related totheproductive stage. Photomicrograph taken from 71-83 raise in the 1200 level.

FIG. 2.—Sphalerite (Sp) and pitted galena (Ga) replacing jasperoid (Ja). Note unreplaced remnants of jasperoid inside sphalerite and galena. The dark patch is a vug. Jasperoid is related to the latebarren stage, and galena and sphalerite to the productive stage. Photomicrograph taken from 73-11 stope in the 1300 level.

FIG. 3.—Sphalerite (Sp) replacing quartz (Qz). Dark patches are vugs. Sphalerite is related to the productive stage, and quartz to the early productive stage. Photomicrograph taken from 73-11 stope in the 1300 level.

FIG. 4.—Sphalerite (Sp) but by quartz (Qz). Dark lines are fractures. Both minerals are related to the productive stage. Photomicrograph taken from 73-11 stope in the 1300 level.

EXPLANATION OF PLATE 8

PHOTOMICROGRAPHS

All X 5.6, Reflected Light

FIG. 1.—Sphalerite (Sp) rimmed by pitted galena (Ga), then by sphalerite, rhodochrosite (Rh), and quartz (Qz). The dark line is a fracture. All minerals are related to the productive stage. Photomicrograph taken from S. crosscut 56-56 raise in the 1300 level.

FIG. 2.—Pitted galena (Ga) cut by rhodochrosite (Rh). Both minerals are related to the productive stage. Photomicrograph taken from 40-04 in the 1300 level.

FIG. 3.—Rhodochrosite (Rh) filling spaces between broken patches of galena (Ga). Note the sharp angularity of galena. Dark patches are vugs. Both minerals are related to the productive stage. Photomicrograph taken from 5-8-C1 (2nd floor) in the 1200 level.

FIG. 4.—Rhodocrosite (Rh) cutting and partly replacing sphalerite (Sp). Note light gray remnants of sphalerite inside rhodochrosite. Dark patches are vugs. Both minerals are related to the productive stage. Photomicrograph taken from DDH B-5 between 157 and 188-foot depth.

EXPLANATION OF PLATE 9

PHOTOMICROGRAPHS

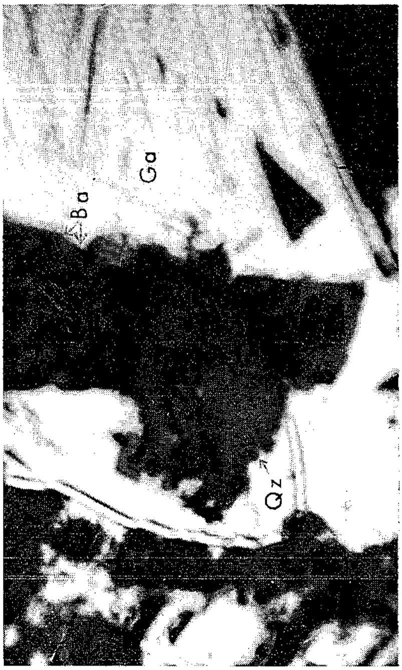
All X 5.6, Reflected Light

FIG. 1.—Sphalerite (Sp) replacing pitted galena (Ga), and both cut and rimmed by rhodochrosite (Rh). Note remnants of galena only inside sphalerite. Dark patches are vugs. All minerals are related to the productive stage. Photomicrograph taken from 40-04 in the 1300 level.

FIG. 2.—Galena (Ga) rimming smithsonite (Sm) including remnants of fresh sphalerite (Sp). Dark patches are vugs. Sphalerite and galena are related to the productive stage. Photomicrograph taken from 5-8-C1 (2nd floor) in the 1200 level.

FIG. 3.—Sphalerite (Sp) rimming and partly replacing galena (Ga), and both included in rhodocrosite (Rh). Dark patches are vugs. All minerals are related to the productive stage. Photomicrograph taken from S. crosscut 56-56 raise in the 1300 level.

FIG. 4.—Shpalerite (Sp) rimming, cutting, and partly replacing galena (Ga). Note pyrite (Py) included in galena. The two dark patches are vugs. All minerals are related to the productive stage.Photomicrograph taken from 71-83 raise in the 1200 level.



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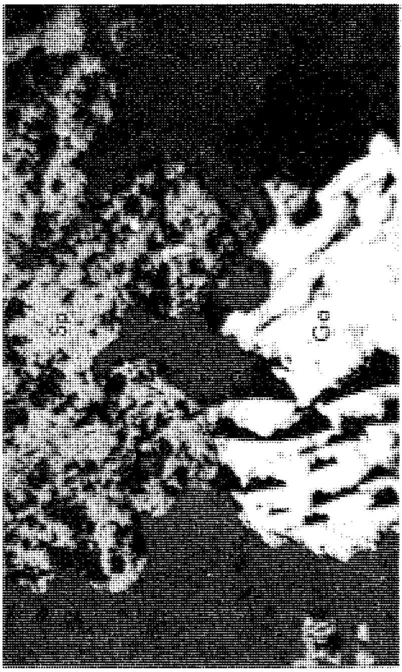

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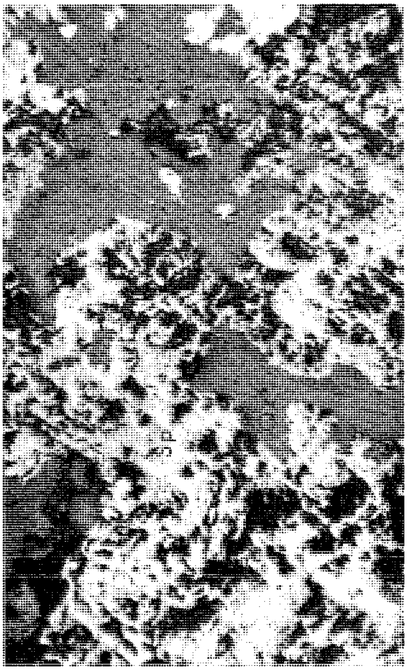

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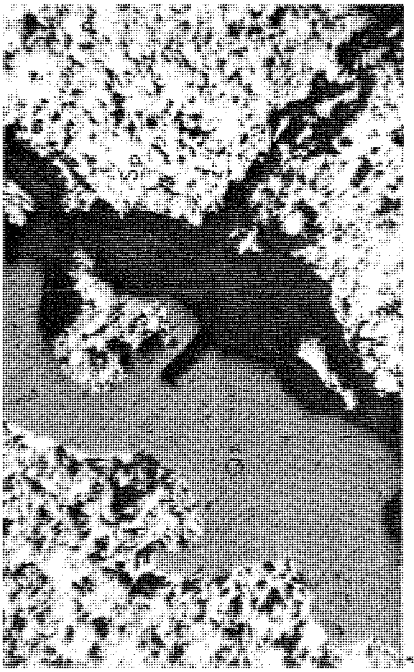

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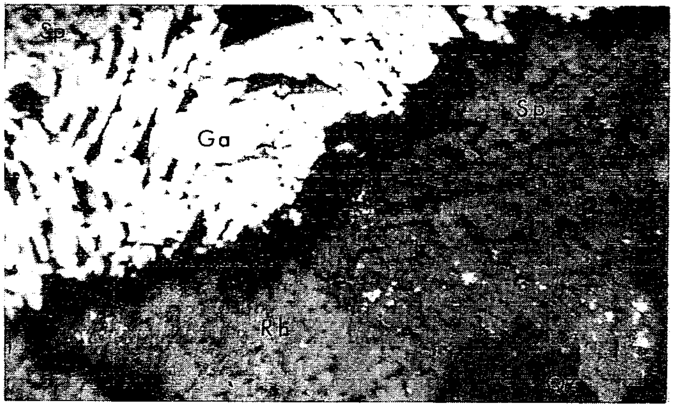
Plate 7



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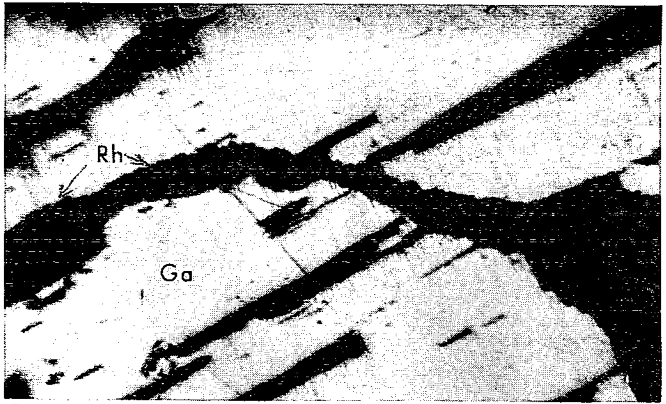

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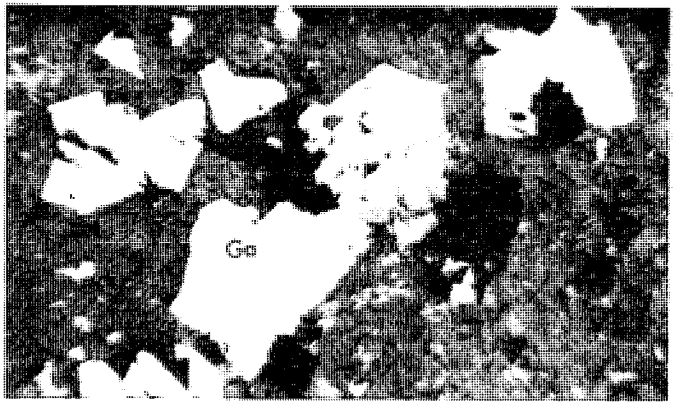

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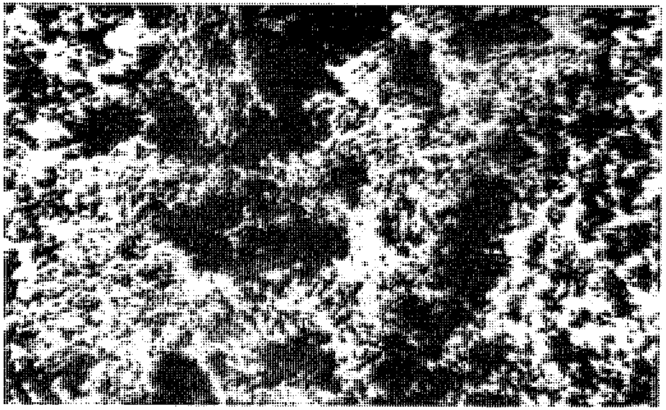

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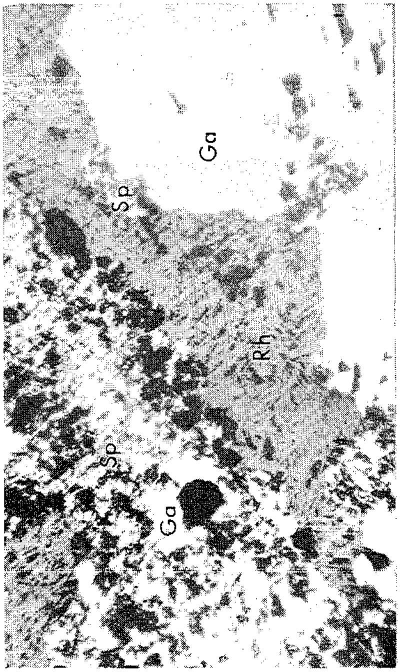
Plate 8



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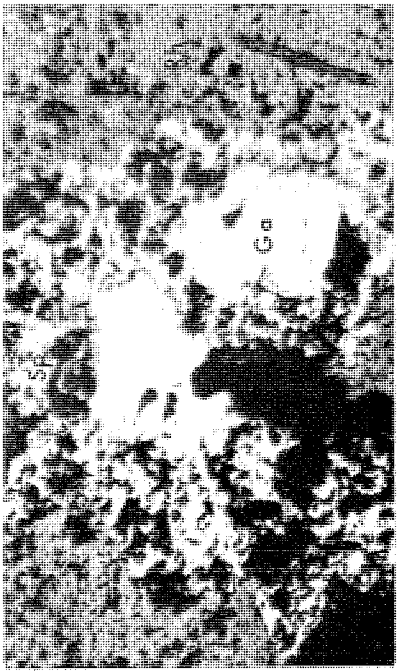

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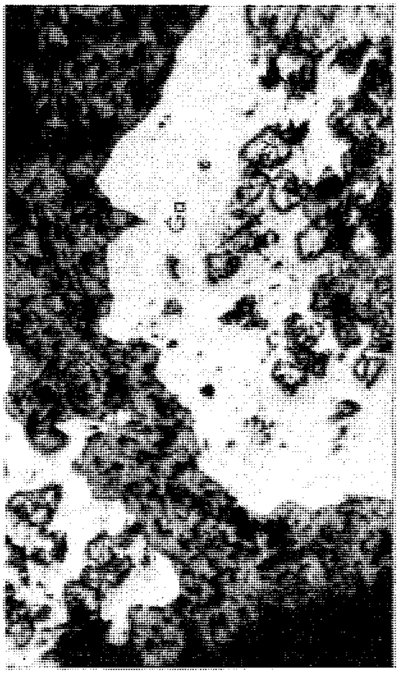

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Plate 9

EXPLANATION OF PLATE 10

PHOTOMICROGRAPHS

All X 5.6, Reflected Light

FIG. 1.—Sphalerite (Sp) replacing galena (Ga). Note unsupported residuals of galena inside sphalerite. Both minerals are related to the productive stage. Photomicrograph taken from 40-04 in the 1300 level.

FIG. 2.—Pyrite (Py) included in galena (Ga), and both rimmed by sphalerite (Sp). Note the knobby contact between sphalerite and quartz (Qz). Dark patches are vugs. Pyrite, sphalerite, and galena are related to the productive stage, and quartz to the early productive stage. Photomicrograph taken from 71-83 raise in the 1200 level.

FIG. 3.—Sphalerite (Sp) cutting and partly replacing pitted galena (Ga). Note unreplaced remnants of galena inside sphalerite. Dark patches are vugs. Both minerals are related to the productive stage. Photomicrograph taken from 71-83 raise in the 1200 level.

FIG. 4.—Pyrite (Py) rimming pitted galena (Ga). Dark patches are vugs. Both minerals are related to the productive stage. Photomicrograph taken from 10-25 in the 1200 level.

EXPLANATION OF PLATE 11

PHOTOMICROGRAPHS

All X 5.6, Reflected Light

FIG. 1.—Galena (Ga) andexsolved chalcopyrite (Ch) replacing dolomite (Do). Note unreplaced remnants of dolomite. The dark patch to the left is a vug. Galena and chalcopyrite are related to the productive stage, and dolomite to the early barren stage. Photomicrograph taken from 80-51 Timber stope in the 1200 level.

FIG. 2.—Galena (Ga) weathered to, and partly replaced by, cerussite (Ce). Note unreplaced remnants of galena inside cerussite. Note also calcite (Ca) with cerussite. Galena is related to the productive stage. Photomicrograph taken from 73-11 stope in the 1300 level.

FIG. 3.—Pyritohedral galena (Ga) pseudomorph of pyritohedral pyrite (Py) inside rhodochrosite (Rh). The large dark patch is a vug. All minerals are related to the productive stage. Photomicrograph taken from 302 in the 1050 level.

FIG. 4.—Sphalerite (Sp) and pitted galena (Ga) with exsolved chalcopyrite (Ch). Dark patches are vugs. All minerals are relaed to the productive stage. Photomicrograph taken from 80-51 Timber stope in the 1200 level.

EXPLANATION OF PLATE 12

PHOTOMICROGRAPHS

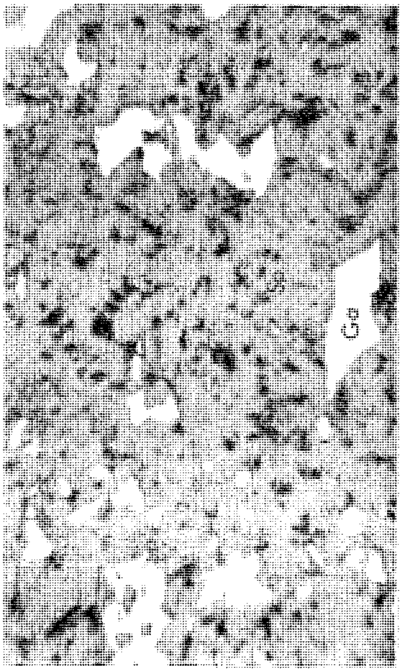
All X 5.6, Reflected Light

FIG. 1.—Chalcopyrite (Ch) cutting galena (Ga) and dolomite. Note the unreplaced residuals of dolomite (Do) inside galena. Dark patches are vugs. Chalcopyrite and galena are related to the productive stage, and dolomite to the early barren stage. Photomicrograph taken from 80-51 Timber stope in the 1200 level.

FIG 2.—Chalcopyrite (Ch) (See arrows) cutting sphalerite (Sp). Note galena (Ga) in sphalerite. All minerals are related to the productive stage. Photomicrograph taken from 73-11 stope in the 1300 level.

FIG. 3.—Tetrahydrite (Te) cutting sphalerite (Sp), and galena (Ga). Dark patches are vugs. All minerals are related to the productive stage. Photomicrograph taken from 80-51 Timber stope in the 1200 level.

FIG. 4.—Tetrahedrite (Te) cutting sphalerite (Sp), and galena (Ga). Note exsolved grains of chalcopyrite Ch), and pyrite (Py). Dark patches are vugs. All minerals are related to the productive stage. Photomicrograph taken from 80-51 Timber stope in the 1200 level.



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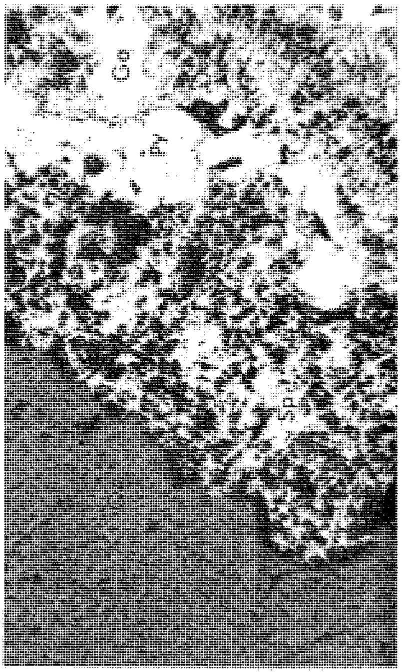

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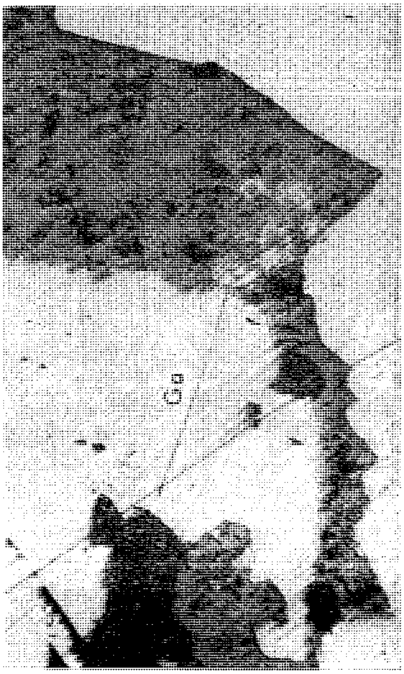

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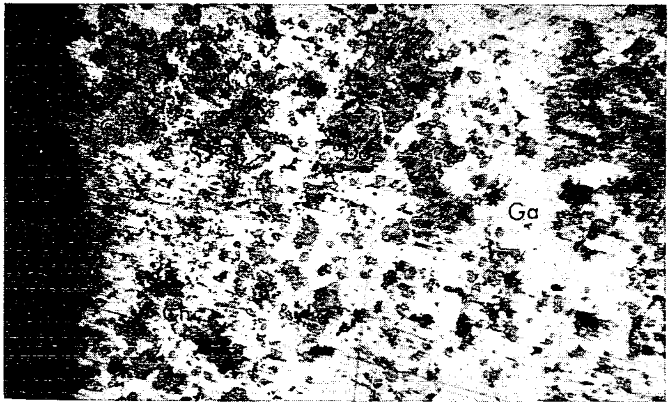
Plate 10



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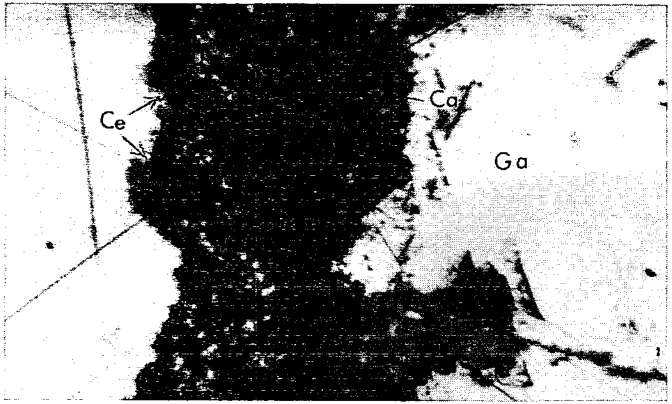

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Plate 11

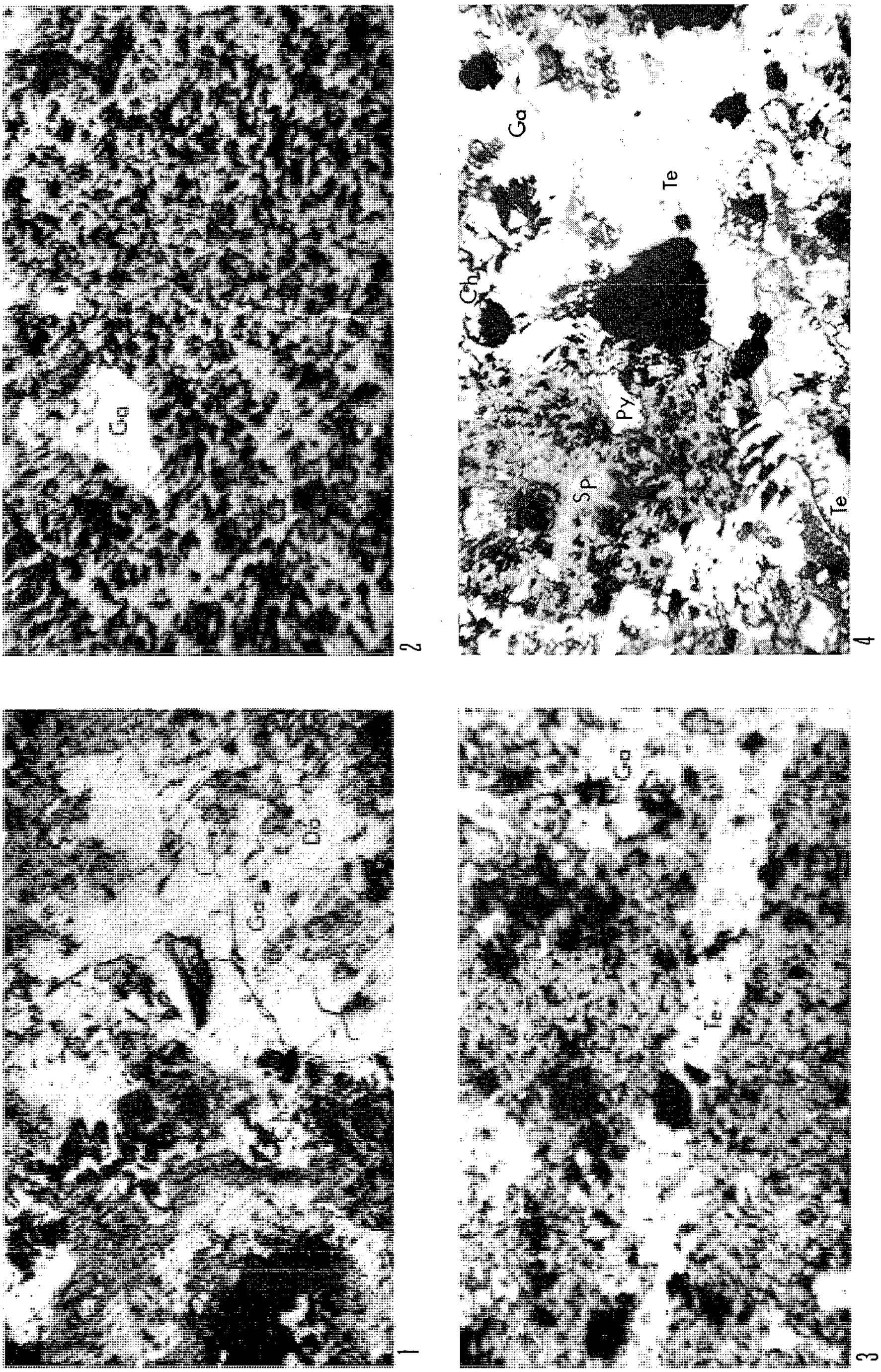


Plate 12

Other less important replacement types are the fibrous, spherulitic, and rhombohedral types acquired by pyrite's replacing botryoidal, spherulitic, and crystallized rhodochrocite, respectively (See Plates 4 and 5). Rarely a blady galena was found after botryoidal rhodochrosite.

Dissemination Types.—Dissemination textural types which gradually merge mostly with the replacement type are widespread and can be subdivided into a fine-grained disseminated variety and a coarse-grained variety. In the second case, galena, sphalerite, and pyrite were found scattered in their individual crystallographic forms (See Plate 2).

Breccia Type.—The breccia textural type is widespread and economically important in the Burgin mine. Ore mineralization is found between rock fragments and carries high lead and moderate zinc and silver values.

Bedding Replacement Types.—Bedding textural types are subdivided into a fine-grained mineralization where carbonate units between thin-bedded clayey to silty material were completely replaced by ores; and a fine to medium-grained mineralization where only a partial replacement of carbonate materials took place along bedding planes. Both subdivisions appear to be rich in lead, poor in zinc, and low in silver. This type is not widespread in the Burgin mine.

Fracture-filling Types.—Fracture-filling textural types are commonly present in the Burgin mine. They are mostly found as narrow microscopic veinlets (See Plates 3, 4, 5, 6, 7, 8, and 12). Macroscopic cracks, however, now filled with ores, were also noticed in the field. They are only a few inches in length and less than one inch in width. Locally, microscopic veinlets show a differential type of deposits along them. The crustification type is rare in the Burgin mine (See Plate 6).

Exsolution Type.—The exsolution type is limited in the mine. It occurs microscopically with intergrowths of galena and sphalerite and between argentite and galena. Where found, chalcopyrite is exsolved as small microscopic grains and, locally, as patches (See Plates 2, 11, and 12). Argentite is usually exsolved as string-like features or blebs (See Plate 1).

Colloidal Type.—The colloidal type is found in the Burgin mine. It seems to be mostly restricted to rhodochrosite which occurs as botryoidal concretions, reaching ten centimeters across or more, or as small spherulites up to one centimeter in diameter.

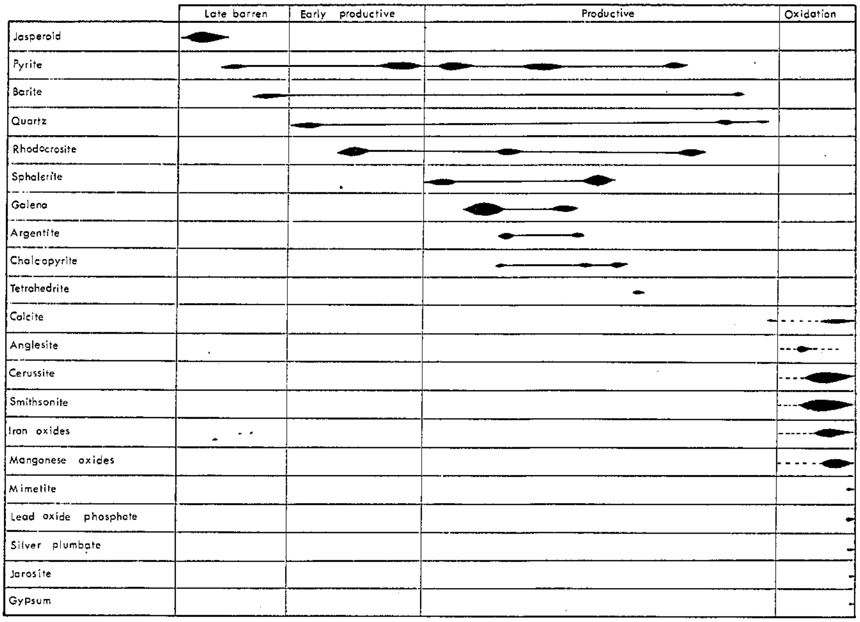
Paragenesis of Ore Minerals

Field observations and polished sections of minerals indicate the presence of an early barren stage of alteration, characterized by widespread hydrothermal dolomite, followed by a late barren stage where jasperoidization is predominant. This is followed by an early productive stage, where pyrite and other gangue minerals took place, and a late productive stage, where the main ore and gangue minerals deposited. A mid-barren stage is recognized by argillic alteration, by the presence of sanded dolomite and also by dickite in vuggy dolomitized limestone. Both minerals are related to this stage according to Lovering et al. (1949).

The hydrothermal dolomite of the first stage of hydrothermal alteration is replaced to a certain extent by jasperoid and ores related respectively to the late barren and productive stages. Presence of unsupported residuals of dolomitized limestone in jasperoid and ores supports the fact that the hydrothermal dolomite was replaced later by silica and sulfides (Plate 2, Figure 1). The sanded dolomite and dickite do not present good field paragenetic evidences in the Burgin mine, which relate them to the mid-barren stage as mentioned by Lovering. As mentioned earlier, the sanded dolomite is not metallized in general, and its relationship with jasperoid of the late barren stage is not clear since no field association was found between them. It locally occurs in the dense dolomitized limestone of the footwall near the thrust fault plane, where rocks appear to be badly fractured by thrusting and fractures are connected with the upper thrust plate by channelways. The sanded dolomite, however, is more commonly present in the upper thrust plate as a yellowish brown gray friable to sandy nonmetallized dolomite. Occurrences of dickite in the Burgin mine indicate that its formation should not be restricted to the mid-barren stage.

Microscopic and chemical studies of some 225 polished sections reveal that paragenetically four periods of silicification, including jasperoid, and at least five periods of pyritization took place during late barren, early productive, and productive stages; and two of barite, in the late barren and productive stages. Studies of sulfide ores in the productive stage indicate two surges of sphalerite, two of galena, one small injection of chalcopyrite, and another of tetrahedrite. Chalcopyrite, however, occurs also as exsolved grains in sphalerite and galena. A small deposit of primary calcite is also discernible in this stage (Text-figure 8).

In order to avoid confusion in the paragenetic discussions, the writer will give priority to minerals which appeared first in the late barren stage, following



TEXT-FIGURE 8.—Paragenesis diagram showing the time sequence of mineral deposition.

with those which appeared in the early productive stage; then he will discuss the minerals of the productive stage. He will describe each mineral in sequence and discuss its paragenetic relationships with other minerals wherever it appears during the late barren, early productive, and productive stages.

Jasperoid is widespread in the late barren stage, it is gray to reddish brown but, locally, black in color and vuggy to dense in nature. It is found replacing dolomite in the upper thrust plate. It is also found locally silicifying and replacing shale fragments. Thin-bedded fine-grained gray to greenish gray fragments of Ophir Shale are found partly silicified and transformed to opal or chert. The silicificed parts maintain the bedding structure. Jasperoid is commonly found disseminated with pyrite. Specks of pyrite, however, are locally aligned in form of veinlets (Plate 2, Figures 2 and 3). Wherever the iron sulfide is oxidized, jasperoid appears yellow brown due to its staining with limonite. It is microscopically cut by younger barite (Plate 2, Figure 4) also related to the late barren stage. Locally, a sharp change from reddish gray or yellowish gray to translucent and a sharp change from vuggy to more or less dense type of silica indicate that another period of silicification took place probably in the early productive stage (Plate 2, Figure 3). Jasperoid is commonly metallized and partly replaced by sulfide ores. Unreplaced remnants are commonly included in galena (Plate 2, Figure 1). It is also cut in places by small microscopic veinlets of galena, sphalerite, and chalcopyrite (Plate 3, Figures 1 and 2).

The paragenesis of pyrite is probably the most difficult one to study in the Burgin mine. The difficulty comes, first, from the appearance of pyrite in the late barren, early productive, and productive stages, second, from its diversified types of occurrences, and, third, from its association with almost every mineral in all stages. It appears in the late barren stage as small disseminated specks and narrow veinlets in jasperoid as mentioned before. It also appears, but more abundantly, toward the end of the early productive stage as specks in barite of the late barren stage, as well as in rhodochrosite of the early productive stage where it is shown under the microscope as specks disseminated in or as massive veinlets cutting rhodochrosite (Plate 3, Figure 3). These veinlets are usually a few millimeters long and less than half a millimeter wide. They locally include islands of rhodochrosite, suggesting that at least some replacement took place, although the contact of pyrite with rhodochrosite looks sharp in general. It is not clear whether the surge of pyrite of the early productive stage ended before, or merged with, pyrite found associated with the first two surges of sphalerite and galena of the metallizing productive stage. In places, pyrite and sphalerite, both partly replacing rhodochrosite, are associated together (Plate 3, Figure 4). Pyritohedral pyrite and unreplaced residuals of rhodochrosite are found here. Two other surges of pyrite are deciphered also in the middle and late parts of the productive stage; one of them preceded the last two surges of lead-zinc sulfides, and the other succeeded them (Text-figure 8). The preceding surge of pyrite is recognized by being found along the middle part of a vein-like feature flanked on both sides by narrow strips of galena cutting sphalerite (Plate 4, Figure 1). Both galena and sphalerite are related to the first two surges of zinc-lead sulfides. This episode of pyrite is found to be preceded also by rhodochrosite as veinlets of pyrite cutting rhodochrosite indicate (Plate 4, Figure 2). Where pyritization is strong, pyrite appears replacing the manganese carbonate and adopting at least three new replacement textures: (1) it is observed as fibers intercalating, or completely replacing, botryoidal rhodochrosite (Plate 4, Figure 3). In this latter case, pyrite as being revealed by X-rays, appears dense fibrous and botryoidal in shape; (2) wherever rhodochrosite is crystallized, the replacing iron sulfide shows faint rhombohedral forms (Plate 4, Figure 4); the replacement is incomplete and only the sides of some rhombs are partly replaced by pyrite; and (3) pyrite is found as small concentric spherulites (Plate 5, Figures 1 and 2), probably after spherulitic rhodochrosite or marcasite. Pyrite of this episode is also recognized by being cut by or rimmed by small narrow veinlets of younger galena (Plate 5, Figures 2, 3, and 4). The last episode of pyrite succeeded the last two surges of lead-zinc sulfides as mentioned before; pyrite appears here as a thin film crustifying sphalerite including galena. This pyrite is in turn crustified outward by younger quartz and calcite along a fracture (Plate 6, Figure 1). Locally, however, specks of pyrite related to this surge are found included in the overlapping and slightly younger rhodochrosite.

Two separated episodes of barite related to the late barren and productive stages are discerned under the microscope. The first episode which marks the end of the late barren stage is recognized by the fact that it cuts jasperoid mineralized only with pyrite (Plate 2, Figure 4). Their contact appears sharp. Barite of this stage, although not common, is locally found mineralized with specks of younger galena and pyrite along microscopic cracks (Plate 2, Figure 4). The second episode took place toward the end of the productive stage. It is recognized by its occurrences as fracture-filling aggregates of barite cutting older quartz, sphalerite, and galena (Plate 6, Figure 2) or as partly replacing galena and chalcopyrite, as the unreplaced remnants and cleavage outline of galena indicate (Plate 6, Figures 3 and 4). Locally, barite is found cutting galena and is cut in turn by younger quartz (Plate 7, Figure 1).

Quartz occurs at the beginning of the early productive and toward the end of the productive stages. In the early productive stage, it appears under the microscope as vuggy to dense translucent masses; such a transparency makes a sharp contrast with the reddish gray to yellowish gray jasperoid of the late barren stage. Wherever both quartz and jasperoid are together, their contact is easily recognized by the sharp variation in their density and vuggy natures (Plate 2, Figure 3; and Plate 3, Figure 1). They both are metallized and partly replaced by sulfide ores as their unreplaced residuals indicate (Plate 2, Figure 1; and Plate 7, Figures 2 and 3). Toward the end of the productive stage, two episodes of silicification took place; one of them preceded barite of this stage, and the second succeeded it. In the first episode, the translucent massive quartz is found filling fractures cutting sphalerite related to the last surge of zinc sulfide (Plate 7, Figure 4). Locally, it is found rimming older rhodochrosite (Plate 8, Figure 1). Quartz of this episode is also observed cut by younger barite (Plate 6, Figure 2). The last quartz deposit is mostly white and well crystallized. It locally occurs as clusters of, or individual, crystals showing their prisms capped in one side with pyramids. This quartz is found in the field crystallized on barite or in vugs and openings. Under the microscope, however, it is found cutting galena and barite (Plate 7, Figure 1). It also occurs as crystals crustifying fractures and crustified in turn by younger calcite (Plate 6, Figure 1).

Three periods of deposition of rhodochrosite are discerned under the microscope; one of them belongs to the early productive and the other two to the productive stages. It should be pointed out, however, that most rhodochrosite is botryoidal and a low-temperature deposit. Only a fraction is locally crystallized. Manganese seems to be leached from the hydrothermally dolomitized limestone, as the chemical analysis showed, along with magnesium and calcium ions during the time of replacement by jasperoid and quartz. Rhodochrosite of the early productive stage is recognized, on the one hand, by being cut by younger pyrite of the same stage (Plate 3, Figure 3) and mineralized and partly replaced, on the other hand, by sphalerite and pyrite of the first surges of zinc-iron sulfides in the productive stage (Plate 3, Figure 4). The first rhodochrosite deposit of the productive stage appears mostly colloidal but locally crystallized. Its appearance as a low-temperature mineral marks the end of the two surges of zinc-lead sulfides. It is easily recognized in places by its occurrence as veinlets cutting older galena (Plate 8, Figure 2) and is cut in turn by younger pyrite and galena (Plate 4, Figure 2; and Plate 5, Figure 4). It is commonly found partly or completely replaced by pyrite in forms of fibers, rhombs, or spherulites; and locally it is found replaced by younger galena in form of blades. It is also found filling spaces between broken and separated patches of galena as the sharp angularity of these patches indicates (Plate 8, Figure 3). The last deposit of rhodochrosite succeeded all sulfide and sulfantimonide deposits. It rims sphalerite of the last surge and is in turn rimmed by younger quartz. (Plate 8, Figure 1); or it is recognized by cutting and probably replacing the same sphalerite as the gradual contact between both minerals indicates (Plate 8, Figure 4) or by cutting and rimming galena and sphalerite of the last two surges of lead-zinc sulfides (Plate 9, Figure 1). In this latter case, unreplaced residuals of galena only are found in sphalerite. Manganese for the two deposits of rhodochrosite in the productive stage may also have been derived from the leaching of the hydrothermally dolomitized limestone during its replacement by ores. A part of manganese, however, may have been derived from the remobilization of rhodochrosite already deposited in the early productive stage.

The productive stage, whose importance comes from the mineable deposits of sulfides, starts with the deposition of sphalerite. Microscopic study of the 225 polished sections, selected from different metallized parts of the Burgin mine, reveals that at least two separated surges of sphalerite took place in this stage. These two surges are evidenced by the fact that zinc sulfide is found rimmed by galena (Plate 9, Figure 2), on the one hand, and rimming galena in turn (Plate 9, Figures 3 and 4), on the other hand. Rimming may have taken place after the depletion of the ore-bearing hydrothermal liquid in the rimmed material. The zinc sulfide of the first surge is disseminated with, and locally cut by small narrow veinlets of pyrite. It looks vuggy under the microscope and locally replaces quartz as the unreplaced remnants of quartz indicate (Plate 7, Figure 3). In a few places, fresh remnants of sphalerite are observed included inside smithsonite rimmed by fresh galena (Plate 9, Figure 2). The freshness of galena and the presence of smithsonite, including fresh remnants of sphalerite, indicate that a certain time has elapsed before the younger surge of galena took place. During this time interval, sphalerite partly weathered out to zinc carbonate. It appears from microscopic studies that the zinc sulfide of the first surge is not widespread and not as common as it is in the second surge. Sphalerite of the second surge seems to have appeared directly, or shortly, after the second surge of galena. No low-temperature mineralizations are found between them under the microscope. Sphalerite looks also vuggy and locally with some exsolved grains of chalcopyrite. Rarely, the zinc sulfide and chalcopyrite are found to differentially fill side by side small narrow microscopic fractures (Plate 3, Figure 2). In several places, sphalerite as mentioned before is found rimming galena (Plate 9, Figures 3 and 4); this indicates the cessation of galena deposition and the appearance of the zinc-bearing solution. An overlapping, however, does exist between both surges, as the local presence of both sulfides together intermixed with exsolved chalcopyrite indicates. It is also found partly replacing galena, as the unreplaced residuals indicate (Plate 9, Figures 1 and 3; and Plate 10, Figures 1, 2, and 3). Locally, the contact between sphalerite and silica, although sharp, is knobby and shows embayments. This may indicate that silica may have been partly replaced by zinc sulfide (Plate 10, Figure 2). Sphalerite and galena are found together with no clear paragenetic relationship between them. They both replace silica in places (Plate 7, Figure 2). Sphalerite of the second surge locally includes remnants of galena and is included in turn into younger rhodochrosite (Plate 9, Figure 3). It is also found cut by younger rhodochrosite and quartz veins (Plate 8, Figure 4; and Plate 7, Figure 4).

Two surges of galena are also differentiated under the microscope; one of them succeeded the first surge of sphalerite, and the other preceded the second surge. These facts are evidenced by the above discussed rimming phenomena. Galena of the first surge is recognized by aureoling older sphalerite and by its being cut by younger rhodochrosite (Plate 8, Figure 2), which is also found to fill spaces between broken and angular fragments of galena (Plate 8, Figure 3). This lead sulfide is also recognized by its being rimmed with younger pyrite (Plate 10, Figure 4). In places, it shows some exsolved grains of chalcopyrite and is observed replacing dolomite and silica, i.e., jasperoid and/or quartz, as the unreplaced residuals of both minerals and their pseudomorphs indicate (Plate 2, Figure 1; and Plate 11, Figure 1). Galena of both surges usually includes some exsolved grains of chalcopyrite; or both may fill side by side very narrow microscopic fractures. Locally, galena of the first surge is found alone as pitted or dense massive patches; as small narrow microscopic veinlets, one to two millimeters long, cutting jasperoid (Plate 3, Figure 1); or as fine specks along small narrow cracks in older barite (Plate 2, Figure 4). Wherever galena, probably of both surges, is fractured, and where fractures are used as channelways for the calcium bicarbonate-bearing ground water, the lead sulfide weathers out to cerussite along, and to a certain distance from, these fractures. Cerussite here tends to replace galena as its unsupported residuals indicate (Plate 11, Figure 2). Galena of the second surge is easily recognized, as mentioned before, by its being rimmed with younger sphalerite on the one hand and by its being found on the other hand as small narrow microscopic veinlets cutting older fibrous pyrite alone (Plate 5, Figure 3) or pyrite and rhodochrosite together (Plate 5, Figure 4). It is also found in pyritohedral forms replacing pyritohedral pyrite (Plate 11, Figure 3) or rarely in form of blades after botryoidal rhodochrosite. Galena is commonly found replaced by younger sphalerite as its unreplaced residuals indicate (Plate 9, Figure 1; and Plate 10, Figure 1) and locally replaced and cut by younger barite as the unsupported remnants and cleavage outline of galena indicate (Plate 6, Figures 3 and 4). In several places, it is found as an aureole surrounding pyritohedral or spherulitic pyrite and rimmed in turn by, or included into patches of, sphalerite (Plate 9, Figure 4; and Plate 5, Figure 2). The lead sulfide of the second surge occurs locally intermixed with exsolved grains of chalcopyrite and sphalerite (Plate 11, Figure 4). Such an occurrence suggests that an overlapping between the last surges of galena and sphalerite did take place and denies consequently the existence of any time of quiescence between these surges. Both minerals are rarely found cut by small narrow microscopic veinlets of chalcopyrite and tetrahedrite. These veinlets are one to two millimeters long and less than half a millimeter wide (Plate 12, Figures 1, 2, 3, and 4).

Chalcopyrite is not widespread in the Burgin mine. It does show, however, two distinct microscopic textures: (1) as exsolved grains found included in both surges of galena (Plate 2, Figure 1; and Plate 11, Figures 1 and 4) and in the second surge of sphalerite (Plate 11, Figure 4); and (2) as small narrow microscopic veinlets, one to two millimeters long and less than half a millimeter wide, cutting galena and sphalerite (Plate 12, Figures 1 and 2). Chalcopyrite is also found differentially filling narrow fractures with galena and sphalerite.

In only a few polished sections, tetrahedrite is found as small narrow microscopic veinlets about one to two millimeters long and less than a half millimeter wide, cutting lead, zinc, and iron sulfides (Plate 12, Figures 3 and 4). Locally, the contact between tetrahedrite and galena appears sharp but with an irregular outline, a fact which indicates that the lead sulfide may have been partly replaced by tetrahedrite. The clear appearance of sulfantimonide in the 80-51 Timber stope, i.e., where the strongest mineralization of chalcopyrite took place, indicates a genetic relationship between both minerals.

Calcite as a secondary mineral is mostly deposited alone, or with cerussite (Plate 11, Figure 2) in fissures and cavities. Locally, however, it is found as the last mineral to line cavities crustified inward with hydrothermal quartz and pyrite, followed by sphalerite and galena. Only in this latter case is calcite more likely to be considered as a primary gangue mineral (Plate 6, Figure 1).

The paragenetic study of secondary ore and gangue minerals is difficult in the Burgin mine. The difficulty comes from the fact that every secondary mineral started to be formed some time ago and continues its formation even today below and above the water table, i.e., wherever the primary minerals are in contact with air and the elements necessary for the formation of secondaryminerals are assured. A definite pargenetic classification, therefore, is hazardous. The only good field evidence found inside the mine is the presence of gypsum needles standing on the Ophir Shale along the drift in the 1050 level. Such an occurrence associated with jarosite suggests that gypsum, and probably jarosite, are the latest minerals to be formed. Other conclusions are the fact that anglesite should be deposited before cerussite, and cerussite and smithsonite, before secondary calcite. Wherever iron oxides are deposited near manganese oxides, the least soluble iron oxides should have been deposited before the more soluble manganese oxides; and, where mixed with smithsonite, iron oxides derived probably from some included siderite should be considered younger than smithsonite. The same conclusion may be applied also to the manganese oxides mixed with zinc carbonate. The position of calcite with respect to iron-manganese oxides is not clear. Mimetite, found locally in vuggy brecciated rocks stained with dark to dark brown manganese oxides, is probably younger than manganese oxides. The lead oxide phosphate, combined with some silver plumbate as revealed by X-rays, and found isolated in one dry locality, has a confused position in the paragenetic classification.

The paragenetic classification of the late barren, early productive, and productive stages, along with that of oxidation minerals, is summarized in Text-figure 8, whereas mineral relationships are represented in plates.

Ore Genesis and Chemistry of Hydrothermal Liquids.—It was mentioned earlier that the early barren stage is characterized by the hydrothermal dolomitization, i.e., the leaching of CaO from the previous limestone and the deposition of MgO from a Mg-bearing hot solution. According to Lovering, the most diagnostic Mg-compound in the magmatic dolomitizing solution is magnesium chloride ($MgCl_2$). Chlorine is a good indication for a magmatic origin. Both magnesium and chlorine are shown to be present in the chemical analysis of two hot water samples from the Burgin mine. The formation of dolomite instead of magnesite inside the mine indicates that some carbon dioxide should be present in solution. Otherwise, the absence of CO_2 encourages the magnesium chloride to convert calcite to magnesite in an open system, such as the one that exists in the mine; i.e., calcium carbonate is far less soluble than magnesism carbonate in the presence of dissolved CO_2 aqueous solutions (Lovering et al., 1949, p. 43). The minor amount of CO_2 present in the hot solution suggests that the pH of the dolomitizing liquid was near neutral or somewhere between 6 and 7. The carbon dioxide may have been derived at least partly from the oxidation of carbonaceous material enclosed in limestone.

In the mid-barren stage, to which the sanding of dolomite and dickite are related according to Lovering, the pH of hot solutions seems to have changed from acid at the beginning to alkaline as the hydrothermal liquid advanced. It was mentioned before that atomic absorption showed increases in magnesium and noticeably in calcium and a decrease in silicon in the sanded dolomite with respect to results obtained from fresh dolomite, a fact which suggests that the hot liquid should be at least slightly alkaline in nature and a Ca-Mg-bearing one at the time of sanding. One should bear in mind, however, that the alkalinity has been acquired successively by the advancing acid solution due to its slow reactions with carbonate rocks. The acidity is responsible for the leaching of calcium and magnesium. The alkalinity, which accounts for the deposition of calcium and magnesium, and the solution of silica in the sanded dolomite depended upon the heat of solution and the amount of calcium and magnesium carried by it. It was also suggested earlier that dickite may be the result of decalcification or may have been formed from the combination of water with SiO_2 and Al_2O_3 derived probably from silicates. In both cases, the hot solution should have been acid in order to dissolve the calcium carbonate or to break down the silicates and liberate silica and alumina. It is not clear what acid radical was in the hot solutions; Lovering, however, predicts that these solutions probably contained more halogens and less sulfuric acids in the early part of the mid-barren stage than near the end of it (Lovering et al., 1949, p. 49). In the dickite's case, both the cooling and neutralization of acid solutions through their reactions with the wallrocks led to the deposition of silica and alumina.

The late barren stage is characterized by the deposition of jasperoid (SiO_2), pyrite (FeS_2), and barite ($BaSO_4$). Field observations show that silicification of this stage is widespread and major sources of silica should have been present. Whether the silica, however, was carried to the place of deposition by an acid or alkaline hot magmatic liquid is not clear. Experiments showed that a diluted hot acid solution is effective in breaking silicates and freeing silica. If this is the case in the Burgin mine, then the silica must have been derived from silicates of igneous rocks present in the district. Experiments showed also that quartz and chalcedony are inert in such an acidic medium while they can be dissolved in a hot alkaline liquid. In this latter case, the silica for jasperoidization might have been derived from the nearby Tintic Quartzite. In both cases, the hot jasperoidizing solution appears to be mostly magmatic in origin due to the presence of Ba and SO_4 in it. Its pH, however, is not definitely clear. The only clues that one can have here are: (1) in order to carry barium in solution, hot neutral bicarbonate liquids should include a minor amount of SO_4 and an excess of CO_2; barite would then be precipitated on loss of CO_2; and (2) zeolites are commonly precipitated from hot alkaline soda springs but have not been formed from neutral or acid solution. The combination of these two factors, i.e., the presence of barite and the absence of zeolites in the Burgin mine, led the writer to favor the acidity over the alkalinity of the original magmatic hydrothermal liquid. The acidity accounts for the breaking of silicates in the igneous rocks and the freeing of silica. In the mine, the presence of CO_2 was necessary at the time of jasperoidization for attacking the bases of the wallrocks such as magnesium and calcium and having them exchanged by silica on cooling. Once silica has replaced dolomite, and the free CO_2 is lost, magnesium and calcium ions carried in solution would then have neutralized the solution and have led barite to deposition. Pyrite was probably derived from the ferrous iron carried into the solution in form of ferrous sulfate and/or ferrous bicarbonate along with CO_2 and H_2S. It is possible that H_2S was derived from the overlying volcanic cover, and at least a part of the iron was included as iron oxides inside the dolomitized limestone.

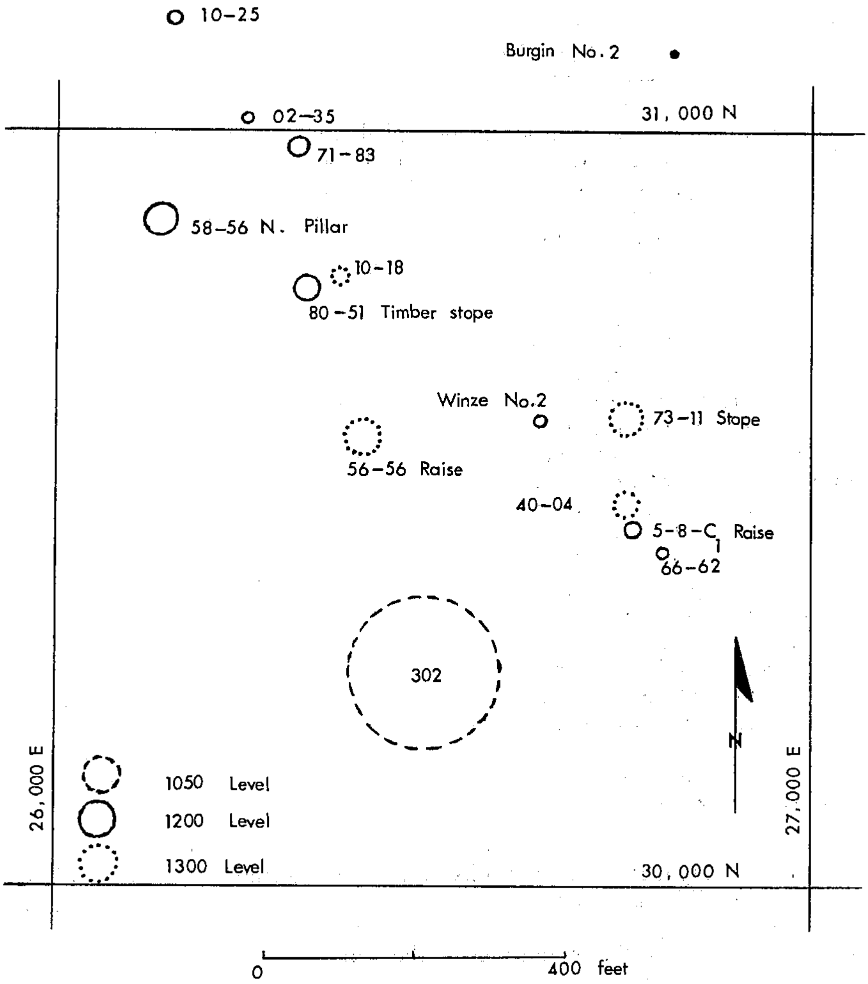
The early productive stage is characterized by the deposition of silica, rhodochrosite, and pyrite. Silica and pyrite deposits may also be explained as their deposits were explained in the late barren stage, i.e., both minerals were carried first by a hot acid liquid then deposited when this liquid cooled and became neutralized. Manganese, however, although it may have been carried in solution as a manganese bicarbonate, may have been derived from different origins. Its presence without any primary sulfide ore in this stage renders its chance slim of being derived from a primary hypogene origin. It may be originated from the volcanic rocks and/or from the hydrothermal dolomite of the mine. The chemical analysis of this type of dolomite in the East Tintic district showed 0.2 to 0.4 percent MnO (Lovering et al., 1949, p. 57). In the latter case, manganese seems to have been released with calcium and magnesium ions, when silica replaced dolomite, and redeposited mostly in form of botryoidal rhodochrosite on cooling. Being related to the late barren and early productive stages, sericite must have been formed also in an acid to neutral medium.

The genesis of ores of the productive stage, such as galena, sphalerite, chalcopyrite, and tetrahedrite, is magmatic. This origin is evidenced in the Tintic mining district in general by the close association of ores and older igneous rocks. The chemistry of the ore-bearing liquids, however, is complicated due to the fact that both jasperoid and dolomitized limestone are found to be replaced by ores. The only clue that one can get to solve this problem is the primary gangue minerals found in this stage, such as rhodochrosite, pyrite, barite, and calcite, with a very minor amount of silica. As mentioned earlier, all these gangue minerals reflect the presence of original acid hot solutions with an excess of CO_2, which have been neutralized later by the addition of leached magnesium and calcium ions. Pyrite also reflects the presence of H_2S in these hot liquids. The primary gangue calcite is probably derived from the calcium carbonate replaced by ores.

The genesis of minerals in the oxidation zone may be summarized as follows: by oxidizing pyrite, galena, and sphalerite in the presence of water, sulfates of iron, zinc, and lead were formed. Both ferrous and zinc sulfates are soluble; they, therefore, were carried by water. Lead sulfate stayed in place and changed to cerussite through an exchange between SO_4 in the sulfate and CO_3 in the calcium carbonate carried by water in form of calcium bicarbonate. In several places, calcite is observed with cerussite replacing galena along fractures. Wherever ferrous and zinc sulfates carried by water contacted carbonate rocks, and exchange between SO_4 and CO_3 took place and formed precipitous iron and zinc carbonates, leaving instead the newly formed calcium sulfate in water. Locally, calcium sulfate precipitated in the form of gypsum. It was mentioned earlier that some siderite may be included in smithsonite; this comes from the fact that zinc carbonate should have a higher concentration than iron carbonate; otherwise the iron carbonate precipitates faster (Loughlin, 1914). Similar reactions between manganese and zinc in solution may have taken place also; so that only a minor amount of manganese carbonate is included inside zinc carbonate. Both siderite and rhodochrosite were later oxidized and colored smithsonite in brown and dark, respectively, as it was discussed before. The oxidation of pyrite may have liberated some sulfur in the form of sulfur dioxide which was dissolved in, and rendered acid, the water. The acid water was useful to dissolve the calcium carbonate necessary for the formation of zinc, lead, and other carbonates. The oxidation of pyrite may also have given ferric sulfate which in contact with calcium carbonate was transformed into, and deposited as, hydrous iron oxide, while leaving calcium sulfate dissolved in water. Jarosite, mimetite, and lead oxide phosphate were formed by combinations of their appropriate elements carried by water to their actual places in the oxidation zone.

Zoning and Distribution of Ores.—In order to study the distribution of ores in the Burgin mine, assay results of forty-two diamond drill holes selected from ten localities are plotted in three dimensional diagrams. These diagrams along with spectographic results of forty fresh sulfide samples, collected from eleven ore bodies in the three levels of the mine, helped the writer in visualizing the zoning aspect of ores. (See Text-figure 9.)

The plotting and correlation led to observe that major centers of mineralizations, through which ore-bearing liquids have passed, are mostly present along and around the intersections of both Apex Standard and Eureka Standard tear faults with the East Tintic thrust fault. Some of these centers are represented in Text-figures 4, 5, and 6 where the strongest mineralizations of lead, zinc, and silver are clearly shown in F and J localities. These three dimensional diagrams show also that mineralizations are diminishing laterally and vertically by spreading out from these centers, which fall mostly between 1050 and 1200 levels. The individual elemental zonation, therefore, is visualized as aureoles representing an outward decrease in lead, zinc, and silver around highly mineralized cores, as the distributions of assay results of these three elements indicate (Text-figures 4, 5, and 6). The most widespread and strongest mineralization appears to be that of lead in the southeastern half of the mineralized zone, where lead spreads laterally toward the southeast for over 400



TEXT-FIGURE 9.—Showing sample locations in the Burgin mine.

feet beyond F locality. Zinc mineralization comes next with a little less than 400 feet; followed by a 350-foot mineralization in silver. In the northwestern half, however, zinc appears to be the most widespread, although lead maintains its stronger mineralization. Here, also, silver retains the third place. The averages plotted on the three figures are arithmetic averages calculated at 5-foot intervals. They clearly show that lead mineralization is higher than that of zinc in the Burgin mine. Except for a few places where ore deposits are found below the 1300 level, mineralizations of lead, zinc, and silver seem to be confined to the space between 1050 and 1300 levels, with the major part being around 1200 level. In other words, plotting of core results showed that mineralizations are mostly found in the upper thrust plate with only local extensions found in the footwall beneath the thrust fault plane. It is worthy to note here that the inhomogeneous spreading of metallizations is influenced by several factors, mainly the availability of passageways and the composition of ore-bearing liquids.

Except for slight deviations between the strongest metallized localities of lead, zinc, and silver, the overall shapes of mineralizations and types of distribution of these elements remain almost similar. This similarity may reflect their close relationships in ore genesis and space. No zoning as such between the sulfide ores of these elements is present in the Burgin mine. The above-mentioned slight deviations between their strongest metallized centers may be referred either to an early partial differentiation of sulfides, i.e., masse exsolution before ore-bearing liquids reached the places of deposition, or to the occurrences of several surges of metallizing liquids with different compositions, or to both partial differentiation and occurrences of several surges. In any case, it should be pointed out here that remobilization of previous ore deposits had probably taken place by later surges and had played an important role in shaping up the distribution of ore as it exists today.

Copper is found to be insignificant as the assay results of core samples indicate. The spectographic analysis showed copper with an average of 0.518 only in 80-51 Timber stope locality, where zinc and silver seem to have the strongest mineralizations.

Manganese deposit is the only mineralization which shows a clear zonal arrangement. The three dimensional plotting reveals the presence of manganese oxides in the southeastern half and rhodochrosite in the northwestern half of the mine. These oxides appear above the 1050 level and extend downward to the 1300 level. Laterally, they extend for several hundred feet but decrease in amount northwestward, until they disappear completely some 200 feet northwest of F locality (Text-figure 7). Rhodochrosite is not totally absent in the southeastern half; it mostly appears below the oxides, either as fresh unoxidized remnants or as lenses up to 200 feet long enclosed in, and surrounded by, oxides. Manganese oxides appear to envelop at least partly the strongly metallized centers in lead, zinc, and silver in and around F locality. Further from these centers, an overlapping does exist between manganese oxides and lower mineralizations of lead, zinc, and silver. Being more extent, however, these oxides appear as a marginal fringe surrounding sulfide ores. In the northwestern half of the mine, manganese oxides and other oxidation ores are absent due to lack of oxygen as mentioned before. Only rhodochrosite and fresh sulfide ores are present. Rhodochrosite, like lead, zinc, and silver sulfides, swings northward toward J but decreases in amount and even disappears before it reaches I locality in the extreme northwestern part of the mine (Text-figure 7). Here again, rhodochrosite partly overlaps lead, zinc, and silver mineralizations but extends higher than, and looks also as a marginal fringe above, them.

The writer refers the extension of manganese mineralizations beyond those of sulfide ores to the higher solubility of manganese. As this element was carried in the ore-bearing hydrothermal liquid in the upper thrust plate, lead, zinc, and silver sulfides were deposited first on cooling and lowering of pressure, while manganese remained in solution for another distance. Somewhere between the ore and the surrounding manganese deposits, the chemical and physical conditions were favorable for both deposits to occur almost simultaneously forming, thus, the above-mentioned zone of overlapping between manganese on the one hand, and lead, zinc, and silver on the other.

In summary, the distribution and zonation of ores in the Burgin mine are influenced by several factors such as (1) the proportion of sphalerite to the argentiferous galena, (2) the several surges of ore-bearing solutions, (3) the types of wallrocks and rock fragments which came in contact with these solutions, (4) their porosity-permeability characteristics, (5) the temperature-pressure effects, (6) the availability of channelways for the ore-bearing solutions, (7) the pH of these solutions and its variations, (8) the chemical composition of hydrothermal liquids and wallrocks, (9) the availability of oxygen for oxidation, (10) the courses of descending waters, and (11) the openness of ore bodies which came in contact with these waters.

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