# General Geology and Mines of the East Tintic Mining District, Utah and Juab Counties, Utah

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*By* H. T. MORRIS *and* T. S. LOVERING

*With sections on* THE GEOLOGY OF THE BURGIN MINE

*By* A. PAUL MOGENSEN, W. M. SHEPARD, H. T. MORRIS, L. I. PERRY, *and* S. M. SMITH

*and* THE GEOLOGY OF THE TRIXIE MINE

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# GENERAL GEOLOGY AND MINES OF THE EAST TINTIC MINING DISTRICT, UTAH AND JUAB COUNTIES, UTAH

BY H. T. MORRIS and T. S. LOVERING

## ABSTRACT

The East Tintic mining district is in the east-central part of the East Tintic Mountains, near the east margin of the Basin and Range province in Utah and Juab Counties, Utah. The district occupies the northeastern part of the Eureka quadrangle and is about 5 mi (8 km) wide and 6 mi (9.7 km) long. Officially it is within the designated boundaries of the Tintic mining district, but it generally though erroneously has been regarded as a separate district since the late 1800's.

Prospecting was first undertaken in East Tintic in 1870; although small quantities of ore were produced in 1899 and from 1909 to 1913, the district first achieved prominence in 1916 with the discovery of the totally concealed Central ore body of the Tintic Standard mine. Within a few years of this discovery, the Tintic Standard became one of the most productive silver mines in the world. Additional discoveries of important concealed ore deposits have continued to be made in the district, including the North Lily mine in 1927, the Eureka Lilly and Eureka Standard mines in 1928, the Burgin mine in 1958, and the Trixie mine in 1969.

In the area of the East Tintic district, the East Tintic Mountains consist of the eroded flank of a composite volcano, which, during the Oligocene, buried a preexisting mountain range that had been carved from folded and faulted Paleozoic sedimentary rocks. During this volcanic episode many stocks, plugs, dikes, and other intrusive bodies were injected into both the sedimentary and volcanic rocks. As the Oligocene volcanic and intrusive episode subsided, great volumes of hydrothermal solutions coursed through the rocks, chiefly among faults and fissures, eventually depositing large replacement ore bodies and veins that occur almost exclusively in the sedimentary rocks beneath the hydrothermally altered lavas.

The Paleozoic sedimentary rocks exposed in the district range from Lower Cambrian to Upper Mississippian. They exceed 9,000 ft (2,743 m) in thickness, and in areas beyond the limits of the East Tintic district, they are underlain by upper Precambrian strata and are overlain by a great thickness of Pennsylvanian and Permian beds. No rocks of Mesozoic age are exposed.

The Cambrian rocks consist of the Lower Cambrian Tintic Quartzite, 2,300-3,200 ft thick (701-975 m), of which only the upper half or less is exposed in the East Tintic district; the Middle Cambrian Ophir Formation, 375-425 ft (114-130 m) thick; Teutonic Limestone, 390-420 ft (119-128 m) thick; Dagmar Dolomite, 60-100 ft (20-30 m) thick; Herkimer Limestone, 350-430 ft (107-131 m) thick; Bluebird Dolomite, about 180 ft (55 m) thick; Cole Canyon Dolomite, 830-900 ft (253-274 m) thick; and the Upper Cambrian Opex Formation, 145-245 ft (44-75 m) thick, and Ajax Dolomite, about 650 feet (198 m) thick. Of these, the middle limestone member and other subunits of the Ophir Formation, the Tintic Quartzite, and the Teutonic Limestone are the principal host rocks for ore in the East Tintic district.

The Ordovician rocks include the Lower Ordovician Opohonga Limestone, 300-850 ft (91-259 m) thick, and the Upper Ordovician Fish Haven Dolomite, 200-345 ft (61-105 m) thick. These formations are separated by an unconformity of low angularity.

The Bluebell Dolomite, which conformably overlies the Fish Haven Dolomite is only 335-600 ft (102-183 m) thick, but it contains strata of Late Ordovician, Middle Silurian, and Middle and Late Devonian age. The unconformities within it are not readily detectable except by hiatuses in the fossil record. The Bluebell Dolomite and the underlying Fish Haven Dolomite are also important host rocks for ore.

Other Devonian rocks consist of the Upper Devonian Victoria Formation, 250-300 ft (76-91 m) thick, the Pinyon Peak Limestone, 70-125 ft (21-38 m) thick, and a few tens of feet of Devonian strata in the lower part of the Fitchville Formation. These units also contain ore bodies.

The Mississippian rocks include the Fitchville Formation, which has a total thickness of about 300 ft (91 m) including the beds of Late Devonian as well as Early Mississippian age; the Lower Mississippian Gardison Limestone, about 500 ft (152 m) thick; and the Upper Mississippian Deseret Limestone, 1,000-1,100 ft (305-335 m) thick; Humbug Formation, 650 ft (198 m) thick; and Great Blue Formation, 2,500 ft (762 m) thick. Within the mining district, the greater part of the Great Blue Formation has been removed by erosion, but the complete formation is present a few miles to the northwest of the district, where it is overlain successively by the Manning Canyon Shale of Mississippian and Pennsylvanian age and the Oquirrh Formation of Pennsylvanian and Permian age.

Many of the thicker sedimentary formations are subdivided into members or other distinctive units to aid in geologic mapping, particularly in the rather restricted openings of the underground mines.

The igneous rocks of the East Tintic district include three groups of volcanic and intrusive rocks of Oligocene age and a large dike and associated flow of Miocene age. The oldest volcanic unit is the Packard Quartz Latite, which was erupted over a surface of mature relief and therefore ranges in thickness from 0 to more than 3,000 ft (914 m). It consists of a lower tuff unit, a lower vitrophyre, a thick porphyritic unit, an upper vitrophyre unit, and a locally rare upper tuff unit. No intrusive bodies of Packard composition crop out in the district, but regional studies indicate that it probably was erupted from vents 3.5 mi (5.6 m) to the south-southwest. Isotopic age-dating methods indicate that the Packard Quartz Latite was emplaced about 33 million years before the present.

Unconformably overlying the eroded Packard Quartz Latite are rocks of the Tintic Mountain Volcanic group, including the Copperpolis Latite, Latite Ridge Latite, and the Big Canyon Latite. Intrusive equivalents of these rocks occur as an extensive sill near Little Gough Spring in the southern part of the district, as a breccia pipe near Eunice siding in the east-central part of the district, and as stocks, plugs, and dikes a few miles south-south-

west of the district in the general area of the Sunrise Peak. Although none of these rocks contain recognizable quartz phenocrysts and are termed latite, monzonite, and monzonite prophyry, they are chemically equivalent to rhyolites, quartz latites, rhyodacites, and quartz monzonite porphyry. The Tintic Mountain Volcanic Group is about 1,000 ft (305 m) thick in East Tintic; however, it may be as much as 5,000 or 6,000 ft (1,524-1,829 m) thick in areas south of the district.

The youngest of the Oligocene eruptive rocks in the East Tintic district is the Laguna Springs Volcanic Group, consisting of the North Standard Latite, Pinyon Queen Latite, and Tintic Delmar Latite. Intrusive rocks that are equivalent to the Laguna Springs Volcanic Group include the Silver City stock of the main Tintic district, and many associated plugs, dikes, and sills of monzonite porphyry of similar composition and age in the East Tintic district. Chemically, however, many of these rocks also are equivalent to rhyodacite, granodiorite, and quartz monzonite. The Laguna Springs Volcanic Group ranges in thickness from 0-1,000 ft (305 m) or more. Isotopic dating methods used on the freshest available rock samples indicate ages of approximately 32 million years.

Associated with dikes and plugs of the Silver City Monzonite are dikes, pods, and pipes of intrusion breccia containing rounded pebbles of quartzite and other rocks. These pebble dikes define the sites of deep intrusive bodies; they also indicate the distribution of quartzite and other types of sedimentary rock beneath the Tertiary lavas. Many of them served as conduits for hydrothermal solutions, including the ore-depositing fluids.

The Miocene igneous rocks include a large dike and flow unit known collectively as the Silver Shield Quartz Latite. These units crop out in the northeastern part of the district where the dike cuts Oligocene volcanic rocks and underlying Paleozoic strata. Their isotopic age has been determined to be about 18 million years.

The postvolcanic deposits in the district are chiefly colluvium, alluvium, and lacustrine beds of Pleistocene and Holocene age.

Structurally, the East Tintic district is near the central part of the Sevier orogenic belt. In central Utah this belt consists of four or more large imbricate thrust plates that were emplaced by gravity-propelled movements during medial and late Montana time, prior to the eruption of the lavas. One of these thrust faults — the Midas — is believed to deeply underlie the northern East Tintic Mountains, and the rocks above it have been compressed into the Tintic-Oquirrh belt of large northtrending asymmetric folds. The tear fault that delimits the folded Midas thrust plate on the south is believed to underlie lavas in the southeastern part of the East Tintic district.

The dominant pre-Tertiary structure in the district is the overturned East Tintic anticline. The west limb of this fold dips moderately west, but the east limb is cut and displaced by the concealed East Tintic thrust fault, which dips west at a low angle at depth in the central part of the district. The folded rocks were also cut by northeast-trending tear faults, northwest-trending strike-slip faults, and at least one east-trending normal fault prior to the eruption of the lavas.

After the main eruptive phases of the Oligocene volcanism, the deformed Paleozoic rocks, the lavas, and the intrusive rocks were all cut by north-northeast-trending fissures, which localized pebble-breccia and igneous dikes and also became conduits for hydrothermal solutions. Later, during the late Miocene and extending to the Holocene, some Basin and Range faulting took place.

Over the past 50 years, production from ore bodies below the water table has been hampered by inflows of hot saline water, which is believed to have its origin in a system of thermal springs resulting from regional Pleistocene basalt volcanism. Temperatures exceeding 150°F (65°C) have been recorded in the lower workings of part of the Burgin mine.

The principal ore deposits of the East Tintic district include (1) replacement bodies in Paleozoic carbonate rocks, (2) veins in the Cambrian Tintic Quartzite, (3) disseminated deposits in the Apex Conglomerate and in adjacent Paleozoic rocks, (4) bodies of iron and manganese oxides, and (5) masses of halloysite clay in limestone and dolomite beds near their contacts with igneous rocks. The metalliferous ores are valuable chiefly for lead, zinc, silver, gold, copper, cadmium, and manganese. The unoxidized minerals are mostly simple sulfides, tellurides, and sulfosalts. The oxidized minerals include a wide variety of sulfates, carbonates, arsenates, antimonates, and other compounds. The gangue minerals include jasperoid, quartz, barite, rhodochrosite, dolomite, and calcite.

Associated with the metalliferous bodies and their related igneous rocks are zones of hydrothermal alteration. These include Early Barren dolomitic and chloritic alteration, Mid-Barren argillic (acid) alteration, Late Barren pyritic, silicic, and calcitic alteration, and Early Productive potassic and manganesic alteration. During the Productive, or or-depositing, stage, traces of the ore metals were deposited in primary halos in the altered rocks above many of the ore bodies.

The production of the East Tintic district from 1899 through 1975 was 4,827,624 short tons (4,378,655 tonnes) of metalliferous ore, having an estimated gross value of $231,014,962. The greater part of this ore was produced from the Tintic Standard and the Burgin mines. Other important producing mines include the North Lily, Eureka Lilly, Eureka Standard, Apex Standard, Iron King, Zuma, and Trixie mines. Iron oxide ores have been produced from the Iron King mine; manganese ores have been produced from the Tip Top, Oxen, Iron King, Apex Standard, and other properties; and halloysite has been produced from the Zuma, Crown Point, and Maple claims. Nonproductive mine developments include the Pinyon Queen, Independence (Silver Shield), East Standard, North Standard, Water Lillie, Central Standard, Copper Leaf, Homansville, East Tintic Coalition, Big Hill, Crown Point, Montana, Roundy, East Crown Point, South Standard, and others.

Production in 1975 was 230,499 tons (209,063 tonnes) of silver-lead-zinc ore, which also contained considerable amounts of cadmium. Important reserves and resources of both high- and low-grade base and precious metal ores are known to be present in the district and are undergoing continuing evaluation and development.

# INTRODUCTION

To December 31, 1975, the East Tintic mining district, Utah, has yielded approximately 4.83 million short tons (4.38 million tonnes) of silver, gold, and base-metal ores, largely from concealed deposits overlain by many hundreds of feet of barren rocks. These ores have a gross valuation of approximately $231 million. The district first achieved prominence in 1916 with the discovery of the ore bodies of the Tintic Standard mine, which for a time was the world's richest silver producer (Lindgren, 1933, p. 588). By 1946 this deposit and a number of other deposits discovered and developed nearby had been exhausted, and the district became dormant. A dramatic revival of mining activities in the East Tintic district began in 1956 after the discovery and subsequent development of the concealed Burgin ore bodies in an area 1 mile (1.6 km) southeast of the Tintic Standard that previously had been only superficially prospected. As in the earlier history of the district, the Burgin development has led to the discovery of other concealed deposits, focusing international attention on the revitalization of a nearly abandoned mining district by the application of geologic and geochemical techniques.

## LOCATION AND ACCESSIBILITY

The East Tintic district is in Utah and Juab Counties approximately 55 mi. (88.5 km) south-south-west of Salt Lake City (fig. 1). Although it is officially a part of the Tintic mining district, it generally has been regarded as a separate mining district since the early 1900's when distrust and later antagonism developed between the residents and mine operators of main Tintic district and the developers of the East Tintic mines.

Loughlin (in Lindgren and Loughlin, 1919, p. 246) originally defined the East Tintic district as "the area within the Tintic quadrangle east of meridian 112°5′ and south of the Denver and Rio Grande Railroad." The area described in the present report, however, is bounded by meridians 112° and 112°05′ and parallels 39°55′ and 40°; this designation more adequately defines the northern, eastern, and southern boundaries of the district. As redefined, it contains about 28 square miles (72 $km^2$) and constitutes the northeastern two-thirds of the Eureka 7½-minute quadrangle.

Dividend, now little more than an abandoned townsite, was the only settlement in the East Tintic district and was largely a company town belonging to the Tintic Standard Mining Co. The main sources of supply for the district are Eureka, about 3 mi (4.8 km) to the west; Provo, 45 mi (72 km) to the northeast; and Salt Lake City, about 80 mi (129 km) north by road. An excellent paved road, U.S. Highway 6-50, passes through the central part of the district, and many reasonably well-maintained secondary roads provide easy routes of haulage for the trucks that carry ore from working mines to railroad sidings. Both the Denver & Rio Grande Western and the Union Pacific Railroads serve the main Tintic district at or near Eureka, but only the Denver & Rio Grande Western has spurs available for loading ore within the East Tintic District.

## PHYSICAL FEATURES

The East Tintic district is in the east-central part of the East Tintic Mountains, a north-trending fault-block range near the east margin of the Great Basin. The topography of the small part of the range in which the district is located is dominated by east- and north-trending ridges and valleys that extend from the range crest, 1 mile (1.6 km) west of the district, to Goshen Valley bordering the eastern part of the district and to Cedar Valley, north of the district.

The topographic relief in the district is moderate; the lowest elevation, about 4,910 ft (1,497 m), is in the southeastern part of the mapped area at the edge of Goshen Valley, which continues to descend northeastward to an elevation of 4,490 ft (1,369 m) at Utah Lake. The highest elevation is Pinyon Peak, 7,720 ft (2,353 m), in the northwestern part of the district.

In the latitude of the East Tintic district, Goshen Valley is approximately 1,000 ft (305 m) lower in elevation than Tintic Valley, which forms the western border of the East Tintic Mountains. Consequently, the east-trending valleys of the East Tintic district are generally steeper and somewhat more rugged than the canyons that cut the western slope of the range.

The gentle to moderate topography that characterizes the central part of the East Tintic district is largely carved out of massive fresh and hydrothermally altered volcanic flow units and welded tuffs. The presence of local centers of hydrothermal alteration in the district is also indirectly responsible for the many semi-isolated hills and much of the local drainage. For example, the silicified areas, such as Big Hill, weather in relief, and the argillized and weathered pyritic rocks nearby erode more rapidly into valleys.

The steepest slopes in the district are on Pinyon Peak, a mountain carved chiefly from Paleozoic carbonate rocks that stood high above the lava fields in Oligocene time before it was finally buried by volcanic debris and flows. This ancient peak is being exhumed by erosion, and it now duplicates in a subdued way the topography of the prevolcanic range. As shown by Morris and Anderson (1962, p. C1), the total prevolcanic relief within the district is at least 4,400 ft (1,341 m) and possibly much greater.

## CLIMATE AND WATER SUPPLY

The climate of the East Tintic Mountains is semiarid and is characterized by warm summers and moderately cold winters. Although no records of precipitation have been kept in the East Tintic district, the average annual rainfall probably lies between 10 and 14 in. (25-36 cm), which is the approximate annual precipitation recorded respectively at Elberta, 5 mi (8 km) east of the district, and at Eureka, 3 mi (4.8 km) to the west. As a rule, the heaviest precipitation occurs during December and January, although rain is fairly common during July and August in the form of afternoon and evening thunderstorms. The driest months are June and September, and periods during which no precipitation falls for 25 days or longer are common throughout the year.

Because of the meager precipitation there are no perennial streams in the East Tintic district, except

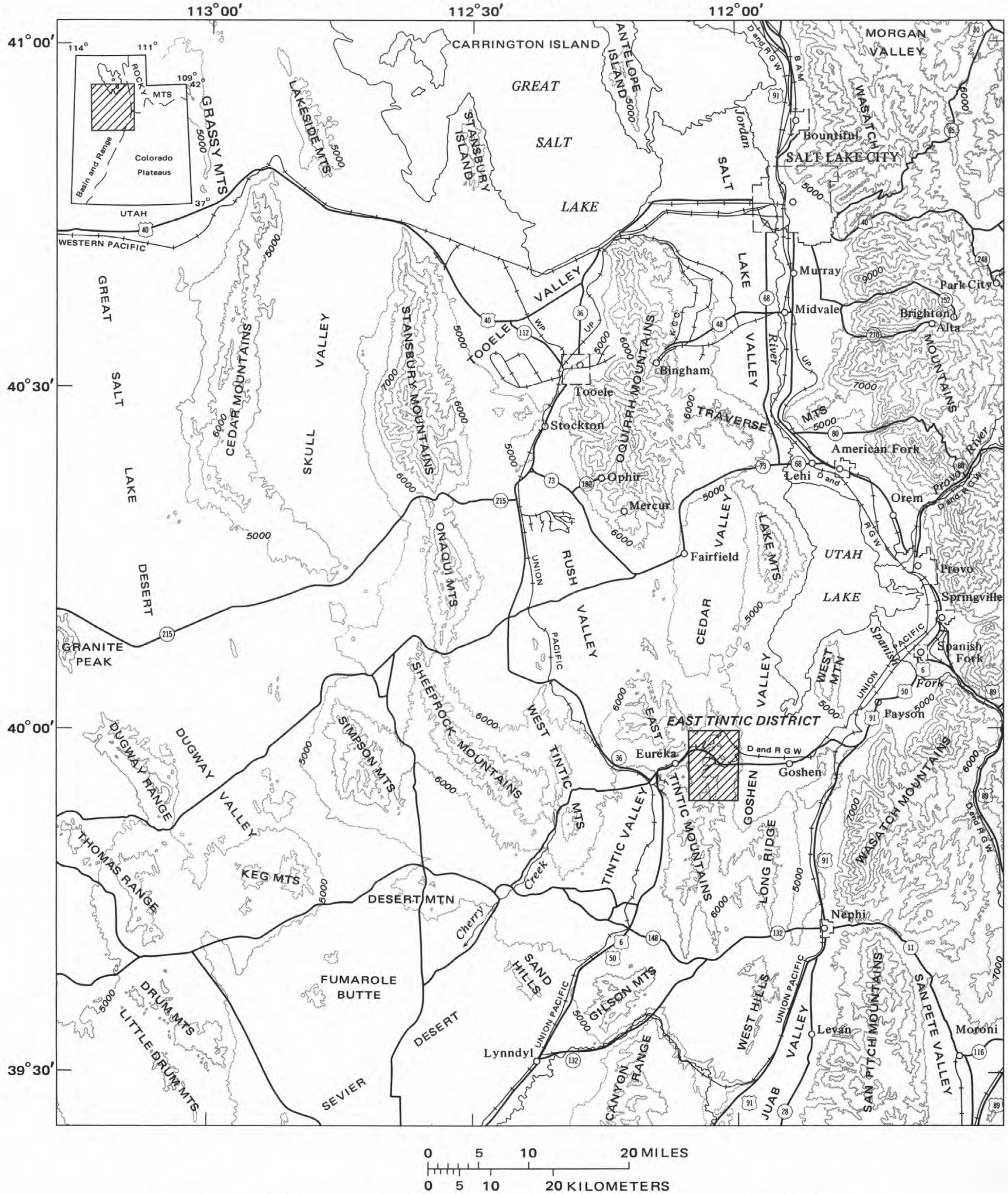



FIGURE 1. — Index map of north-central Utah showing location of East Tintic mining district.

for short stretches below some of the larger springs. Such springs are relatively abundant, however, and many of them have been developed and covered for use as local water supplies. The most productive springs in the area are Little Gough spring in the southwestern corner of the district and Big Gough spring a third of a mile farther to the south, just south of the map area boundary. These springs are the principal source of water for the Burgin and Trixie mines, and they formerly supplied Dividend and the Tintic Standard mine.

According to the U.S. Weather Bureau (1960), the mean monthly temperatures at Elberta from 1931 to 1955 ranged from a low of 26.3°F (-3.16°C) in January to a high of approximately 73°F (22.8°C) in August. The highest recorded daily temperature at Elberta is 114°F (45.5°C), and the lowest is -15°F (-26°C). These temperatures also should be fairly typical for the East Tintic district. In general, the prevailing low humidity makes both the commonly high summer temperatures and the commonly low winter temperatures quite tolerable.

## VEGETATION

In the semiarid climate of the East Tintic district the natural plant assemblages display a remarkably delicate adjustment to slightly differing local environments. The hotter and drier south-facing slopes near the base of the range are dominated by sage (*Artemesia*), juniper (*Juniperus utahensis*), Brighams tea (*Ephederis*), pricklypear (*Opuntia echinocacus*), and hedgehog cactus (*Pediocactus*). On the slopes above an elevation of 6,000 (1,829 m), pinon pines (*Pinus edulis* and *P. monophyllum*) are interspersed among the junipers, and antelope-brush (*Purshia tridentata*) is particularly common in areas of dolomite outcrops.

A somewhat greater variety of plants is found in the ravines and watercourses. The broad alluviated parts of the valleys near the base of the range are characterized by rabbitbrush (*Chrysothamnus*) of several species, tamarisk (*Tamarix*), also called saltcedar, an exotic species that has recently invaded the district, and by broad areas of June grass. The higher parts of the valleys, and particularly areas near springs, contain locally dense tangles of dwarf and bigtooth maple (*Acer glabrum* and *A. grandidentatum*), chokecherry (*P. melanocarpa*), mountain alder (*Alnus tenuifolia*), gooseberry (*Ribes inerine*), barberry (*Berberis repens*), and other phreatophytes. The highest north-facing slopes of Pinyon Peak contain scattered small stands of quaking aspen (*Populus tremuloides*), Douglas fir (*Pseudotsuga taxifolia*), white fire (*Abies concolor*), and Engelmann spruce (*Picea engelmanni*).

Any discussion of the vegetation of the East Tintic district would be incomplete without mention of the spring wildflowers that brighten an otherwise drab and monotonous landscape. The varieties are too numerous to mention in this report, except, perhaps, for the more characteristic lupine (*Lupinus*), segolily (*Calochortus nuttallii*), and Indian paintbrush (*Castilleja*).

## PREVIOUS STUDIES

Prior to the discovery of the Tintic Standard ore deposit in 1916, only scant attention had been given to the East Tintic district. The area is included on the geologic maps of the Tintic quadrangle by Tower and Smith (1899, pl. 74), but the lack of mining activity in the area at the time apparently discouraged these geologists from taking any special notice.

Similarly, there was little activity to warrant the attention of Lindgren and Loughlin (1919) during their principal examination of the main Tintic district in 1911 and 1913. However, by 1914 work was well underway in the Tintic Standard No. 1 shaft, and Loughlin apparently examined these workings and the surrounding area at that time. A later visit in December 1916 allowed him to examine ore bodies being mined on the 1,600 ft level of the No. 1 shaft. However, the discovery of the main Tintic Standard ore body postdated this last examination of the mine, and the discussion of the main ore body and the geology of the No. 2 shaft area by Loughlin (in Lindgren and Loughlin, 1919, p. 252-253) is based on samples of ore and descriptions of the mine provided by E. J. Raddatz, the discoverer and developer of the mine.

After 1918, the increasing number of underground workings and drill holes in the district began to reveal the lava-concealed rocks, structure, and hydrothermal alteration of the area in detail. Crane (1925) was probably the first to present a comprehensive discussion of the geology of the East Tintic district in a paper that stressed the structural and stratigraphic localization of the ore deposits.

The size and richness of the blind ore bodies of the Tintic Standard mine prompted many other geologic studies and exploration programs in the surrounding area, and several additional concealed ore bodies were discovered. In particular, the halo of pyritized quartz latite above the rich Central ore body cut by the Tintic Standard No. 2 shaft stimulated the study of similar-appearing hydrothermally altered rocks nearby. The combination of strongly altered lava and favorable structure 1 mi (1.6 km) northwest of the Tintic Standard led Billingsley (1927) to recommend the underground development that resulted in the discovery of the North Lily ore center. Billingsley and Crane (1933) later presented a short but comprehensive and highly useful summary of the major features of the geology of the East Tintic and main Tintic districts, together with a short history of the minig camps.

Probably the most extensive coverage of the geology and ore deposits of the East Tintic district, prior to the studies by the U.S. Geological Survey that began in 1943, is in the unpublished doctoral dissertation of Kildale (1938), which has been widely copied and used by many of the mining geologists who have worked in the district. In this report he stressed the geologic structure and ore deposits of the Tintic and East Tintic districts and included several subsurface maps, as well as a generalized geologic map of the area at a scale of 1:19,200. Shorter discussions of more specific features of East Tintic geology have been presented by Parsons (1925) and Farmin (1934).

Since 1943, when the U.S. Geological Survey first began its long-continued surface and subsurface studies in the East Tintic district, several papers have been prepared by mining geologists, some in collaboration with Geological Survey personnel. The more comprehensive papers are by Bush (1957, a, b), Kildale (1957), Howd (1957), Bush, Cook, Lovering and Morris (1960), Morris and Anderson (1962), Morris and Shepard (1964), Shepard (1966), and Shepard, Morris, and Cook (1968).

## HISTORY OF THE U.S. GEOLOGICAL SURVEY STUDIES

In 1942 and 1943 the temporary success of the German submarine campaign against Allied shipping had reached such proportions that grave concern arose about whether the supply of ores and other raw materials from foreign sources could continue. In the event of a long war, it seemed possible that the United States would require many new sources of ore within her own boundaries to augment those currently in use. As part of a long-range program designed to prepare for such contingencies, a detailed and comprehensive study of known blind ore bodies was decided upon. The excellent rock exposures at the surface, the extensive underground openings, and the many known blind ore bodies in the Tintic and East Tintic districts led to the selection of this area for an intensive study of the chemical, physical, and geological expressions of blind ore bodies at the surface.

Work was started in the East Tintic district early in 1943 and continued with only infrequent interruptions until 1951. From 1951 to 1969, continuing exploration and the development of new mine openings in the district, which culminated in the discovery of the Burgin mine in 1956 and the Trixie mine in 1969, prompted several subsequent short studies; all were related to the original plan of a comprehensive, integrated study of the area, embracing many types of investigations.

At the start of the work it seemed probable that spectrocscopic examination of altered rocks above blind ore bodies would indicate the presence of the underlying ores, either by the presence of unusual amounts of the ore metals or by the presence of some unsuspected chemical element or compound not ordinarily found in the fresh rock. Spectroscopic examination of the ore minerals, the gangue minerals, and the fresh and altered lava above the ore bodies, however, yielded no reliable correlation. On the contrary, it was found that many of the altered rocks above the ore bodies carried perceptibly smaller amounts of heavy metals than the fresh unaltered rock in the periphery of the altered areas. It was later discovered that this was not everywhere true, but that in many places the primary metal content of the lavas had been leached by hydrothermal solutions prior to the formation of ore bodies at depth; thus the amount of metal added to the overlying altered lavas during the ore stage was insufficient to compensate for the losses that occurred during the earlier leaching stage.

After the apparent failure of the geochemical method, attention was centered on stratigraphic, structural, and petrographic studies for several years. Detailed maps of alteration zones related to blind ore bodies were made in the field, and specimens were collected almost daily for microscopic work that was carried concomitantly with the geologic mapping. The preliminary results of these studies are in publications by Lovering (1949, 1950a) and Lovering and others (1960).

After World War II, geochemical methods using new techniques for determining minute traces of introduced ore-stage metals by wet-chemical, atomic absorption, and other methods were adopted with considerable success. The results of these studies have appeared in a series of papers including reports by Lovering, Sokoloff, and Morris (1948), Almond and Morris (1951), Morris and Lovering (1952), and Lovering and Morris (1959).

Because a thorough knowledge of the geology of the district as a whole was a critical necessity to the geochemical and geophysical investigations, detailed stratigraphic and structural studies were made not only within the East Tintic district but also throughout the East Tintic Mountains and adjacent areas. Many of these studies have been the subject of separate reports, and those that incorporate data from the East Tintic district are in papers by Morris (1957), Morris and Lovering (1961), and Morris (1964) as well as in reports listed above. Aspects of East Tintic geology also have been presented in other papers that describe the discovery of the Burgin mine (Morris, 1964b, p. 271-295) and the micromineralogy of galena ores from the Burgin mine by Radtke, Taylor, and Morris (1969), and in papers related to geothermal studies in the district, including reports by Lovering and Goode (1963) and Lovering and Morris (1965).

## OBJECTIVES OF PRESENT REPORT

Although the results of many of the studies carried out in the East Tintic district since 1943 have been published, this report has been prepared to present an integrated, comprehensive review of the general geology of the East Tintic district in a single publication. In addition, the constantly increasing number of drill holes and mine workings in areas covered by lava and surficial deposits have revealed geologic relations and other data that require modification of some earlier concepts and conclusions.

The description of the sedimentary rocks in this report is modified from more comprehensive discussions in an earlier paper on the stratigraphy of the East Tintic Mountains (Morris and Lovering, 1961). The summaries given here emphasize the specific characteristics of the Paleozoic strata in the productive or potentially productive parts of the East Tintic district and their importance as host rocks for the replacement ore bodies and veins.

The sections dealing with the igneous rocks in this report contain lithologic and petrographic descriptions for seven new volcanic formations and one new volcanic-sedimentary formation, which have been established from the sequence of latitic rocks that overlie the Packard Quartz Latite. Some earlier interpretations of the geologic structures also have been revised on the basis of new information, both from surface and underground exposures.

The geologic map (pl. 1) is a revision of a preliminary map of the East Tintic district (Lovering and others, 1960, sheet 1). The geologic cross sections (pl. 2) accompanying the map are drawn through areas containing the largest number of mines and drill holes. The structural plan at 4,500-ft (1,372 m) elevation (pl. 3) supplements the geologic map and cross sections.

Except for some information concerning the Burgin and Trixie mines, which is current through February, 1977, the data presented in this report are fairly complete through January 1976, and no attempt has been made to modify them after this date.

## ACKNOWLEDGMENTS

Many individuals and companies have contributed in greater or lesser ways to the various studies by the Geological Survey in the East Tintic district. Without access to the extensive underground workings and drill-hole data of the mines operated by the Tintic Standard, Anaconda, Chief Consolidated, Newmont, Central Standard, Kennecott, Western States, and other mining companies, the investigations would have been seriously restricted and largely without point. It is, therefore, a pleasure to acknowledge the cooperation that was extended by the mine operators, geologists, and engineers in the district, several of whom are now deceased. Special acknowledgment is made of the cooperation and assistance provided by the following individuals: Milton Payne, James Wade, Fred Hanson, Earl Hanson, Wesley Christensen, and Clarence Kirk, of the Tintic Standard Mining Co., who offered every facility and support at their disposal; M. B. Kildale, Dudley Davis, W. P. Fuller, Robert Thomas, and Leonard Ryan of the International Mining, Smelting and Refining Co., who allowed the writers full access to the North Lily mine and gave generously of their time and information so far as was possible under the limitations of an extensive exploration campaign which was underway from 1945 to 1950; C. A. Fitch, Sr., C. A. Fitch, Jr., Louis Cramer, W. G. Stevenson, Hollis Peacock, M. T. Evans, and Harry Pitts of the Chief Consolidated Mining Co., who made the records of their company completely available and assisted the writers in many ways; John Gustafson, Mayer Hansen, and George Murray of the Newmont Mining Co., who contributed invaluable information on the Apex Standard mine and neighboring ground; Thomas Pierpont and John Taylor provided much information on the inaccessible Central Standard and Copper Leaf mines; William Burgin, Douglas Cook, John B. Bush, Donald O. Rausch, William M. Shepard, James Anderson, Roger Banghart, A. Paul Mogensen, Samuel M. Smith, L. I. Perry, Paul Spor, and others of the Kennecott Copper Co. worked in close collaboration with the members of the Geological Survey during Kennecott's development of the Burgin, Trixie, and Ballpark ore bodies; R. T. Walker and John H. Manson provided information on the inaccessible North Standard mine, which would otherwise have remained a complete enigma; L. E. Stein, J. F. Greer, and J. George Jones kindly supplied maps of the Silver Shield, Crown Point and Zuma mines, respectively, and gave what information they could on the largely inaccessible underground workings of these properties.

It is appropriate here to mention also the seemingly intangible but invaluable help given to the Geological Survey by the late John M. Boutwell of Salt Lake City, whose wide acquaintance with members of the mining profession and friendly attitude toward the Survey did much to create the good will so essential to a healthy climate for Survey investigations.

The work of many mining geologists has been utilized by the mining companies who have engaged in exploration in the East Tintic district, and it is appropriate to acknowledge these authors of the many geologic reports and maps that were made accessible to the Geological Survey: Guy Walter Crane and Louis Cramer, while employed by the Chief Consolidated Mining Co., did much excellent surface and underground work in the Apex Standard mine, and Crane's detailed work on the stratigraphy of the Tintic district was the standard for the camp for at least two decades. The reconnaissance maps of Paul Billingsley, M. B. Kildale, L. Kenneth Wilson, and Walter Landwehr were used by the writers in gaining a perspective of the overall geology of the area prior to their own investigations. Lee C. Armstrong and Rudolph C. Gebhardt of the Longyear Drilling Co. made available detailed maps of the alteration and geology in the areas adjoining the East Tintic district and participated in many discussions of the problems of geochemistry and alteration.

Because of the relatively long duration of the study, and also because of the widespread general interest in the many geologic and geochemical problems of the East Tintic district, the project was favored by the visits and stimulating discussions of many individuals. Something of value came out of each of these visits, but it is manifestly impossible to list the aid received in this manner or to enumerate the scores of geologists who contributed significant observations and ideas. However, we recall the especially outstanding contributions by B. S. Butler and F. C. Calkins, whose wide experience suggested the answers to certain difficult problems at an early stage in the investigations.

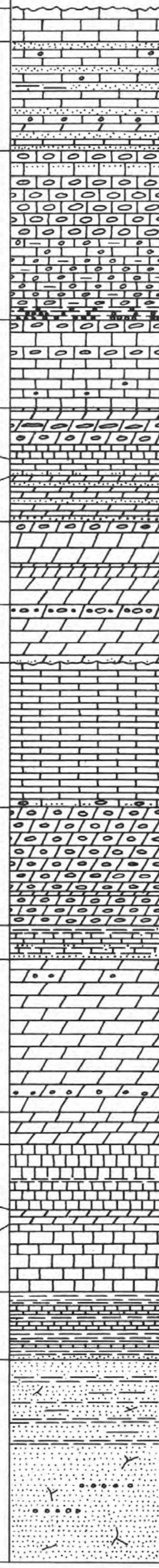
The actual labor of writing this report has devolved upon H. T. Morris and T. S. Lovering, but many of the data that are presented here represent the work of other full- and part-time members of the Geological Survey and other scientists who have been associated with us in one capacity or another. These individuals include W. M. Stoll, A. H. Wadsworth, H. V. Wagner, B. F. Stringham, L. S. Hilpert, J. Fred Smith, and Alberto Terrones L., who were associated with the East Tintic project for intervals ranging from 4 months to 2 years during the period 1943-45; J. W. Odell and Eduardo Mapes V., who provided valuable assistance during the summer months of 1946; F. G. Bonorino, J. J. Rossi, John Lemish, and Carlisle Hill, Jr., each of whom spent from 2 to 6 months in the district between 1948 and 1950; H. D. Goode studied the Quaternary deposits and made other investigations between 1949 and 1956; Allan Disbrow, A. M. Bassett, and W. A. Bassett, who were associated with the project at intervals during 1951-53; R. E. Lehner, who contributed to studies in the Chief Oxide (Burgin) area during the early part of 1955; and R. L. Mauger, Robert Kayser, and Daniel Gorski, who carried out semi-independent studies under a National Science Foundation grant during 1967-69.

## ROCKS

The rocks in the East Tintic district include a wide variety of consolidated sedimentary strata of Paleozoic age, extrusive and intrusive igneous rocks of Oligocene and Miocene age, and semiconsolidated and unconsolidated sedimentary deposits of Quaternary age. Detailed descriptions, fossil faunas, and regional correlations of the Paleozoic formations are given in other reports (Lindgren and Loughlin, 1919, p. 22-42; Morris, 1957, p. 3-26; Morris and Lovering, 1961); therefore, only generalized descriptions of these formations are presented here. The igneous rocks have not been fully described in other reports and are presented here in greater detail. The descriptions of the semiconsolidated and unconsolidated deposits in part are summarized from Goode (in Morris and Lovering, 1961, p. 129-138).

### PALEOZOIC ROCKS

The pre-Tertiary rocks exposed in the East Tintic district range in age from Early Cambrian to Late Mississippian (fig. 2). They are largely miogeosynclinal in origin, total more than 9,000 ft (2,743 m) in thickness, and belong to a Paleozoic section whose thickness exceeds 28,000 ft (8,534 m) in adjacent parts of the East Tintic Mountains. More than three-quarters of these rocks consist of limestone and dolomite, quartzite and sandstone are next in abundance, and shale is least abundant. In the general vicinity of the ore deposits, many of the limestone units have been hydrothermally altered to dolomite. Most commonly this dolomite lies between faults or within breccia zones, but some units, notably the Cole Canyon and Bluebird Dolomites and black cherty dolomite beds of the Fitchville Formation, are dolomite from base to top throughout the greater part of the district; in contrast, they are largely limestone in outlying parts of the East Tintic Mountains remote from igneous rocks and major solution channelways. Consequently, we believe these units are not syngenetic dolomite strata. Other formations, notably the Ajax, Fish Haven, and Bluebell Dolomites, are dolomitic from top to bottom over their entire areas of exposure in western Utah and beyond and thus are believed to be syngenetic and not the product of Tertiary hydrothermal alteration.



| SYSTEM or SERIES | FORMATION | LITHOLOGIC CHARACTER | THICKNESS (FEET) | DESCRIPTION |
|---|---|---|---|---|
| Upper Mississippian | Great Blue Formation | | +100 | Topliff Limestone Member: blue-gray limestone |
| | Humbug Formation | | 650 | Interbedded blue-gray sparsely cherty limestone and persistent lenses of buff sandstone |
| | Deseret Limestone | | 1,000-1,100 | Uncle Joe Member: light-gray massive cherty coquinoid limestone about 550 feet thick<br>Tetro Member: medium-gray, cherty, sandy, and argillaceous limestone about 475 feet thick<br>Phosphatic shale member: sooty black phosphatic shale and silty limestone 5 – 150 feet thick |
| Lower Mississippian | Gardison Limestone | | 500 | Upper member, about 125 feet thick, is blue-gray massive cherty limestone; lower member, about 375 feet thick, is blue-gray medium-bedded fossiliferous limestone |
| Lower Mississippian and Upper Devonian | Fitchville Formation | | 300 | Eight distinctive units of limestone and dolomite, some cherty. Stromatolitic limestone at top |
| Upper Devonian | Pinyon Peak Limestone | | 70–125 | Blue-gray silt-streaked limestone |
| | Victoria Formation | | 250-300 | Interbedded gray dolomite and buff quartzite; some lenses of penecontemporaneous breccia |
| Devonian, Silurian, and Upper Ordovician | Bluebell Dolomite | | 335-600 | Dusky-gray massive dolomite; cherty near top. Prominent stromatolitic dolomite unit 275 – 300 feet above base |
| Upper Ordovician | Fish Haven Dolomite | | 200-345 | Dusky-gray massive dolomite; mottled and cherty near top |
| Lower Ordovician | Opohonga Limestone | | 300-850 | Light-blue-gray thin-bedded argillaceous limestone with many thin layers of flat-pebble conglomerate. Cherty and sandy at base |
| Upper Cambrian | Ajax Dolomite | | 650 | Mostly dusky-blue-gray medium-bedded cherty dolomite. Emerald Member, a thin unit of grayish-white, mottled dolomite, 90 – 180 feet above base |
| | Opex Formation | | 145–245 | Interbedded sandy limestone, shale, and sandstone |
| Middle Cambrian | Cole Canyon Dolomite | | 830-900 | Interbedded dusky blue-gray dolomite like Bluebird Dolomite, and creamy white laminated dolomite like Dagmar Dolomite. Sparsely cherty |
| | Bluebird Dolomite | | 185 | Dusky-gray dolomite with short white markings |
| | Herkimer Limestone | | 350-430 | Blue-gray argillaceous limestone; zone of gray-green shale about 180 feet above base |
| | Dagmar Dolomite | | 65–100 | Creamy-white laminated dolomite |
| | Teutonic Limestone | | 390-420 | Blue-gray argillaceous limestone with pisolitic beds in lower part |
| | Ophir Formation | | 375-425 | Upper shale member: gray-green shale<br>Middle limestone member: limestone and shale<br>Lower shale member: shale; sandy at base |
| Lower Cambrian | Tintic Quartzite | | +1,200 (Base not exposed) | Buff, prominently bedded quartzite; gray-green phyllitic shale beds in upper 500 feet. Chloritized basalt flow 980 feet above base, and lower 500 feet or so conglomeratic in adjacent areas<br>Total thickness in adjacent areas is 2,300 – 3,200 feet |

FIGURE 2. — Columnar section of Paleozoic rocks, East Tintic mining district.

## CAMBRIAN SYSTEM

### LOWER CAMBRIAN SERIES

#### TINTIC QUARTZITE

The oldest rock unit exposed in the East Tintic district is the Tintic Quartzite, which crops out only in the isolated lava-surrounded exposure one-third of a mile (0.5 km) north of the Tintic Standard No. 2 shaft. Underground it has been traversed by many miles of workings in the mines of the central part of the district extending from the Central Standard mine on the north to the Trixie mine on the south, and from the North Lily mine on the west to the Burgin mine on the east. It has also been penetrated by many surface and underground drill holes.

The base of the Tintic Quartzite is not exposed in the district, but in the northwestern part of the adjacent Tintic district, it is unconformably underlain by the Big Cottonwood Formation of Precambrian age. The top of the Tintic Quartzite throughout much of the central part of the East Tintic district is marked by a zone of low-angle faults but elsewhere is conformably overlain by the Ophir Formation.

The Tintic is composed chiefly of buff-colored medium-grained quartzite that displays conspicuous bedding. The quartzite conglomerate beds that are characteristic of the lower part (Morris and Lovering, 1961, p. 14-16) are not exposed in the East Tintic district, and the intercalated flow of altered basalt that occurs about 980 ft (299 m) above the base in the main Tintic district and on Long Ridge has been reported only questionably by Kransdorff (1934). Within the upper 500 ft (152 m) of the Tintic, moderately thick beds of gray-green medium-grained sericitic shale are common, and locally these beds may be confused with the more typically olive-brown fine-grained shales of the overlying Ophir Formation. Because of the general similarity of the shale beds of the two formations, the top of the Tintic Quartzite is placed arbitrarily at the top of the uppermost buff-colored quartzite.

In stratigraphic sections measured at complete exposures of the Tintic Quartzite 4.5 m (7.2 km) northwest of the district, it is 2,300-3,200 ft (701-975 m) thick and averages about 2,800 ft (853 m) in thickness. Probably only the uppermost 1,000 ft (305 m) of the formation is penetrated by the East Tintic mines.

The Tintic Quartzite has long been considered to be of Early Cambrian age, although the evidence provided by the sparse collections of fossils for placing the Lower-Middle Cambrian boundary at the top of the formation is not entirely convincing (Morris and Lovering, 1961, p. 17).

The Tintic Quartzite is an important host rock for pyritic copper-gold veins and other ore bodies. Because it consists predominantly of silica-cemented sand grains with little or no admixed mica or clay, it is comparatively brittle and fractures readily adjacent to faults and pebble dikes, producing breccia zones that locally became filled with ore minerals.

### MIDDLE CAMBRIAN SERIES

#### OPHIR FORMATION

The Ophir Formation consists of three members: a lower shale member, a middle limestone member, and an upper shale member. In total it is 375-425 ft (114-130 m) thick. Although no complete sections of the Ophir crop out in the district, incomplete sections are exposed in the vicinity of the Trixie and Apex Standard No. 1 mines. Underground, the Ophir has been extensively explored in the Central Standard, Copper Leaf, North Lily, Tintic Standard, Burgin, Eureka Standard, Apex Standard, Trixie, and other mines and prospects. It has also been the principal stratigraphic target of many drilling programs in the general vicinity of these mines.

The lower shale member of the Ophir Formation is about 175 ft (53 m) thick. It consists chiefly of gray- to olive-green sericitic shale, but near the base it is characterized by one or more beds of medium- to coarse-grained brown-weathering porous sandstone and about 90 ft (27 m) above the base by a bed of blue-gray medium- to fine-grained limestone 8-15 ft (2.4-4.6 m) thick, commonly altered to dolomite, which has been termed the carbonate marker bed (Morris and Lovering, 1961, p. 20). The surfaces of many shale beds are marked by ropy structures and irregular grooves that are probably of organic origin.

The middle limestone member consists of two or more beds of blue-gray fine-grained argillaceous limestone separated by beds of olive-green limy shale; it is 100-175 ft (30.5-53.3 m) thick. In the Tintic Standard mine area, four limestone beds are separated by three beds of limy shale; the lowest, or No. 1, limestone commonly contains layers that are crowded with ovoid to irregularly circular markings resembling *Girvanella*. The uppermost, or No. 4, limestone is somewhat lighter hued than the other limestone beds and commonly weathers creamy white. On the east side of Silver Pass Canyon 1,000 ft (305 m) east of the Trixie shaft, the middle limestone member is apparently represented by a single bed of thin-layered argillaceous limestone about 100 ft (30.5 m) thick, of which approximately the upper 6 ft (1.8 m) weathers grayish white.

The upper shale member consists of 70-90 ft (21-27 m) of light-greenish-gray fissile shale that weathers tan, ocherous brown, or light brownish to yellowish green. Below an exceptionally thin bedded zone about 30 ft (9 m) above its base, short lenses of calcareous sandstone are locally abundant. In general these lenses are thinner, less persistent, finer grained, and lighter hued than the sandstone beds at the base of the lower shale member. The upper part of the upper shale member is somewhat limy, and near its conformable contact with the overlying Teutonic Limestone, it contains many small lenses and pods of limestone and limy shale.

The Ophir Formation is the most extensively altered stratigraphic unit in the East Tintic district. Owing to its position above the thick, relatively unreactive Tintic Quartzite, it was commonly the first unit affected by the successive floods of hydrothermal solutions. Close to faults the limestone beds have been dolomitized, producing a rock that is somewhat darker and coarser grained than the original. In the vicinity of many of the monzonite porphyry plugs and dikes, the shale beds are argillized, and the hydrothermal dolomite beds are sanded and cavernous, resulting from the reaction with hot acidic solutions (Lovering, 1949, p. 25-28). Near veins and mineralized fissures, the sanded hydrothermal dolomite is extensively altered to jasperoid and ore, and the shale beds are pyritized and sericitized. The unweathered jasperoid ranges from light gray to black and in texture from fine grained to vuggy; the more highly metallized jasperoids that constitute siliceous ore commonly show more than one period of deposition and brecciation. In some of the ore bodies in the Burgin mine, replacement of the Ophir's limestone beds by rhodochrosite is more common than replacement by jasperoid.

The Ophir Formation has yielded fossils of Middle Cambrian age in the adjoining main Tintic district, and Gilluly (1932, p. 11) also reported Middle Cambrian fossils from beds less than 50 ft (15 m) above the base in the central Oquirrh Mountains. The occurrence of *Olenellus* reported by Walcott (1891, p. 319-320) in rocks that were later named the Ophir Formation in its type locality near Ophir, Utah, has not been confirmed by other collections. It is now generally accepted that the Ophir Formation, at least in the East Tintic Mountains, is entirely Middle Cambrian in age.

The Ophir Formation is the principal host rock for ore in all of the main productive mines in the East Tintic district; together the middle limestone member and a carbonate marker bed in the lower shale member probably have localized 60-70 percent of all the ore produced to date in the district. Ore bodies in this formation alone are estimted to have accounted for $135-$150 million of the nearly $231 million gross production credited to the district from 1899 to 1975. Some ore bodies in the Ophir are yet to be mined in the Burgin and other mines, and unexplored blocks believed to contain the Ophir Formation are present in several potentially productive parts of the district.

### Teutonic Limestone

Incomplete sections of the Teutonic Limestone crop out in a number of localities throughout the central part of the district. The most extensive exposures are on Mineral Hill, were the Teutonic conformably underlies the Dagmar Dolomite. The basal contact, which is conformable with the upper shale member of the Ophir, is exposed in several localities between the Apex Standard No. 1 and Trixie shafts. The upper contact is also exposed in the vicinity of the Eureka Lilly shaft and in the lower part of Homansville Canyon northwest of the Copper Leaf shaft. Like the Ophir Formation, the Teutonic Limestone is extensively exposed in the workings of the principal productive mines of the district.

In the areas where it has not been altered by hydrothermal solutions, the Teutonic Limestone is predominantly medium-bedded light- to dark-hued blue-gray limestone that is characteristically mottled and banded by irregular segregations of tan- and brown-weathering argillaceous and silty limestone. Oolitic and pisolitic beds are locally common in the upper two-thirds of the formation, and in the area southwest of the Apex Standard No. 1 shaft, the basal bed, 1-2 ft (0.3-0.6 m) thick, contains abundant Girvanella (?) spherules about three-eighths of an inch (0.95 cm) in diameter. A distinctive zone of dark-blue-gray thin-bedded fine-grained clastic limestone about 80 ft (24 m) above the base provides an excellent marker horizon throughout the district. The total thickness of the Teutonic is 390-420 ft (116-128 m), and it averages about 400 ft (122 m).

The Teutonic Limestone resembles the limestone beds of the middle limestone member of the Ophir Formation and of the Herkimer Limestone, and it is difficult to distinguish it from these units in limited exposures or drill holes unless the upper or lower contact is visible. Like the limestones in the Ophir Formation, the Teutonic is extensively dolomitized, sanded, jasperoidized, and replaced by ore in many places throughout the central part of the district.

The Teutonic Limestone is the host rock for ore in the Tintic Standard, Eureka Lilly, and other mines, but its importance has been overshadowed by the middle limestone member of the Ophir Formation. Because the limestone beds of both of these formations are nearly identical, both should be equally susceptible to ore replacement where the structural settings are similar.

### Dagmar Dolomite

The Dagmar Dolomite is the most distinctive and useful marker formation in the lower part of the stratigraphic sequence. It is conspicuously exposed on both sides of U.S. Highway 6-50 near the eastern entrance to Homansville Canyon and on both sides of State Road 159 between the Tintic Standard No. 1 and Eureka Lilly shafts. Less readily accessible exposures can be seen on Mineral Hill and in the area of sedimentary rock exposures half a mile (0.8 km) south-southwest of the Apex Standard No. 1 shaft. In all of these areas, the Dagmar is cut by faults, and its full thickness can be measured only in the exposures near the White Star adit in Homansville Canyon and on the south ridge of Mineral Hill. Underground, it has been recognized in the Tintic Standard, Eureka Lilly, Eureka Standard, and Apex Standard mines.

The Dagmar is a thin-bedded fine-grained laminated limy dolomite that weathers with a characteristic blocky fracture and a distinctive creamy white color. On fresh fractures it is medium gray, and thin chips are semitranslucent. In the section exposed near the White Star adit, several thin layers of siltstone are present near the base, and a shaly zone about 3 ft (1 m) thick is present within about 10 ft (3 m) of the top of the formation. The contact with the underlying Teutonic Limestone is gradational through an interval of 10-20 ft (3-6 m). The upper contact is somewhat more abrupt, but it is also conformable. No fossils have been found in the Dagmar Dolomite, but it is of Middle Cambrian age on the basis of definitive fossils found in underlying and overlying formations. The total thickness of the Dagmar ranges from 65 to 100 ft (20-30 m) and averages about 80 ft (24 m).

Some ore bodies have been mined from the Dagmar Dolomite in the Tintic Standard and Eureka Lilly mines, but the total value of these ores is probably less than $1 million.

### Herkimer Limestone

The Herkimer Limestone is probably the most extensively exposed unit of Middle Cambrian age in the East Tintic district. The broadest exposures are on the hill west of the Tintic Standard No. 2 shaft and on the south half of Mineral Hill. Somewhat smaller exposures are on the south side of Homansville Canyon and in the area west of South Apex Hill. In all of these exposures, the Herkimer is considerably faulted and altered. Underground, parts of the formation have been exposed in the Tintic Standard, Apex Standard, and Eureka Standard mines.

The Herkimer Limestone is 350-400 ft (107-131 m) thick and is subdivided into a lower limestone member 180 ft (55 m) thick, a shale member 20-30 ft (6-9 m) thick, and an upper limestone member 150-210 ft (46-64 m) thick (Morris and Lovering, 1961, p. 31-36). The lower and upper limestone members are chiefly medium-bedded blue-gray argillaceous limestone that is mottled and streaked by thin irregular layers and patches of limy mudstone. Because the shale member is commonly cut out by low-angle faults, the Herkimer Limestone is not subdivided on plate 1. In isolated exposures the limestones of the Herkimer commonly may be distinguished from somewhat similar-appearing beds in the Teutonic and Ophir Formations by the prevailing pink to brick-red color of the weathered argillaceous mottles and stripes in the Herkimer, the relative absence of oolitic and pisolitic beds, and the common presence of thin beds of flat-pebble conglomerate, especially in the upper limestone member.

The shale member is dominantly olive-green to buff fissile shale in beds 3 in. (7.6 cm) to 10 ft (3 m) thick interlayered with lenticular beds of argillaceous limestone and flat-pebble conglomerate. Commonly it is concealed by surface debris or cut out by low-angle faults.

Although the Herkimer contains only poorly preserved fossils, it lies between formations that have yielded definitive fossils of Middle Cambrian age; so it also is Middle Cambrian.

In many parts of the district, the limestones of the Herkimer have been dolomitized. This dolomite is darker colored and coarser grained than the original limestone, and locally it closely mimics the appearance of the conformably overlying Bluebird Dolomite. In some areas, as in the vicinity of the Tintic Standard No. 1 shaft, the Herkimer Limestone has also been jasperoidized or converted to fine-grained pulverulent silica.

The Herkimer Limestone is not considered to be an important host rock for ore. Some of the argentiferous lead ore mined above the 700-ft level of the Tintic Standard mine probably came from replacement deposits in the Herkimer, as did some of the oxidized lead and zinc ore in the uppermost part of the Eureka Lilly mine. At the Tip Top manganese mine, it probably also was replaced by rhodochrosite, now represented by mixtures of manganese oxide minerals; more than 5,000 short tons (4,535 tonnes) of ores averaging 25-30 percent manganese have been shipped from this deposit (Crittenden, 1951, p. 49).

### Bluebird Dolomite

The Bluebird Dolomite crops out in many of the same areas as the Herkimer Limestone. The most complete exposures are at the southern tip of Mineral Hill and a quarter of a mile (0.4 km) east of the Trixie shaft. Incomplete sections are exposed (1) on the south side of Homansville Canyon, (2) in the area between the North Lily and Tintic Standard No. 2 shafts, (3) in Burriston Canyon a quarter of a mile (0.4 km) south of the Eureka Standard shaft, (4) near the Iron King No. 2 shaft, and (5) on the north flank of South Apex Hill.

The Bluebird Dolomite is a massive-bedded dusky-blue medium-grained locally oolitic dolomite that is studded with many short white dolomite rods averaging a quarter inch (0.6 cm) in length and about a twentieth of an inch (0.13 cm) in diameter. Most of these distinctive inclusions are straight or slightly curved, but some are branched and resemble minute twigs. Although no definitive structures are preserved, they seem to be of organic origin.

The contact of the Bluebird Dolomite with the underlying Herkimer Limestone is conformable and reasonably well defined. Where the Herkimer is dolomitized, the boundary is arbitrarily placed at the base of the lowest bed in which white dolomite rods are abundant. The upper contact also is conformable and is placed at the base of the lowest Dagmar-like laminated bed in the Cole Canyon Dolomite. Because of the somewhat imprecise nature of the upper and lower contacts, the thickness of the Bluebird Dolomite may differ by 10 ft (3 m) or more between nearby outcrops; in general, however, the formation is 180-190 ft (55-58 m) thick in the East Tintic district.

Beyond the areas of ore production in the East Tintic Mountains, the Bluebird is largely medium-blue-gray fine-grained argillaceous limestone, suggesting that the dusky-gray twiggy dolomite in the vicinity of the monzonite and monzonite porphyry intrusions and ore deposits is a product of hydrothermal alteration. The significance and geochemistry of this type of regional dolomitization have been discussed by Morris and Lovering (1961, p. 38-39), Banks (1967), and Lovering (1969).

Trilobites of Middle Cambrian age have been collected by A. R. Palmer (in Morris and Lovering, 1961, p. 38) from beds near the top of the Bluebird Dolomite in the main Tintic district. Thus it is Middle Cambrian.

The Bluebird Dolomite is not known to be a host rock for ore in the East Tintic district.

### COLE CANYON DOLOMITE

The Cole Canyon Dolomite is widely distributed in the East Tintic district, but nowhere in this area is a complete stratigraphic section exposed at the surface or in mine openings. The northernmost exposures, extending from the vicinity of the North Standard shaft to the northern boundary of the district, afford an examination of the upper part of the Cole Canyon and its contact with the overlying Opex Formation. More readily accessible exposures are present in Homansville Canyon; however, these exposures are strongly faulted, the top is eroded, and the base is only doubtfully exposed in one small fault block. Less extensive partial exposures of the Cole Canyon crop out in the vicinity of (1) the Eureka Bullion shaft, (2) Iron King No. 2 shaft, (3) Montana shaft, (4) on the north flank of South Apex Hill, and (5) on the ridge crest a quarter of a mile (0.4 km) east of the Trixie shaft. In several of these areas, the base of the Cole Canyon is adequately exposed; however, the top is exposed only in an area of intense hydrothermal alteration 1,000 ft (0.3 km) west of the Iron King No. 2 shaft. Underground, the Cole Canyon has been penetrated by mine workings in the Water Lillie, Eureka Bullion, and probably the North Standard mines and by several exploration drill holes.

Most of the Cole Canyon Dolomite consists of alternating beds of light-gray fine-grained laminated dolomite resembling the Dagmar Dolomite, and dusky-blue-gray commonly twiggy dolomite resembling the Bluebird Dolomite. The light-gray beds, which weather creamy white are about 1-25 ft (0.3-7.6 m) thick; however, one rather massive light-gray-weathering bed is 60-90 ft (18-27 m) thick. The dusky-blue-gray beds are 10-30 ft (3-9 m) thick and are the dominant rock type in the upper 200-300 ft (61-91 m) of the formation. Both the light- and dark-colored beds locally contain small nodules of chert.

Complete exposures in adjacent parts of the East Tintic Mountains show that the Cole Canyon Dolomite ranges in thickness from 830 to 900 ft (253-274 m). The variation in thickness may be due to a disconformity, inasmuch as the boundary between the Cole Canyon Dolomite and the Opex Formation marks a rather abrupt change from massive dolomite to calcareous shale, shaly limestone, and sand-streaked flat-pebble conglomerate.

Like the Bluebird Dolomite, the Cole Canyon is largely blue-gray mottled argillaceous limestone in areas remote from intrusive rocks and ore deposits. In the area of transition between the dolomitic and the limy Cole Canyon, several of the dolomite beds terminate abruptly against faults, indicating a hydrothermal rather than syngenetic origin.

As reported by Lindgren and Loughlin (1919, p. 29) and Morris and Lovering (1961, p. 43), the Cole Canyon has yielded brachiopods and trilobites of Middle Cambrian age.

Although the Cole Canyon Dolomite is of moderate importance as a host rock for ore in the main Tintic district, it is not known to localize replacement ore bodies in the East Tintic district, except for small manganese deposits on the Oxen claims, which are south of Homansville Canyon.

## UPPER CAMBRIAN SERIES

### OPEX FORMATION

The Opex Formation crops out conspicuously across the eastern base of Pinyon Peak, extending from a point that is approximately midway between the Water Lillie and North Standard shafts to the north edge of the district. In this area, complete and unaltered sections in several separate fault blocks are eminently suitable for detailed study of the formation. In the central part of the district, where the Opex is perhaps the least well-known formation in the stratigraphic sequence, it crops out only in a strongly altered and metamorphosed area lying between the Iron King No. 1 and No. 2 shafts. In this locality it is intruded by many monzonite porphyry plugs and dikes and is cut by faults. Underground it is penetrated by the Big Hill and Water Lillie shafts, and it may also be exposed in workings from the Iron King No. 1 shaft.

Unlike the massive dark dolomitic rocks above and below it, the Opex Formation is chiefly light-grayish-blue thin-bedded argillaceous and arenaceous limestone interlayered with beds and lenses of dolomite, shale, and sandstone. Many of the limestone beds are shaly, oolitic, and conglomeratic, and they intergrade with calcareous shale along the strike and dip. The shale beds are 1 in. (2.5 cm) to as much as 20 ft (6 m) thick; they are generally greenish gray on fresh fractures and weather buff, yellow, and pink. A persistent bed of purple-weathering sandstone about 1 ft (0.3 m) thick marks the base of the formation in the Pinyon Peak area, and a somewhat thicker bed of brown-weathering sandstone occurs about 30 ft (9 m) below the top in the central part of the district. Because of its prevailing thin-bedded character and shaly composition, the Opex is readily eroded and commonly is concealed by talus and soil. In the Pinyon Peak area, the Opex Formation is 145 ft (44 m) thick — about 100 ft (30 m) less than a section measured at the type area near the Opex shaft in the main Tintic district (Morris and Lovering, 1961, p. 45).

The sharp contacts of the Opex Formation with the Cole Canyon and Ajax Dolomites record a sudden and temporary change during the deposition of the Opex Formation to a shallow depositional environment that received considerable amounts of clastic sediment. This abrupt change may indicate as disconformity within the Cambrian section; if so, the hiatus was of short duration.

In the exposures near the Iron King No. 1 shaft, the carbonate beds of the Opex have been strongly sanded, and the shale beds have been altered to kaolinite and other clays. Some porous granular brown-weathering limestone beds — termed "sawdust rock" in field notes — are believed to have resulted from the dedolomitization of syngenetic as well as hydrothermally derived dolomite beds.

Collections of fossils from the Opex Formation in several areas in the East Tintic Mountains contain representatives of the *Elvinia* zone, the most widespread faunal zone in the Upper Cambrian, according to A. R. Palmer (in Morris and Lovering, 1961, p. 46). These collections confirmed the Late Cambrian age of fossils collected from an unspecified formational unit in 1905 by Weeks (in Lindgren and Loughlin, 1919, p. 30).

No ore bodies are known to occur in the Opex Formation in the East Tintic district. It is an ore host rock of moderate importance in the main Tintic district, however, and like other carbonate-rich units should be considered a potential host rock of ore in areas of the district where prospecting is considered favorable.

### AJAX DOLOMITE

The outcrop pattern of the Ajax Dolomite in the East Tintic district closely approximates that of the Opex Formation. It is best exposed at the eastern base of Pinyon Peak, where its low-dipping beds, including the top and the bottom of the formation, may be followed across several faults of small displacement for more than two-thirds of a mile (1 km). Incomplete sections crop out in isolated exposures and in fault blocks near the Iron King No. 1 and No. 2 shafts. Although some of these latter exposures include both the lower and upper contacts, the formation is so altered and broken by faults that it is not possible to piece together a complete section. Similarly, the outcrops that are shown as Ajax Dolomite within half a mile (0.8 km) west of the Iron King No. 1 shaft are so strongly bleached, marbleized, and desilicified that their identification is not certain. Less altered, incomplete sections of the Ajax crop out in the vicinity of the Big Hill and East Tintic shafts, both of which penetrate substantial parts of the formation. The Ajax is also partly exposed in the Burgin mine and the Iron King tunnel, and a complete section may have been cut by the Water Lillie shaft and drill holes in the vicinity.

The Ajax Dolomite consists of three members: (1) a lower member, 90-180 ft (27-55 m) thick; (2) the Emerald Member, about 30 ft (9 m) thick; and (3) an upper member, 265-520 ft (81-159 m) thick. The lower member is dominantly medium- to thin-bedded light- to dark-blue-gray dolomite containing scattered small pods of black, brown, and white chert. The Emerald Member is a single bed of creamy or grayish-white medium- to coarse-grained faintly mottled massive dolomite. This bed is an excellent horizon marker and is an invaluable mapping aid in underground workings and in areas of complex structural deformation. The upper member closely resembles the lower member and is mostly medium-bedded dark-bluish-gray fine-grained dolomite containing a profusion of chert nodules, lenses, and stringers. The contacts with both the underlying Opex Formation and the overlying Opohonga Limestone are conformable but sharp and may represent disconformities. In the East Tintic district the average thickness of the most complete sections of the Ajax Dolomite is about 650 ft (198 m).

Desilication and dedolomitization of the Ajax Dolomite in the vicinity of the Iron King No. 1 shaft have produced the granular, porous, iron-stained calcic sawdust rock that is also described in the section of the Opex Formation. The solutions that accomplished this alteration apparently predate ore formation and are associated with plugs and dikes of monzonite porphyry.

The Ajax Dolomite was originally considered by Lindgren and Loughlin (1919, p. 32) to be Lower Ordovician; however, it was later found to contain definitive fossils of Late Cambrian age (Morris and Lovering, 1961, p. 50-51).

In the Burgin mine the western part of the main ore body rests on the Ajax Dolomite and presumably replaces a small part of it. In the main Tintic district the Ajax is a major host rock for ore bodies in parts of the Gemini and Mammoth-Chief ore zones and thus should also be considered a possible ore host in areas of favorable structural deformation and hydrothermal alteration in the East Tintic district.

## ORDOVICIAN SYSTEM

### LOWER ORDOVICIAN SERIES

#### OPOHONGA LIMESTONE

Outcrops of the Opohonga Limestone are rather widely distributed in the East Tintic district. The most complete exposures are on the eastern flank of Pinyon Peak, extending from the vicinity of the railroad tunnel in Pinyon Creek Canyon to a point beyond the northern boundary of the district. An incomplete section is also exposed close by in the lower plate of the Pinyon Peak thrust fault near the North Standard shaft. Another complete section is exposed a short distance west of the portal of the Iron King tunnel, and partial sections are exposed in the area between the Zuma and Iron King No. 1 shafts. A somewhat larger exposure underlies the hill immediately west of the East Tintic Coalition shaft and may include nearly all of the formation. Underground, the Opohonga is extensively exposed in the footwall of the East Tintic thrust fault in the Burgin mine; it is also present in the North Standard, East Tintic Coalition, Tintic Central, and Zuma mines, and in the Iron King tunnel.

The Opohonga Limestone is a distinctive and easily recognized unit consisting of a uniform sequence of medium- to thin-bedded light-blue-gray medium- to fine-grained argillaceous limestone with many thin beds of calcareous flat-pebble conglomerate. The limestone and conglomerate beds are separated by thin layers of silty and argillaceous limestone that weather brown, buff, yellow, and light red. In many beds small elongate pods and chips of blue-gray limestone are surrounded by seams of shaly material that divide and rejoin in a pattern resembling flattened hexagons, suggesting the term "chicken-wire structure" (Morris and Lovering, 1961, p. 54).

The base of the Opohonga, which conformably overlies the Ajax Dolomite, is locally marked by a bed of sandstone 2-6 ft (0.6-1.8 m) thick. This sandstone bed, and a zone a few feet (about 1 m) above it that contains large nodules of milky-white chert, are helpful features in establishing the Ajax-Opohonga contact throughout the district. The upper contact of the Opohonga apparently marks a disconformity that represents the planation of a substantial thickness of beds; as a result, the Opohonga varies widely in thickness; it is about 850 ft (259 m) thick in the southwestern part of the district but only about 300 ft (91 m) thick on Pinyon Peak.

In the vicinity of the Zuma and Iron King mines, the Opohonga is cut by many small bodies of monzonite porphyry and locally is converted to coarse granular calcite containing scattered crystals of pale-greenish-gray zoisite and pale-pink adularia. Thin sections of the marbleized limestone exposed in the access road to the Zuma shaft show interlocking calcite crystals that are veined and replaced by adularia, okenite, and celadonite.

The Opohonga Limestone has yielded many collections of fossils of Early Ordovician age (Lindgren and Loughlin, 1919, p. 33-34; Hintze, 1951; Morris and Lovering, 1961, p. 55-56). In its most complete exposures in the East Tintic Mountains, the Opohonga contains faunal zones *A* through *H* of Ross (1951).

Although there are many prospects in the Opohonga, only a relatively small amount of ore has been mined from it in the East Tintic district. Small lead-silver ore bodies occur in the Opohonga in the Zuma mine, and a few relatively unimportant deposits of manganese and iron ore were mined on the Iron King property. In the Burgin mine, where the Opohonga Limestone forms part of the footwall of the main ore body, it localizes a few small ore bodies, but as in the main Tintic district (Morris and Lovering, 1961, p. 57), it is not considered by the miners to be a favorable host rock for ore. Halloysite on the Maple Claim in Burriston Canyon probably replaces, in part, the Opohonga; however, the intense alteration precludes accurate identification.

## UPPER ORDOVICIAN SERIES

### Fish Haven Dolomite

The most extensive and complete exposures of the Fish Haven Dolomite are on the eastern and northern slopes of Pinyon Peak, extending from the central part of Pinyon Creek Canyon to beyond the north boundary of the district. In the same general area, other partial exposures crop out in the lower plate of the Pinyon Peak thrust fault near the North Standard shaft. A faulted but nearly complete section also crops out south of the Iron King No. 1 shaft; other incomplete exposures are nearby across Burriston Canyon. Underground, the Fish Haven is cut by several levels of the Burgin mine and probably also by the North Standard shaft.

The Fish Haven Dolomite disconformably overlies the Opohonga Limestone and marks a change in sedimentation. In contrast to the flaggy thin-layered limestone of the Opohonga, the Fish Haven consists of medium- to massive-bedded dark- to light-gray medium- to coarse-grained dolomite. Chert is a distinctive feature of the Fish Haven, occurring as sparse nodules near the base and as large nodules, pods, and stringers in the upper third of the formation. The uppermost bed is a massive ledge-forming unit of dark granular dolomite conspicuously mottled with irregular cream-colored spots 1 in. (2.5 cm) or more in diameter; this easily recognized unit is known in the Tintic and East Tintic districts as the Leopard Skin marker bed (Morris and Lovering, 1961, p. 60). The Leopard Skin bed is about 95 ft (29 m) thick on Pinyon Peak, where the complete section of the Fish Haven is about 345 ft (105 m) thick. In the Burriston Canyon area, the Fish Haven is estimated to be less than 200 ft (61 m) thick but may lie above an obscure low-angle fault.

In hydrothermally altered areas, particularly near ore, the chert nodules and stringers are commonly replaced by white dolomite or calcite. In alteration fringe zones the first noticeable effect is corrosion of the chert resulting in the development of calcite rims or crystal-lined cavities containing loose pieces of vuggy chert. Inward toward the solution conduit, the loose chert fragments are progressively smaller and more corroded, and the cavity linings are thicker and more noticeable. Within a few feet of the conduit, the chert nodules and stringers are represented only by small, ovoid, or tabular masses of white dolomite. Because of this effect, the contact between the Fish Haven and Bluebell Dolomites has not been recognized in some drill holes and mine workings.

The Fish Haven Dolomite contains an abundant and varied fauna of Late Ordovician (Richmond) age. These fossils have been collected, in part, and identified by Helen Duncan and Jean Berdan (reported in Morris and Lovering, 1961, p. 62).

In the Burgin mine, large bodies of zinc-rich sulfide ore have been discovered and mined in the Fish Haven and Bluebell Dolomites in the footwall block of the East Tintic thrust. Undiscovered replacement ore bodies may also occur in these formations elsewhere in the district.

## ORDOVICIAN, SILURIAN, AND DEVONIAN SYSTEMS

### BLUEBELL DOLOMITE

The Bluebell Dolomite is conspicuously exposed on Pinyon Peak from the Selma fault zone across the broad north spur and along the eastern slopes to the southeast base of the mountain. Scattered partial exposures, some showing either the lower or upper contacts, also crop out in Pinyon Creek Canyon within half a mile (0.8 km) north of the Central Standard shaft and in Burriston Canyon east, northeast, and west of the Zuma shaft. In the Burgin mine, southeast of the No. 2 shaft, parts of the Bluebell have been traversed by workings at the 1,050-, 1,200-, and 1,300-ft levels in an area of strong faults that are generally parallel to the strike of the steeply dipping beds. The upper part of the Bluebell is also extensively explored by workings at the 1,250-ft level of the Roundy shaft and the 1,000-ft level of the Crown Point No. 2 shaft.

The Bluebell is entirely dolomite, and it contains several distinctive marker horizons and key beds. The lower half of the formation largely consists of thin- to medium-bedded medium-gray mostly fine-grained faintly laminated dolomite that weathers creamy white to grayish white. A horizon of medium-gray mottled dolomite containing small corals lies 30-60 ft (9-18 m) above the base and is an excellent marker throughout the East Tintic Mountains. The upper half of the Bluebell is largely medium- to thick-bedded medium- to dark-gray coarse-grained dolomite, the upper part of which contains many nodules of black and brown chert and scattered small pods of white dolomite that may represent completely dolomitized fossils. The distinctive light- and dark-gray wavy laminated Colorado Chief marker bed, a stromatolite horizon that is a definitive mapping datum near the middle of the

Bluebell Dolomite in the main Tintic district (Morris and Lovering, 1961, p. 64-65), has not been recognized in the East Tintic district.

The Bluebell Dolomite is apparently conformable with both the underlying Fish Haven Dolomite and the overlying Victoria Formation. The absence of the Colorado Chief and other distinctive beds in the middle of the section that is exposed on Pinyon Peak, however, may indicate the presence of one or more obscure disconformities within the formation. Also, the Bluebell is only about 335 ft (102 m) thick on Pinyon Peak as compared to a thickness of nearly 500 ft (152 m) in the main Tintic district and about 600 ft (183 m) in the North Tintic district (Morris and Lovering, 1961, p. 64-67).

The general lithologic similarity of the Fish Haven and Bluebell Dolomites makes it difficult to distinguish them with confidence in small surface or underground exposures. In general, the Bluebell has a banded appearance in contrast to the mottled aspect of the Fish Haven and does not contain as much chert.

Sparse, moderately well preserved fossils collected from several horizons in the lower, middle, and upper horizons of the Bluebell indicate the presence of Late Ordovician, Silurian, and Devonian strata (Morris and Lovering, 1961, p. 67-69). Loughlin (Lindgren and Loughlin, 1919, p. 35) had earlier speculated on this possibility but did not present definitive lists of fossils. Of particular interest in the East Tintic district is a bed cropping out on the northwestern flank of Pinyon Peak that locally contains the abundant remains of the antiarch fish *Bothriolepis* (Morris and Lovering, 1961, p. 69).

Since 1970 zinc-rich sulfide ore bodies of considerable economic importance have been mined from the Bluebell and Fish Haven Dolomites in the footwall of the East Tintic thrust in the Burgin mine. Similar ore bodies are believed to occur in these formations beneath the Packard Quartz Latite four-fifths of a mile (1.3 km) north of the Burgin No. 2 shaft and await further exploration and development.

## DEVONIAN SYSTEM

### UPPER DEVONIAN SERIES

#### VICTORIA FORMATION

In the northern part of the East Tintic district, the Victoria Formation is conspicuously exposed in a horseshoe-shaped exposure on the northern and eastern sides of Pinyon Peak and in scattered outcrops surrounded by alluvium a third of a mile (0.5 km) north and northwest of the Central Standard shaft. In the southwestern part of the district, the Victoria crops out on both sides of the gulch that lies about midway between the Zuma and Crown Point No. 3 shafts. In this area the rocks are considerably bleached by contact pyrometasomatism and locally argillized to halloysite. In underground workings, the Victoria is exposed in the Burgin and Crown Point No. 2 and No. 3 mines.

The Victoria Formation consists chiefly of medium-grained wood-ash gray dolomite interlayered with fine- to medium-grained light-pinkish-brown rusty-weathering quartzite and quartzite-dolomite breccia. The quartzite beds are from 3 in. (7.6 cm) to 20 ft (6 m) thick, and the dolomite units between them are 5-40 ft (1.5-12 m) thick. In most places the quartzite beds are sparse to absent in the topmost 50-100 ft (15-30 m) of the formation. The Victoria conformably overlies the Bluebell Dolomite, and the base is placed at the lower contact of the lowest conspicuous quartzite bed. Throughout most of the East Tintic Mountains this quartzite bed is only a few feet (about 1 m) above the speckled dolomite marker bed, a bed of bluish-gray dolomite studded with dolomite crystals and clumps of crystals up to a quarter of an inch (0.6 cm) in diameter. The top of the Victoria is marked by a disconformity of regional importance that lies at the base of the shaly limestone sequence of the Pinyon Peak Limestone. Locally, this disconformity is marked by a lenticular bed of poorly sorted dolomitic and quartzitic sandstone several feet thick which is considered to be the basal bed of the Pinyon Peak. The total thickness of the Victoria is 250-300 ft (76-91 m).

The sedimentary breccias of the Victoria are particularly abundant on Pinyon Peak, where they form lenticular masses as much as 30 ft (9 m) thick. They are composed of jumbled tabular blocks of sand-streaked dolomite and brown-weathering quartzite 2-5 in. (5.1-12.7 cm) thick and 10-12 in. (25.4-30.5 cm) long; like the quartzite beds, the breccia masses commonly have irregular lower contacts that seem to mark channels. The breccias are all overlain by undisturbed beds of fine-grained laminated dolomite, and they interfinger along the strike with less conglomeratic and normal quartzite beds. They are believed to have originated by the sudden failure and slippage of semiconsolidated beds during minor tectonic distrubances.

The Victoria Formation, so far as is known, is not fossiliferous, but it lies between formations that have yielded Devonian fossils; so it is considered to be Late Devonian in age (Morris and Lovering, 1961, p. 73).

The Victoria contains several ore bodies near the Burgin No. 1 shaft that were developed and mined beginning in 1971. One of these ore deposits is the 274 ore body, which was the first deposit of commercial size and grade discovered in the Burgin mine (see section "274 Ore Zone"). Because it was below the water table and also because it contained less silver than the deposits near the East Tintic thrust fault, its development was delayed for approximately 15 years. Drill holes from the surface in the Ballpark area about 1 mile (1.6 km) north of the Burgin No. 2 shaft also indicate extensive low-grade lead-zinc mineralization in the Victoria Formation.

In the western part of the Zuma property a considerable amount of halloysite clay also has been produced by the Western States Mining Co. from replacement deposits in the Victoria Formation.

### Pinyon Peak Limestone

The distribution of the Pinyon Peak Limestone is similar to that of the Victoria Formation. The most extensive outcrops extend from the south base of Pinyon Peak upward along the eastern, northern, and northwestern sides of the peak to the Selma fault. It crops out less extensively in the southwestern part of the district northeast of the Crown Point No. 3 shaft. The formation is also exposed underground in this mine, as well as in the Crown Point No. 2 mine and in the workings off the Burgin No. 1 shaft.

The Pinyon Peak Limestone consists almost entirely of thin-bedded medium-blue-gray fine-grained argillaceous limestone that weathers light blue. A characteristic feature is wispy stringers and partings of buff- to brown-weathering clay and silt. Locally the base of the Pinyon Peak is marked by a bed of coarse-grained sandstone 1-10 ft (0.3-3 m) thick, but in most exposures this horizon is only a bed of limestone that is somewhat more shaly or sandy than the limestone higher in the formation. The top of the Pinyon Peak is placed at the lower contact of a distinctive bed of limestone that is streaked with frosted sand grains and small pebbles of white quartz; this is the basal sand-grain marker bed of the Fitchville Formation. On Pinyon Peak, the lower 25-35 ft (7.6-10.7 m) of the Pinyon Peak Limestone is a single massive bed in which large reentrants and shallow caves have formed. The total thickness of the formation is 70-125 ft (21-38 m).

Northward from the East Tintic Mountains to the central Oquirrh Mountains, the Pinyon Peak Limestone, or the partly equivalent Stansbury Formation, overlies successively older beds. Paleogeographic reconstructions of this unconformity define a relatively narrow west-trending area extending through the central parts of the Wasatch, Oquirrh, and Stansbury Mountains that apparently became emergent during the Late Devonian Epoch (Rigby, 1959; Morris and Lovering, 1961, p. 78-81). This positive area has been termed the Tooele arch (Webb, 1958) and is shown by Roberts, Crittenden, Tooker, Morris, Hose, and Cheney (1965, p. 1927-1932) as being a segment of the Cortez-Uinta axis, a zone that has been intermittently active since the late Precambrian. By latest Devonian time the positive area had been eroded to sea level, and the Pinyon Peak Limestone and equivalent beds had been deposited across it. This arch apparently was the source for the clastic beds of both the Victoria and Pinyon Peak Formations.

Megafossils from the uppermost part of the Pinyon Peak Limestone were originally considered by Duncan and Berdan (in Morris and Lovering, 1961, p. 77-78) to have Carboniferous aspects, and the formation was assigned a Late Devonian and Early Mississippian age. Clark and Becker (1960), Beach (1961), Clark and Beach (1962), and Clark and Ethington (1967) later described assemblages of Fammenian (upper Upper Devonian) conodonts collected from the Pinyon Peak Limestone and the lower part of the overlying Fitchville Formation exposed on Rattlesnake Spur in the Allens Ranch quadrangle, 6 mi (9.7 km) north of the East Tintic district. In an effort to resolve this conflict, the following collections of conodonts were made in 1969 and 1972 from the type section of the Pinyon Peak by Charles A. Sandberg, Forrest G. Poole, and Rafaël Conil (written commun., April 3, 1973).

Colln. PIN-3. Medium-light-gray very finely crystalline dolomitic limestone, 7 ft (2.1 m) below top of Pinyon Peak Limestone at Pinyon Peak, East Tintic Mountains, Utah. Same location as PIN-8. Collectors: C. A. Sandberg and F. G. Poole, 1969.

*Palmatolepis rugosa postera,* Ziegler
*Palmatolepis rugosa rugosa,* Branson and Mehl
*Palmatolepis gracilis gracilia,* Branson and Mehl
*Polygnathus semicostatus,* Branson and Mehl
*Polygnathus perplexus,* Thomas
*P.* cf. *P. perplexus,* Thomas
*P. nodocostatus* s. 1, Branson and Mehl
*P. homoirregularis,* Ziegler
*Spathognathodus stabilis,* Branson and Mehl
*Apatognathus* varians, Branson and Mehl
Ozarkodina sp.
Hindeodella sp.
Misc. ramiform elements
Simple cones

Age: late Late Devonian; upper *Polygnathus styriacus* zone

Colln. PIN-8. Medium-gray fossil-fragmental limestone, 54 ft (16.4 m) below top of Pinyon Peak Limestone at Pinyon Peak, East Tintic Mountains. In SE¼ sec. 33, T. 9 S., R. 2 W., Utah County, Utah. Collectors: C. A. Sandberg and R. Conil, 1972.

*Palmatolepis rugosa postera,* Ziegler
*Palmatolepis rugosa rugosa,* Branson and Mehl
?*Nothognathella* sp.
n. gen., n. sp.
*Polygnathus* cf. *P. perplexus,* Thomas
*P. homoirregularis* nom. nud., Ziegler
*P.* cf. *P. hassi,* Helms
*P. nodocostatus* s. 1, Branson and Mehl
*P. glaber plaber,* Ulrich and Bassœr
*P. brevilaminus,* Branson and Mehl
*P. semicostatus,* Branson and Mehl
*Spathognathodus inornatus,* Branson and Mehl
*S. stabilis,* Branson and Mehl
*S. strigosus,* Branson and Mehl
*Apatognathus* varians, Branson and Mehl
Misc. ramiform elements
Simple cones

Age: late Late Devonian; upper *Polygnathus styriacus* zone.

In addition, a collection of brachiopods was made from the uppermost part of the Pinyon Peak Limestone on Rattlesnake Ridge, 5.5 mi (8.8 km) northwest of Pinyon Peak by Mckenzie Gordon, Jr., Keith Moore, and H. T. Morris.

Colln. USGS 9152-SD Utah, Allens Ranch 7½' quad; Rattlesnake Ridge, section along middle of south slope; fossils from 3 to 7 ft (0.9-2.1 m) below base of Fitchville Formation in the Pinyon Peak Limestone. Collectors: M. Gordon, Jr., K. Moore, H. Morris, 9/23/72.

*Ptychomaletoechia* sp.
*Litothyris?* sp.
*Crurithyris?* sp.
large spiriferoid, indet.
gastropod fragments, indet.

Silicified residues from colln. 72G27 (USGS 9152-SD) contain brachiopods that indicate a late Famennian age. The three common forms are a spiriferoid that is closest to *Litothyris,* described by Roberts from the Famennian of Australia. A rhynchonellid, most likely *Ptychomaletoechia* Sartenaer, is also present. The third common genus is a crurithyrid, perhaps *Crurithyris* itself, although the critical brachial interiors are poorly preserved.

All of these collections confirm a Late Devonian age for the entire Pinyon Peak Limestone.

The Pinyon Peak Limestone is known from drilling to contain low-grade zinc and lead deposits at considerable depth in the area of the Burgin No. 1 shaft, but as yet no detailed exploration or development of these mineral occurrences has been undertaken. Similar but much more extensive lead-zinc-bearing rocks also have been cut by drill holes in the Pinyon Peak Limestone at depth in the Ballpark area north of the Burgin No. 2 shaft. Up to 1975 only minor efforts had been made to examine this mineralized area.

## DEVONIAN AND MISSISSIPPIAN SYSTEMS

### UPPER DEVONIAN AND LOWER MISSISSIPPIAN SERIES

#### FITCHVILLE FORMATION

The Fitchville Formation crops out extensively on the western and uppermost slopes of Pinyon Peak and in a series of fault blocks in the Selma fault zone northwest of the mountain. In the same general area, the upper part of the Fitchville also crops out in several exposures at the base of Lime Peak. In the southwestern part of the district, the Fitchville is exposed in a narrow band of outcrops on the hill between the original Iron King and the Crown Point No. 3 shafts. Underground, it is cut by many of the workings of the Crown Point No. 2 mine.

The Fitchville Formation consists of eight highly distinctive lithologic units that make it one of the most easily recognized formations in the thick carbonate section in central Utah. In sequence from the base, these units include (1) the sand-grain marker bed, a persistent layer of limestone commonly less than 1 ft (0.3 m) thick that is streaked with frosted sand grains; (2) a thin-bedded blue argillaceous limestone 50-55 ft (15-17 m) thick ("blue flaky limestone" of local usage); (3) a massive light-gray to white medium-grained limestone 40-50 ft (12-15 m) thick ("white limestone" of local usage); (4) a thin-bedded blue-gray fossiliferous shaly limestone 40-50 ft (12-15 m) thick ("blue shaly limestone" of local usage); (5) massive dusky-blue-gray to black medium- to coarse-grained cherty dolomite 60-70 ft (18-21 m) thick ("black cherty dolomite" of local usage); (6) medium-gray medium-grained limestone 55-65 ft (17-20 m) thick, containing one or more beds of novaculitic quartzite in the upper part ("sugary limestone" of local usage); (7) massive pinkish-gray fine-grained to sublithographic limestone 5-15 ft (1.54-4.6 m) thick ("pink lithographic limestone" of local usage); and (8) dense medium- and dark-gray laminated stromatolitic limestone a few inches to 4 ft (1.2 m) thick ("curly limestone" of local usage). The total thickness of the Fitchville Formation in the East Tintic district is about 300 ft (91 m). The broad regional extent, distinctive appearance, and limited thickness of the black cherty dolomite horizon, the novaculitic quartzite beds, the pink sublithographic limestone horizon, and the laminated curly bed at the top of the Fitchville (Clark, 1954; Proctor and Clark, 1956) make these units particularly useful marker beds in areas of complex structure and in underground openings.

On the basis of collections of conodonts and other fossils made recently from the lower part of the Fitchville Formation, the Fitchville's age is here revised from Early Mississippian (Morris and Lovering, 1961, p. 85) to Late Devonian and Early Mississippian. Collections made from exposures on Pinyon Peak in the East Tintic district include:

Colln. PIN-1. Dark-gray finely crystalline fossil-fragmental dolomitic limestone, 1½ ft (0.5 m) above base of Fitchville Formation (about 1 ft (0.3 m) above sand grain marker bed of Crane) at Pinyon Peak, East Tintic Mountains, Utah. Same location as PIN-8. Collectors: C. A. Sandberg and F. G. Poole, 1969.

*Pseudopolygnathus brevipennatus*, Ziegler
*Polygnathus semicostatus*, Branson and Mehl
*P. communis communis*, Branson and Mehl
*P. nodocostatus* s. 1, Branson asnd Mehl
*Spathognathodus stabilis*, Branson and Mehl
*Apatognathus* varians, Branson asnd Mehl
Misc. ramiform elements

Age: late Late Devonian; upper *Polygnathus styriacus* or lower *Spathognathodus costatus* zone.

Colln. PIN-7. Dark-gray finely crystalline fossil-fragmental limestone, 5 ft (1.5 m) above base of Fitchville Formation at Pinyon Peak, East Tintic Mountains, Utah. Same location as PIN-8. Collectors: C. A. Sandberg and R. Conil, 1972.

*Polygnathus semicostatus*, Branson and Mehl
*P. communis communis*, Branson and Mehl
*Spathognathodus stabilis*, Branson and Mehl
*S. inornatus*, Branson and Mehl
*S. stringosus*, Branson and Mehl
*Apatognathus* varians, Branson and Mehl
Ozarkodina sp.
Misc. ramiform elements
Simple cones

Age: late Late Devonian; zonally indeterminate but compatible with assignment to either upper *Polygnathus styriacus* or lower *Spathognathodus costatus* zone.

Colln. PIN-6 Medium-dark-gray bioclastic (crinoidal) limestone, approximately 40 ft (12 m) above base of Fitchville Formation (top 1 ft (0.3 m) of upper blue flaky limestone of Crane) at Pinyon Peak, East Tintic Mountains, Utah. Same location as PIN-8. Collectors: C. A. Sandberg and R. Conil, 1972.

*Polygnathus obliquicostatus*, Ziegler
*P. communis communis*, Branson and Mehl
*Spathognathodus aculeatus*, Branson and Mehl
*S. stablis*, Branson and Mehl
*Apatognathus* varians, Branson and Mehl
Misc. ramiform elements
Simple cones

Age: late Late Devonian; lower *Spathognathodus costatus* zone.

Colln. PIN-5 Light-gray bioclastic (crinoidal) limestone, approximately 41 ft (12.5 m) above base of Fitchville Formation (bottom 1 ft (0.3 m) of white limestone of Crane) at Pinyon Peak, East Tintic Mountains, Utah. Same location as PIN-8. Collectors: C. A. Sandberg and R. Conil, 1972.

*Polygnathus obliquicostatus*, Ziegler
*P. communis communis*, Branson and Mehl
*P. triangularis*, Branson and Mehl
*Spathognathodus aculeatus*, Branson and Mehl
*S. stabilis*, Branson and Mehl
*S. strigosus*, Branson and Mehl
*Apatognathus* varians, Branson and Mehl
Ozarkodina sp.
Misc. ramiform elements
Simple cones

Age: late Late Devonian; lower *Spathognathodus costatus* zone.

These collections indicate a late Late Devonian age for the blue flaky and white limestone marker units suggesting that the Devonian-Mississippian boundary is at or near the base of the blue shaly limestone marker unit, which has yielded collections containing the Early Mississippian guide fossil *Siphonodella* sp. (Clark and Ethington, 1967, p. 88). The Early Mississippian age of the horizon of the black cherty dolomite above the blue shaly limestone is also indicated by well-preserved Early Mississippian syringoporid corals (Morris and Lovering, 1961, p. 86-87).

The pink sublithographic and stromatolitic limestones at the top of the Fitchville Formation were the principal units quarried near the west entrance of Homansville Canyon for the production of lime at the Chief Lime Plant. This plant terminated operations in 1952 owing to rising costs resulting from the necessity to remove an increasing thickness of overlying limestone of higher silica, alumina, and iron content. The Fitchville Formation is not known to contain sulfide ore bodies in the East Tintic district, but its proximity to large masses of mineralized rocks in the Ballpark area 1 mi (1.6 km) north of the Burgin mine suggests that it may be a host rock for ore there as it is in the main Tintic district.

## MISSISSIPPIAN SYSTEM

### LOWER MISSISSIPPIAN SERIES

#### GARDISON LIMESTONE

The most complete exposures of the Gardison Limestone in the East Tintic district are in the area north of the Crown Point No. 3 shaft. In this locality the top of the Gardison is cut by low-angle faults that may eliminate the uppermost beds, but probably not more than 20 or 30 ft (6-9 m) of beds are missing. In the northern part of the district the Gardison Limestone forms most of Lime Peak, but the upper part is eroded. Exposures of parts of the formation also are found in fault blocks in the Selma fault zone between Lime Peak and the northern boundary of the district and in two thin remnants on the crest and southwest ridge of Pinyon Peak. Underground, all but the uppermost part of the Gardison is exposed in the higher workings of the Crown Point No. 2 mine.

In the central East Tintic Mountains, the Gardison is 500 ft (152 m) thick and is divided into a lower member, of conspicuously bedded limestone, and an upper member, of more massively bedded cherty limestone. These members are chiefly useful in the preparation of large-scale underground maps and are not differentiated on plate 1. The lower member consists of thin- to medium-bedded medium-blue-gray sparsely to moderately fossiliferous limestone and is about 375 ft (114 m) thick. The lower half or so of this member is fine grained and contains a few beds in which scattered nodules of chert are common. The upper half of the lower member is chiefly coarse-grained locally crossbedded clastic limestone.

The upper member, which is about 125 ft (38 m) thick, is largely medium-bedded to massive blue-gray limestone containing many nodules and thin lenses of light-gray-, brown-, and black-weathering chert. This member is coarse grained near the base, but most of it is fine grained; in general it is noticeably less well bedded than the lower member.

Abundant well-preserved fossils are a characteristic feature of the upper member of the Gardison Limestone. These fossils include both colonial and solitary corals, several types of brachiopods, straparollid gastropods, and other forms of Early Mississippian age (Morris and Lovering, 1961, p. 91-93). In many areas the fossils are silicified and weather in relief.

Although the Gardison Limestone is an important host rock for ore bodies in several mines in the main Tintic district, it is not known to contain ore in the East Tintic district.

### UPPER MISSISSIPPIAN SERIES

#### DESERET LIMESTONE

Incomplete sections of the Deseret Limestone are exposed in the northwestern corner of the East Tintic district and also near the Crown Point No. 2 shaft. In the northwestern part of the district, the upper two-thirds of the formation is exposed across a minor anticline. The only part of the Deseret Limestone that is cut by mine workings in the district is the faulted basal beds adjacent to the small thrust exposed in the upper levels of the Crown Point No. 2 mine.

The Deseret is subdivided into three members (ascending): (1) a phosphatic shale member, (2) the Tetro Member, and (3) the Uncle Joe Member; they are not differentiated on plate 1. The phosphatic shale member, which crops out 500 ft (152 m) southwest of the Crown Point No. 2 shaft, is largely sooty-black carbonaceous shale or shaly limestone that contains anomalous quantities of phosphorous, vanadium, lanthanum, yttrium, chromium, zinc, nickel, and other elements. Some beds of pelletal phosphorite and vanadiferous shale near the base approach the thickness and grade of beds currently being mined in other western states as a source of phosphate rock and vanadium (Lewis, 1967, p. 949-964). The phosphatic shale member is commonly concealed at the surface by soil and an accumulation of blocky fragments of gray cherty dolomite and limestone, although a careful search commonly reveals a few thin chips of phosphatic shale. The phosphatic shale fragments weather lavender gray to orange red but are sooty black on fresh fractures. The full thickness of the phosphatic shale member is diminished by faults in the East Tintic district; it is as much as 150 ft (46 m) thick in the main Tintic district, but locally it is no more than 5-10 ft

(1.5-3 m) thick in the northern part of the East Tintic Mountains.

The Tetro Member, which is about 475 ft (145 m) thick, is massive-bedded medium- to light-blue-gray cherty limestone containing a high percentage of silt and fine sand grains that accumulate on the weathered surface of the rock. Fossils are sparse and are characterized by poorly preserved fragments of bryozoa and scattered solitary corals.

The Uncle Joe Member, which is about 550 ft (168 m) thick, is composed largely of massive medium- to light-pinkish-gray coarse-grained limestone containing large nodules of black, brown, and gray chert. Many of the limestone beds in the Uncle Joe Member are composed of the fossilized fragments of shells, crinoid columnals, and corals; some of these layers are distinctly crossbedded. Interlayered with the bioclastic strata are beds of medium- to dark-blue-gray fine- to medium-grained sand-streaked limestone and dolomite. Commonly, these beds are even more cherty than the coarse-grained limestone, and they contain individual chert nodules that are from 6 to 18 in. (15-46 cm) thick and 1 to 4 ft (0.3-1.2 m) long. Locally near the middle of the Uncle Joe Member a few lenses and beds of sandstone and sand-streaked limestone cause a superficial resemblance to the Humbug Formation. A short distance above these beds, within 100-150 ft (30-46 m) of the top of the Uncle Joe, a zone of platy weathering thin-bedded medium-gray dolomite is a useful marker.

In total, the Deseret Limestone is about 1,000 ft (305 m) thick. It is conformably overlain by the Humbug Formation, and the contact is placed at the base of the lowest sandstone bed in the Humbug.

The Late Mississippian age of the Deseret Limestone is based on extensive collections of corals, bryozoa, brachiopods, and other fossils from several localities in the East Tintic Mountains (Morris and Lovering, 1961, p. 97-99), and in adjacent areas (Gilluly, 1932, p. 26; Calkins and Butler, 1943, p. 24-26; Baker, 1947).

The Deseret Limestone is not known to contain ore in any of the mines in the East Tintic district, but it is the principal host rock for ore in the northern part of the Iron Blossom ore zone, which is only a short distance beyond the western boundary of the East Tintic district.

### HUMBUG FORMATION

The Humbug Formation crops out in several discontinuous exposures in the northwest corner of the East Tintic district. It conformably overlies the Deseret Limestone and is conformably overlain by the Topliff Limestone Member of the Great Blue Formation. It is not exposed in any mine workings in the East Tintic district.

The Humbug is readily distinguished from the other units of Mississippian age by its interbedded quartzitic sandstone and sand-streaked limestone. The sandstone layers are 8 in. (20 cm) to about 20 ft (6 m) thick; most of them are dark reddish brown, medium to coarse grained, and some are crossbedded. The sand-streaked limestone beds are 1-10 ft (0.3-3 m) thick. They include both fine- and coarse-grained bioclastic beds and generally resemble the medium- to light-blue-gray limestone beds of the Deseret and Great Blue Formations. A particularly useful marker is a persistent zone of light-gray- to white-weathering fine-grained relatively sand free limestone beds that lies a short distance below the middle of the Humbug in most of its exposures. The formation also contains a few thin beds of gray dolomite and at least one thin bed of reddish-brown shale.

The lower and upper boundaries of the Humbug Formation are gradational; they are placed at the base of the lowest sandstone bed and the top of the highest sandstone bed in the part of the Upper Mississippian section where sandstone is abundant. Despite the lensing character of the sandstone beds, the thickness of the Humbug is close to 650 ft (198 m) throughout its exposures in the East Tintic Mountains.

The Humbug Formation contains fossils of Late Mississippian age and also lies between formations that contain extensive Upper Mississippian faunas (Morris and Lovering, 1961, p. 106-107; Baker, 1947; Gilluly, 1932, p. 28).

The Humbug Formation is not a host rock for ore in either the East Tintic or main Tintic district.

### GREAT BLUE FORMATION

The youngest rocks of Paleozoic age exposed in the East Tintic district are the basal beds of the Great Blue Formation. These beds, which probably are less than 100 ft (30 m) thick, crop out in the northwestern part of the district at the crest of a small knoll three-quarters of a mile (1.2 km) north of Homansville Pass. In exposures northwest of this area, beyond the East Tintic district, the Great Blue Formation has a total thickness of about 2,500 ft (762 m), and it is subdivided into the Topliff Limestone Member, 300-470 ft (91-143 m) thick, Paymaster Member, 625 ft (191 m) thick, Chiulos Member, 850-900 ft (259-274 m) thick, and the Poker Knoll Limestone Member, 600-70 ft [183-213 m) thick (Morris and Lovering, 1961, p. 107-113). It is succeeded by the Manning Canyon Shale.

The remnant beds exposed in the East Tintic district are the basal part of the Topliff Limestone Member. They are predominantly medium-bedded blue-gray fine-grained limestone but locally contain a few thin lenses of sandstone and quartzite like the thicker beds in the underlying Humbug Formation.

The Late Mississippian age of the Great Blue Formation has been well established by Gilluly (1932, p. 30-31), Nolan (1935, p. 29-31), and others on the basis of extensive and well-preserved coral, bryozoa, brachiopod, and other faunas.

The Topliff Limestone Member is not a host rock for ore in the East Tintic Mountains, but it was once the source of metallurgical limestone near Tenmile Pass 10 mi (16 km) northwest of the East Tintic district (see Disbrow, 1957).

### PRE-TERTIARY UNCONFORMITY

Prior to the eruption of the Oligocene volcanic rocks of the East Tintic district, a youthful erosion surface had been carved into the folded and faulted Paleozoic rocks. The total relief of this surface was at least 4,000 ft (1,219 m), which is indicated by the thickness of lava near Low Lonesome point, where a drill hole, TS-6, bottomed in the Packard Quartz Latite at an elevation of about 3,100 ft (945 m), and by the occurrence of remnant patches of its basal tuff on Pinyon Peak at an elevation of 7,150 ft (2,179 m). The topography of the prevolcanic surface, as indicated from geologic mapping, mine workings, and drill holes, is considerably steeper and more rugged than the present surface and in the East Tintic district is dominated by a deep east-sloping valley that lies between the North Lily and Copper Leaf shafts (Morris and Anderson, 1962). The headwaters area of this ancient valley was apparently in the northwestern part of the main Tintic district, where its upper tributary valleys are sharply defined by the outcrop pattern of the lavas that fill them. The axis of a similar, east-southeast-trending lava-filled valley underlies the northeastern corner of the district; this valley had a headwaters 2 mi (3.2 km) north of Homasville Pass in the south-central part of the Allens Ranch quadrangle (Proctor and others, 1956).

The prelava topography of the southern part of the district is less well known than the central and northern parts. The area between the Trixie and Roundy shafts was apparently the upper reaches of a valley that extended south or southeastward. However, after the eruption of the Packard Quartz Latite, the part of this lava-filled valley immediately south of the district possibly was dropped down in an inferred caldera (see pages 33-34). Continuing subsurface exploration in this general area by Kennecott Copper Corporation eventually may provide enough penetrations of the prevolcanic surface to allow reconstruction of the buried topography.

In general, all the prelava valleys are V-shaped, with moderate to steep walls, and with gradients of approximately 1,000 ft (305 m) per mile. The strong relief of the prevolcanic surface, which is only partly preserved, suggests that it was part of a steep and rugged highland area bordering a basin lying 10-20 mi (16-32 km) east of the East Tintic district. As shown by Spieker (1946, 1949), Schoff (1951, p. 619-646), Muessig (1951), and others, this basin first received coarse orogenic conglomerate and sandstone during Colorado time, thick fluviatile and lacustrine deposits from Montana time probably to Oligocene time, and then the great floods of volcanic debris.

## CENOZOIC ROCKS

The consolidated rocks that unconformably overlie the tectonically deformed and eroded Paleozoic sedimentary formations are chiefly tuffs, lavas, and agglomerates all of Tertiary age (fig. 3).

These volcanic rocks are cut by many small plugs, dikes, and sills, some of which were the eruptive sources of the layered extrusive rocks. The lowest Tertiary unit is a discontinuous deposit of poorly sorted conglomerate and mudstone that was derived from prevolcanic talus, colluvium, and gravel. The volcanic rocks overlying this basal conglomerate are subdivided into four series: the Packard Quartz Latite, the Tintic Mountain Volcanic Group, and the Laguna Springs Volcanic Group, all of Oligocense age, and the Silver Shield Quartz Latite of Miocene age. The Packard, Tintic Mountain, and Laguna Springs eruptive rocks are part of a volcanic field about 50 mi (80 km) in diameter that extends from Sage Valley on the south to the northern part of the East Tintic Mountains, and from the West Tintic Mountains on the west to the Wasatch Mountains and beyond on the east. The Silver Shield rocks are of local origin and have not been recognized outside of the East Tintic district. They are separated from the underlying Laguna Springs Volcanic Group by the Pinyon Creek Conglomerate, also presumed to be of Miocene age.

The plugs, dikes, and irregular sills that cut the eruptive rocks are composed chiefly of monzonite and quartz monzonite porphyry; most of them were emplaced during or shortly after the eruption of the Laguna Springs Volcanic Group. The intrusion of these bodies was accompanied or shortly followed by floods of acidic hydrothermal solutions that profoundly altered adjacent lavas and sedimentary wallrocks and in many areas altered the intrusive bodies themselves. Most of the intrusive bodies are concentrated in three north-northeasterly-trending *en echelon* zones in the west half of the district. These zones are regionally

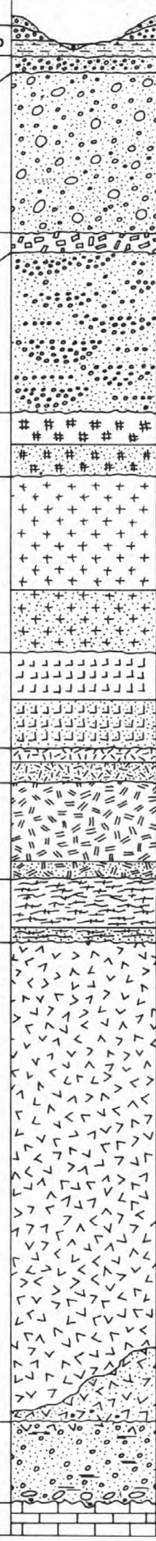
| SERIES | GROUP, FORMATION, OR UNIT | | LITHOLOGIC CHARACTER | THICKNESS (FEET) | DESCRIPTION |
|---|---|---|---|---|---|
| Holocene | Younger alluvium | |  | 0 - 50 | Alluvium in most modern stream valleys |
| Pleistocene | Lake Bonneville Group | | | 0 - 200 | Lacustrine deposits of Alpine and Bonnevile Formations |
| | Terrace gravel | | | 0 - 100 | Gravel and sand in partly dissected benches |
| | Older alluvium | | | 0- 1,000+ | Chiefly fanglomerate underlying thin alluvium and lacustrine deposits in Goshen Valley and the larger stream valleys that extend into the range |
| Miocene | Silver Shield Quartz Latite | | | 0 - 125 | Dark-gray coarse-grained quartz latite porphyry |
| | Pinyon Creek Conglomerate | | | 0- 1,000+ | Poorly sorted moderately well stratified conglomerate consisting of boulders and cobbles of volcanic rock embedded in grit and sand; many channeled contacts |
| Oligocene | Laguna Springs Volcanic Group | Tintic Delmar Latite | | 0- 400+ | Flow member is gray to dark-reddish-brown medium-grained latite porphyry; tuff member is buff to white fine- to coarse-grained tuff |
| | | Pinyon Queen Latite | | 0- 1,100+ | Flow member is dark-reddish-brown medium- to coarse-grained latite porphyry characterized by large white plagioclase phenocrysts; tuff member consists of inter-mixed fine-grained and boulder tuff, and agglomerate |
| | | North Standard Latite | | 0- 600 | Flow member is purplish-gray medium-grained latite vitrophyre; tuff member is gray to white heterogeneous boulder tuff |
| | Tintic Mountain Volcanic Group | Big Canyon Latite | | 0 - 200 | Flow member is dark-gray fine-grained latite; tuff member is buff to white fine-grained tuff |
| | | Latite Ridge Latite | | 0 - 600 | Welded tuff member is reddish-brown densely welded tuff and breccia; airfall tuff member is fine-grained white tuff |
| | | Copperopolis Latite | | 0- 400+ | Flow member is black to reddish-brown fine-grained latite; tuff member is white fine-grained vitric tuff |
| | Packard Quartz Latite | | | 0- 3,000+ | Chiefly pinkish- or lavender-gray medium-grained quartz latite porphyry. Generally divisible into an upper unit of dark-green to black vitrophyre and tuff as much as 500 feet thick; a middle unit of quartz latite porphyry locally more than 2,700 feet thick; a lower unit of dark-green to black vitrophyre as much as 200 feet thick; and a basal unit of fine-grained tuff as much 700 feet thick |
| | Apex Conglomerate | | | 0 - 500 | Prelava soil and rubble, ranging from claystone to coarse conglomerate |
| Paleozoic rocks | | | | | Folded, faulted, and deeply eroded sedimentary strata |

FIGURE 3 — Columnar section of layered Cenozoic rocks, East Tintic district.

alined with the axis of the Silver City stock, which lies a short distance southwest of the East Tintic district. This stock has an area of about 7 $mi^2$ (18 $km^2$), is elliptical in general outline, but has a broad irregular apophysis about 1½ mi (2.4 km) long elongated toward the intrusive zones that are named from the North Lily and Iron King mines. The third zone of intrusive bodies, which is named from the Trixie mine, is southeast of the Iron King zone and is not directly alined with an apophysis from the stock, but it is marked by a linear zone of intensely altered lava extending north-northeasterly from the stock. Like the Iron King and North Lily zones, it is also alined with zones of mineralized veins that cut the Silver City stock. A fourth zone of intrusions, which are latitic in character, is located half a mile (0.8 km) north of the East Standard shaft; it is the northeasternmost of the East Tintic intrusive centers. Unlike the others, it does not seem to be a center of intensive hydrothermal alteration.

Other Cenozoic rocks include the Silver Shield dike, which was the source of the extrusive Miocene Silver Shield Quartz Latite, and the ubiquitous alluvium, gravel, and lacustrine deposits of Pleistocene age.

In this report the igneous rocks are classified and named on the basis of their modal mineralogy and not on their chemical or normative compositions. In general, only those minerals that can be identified with a hand lens are considered, but because many of the intrusive and extrusive rocks have groundmasses that are vitric, aphanitic, or microcrystalline, the modal compositions do not always precisely reflect their chemical character. The names and modal fields are from Johannsen (1932).

## OLIGOCENE ROCKS

### APEX CONGLOMERATE

The Apex Conglomerate, which was named by Morris and Lovering (1961, p. 123) from exposures in and near the Apex Standard mine, is characterized by patchy outcrops and irregular thickness. It underlies the Packard Quartz Latite in several exposures throughout the East Tintic Mountains. It is probably more widespread than outcrops would indicate, inasmuch as it is generally thin and poorly cemented and weathers into debris that is indistinguishable from the talus and soil overlying the adjacent Paleozoic rocks. The best outcrops are 2,000 ft (610 m) southwest of the East Tintic Coalition shaft, 700 ft (213 m) south-southeast of the Apex Standard No. 1 shaft, 500 ft (152 m) west-southwest of the Tintic Standard No. 2 shaft, and 450 ft (137 m) north of the Copper Leaf shaft. Better exposures are available in mine workings, particularly on the 700 ft level of the Apex Standard No. 2 shaft (the type section), the 900-ft level of the Tintic Standard mine, and the 1,050-ft level of the Burgin mine. It has also been penetrated by many drill holes. Since the type section is not readily accessible, the outcrop in the center of sec. 22, T. 10 S., R. 2 W., S.L.B.M., south of the Apex Standard No. 1 shaft, is designated a reference section.

The Apex is a massive semilithified poorly sorted conglomerate composed largely of subangular cobbles of limestone, shale, and quartzite embedded in a matrix of shaly and clayey mudstone. The cobbles are similar in character to modern talus blocks; they are 2-10 in. (5-25 cm) in largest dimension and range in shape from blocky to platy. Lava fragments are constituents of the conglomerate only at the top of the uppermost layer. The matrix of the conglomerate is brick red and may, in part, represent a fossil soil. In most exposures the matrix is dense and structureless, but in some areas it is cut by many closely spaced slip-planes that are characterized by curving slickensided surfaces. In some underground exposures the matrix of the uppermost part of the Apex is fine-grained volcanic ash that apparently sifted down between loose blocks during the beginning stage of volcanic activity.

The Apex Conglomerate ranges in thickness from 0 to about 200 ft (61 m), the thickest section having been cut in two exploration drill holes between the Roundy and Trixie shafts. The average thickness is about 25 ft (7.6 m).

No fossils have been found in the Apex Conglomerate, but the close physical association of the deposits with the Packard Quartz Latite dates them as middle Oligocene, as described later.

Parts of the Apex Conglomerate have been silicified and consist of a dark-gray to black jasperoid that preserves the original conglomeratic texture. This feature is best seen in the prominent ledgy exposures southwest of the East Tintic Coalition shaft. Some of the bodies of jasperoid undoubtedly originated during the period of late hydrothermal silicification and contain barite and traces of the ore metals; however, most of them are barren, and they are believed to have been silicifed through deposition and replacement by chalcedonic silica from ground water that moved downward through the overlying tuffs and lavas and spread outward in the porous basal part of the formation. This type of silicification may have been particularly common during the early stages of the volcanic period, when the downward-percolating ground water was heated by the still-warm silica-rich tuffs.

In the Tintic Standard, Trixie, and many other mines in the East Tintic district, the Apex Conglomerate contains only thin stringers and veinlets of ore minerals in areas where it directly overlies large ore bodies. In a recently explored area of the Ballpark section of the northern part of the Burgin mine, however, extensive mineralized zones have been found in the Apex Conglomerate and the lowermost part of the Packard Quartz Latite near the intersection of the South fault and the East Tintic thrust (see p. 120-121). No estimate of the tonnage or grade of these deposits has been released by the Kennecott Copper Corp., but the resources of marginal grade lead-zinc-silver ore may be large.

## PACKARD QUARTZ LATITE

### Name And General Features

The Packard Quartz Latite was originally named the Packard Rhyolite by Tower and Smith (1899, pl. 74) from conspicuous exposures at Packard Peak in the main Tintic district. The term "rhyolite" was also used by Lindgren and Loughlin (1919, p. 45-49), although Loughlin (in Lindgren and Loughlin, p. 47) noted that orthoclase is only slightly more abundant than plagioclase. The calcic character of the plagioclase, which ranges from $An_{35}$ to $An_{60}$, and the ratio of plagioclase to potassium feldspar, which ranges from 1:1 to 3:1, indicate that the Packard more nearly approaches quartz latite in mineral composition (Johannsen, 1932, p. 309). A plot of the normative quartz-orthoclase-albite + anorthite of the Packard (fig. 4) shows that it lies in the modal field of quartz latite.

### Distribution And Thickness

The Packard Quartz Latite underlies approximately 60 percent of the surface area of the East Tintic district, much of it under thin alluvial cover. Excepting for scattered exhumed prevolcanic mountains and ridgetops, it occupies nearly all of the middle part of the district, extending from its western border to the edge of Goshen Valley and from the Trixie mine in the southern part of the district to the vicinity of the North Standard mine near the northern border of the district. It and its correlative units are well known beyond the limits of the district and are believed to have originally extended for many miles northward to the east-central part of the Allens Ranch quadrangle (Proctor and others, 1956) and for even greater distances westward to the West Tintic Mountains, eastward to the eastern slopes of the Wasatch Mountains (Schoff, 1951; Phillips, 1962), and southward to the southern part of the East Tintic Mountains (Morris, 1957, p. 30) and beyond into Sage Valley. Overall, its original depositional area approximated 500 square miles (1,295 km²).

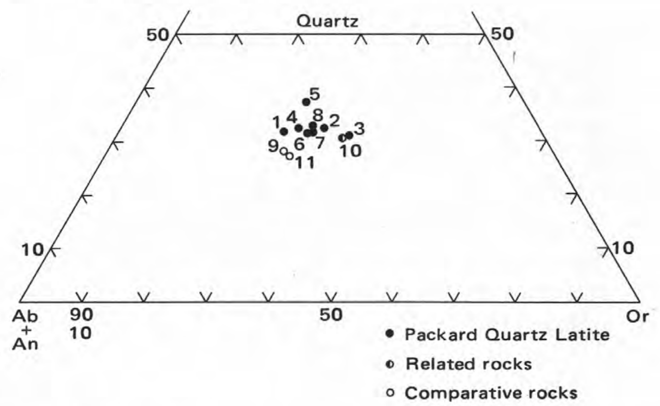



FIGURE 4 — Plot of normative quartz-orthoclase-albite + anorthite of selected samples of the Packard Quartz Latite and related and comparative rocks. Sample numbers are the same as shown in table 1.

Within the East Tintic district, the Packard forms an eastward-thickening highly irregular wedge of lavas and minor pyroclastic rocks that expands from a featheredge along the prelava mountains in the western part of the district and adjacent part of the main Tintic district to a large but unknown thickness at the edge of Goshen Valley. The thickest known section is in the S½SE¼ sec. 11, T. 10 S., R. 2 W., where a drill hole collared at a point 300 ft (91 m) below the base of the overlying Latite Ridge Latite bottomed in quartz latite at a total depth of 2,700 ft (823 m), indicating that the Packard was more than 3,000 ft (914 m) thick in this general area. In the central part of the district, where the prelava topography was particularly steep and irregular, the thickness of the Packard may differ by many hundreds of feet in closely adjacent drill holes or mine shafts. In the Burgin mine area, for example, the Burgin No. 1 shaft penetrates 684 ft (208 m) of quartz latite, whereas a diamond-drill hole less than a quarter of a mile (0.4 km) to the north-northwest penetrated more than 2,000 ft (610 m) of similar rock. Because of its irregular thickness, it is difficult to make an accurate estimate of the total volume of the Packard Quartz Latite. Where it is best known from drill holes and mine workings in the central part of the East Tintic district, its volume is estimated to be about 5 cubic miles (21 km³).

### Lithology And Petrography

The Packard Quartz Latite is subdivided into four units: (1) a basal tuff, (2) a lower vitrophyre, (3) a porpyritic unit, and (4) an upper vitrophyre. Because the basal tuff, lower vitrophyre, and upper vitrophyre are all thin compared to the quartz latite porphyry unit, they have not been differentiated on plate 1. In addition, intense hydrothermal alteration in the central part of the district locally obliterates the original character of the basal tuff and the lower vitrophyre, making it difficult or impossible to distinguish these units from similar, altered massive porphyritic quartz latite.

### Basal Tuff Unit

The basal tuff unit of the Packard Quartz Latite is discontinuous in habit and irregular in thickness, ranging from 1 to 300 ft (0.3-91 m) but probably averaging only 20 ft (6 m). Locally it is absent, indicating a patchy distribution prior to the deposition of the more continuous units that overlie it. The most readily accessible exposures are (1) in Pinyon Creek Canyon near the North Standard shaft, (2) in the eastern part of Homansville Canyon north of Highway 6-50, (3) in the abandoned quarry 500 ft (152 m) west of the Tintic Standard No. 2 shaft, and (4) in the central part of Burriston Canyon a quarter of a mile (0.4 km) southwest of the Iron King No. 1 shaft.

In most exposures the tuff is massive, exhibiting only a rude stratification that generally conforms to the slope of the underlying surface. In a few localities, as for example in the eastern part of Homansville Canyon, the tuff is distinctly bedded and contains carbonized impressions of rushes and other plant fossils, suggesting local deposition in a small pond or stream.

The tuff is mostly fine grained, although some beds of lapilli tuff observed in mine workings contain fragments of quartz latite, vitrophyre, and rare limestone as much as 2 in. (5 cm) in diameter. The unaltered tuff is mostly light bluish-gray or greenish-gray, but some beds are also white, buff, and brick-red. Locally chloritic alteration has produced a darker gray-green color; argillic alteration has converted the tuff to a brilliant white clay; and silicification has produced a dark-gray to black jasperoid. The weathering of introduced pyrite has also bleached the rock and created streaks and patches of yellowish-brown iron oxides.

Thin sections of the unaltered tuffs reveal shattered and broken fragments of quartz, andesine ($An_{35-55}$), sanidine, biotite, magnetite, and rare basaltic hornblende, all embedded in a groundmass of glass shards that show typical bogen structure. The crystal fragments are 0.5-1.5 mm in diameter and constitute 10-20 percent of the rock. Most of them have only one or two edges that preserve the original crystal boundary, but in some deposits the quartz crystals are nearly perfect bipyramids. In the thin sections examined, plagioclase is slightly more abundant than sanidine.

### Lower Vitrophyre Unit

The freshest exposures of the lower vitrophyre member of the Packard Quartz Latite are adjacent to the basal tuff member 1,800 ft (549 m) north-northwest of the Copper Leaf shaft and in the small gulches that are 2,000 ft (610 m) due east of Lime Peak. Somewhat chloritized vitrophyre crops out on the south side of Homansville Canyon about 2,100 ft (640 m) west-northwest of the Copper Leaf shaft. Vitrophyre is also present at the base of the Packard half a mile (0.8 km) northwest of Homansville Pass. Overall, the lower vitrophyre unit ranges in thickness from 0 to 200 ft (61 m).

In its least altered exposures, the lower vitrophyre unit is an adamantine greenish-black volcanic glass containing large scattered phenocrysts of andesine and smaller crystals of biotite, quartz, and sanidine (fig. 5). Most of the vitrophyre has a pronounced flow structure, and some exposures are distinctly bedded, with individual layers ranging in thickness from 3 in. (7.5 cm) to 20 ft (6 m).

Average specimens of the lower vitrophyre consist of approximately 30 percent phenocrysts and 60 percent volcanic glass. Andesine and biotite each make up about 40 percent of the phenocrysts; sanidine is less

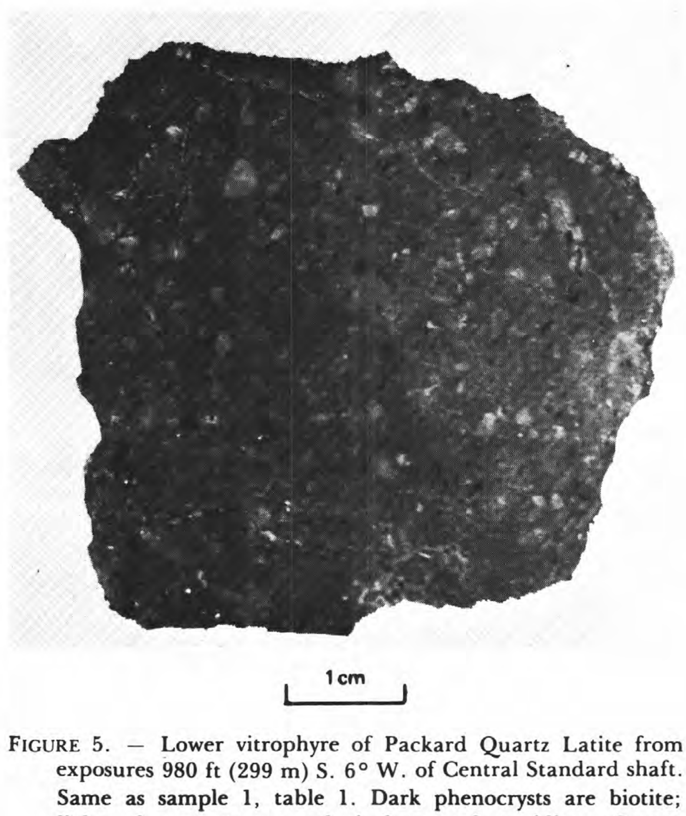



FIGURE 5. — Lower vitrophyre of Packard Quartz Latite from exposures 980 ft (299 m) S. 6° W. of Central Standard shaft. Same as sample 1, table 1. Dark phenocrysts are biotite; light phenocrysts are plagioclase and sanidine. Quartz phenocrysts are present but not distinguishable in photograph from obsidian matrix.

abundant, constituting 7-10 percent of the phenocrysts, and quartz is least abundant, averaging about 5-6 percent. Rare well-formed crystals of basaltic hornblende were also noted in some thin sections. Accessory minerals include magnetite, apatite, sphene, and zircon. Specimens of the lower vitrophyre from the exposures west-northwest of the Copper Leaf shaft also contain abundant fragments of shale, limestone, and other sedimentary rocks that were apparently incorporated as the viscous lava moved over the unconsolidated debris littering the prelava surface.

The obsidian matrix commonly has a pronounced fluidal texture that is defined by swarms of subparallel microlites. Where phenocrysts are sparse, perlitic fractures are common. The largest felsic phenocrysts are 4-5 mm long, but most of them are shattered and the fragments are drawn out in trains of broken crystals. The biotite phenocrysts are mostly 1-2 mm long and well formed; many are crowded with tiny chadacrystic magnetite crystals. Pleochroism of the biotite is strong and most commonly X = pale brownish orange, Y = Z = dark russet brown. The rare phenocrysts of basaltic hornblende are greenish brown and also are well formed.

### PORPHYRITIC UNIT

The porphyritic unit of the packard Quartz Latite is the most widely distributed rock unit in the East Tintic district. It crops out throughout the central, productive part of the district and is almost the only rock exposed at the surface in the vicinity of the Burgin and some other mines. The unit ranges in thickness from 10 ft (3 m) to at least 3,000 ft (914 m), and undoubtedly it is thicker in the central parts of the deep prelava valleys. In general aspect the porphyritic lavas are strikingly uniform, varying only slightly in porphyritic texture from outcrop to outcrop. No scoria, aa, pahoehoe, or vitrophyric layers that could be interpreted to be the tops or bases of individual flows are known, and similarly no lenses of gravel, alluvium, or talus have been recognized. In addition, 30 or more deep drill holes, several of which penetrate sections of porphyritic lava more than 2,000 ft (610 m) thick in the east-central part of the East Tintic district, confirm the uniform nature of the member except for minor color banding, variations in the size and percentage of phenocrysts, and a few intercepts of breccia identical in texture and composition to the enclosing quartz latite. The only known exception is an area 1,600 ft (488 m) southeast of the Burgin No. 1 shaft where a drill hole cut a water-saturated lens of tuff interlayered with the porphyritic lavas.

The predominant color of the porphyritic lava is pale pinkish to lavender gray, but gray, brown, and dark-purple varieties are locally predominant. Most weathered exposures are massive and conspicuously even textured and commonly are partly mantled by a granular debris composed of disaggregated phenocrysts and rock fragments. Typical hand specimens of the lava are fine- to medium-grained and porphyritic in texture (fig. 6).

Thin sections of the quartz latite lavas show phenocrysts to compose 20-30 percent of the rock. The groundmass is uniformly fine grained, and in many specimens the individual components can be resolved only under high magnification. In some samples that may be devitrified vitrophyres, the groundmass displays a distinct flow structure that bends around the phenocrysts and fills embayments and fractures in the phenocrysts.

The phenocrysts consist of plagioclase, sanidine, quartz, biotite, and rare basaltic hornblende. Most of the larger crystals are corroded and embayed, and in many layers the feldspar and quartz crystals also are shattered and represented only by angular fragments that may or may not retain an original crystal boundary.

Plagioclase is the most abundant mineral and commonly makes up 45-75 percent of the phenocrysts. It chiefly occurs as clear distinctly zoned crystals or crystal fragments 0.5 to 5 mm long. Most commonly,

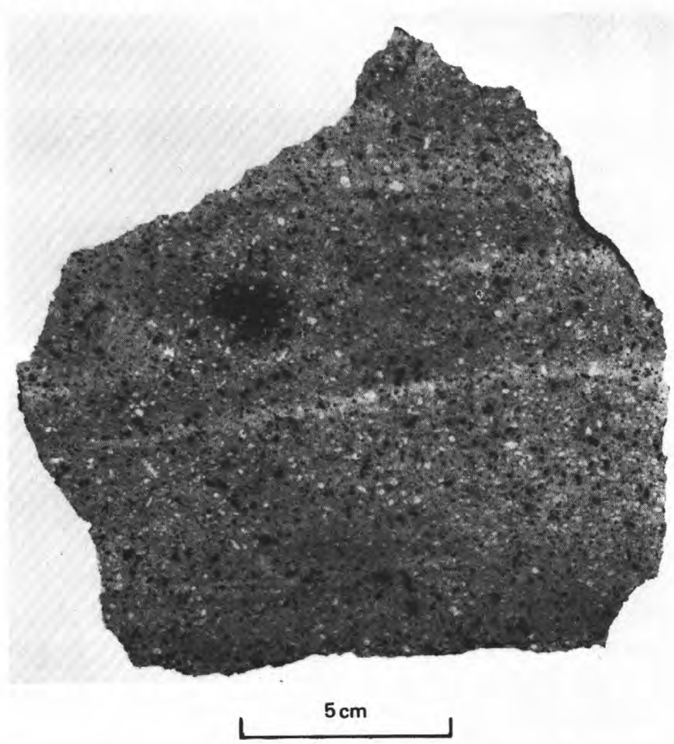



FIGURE 6. — Porphyritic unit of Packard Quartz Latite from exposure on Highway 6-50, 1,700 ft (518 m) east-southeast of Copper Leaf Shaft.

the zones range in composition from $An_{35}$, or even more sodic, to $An_{60}$ and show no well-defined trend in compositional variation; the average composition of rare unzoned phenocrysts of plagioclase is $An_{40}$.

Well-formed biotite constitutes 20-40 percent of the phenocrysts. It is strongly pleochroic from X = light greenish brown to yellowish brown and Y = Z = dark russet brown. In many thin sections the biotite is completely altered to clay and other minerals and is indicated only by rectangular segregations of dusty magnetite. In unaltered biotite phenocrysts, the magnetite is most abundant near the outer edge of the crystal and forms a distinct rim. Rutile is also present as sagenite twins in some biotite crystals.

Quartz and sanidine phenocrysts are both greatly subordinate to the plagioclase and biotite phenocrysts. In the lower part of the porphyritic member, strongly resorbed and shattered quartz crystals commonly make up from 8 to 12 percent of the phenocrysts and sanidine about 5-10 percent. In the middle and upper parts of the member, the relative quantities diminish, and in general, quartz makes up about 5 percent and sanidine only from 1 to 3 percent of the phenocrysts. Locally some of the quartz and sanidine phenocrysts are mantled by tiny crystals of similar composition that have grown in crystallographic continuity with the host mineral.

Magnetite is, by far, the most abundant accessory mineral; apatite is also common, and zircon and sphene are sparse but ubiquitous. Basaltic hornblende was observed in a few of the thin sections examined. It is dark reddish brown and moderately pleochroic.

The resolvable groundmass of the porphyritic lava is a microcrystalline aggregate of interlocking orthoclase and quartz crystals that enclose scattered tiny lath-shaped crystals of andesine and more equidimensional crystals of sanidine. Sodium cobaltinitrite stain invariably indicates a much higher proportion of potassium feldspar than is indicated by the ratio of sanidine to plagioclase phenocrysts.

### UPPER VITROPHYRE UNIT

The upper unit of the Packard Quartz Latite consists of dark-colored vitrophyre flows interlayered with a few beds of tuff, both welded and unwelded, and quartz latite lava. This unit is similar in general appearance to the lower vitrophyre unit but is thicker and has a wider distribution. It is almost continuously exposed beneath the Laguna Springs Volcanic Group from Pinyon Creek Canyon southward to the southeastern corner of the district and is particularly well exposed in Pinyon Creek Canyon a third of a mile (0.05 km) north-northeast of the Pinyon Queen shaft and on the ridge connecting High Lonesome and Low Lonesome Points. The maximum thickness of the unit is not known; it is more than 500 ft (152 m) thick near Low Lonesome Point and may be several times this thickness in other areas nearby. The lower contact of the upper vitrophyre unit is gradational, and the base is placed where the rock matrix is dominantly glass. The uppermost part of the upper vitrophyre unit locally consists of agglomerate and talus debris that is abruptly overlain by one or another unit of the Laguna Springs Volcanic Group, as shown in the exposures near Laguna siding.

The upper vitrophyre unit commonly erodes to rounded hills that are characterized by a somber dark-gray color and uniform texture. In many areas it has a pronounced flow banding that from a distance or on aerial photographs resembles the bedding of the dark-colored limestones and dolomites. Like the porphyritic unit, the vitrophyre is readily disaggregated by frost riving and is partly concealed by a grus of mineral and rock fragments.

Hand specimens of vitrophyre from the upper vitrophyre unit consist of lustrous greenish-black volcanic glass enclosing shattered phenocrysts and fragments of clear feldspar, biotite, and quartz. Near the base of the unit the matrix is microgranular and merges imperceptibly with the felsitic matrix of the porphyritic unit. Phenocrysts are moderately abundant in all parts of the member, and there are few zones or lenses that may be classified as obsidian.

Under the petrographic microscope the vitrophyre displays a strong fluidal texture; in some thin sections perlitic fractures are also common. Many of the phenocrysts are shattered, and the fragments are separated and drawn out in lenses or trains of broken anhedra. Andesine, averaging $An_{40}$ in composition, is the most abundant phenocryst and generally is embayed and corroded. Biotite is next in abundance and is characterized by strong pleochroism and many inclusions of magnetite crystals. Some biotite phenocrysts are bent, and others are frayed, indicating strong physical deformation, probably during eruption. Water-clear sanidine and quartz, both strongly embayed and corroded, are markedly subordinate to andesine and biotite but are distinctive constituents of all of the specimens examined. Constituents forming less than 1 percent of the rock include brown hornblende, magnetite, apatite, and zircon. The groundmass of the vitrophyre is somewhat turbid and crowded with crystallites, chiefly trichites and globulites, that show flow patterns around the phenocrysts.

The interlayered tuffs of the upper vitrophyre unit commonly show the characteristics of air-fall ash or lapilli — a matrix of shards enclosing small fragments of pumice and porphyritic lava.

### CHEMICAL AND PHYSICAL CHARACTER

The lavas of the Packard Quartz Latite are remarkably uniform in chemical composition throughout the entire thickness of the formation (table 1), and all fall well within the quartz latite field as shown in figure 4. The largest differences are found in the lower vitrophyre unit, which contains an expectably larger amount of water than the holocrystalline lavas. It also appears to contain slightly less $K_2O$ and slightly more CaO and $Na_2O$ than the overlying porphyritic lavas. In general, the average composition of the analyzed samples of Packard Quartz Latite (analysis 8, table 1) is closely similar to the average composition of 58 dellenites (analysis 9, table 1) presented by Nockolds (1954, p. 1014), the only notable differences being the somewhat smaller quantities of FeO and $Na_2O$ in the Packard. Also shown in table 1 is an analysis of the quartz monzonite of the Swansea stock in the adjacent Tintic district, which is the principal intrusive body of similar mineralogical and chemical composition to the Packard Quartz Latite in the East Tintic Mountains, and the average composition of 121 adamellites (quartz monzonite) presented by Nockolds (1954, p. 1014). These analyses show that the quartz monzonite of the Swansea stock contains significantly higher $K_2O$, slightly higher $SiO_2$, and lower CaO and $Na_2O$.

With the exception of sample 5, all of the samples of Packard Quartz Latite contain approximately the same amount of normative quartz. Some differences are noted in the relative amounts of normative orthoclase and normative albite plus anorthite, but with the exception of sample 1, these differences do not indicate progressive enrichment or depletion of any element through the entire thickness of the porphyritic member of the Packard.

The content of minor elements, as indicated by the spectrochemical analyses presented in table 1, suggests that the Packard Quartz Latite contains somewhat more barium and lead and generally less chromium and vanadium than rocks of similar composition in the east-central Sierra Nevada, the Crater Lake area, Oregon, and in the Lesser Antilles (Nockolds and Allen, 1953, p. 122-127; Nockolds and Allen, 1954, p. 280-281).

The few data that are available on the physical properties of the rocks of the Packard Quartz Latite are presented in table 2. They are comparable to data for other igneous rocks of similar mineralogic composition (Clark, 1966).

Irregular, downward-flaring zones of bleached and partly disintegrated quartz latite are locally present within the porphyritic member of the Packard Quartz Latite. Lovering (1949, p. 20-21) and his coworkers have termed these zones "accelerated weathered" quartz latite. In some places, as in the railroad cut 1,000 ft (305 m) east-southeast of the Central Standard shaft, the effects of this alteration terminate abruptly beneath unaltered lava, which appears to have been deposited over the irregular surface of the underlying lava (fig. 7). This relation, the downward-flaring form of many of the altered zones, the absence of any obvious localization by post-Packard faults or intrusive bodies, and the abrupt contact with overlying fresh flows all indicate an intravolcanic age and origin for the altered areas.

TABLE 1. *Chemical analyses, CIPW norms, Niggli values, and spectrochemical analyses of selected samples of Packard Quartz Latite and similar rocks*

| Sample No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rock unit | Lower vitrophyre | Near base | | Porphyritic unit | | | Near top | Average of 1-7 | Average dellenite | Swansea Quartz Monzonite | Average adamellite |
| | | | | Packard Quartz Latite | | | | | | | |
| Laboratory No. | D102203 | .......... | D102204 | D101864 | .......... | D101871 | D101872 | .......... | .......... | D102252 | .......... |
| | | | | | **Chemical analyses (weight percent)** | | | | | | |
| $SiO_2$ | 67.68 | 71.10 | 70.87 | 69.76 | 70.82 | 69.27 | 69.33 | 69.90 | 70.15 | 70.08 | 69.15 |
| $Al_2O_3$ | 14.73 | 14.45 | 14.36 | 14.75 | 13.95 | 14.52 | 14.49 | 14.46 | 14.41 | 15.01 | 14.63 |
| $Fe_2O_3$ | 1.71 | 2.02 | 1.91 | 2.16 | 1.82 | 1.64 | 1.63 | 1.84 | 1.68 | 1.66 | 1.22 |
| FeO | .59 | .61 | .49 | .22 | 1.46 | .52 | .53 | .63 | 1.55 | .57 | 2.27 |
| MgO | .67 | .48 | .46 | .50 | .43 | .59 | .59 | .53 | .63 | .69 | .99 |
| CaO | 2.50 | 2.01 | 1.62 | 2.20 | 1.94 | 2.08 | 2.05 | 2.06 | 2.15 | 1.12 | 2.45 |
| $Na_2O$ | 3.05 | 2.78 | 2.61 | 3.02 | 2.76 | 2.96 | 2.89 | 2.87 | 3.65 | 2.96 | 3.35 |
| $K_2O$ | 3.98 | 5.13 | 5.95 | 4.50 | 4.18 | 4.67 | 4.79 | 4.74 | 4.50 | 5.69 | 4.58 |
| $H_2O+$ | 3.47 | .29 | .44 | .76 | .86 | 2.51 | 2.52 | 1.55 | .68 | .75 | .54 |
| $H_2O-$ | .65 | .10 | .03 | 1.11 | .80 | .14 | .10 | .42 | .......... | .25 | .......... |
| $TiO_2$ | .38 | .39 | .38 | .36 | .34 | .34 | .35 | .36 | .42 | .41 | .56 |
| $P_2O_5$ | .13 | .14 | .18 | .11 | .14 | .10 | .10 | .13 | .12 | .12 | .20 |
| MnO | .06 | .05 | .03 | .04 | .02 | .06 | .06 | .05 | .06 | .07 | .06 |
| $CO_2$ | .01 | .13 | .01 | .14 | .10 | .05 | .02 | .07 | .......... | .01 | .......... |
| Cl | .03 | tr | .02 | .00 | .......... | .03 | .04 | .02 | .......... | .02 | .......... |
| F | .05 | .05 | .05 | .09 | .......... | .05 | .06 | .05 | .......... | .05 | .......... |
| S | .01 | .02 | .01 | .01 | .......... | .02 | .02 | .02 | .......... | .01 | .......... |
| $SO_3$ | .......... | .......... | .......... | .......... | .15 | .......... | .......... | .......... | .......... | .......... | .......... |
| Subtotal | 99.70 | | 99.42 | 99.73 | | 99.55 | 99.57 | | | 99.47 | |
| Less O | .04 | | .03 | .05 | | .04 | .05 | | | .03 | |
| Total | 99.66 | 99.94 | 99.39 | 99.68 | 99.77 | 99.51 | 99.52 | 99.70 | 100.00 | 99.44 | 100.00 |

**TABLE 1.** — *Chemical analyses, CIPW norms, Niggli values, and spectrochemical analyses of selected samples of Packard Quartz Latite and similar rocks*

| Sample No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rock unit | Lower vitrophyre | Near base | | Porphyritic unit | | | Near top | Average of 1-7 | Average dellenite | Swansea Quartz Monzonite | Average adamellite |
| | | | | Packard Quartz Latite | | | | | | | |
| Laboratory No. | D102203 | .......... | D102204 | D101864 | .......... | D101871 | D101872 | .......... | .......... | D102252 | .......... |
| **CIPW norms (weight percent)** | | | | | | | | | | | |
| Q | 30.10 | 30.95 | 29.62 | 30.56 | 34.84 | 30.12 | 30.18 | 31.00 | 26.39 | 28.48 | 25.11 |
| C | 1.23 | 1.01 | 1.12 | 1.20 | 1.73 | 1.09 | 1.10 | 1.20 | .......... | 2.27 | .19 |
| or | 24.65 | 30.59 | 35.58 | 27.25 | 25.25 | 28.54 | 29.26 | 28.72 | 26.79 | 34.20 | 27.23 |
| ab | 27.05 | 23.74 | 22.35 | 26.19 | 23.87 | 25.90 | 25.28 | 24.90 | 31.12 | 25.48 | 28.52 |
| an | 12.11 | 9.14 | 6.94 | 10.45 | 8.90 | 10.00 | 9.84 | 9.61 | 9.72 | 4.85 | 10.91 |
| Normative An | ($An_{31}$) | ($An_{28}$) | ($An_{24}$) | ($An_{28}$) | ($An_{27}$) | ($An_{28}$) | ($An_{28}$) | ($An_{28}$) | ($An_{24}$) | ($An_{16}$) | ($An_{28}$) |
| (di) wo | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .10 | .......... | .......... |
| (di) en | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .......... | (.19) .06 | .......... | .......... |
| (di) fs | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .03 | .......... | .......... |
| (hy) en | (1.75) 1.75 | (1.21) 1.21 | (1.16) 1.16 | (1.27 1.27 | (1.72) 1.09 | (1.52) 1.52 | (1.52) 1.52 | (1.35) 1.35 | (2.26) 1.52 | (1.75) 1.75 | (4.73) 2.48 |
| (hy) fs | .......... | .......... | .......... | .......... | .63 | .......... | .......... | .......... | .74 | .......... | 2.25 |
| mt | .84 | .84 | .48 | .......... | 2.70 | .71 | .72 | 1.01 | 2.45 | .66 | 1.78 |
| hm | 1.21 | 1.46 | 1.60 | 2.21 | .......... | 1.20 | 1.19 | 1.19 | .......... | 1.23 | .......... |
| il | .76 | .75 | .73 | .48 | .66 | .67 | .69 | .70 | .80 | .79 | 1.07 |
| ru | .......... | .......... | .......... | .12 | .......... | .......... | .......... | .......... | .......... | .......... | .......... |
| ap | .32 | .34 | .43 | .27 | .34 | .25 | .25 | .32 | .29 | .29 | .48 |
| Total | 100.02 | 100.03 | 100.01 | 100.00 | 100.01 | 100.00 | 100.03 | 100.00 | 100.01 | 100.00 | 100.02 |
| Salic/femic ratio | 19.49 | 20.80 | 21.71 | 21.98 | 17.45 | 21.99 | 21.95 | 20.88 | 15.68 | 20.18 | 11.41 |
| Diff. index | 81.80 | 85.28 | 87.55 | 84.00 | 83.96 | 84.56 | 84.72 | 84.62 | 84.30 | 88.16 | 80.86 |
| **Niggli values** | | | | | | | | | | | |
| Al | 44.21 | 43.93 | 44.41 | 44.80 | 43.56 | 44.61 | 44.61 | 44.30 | 41.02 | 45.83 | 39.72 |
| Fm | 14.15 | 14.17 | 13.29 | 13.17 | 17.12 | 13.29 | 13.32 | 14.04 | 16.90 | 14.27 | 19.77 |
| C | 13.64 | 11.11 | 9.11 | 12.15 | 11.01 | 11.62 | 11.47 | 11.47 | 11.13 | 6.22 | 12.09 |
| Alk | 27.99 | 30.79 | 33.19 | 29.88 | 28.30 | 30.49 | 30.60 | 30.18 | 30.95 | 33.68 | 28.42 |
| Si | 344.73 | 366.84 | 371.91 | 359.56 | 375.26 | 361.13 | 362.20 | 363.39 | 338.83 | 363.14 | 318.56 |
| Ri | 1.46 | 1.51 | 1.50 | 1.40 | 1.35 | 1.33 | 1.38 | 1.41 | 1.53 | 1.60 | 1.94 |
| P | .28 | .31 | .40 | .24 | .31 | .22 | .22 | .29 | .25 | .26 | .39 |
| H | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .......... | .......... |
| K | .46 | .55 | .60 | .50 | .50 | .51 | .52 | .52 | .45 | .56 | .47 |
| Mg | .36 | .26 | .27 | .29 | .20 | .35 | .34 | .29 | .27 | .37 | .34 |
| Si' | 211.96 | 223.15 | 232.77 | 219.53 | 213.22 | 221.95 | 222.39 | 220.73 | 223.82 | 234.70 | 213.67 |
| Qz | 132.77 | 143.69 | 139.13 | 140.02 | 162.04 | 139.17 | 139.81 | 142.67 | 115.02 | 128.44 | 104.88 |
| **Spectrochemical analyses[1] (parts per million)** | | | | | | | | | | | |
| Ba | 2,000 | .......... | 2,000 | 3,000 | .......... | 3,000 | 3,000 | .......... | .......... | 3,000 | .......... |
| Be | 1.5 | .......... | 1 | [2]N | .......... | N | N | .......... | .......... | 2 | .......... |
| Ce | 200 | .......... | 150 | N | .......... | 200 | 200 | .......... | .......... | 150 | .......... |
| Co | 3 | .......... | 3 | 5 | .......... | 3 | 3 | .......... | .......... | 5 | .......... |
| Cr | 2 | .......... | 1.5 | 2 | .......... | 1 | 1 | .......... | .......... | 2 | .......... |
| Cu | 3 | .......... | 3 | 2 | .......... | 1.5 | 2 | .......... | .......... | 5 | .......... |
| Ga | 30 | .......... | 30 | 20 | .......... | 15 | 20 | .......... | .......... | 20 | .......... |
| La | 150 | .......... | 150 | 150 | .......... | 100 | 100 | .......... | .......... | 150 | .......... |
| Nb | 10 | .......... | 10 | N | .......... | N | N | .......... | .......... | 10 | .......... |
| Nd | 100 | .......... | 70 | N | .......... | N | N | .......... | .......... | 100 | .......... |
| Pb | 30 | .......... | 30 | 30 | .......... | 20 | 20 | .......... | .......... | 30 | .......... |
| Sc | 5 | .......... | 5 | 5 | .......... | 5 | 5 | .......... | .......... | 5 | .......... |
| Sr | 700 | .......... | 500 | 500 | .......... | 300 | 500 | .......... | .......... | 500 | .......... |
| V | 30 | .......... | 30 | 30 | .......... | 15 | 20 | .......... | .......... | 50 | .......... |
| Y | 30 | .......... | 30 | 20 | .......... | 15 | 15 | .......... | .......... | 30 | .......... |
| Yb | 2 | .......... | 2 | 2 | .......... | 1 | 1.5 | .......... | .......... | 3 | .......... |
| Zr | 200 | .......... | 200 | 150 | .......... | 150 | 150 | .......... | .......... | 100 | .......... |

[1]Also looked for and not detected at limit of detection, or detected but below limit of determination: Ag, As, Au, B, Bi, Cd, Eu, Ge, Hf, Hg, In, Li, Mo, Ni, Pd, Pt, Re, Sb, Sm, Sn, Ta, Te, Th, Tl, Pr, U, W, and Zn.

[2]N = not detected.

1. Vitrophyre, lower vitrophyre unit about 30 ft (9 m) above base of Packard Quartz Latite, 980 ft (299 m) S. 6° W. from Central Standard shaft. G. O. Riddle, chemical analyst; J. C. Hamilton, spectrochemical analyst, U.S. Geological Survey.
2. Porphyritic quartz latite, porphyritic unit about 60 ft (18 m) above base of Packard Quartz Latite, 550 ft (167.6 m) N. 34° E. from Copper Leaf Shaft. L. C. Peck, analyst, Grout Rock Analysis Laboratory.
3. Porphyritic quartz latite, lower part of porphyritic unit of Packard Quartz Latite, about 800 ft (244 m) due south from Central Standard shaft. G. O. Riddle, chemical analyst; J. C. Hamilton, spectrochemical analyst, U.S. Geological Survey.
4. Porphyritic quartz latite, lower part of porphyritic unit of Packard Quartz Latite, 880 ft (268.2 m) S. 22° E. from Central Standard shaft. E. E. Engleman, chemical analyst; J. L. Finley, spectrochemical analyst, U.S. Geological Survey.
5. Porphyritic quartz latite, porphyritic unit of Packard Quartz Latite, 2,930 ft (893 m) N. 71° W. from North Lily shaft. R. E. Stevens, analyst, U.S. Geological Survey.
6. Porphyritic quartz latite, upper part of porphyritic unit of Packard Quartz Latite, 600 ft (183 m) S. 72° E. from crest of High Lonesome Point. E. E. Engleman, chemical analyst; J. L. Finley, spectrochemical analyst, U.S. Geological Survey.
7. Porphyritic quartz latite, upper part of porphyritic unit of Packard Quartz Latite, 2,800 ft (854 m) S. 74° W. from crest of Low Lonesome Point. E. E. Engleman, chemical analyst; J. L. Finley, spectrochemical analyst, U.S. Geological Survey.
8. Average of analyses 1-7.
9. Average of 58 dellenites (quartz latite) and dellenite obsidians (Nockolds, 1954, p. 1014).
10. Quartz monzonite of Swansea stock, Tintic mining district. E. E. Engleman, chemical analyst. L. A. Bradley, spectrochemical analyst, U.S. Geological Survey.
11. Average of 121 adamellites (quartz monzonite) (Nockolds, 1954, p. 1014).

The altered rocks are pale bluish gray to white and have a granular texture that is similar to the unbleached lavas in nearby outcrops. The rock crumbles easily under the hammer and is stained by limonite and cut by veinlets of caliche as much as a quarter of an inch (0.6 cm) wide.

TABLE 2.—*Physical constants of rocks of the Packard Quartz Latite*

| Rock type | Bulk density ($gm/cm^3$) | Powder density | Porosity (percent) | Thermal conductivity $10^{-3}$ cal/cm/sec/°C | Resistivity $10^3$ohm/cm |
|---|---|---|---|---|---|
| (1) Basal tuff | .......... | .......... | .......... | [1]1.63-2.23 | [2]25-30 |
| (2) Lower vitrophyre | 2.38 | 2.45 | 2.86 | .......... | .......... |
| (3) Porphyritic unit | 2.48 | 2.56 | 3.2 | [1]4.8 | [2]170-200 |

[1]Data originally presented by Lovering and Morris (1965, p. F10-F11).
[2]Determined by Earl Ingerson, U.S. Geological Survey.

As seen under the microscope, many of the plagioclase phenocrysts and a few of the biotite phenocrysts of the altered lava are partly replaced by montmorillonite, and the groundmass contains minute blebs of allophane. Much of the biotite is unaltered, which distinguishes this intravolcanic alteration from the later hypogene argillization that readily converted biotite and plagioclase to halloysite, kaolinite, and dickite, or to montmorillonite.

Chemical analyses of the intravolcanic altered rock are compared with analyses of unaltered quartz latite in table 3. The most apparent effect of the alteration is partial removal of all of the principal constituents of the quartz latite, particularly iron, $Na_2O$, and CaO, with a concommitant increase in $H_2O$, chiefly reflecting the replacement of plagioclase and biotite by montmorillonite. The increase in $CO_2$ is probably accounted for by ubiquitous caliche. This type of chemical change suggests an attack by mildly acid bicarbonate waters perhaps similar to the waters of Hillside Springs in Yellowstone Park (Allen and Day, 1935, p. 353), which have partially decomposed rhyolite in the same general manner and to the same degree as the altered Packard Quartz Latite, producing beidellite clay. According to D. E. White (oral commun., Feb. 1970), the waters discharged at Hillside Springs have a pH of approximately 6.

## INTRUSIVE COUNTERPARTS

The only intrusive rocks with chemical and mineralogical compositions similar to the Packard Quartz Latite in the East Tintic Mountains are the Swansea stock and an adjacent dike in the southern part of the Tintic district (Lindgren and Loughlin, 1919, p. 49-52). The quartz monzonite of the stock is a pinkish-gray fine-grained porphyritic rock containing phenocrysts of orthoclase, sodic andesine, quartz, and biotite in a granular mosaic of quartz and orthoclase. Accessory minerals include magnetite, apatite, and zir-

FIGURE 7. — Zone of accelerated weathering in Packard Quartz Latite in railroad cut 1,000 ft (305 m) east-southeast of Central Standard shaft. Unaltered lava overlying altered zone has an irregular but sharp lower contact.

con. Like their counterparts in the Packard Quartz Latite, the quartz phenocrysts of the Swansea stock are strongly corroded and embayed, many of which also are shattered and are preserved only as sharp-edged fragments. The only mineral not observed in the quartz monzonite of the Swansea stock that is present in the Packard is basaltic hornblende, but inasmuch as it occurs only rarely and as small phenocrysts, it may have escaped detection in the freshest, but still altered, samples of Swansea that were examined.

### Source And Eruptive History

The eruptive center of the volcanic rocks of the Packard Quartz Latite is not known with certainty. In the earlier investigations of the Tintic area, both Tower and Smith (1899, p. 651-652) and Lindgren and Loughlin (1919, p. 45) concluded that the source of the Packard lavas was at Packard Peak, about 1 mi (1.6 km) north of Eureka. According to Lindgren and Loughlin:

> At Packard Peak* * * the rhyolite [quartz latite] is 800 to 1,000 feet thick* * * and is of uniform texture, the only irregularities noted being small inclusions of bleached rhyolite tuff a few inches in diameter. This great thickness and the uniformity of character suggests strongly, as stated in the earlier [Tower and Smith] report, that the center of eruption underlies Packard Peak and the ridge just east of it.

During the years after the studies of Lindgren and Loughlin, much new geologic information has become available that considerably alters their conclusions. Detailed studies by Morris and Anderson (1962) have shown that the Packard Quartz Latite in the area of Packard Peak in fact fills a large east-trending valley that is the westward extension of the prelava valley that lies between the North Lily and Copper Leaf shafts. The extrusive nature of the Packard Quartz Latite in the Packard Peak area is also corroborated by exploration drill holes that have penetrated the base of the Packard and cut the underlying sedimentary rocks, as well as by mine workings that extend for long distances in Paleozoic rocks beneath the lavas and do not intersect intrusive rocks or related zones of contact pyrometasomatism.

In 1973 and 1974, work in the central part of the East Tintic Mountains (Morris, 1975) indicated the presence of a large caldera of Packard or post-Packard age that is completely filled and overtopped by younger volcanic rocks and intruded by many dikes, plugs, and stocks. The recognition of this buried caldera now suggests that it approximates the site of the initial Packard eruptions, and it also suggests a possible welded-tuff origin for the Packard, as described below.

The large volume of the Packard volcanic rocks and the remarkably uniform texture and composition of its more than 3,000-ft thick (914 m) porphyritic unit indicate an abrupt and rapid eruption of great quantities of partly crystallized magma uninterrupted by periods of volcanic quiescence and erosion. Aside from the relatively thin and volumetrically insignificant beds of tuff and tuff-breccia at the base and near the top of the formation, no features of periodic eruption, such as interbedded lenses of conglomerate or tuff, or slaggy, scoriaceous, or oxidized flow contacts, crop out in the East Tintic Mountains. These relations indicate a fulminating eruption, which persisted until virtually all of the available magma was exhausted, and volcanism terminated as abruptly as it began. At this time it is believed that caldera collapse took place, creating a structural depression approximately 8.5 mi (13.7 km) in diameter and perhaps 3,000 ft (914 m) deep. The north edge of this feature is inferred to lie beneath younger volcanic rocks approximately at the southern boundary of the East Tintic district.

Evidence for the nature of the fulminating eruptions—whether they were chiefly nuées ardentes or highly fluidized lavas—is not conclusive. Within the East Tintic district itself, the absence of relict shards in the vitrophyre and quartz latite units argues against a welded tuff origin. However, the overwhelming abundance of ignimbrites and air-fall tuffs making up the volcanic rocks that are equivalent in age, composition, and stratigraphic position to the Packard in the Wasatch and San Pitch Mountains and in the Gunnison and Wasatch Plateaus—areas that were both downwind and downslope from the inferred eruptive center—in part supports such an origin. If the Packard porphyries had been chiefly erupted as clouds of glowing ash, then they must have become completely welded as a consequence of being deposited in relatively narrow, deep valleys, thus maintaining high temperatures for a considerable period of time.

TABLE 3.—*Analyses of intravolcanic altered and unaltered porphyritic quartz latite of Packard Quartz Latite and chemical changes*

| | Chemical analyses (weight percent) | | Weight of oxides (mg cm³) | | Loss or gain (mg/cm³ of rock) |
|---|---|---|---|---|---|
| | 1, altered | 2, unaltered | 1, altered | 2, unaltered | |
| $SiO_2$ | 69.40 | 70.82 | 1526.80 | 1749.25 | -222.45 |
| $Al_2O_3$ | 14.64 | 13.95 | 322.08 | 344.57 | -22.49 |
| $\overline{Fe_2O_3}$ / FeO | 2.77 | 3.28 | 60.94 | 83.49 | -22.55 |
| MgO | .50 | .43 | 11.00 | 10.62 | + .38 |
| CaO | 1.84 | 1.94 | 40.48 | 47.92 | -7.44 |
| $Na_2O$ | 2.69 | 2.76 | 59.18 | 68.17 | -8.99 |
| $K_2O$ | 4.41 | 4.18 | 97.02 | 103.25 | -6.23 |
| $H_2O+$ | 1.47 | .86 | 32.34 | 21.24 | + 11.10 |
| $H_2O-$ | 1.05 | .80 | 23.10 | 19.76 | + 3.34 |
| $TiO_2$ | .36 | .34 | 7.92 | 8.40 | -.48 |
| $P_2O_5$ | .15 | .14 | 3.30 | 3.46 | -.16 |
| MnO | .04 | .02 | .88 | .49 | .39 |
| $CO_2$ | .17 | .10 | 3.74 | 2.47 | + 1.27 |
| Total | 99.49 | 99.72 | .......... | .......... | .......... |
| Bulk density | 2.20 | 2.47 | .......... | .......... | .......... |

1. Intravolcanic altered porphyritic quartz latite of Packard Quartz Latite 6,500 ft (1,981 m) S. 60° E. from Copper Leaf shaft. R. E. Stevens, analyst, U.S. Geological Survey.
2. Unaltered porphyritic quartz latite of Packard Quartz Latite 2,930 ft (893 m) N. 71° W. from North Lily shaft. R. E. Stevens, analyst, U.S. Geological Survey.

### AGE

The Packard Quartz Latite is the oldest post-tectonic volcanic unit in the northern East Tintic Mountains, and in all of its exposures it overlies folded, faulted, and eroded Paleozoic rocks or the thin rubble that was derived from them. Evidence of volcanic units older than the Packard in the Tintic and East Tintic districts, as presented by Lindgren and Loughlin (1919, p. 42-43) and others, has not been substantiated by the more inclusive and detailed surveys and the subsurface explorations that have been carried out since 1943.

Isotopic age-dating techniques, based on potassium-argon age determinations, recently have provided what seem to be the most reliable estimates of the age of the Packard and younger volcanic rocks in the East Tintic Mountains. Biotite and sanidine from a sample of the porphyritic member of the Packard Quartz Latite 880 ft (268 m) S. 20° E. from the Central Standard shaft (see sample 4, table 1) yielded isotopic ages of $32.8 \pm 1.0$ and $32.07 \pm 1.0$ m.y. (million years), respectively (Laughlin and others, 1969). These ages indicate eruption during the middle Oligocene and are compatible with the isotopic ages of the post-Packard volcanic and intrusive rocks described elsewhere in this report.

Rare fossils that occur in the basal tuffs near Homansville Canyon are preserved only as carbonaceous films that suggest rushes or some other aquatic plant and are not suitable to substantiate the isotopic ages

### ECONOMIC IMPORTANCE

Although the Packard Quartz Latite directly overlies the host rocks for some of the largest replacement ore bodies in the East Tintic district and locally was intensely altered by ore-related hydrothermal solutions, it has yielded only small quantities of ore. The most extensively mineralized zone known in the Packard is adjacent to the sphalerite- and galena-bearing Apex Conglomerate in the Ballpark section of the Burgin mine (see section "Ballpark Area"). Other occurrences of mineralized Packard include the pod of pyritic jasperoid that is localized by a north-northeast-trending fault in the roadcut of U.S. Highway 6-50 about 1,300 ft (396 m) N. 66° W. from the Copper Leaf shaft. Assays of this material indicate as much as 33 parts per million silver and several hundred parts per million lead and zinc. Except for its low grade, this jasperoidized lava is similar to some replacement ore bodies in the igneous rocks in the southern part of the main Tintic district.

In many other parts of the East Tintic district, the hydrothermally altered Packard lavas up rake from ore bodies also contain trace concentrations of introduced copper, lead, zinc, silver, gold, and other metals (Lovering and others, 1948; Bush and others, 1960, p. 1140-1146; Shepard, 1966; and other papers). In general, the metals are dispersed along minute fractures, as near the Trixie mine, where parts of the altered basal tuff of the Packard Quartz Latite contain as much as 1 percent disseminated galena and sphalerite that can be readily concentrated by panning the unweathered tuff. These geochemical anomalies have proved to be highly useful in the search for ore bodies that have only indirect surface expressions.

## POST-PACKARD OLIGOCENE ROCKS

The eruptive rocks of Oligocene age that overlie the Packard Quartz Latite are subdivided into two

TABLE 4.—*Chemical analyses, CIPW norms, Niggli values, and spectrochemical analyses of selected samples of lavas of the Tintic Mountain Volcanic Group and intrusive rocks of the Sunrise Peak Monzonite Porphyry*

| Sample No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Formation | Copperopolis Latite | | Latite Ridge Latite | | Big Canyon Latite | Monzonite porphyry of the Gough sill | | | Latite breccia pipe | Sunrise Peak Monzonite Porphyry |
| Laboratory No. | M110 361W | M110 362W | M110 357W | D102257 | M110 359W | M110 363W | M110 364W | D101873 | D102260 | |
| **Chemical analyses (weight percent)** | | | | | | | | | | |
| $SiO_2$ | 60.2 | 61.9 | 63.7 | 64.09 | 57.7 | 61.0 | 60.3 | 59.9 | 59.23 | 58.22 |
| $Al_2O_3$ | 19.0 | 18.2 | 17.4 | 16.87 | 16.1 | 17.1 | 16.9 | 17.2 | 17.17 | 15.68 |
| $Fe_2O_3$ | 2.5 | 3.8 | 4.2 | 3.30 | 4.8 | 5.9 | 5.1 | 6.0 | 3.31 | 3.41 |
| FeO | 1.2 | .60 | .36 | .54 | 3.4 | .12 | .68 | .20 | 1.28 | 3.17 |
| MgO | 1.0 | .74 | .82 | .87 | 2.8 | 1.0 | 1.7 | 1.5 | 1.08 | 2.75 |
| CaO | 4.7 | 4.4 | .83 | 1.97 | 5.7 | 3.7 | 4.5 | 3.9 | 3.08 | 4.03 |
| $Na_2O$ | 3.5 | 3.6 | 3.7 | 3.66 | 3.1 | 3.4 | 3.6 | 2.9 | 2.45 | 3.10 |
| $K^2O$ | 4.7 | 5.0 | 6.4 | 6.10 | 2.9 | 4.8 | 4.6 | 4.7 | 4.94 | 4.72 |
| $H^2O+$ | 1.2 | .50 | 1.2 | .72 | .60 | 1.0 | .60 | 1.1 | 3.55 | 1.71 |
| $H^2O-$ | .53 | .79 | 1.2 | .35 | .91 | .50 | 1.1 | 2.3 | 1.87 | .20 |
| $TiO_2$ | .89 | .85 | .82 | .76 | 1.1 | .84 | .87 | .85 | .93 | .86 |
| $P_2O_5$ | .35 | .35 | .30 | .26 | .44 | .42 | .45 | .47 | .32 | .39 |
| MnO | .08 | .11 | .18 | .11 | .08 | .20 | 08 | .06 | .07 | .14 |
| $CO_2$ | .08 | .02 | .02 | .06 | .01 | .36 | .01 | .01 | .10 | 1.36 |
| Cl | .......... | .......... | .......... | .01 | .......... | .......... | .......... | .......... | .03 | .02 |
| F | .......... | .......... | .......... | .17 | .......... | .......... | .......... | .......... | .16 | .12 |
| S | .......... | .......... | .......... | .01 | .......... | .......... | .......... | .......... | .04 | .02 |
| Subtotal | | | | 99.85 | | | | | 99.61 | 99.90 |
| Less 0 | | | | .08 | | | | | .10 | .06 |
| Total | 100 | 101 | 101 | 99.77 | 101 | 100 | 100 | 101 | 99.51 | 99.84 |

TABLE 4. — *Chemical analyses, CIPW norms, Niggli values, and spectrochemical analyses of selected samples of lavas of the Tintic Mountain Volcanic Group and intrusive rocks of the Sunrise Peak Monzonite Porphyry*

| Sample No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Formation | Copperopolis Latite | | Latite Ridge Latite | | Big Canyon Latite | Monzonite porphyry of the Gough sill | | | Latite breccia pipe | Sunrise Peak Monzonite Porphyry |
| Laboratory No. | M110 361W | M110 362W | M110 357W | D102257 | M110 359W | M110 363W | M110 364W | D101873 | D102260 | |
| **CIPW norms (weight percent)** | | | | | | | | | | |
| Q | 11.71 | 12.54 | 15.79 | 15.54 | 14.28 | 15.79 | 11.66 | 16.18 | 20.82 | 14.03 |
| C | .65 | .......... | 3.69 | 1.86 | .......... | 1.44 | .......... | 1.43 | 3.81 | 2.54 |
| or | 28.28 | 29.67 | 38.31 | 36.49 | 17.46 | 28.70 | 27.52 | 28.43 | 30.99 | 28.46 |
| ab | 30.16 | 30.59 | 31.71 | 31.28 | 26.73 | 29.11 | 30.84 | 25.12 | 21.77 | 26.62 |
| an | 20.90 | 18.82 | 2.06 | 6.70 | 21.86 | 13.49 | 16.57 | 16.60 | 12.31 | 8.39 |
| Normative An | ($An_{41}$) | ($An_{38}$) | ($An_{6}$) | ($An_{18}$) | ($An_{45}$) | ($An_{32}$) | ($An_{35}$) | ($An_{40}$) | ($An_{41}$) | ($An_{23}$) |
| (di) wo | .......... | .20 | .......... | .......... | 1.66 | .......... | 1.21 | .......... | .......... | .......... |
| (di) en | .......... | (0.37) .17 | .......... | .......... | (3.12) 1.34 | .......... | (2.26) 1.05 | .......... | .......... | .......... |
| (di) fs | .......... | .......... | .......... | .......... | .12 | .......... | .......... | .......... | .......... | .......... |
| (hy) en | (2.54) 2.54 | (1.68) 1.68 | (2.07) 2.07 | (2.19) 2.19 | (6.28) 5.77 | (2.52) 2.52 | (3.24) 3.24 | (3.82) 3.82 | (2.86) 2.86 | (8.83) 6.99 |
| (hy) fs | .......... | .......... | .......... | .......... | .51 | .......... | .......... | .......... | .......... | 1.84 |
| mt | 1.58 | .......... | .......... | .......... | 7.09 | .......... | .......... | .......... | 1.61 | 5.05 |
| hm | 1.46 | 3.82 | 4.25 | 3.34 | .......... | 5.97 | 5.16 | 6.14 | 2.41 | .......... |
| il | 1.72 | 1.51 | 1.16 | 1.37 | 2.13 | .69 | 1.63 | .56 | 1.88 | 1.67 |
| ru | .......... | .......... | .22 | .05 | .......... | .49 | .......... | .57 | .......... | .......... |
| ap | .84 | .83 | .72 | .62 | 1.06 | 1.01 | 1.08 | 1.14 | .81 | .94 |
| cc | .19 | .05 | .05 | .14 | .02 | .83 | .02 | .02 | .24 | .02 |
| Total | 100.03 | 99.88 | 100.03 | 99.58 | 100.03 | 100.04 | 99.98 | 100.01 | 99.51 | 99.69 |
| Salic/Femic ratio | 11.02 | 10.91 | 10.81 | 11.43 | 4.08 | 7.70 | 6.44 | 7.15 | 8.84 | 4.03 |
| Diff. index | 70.15 | 72.81 | 85.80 | 83.31 | 58.48 | 73.59 | 70.01 | 69.73 | 73.57 | 69.12 |
| **Niggli values** | | | | | | | | | | |
| Al | 41.37 | 40.21 | 43.36 | 41.74 | 30.46 | 37.88 | 35.30 | 37.41 | 41.85 | 31.85 |
| Fm | 16.42 | 17.08 | 20.45 | 18.16 | 34.34 | 23.31 | 24.84 | 25.72 | 21.64 | 32.52 |
| C | 18.61 | 17.67 | 3.76 | 8.86 | 19.61 | 14.90 | 17.09 | 15.42 | 13.65 | 14.88 |
| Alk | 23.61 | 25.04 | 32.43 | 31.24 | 15.59 | 23.90 | 22.77 | 21.44 | 22.86 | 20.74 |
| Si | 222.42 | 232.04 | 269.37 | 269.11 | 185.25 | 229.33 | 213.74 | 221.10 | 245.01 | 200.70 |
| Ri | 2.47 | 2.40 | 2.61 | 2.40 | 2.66 | 2.37 | 2.32 | 2.36 | 2.89 | 2.23 |
| P | .55 | .56 | .54 | .46 | .60 | .67 | .68 | .73 | .56 | .57 |
| K | .47 | .48 | .53 | .52 | .38 | .48 | .46 | .52 | .57 | .50 |
| Mg | .34 | .24 | .25 | .30 | .39 | .24 | .36 | .32 | .31 | .43 |
| Si' | 194.45 | 200.15 | 229.72 | 224.94 | 162.35 | 195.61 | 191.08 | 185.77 | 191.43 | 182.95 |
| Qz | 27.97 | 31.89 | 39.65 | 44.17 | 22.90 | 33.73 | 22.66 | 35.33 | 53.58 | 17.75 |
| **Spectrochemical analyses[1] (parts per million)** | | | | | | | | | | |
| B | 15 | [2]N | 10 | 50 | N | N | N | N | 50 | 20 |
| Ba | 2,000 | 2,000 | 2,000 | 1,500 | 1,500 | 2,000 | 2,000 | 2,000 | 2,000 | 1,000 |
| Be | 1.5 | 1.5 | 3 | 5 | N | N | 1 | 1 | N | 5 |
| Ce | 200 | 200 | 200 | 200 | 100 | 150 | 150 | 150 | 200 | 150 |
| Co | 7 | 10 | 7 | 10 | 30 | 20 | 15 | 15 | 5 | 20 |
| Cr | 1.5 | 1.5 | 5 | 5 | 30 | 5 | 7 | 5 | 1.5 | 50 |
| Cu | 10 | 20 | 3 | 30 | 70 | 200 | 50 | 50 | 20 | 100 |
| Ga | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 50 |
| La | 100 | 150 | 150 | 200 | 70 | 100 | 100 | 100 | 100 | 100 |
| Mo | N | 5 | 2 | 3 | N | N | N | N | N | 5 |
| Nb | 15 | 15 | 20 | 10 | 10 | 10 | 10 | 15 | N | 5 |
| Nd | 100 | 100 | 100 | 150 | 70 | 70 | 100 | 100 | N | 100 |
| Ni | N | N | N | 5 | 30 | 7 | 7 | 5 | N | 20 |
| Pb | 30 | 20 | 50 | 50 | 20 | 50 | 30 | 20 | 30 | 50 |
| Sc | 15 | 15 | 15 | 15 | 30 | 15 | 20 | 20 | 15 | 20 |
| Sr | 1,000 | 1,500 | 500 | 700 | 1,000 | 1,500 | 1,500 | 1,000 | 1,000 | 1,000 |
| V | 50 | 70 | 50 | 100 | 300 | 70 | 150 | 100 | 70 | 200 |
| Y | 30 | 30 | 50 | 70 | 30 | 30 | 30 | 30 | 30 | 70 |
| Yb | 3 | 3 | 3 | 5 | 3 | 3 | 3 | 3 | 3 | 5 |
| Zr | 300 | 300 | 700 | 500 | 200 | 300 | 300 | 200 | 300 | 200 |

[1]Also looked for and not detected at limit of detection, or detected but below limit of determination: Ag, As, Au, Bi, Cd, Eu, Ge, Hf, Hg, In, Li, Pd, Pt, Re, Sb, Sm, Sn, Ta, Te, Th, Tl, Pr, U, W, and Zn.
[2]N = not detected.

1. Fine-grained black porphyritic latite, flow member of Copperopolis Latite from SE¼SE¼NW¼ sec. 26, T. 10 S., R. 2 W. Chemical analysis performed in the Rapid-Rock Analysis Laboratory under Leonard Shapiro; Chris Heropoulos, spectrochemical analyst.
2. Fine-grained brown porphyritic latite, flow member of Copperopolis Latite from center SE¼NW¼ sec. 26, T. 10 S., R. 2 W. Chemical analysis performed in the Rapid-Rock Analysis Laboratory under Leonard Shapiro; Chris Heropoulos, spectrochemical analyst.
3. Flow member, Latite Ridge Latite from Silver Pass Gulch 900 ft (273 m) south-southwest from South Standard shaft. Chemical analysis performed in the Rapid-Rock Analysis Laboratory under Leonard Shapiro; Chris Heropoulos, spectrochemical analyst.
4. Flow member, Latite Ridge Latite from center E½E½NW¼ sec. 27, T. 10 S., R. 2 W. E. E. Engleman, chemical analyst; L. A. Bradley, spectrochemical analyst.
5. Flow member, Big Canyon Latite from NW¼NE¼ sec. 13, T. 10 S., R. 2 W. Chemical analysis performed in the Rapid-Rock Analysis Laboratory under Leonard Shapiro; Chris Heropoulos, spectrochemical analyst.
6. Monzonite porphyry of Gough sill near Gold Bond Spring, center E½E½SE¼ sec. 28, T. 10 S, R. 2 W. Chemical analysis performed in the Rapid-Rock Analysis Laboratory under Leonard Shapiro; Chris Heropoulos, spectrochemical analyst.
7. Monzonite porphyry of Gough sill from extreme SW corner of sec. 26, T. 10 S., R. 2 W. Chemical analysis performed in the Rapid-Rock Analysis Laboratory under Leonard Shapiro; Chris Heropoulos, spectrochemical analyst.
8. Monzonite porphyry of Gough sill from E½SW¼SE¼ sec. 27, T. 10 S., R. 2 W. Chemical analysis performed in the Rapid-Rock Analysis Laboratory under Leonard Shapiro; Chris Heropoulos, spectrochemical analyst.
9. Intrusion breccia, latite breccia pipe in W½W½SE¼ sec. 11, T. 10 S., R. 2 W. E. E. Engleman, chemical analyst; J. L. finley, spectrochemical analyst.
10. Sunrise Peak Monzonite Porphyry from exposures in the extreme southwest corner of sec. 17, T. 11 S., R. 2 W. Tintic mining district. E. E. Engleman, chemical analyst; L. A. Bradley, spectrochemical analyst.

volcanic groups that are similar in chemical composition but are characterized by distinctive mineral assemblages. The older of these two groups, which is extensively exposed on the west slopes of Tintic Mountain 8 mi (13 km) south of the East Tintic district, is compositionally similar to the monzonite of the Sunrise Peak stock and related intrusive bodies of the main Tintic district (Lindgren and Loughlin, 1919, p. 57-61). It is distinguished by the common occurrence of hypersthene in association with augite and biotite and the virtual absence of hornblende. In contrast, the younger group is characterized by the nearly ubiquitous occurrence of hornblende in association with either biotite or augite, or with both minerals. This latter group is chiefly exposed in the northern part of the East Tintic district near Laguna Springs and is the eruptive equivalent of the Silver City stock of the main Tintic district and related plutons. The two groups are separated by an unconformity representing a hiatus of only short to moderate duration.

## TINTIC MOUNTAIN VOLCANIC GROUP

The older of the two post-Packard Oligocene volcanic groups is here named the Tintic Mountain Volcanic Group after its type locality on the lower western slopes of Tintic Mountain, 10 mi (16 km) south of Dividend, where it is thickest and shows the greatest lithologic diversity. The group consists of three volcanic formations of similar mineralogic composition, but each representing a distinct eruptive cycle separated from the succeeding cycle by a period of volcanic quiescence. Although the three formations of the Tintic Mountain Volcanic Group extend into the southern part of the East Tintic district, their eruptive center is believed to be near the type locality.

The intrusive rocks that are related to the Tintic Mountain Volcanic Group are chiefly exposed in the area of Sunrise Peak in the main Tintic district 6 mi (9.6 km) south-southwest of Dividend, but within the East Tintic district they are represented by a thick sill exposed near Little Gough Spring and a breccia pipe half a mile southwest of Low Lonesome Point.

Chemical analyses of representative samples from each of the formations of the Tintic Mountain Volcanic Group are presented in table 4, along with samples of related intrusive rocks. The normative composition of quartz, orthoclase, and albite + anorthite of these same samples is presented in figure 8.

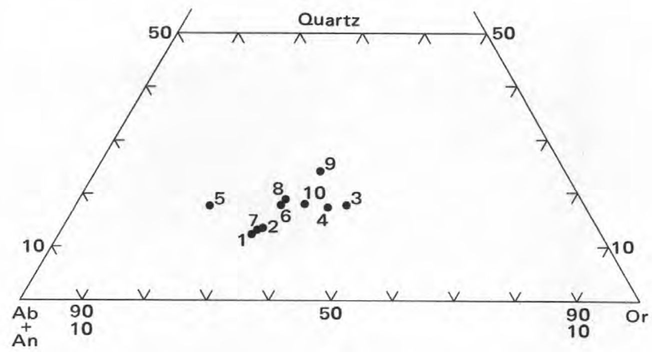



FIGURE 8. — Plot of normative quartz-orthoclase-albite ± anorthite of selected samples of the Tintic Mountain Volcanic Group and related and comparative rocks.

### COPPEROPOLIS LATITE

#### NAME, DISTRIBUTION, AND THICKNESS

The lowest formation in the Tintic Mountain Volcanic Group is here named the Copperopolis Latite from its type locality in Copperopolis Canyon in the west-central part of the East Tintic Mountains 10 mi (16 km) southwest of the East Tintic district; this locality is in secs. 31, 32, and 33, T. 11 S., R. 2 W. In this area the formation consists of a basal member of agglomerate and spatter breccia, a tuff member, and an overlying flow member. All three members are of irregular thickness, but locally each are several hundred feet or more thick. In Kimball Creek Canyon, 6 mi (7.9 km) southeast of the East Tintic district, and on Long Ridge south of Goshen, the fine-grained flow member is in turn overlain by other agglomerate, tuff, and flow units.

The only member of the Copperopolis Latite that is known with certainty to crop out in the East Tintic district is the dark fine-grained flow member, which is conspicuously exposed through the central part of sec. 26, T. 10 S., R. 2 W., at the south boundary of plate 1. Part of this member also crops out southeast of the Trixie shaft, where it directly overlies the Packard Quartz Latite. Parts of the tuff member also may crop out in the southwestern part of the district near the Nevada Tunnel shaft; however, the intense hydrothermal alteration in this area precludes accurate identification of any members of the formation. The exposed part of the flow member near the southern boundary of the district is at least 400 ft (122 m) thick.

#### LITHOLOGY AND PETROGRAPHY

In exposures south of the East Tintic district, the tuff member is largely fine- to medium-grained gray-green airfall tuff containing weakly altered fragments of orthoclase, plagioclase, augite, hypersthene, and magnetite in a matrix of comminuted minerals and glass shards. In most exposures bedding is conspicuous, with dips of 10°-20°. It disconformably overlies the basal member of agglomerate, spatter breccia, and minor flows (Morris, 1975). This basal unit is dark green, moderately coarse grained, and massive, in contrast to the light colored fine- to medium-grained conspicuously layered tuff member.

The flow member is dark greenish-gray, black, or reddish-brown fine-grained vitrophyre and fine-grained porphyry (fig. 9). Some flows exposed in the southernmost part of the district are characterized by a slaggy upper surface or by amygdules. On freshly broken surfaces, the fine-grained lava displays many small lath-shaped phenocrysts of feldspar and tiny grains of pyroxene that range from 5 mm in length and

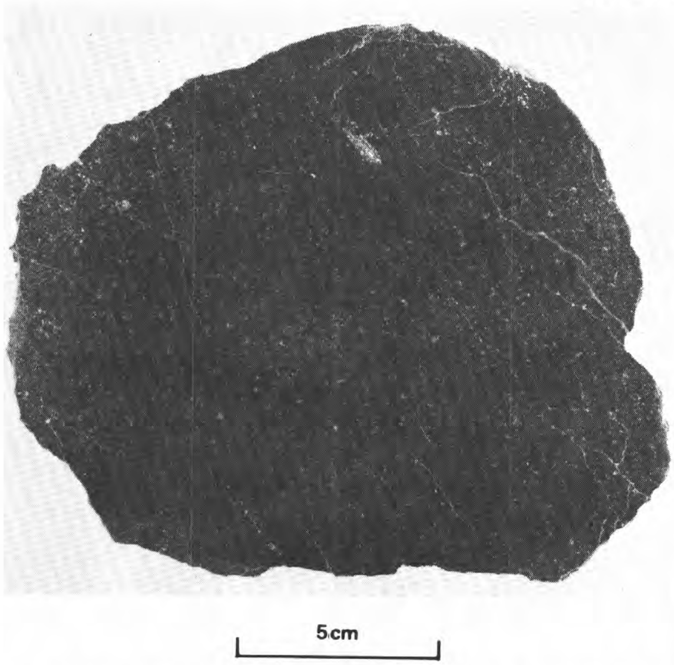


FIGURE 9. — Flow member of Copperopolis Latite from exposures 2,500 ft (762 m) S. 15° W. of Willow Spring. Same as sample 1, table 4. Light phenocrysts are all plagioclase.

3 mm in width to minute specks identifiable only by virtue of their light-reflecting character.

Modal analyses of thin sections indicate that phenocrysts make up less than 25 percent of the rock; of these, plagioclase is by far predominant, constituting about 90 percent of the identifiable phenocrysts. Of the other phenocrysts, more than half are augite, a third are hypersthene, a tenth are magnetite, and the rest are accessory minerals including apatite, sphene, and rare zircon. The groundmass of many specimens consists of a dark glass that is crowded with minute elongated crystals and microlites of potassium feldspar and interstitial granules of pyroxene that produce a fine-grained ophitic texture.

The plagioclase phenocrysts have a composition near $An_{70}$; most are zoned, with cores that are more calcic than their rims. Many also contain tiny, symmetrically arranged inclusions of glass, pyroxene, and other minerals. Nearly all are somewhat resorbed and have rounded edges, corners, and broken surfaces.

Augite grains that are 2 mm long or less and 1 mm wide or less commonly tend to form glomerophyric clusters. Both simple and polysynthetically twinned crystals are abundant. Faint pleochroism indicates the possible presence of the aegirine molecule.

Hypersthene phenocrysts are slightly smaller than the augites. Pleochroism from pale green to pale brownish red, parallel extinction, and weak birefrigence also readily distinguish it from this mineral. Magnetite is abundant as minute cubes.

The vesicles of the scoriaceous lava commonly are lined or partly filled with iron-stained caliche, but a few contain thin rinds of opal or penninite.

#### CHEMICAL COMPOSITION

As shown in table 4 (analyses 1 and 2), the composition of selected samples of fine-grained porphyritic lava from the flow member of the Copperopolis Latite is closely similar to that of most of the other formations of the Tintic Mountain Volcanic Group and their allied intrusive rocks. Compared to the average of 42 latite analyses presented by Nockolds (1954, p. 1017), these samples contain somewhat more $SiO_2$ and $K_2O$, and somewhat less CaO and total iron. This is confirmed by a plot of the normative compositions of the samples of Copperopolis Latite (fig. 8), which places them well within the quartz latite field.

The relatively high ratio of normative albite to normative anorthite is noteworthy in consideration of the high anorthite content of the modal plagioclase and the presence of calcium-bearing augite. These relations suggest that the minute plagioclase phenocrysts of the groundmass are more sodic than the large plagioclase phenocrysts and that the potassium feldspar and augite phenocrysts and microlites are also rich in $Na_2O$. The groundmass also apparently contains much sodic orthoclase and some quartz, or a glass of equivalent composition.

#### AGE AND ERUPTIVE HISTORY

The Copperopolis Latite unconformably overlies the Packard Quartz Latite and is cut by the monzonite of the Silver City stock. These latter two units have been isotopically dated as $32.8 \pm 1.0$ and $31.5 \pm 0.9$ m.y., respectively, by Laughlin, Lovering, and Mauger (1969, p. 915); thus the Copperopolis is middle Oligocene. The regional distribution and lithologic characteristics of the various members of the Copperopolis indicate that it was erupted from one or more vents near Volcano Ridge, about 9 mi (14 km) south of Dividend (Morris, 1975). The initial eruptions are believed to have taken place within the caldera that formed after the eruption of the Packard Quartz Latite (Morris, 1975). They consisted of spatter deposits, breccias, tuffs and a few small flows and apparently created a cone several thousand feet high. These deposits were next overlain by fine-grained tuffs that spread chiefly eastward and northward from the vents and may have extended into the East Tintic district. The explosive phase of the eruption was succeeded by the extrusion of lava, which initially was relatively fluid but which locally became viscous as it cooled and developed large asymmetric flow folds. This unit extended at least as far north as the area of the present Trixie Shaft. The younger tuff, breccia, and flow units above the main flow unit in exposures southeast of the district, particularly on Long Ridge and in the central and southern parts of the East Tintic Mountains, indicates one or more successive cycles of explosive eruption followed again by relatively quiet lava extrusion.

At the edges of the volcanic field, 20-50 mi (32-80 km) east, southeast, and south of the East Tintic district, the uppermost rocks of the Copperopolis Latite consist of thick and extensive volcanic-boulder agglomerates that interfinger with continental and lacustrine sedimentary deposits. These agglomerates are chiefly erosional in origin and indicate a substantial degradation of the Copperopolis volcano prior to succeeding eruptions.

#### Economic importance

The Copperopolis Latite is not an ore-host rock in the East Tintic district, but it is cut by many base-metal and silver-bearing quartz veins in the southern part of the main Tintic district, particularly in the vicinity of Volcano Ridge. In general the veins are narrow, and they are especially persistent where the latitic tuffs and lavas are silicified or are underlain at shallow depth by monzonite or older rocks. In other areas where the Copperopolis was argillized by hydrothermal solutions related to monzonite intrusion, the minor tectonic activity that shortly preceded ore deposition produced only narrow, impermeable fault zones that were poor conduits for mineralizing solutions.

### Latite Ridge Latite

#### Name, distribution, and thickness

Throughout much of the southern and eastern parts of the East Tintic district, the Copperopolis Latite and the Packard Quartz Latite are overlain by a highly distinctive formation consisting of a discontinuous lower member of air-fall and water-laid tuff, herein termed the airfall tuff member, and an upper member of reddish-brown welded tuff, termed the welded tuff member. This formation is here named the Latite Ridge Latite from its type locality on Latite Ridge. These exposures are in the NW¼ sec. 23, and NE¼ sec. 27, T. 10 S., R. 2 W.; they include both members of the formation and are mostly unaltered. An exposure almost as large occurs in the southwestern corner of the district south of the Zuma and Crown Point No. 3 shafts, but strong argillic and pyritic alteration throughout much of this area has destroyed many of the primary characteristics of the rocks making specific identification difficult. Other exposures of the Latite Ridge Latite are present both north and south of Highway 6-50 near the east edge of the district and about half a mile (0.8 km) north-northwest of the North Standard shaft.

Extensive exposures of the Latite Ridge Latite have also been recognized outside of the East Tintic district in the southern part of the Tintic volcanic center south of Hop Creek and in Kimball Creek Canyon between Long Ridge and the East Tintic Mountains.

In the exposure east of Low Lonesome Point, on the south side of Latite Ridge, and near the south-central boundary of the district, the airfall tuff member of the Latite Ridge Latite ranges in thickness from 0 to 100 ft (30 m) or more; however, it may be somewhat thicker in the exposures that are about 1 mi (1.6 km) east-southeast of the Silver Shield (Independence) shaft. The overlying welded tuff member is partly eroded in all of its exposures and consequently is incomplete. Near Low Lonesome Point the remnant portion of the member has a maximum thickness of about 125 ft (38 m). On Latite Ridge and in the area to the south of it, the welded tuff member is locally more than 500 ft (152 m) thick, and in the Roundy shaft the welded tuff member extends from the surface to a depth of 440 ft (134 m) where it directy overlies the porphyritic member of the Packard Quartz Latite.

#### Lithology and petrography

The airfall tuff member ranges in color from medium greenish gray to white, depending on the degree of hydrothermal alteration. It is medium to fine grained and mostly of uniform texture. Although many exposures are moderately well bedded, layering is only rarely discernible in samples that are as small as hand specimens. Thin sections show the tuff to consist of angular fragments of calcic albite, rare sanidine, magnetite, and rare quartz embedded in an altered and devitrified matrix of glass shards. The former presence of biotite is commonly indicated by rectangular aggregates of alteration minerals. Secondary products, especially calcite, fine-grained silica, and chlorite minerals are abundant.

The welded tuff member is most commonly medium reddish brown, locally grading to brownish black. In areas of hydrothermal alteration, it grades through lavender and pale pinkish brown to dazzling white. Fresh hand specimens are fine grained and are characterized by angular fragments of older rocks and scattered fragments of phenocrysts embedded in a glassy to cryptocrystalline matrix marked by discontinuous, dark horizontal lines and short undulating streaks (fig. 10). The phenocrysts consist of feldspar, biotite, and rare quartz, all averaging about 2 mm in diameter. The

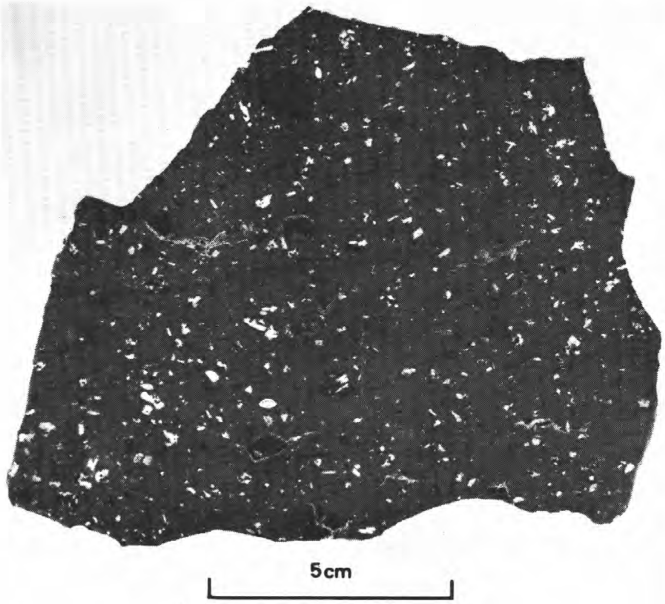



FIGURE 10. —Welded tuff member of Latite Ridge Latite 1,900 ft (579 m) N. 75° W. of Low Lonesome Point. Dark areas are flattened pumice fragments. Larger light areas are rock fragments, smaller light areas are plagioclase phenocrysts.

rock fragments are composed mostly of fine-grained latite but also include coarse-grained latite, rare fragments of quartzite, and some flattened disks of scoria and pumice.

The petrographic microscope reveals the rock to be composed of 75-80 percent nearly opaque brown glass that appears to contain masses of cloudy inclusions. The short dark streaks that are conspicuous in hand specimens are mostly tiny veinlets and segregations of iron-stained chalcedony that fill wavy contraction fractures, although some also fill open spaces adjacent to collapsed pumice fragments, shards, and the rare pieces of Paleozoic sedimentary rocks. In the freshest material, collapsed shards are readily apparent at the thinner edges of the thin seciton; however, typical shard structure in much of the rock is largely obscured by dense welding and compression, by the opacity of the matrix glass, or by devitrification and hydrothermal alteration.

Phenocrysts, many of which are broken or fragmental, make up 25 percent or less of the rock. Of these about 60 percent are plagioclase, 25 percent are biotite, about 10 percent are sanidine, about 4 percent are quartz, and about 1 percent of hypersthene, magnetite, and apatite. The plagioclase phenocrysts display the low index of refraction, narrow twin planes, and extinction angles that are characteristic of calcic albite; they have a composition of approximately $An_{10}$. The quartz phenocrysts are all strongly corroded and embayed, and some may actually be largely resorbed remnants of quartzite xenoliths. The sanidine phenocrysts occur as scattered, relatively clear, commonly twinned crystals and somewhat more abundantly as angular broken fragments. Some of the sanidine, however, is untwinned and highly transparent, and thus small fragments may easily be confused with quartz. The biotite phenocrysts also are partly resorbed; they are strongly pleochroic with X = reddish brown and Y = Z = dark greenish or grayish brown. Some of biotite crystals are frayed and show other evidence of physical distortion.

The xenolithic rock fragments examined in thin section consist mostly of fine-grained latite similar to the Copperopolis Latite but also include medium-grained latite, rare fragments of quartzite, and deformed disks of scoria and pumice.

The small exposures of the Latite Ridge Latite north of the North Standard shaft are characterized by conspicuous fiamme of black obsidian. In thin seciton, these dark flame-shaped inclusions appear to represent pumice lapilli that have been completely welded and compressed with the resulting elimination of all of the original pore space.

### CHEMICAL COMPOSITION

Chemical analyses of samples of the upper member of the Latite Ridge Latite (analyses 3 and 4, table 4) indicate less CaO and more $K_2O$ and $SiO_2$ than both the flow rocks of the Copperopolis Latite that underlie it and the monzonite of the Gough sill that cuts it and thus is distinctly younger. This relatively low ratio of $CaO{:}K_2O + SiO_2$ as compared to related rocks from a comparable magma source suggests that crystal settling of early formed calcic plagioclase and augite phenocrysts may have depleted the parent magma in CaO prior to eruption of the Latite Ridge tuffs, as discussed on page 41.

Although the mineral components of the Latite Ridge indicate a classification as biotite latite, the ratio of normative quartz, orthoclase, and albite + anorthite reveals that the rock is chemically equivalent to a sodium-rich quartz latite. Much $SiO_2$ probably is present in the glass of the groundmass, but some of the excess quartz also must be attributed to the chalcedony veinlets and minor quartzite fragments.

### AGE AND ERUPTIVE HISTORY

No isotopic age determinations have been made of the mineral components of the Latite Ridge Latite, but it locally overlies the Packard Quartz Latite and the Copperopolis Latite and is locally cut by the monzonite of the Silver City stock; thus its middle Oligocene age is fixed with confidence. The eruptive source of the Latite Ridge is believed to be a now strongly argillized intrusive body in the south-central part of Copperopolis Canyon 10 mi (16 km) south-southwest of Dividend in the southern part of the main Tintic district. This body cuts the Copperopolis Latite and is characterized by clear sanidine phenocrysts and crystal fragments thinly scattered through a matrix of halloysite, kaolinite, and other clay minerals.

The lithologic and textural character of the Latite Ridge Latite indicates an initial eruption of mostly fine-grained pyroclastic material, some of which was deposited in lakes or ponds as volcanic tuff and tuff breccia. This eruption was immediately followed by one or more nuées ardentes, each consisting of a mixture of rock fragments, whole and broken phenocrysts, and vitric ash propelled by high-temperature gases. The massive character of the welded tuff member indicates only one cooling unit and, therefore, only one general period of eruption. No upper nonwelded tuff horizon has been recognized, and if any such horizon was originally present, it was apparently removed by erosion prior to the eruption of the Big Canyon Latite.

#### ECONOMIC IMPORTANCE

In its exposures in the southwestern part of the East Tintic district, the Latite Ridge Latite is cut by several fissure zones that have served as conduits for argillizing, pyritizing, and jasperoidizing solutions. These fissure zones may have localized ore shoots in more brittle rocks at depth, but no ore bodies are known to have been deposited in the altered volcanic rocks near the surface.

### BIG CANYON LATITE

#### NAME, DISTRIBUTION, AND THICKNESS

In the east-central part of the East Tintic district, the Latite Ridge Latite is unconformably overlain by the here-named Big Canyon Latite, which consists of a lower member of air-fall tuff, herein termed the tuff member, and an upper member of dark-gray fine-grained latite, termed the flow member. The largest known exposure of this unit caps the east-trending ridge in the NW¼ sec. 13, T. 10 S., R. 2 W. that marks the south side of the entrance to Big Canyon, from which the unit is named and which is considered its type locality. Other exposures, which appear to be remnants of a sinuous, lava-filled rill or gulch, crop out east of Low Lonesome Point. The only other occurrence that is recognized in the district is a group of small exposures near Wing Spring in the SE¼SE¼ sec. 23, T. 10 S., R. 2 W.

The tuff member is exposed only on the ridge marking the south side of the entrance to Big Canyon, where it is as much as 125 ft (38 m) thick. In the same area, the overlying flow member, which is eroded at the top, is about 95 ft (29 m) thick. Elsewhere only thinner remnants have been preserved.

#### LITHOLOGY AND PETROGRAPHY

The tuff member of the Big Canyon Latite is moderately to strongly altered and consequently is poorly exposed. In many fresh exposures it is largely white clay that is stained yellow, brown, and black by iron and manganese oxides. Bedding is moderately well developed, and the rock is uniformly fine grained. Microscopic examination reveals much montmorillonite, limonite, and late caliche, all apparently derived from the alteration of glass shards, and scattered remnant phenocrysts of plagioclase, pyroxene minerals, biotite, and magnetite.

The flow member of the Big Canyon Latite is a medium- to dark-gray compact finely porphyritic rock that is characterized by small white plagioclase phenocrysts and dark lustrous granules of pyroxene (fig. 11). Much of the rock shows well-developed planar partings spaced from a few inches to several feet apart. The slabby, weathered fragments of this rock are surprisingly tough and break with difficulty under the hammer. In one exposure near Wing Spring, the rock is vesicular and locally amygdaloidal.

Under the microscope the latite of the flow member has a pronounced trachytic texture, largely defined by a subparallel alinement of minute feldspar crystals in a fine-grained fluidal groundmass. The larger pheno-

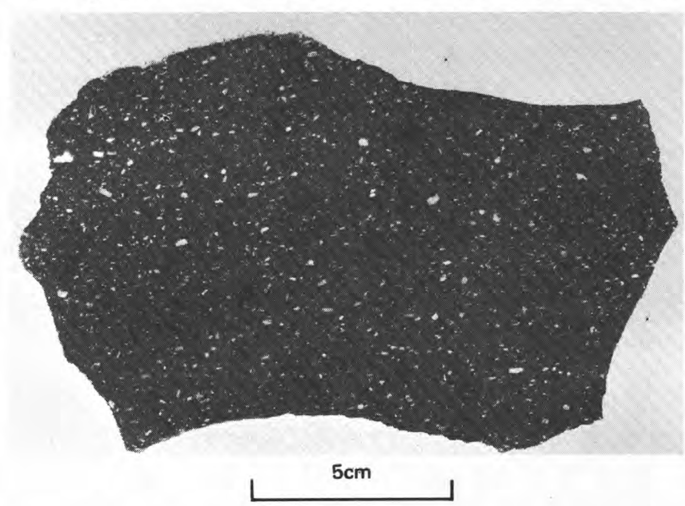



FIGURE 11. — Flow member of Big Canyon Latite from exposures on south side of entrance to Big Canyon 1 mi (1.6 km) S. 45° W. of Low Lonesome Point. Light phenocrysts are plagioclase. Same as sample 5, table 4.

crysts make up 25-30 percent of the rock. They include about 65 percent labradorite, 20 percent augite, 10 percent hypersthene, 4 percent magnetite, and 1 percent apatite, sphene, and other accessory minerals. The groundmass is holocrystalline and consists chiefly of tiny lath-shaped crystals of labradorite and nearly equidimensional grains of augite and hypersthene, with irregular patchy aggregates of orthoclase and possibly quartz filling the interstices between them.

The larger plagioclase phenocrysts, which are about 3 mm long, are strongly zoned, with the interior parts crowded with symmetrically arranged crystals of earlier minerals; many have narrow clear rims. Extinction angles on the best twinned phenocrysts indicate a composition ranging from $An_{50}$ to $An_{60}$. Rare, small, nearly cubic crystals that most commonly are less than half the size of the plagioclase phenocrysts probably are sanidine.

Augite occurs as well-defined phenocrysts that range in length from 2 mm to tiny granules in the groundmass. Many of the grains also have narrow reaction rims, but the reaction products are so fine grained that specific identification is impossible. Twinned crystals are abundant.

Hypersthene occurs as somewhat smaller phenocrysts than the augite and is readily distinguished by its pronounced pleochroism from pale bluish green to pinkish tan. Many of the hypersthene crystals are partly resorbed and show caries structures.

Magnetite is abundant, possibly ranking as a major constituent of the rock. Like the hypersthene phenocrysts, many of the magnetite crystals are partly resorbed.

The amygdules in the vesicular rock near Wing Spring chiefly contain calcite, but some also contain penninite and opaline silica.

#### Chemical Composition and Origin

Chemically, the Big Canyon Latite is the least acidic rock of the Tintic Mountain Volcanic Group, containing somewhat more CaO, $TiO_2$, and iron and less $SiO_2$ and $K_2O$ than the other eruptive formations and the Sunrise Peak Monzonite (table 4). This less acidic character is indicated by the position of the Big Canyon Latite in the rhyodacite field in a plot of normative quartz:orthoclase:albite + anorthite in figure 8.

The averaged compositions of the Latite Ridge Latite and the Big Canyon Latite, respectively the most siliceous and least siliceous of the Tintic Mountain Volcanic Group, are close to the average compositions of the Copperopolis Latite and the younger monzonite porphyry of the Gough sill and the Sunrise Peak stock. This relation suggests that magma of the general composition of the Sunrise Peak stock began to differentiate at depth by the settling of early formed calcium feldspars, magnetite, sphene, and possibly other minerals. In time the silica- and potassium-enriched upper part of this magma was erupted as the Latite Ridge Latite, and the calcium-, iron-, and titanium-enriched lower part was erupted a short time later as the Big Canyon Latite. This concept of crystal settling is corroborated by the highly corroded character of the magnetite, hypersthene, and much of the plagioclase in the Big Canyon Latite, suggesting that they may have been partly resorbed as they moved downward into hotter and presumably more chemically active parts of the resting magma.

The eruptive center of the Big Canyon Latite is unknown. On the basis of the regional distribution of the formation, the eruptive center was probably in the general area of Diamond Gulch, 8 mi (12.8 km) southwest of Dividend in the west-central part of the range.

#### Age

Repeated attempts to separate individual mineral components of the Big Canyon Latite for dating by isotopic techniques met with little success because of the extremely fine grained texture of the rock. Consequently, the whole rock was used, yielding a potassium-argon date of $35.3 \pm 1.4$ m.y. (U.S. Geol. Survey unpublished data, Menlo Park). As with many whole-rock dates, the resultant figure seems to be approximately 10 percent older than equivalent dates of single minerals concentrated from closely related igneous rocks. Discrepancies in whole-rock ages are commonly the result of excess argon in either fresh or devitrified glass, xenoliths of older igneous rocks, or of alteration or secondary mineralization resulting in a loss of potassium. It is unknown which of these factors is chiefly responsible for the anomalously old date of the Big Canyon Latite sample. The geologic age of the Big Canyon Latite, however, is considered to be middle Oligocene.

#### Economic Importance

The Big Canyon Latite is not a host rock for known ore bodies of any type and is not suitable as a source of nonmetallic mineral commodities.

### SUNRISE PEAK MONZONITE PORPHYRY

Porphyritic intrusive rocks that are chemically, mineralogically, and genetically equivalent to the tuffs and lavas of the Tintic Mountain Volcanic Group are here named the Sunrise Peak Monzonite Porphyry from its type locality, the stock that underlies Sunrise Peak in the south-central part of the main Tintic district 6 mi (9.6 km) south-southwest of the townsite of Dividend. This name is adopted from Lindgren and Loughlin (1919, p. 57-61), who described the stock as "***a uniform mass of dark-gray to greenish-gray porphyry, having the chemical composition of monzonite but ranging in texture from monzonite to latite." These textural relations indicated to Lindgren and Loughlin (1919, p. 57) that the Sunrise Peak mass was chiefly intrusive, but they also believed that it was connected with "undoubted surface flows" along the east half of the peak. More recent studies, including the field investigations on which this report is based, indicate that these so-called surface flows are actually thick, massive sill-like bodies that locally have crosscutting contacts. One of these sills extends into the East Tintic district and is described in following section of this report. Another intrusion of similar composition is the pipelike body of latite intrusion breccia that crops out west-southwest of Low Lonesome Point in the east-central part of the district and which is described in the section "Latite Breccia Pipe." Because of the great dissimilarities in texture and habit of these two intrusive bodies, they are described separately.

## Gough Sill

### Name, Distribution, and Character

The large sill-like body of Sunrise Peak Monzonite Porphyry that is apparently continuous with the Sunrise Peak stock of the main Tintic district intrudes the tuff and flow rocks of the Tintic Mountain Volcanic Group in the southwestern part of the East Tintic district. It is here named the Gough sill from exposures in the vicinity of Little Gough and Big Gough Springs in the NE¼ sec. 33, T. 10 S., R. 2 W. In this general area, the sill crops out in a massive somber-colored cliff that caps the ridge between Silver Pass Gulch and Goshen Valley.

In the vicinity of Big and Little Gough Springs and on the northern and eastern sides of Ruby Hollow a short distance south of plate 1, the contacts of the Gough sill are clearly intrusive, cutting both the Copperopolis Latite and the Latite Ridge Latite. Intrusive contacts are also conspicuously exposed on both sides of Silver Pass Creek 1,000 ft (305 m) south of the South Standard shaft, in the upper part of the small gully immediately northeast of Gold Bond Spring, at the ridge crest east of Gold Bond Spring, and in many other localities.

Although the thickness of the Gough sill is unknown, geologic relations in the area of Little Gough Spring suggest that the sill is a north-trending tongue-shaped mass 500-1,000 ft (152 to 305 m) thick and that it plunges to the north at 8°-10°. Because the top of the sill is eroded at all of its exposures, the original thickness is unknown; prior to erosion, however, it probably exceeded 1,500 ft (457 m) in thickness in the area east of Ruby Hollow a few miles south of the East Tintic district.

### Lithology and Petrography

In its freshest exposures the Gough sill is a fine- to medium-grained porphyritic rock (fig. 12) that ranges in color from dark greenish gray to medium pinkish gray.

Phenocrysts make up about 50 percent of the rock and include approximately 60-65 percent plagioclase, 15 percent each biotite and augite, 3-7 percent sanidine, and 1-2 percent magnetite. In some specimens hypersthene is also abundant as a phenocrystic component. Quartz is an accessory.

Examination of thin sections shows most of the plagioclase crystals to be moderately to strongly corroded and partly resorbed. Measurement of the extinction angles of albite and combined albite-carlsbad twin lamellae indicate two types of plagioclases: one with an indicated content of $An_{48}$ and the other a somewhat more corroded variety with a composition of $An_{60}$. Zoning that is defined both by compositional variation and bands of mineral inclusions is common.

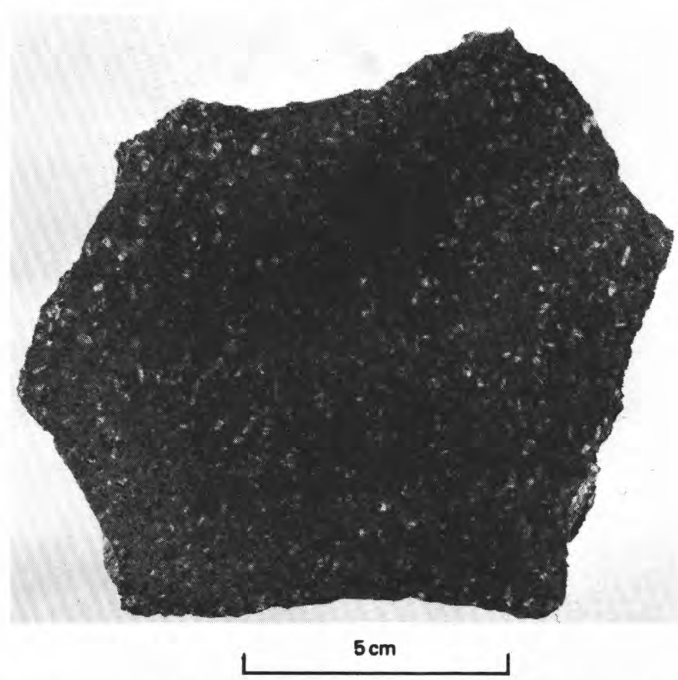



Figure 12. — Monzonite porphyry of the Gough sill 1,650 feet (503 m) S. 80° E. of Gold Bond Spring. Light phenocrysts are conspicuously zoned plagioclase; dark phenocrysts are chiefly biotite but also included augite and hypersthene.

The biotite phenocrysts average 1-3 mm in length and are also partly resorbed; they are commonly bordered or replaced by tiny grains of magnetite. Pleochroism is strong, with X = light greenish brown and Y = Z = dark brownish red.

The augite grains are all less than 1 mm in diameter and diminish in size to minute specks in the groundmass. In many exposures nearly all of the augite is replaced by calcite and penninite.

Magnetite, or its alteration product, is abundant both as large partly resorbed cubic crystals and as tiny blebs that locally replace biotite. Other accessory minerals in addition to quartz include clear sanidine, reddish-brown allanite, apatite, and sphene.

The groundmass of the Gough sill is fine grained but holocrystalline, with a pilotaxitic texture. It is characterized by short distinct laths of plagioclase and small grains of biotite and augite with abundant interstitial grains and masses of alkalic feldspar, and considerable quartz. Sodium cobaltinitrite-staining techniques indicate a higher content of potassium-bearing feldspar than might be assumed from visual examination.

#### Chemical Composition and Origin

Specimens from three widely separated parts of the Gough sill are closely similar in composition, and their averaged composition is almost identical with the composition of the Copperopolis Latite and the monzonite of the Sunrise Peak stock (table 4). The normative mineral composition places the rock within the quartz latite field (fig. 8), corroborating a high content of quartz and potassium-rich feldspar in the groundmass. The relatively low content of FeO suggests that the modally abundant magnetite is probably pseudomorphic martite.

The continuity of the Gough sill with the Sunrise Peak stock in the north-central part of the Tintic Mountain quadrangle and its crosscutting contacts indicates an intrusive origin. The fine-grained groundmass suggests rapid cooling under shallow cover. The moderate to strong partial resorption of phenocrysts also indicates a marked disruption during the course of crystallization, possibly related to an abrupt, shallow injection of the sill or, more speculatively, to the mixing of magmas of slightly to moderately dissimilar compositions.

#### Age

Because of the relatively poor preservation of the biotite of the Sunrise Peak Monzonite Porphyry and the paucity of large phenocrysts of sanidine, no age determinations were attempted. Like the Tintic Mountain Volcanic Group, the Gough sill is younger than the 32.8 m.y. Packard Quartz Latite, and it is also cut by the 31.5 m.y. Silver City stock of the main Tintic district; thus is of middle Oligocene age (Laughlin and others, 1969).

#### Economic Importance

Although the Sunrise Peak stock and its associated sheetlike intrusive bodies are cut by veins of base metal and silver ores on Sunrise Peak, Treasure Hill, and in Dry Canyon near Diamond in the southern part of the main Tintic district, the Gough sill in the East Tintic district is not known to be a host rock for ore. Intense late-stage hydrothermal alteration bleached the sill, however, and obliterated its contacts with the Latite Ridge Latite in a side branch of Silver Pass Creek half a mile southwest of the South Standard shaft, suggesting the possible presence of ore deposits at depth in this area.

### Latite Breccia Pipe

#### Location and General Features

About 2,500 ft (762 m) west-southwest of Low Lonesome Point, the Packard Quartz Latite is cut by a pipe-shaped intrusive body composed largely of pebbles and boulders of fine-grained latite, pumice, and other rocks embedded in an obsidian-streaked ashy matrix of rock and pumice fragments and glass shards. Near the center of the exposure, as well as near the contacts of the pipe, fragments and blocks of Packard Quartz Latite are especially abundant. The outcrop of the breccia mass is roughly triangular in outline and is approximately 250 ft (76 m) across its greatest dimension. The sharp contacts with the Packard Quartz Latite appear to be nearly vertical; however, as shown on plate 1, some internal planar features have an easterly component of dip. Although the Packard Quartz Latite surrounding the pipe is moderately argillized, pyritized, and calcitized, the matrix and fragments of the intrusion breccia are unaltered.

#### Lithology and Petrography

The breccia pipe consists of heterogeneous partly welded tuff breccia that is composed of fragments of latite, Packard Quartz Latite, light-colored vitrophyre, and rare sedimentary rocks ranging in size from blocks that are as much as 5 ft (1.5 m) in diameter to tiny grains of dust. On the weathered surface, the prevailing color of the igneous matrix of the breccia is medium purplish gray; on fresh surfaces it is dull medium gray. The largest fragments embedded in it are angular chips and blocks of Packard Quartz Latite, but these are exceeded in number by fist-sized and smaller clasts of very fine grained latite, some of which are pumiceous or vesicular. These fragments are surrounded by a matrix of friable tuff-breccia consisting of comminuted rock fragments of all sizes, crystal fragments, glass shards, and many almond-shaped pods and thin stringers of dull black vitrophyre and obsidian (fig. 13).

Under the microscope, the fragments and blocks of fine-grained latite, which appear to be the principal constituents of the pipe, most closely resemble the flow rocks of the Copperopolis and Big Canyon Latites. This fine-grained porphyritic rock has a pilotaxitic to trachytic texture that is defined by densely packed lath-shaped feldspar crystals that dominate the groundmass. The larger phenocrysts, which are all less than 4 mm long and constitute less than 5 percent of the rock, include labradorite ($An_{68}$), biotite, and magnetite. Many tiny granules of magnetite, biotite, and possibly augite and hypersthene occupy the interstices of the feldspar laths in the groundmass.

The matrix between the blocks and clasts consists of a chaotic mixture of small fragments of the larger rocks along with angular fragments of andesine, sanidine, quartz, and biotite, all of which are embedded in a matrix of partly collapsed glass shards. Most of the crystal fragments are identical with the phenocrysts of the Packard Quartz Latite, but some that are embedded in the fragments of fine-grained and pumiceous latite and in the vitrophyre pods are obviously not derived from this source.

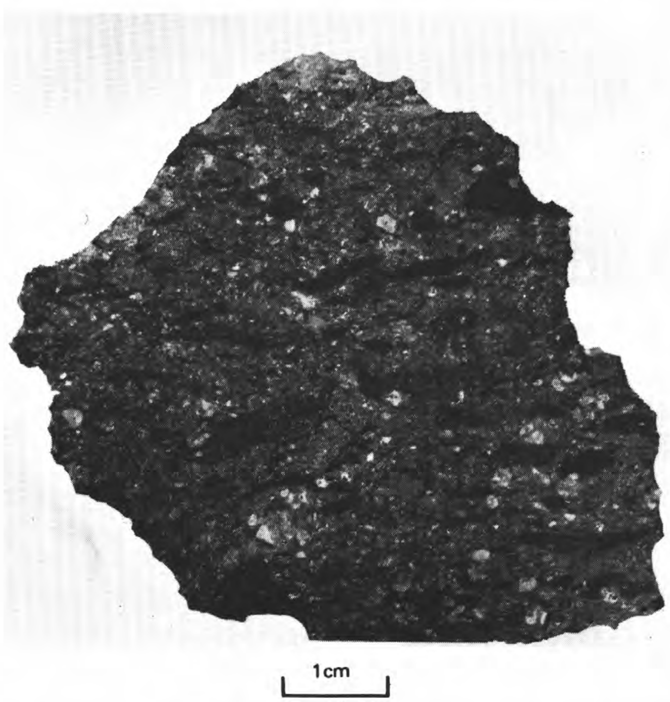



FIGURE 13. — Intrusive latite breccia from small pipe 2,500 ft (762 m) west-southwest of Low Lonesome Point. Dark areas are flattened pumice fragments; light areas are chiefly fragments of quartz latite. Same as sample 9, table 4.

The most distinctive microscopic feature of the rock matrix are the lenses of vitrophyre and obsidian that are believed to be welded and thoroughly compacted fragments of pumice. The lenses are composed of dark-reddish-brown volcanic glass marked by myriads of short dark lines interpreted to be completely collapsed vesicles. Most of them also display the highly frayed or seriate edges that are typical of the fiamme of welded tuffs. Commonly, the collapsed pumice fragments are molded against larger rock and crystal fragments indicating contemporaneous deformation of the pumiceous glass as the tuff-breccia was compacted and partly welded. In general, the pumice fragments are unaltered and do not show the incipient devitrification displayed by the glass shards that lie between the fragments.

#### CHEMICAL COMPOSITION AND ORIGIN

Because of the obvious welded-tuff origin of the upper member of the Latite Ridge Latite, it was originally assumed that the breccia pipe represented an eruptive center of this unit (Lovering and others, 1960). Chemical analyses indicate, however, that the latite intrusion breccia of the pipe contains less $SiO_2$, $Na_2O$, and $K_2O$ and significantly more CaO and MgO than the Latite Ridge Latite and is more closely similar in its general chemical character to the monzonite porphyry of the Sunrise Peak stock and Gough sill. The latite intrusion breccia has the lowest $Na_2O$ content of any of the igneous rocks in the East Tintic district; the reason for this difference is unknown.

#### AGE

The specific age of the latite breccia pipe is unknown. It intrudeds the Packard Quartz Latite and thus may be dated with certainty only as being younger than that formation. Its general mineralogic and chemical simiarity to the Tintic Mountain Volcanic Group and the Sunrise Peak Monzonite Porphyry including the Gough sill suggests that it is approximately equivalent in age to them.

#### ECONOMIC IMPORTANCE

Although breccia pipes are important ore-localizing features in many mining districts throughout the world, the lack of hydrothermal alteration of the included breccia and the absence of anomalous trace quantities of ore metals seem to preclude the presence of ore bodies at depth in the latite breccia pipe.

## LAGUNA SPRINGS VOLCANIC GROUP

The name Laguna Springs Latite was originally proposed by Lovering and others (1960) for a single volcanic formation that included all of the effusive latitic rocks in the East Tintic district that were younger than the Packard Quartz Latite. Subsequent studies have indicated, however, that the latitic lavas that overlie the Packard near Laguna Springs form a distinctive group of interrelated volcanic formations that elsewhere in the district actually overlie the thick Tintic Mountain Volcanic Group and its contact with the Packard. Moreover, isotopic age-dating techniques have indicated that the Silver Shield dike and flow, which are similar in general aspect to flow rocks of the Laguna Springs and which were originally mapped as the uppermost member of that formation, are actually Miocene rather than Oligocene age and thus represent a younger, separate period of eruption.

Consequently, the name Laguna Springs Volcanic Group is here proposed to include three new volcanic formations whose type areas are all near Laguna Springs in the north-central part of the East Tintic district. These formations are similar in chemical and mineralogical compositions, and all of them contain hornblende, which distinguishes them from both the Tintic Mountain Volcanic Group and the Silver Shield Quartz Latite. They are the extrusive equivalents of the monzonite of the Silver City stock in the main Tintic district and its satellitic monzonite porphyry plutons in the East Tintic district.

The chemical compositions of the members of the Laguna Springs Volcanic Group and equivalent intrusive rocks, and other data, are presented in table 5. A plot of the normative quartz, orthoclase, and albite + anorthite of the same samples is presented in figure 14.

### NORTH STANDARD LATITE

#### NAME, DISTRIBUTION, AND THICKNESS

The oldest formation of the Laguna Springs Volcanic Group crops out in the area of the North Standard shaft in secs. 27 and 34, T. 9 S., R. 2 W. — its type locality — and is here named the North Standard Latite. It has not been recognized elsewhere in the Tintic or East Tintic mining districts. The North Standard Latite appears to fill a northeasterly trending valley that had been eroded into the Latite Ridge Latite, the Packard Quartz Latite, and the Paleozoic rocks after eruption of the Tintic Mountain volcanic rocks. Prior to the extrusion of the lavas of the North Standard Latite, this valley was partly filled with an irregular thickness of alluvium, colluvium, and fine-grained tuff, which are here considered to be its lower member. The latitic flow rocks that overlie the basal tuffs are designated the upper member and are 300-500 ft (91-152 m) thick in their most extensive exposure.

#### LITHOLOGY AND PETROGRAPHY

The tuff member of the North Standard Latite is a heterogeneous tuffaceous agglomerate containing a large proportion of partly rounded boulders 10-12 in. (25-30 cm) in diameter that are embedded in a matrix of volcanic ash and gravel. Much of the coarser grained material was derived from the weathering of the older volcanic rocks; the matrix ash and some lapilli and boulders, however, appear to have been emplaced during the resumption of volcanic activity that led to the eruption of the overlying flow member.

The original lithologic composition of the tuff member is not well known because of the moderate to strong hydrothermal alteration of the volcanic rocks in the North Standard area. The few blocks of rocks that are recognizable include the Packard Quartz Latite, the Latite Ridge Latite, and a fine- to medium-grained latite resembling the upper member of the North Standard Latite.

The flow member of the North Standard Latite resembles the Packard Quartz Latite in its general texture and coloration, but it does not contain quartz phenocrysts. It is dull-purplish-gray to brownish-gray, massive, fine- to medium-grained porphyry (fig. 15). The freshest outcrops consist of fragments of vitrophyre embedded in a matrix of slightly lighter colored vitrophyre of similar texture and composition. The most conspicuous minerals are glassy to chalk-white phenocrysts of plagioclase and lustrous crystals of biotite. In some specimens tiny needles of dark-green hornblende are also discernible.

The texture is vitrophyric but not appreciably rhyotaxitic. The megaphenocrysts are considerably broken, and the feldspars, especially, occur mostly as angular fragments. The groundmass makes up 40-50 percent of the rock and locally is crowded with tiny crystals and crystallites. In some specimens the groundmass is considerably altered and devitrified.

The megaphenocrysts include about 50 percent plagioclase, 15 percent each of biotite and hornblende, 10 percent augite, 8 percent sanidine, and 2 percent accessory minerals. The plagioclase occurs as large phenocrysts and broken fragments as much as 4 mm long. Many of the larger crystals have conspicuous oscillatory zonation but are relatively free from zones of mineral inclusions. The most diagnostic twinned crystals indicate a composition of $An_{50-55}$. The hornblende phenocrysts range in length from 2 mm to minute specks in the glassy groundmass. They are pale

TABLE 5.—*Chemical analyses, CIPW norms, Niggli values, and spectrochemical analyses of selected samples of lavas of the Laguna*

| Sample No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Formation | Pinyon Queen Latite | | Tintic Delmar Latite | | | | Monzonite and |
| Laboratory No. | M110 358W | D102256 | M110 365W | D102261 | D102259 | D101859 | D102253 |
| | | | | | | | **Chemical (weight** |
| $SiO_2$ | 59.70 | 58.64 | 59.70 | 52.84 | 60.90 | 53.24 | 57.67 |
| $Al_2O_3$ | 15.20 | 15.61 | 15.40 | 12.96 | 16.51 | 12.90 | 15.59 |
| $Fe_2O_3$ | 6.00 | 5.00 | 4.60 | 4.20 | 6.69 | 4.51 | 5.11 |
| FeO | 1.60 | 1.88 | 2.50 | 3.78 | .42 | 3.05 | 1.98 |
| MgO | 2.80 | 2.95 | 3.10 | 7.36 | .78 | 6.66 | 3.46 |
| CaO | 5.70 | 5.88 | 5.90 | 8.14 | 4.02 | 7.87 | 5.40 |
| $Na_2O$ | 3.10 | 2.78 | 3.10 | 2.76 | 3.41 | 2.67 | 3.47 |
| $K_2O$ | 3.00 | 2.90 | 3.00 | 2.60 | 3.37 | 2.63 | 3.09 |
| $H_2O+$ | .65 | 1.51 | 1.40 | 1.19 | .93 | 1.56 | .68 |
| $N_2O-$ | .45 | 1.02 | .36 | 1.08 | 1.34 | 1.82 | .92 |
| $TiO_2$ | 1.10 | .85 | .94 | 1.00 | 1.06 | .90 | 1.15 |
| $P_2O_5$ | .42 | .29 | .35 | .42 | .29 | .39 | .59 |
| MnO | .12 | .11 | .12 | .13 | .10 | .11 | .09 |
| $CO_2$ | .08 | .06 | .08 | 1.16 | .02 | 1.36 | .33 |
| Cl | ... | .04 | ... | .02 | .02 | .01 | .02 |
| F | ... | .09 | ... | .09 | .10 | .09 | .14 |
| S | ... | .02 | ... | .01 | .01 | .02 | .03 |
| Subtotal | ... | 99.63 | ... | 99.74 | 99.97 | 99.79 | 99.72 |
| Less O | ... | .06 | ... | .05 | .05 | .05 | .08 |
| Total | 100.00 | 99.57 | 101.00 | 99.69 | 99.92 | 99.74 | 99.64 |
| | | | | | | | **CIPW (weight** |
| Q | 16.77 | 17.28 | 15.89 | 5.39 | 20.06 | 8.54 | 12.61 |
| C | ... | ... | ... | ... | .93 | ... | ... |
| or | 17.94 | 17.65 | 17.95 | 15.76 | 20.38 | 16.12 | 18.61 |
| ab | 26.55 | 23.92 | 26.55 | 23.81 | 29.38 | 23.36 | 29.77 |
| an | 18.92 | 22.36 | 19.48 | 15.77 | 17.79 | 16.06 | 18.26 |
| Normative An | ($An_{42}$) | ($An_{48}$) | ($An_{42}$) | ($An_{40}$) | ($An_{38}$) | ($An_{41}$) | ($An_{38}$) |
| (di) wo | 2.67 | 2.03 | 3.06 | 6.23 | ... | 5.20 | .98 |
| (di) en | (4.98) 2.31 | (3.78) 1.75 | (5.70) 2.64 | (11.75) 4.97 | ... | (9.73) 4.38 | (1.82) .84 |
| (di) fs | ... | ... | ... | .55 | ... | .15 | ... |
| (hy) en | 4.75 | 5.81 | 5.17 | 13.84 | 1.99 | 12.82 | 7.94 |
| (hy) | (4.75) | (5.81) | (5.17) | (15.38) | (1.99) | (13.25) | (7.94) |
| (hy) fs | ... | ... | ... | 1.54 | ... | .43 | ... |
| mt | 2.39 | 4.00 | 5.79 | 6.25 | ... | 6.78 | 3.30 |
| hm | 4.42 | 2.39 | .66 | ... | 6.85 | ... | 2.94 |
| il | 2.11 | 1.66 | 1.81 | 1.95 | 1.10 | 1.77 | 2.23 |
| ru | ... | ... | ... | ... | .50 | ... | ... |
| ap | 1.01 | .71 | .84 | 1.02 | .70 | .96 | 1.42 |
| cc | .18 | .14 | .18 | 2.71 | .05 | 3.21 | .77 |
| Total | 100.02 | 99.70 | 100.02 | 99.79 | 99.73 | 99.78 | 99.67 |
| Salic/femic ratio | 4.04 | 4.35 | 3.96 | 1.55 | 7.79 | 1.79 | 3.84 |
| Diff. index | 61.25 | 58.85 | 60.38 | 44.96 | 69.83 | 48.02 | 60.99 |
| | | | | | | | **Niggli** |
| Al | 29.75 | 30.80 | 29.67 | 20.05 | 37.24 | 20.96 | 29.60 |
| Fm | 33.64 | 32.89 | 33.59 | 45.68 | 25.39 | 44.02 | 34.58 |
| C | 20.28 | 21.09 | 20.67 | 22.89 | 16.49 | 23.25 | 18.64 |
| Alk | 16.34 | 15.22 | 16.08 | 11.38 | 20.88 | 11.76 | 17.19 |
| Si | 198.26 | 196.33 | 195.16 | 138.71 | 233.12 | 146.81 | 185.78 |
| Ri | 2.75 | 2.14 | 2.31 | 1.97 | 3.05 | 1.87 | 2.79 |
| P | .59 | .41 | .48 | .47 | .47 | .46 | .80 |
| K | .39 | .41 | .39 | .38 | .39 | .39 | .37 |
| Mg | .41 | .45 | .45 | .63 | .18 | .62 | .48 |
| Si' | 165.34 | 160.86 | 164.32 | 145.51 | 183.53 | 147.05 | 168.74 |
| Qz | 32.92 | 35.46 | 30.85 | -6.80 | 49.59 | -.24 | 17.04 |
| | | | | | | | **Spectrochemical (parts per** |
| B | [2]N | N | N | N | 20 | N | N |
| Ba | 1,500 | 1,000 | 1,500 | 1,500 | 1,000 | 1,000 | 1,500 |
| Be | N | 1 | N | 1 | 1 | N | 1 |
| Ce | 150 | N | 100 | 150 | 150 | N | 200 |
| Co | 50 | 20 | 20 | 50 | 20 | 30 | 20 |
| Cr | 70 | 150 | 70 | 700 | 30 | 300 | 70 |
| Cu | 30 | 70 | 30 | 100 | 50 | 100 | 50 |
| Ga | 20 | 20 | 20 | 20 | 20 | 20 | 50 |
| La | 70 | 100 | 70 | 100 | 70 | 70 | 100 |
| Mo | N | 3 | N | 5 | 5 | N | N |
| Nb | 15 | 10 | 10 | N | N | N | 10 |
| Nd | 70 | 70 | 70 | 70 | 100 | N | 150 |
| Ni | 20 | 20 | 20 | 300 | 20 | 150 | 50 |
| Pb | 30 | 50 | 20 | 20 | 20 | 20 | 20 |
| Sc | 30 | 30 | 30 | 30 | 20 | 20 | 20 |
| Sr | 1,000 | 1,000 | 1,000 | 1,500 | 1,000 | 1,000 | 1,000 |
| V | 150 | 200 | 200 | 300 | 200 | 150 | 200 |
| Y | 30 | 50 | 30 | 50 | 50 | 20 | 50 |
| Yb | 3 | N | 3 | 5 | 5 | 3 | 5 |
| Zr | 200 | 150 | 200 | 200 | 200 | 150 | 200 |

[1]Also looked for and not detected at limit of detection, or detected but below limit of determination: Ag, As, Au, Bi, Cd, Eu, Ge, Hf, Hg, In, Li, Pd, Pt, Re, Sb, Sm, Sn, Ta, Te, Th, Tl, Pr, U, W, and Zn.

[2]N = not detected.

1. Coarse-grained greenish-gray latite porphyry; west side of lower Pinyon Creek Canyon, 4,200 ft (1,280 m) N. 26° E. of Pinyon Queen shaft; NE¼ sec. 34, T. 9 S., R. 2 W. Chemical analysis performed in the Rapid-Rock Analysis Laboratory under Leonard Shapiro; Chris Heropoulos, spectrochemical analyst.
2. Coarse-grained gray latite porphyry; boulder in lower tuff member, 750 ft (229 m) N. 83° E. of Bluff shaft; SE¼ sec. 34, T. 9 S., R. 2 W. Edythe E. Engleman, chemical analyst; Leon A. Bradley, spectrochemical analyst.
3. Coarse-grained greenish-gray latite porphyry; southeastern part of Allens Ranch quadrangle, 2,800 ft (854 m) N. 77° E. of Tintic Delmar shaft; center E½, SW¼ sec. 23, T. 9 S., R. 2 W. Chemical analysis performed in the Rapid-Rock Analysis Laboratory under Leonard Shapiro; Chris Heropoulous, spectrochemical analyst.
4. Coarse-grained greenish-gray monzonite porphyry; small plug exposed in railroad cut, 1,900 ft (579 m) S. 54° W. of Water Lillie shaft; NW¼SW¼ sec. 3, T. 10 S., R. 2 W. Edythe E. Engleman, chemical analyst; Leon A. Bradley, spectrochemical analyst.
5. Medium-grained gray monzonite porphyry; plug exposed in gulch 2,100 ft (640 m) N. 15° E. of East Standard shaft; NW¼NE¼ sec. 2, T. 10 S., R. 2 W. Edythe E. Engleman, chemical analyst; Leon A. Bradley, spectrochemical analyst.
6. Medium-grained gray monzonite porphyry; small dike exposed on hill 1,150 ft (351 m) S. 15° W. of Central Standard shaft; NE¼NE¼ sec. 9, T. 10 S., R. 2 W. Edythe E. Engleman, chemical analyst; J. L. Finley, spectrochemical analyst.
7. Coarse-grained dark-greenish-gray monzonite porphyry of Endline dike system; 1,150 ft (351 m) S. 27° W. of Copper Leaf shaft; NE¼SE¼ sec. 9, T. 10 S., R. 2 W. Edythe E. Engleman, chemical analyst; Leon A. Bradley, spectrochemical analyst.

*Springs Volcanic Group and monzonite and quartz monzonite porphyry of the Silver City stock and associated intrusions*

| | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|
| | quartz monzonite porphyry | | | | | | Average of 5 and 7-13 | Monzonite of Silver City stock | |
| | D102250 | D101867 | D102263 | D102249 | D102262 | D102258 | .............. | D102251 | (Tower and Smith, 1899, p. 647) |
| **analyses percent)** | | | | | | | | | |
| | 64.04 | 59.83 | 58.95 | 58.29 | 62.29 | 62.99 | 60.62 | 61.35 | 59.76 |
| | 15.70 | 15.11 | 16.38 | 15.00 | 15.66 | 15.29 | 15.66 | 15.94 | 15.79 |
| | 3.13 | 4.47 | 5.39 | 4.08 | 3.75 | 3.95 | 4.57 | 3.55 | 3.77 |
| | 1.85 | 2.30 | 1.26 | 2.97 | 2.07 | 1.61 | 1.81 | 2.43 | 3.30 |
| | 2.00 | 3.37 | 2.92 | 4.19 | 2.27 | 2.15 | 2.64 | 2.22 | 2.16 |
| | 3.88 | 5.21 | 4.09 | 4.39 | 4.08 | 3.73 | 4.35 | 4.46 | 3.88 |
| | 3.76 | 3.40 | 3.53 | 4.06 | 3.43 | 3.47 | 3.57 | 3.52 | 3.01 |
| | 3.43 | 3.14 | 3.05 | 3.18 | 3.77 | 3.86 | 3.36 | 3.89 | 4.40 |
| | .53 | .84 | 1.35 | 1.25 | .75 | .83 | .89 | .65 | 1.11 |
| | .21 | .67 | 1.18 | .58 | .34 | .42 | .71 | .17 | .31 |
| | .71 | .88 | .93 | 1.04 | .82 | .78 | .92 | .84 | .87 |
| | .29 | .34 | .35 | .37 | .30 | .36 | .36 | .34 | .42 |
| | .09 | .12 | .13 | .11 | .10 | .05 | .10 | .10 | .12 |
| | 0.00 | .11 | .16 | .24 | .01 | .08 | | | .78 |
| | .04 | .02 | .02 | .04 | .03 | .02 | .03 | .04 | .04 |
| | .08 | .09 | .11 | .09 | .10 | .10 | .10 | .10 | .............. |
| | .03 | .02 | .01 | .02 | .01 | .02 | .02 | .02 | .............. |
| | 99.77 | 99.92 | 99.81 | 99.90 | 99.78 | 99.71 | 99.83 | 99.89 | .............. |
| | .06 | .05 | .06 | .06 | .06 | .05 | .06 | .06 | .............. |
| | 99.71 | 99.87 | 99.75 | 99.84 | 99.72 | 99.66 | 99.77 | 99.83 | 99.72 |
| **norms percent)** | | | | | | | | | |
| | 19.34 | 14.87 | 15.84 | 9.74 | 17.57 | 18.75 | | 15.54 | 16.87 |
| | .............. | .............. | 1.32 | .............. | .............. | .............. | | .............. | 1.92 |
| | 20.47 | 18.86 | 18.53 | 19.16 | 22.57 | 23.17 | | 23.20 | 26.44 |
| | 31.83 | 29.08 | 30.55 | 34.73 | 29.18 | 29.67 | | 29.77 | 25.60 |
| | 16.15 | 17.04 | 16.88 | 13.74 | 16.53 | 15.06 | | 16.52 | 11.77 |
| | ($An_{34}$) | ($An_{37}$) | ($An_{36}$) | ($An_{28}$) | ($An_{36}$) | ($An_{34}$) | | ($An_{36}$) | ($An_{31}$) |
| | .41 | 2.43 | .............. | 1.69 | .58 | .14 | | .56 | .............. |
| | (.76) .35 | (4.53) 2.10 | .............. | (3.16) 1.40 | (1.08) .50 | (.26) .12 | | (1.05) .47 | .............. |
| | .............. | .............. | .............. | .07 | .............. | .............. | | .02 | .............. |
| | 4.68 | 6.43 | 7.48 | 9.24 | 5.23 | 5.32 | | 5.12 | 5.47 |
| | (4.68) | (6.43) | (7.48) | (9.71) | (5.23) | (5.32) | | (5.39) | (7.29) |
| | .............. | .............. | .............. | .47 | .............. | .............. | | .27 | 1.82 |
| | 4.13 | 5.27 | 1.80 | 6.03 | 4.65 | 3.07 | | 5.20 | 5.56 |
| | .31 | .91 | 4.30 | .............. | .60 | 1.90 | | .............. | .............. |
| | 1.36 | 1.70 | 1.82 | 2.01 | 1.58 | 1.51 | | 1.61 | 1.68 |
| | .............. | .............. | .............. | .............. | .............. | .............. | | .............. | .............. |
| | .69 | .82 | .85 | .89 | .72 | .87 | | .81 | 1.01 |
| | .............. | .25 | .37 | .56 | .02 | .19 | | .62 | 1.80 |
| | 99.72 | 99.76 | 99.74 | 99.73 | 99.73 | 99.77 | | 99.71 | 99.94 |
| | 7.26 | 3.98 | 4.95 | 3.44 | 6.12 | 6.53 | | 5.73 | 4.77 |
| | 71.63 | 62.81 | 64.92 | 63.63 | 69.33 | 71.58 | | 68.51 | 68.91 |
| **values** | | | | | | | | | |
| | 35.31 | 29.49 | 33.31 | 28.15 | 33.74 | 34.13 | | 33.35 | 33.08 |
| | 26.56 | 34.48 | 33.04 | 37.87 | 29.33 | 28.66 | | 28.75 | 31.79 |
| | 15.87 | 18.49 | 15.12 | 14.98 | 15.98 | 15.14 | | 16.97 | 14.78 |
| | 22.26 | 17.55 | 18.52 | 18.99 | 20.95 | 22.07 | | 20.93 | 20.35 |
| | 244.41 | 198.13 | 203.46 | 185.64 | 227.75 | 238.61 | | 217.84 | 212.45 |
| | 2.04 | 2.19 | 2.41 | 2.49 | 2.25 | 2.22 | | 2.24 | 2.33 |
| | .47 | .48 | .51 | .50 | .46 | .58 | | .51 | .63 |
| | .38 | .38 | .36 | .34 | .42 | .42 | | .42 | .49 |
| | .43 | .48 | .45 | .53 | .42 | .42 | | .41 | .36 |
| | 189.05 | 170.19 | 174.10 | 175.98 | 183.80 | 188.28 | | 183.71 | 181.40 |
| | 55.37 | 27.94 | 29.36 | 9.66 | 43.95 | 50.34 | | 34.13 | 31.05 |
| **analyses[1] million)** | | | | | | | | | |
| | N | N | N | N | N | N | N | | N |
| | 1,000 | 1,500 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | | 1,000 |
| | 1 | N | 1 | 1 | 1 | 2 | 1 | | 2 |
| | N | 300 | 150 | 150 | 150 | 150 | 150 | | 150 |
| | 20 | 20 | 20 | 30 | 20 | 20 | 20 | | 20 |
| | 50 | 70 | 20 | 100 | 30 | 20 | 50 | | 30 |
| | 20 | 30 | 50 | 50 | 50 | 50 | 50 | | 50 |
| | 50 | 30 | 20 | 50 | 20 | 20 | 30 | | 50 |
| | 100 | 70 | 100 | 100 | 100 | 100 | 100 | | 100 |
| | N | N | 3 | N | 3 | N | 3 | | N |
| | N | N | N | N | 10 | N | 1 | | 10 |
| | 70 | N | 70 | 70 | 70 | 70 | 70 | | 100 |
| | 20 | 30 | 10 | 50 | 20 | 10 | 30 | | 20 |
| | 50 | 30 | 20 | 20 | 20 | 20 | 20 | | 30 |
| | 15 | 15 | 20 | 20 | 20 | 15 | 20 | | 20 |
| | 1,000 | 700 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | | 1,000 |
| | 150 | 150 | 200 | 200 | 200 | 150 | 175 | | 200 |
| | 30 | 20 | 50 | 50 | 50 | 50 | 50 | | 50 |
| | 5 | 2 | 5 | 5 | 5 | 3 | 5 | | 5 |
| | 100 | 150 | 200 | 200 | 200 | 100 | 150 | | 100 |

8. Medium-grained brownish-gray quartz monzonite from southeastern part of large plug 1,550 ft (473 m) N. 12° W. of North Lily shaft; SW¼SE¼ sec. 9, T. 10 S., R. 2 W. Edythe E. Engleman, chemical analyst; Leon A. Bradley, spectrochemical analyst.
9. Fresh, medium- to coarse-grained, dark-gray monzonite porphyry from small plug cutting argillized lava 1,250 ft (381 m) N. 35° W. of North Lily shaft; NE¼NW¼ sec. 16, T. 10 S., R. 2 W. Edythe E. Engleman, chemical analyst; J. L. Finley, spectrochemical analyst.
10. Coarse-grained greenish-gray monzonite porphyry from dike exposed 2,200 ft (671 m) N. 71° W. of Burgin No. 1 shaft; center S½ sec. 15, T. 10 S., R. 2 W. Edythe E. Engleman, chemical analyst; Leon A. Bradley, spectrochemical analyst.
11. Medium-grained gray monzonite porphyry from center of plug that is 1,550 ft (473 m) N. 80° E. of Maple shaft, NE¼NE¼ sec. 20, T. 10 S., R. 2 W. Edythe E. Engleman, chemical analyst; Leon A. Bradley, spectrochemical analyst.
12. Medium-grained greenish-gray monzonite porphyry from irregular plug exposed 800 ft (244 m) S. 70° W. of Trixie shaft; NW¼NE¼ sec. 28, T. 10 S., R. 2 W. Edythe E. Engleman, chemical analyst; Leon A. Bradley, spectrochemical analyst.
13. Medium-grained brownish-gray monzonite porphyry from large plug on west side of Silver Pass Gulch, 2,000 ft (610 m) N. 75° W. of Little Gough spring; SE¼SW¼ sec. 28, T. 10 S., R. 2 W. Edythe E. Engleman, chemical analyst; Leon A. Bradley, spectrochemical analyst.
14. Average of analyses 5 and 7-13.
15. Medium-grained pinkish-gray monzonite from exposure of Silver City stock in southern part of main Tintic district at Cleveland shaft; NE¼NE¼ sec. 36, T. 10 S., R. 3 W. Edythe E. Engleman, chemical analyst; Leon A. Bradley, spectrochemical analyst.
16. Medium-grained gray monzonite from exposure of Silver City stock in old railroad cut immediately north of Iron Duke mine in southern part of main Tintic district; SW¼NE¼ sec. 36, T. 10 S., R. 3 W. (Tower and Smith, 1899, p. 647).

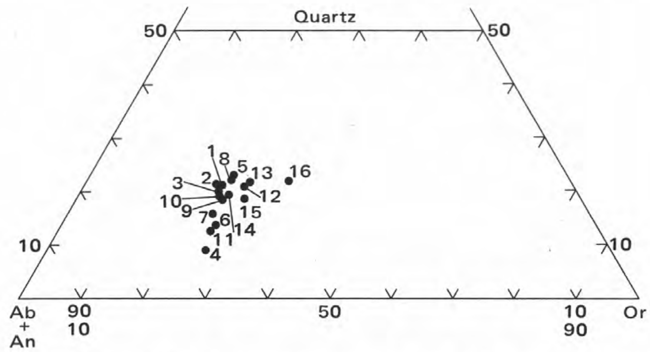



FIGURE 14. — Plot of normative quartz-orthoclase-albite + anorthite of selected samples of the Laguna Springs Volcanic Group, Silver City monzonite stock and associated monzonite and quartz monzonite porphyry, and comparative rocks.

yellow green in transmitted light and pleochroic, with X = pale yellow green, Y = medium yellow green, and Z = green. Some crystals show polysynthetic twinning. Biotite phenocrysts are about the same size as the hornblende. They are strongly pleochroic with X = yellowish brown, Y = Z = dark grayish brown. Nearly all the biotite encloses tiny crystals of early plagioclase, zircon, and magnetite. The augite occurs chiefly in fractured and partly resorbed pale-greenish to almost colorless phenocrysts 2-3 mm in diameter. It also contains many included crystals of apatite, zircon, and magnetite.


FIGURE 15. — Flow member of North Standard Latite from exposures 500 ft (152 m) due north of North Standard shaft. Dark areas are fragments of vitrophyre embedded in a vitrophyre of lighter hue.

Sanidine chiefly forms small fragments of clear crystals, some of which are Carlsbad twins. Of the accessory minerals, magnetite and zircon are especially abundant; a few crystals of hypersthene and quartz, probably derived from other rocks, were also noted in one specimen. The abundance of hornblende and relative absence of quartz and hypersthene readily distinguish the North Standard Latite from both the Packard Quartz Latite and the latites of the Tintic Mountain Volcanic Group.

#### CHEMICAL COMPOSITION AND AGE

Because of the limited exposures of the North Standard Latite as compared to the more widely exposed volcanic rocks that are younger and older, no chemical analyses were made. Mineralogically it is similar to the overlying part of the Laguna Springs Volcanic Group and is assumed to be similar in chemical composition. Staining techniques indicate a relatively high proportion of $K_2O$, particularly in the groundmass.

The North Standard Latite has not been dated isotopically inasmuch as it clearly overlies the 32.8 ± 1.0-m.y. Packard Quartz Latite and underlies higher formations of the Laguna Springs Volcanic Group that are only slightly younger than the Packard (see p. 50 and 51). Like these units it is considered to be middle Oligocene.

#### ECONOMIC IMPORTANCE

The exposures of the North Standard Latite have been weakly to moderately argillized and strongly pyritized, but no ore bodies are known in the area despite prospecting efforts from the North Standard shaft and by drilling.

### PINYON QUEEN LATITE

#### NAME, DISTRIBUTION, AND THICKNESS

The most widely distributed formation of the Laguna Springs Volcanic Group is here named the Pinyon Queen Latite from easily accessible exposures east of the Pinyon Queen shaft in secs. 34 and 35, T. 9 S., R. 2 W., its type locality. This formation consists of two members, a lower member of tuff, breccia, and agglomerate, and an overlying flow member of coarse-grained porphyritic latite. In addition to the exposures on the high ridges east of the Pinyon Queen and Bluff shafts, both members of the Pinyon Queen Latite crop out (1) northwest of the district in the upper part of Eureka Gulch near Homansville Pass, (2) in the south-central part of the Allens Ranch quadrangle near the Tintic Paymaster Nos. 1 and 2 shafts, also north of the district, (3) on the north side of Pinyon Creek Canyon in a broad, irregular band that extends from the vicinity of the North Standard shaft eastward to Laguna and thence northward into the south-central part of the Allens Ranch quadrangle, and (4) on the low hill immediately north of Wing Spring in the south-eastern part of the district.

The tuff member was erupted over an irregular topography, and consequently it ranges in thickness from about 6 in (15 cm) to more than 400 ft (122 m). It chiefly overlies the Packard Quartz Latite, but in the Pinyon Creek area, north of the North Standard shaft, it is locally underlain by the North Standard Latite; near Wing Spring it overlies the Latite Ridge and Big Canyon Latites. The flow member is incomplete in all of its exposures, having been eroded prior to eruption of the volcanic rocks that overlie it as well as during the present erosion cycle. The maximum thickness of 700 ft (213 m) is on the ridge west of the head of Eureka Gulch, but the top and overlying rocks are missing.

### Lithology and Petrography

The tuff member is a heterogeneous unit ranging in texture from soft fine-grained sandy tuff to boulder agglomerate. Most exposures weather to rounded hills and ridges that are mantled by large and small residual boulders of both older rocks and coarse-grained latite. As best shown in exposures in Pinyon Creek Canyon near Laguna and elsewhere, the tuff member consists of a basal zone that is characterized by cobbles and boulders of vitrophyre and other rocks embedded in fine-grained ashy tuff. This agglomeratic material is overlain by lenses of unsorted but rudely stratified lapilli tuff, which in turn are cut by many channels containing conspicuously stratified volcanic gravels and lenses of fine-grained sand.

Under the microscope, the tuff is seen to consist of fragments of latite, quartz latite, vitrophyre, quartzite, and, rarely, limestone surrounded by a matrix of finer grained rock fragments, broken mineral grains, and glass shards. The mineral fragments include plagioclase, augite, basaltic hornblende, biotite, magnetite, quartz, and a variety of alteration products. The plagioclase fragments are chiefly labradorite, but they also include much sodic andesine presumably derived from the weathering of older rocks. Much of the quartz and a few rare grains of hypersthene were also undoubtedly derived from older formations. Because of the porous nature of the tuff member, it has been a conduit for hydrothermal solutions and ground water; as a consequence, many zones contain secondary chlorite and clay minerals, epidote, sericite, calcite, quartz, opaline silica, and, particularly in the vicinity of the North Standard, Pinyon Queen, and Bluff shafts, much hydrothermal pyrite or its oxidation products.

The flow member of the Pinyon Queen Latite is a massive unit displaying only a faint to moderate planar structure. Hand specimens are medium- to coarse-grained porphyritic and are characterized by large glassy to chalk-white phenocrysts of feldspar, shiny black crystals of biotite, and rare phenocrysts of hornblende and augite embedded in a medium- to dark-gray dense to granular matrix that weathers pinkish gray, lavender gray, or purplish gray (fig. 16). Near Homansville Pass, and locally in other parts of the district, the member contains distinct xenolithic fragments and blocks of similar latite that probably represent chilled crusts that were broken and incorporated into the viscous lava as it moved slowly down the slopes of the volcano. North of the North Standard shaft on the boundary of the Eureka quadrangle, one exposure is highly vesicular, which contrasts with the generally dense character of the rock elsewhere in the district.

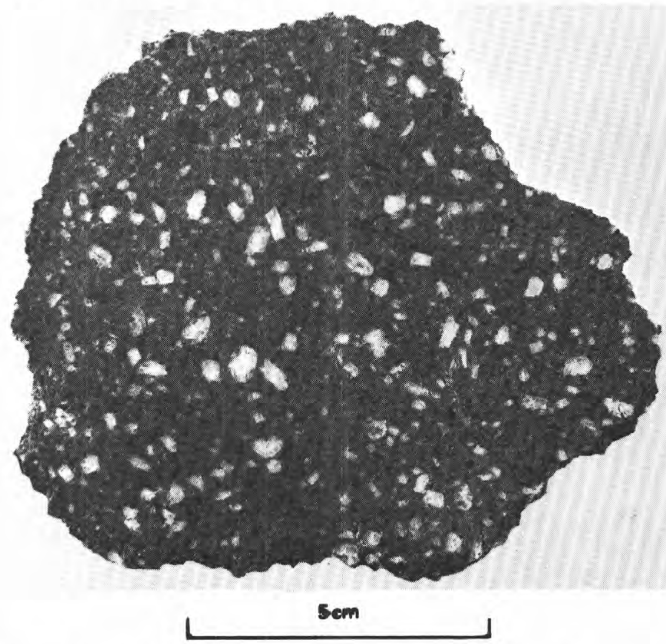



FIGURE 16. — Flow member of Pinyon Queen Latite from exposure 2,500 ft (762 m) N. 5° W. from Independence shaft. Large light phenocrysts are plagioclase; nearly equidimensional dark phenocrysts are biotite, more acicular dark phenocrysts are chiefly hornblende but include some augite.

Under the microscope, the groundmass of the upper latite flow rocks ranges from hemihyaline to holocrystalline and has a hyalopilitic to pilotaxitic texture defined by tiny crystals of feldspar and basaltic hornblende with interstitial grains of augite and orthoclase or patches of glass. The position of the rock in the rhyodacite field (fig. 14) also suggests the presence of much fine-grained quartz or silica-rich glass in the matrix. The megaphenocrysts, which constitute 40-55 percent of the rock, include an average of 50 percent plagioclase, 32 percent basaltic hornblende, 10 percent biotite, 5 percent augite, and 3 percent magnetite. Despite the abundance of basaltic hornblende and biotite as phenocrysts, both are rare in the groundmass, which, instead, contains abundant augite and orthoclase. Apatite, zircon, sphene, and quartz are accessory minerals.

The plagioclase phenocrysts, which are as much as 15 mm long and 6 mm wide, are strongly zoned, commonly doubly twinned, and have an average composition of $An_{54}$. Many of the crystals have relatively wide reaction rims consisting of minute nearly equidimensional grains of what seems to be a pale-green pyroxene.

The basaltic hornblende phenocrysts are 1-3 mm long and smaller; they are moderately to strongly pleochroic with X = yellowish brown, Y = medium brown, and Z = dark brown. In many specimens the basaltic hornblende is partly to completely resorbed. As noted also by Lindgren and Loughlin (1919, p. 62), some of the reaction rims consist of short rods of augite and minute grains of magnetite and ilmenite embedded in a matrix of small plagioclase anhedrons.

The biotite phenocrysts, some of which are 5 mm long, are also pleochroic, with X = yellowish brown, Y = dark grayish brown, and Z = dark reddish brown. Some basal sections could be mistaken for basaltic hornblende.

Augite forms a few phenocrysts as much as 3 mm long in most specimens, but it occurs chiefly as small rounded to stubby crystals in the groundmass. It is faintly green, and the larger phenocrysts commonly contain many inclusions of magnetite. The poorly developed cleavage of the augite is in marked contrast with the prominent cleavage displayed by the basaltic hornblende.

Magnetite is fairly abundant as partly resorbed cubic grains, and in some specimens it should be listed with the major constituents of the latite. In the rocks exposed near Wing Spring, much of the magnetite forms clumps of three or more crystals.

#### Chemical composition

As shown in table 5, samples 1 and 2, the flow member of the Pinyon Queen Latite is somewhat more calcic than the monzonite porphyry dikes and plugs that are believed to be its intrusive counterparts, including the monzonite of the Silver City stock. As compared to the lavas of the Tintic Mountain Volcanic Group and the monzonite porphyry of the Gough sill and Sunrise Peak stock, the Pinyon Queen Latite contains more CaO and total Fe and correspondingly less $K_2O$.

#### Age

Biotite from the tuff member of the Pinyon Queen Latite exposed about 750 ft (229 m) east of the Bluff shaft yielded an apparent potassium-argon age of 27.8 ± 0.8 m.y. (Laughlin and others, 1969, p. 917). This date is anomalously young when compared to the 32.2 ± 1 and 32.3 ± 1-m.y. ages of biotite and hornblende from the overlying Tintic Delmar Latite as described on p. 51. A possible explanation may be that although the biotite from the Pinyon Queen in this area appeared to be lustrous and unaltered, the tuff and breccia in the vicinity of the Bluff shaft are moderately to strongly pyritized, indicating a hydrothermal event that may have resulted in the loss of accumulated radiogenic argon. Because it lies between formations that have isotopic ages of about 32 m.y., however, it is considered to be middle Oligocene.

#### Economic importance

No known ore bodies are localized within the Pinyon Queen Latite, and the formation does not appear to be suitable for the production of nonmetallic or industrial mineral products.

### Tintic Delmar Latite

#### Name, distribution, and thickness

Overlying the Pinyon Queen Latite is a nearly identical unit also consisting of a tuff member and an overlying flow member. In the East Tintic district this formation crops out only on the northwest side of Pinyon Creek Canyon half a mile (0.8 km) northwest of Laguna Station, but it crops out somewhat more extensively in the type locality just south of the Tintic Delmar mine in the south-central part of the adjacent Allens Ranch quadrangle from which the formation is here named. This locality is in the W½ sec. 26, T. 9 S., R. 2 W. In most other parts of the East Tintic Mountains the formation appears to have been completely eroded, but it is lithologically similar and probably correlative with thick agglomerates and some flow rocks on the eastern slopes of the southern Wasatch Mountains and the central part of Long Ridge.

In the exposures in the East Tintic district, the tuff member is 75-190 ft (23-58 m) thick. The flow member is partly eroded, but the remnant is 100-200 ft (30-61 m) thick.

#### Lithology and petrography

The Tintic Delmar Latite is virtually indistinguishable from the underlying Pinyon Queen Latite but is established as a separate formation for mapping convenience and because it represents a distinctive cycle of early eruption of tuff and breccia followed by eruption of lava flows like other eruptive units in the district.

The tuff member is a heterogeneous assemblage of volcanic ash, lapilli tuff, and agglomeratic breccia. It is less well stratified than the tuff member of the Pinyon Queen Latite and only locally contains stream deposits and boulders of the older volcanic and sedimentary units.

The constituents of the tuff member include abundant boulders and lapilli-sized clasts of the coarse-grained lavas that lie above and below it as well as many fragments of plagioclase, hornblende, biotite, and augite, all embedded in a matrix of glass shards, comminuted rock, and arkosic sand. Appreciable amounts of quartz, andesine, hornblende, and fragments of sedmentary rocks are rare.

The flow member is a massive porphyritic lava with an imperfectly developed planar structure. Hand specimens are medium to coarse grained with feldspar phenocrysts as much as 10 mm long and 6-8 mm wide and biotite, hornblende, and augite crystals 6 mm long or less enclosed in an aphanitic to fine-grained groundmass (fig. 17). The prevailing color of the fresh rock is medium gray, commonly with tones of brick red, lavender, purple, or bluish gray on the weathered surface.

In thin section the Tintic Delmar Latite is also identical with the Pinyon Queen Latite in containing partly resorbed phenocrysts of labradorite ($An_{56}$), basaltic hornblende, biotite, and augite in a faintly trachytic groundmass that contains much augite, magnetite, and, presumably, orthoclase and quartz. The characteristics of the minerals in both formations are so closely similar that they are not repeated here.

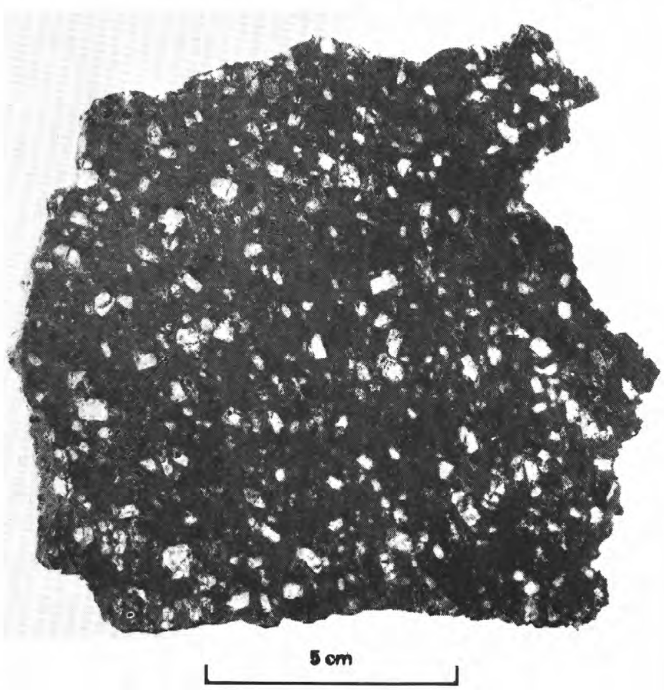



FIGURE 17. — Flow member of Tintic Delmar Latite from exposure in Allens Ranch quadrangle 8,000 ft (2,438 m) N. 49° E. of North Standard shaft. Large white phenocrysts are plagioclase. Mafic phenocrysts are deuterically altered, but some biotite crystals are faintly visible.

#### CHEMICAL COMPOSITION

The close similarity of the mineralogical and chemical composition of the porphyritic lavas of the Pinyon Queen and Tintic Delmar Latites leaves little question that they were derived from the same magma source. Because of this similarity, discussion of the chemical composition of latite flow rocks is presented on page 50 and is not repeated here.

#### AGE

Because of the importance of the Tintic Delmar Latite as the youngest extrusive unit of the Laguna Springs Volcanic Group, age dating by the potassium-argon method was carried out on coexisting biotite and hornblende from the flow member. The sample locality is in the N½SE¼SW¼ sec. 23, T. 9 S., R. 2W., in the Allens Ranch quadrangle 1 mi (1.6 km) north of the East Tintic district. In this area a thin remnant slab of dark-gray porphyritic latite overlies the tuff member close to the north edge of the East Tintic volcanic field. Microscopic examination indicates that the rock is not deeply weathered and that the minerals are entirely fresh and unaltered.

The apparent age of the biotite is 32.2 ± 1 m.y. and of the hornblende is 32.3 ± 1 m.y. These ages are nearly the same as the ages of biotite and sanidine from the middle Oligocene Packard Quartz Latite as reported by Laughlin, Lovering, and Mauger (1969) and confirm the middle Oligocene age of the Tintic Delmar Latite and relatively short duration of the Oligocene eruptive episode of the Tintic volcanic center.

#### ECONOMIC IMPORTANCE

Although the tuff member of the Tintic Delmar Latite is moderately pyritized and argillized in the East Tintic district, no ore bodies are known in any part of the formation. Its heterogeneous nature, lack of pumice and scoria, and general inaccessiblity also make it unsuitable as a source of nonmetallic and industrial mineral products.

### LATITE PLUGS AND DIKES

In the northeastern part of plate 1 north and northwest of the East Standard shaft, several small plugs and dikes cut the tuff member of the Pinyon Queen Latite and the underlying Packard Quartz Latite. The largest of the plugs is about 900 ft (274 m) long and 500 ft (152 m) wide. These intrusive bodies consist of latite porphyry similar in mineralogical composition and texture to the Pinyon Queen and Tintic Delmar Latites and may be some of the eruptive sources of these rocks.

In general the plugs and dikes are slightly less resistant to erosion than the enclosing rocks, and most of them crop out in small basins or in stream gullies. Their contacts are commonly marked by breccia zones, suggesting forceful intrusion.

The rocks are medium-grained porphyritic and are characterized by chalk-white feldspar and lustrous to iron-stained black biotite and hornblende phenocrysts embedded in a fine-grained to aphanitic matrix that ranges in color from brown to medium and dark gray (fig. 18) The feldspar phenocrysts are generally 5 mm or less long and 3 mm wide or less; the biotite and hornblende phenocrysts are rarely more than 3 mm long.

FIGURE 18. — Latite porphyry from small intrusive plug 2,400 ft (732 m) north of East Standard shaft.

Thin sections indicate about 25 percent large phenocrysts and 75 percent groundmass. Almost half the groundmass, in turn, consists of small much altered iron-stained phenocrysts of hornblende, augite, and biotite embedded in a felted mass of irresolvable crystals, some of which are lath shaped to acicular and appear to be feldspar. Sodium cobaltinitrite staining techniques indicate a high proportion of potassium feldspar or potassium-rich glass. Rare vugs are filled with brown chalcedonic silica.

The larger phenocrysts consist of 60 percent or more andesine ($An_{50-55}$), 30 percent biotite, 7 percent or less basaltic hornblende, and a few percent magnetite, quartz, sphene, apatite, and other accessory minerals. Many of the feldspar phenocrysts have conspicuous peripheral overgrowths or reaction rims. Symmetrical dark patches consisting of minute aggregates of clay and chlorite minerals heavily impregnated with iron oxide and other opaque minerals are probably remnants of augite phenocrysts.

Mineralogically, the latite porphyry closely resembles the monzonite porphyry of the satellitic intrusive bodies of the Silver City stock. Texturally, however, the rock is somewhat finer grained and has a smaller proportion of phenocrysts; therefore, it is considered to be a separate rock unit.

The country rocks near the latite plugs and dikes are only weakly chloritized, argillized, and pyritized. Minor prospecting in the area has not disclosed any ore.

### SILVER CITY STOCK AND ASSOCIATED PLUTONS

The Silver City stock, which has an outcrop area of about 3 square miles (7.8 km$^2$) and is the largest intrusive body in the East Tintic Mountains, extends for a short distance into the southwestern part of the East Tintic district, 1,500 ft (457 m) southwest of the Roundy shaft. The part of the stock that crops out in the East Tintic district is the tip of the westernmost of two northeasterly trending lobes of this intrusive body that cut sedimentary rocks and lavas on its northern and eastern sides.

The monzonite in the central and western part of the Silver City stock is medium to light pinkish or purplish gray and has a medium- to fine-grained granular texture. In contrast, specimens from the northeastern lobes of the stock are distinctly porphyritic and are virtually identical in texture to the monzonite porphyry plugs and dikes to the northeast in the central part of the district. The average mineralogic composition of the monzonite is 30 percent andesine, 30 percent potassium feldspar, 5 percent or more quartz, 15 percent augite, 10 percent hornblende, 7 percent biotite, and a total of 3 percent magnetite, apatite, zircon, and sphene. Propylitic alteration affects most of the stock, and many of the ferromagnesian minerals have been replaced by aggregates of chlorite and clay minerals and calcite, or by uralitic hornblende. The chemical composition, CIPW norms, Niggli values, and spectrochemical composition of the monzonite of the Silver City stock are presented in table 5.

The contact of the Silver City stock with the sedimentary rocks in the main Tintic district is characterized by myriads of irregular apophyses that invade bedding planes, joints, and faults in a manner that strongly suggests magmatic stoping as the principal method of emplacement. Numerous xenoliths of shale, quartzite, and carbonate rock that generally remain in their expected preintrusive stratigraphic and structural positions are corroborative evidence of a quiet mode of emplacement. In contrast, the walls of many of the smaller plutons and dikes in the East Tintic district commonly are shattered, which may indicate that these bodies were more aggressively emplaced.

Biotite from fresh Silver City monzonite exposed near the Iron Duke and Cleveland shafts in the main Tintic district 4½ mi (7.2 km) southwest of Dividend has yielded an apparent age of $31.5 \pm 0.9$ m.y. (Laughlin and others, 1969, p. 915, 917), and the intrusion is considered to be middle Oligocene. Geologically, the stock appears to be the youngest of the Oligocene igneous rocks in the East Tintic Mountains.

## Monzonite Porphyry Plugs and Dikes

### Distribution and General Features

Porphyritic intrusive bodies in the East Tintic district that are similar in composition and presumably related to the Silver City stock range in size from dikes and sills about 1 in. (2.5 cm) wide and less than 5 ft (1.5 m) long to elliptical plutons as much as 1,500 ft (457 m) long and 700 ft (213 m) wide. The larger pluglike and pipelike plutons chiefly occur in three intrusive centers, two of which are locallized within zones of linear fissures that extend from the northeasterly trending lobes of the Silver City stock in the southwestern part of the East Tintic district nearly to its northern border. The fissured areas are characterized by swarms of injected pebble breccias (pebble dikes), dikes of monzonite porphyry, elongate masses of tectonic breccia, and linear zones of hydrothermal alteration.

The three intrusive centers are similar in consisting of moderately well defined groups of intrusive bodies that have a wide range of sizes and shapes. The best defined of these centers lies a short distance northwest of the North Lily shaft, from which it is named. It consists of 25 or more plutons cutting the Packard Quartz Latite within a roughly circular area about 1,800 ft (549 m) in diameter. Extending northeasterly from the outer parts of the center are two swarms of monzonite porphyry dikes. A second cluster of plugs between the Maple and Iron King No. 1 shafts, which is referred to as the Iron King intrusive center, is similar to the North Lily center, but it contains only a few intrusive rocks that are tabular enough to call dikes. The third cluster of plutons lies between the Zuma and Trixie shafts and is referred to as the Zuma intrusive center. Like the Iron King center it has relatively few monzonite dikes, but the northeasterly trending zone of pebble dikes, fissures, and linear zones of alteration along its southeastern side bears a close similarity to parts of the North Lily center.

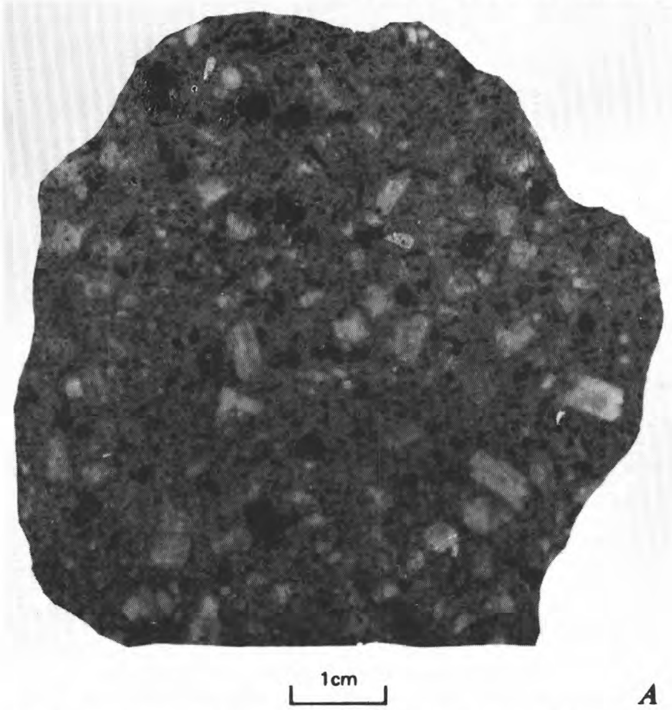
Some relatively isolated plugs and dikes within the general zone of fissures and pebble dikes, however, do not seem to belong to any one of these intrusive centers. Examples of such isolated intrusive bodies include the plug exposed in the railroad cut 1,900 ft (579 m) southwest of the Water Lillie shaft and the fairly large intrusive body that crops out about 2,000 ft (610 m) west-northwest of Little Gough Spring.

### Lithology and Petrography

All the monzonite or quartz monzonite intrusive rocks in the East Tintic district are porphyritic (fig. 19). Their texture ranges from fine to coarse grained, but most of the stocks are medium grained, with conspicuous phenocrysts of feldspar, biotite, and hornblende and stubby grains of augite.

The groundmass of typical specimens of the monzonite porphyry is dense to fine grained; its prevailing color is medium gray, commonly with a faint pinkish cast due to an abundance of potassium feldspar. In some dikes and plugs the groundmass is dark gray, and in others that have been deuterically altered it is various shades of greenish gray to olive green. The weathered surfaces range from tan to brown. Many of the plugs are fresh but are intruded into strongly altered Packard Quartz Latite. Other plugs are surrounded by halos of argillic alteration and are themselves argillized and, thus, may also exhibit all degrees of bleaching from faint discoloration to complete conversion to dazzling white clay in which nearly all of the primary minerals are replaced by kaolinite, halloysite, montmorillonite, and other clay minerals. Outcrops are generally massive and moderately well jointed. Planar structures and lineation features are distinct, and most commonly plunge steeply south-southwest. As a rule, contacts are sharp and locally are marked by zones of intrusion breccia that have served as conduits for hydrothermal solutions.

In thin section the freshest, most typical monzonite porphyry consists of plagioclase, potassium feldspar, biotite, hornblende, augite, and, in some rocks, quartz. The groundmass is holocrystalline; in the larger plutons it commonly is microgranular, but in the smaller plutons, dikes, and sills it is generally aphanitic, and the rock has a trachytic texture. The relative abundance of phenocrystic quartz, augite, biotite, and hornblende differs somewhat from pluton to pluton and, to some extent, within individual plutons, prompting such specific names as augite-biotite monzonite, hornblende-biotite monzonite, or quartz monzonite.



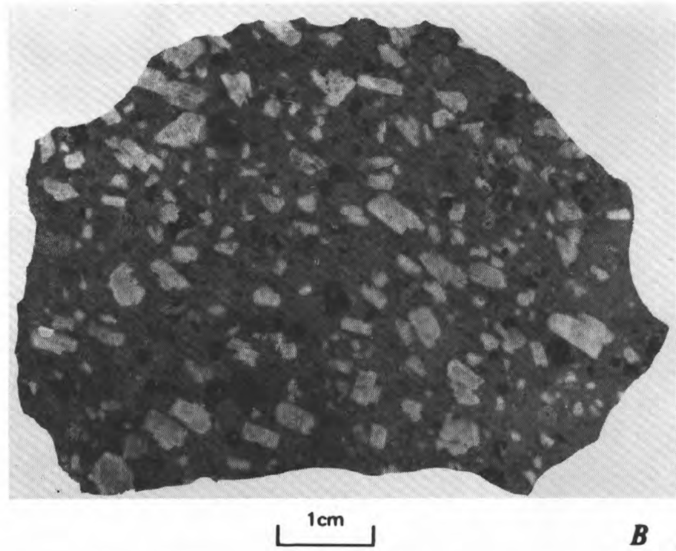


FIGURE 19. — Representative samples from intrusive bodies in East Tintic district: A, Quartz monzonite porphyry from North Hill stock 1,500 ft (457 m) N. 10° W. of North Lily shaft; similar to sample 8, table 5. B, Monzonite porphyry from large plug 1,550 ft (472 m) N. 80° E. of Maple shaft; same as sample 11, table 5. In both samples light phenocrysts are predominantly plagioclase; nearly equidimensional dark phenocrysts are biotite; smaller more acicular phenocrysts in A are hornblende, and some of the dark phenocrysts in both specimens are augite. Quartz phenocrysts in A are rounded and somewhat fractured.

The common occurrence of all of these minerals in many of the intrusive bodies, however, as well as the geologic relations of the bodies and the similarity of their chemical compositions, leaves little doubt that all of them originated from the same parent magma and that they were essentially contemporaneous.

Plagioclase is the most abundant phenocryst, constituting 25 percent or more of most of the plutonic rocks, and is as much as 10 mm long and 5 mm wide, although most are only about half as large. The composition ranges from $An_{38}$ to $An_{55}$. Most of the phenocrysts are surrounded by narrow reaction rims.

Potassium feldspar is greatly subordinate to plagioclase as large phenocrysts but is an abundant constituent, along with quartz, in the groundmass. Most of the phenocrysts are strongly zoned, and many are corroded and partly resorbed.

Quartz occurs as deeply embayed and highly resorbed phenocrysts in nearly all the plutons, but it is present in amounts that are sufficient to classify the rock as a quartz monzonite only in the large plug that crops out 2,000 ft (610 m) north-northwest of the North Lily shaft. It is also surprisingly abundant in the dark-colored monzonite pipe exposed in the railroad cut 1,900 ft (579 m) southwest of the Water Lillie shaft. In many thin sections, the quartz phenocrysts are readily recognized by the fact that they show virtually no deuteric or hydrothermal alteration.

Biotite is ubiquitous, commonly forming 10-20 percent of the monzonitic intrusive rocks and occurring as crystals as much as 3-4 mm in diameter. The prevailing color is yellowish brown in plain light, and the pleochroism formula is X = light brownish yellow and Y = Z = dark reddish brown. Some phenocrysts are moderately resorbed, and many contain chadacrysts of magnetite and apatite.

Hornblende is generally more abundant than augite in all of the plutonic rocks excepting the plug that crops out 3,000 ft (914 m) west-southwest and that which crops out 4,200 ft (1,280 m) south-southwest from the Trixie shaft. Both of these plugs contain little if any hornblende. Most of the hornblende is the common, or green, variety; however, some brown basaltic hornblende occurs with common hornblende in many of the smaller intrusive bodies. Late deuteric alteration has uralitized the hornblende and augite in a number of plugs, particularly the pluton that is 2,000 ft (610 m) northwest of the Trixie shaft, the plug that is 1,900 ft (579 m) southwest of the Water Lillie shaft, and the outermost parts of the Silver City stock.

Augite occurs as pale-green phenocrysts as much as 3 mm long in some hornblende-deficient plutons and more commonly as microscopic granules in the groundmass of the monzonite bodies that contain abundant hornblende and biotite. The larger augite phenocrysts in the plutons in the southwestern part of the district are nearly all partly resorbed, but in other areas they are relatively fresh and unaltered.

Accessory minerals include abundant magnetite, apatite, zircon, and sphene.

Under high magnification the groundmass of the intrusive monzonite is shown to consist of a mosaic of potassium feldspar and quartz anhedrons, with minor amounts of plagioclase feldspar and the ferromagnesian and accessory minerals.

### CHEMICAL COMPOSITION

Analyses of samples collected from 10 of the monzonite porphyry intrusive bodies in the East Tintic district are presented in table 5. Samples 4 and 6 contain unexpectedly large proportions of CaO, MgO, and $CO_2$, suggesting contamination by limestone or dolomite; they probably should be disregarded. The remaining eight samples have an average composition similar to the monzonite of the Silver City stock (samples 15 and 16) except for slightly less $K_2O$ and slightly more CaO and MgO.

The content of $SiO_2$ of the eight relatively uncontaminated samples ranges from 57.67 to 64.04 percent, averaging 60.62 percent. The contents of $K_2O$ and $Na_2O$ are both relatively uniform in all of the analyses, but the variation in the contents of MgO and CaO apparently reflects slight contamination by limestone and dolomite. As compared to the average of the analyses of the flow members of the Pinyon Queen and Tintic Delmar Latites, the monzonite porphyries are somewhat higher in $SiO_2$, $K_2O$, and $Na_2O$ and correspondingly lower in CaO and possibly MgO and total Fe, possibly indicating slightly more advanced differentiation of the intrusive rocks.

The content of normative quartz, orthoclase, and albite + anorthite of the monzonite and quartz monzonite intrusive bodies places all of them in the granodiorite field, close to the quartz monzonite boundary. As compared to the modal composition, these relations suggest a fairly high proportion of $Na_2O$ in the sanidine of both the megascopic phenocrysts and the microcrystals of the groundmass.

### AGE

The ages of two of the monzonite porphyry plutons in the East Tintic district have been determined by the potassium-argon method by Laughlin, Lovering, and Mauger (1969). Biotite from the small plug of fresh monzonite porphyry that cuts argillized Packard Quartz Latite 1,200 ft (366 m) N. 35° W. of the North Lily shaft yielded an apparent age of $34.1 \pm 1.0$ m.y. In comparison, biotite from the larger quartz monzonite pluton 700 ft (213 m) north of it yielded an apparent age of $32.1 \pm 0.9$ m.y. and coexisting hornblende an apparent age of $38.7 \pm 1.9$ m.y. Laughlin, Lovering, and Mauger explained the anomalously old age of the hornblende from the quartz monzonite plug as being due to the incorporation of excess $Ar^{40}$ during crystallization. The exact validity of all of these ages should be questioned, however, inasmuch as they are approximately equivalent to, or older than, the apparent isotopic age of the Packard Quartz Latite ($32.75 \pm 1.0$ m.y.), which had been erupted, deeply eroded, and in part argillized prior to being intruded by the monzonite and quartz monzonite intrusive bodies.

On the basis of the geologic relations, it seems reasonable that the absolute ages of the plutons of the East Tintic district should be more closely compatible with the $31.5 \pm 0.9$-m.y. apparent age of the biotite of the Silver City monzonite stock than with the rocks they intrude. Geologically the age is considered to be middle Oligocene.

### EMPLACEMENT

The intensely shattered wallrocks of the East Tintic plutons, and the abundant xenoliths in some of them, indicate that forceful intrusion as well as stoping was important in their emplacement. The textures of the rocks give ample evidence that the rocks were partly crystallized and highly viscous, suggesting that forceful emplacement was probably dominant. The abundance of pebble dikes (intrusion breccia) further suggests that the monzonite intrusions were accompanied and perhaps aided by phreatic explosions.

### ECONOMIC IMPORTANCE

The north-northeasterly trending fracture zones that guided the emplacement of the monzonite and quartz monzonite intrusive bodies in the East Tintic district also served as the channelways for the hydrothermal solutions that deposited the extensive ore bodies and altered their wallrocks. These solutions began to flow shortly after the consolidation of the Silver City stock and generally flowed in substantial volume only in the general vicinity of the intrusive bodies.

The plutons generally are not cut by ore-bearing fractures, although some ore bodies in the North Lily and other mines are localized in the broken wallrocks of some dikes and plugs (Kildale, 1957, p. 109). In the main Tintic district, however, the monzonite of the Silver City stock is cut by many veins that have produced substantial amounts of ore.

## PEBBLE DIKES

### DISTRIBUTION

Tabular and lens-shaped bodies of intrusion breccia that consist chiefly of rounded pebblelike fragments of quartzite and other rocks in a fine-grained matrix are closely associated with the monzonite dikes and plugs in the East Tintic district (fig. 20). These bodies are especially abundant in the vicinity of the North Lily intrusive center, particularly in a zone extending northeasterly from the area of the Big Hill shaft to central Pinyon Creek Canyon. A second major zone extends northeasterly from the vicinity of the Nevada Tunnel shaft and Silver Pass through the area of the South Standard and Trixie mines to Burriston Canyon. This zone is tangent to the southwestern part of the Zuma intrusive center. A third, less well defined, zone is adjacent to the North Lily zone in the general area that is north, east, and south of the Tintic Standard mine. A few dikes are present outside of these three zones, as for example in central Homansville Canyon and southeast of South Apex Hill, but they are not common.

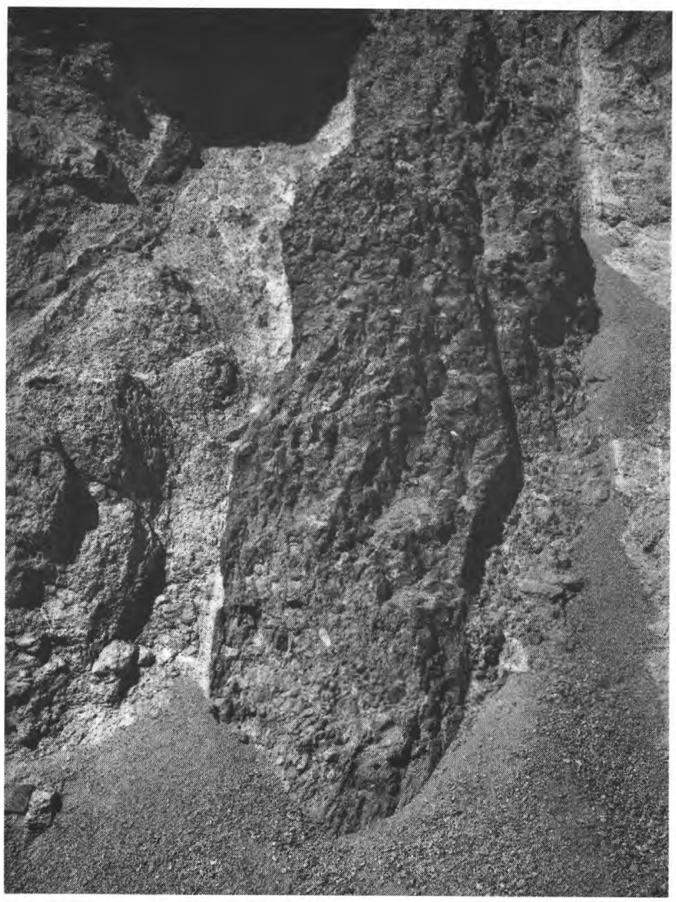


FIGURE 20. — Pebble dike cutting Packard Quartz Latite exposed in a roadcut 1,260 ft (384 m) N. 66° W. of Copper Leaf shaft. Rounded and ovoid pebbles are chiefly quartzite. Note shattered quartz latite and smaller pebble dike in upper left-hand part of photograph. The larger dike is approximately 2.5 ft (0.76 m) wide.

Within the pebble dike swarm that is associated with the North Lily intrusive center, two major, nearly parallel concentrations of dikes are recognized. One of these subzones crosses North Hill and extends to a point beyond the Central Standard shaft. It is locally referred to as the Baltimore fissure zone, named from exposures underground on the Baltimore claim. The other subzone generally extends between the North Lily and Copper Leaf shafts and locally is referred to as the Endline or North Lily dike and fissure zone. The pebble dike zone that extends through the area of the Trixie mine, from which it is named, also consists of two northeast-trending virtually parallel subzones, which crop out on either side of the Trixie and South Standard shafts.

Most of the dikes within all of the zones are easily eroded and commonly are recognized at the surface only by linear trains of quartzite pebbles that occur in the soil above narrow zones of pyritized lava. Some dikes that have been silicified, however, crop out boldly, and one, in particular, near Hidden Treasure Spring northeast of the Tintic Standard mine stands several feet above the enclosing Packard Quartz Latite as a narrow wall. A specimen from this dike is shown in figure 21.


FIGURE 21. Polished slab of silicified pebble dike from exposure 775 ft (236 m) southeast of Hidden Treasure Spring. White areas are kaolinized fragments of shale from Ophir Formation.

### General Characteristics

Most of the bodies of pebble breccia are tabular, ranging in size from half an inch (1.3 cm) to 2 ft (0.6 m) wide and from 5 ft (1.5 m) to more than 1,300 ft (396 m) long. Some have been intermittently followed in mine workings to depths of 1,000 ft (305 m) or more and are believed to extend to far greater depths. A few of the bodies form narrow lenses, but no distinctly pipelike bodies have been found.

Most of the dikes have sharp walls and only rarely have sills or apophyses extending from them. The majority of them occupy steeply dipping fissures and faults that cut the Packard Quartz Latite, but they also extend laterally and downward into the Paleozoic sedimentary rocks, where they locally have been injected along bedding planes.

Some of the pebble dikes apparently rest on the top of monzonite porphyry dikes or merge downward into them; some also are found alongside such dikes, and a few others occur as a selvage at the upper or lower sides of monzonite porphyry sills. Most pebble dikes, however, have no visible contacts with igneous rocks and appear to be isolated lenses within fissures that elsewhere may or may not contain igneous dikes or other lenses of pebble breccia.

Because of the close temporal and spatial relations of the pebble dikes with the monzonite porphyry intrusive bodies, and their localization along the late commonly mineralized north-northeast-trending fissures, many of the pebble dikes are pyritized and silicified, and some locally contain ore. Such altered and weakly mineralized pebble dikes are conspicuously exposed in cuts along Highway 6-50 in the vicinity of the Copper Leaf shaft.

### Lithology and Petrography

The intrusion breccias that characterize most of the pebble dikes consist of densely crowded, smoothly rounded, or slightly faceted pebbles of light-colored fine-grained quartzite and other rocks embedded in a fine-grained matrix of pulverized carbonate rock, quartzite, or quartz latite lava. The pebbles range in diameter from a quarter of an inch (0.6 cm) or less to 10 in. (25 cm) or more, but fragments larger than 4 in. (10 cm) are not common. More than 90 percent are derived from the Tintic Quartzite, and commonly less than 2 percent can be ascribed to overlying units of shale and limestone. Fragments of volcanic rocks and monzonite porphyry are only rarely abundant.

Many of the quartzite pebbles clearly show an onionskin structure, consisting of concentric shells that range in thickness from a millimeter to several centimeters (fig. 22) These shells are small-scale replicas of the exfoliation structures that commonly form on weathered boulders or outcrops of granite or other dense rock. No cement occurs between the shells, and microscopic examination shows only a clean fracture plane between them. Rare pebbles display as many as five or six concentric shells, but most commonly only one to three distinct shells are present.

Pebbles of the other rocks commonly are less rounded than the pebbles of quartzite and do not appear to have moved as far from their source. Pebbles of shale, in particular, are discoidal and do not attain the nearly spheroidal form of the pebbles of the harder, more resistant rocks.

The matrix surrounding the pebbles in the least altered dikes is a rock flour consisting of various proportions of comminuted shale, quartzite, limestone, dolomite, and igneous rock. In the breccias that rest on dikes or envelop sills of monzonite porphyry, the matrix commonly is fine-grained igneous material that gradually merges with pebble-rich monzonite porphyry.

Under the microscope, the typical matrix is seen to consist of unsorted angular fragments of quartzite, quartz phenocrysts, and other rocks and minerals embedded in a limy or argillaceous rock powder. In some thin sections splintery fragments of quartz in the matrix show a pronounced trachytic texture, with their long axes oriented parallel to the walls of the dike or to the sides of adjacent large pebbles.

In all but a few dikes, the limy and argillaceous material is partly to wholly silicified, and near the major mineralized centers, some dikes contain shoots of ore, especially at depths of 1,000-1,500 ft (305-457 m) below the surface, probably reflecting a high porosity caused by the greater angularity of the larger fragments and the relative absence of fine-grained matrix material.

### Origin

As first pointed out by Farmin (1934, p. 364-366), the intimate association of the pebble dikes of the East Tintic district with the monzonite porphyry intrusive bodies leaves little question that they originated during a comparatively late stage in the emplacement of the Silver City stock and related plutons. In addition, the pebble dikes are invariably later than the zones of hydrothermal dolomite in the carbonate rocks, but they are generally contemporaneous with the period of argillization and are unquestionably older than the periods of pyritization, silicification, and ore deposition.

In all of the pebble dikes, the fragments have been derived from formations adjacent to or below the point of observation. In many dikes, unequidimensional pebbles show a marked orientation with the plane of

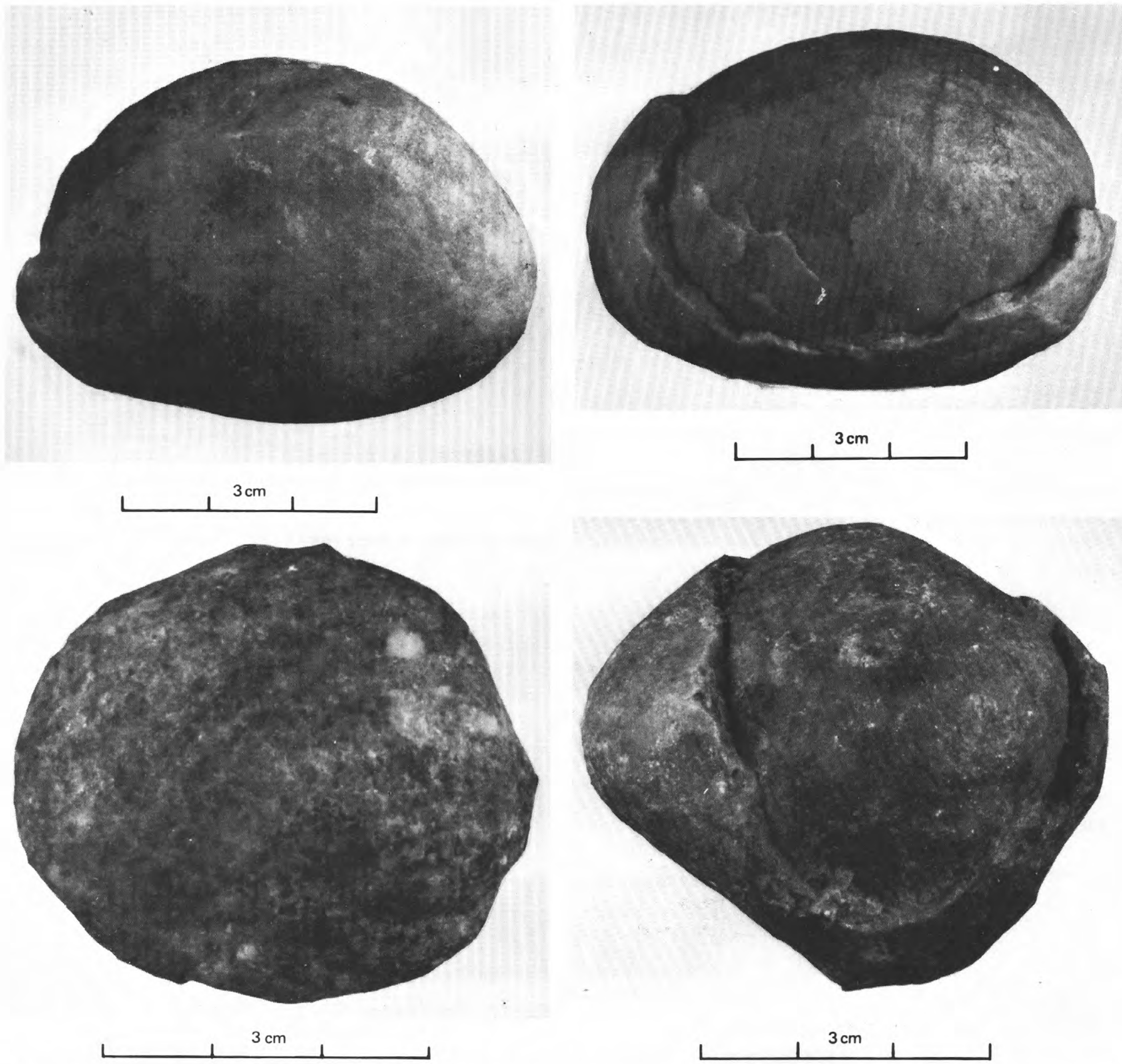



FIGURE 22. — Four quartzite clasts from pebble dike 250 ft (76 m) east of Copper Leaf shaft. Onionskin structure is conspicuous on two of pebbles. Pebble in lower left is from upper Precambrian Mutual Formation, which apparently underlies Tintic Quartzite at depth.

the two longer axes approximately normal to the walls in the central part and parallel to the walls near the dike margins, thus indicating emplacement by forces that acted vertically or at a steep angle, generally up to the northeast.

In general, the evidence suggests that most of the pebble dikes are explosion breccias that originated at substantial depths. They probably were emplaced where superheated steam under high pressure penetrated into the walls and breccias of preexisting faults and fissures, which subsequently opened abruptly, causing an explosive release of steam and water vapor to tear fragments loose from the walls and inject them upward with great violence. Some dikes, however, are believed to represent material that rode on top of quietly upwelling viscous magma or was dragged along the edge of viscous monzonite porphyry dikes and sills.

The onionskin structure of many of the quartzite pebbles is believed to result from the temporary surges of intense heat produced by the phreatic explosions, causing abrupt expansion of the outer parts of the abrasion-rounded quartzite pebbles. Other pebbles, which are composed of minerals with lower coefficients of thermal expansion than quartz, only rarely display similar structure. Successive concentric shells thus indicate emplacement of the dikes by a series of explosions of greater or lesser magnitude than the initial thermal event that first opened the fractures and began to abrade the angular fault breccias into nearly spherical pebbles.

The degree of rounding of the pebbles is, in part, a function of the distance of transport upward from the point of origin. In the deepest mine workings the dikes consist of angular breccias that display little if any rounding. At intermediate levels, the fragments are more rounded, and in the dikes exposed at the surface, nearly spherical pebbles of quartzite make up 50-80 percent of the total volume. The total range of vertical exposure, according to Kildale (1938, p. 56), is 6,000 ft (1,829 m), but the average in the central part of the East Tintic district is 2,000 ft (610 m).

### Economic Importance

The pebble dikes, and the altered fissure and igneous dike zones within which they occur, rank high among the most useful direct and indirect guides to concealed ore deposits. As indicated earlier, many of the dikes at depth contain shoots of ore or occur along faults and fissures that elsewhere contain shoots of ore. In general these ore bodies are narrow and not of economic significance except where they contain high values in gold or silver. However, the areas where the mineralized fissure zones cut thrust faults, cross-breaking faults, or crumpled zones that bring brecciated carbonate rocks against the Tintic Quartzite or other massive units commonly are the sites of major replacement ore bodies. Geochemical exploration has been useful in identifying the fissure zones and pebble dikes that are mineralized at depth.

Pebble dikes also are used to define the geology of the sedimentary rocks beneath the lavas that cover the greater part of the district. The preponderance of pebble dikes in the general vicinity of the Trixie, Tintic Standard, North Lily, and Copper Leaf mines indicates areas where the Tintic Quartzite closely underlies the surficial lavas. In addition, the apparent line of termination of the quartzite-bearing pebble dikes in Pinyon Creek Canyon near the Central Standard shaft marks the general lava-concealed position of the Homansville fault, which may terminate many of the dike-bearing fissures and which brings a thick section of carbonate rocks against the Tintic Quartzite. Similarly the line of termination of the pebble dikes north and northeast of Dividend marks the concealed trace of the East Tintic thrust fault, and the termination of the pebble dike swarm north of the Trixie mine probably marks the concealed position of the Eureka Standard and Trixie faults.

Elsewhere, the presence of shale or limestone in dikes that are preponderantly composed of quartzite indicates the presence of carbonate rocks at depth. Locally, however, such fragments of carbonate rocks and shale could have been derived from the rubble zone beneath the lavas that commonly lies directly on quartzite, as in the area between the Burgin No. 2 and Tintic Standard No. 2 shafts.

## DIKES OF BIOTITE-AUGITE ANDESITE PORPHYRY AND ASSOCIATED INTRUSION BRECCIAS

### General Character and Distribution

Highly altered dikes of biotite-augite andesite porphyry and associated intrusion breccias, locally called the purple porphyry, cut monzonite and quartz monzonite dikes and may even cut ore in the North Lily and possibly the Burgin mine in the East Tintic district and in the Chief No. 1 mine in the main Tintic district. The best surface exposures of these dikes are three-fifths of a mile (1 km) northeast of the Tintic Standard No. 2 shaft; other formerly available exposures about midway between the Burgin No. 1 and No. 2 shafts are now buried by mine dumps. These dikes range in width from 1 in. (2.54 cm) to about 5 ft (1.5 m); they are moderately extensive, but their total length and vertical extent are unknown. In contrast to the monzonite porphyry and pebble dikes, the purple porphyry dikes chiefly trend easterly rather than northeasterly, and they are later than the youngest premineral movements on the faults in which veins are found.

### Lithology and Petrography

In all of the known exposures in the East Tintic district, the purple porphyry dikes are strongly argillized and hematitized. Fresh unaltered dikes of apparently similar composition and age, however, occur near the Leadville fault on the 1,800-ft level of the Chief No. 1 mine in the main Tintic district. This rock is fine-grained porphyry with a well-defined trachytic texture. Examination with a hand lens reveals swarms of white plagioclase phenocrysts 1-3 mm long and scattered crystals of biotite and augite, some of which are 5 mm in diameter. Under the microscope the plagioclase forms ragged lath-shaped crystals with extinction angles that indicate a composition of calcic andesine. No quartz or potassium feldspar was recognized, but these minerals may be significant constituents of the exceptionally fine-grained groundmass as in all other igneous rocks of the district.

The purple porphyry of the North Lily mine consists almost entirely of kaolinite, halloysite, and siderite, which preserve the original trachytic and possibly fragmental texture of the rock. The clay minerals replace the tiny lath-shaped phenocrysts that are identical in size and shape to the andesine phenocrysts of the fresh rock from the Chief No. 1 mine. Siderite and possibly other minerals replace augite and biotite, which apparently were less abundant in the East Tintic district than they are in the main Tintic district. The groundmass is also argillized to kaolinite and halloysite and is liberally flecked with tiny grains of earthy hematite, which gives the rock its prevailing lavender or purplish-red coloration.

In the purple porphyry dikes northeast of the Tintic Standard mine and formerly exposed near the Burgin mine, intrusion breccia predominates over the andesite porphyry. The fragments of this breccia are chiefly angular and consist largely of fine-grained igneous rocks and substantially smaller quantities of Packard Quartz Latite, Tintic Quartzite, and other sedimentary rocks (fig. 23). The groundmass of the intrusion breccia consists of both finely comminuted rock fragments and strongly hematized and argillized andesite porphyry. None of the original minerals is preserved.

#### Age

The biotite-augite andesite dikes and intrusion breccias distinctly cut across the North Lily vein and are themselves weakly replaced by barite, pyrite, and base-metal sulfide minerals. However, their precise relations to ore deposition are unknown; it is possible that they predate even the oldest ore bodies and that their dense clayey character prevented extensive replacement by ore minerals. It is equally possible that they were emplaced during the latter part of the interval when ores were being deposited. This second possibility seems most likely, inasmuch as ores are markedly higher in grade on one side of a purple porphyry dike than the other in both the Chief No. 1 and North Lily mines, suggesting that the dikes may have acted as an impermeable or semipermeable barrier to the latest ore-depositing solutions that were rising from depth.

#### Economic Importance

The restricted occurrence of the purple porphyry dikes to the vicinity of ore bodies is considered to be a useful prospecting guide in the East Tintic district. Such a relation may be entirely coincidental, however, and more specifically related to the greater number of mine workings in ore-bearing areas that would tend to reveal such small and easily concealed features as the highly altered dikes.

## MIOCENE ROCKS

### PINYON CREEK CONGLOMERATE

#### Name and Distribution

Well-bedded semi-indurated conglomerate that disconformably overlies the eruptive rocks of the Laguna Springs Volcanic Group and Packard Quartz Latite and disconformably underlies the Silver Shield Quartz Latite flow in the northeastern part of the East Tintic district is here named the Pinyon Creek Conglomerate. Its type locality is the excellent exposures in the lower reaches of Pinyon Creek Canyon, in the north-central part of sec. 35, T. 9 S., R. 2 W. In this area, beds dipping 10°-15° E. crop out in a cutbank of the canyon for more than 2,000 ft (610 m) and extend for an equal or greater distance eastward into the NW¼ sec. 36, T. 9 S., R. 2 W. An equally conspicuous exposure of the Pinyon Creek Conglomerate is found north of Pinyon Creek Canyon in the railroad cuts and tunnel in the south-central part of sec. 26, T. 9 S., R. 2 W., considered a reference locality, and smaller exposures have been mapped south to Pinyon Creek in secs. 1, 2, and 12, T. 10 S., R. 2 W. The formation has not been recognized in other parts of the East Tintic Mountains but may underlie Quaternary de-

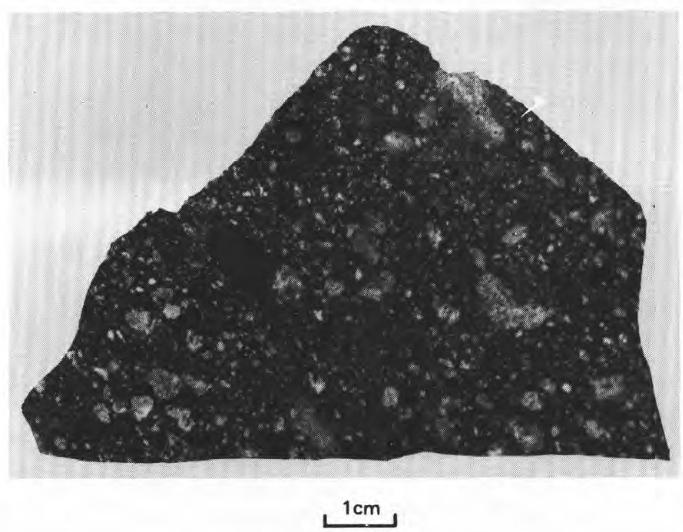



FIGURE 23. — Argillized hematite-stained intrusion breccia from dike 3,150 ft (960 m) N. 50° E. of Tintic Standard No. 2 shaft. Light fragments are chiefly altered Packard Quartz Latite; dark fragments and some matrix material appear to have originally been biotite-augite andesite.

posits, particularly to the north in the Allens Ranch quadrangle.

### Lithology

The Pinyon Creek Conglomerate consists of lenses and beds of subangular to rounded pebbles, cobbles, and boulders that are interlayered with thin and thick beds of silt-, sand-, and grit-sized volcanic debris. Most of the cobbles and boulders were derived from the Laguna Springs Volcanic Group, and only a few percent can be identified as fragments of the Packard Quartz Latite or the Paleozoic sedimentary rocks. Some of the clasts are of altered igneous rocks, but most of them are fresh. The overall color of the formation is grayish tan, but some beds are so dominantly composed of boulders from the Laguna Springs lavas that they appear uniformly reddish or purplish brown or drab gray.

The most characteristic features of the Pinyon Creek Conglomerate are its conspicuous bedding and the great range in the size of its component fragments. On close inspection, the beds that seem to be uniform from a distance are lenslike and cut downward for as much as 3 ft (0.9 m) into the units that underlie them. The individual lenses or beds range in thickness from less than 1 in. (2.5 cm) to 4 ft (1.2 m); the thicker beds are almost invariably composed of cobbles or boulders. Within many individual beds the rock fragments are reasonably well sorted, consisting predominantly of either boulders, cobbles, pebbles, grit, sand, or silt. Other beds are less well sorted and are composed of chaotic mixtures of fragments of all sizes embedded in a matrix of sand, silt, or fine gravel.

In general the Pinyon Creek Conglomerate is not resistant to erosion and weathers into rounded boulder-strewn hills. Such outcrops may be distinguished from similar-appearing alluvial fans of Pleistocene age by the great predominance of volcanic debris as compared with the more heterogeneous composition of the Pleistocene fans.

### Thickness

The Pinyon Creek Conglomerate in the northeastern part of the district appears to partly fill an ancient valley similar to the present canyon of Pinyon Creek. In this area beds with an average dip of about 12° extend over a linear distance of at least 5,000 ft (1,524 m), indicating an apparent thickness of more than 1,000 ft (305 m). In the areas southeast of the Pinyon Creek exposures, the Pinyon Creek Conglomerate is from about 5 ft (1.5 m) to more than 300 ft (91 m) thick and locally is missing.

### Origin and Age

The strongly channeled bedding contacts and the great range in the sizes of the rock fragments in the Pinyon Creek Conglomerate indicate an origin as an alluvial fan or alluvial apron. The generally monolithologic composition indicates a source in nearby outcroppings of the Laguna Springs Volcanic Group, and the relative absence of fragments of Packard Quartz Latite and Paleozoic rocks indicates accumulation prior to the general exposure of these units by erosion.

The age of the Pinyon Creek Conglomerate is known only from its position between the middle Oligocene Laguna Springs Volcanic Group and the middle Miocene Silver Shield Quartz Latite (see p. 62). The occurrence of the scattered fragments of argillized and pyritized latite indicates an age generally younger than the period of hydrothermal alteration and ore deposition. Similarly, the presence of a deeply weathered zone and a fossil soil beneath the Silver Shield Quartz Latite flow indicates a period of erosion and weathering prior to the eruption of the Silver Shield lavas. On the basis of these relations, the best dating possible is considered to be early Miocene.

### Economic Importance

The Pinyon Creek Conglomerate is not known to contain either primary ore bodies or placer accumulations of detrital minerals.

## SILVER SHIELD QUARTZ LATITE

### Name and General Features

The youngest volcanic rocks in the East Tintic district consist of a wide dike and an associated flow unit of quartz latite; they are here named the Silver Shield Quartz Latite from exposures in the general vicinity of the Silver Shield (Independence) shaft in the northeastern part of the Eureka quadrangle. The type locality is in the SE¼ sec. 35, T. 9 S., R. 2 W., and the adjacent parts of secs. 1 and 2, T. 10 S., R. 2 W. SLBM. Previously, this name has been used informally in reference only to the dike (Laughlin and others, 1969, p. 917) but here is applied formally to both the dike and flow unit. The dike crops out boldly, locally standing 50-75 ft (15-23 m) above the general elevation of the Packard Quartz Latite, which it intrudes (fig. 24). It is characterized by a well-defined planar structure that strikes parallel to its walls and dips 70°-80° S. In the zone where the dike merges with the Silver Shield flow unit, the dip of planar

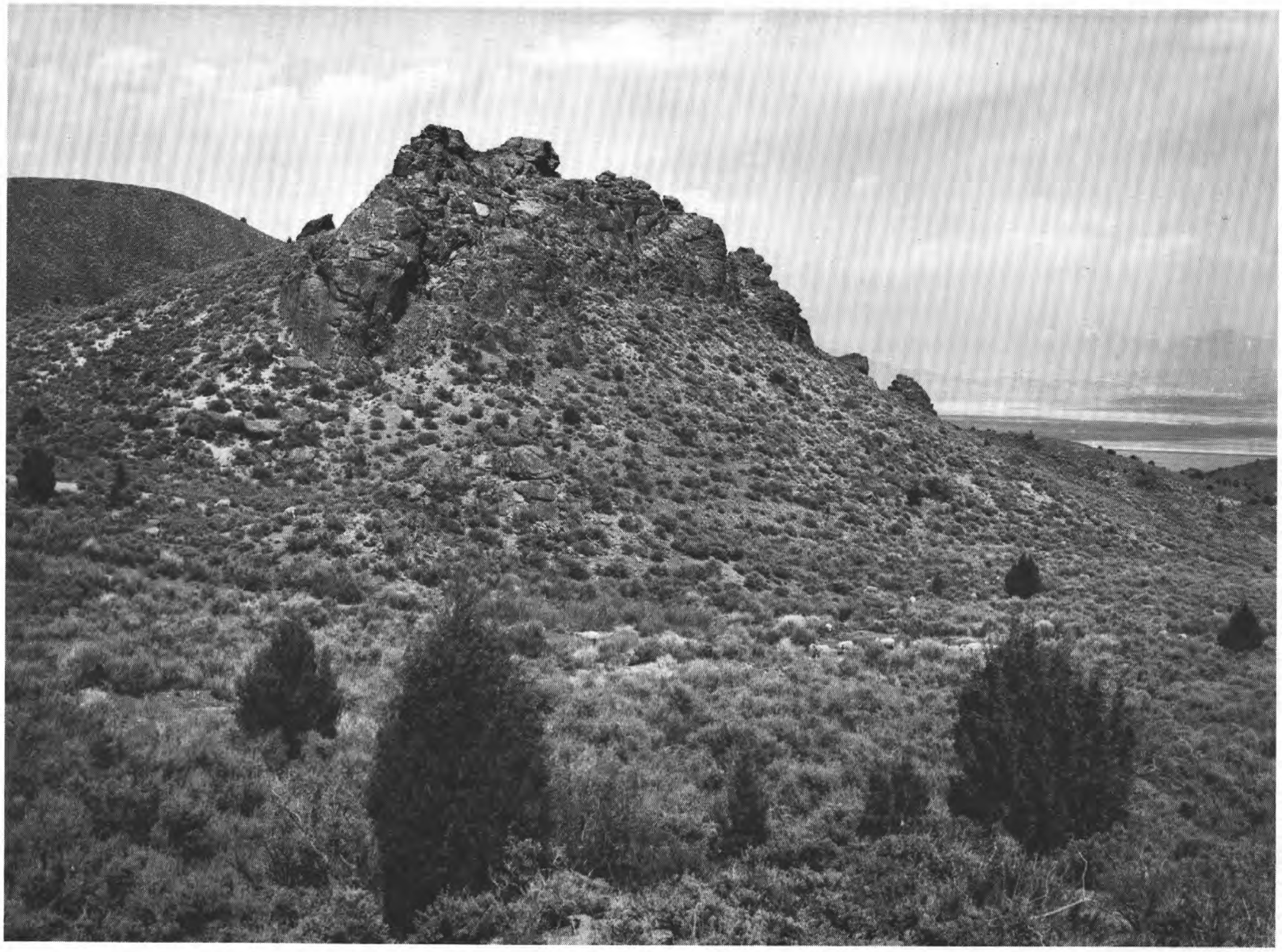


FIGURE 24. — Outcrop of Silver Shield Quartz Latite dike 1,600 ft (488 m) N. 75° W. of Silver Shield (Independence) shaft. Dike is about 135 ft (41 m) wide at the crest of ridge where it cuts Packard Quartz Latite.

structure abruptly flattens to 20° or less, and the strike changes from approximately N. 65° E. to approximately N. 5° W. The area of transition from dike to flow is also characterized by the presence of elongated vesicles that probably originated by the unmixing of dissolved gases when the molten magma underwent a drop in pressure as it erupted at the surface.

### Distribution and Relations to Other Units

The Silver Shield dike is about 1½ mi (2.4 km) long, extending nearly due eastward from a point about 2,100 ft (640 m) west-northwest of the Silver Shield (Independence) shaft to a point 6,150 ft (1,874 m) east-northeast of the shaft, near the east margin of the range. It ranges in width from less than 25 ft (7.6 m) to more than 300 ft (91 m) and apparently was localized by a zone of tensional fractures. In addition to the Packard Quartz Latite and underlying rocks, the Silver Shield dike also cuts the Pinyon Creek Conglomerate, which underlies the Silver Shield flow in most areas of its exposure.

The remnants of the once-extensive flow unit that originally connected with the Silver Shield dike are preserved as five flatiron-like exposures along the east edge of the district. Four of these flatirons directly overlie the Pinyon Creek Conglomerate, but the southernmost flatiron rests on the Packard Quartz Latite and the air-fall and welded tuffs of the Latite Ridge Latite. Fossil soil horizons underlying the basal contact of the Silver Shield flow unit, as well as pipe vesicles and other features, confirm the origin as an eruptive lava flow rather than a sill.

The original thickness of the flow is unknown; the remnants, however, are 7-125 ft (2-38 m) thick. The only deposits that overlie the Silver Shield flow are alluvium, colluvium, and lacustrine gravels of Pleistocene age.

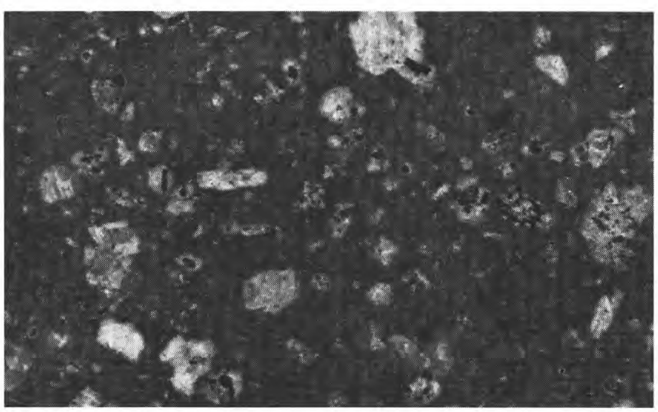
### Lithology and Petrography

The quartz latite of the Silver Shield dike and flow is medium to dark gray and coarsely porphyritic (fig. 25).

Large phenocrysts, ranging in length from 5 to 15 mm and in width from 2 to 10 mm, make up from 25 to 30 percent of the rock. They consist of approximately 55 percent plagioclase, 20 percent quartz, 10 percent each biotite and augite, and 4 percent or less potassium feldspar. Accessory minerals include hypersthene, apatite, zircon, sphene, and as much as 1 percent magnetite. The plagioclase phenocrysts show a distinct tendency to clump, commonly producing irregular rosettes. Extinction angles of albite and combined Carlsbad and albite twin planes of the plagioclase phenocrysts indicate that it is andesine, with a general composition of $An_{45}$. Some of these phenocrysts show narrow reaction rims, indicating disequilibrium with the groundmass, probably at the time of eruption.

Although they are relatively few in number, the potassium feldspar crystals commonly form the largest phenocrysts in most specimens of the dike and flow. Some of these phenocrysts are exceptionally clear, not unlike quartz in general appearance, and nearly all are marked by wide reaction rims, although a few are corroded and embayed.

Biotite and augite both occur as large- and intermediate-sized euhedral phenocrysts. The biotite crystals are strongly pleochroic from X = light yellowish brown to Y = Z dark brownish red. Some of the largest biotites are crowded with exsolved grains of magnetite and are moderately resorbed. The augite phenocrysts are commonly 5 mm long and are the least altered and least resorbed minerals in the rock. Hypersthene is present as scattered large phenocrysts and somewhat more abundantly as small phenocrysts but is greatly subordinate to the other mafic minerals.



1 cm

FIGURE 25. — Silver Shield Quartz Latite from flow unit exposed in railroad cut 2,200 ft (671 m) southeast of mouth of Pinyon Creek Canyon. Light phenocrysts include quartz (rounded, medium gray, fractured), sanidine (rectangular, medium gray, unfractured), and plagioclase (light gray to white). Dark phenocrysts visible in photograph are predominantly biotite. Same as sample 1, table 6.

Large rounded and fractured grains of clear quartz are a distinctive feature of the rock. They are readily identified in both thin sections and hand specimens by the absence of alteration products.

The groundmass minerals range in length from a few tenths of a millimetre to minute crystals that are below the power of resolution. Staining techniques indicate a high proportion of potassium feldspar, presumably intergrown with quartz. Biotite and augite are also common.

### Chemical Composition

Chemical analyses of selected samples from the Silver Shield dike and flow are shown in table 6, and a plot of the ratios of their normative quartz-orthoclase-albite + anorthite is presented in figure 26. The compositional differences between the two specimens, particularly the higher $SiO_2$ and $K_2O$ content and the lower $Al_2O_3$, CaO, $Na_2O$, and total iron content of the dike sample, probably represent differences in the relative amounts of quartz, plagioclase, and magnetite phenocrysts in the coarsely porphyritic samples that were analyzed and not fundamental differences in the composition of the two closely related bodies. It is not known which of the two analyses is most typical of the Silver City Quartz Latite as a whole, but on the basis of the general characteristics of the two samples as seen under the microscope, the dike rock is assumed to be most characteristic.

As shown in table 6, the composition of the Silver Shield dike is reasonably close to the average composition of the Packard Quartz Latite. The most notable exceptions are the relatively higher $Na_2O$ content and the relatively lower CaO content of the Silver Shield dike; the Packard also contains slightly more $Al_2O_3$ and less $K_2O$ and total iron. As compared to the average dellenite (quartz latite), the Silver Shield dike contains significantly less $Na_2O$ and somewhat less MgO, CaO, and $TiO_2$, which is probably attributable to the abundance of augite in the Silver Shield. Despite these differences, the contents of $SiO_2$, $Al_2O_3$, and $K_2O$ in the Silver Shield dike are approximately equal to those of the average quartz latite.

The minor-element contents of the dike and flow rocks are generally similar to the Packard Quartz Latite and the lavas of the Laguna Springs Volcanic Group.

TABLE 6. — *Chemical analyses, CIPW norms, Niggli values, and spectrochemical analyses of selected samples of the Silver Shield Quartz Latite and rocks of similar composition.*

| Sample No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Rock unit | Flow unit, Silver Shield Quartz Latite | Dike, Silver Shield Quartz Latite | Average Packard Quartz Latite | Average of 58 dellenites (Nockolds, 1954) |
| Laboratory No. | M110 360W | D102254 | | |
| **Chemical analyses (weight percent)** | | | | |
| $SiO_2$ | 63.9 | 70.58 | 69.90 | 70.15 |
| $Al_2O_3$ | 15.4 | 13.97 | 14.46 | 14.41 |
| $Fe_2O_3$ | 3.6 | 2.20 | 1.84 | 1.68 |
| FeO | 1.3 | .72 | .63 | 1.55 |
| MgO | 1.2 | .59 | .53 | .63 |
| CaO | 3.6 | 1.52 | 2.06 | 2.15 |
| $Na_2O$ | 3.9 | 3.59 | 2.87 | 3.65 |
| $K_2O$ | 4.5 | 4.97 | 4.74 | 4.50 |
| $H_2O+$ | .60 | .29 | 1.55 | .68 |
| $H_2O-$ | .70 | .22 | .42 | ... |
| $TiO_2$ | 1.1 | .62 | .36 | .42 |
| $P_2O_5$ | .52 | .12 | .13 | .12 |
| MnO | .08 | .05 | .05 | .06 |
| $CO_2$ | .06 | .20 | .07 | ... |
| Cl | ... | .01 | .02 | ... |
| F | ... | .11 | .05 | ... |
| S | ... | .02 | .02 | ... |
| Subtotal | ... | 99.78 | ... | ... |
| Less 0 | ... | .06 | ... | ... |
| Total | 100.00 | 99.72 | 99.72 | 100.00 |
| **CIPW norms (weight percent)** | | | | |
| Q | 16.87 | 28.00 | 31.00 | 26.39 |
| C | ... | .96 | 1.20 | ... |
| or | 26.82 | 29.59 | 28.72 | 26.79 |
| ab | 33.28 | 30.53 | 24.90 | 31.12 |
| an | 11.32 | 4.80 | 9.61 | 9.72 |
| Normative An | ($An_{25}$) | ($An_{27}$) | ($An_{28}$) | ($An_{24}$) |
| (di) wo | 1.23 | ... | ... | .10 |
| (di) en | (2.29) 1.06 | ... | ... | (.19) .06 |
| (di) fs | ... | ... | ... | .03 |
| (hy) en | (1.95) 1.95 | (1.48) 1.48 | (1.35) 1.35 | (2.26) 1.52 |
| (hy) fs | ... | ... | ... | .74 |
| mt | 1.27 | .62 | 1.01 | 2.45 |
| hm | 2.75 | 1.79 | 1.19 | ... |
| il | 2.11 | 1.19 | .70 | .80 |
| ru | ... | ... | ... | ... |
| ap | 1.22 | .29 | .32 | .29 |
| cc | .14 | .46 | ... | ... |
| Total | 100.02 | 99.71 | 100.00 | 100.01 |
| Salic/femic ratio | 7.52 | 15.49 | 20.88 | 15.68 |
| Diff. index | 76.97 | 88.12 | 84.62 | 84.30 |
| **Niggli values** | | | | |
| Al | 35.96 | 41.81 | 44.30 | 41.02 |
| Fm | 22.40 | 16.15 | 14.04 | 16.90 |
| C | 15.28 | 8.27 | 11.47 | 11.13 |
| Alk | 26.36 | 33.77 | 30.18 | 30.95 |
| Si | 253.21 | 358.44 | 363.39 | 338.83 |
| Ri | 3.28 | 2.37 | 1.41 | 1.53 |
| P | .86 | .26 | .29 | .25 |
| K | .43 | .48 | .52 | .45 |
| Mg | .32 | .28 | .29 | .27 |
| Si' | 205.42 | 235.09 | 220.73 | 223.82 |
| Qz | 47.79 | 123.35 | 142.67 | 115.02 |
| **Spectrochemical analyses[1] (parts per million)** | | | | |
| Ba | 1,500 | 1,000 | ... | ... |
| Be | 2 | 5 | ... | ... |
| Ce | 300 | 200 | ... | ... |
| Co | 10 | 5 | ... | ... |
| Cr | 3 | 2 | ... | ... |
| Cu | 2 | 2 | ... | ... |
| Ga | 20 | 50 | ... | ... |
| La | 150 | 200 | ... | ... |
| Mo | 5 | 5 | ... | ... |
| Nb | 50 | 20 | ... | ... |
| Nd | 150 | 150 | ... | ... |
| Pb | 20 | 30 | ... | ... |
| Sc | 10 | 10 | ... | ... |
| Sr | 1,000 | 500 | ... | ... |
| V | 70 | 50 | ... | ... |
| Y | 50 | 70 | ... | ... |
| Yb | 3 | 5 | ... | ... |
| Zr | 500 | 200 | ... | ... |

[1]Also looked for and not detected at limit of detection, or detected but below limit of determination: Ag, As, Au, B, Bi, Cd, Eu, Ge, Hf, Hg, In, Li, Ni, Pd, Pt, Re, Sb, Sm, Sn, Ta, Te, Th, Tl, Pr, U, W, and Zn.

1. Quartz latite, upper part of Silver Shield flow unit exposed in railroad cut 8,350 ft (2,545 m) N. 43½° E. from Independence shaft. Chemical analysis performed in the Rapid-Rock Analysis Laboratory under Leonard Shapiro; spectrochemical analysis by Chris Heropoulos, U.S. Geological Survey.
2. Quartz latite, central part of Silver Shield dike 720 ft (220 m) N. 10° W. from Independence shaft. E. E. Engleman, chemical analyst; L. A. Bradley, spectrochemical analyst, U.S. Geological Survey.
3. Average of seven analyses of Packard Quartz Latite; analysis 8, table 1.
4. Average of 58 dellenites (quartz latites) and dellenite obsidians (Nockolds, 1954, p. 1014).

## AGE AND ERUPTIVE HISTORY

Both the Silver Shield dike and Silver Shield flow have been dated by the potassium-argon method, and the closely similar results indicate a middle Miocene age (Laughlin and others, 1969, p. 916). Biotite separated from the dike yielded an isotopic age of 17.9 ± 0.5 m.y., and potassium feldspar from the porphyritic flow rock an apparent age of 18.3 ± 0.5 m.y. A check determination on a second separate of potassium feldspar from the flow unit yielded an apparent age of 15.9 ± 2.6 m.y. According to Laughlin, Lovering, and Mauger (1969, p. 916), the relatively large range in the analytical uncertainty of the second sample results from a high correction for atmospheric $^{40}Ar$, and they concluded that the age is about 18 m.y.

As compared to other volcanic rocks in the east-central Great Basin, the Silver Shield dike and flow are unusual for their middle Miocene age, their intermediate composition, and the abruptness of their eruption after a period of volcanic quiescence of approximately 13 m.y. As shown recently by Lipman, Prostka, and Christensen (1970) and Christensen and Lipman (1970), volcanism in the Basin and Range province changed in early and middle Miocene time from predominantly calc-alkaline andesitic eruptive rocks and related, but more siliceous, ash flows to fundamentally basaltic eruptive rocks. This change was coincident with the development of Basin and Range faults. A plot of the isotopic ages of volcanic and intrusive rocks in this province further indicates that the intermediate rocks of early Cenozoic age achieved a maximum in early Oligocene time and that during the early and middle Miocene, including the time when the intermediate Silver Shield Quartz Latite was emplaced, relatively few volcanic rocks were being erupted. On the basis of the present evidence, it is not possible to explain the resumption of volcanic activity in the East Tintic dis-

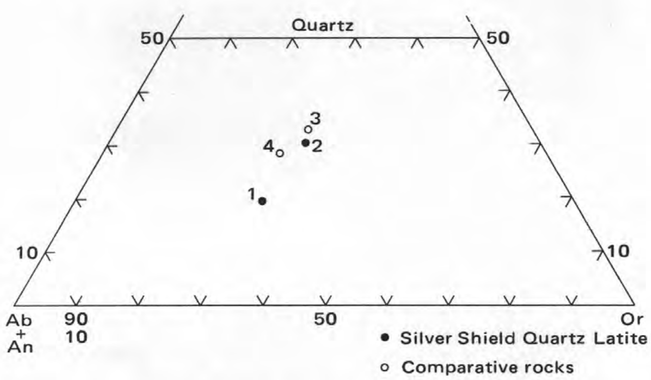



FIGURE 26. — Plot of normative quartz-orthoclase-albite + anorthite of selected samples of the Silver Shield Quartz Latite flow unit and dike and comparative rocks.

trict after a long period of quiescence, especially during a period when few volcanic rocks were being erupted in adjacent areas, or to account for the eruption of quartz latite lava at the beginning of a general era of basaltic eruptions.

### Economic Importance

Underground exploration from the Silver Shield (Independence) shaft has disclosed small amounts of base-metal and silver ores in Paleozoic rocks that are not far from the south margin of the Silver Shield dike (R. T. Walker and Paul Billingsley, written commun.) Extensive drifting along the contact of the dike and the sedimentary rocks and within the dike itself, however, failed to disclose ore bodies of any consequence. Recent drilling by the Bear Creek Mining Co. near the west end of the dike also has failed to disclose any direct indications of ore, although some pyritic alteration of uncertain origin was found in several of the drill holes not far from the dike.

At the surface, particularly in the general vicinity of the East Standard shaft, large masses of the Packard Quartz Latite have been replaced by opaline silica, a feature that may be related to the emplacement of the Silver Shield dike. This correlation is by no means assured, inasmuch as older latite plugs and dikes also crop out in the same general area. This opaline silica, however, is apparently barren of ore metals.

## CHEMISTRY AND GENESIS OF THE IGNEOUS ROCKS

The chemical compositions of the Oligocene igneous rocks of the East Tintic Mountains indicate that they probably are the differentiates of a single magma, originally of granodioritic or more basic character. In table 7 the average compositions of samples of volcanic and intrusive units are presented in order of decreasing age. Norms computed from the average analyses indicate normative compositions ranging from rhyolite to rhyodacite (fig. 27). No rocks as mafic as andesite are known despite earlier descriptions by Tower and Smith (1899, p. 638-643) and Lindgren and Loughlin (1919, p. 57).

$SiO_2$ variation diagrams (fig. 28) prepared from the analyses presented in table 7 are characterized by relatively wide scatter and interrupted linear trends, suggesting irregular changes in magma composition with time. An alkali-lime index of approximately 58 may be estimated (fig. 29), indicating that the rocks are calc-alkalic in character. The oldest rocks are high in silica and low in iron, calcium, and magnesia, suggesting probable differentiation prior to the initial eruptions. The silica content of the younger rocks has a moderately wide range, probably reflecting continued differentiation after the initial eruptions, or possibly the mixing of separate pockets of magma.

Triangular variation diagrams that illustrate the ratios of $K_2O$-$Na_2O$-CaO and alkalies-total iron-MgO are presented in figures 30 and 31 along with similar ratios from the average rhyolite, dacite, andesite, basaltic andesite, and basalt from the well-studied differentiation sequence of the Cascade province (Carmichael, 1964, p. 451). In such diagrams, smooth curves are believed to represent lines of magmatic evolution that produce a continuous series of related magmatic liquids (Nockolds and Allen, 1953, p. 106). As might be anticipated, the East Tintic data show considerable scatter; despite this, however, it may be noted that, as compared to the Cascade lavas, the equivalent East Tintic rocks contain proportionately greater amounts of $K_2O$ and Fe, and less $Na_2O$ and MgO.

A third useful variation diagram (fig. 32) is a plot of the molecular ratio of $K_2O$ to $K_2O + Na_2O$ — Niggli's "k" ratio — against silica. In this diagram, which was originally proposed by Merriam and Anderson (1942, p. 1723-1725), "k" equals 0.4 when the weight percent of $K_2O$ and $Na_2O$ in a particular rock are equal. When "k" is higher than 0.4, the weight percent of $K_2O$ exceeds that of $Na_2O$. As might be anticipated, most of the East Tintic igneous rocks equal or exceed 0.4; the notable exceptions are the Big Canyon Latite and the monzonite porphyry plugs and dikes. For comparison the "k" ratios are shown for basaltic andesite, andesite, and dacite of the Cascade province. These ratios emphasize the enrichment in $K_2O$ of the East Tintic rocks as compared to Cascade rocks of similar $SiO_2$ content.

As noted by Merriam and Anderson (1942, p. 1725), "k" ratios ranging from 0.4 to 0.6 or higher are typical of east-central Nevada, western Utah, and parts of New Mexico. In contrast, the "k" ratios of the volcanic rocks of western Nevada range from 0.3 to 0.5, decreasing to 0.3 to 0.4 or less in California and 0.1 to 0.4 in the Cascade province. In a more recent paper, Moore (1962) showed the area of potassium enrichment to be much broader, underlying east-central Nevada, all of Utah except the northwestern corner, northeastern Arizona, most of western New Mexico, central and northwestern Colorado, western Wyoming, and central Montana. Moore believed that the igneous rocks acquired their high $K_2O$ content from the crust in which they were formed, which unlike the area nearer the Pacific Coast, contains a high proportion of granite and granodiorite. This crust is assumed to be the highly differentiated sialic layer that underlies the continent, a conclusion that is partly confirmed by the remarkable coincidence of the potassium-rich area and the areas

TABLE 7.—*Average chemical compositions and CIPW norms of Oligocene igneous rocks in the East Tintic Mountains*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Packard Quartz Latite | Swansea Quartz Monzonite | Copperopolis Latite | Latite Ridge Latite | Big Canyon Latite | Monzonite porphyry of Gough sill | Sunrise Peak Monzonite Porphyry | Pinyon Queen Latite | Tintic Delmar Latite | Monzonite porphyry of East Tintic district | Monzonite of Silver City stock |
| | | | | | **Chemical compositions (weight percent)** | | | | | | |
| $SiO_2$ | 69.90 | 70.08 | 61.05 | 63.90 | 57.70 | 60.40 | 58.22 | 59.12 | 59.70 | 60.62 | 60.56 |
| $Al_2O_3$ | 14.46 | 15.01 | 18.60 | 17.12 | 16.10 | 17.07 | 15.68 | 15.41 | 15.40 | 15.66 | 15.87 |
| $Fe_2O_3$ | 1.84 | 1.66 | 3.15 | 3.75 | 4.80 | 5.66 | 3.41 | 5.50 | 4.60 | 4.57 | 3.66 |
| FeO | .63 | .57 | .90 | .45 | 3.40 | .33 | 3.17 | 1.74 | 2.50 | 1.81 | 2.87 |
| MgO | .53 | .69 | .87 | .85 | 2.80 | 1.40 | 2.75 | 2.88 | 3.10 | 2.64 | 2.19 |
| CaO | 2.06 | 1.12 | 4.55 | 1.40 | 5.70 | 4.03 | 4.03 | 5.79 | 5.90 | 4.35 | 4.17 |
| $Na_2O$ | 2.87 | 2.96 | 3.55 | 3.68 | 3.10 | 3.30 | 3.10 | 2.94 | 3.10 | 3.57 | 3.27 |
| $K_2O$ | 4.74 | 5.69 | 4.85 | 6.25 | 2.90 | 4.70 | 4.72 | 2.95 | 3.00 | 3.36 | 4.15 |
| $H_2O+$ | 1.55 | .75 | .85 | .97 | .60 | .90 | 1.71 | 1.08 | 1.40 | .89 | .88 |
| $H_2O-$ | .42 | .25 | .65 | .78 | .91 | 1.30 | .20 | .74 | .36 | .71 | .24 |
| $TiO_2$ | .36 | .41 | .87 | .79 | 1.10 | .86 | .86 | .97 | .94 | .92 | .85 |
| $P_2O_5$ | .13 | .12 | .35 | .28 | .44 | .45 | .39 | .36 | .35 | .36 | .38 |
| MnO | .05 | .07 | .09 | .15 | .08 | .11 | .14 | .11 | .12 | .10 | .11 |
| $CO_2$ | .07 | .01 | .05 | .04 | .01 | .13 | 1.36 | .07 | .08 | .12 | .53 |
| Cl | .02 | .02 | .......... | .01 | .......... | .......... | .02 | .04 | .......... | .03 | .04 |
| F | .05 | .05 | .......... | .17 | .......... | .......... | .12 | .09 | .......... | .10 | .10 |
| S | .02 | .01 | .......... | .01 | .......... | .......... | .02 | .02 | .......... | .02 | .02 |
| Subtotal | 99.70 | 99.47 | .......... | 100.60 | .......... | .......... | 99.90 | 99.81 | .......... | 99.83 | 99.89 |
| Less O | .04 | .03 | .......... | .08 | .......... | .......... | .06 | .06 | .......... | .06 | .06 |
| Total | 99.66 | 99.44 | 100.38 | 100.52 | 101.00 | 100.64 | 99.84 | 99.75 | 101.00 | 99.77 | 99.83 |
| | | | | | **CIPW norms (percent)** | | | | | | |
| Q | 31.00 | 28.48 | 11.87 | 15.15 | 14.28 | 14.03 | 14.04 | 16.54 | 15.89 | 15.50 | 15.54 |
| C | 1.20 | 2.27 | 1.91 | 2.51 | .......... | .60 | 2.54 | .......... | .......... | .......... | .56 |
| or | 28.72 | 34.20 | 28.55 | 36.78 | 17.46 | 27.60 | 28.46 | 17.49 | 17.95 | 19.92 | 24.59 |
| ab | 24.90 | 25.48 | 29.93 | 31.01 | 26.73 | 27.75 | 26.62 | 24.96 | 26.55 | 30.31 | 27.75 |
| an | 9.61 | 4.85 | 19.89 | 4.84 | 21.86 | 16.13 | 8.39 | 20.21 | 19.48 | 16.84 | 14.90 |
| di | .......... | .......... | .......... | .......... | 3.11 | .......... | .......... | 4.52 | 5.70 | 1.32 | .......... |
| hy | 1.35 | 1.75 | 2.16 | 2.11 | 6.27 | 3.47 | 8.83 | 5.10 | 5.17 | 5.99 | 6.52 |
| mt | 1.01 | .66 | .67 | .......... | 7.09 | .......... | 5.05 | 3.17 | 5.79 | 3.51 | 5.32 |
| hm | 1.19 | 1.23 | 2.68 | 3.74 | .......... | 5.62 | .......... | 3.34 | .66 | 2.17 | .......... |
| il | .70 | .79 | 1.65 | 1.27 | 2.13 | .93 | 1.67 | 1.85 | 1.81 | 1.75 | 1.62 |
| ru | .......... | .......... | .......... | .12 | .......... | .37 | .......... | .......... | .......... | .......... | .......... |
| ap | .32 | .29 | .83 | .66 | 1.06 | 1.06 | .94 | .86 | .84 | .86 | .90 |
| cc | .......... | .......... | .11 | .09 | .02 | .29 | 3.16 | .16 | .18 | .27 | 1.21 |
| Total | 100.00 | 100.00 | 100.25 | 98.28 | 100.01 | 97.85 | 99.70 | 98.20 | 100.00 | 98.44 | 98.91 |
| Diff. index | 84.62 | 88.16 | 70.35 | 82.94 | 58.48 | 69.37 | 69.12 | 59.00 | 60.38 | 65.72 | 67.88 |

1. Average of seven samples from East Tintic district.
2. One sample from main Tintic district.
3. Average of two samples from main Tintic district.
4. Average of two samples from East Tintic district.
5. One sample from East Tintic district.
6. Average of three samples from Tintic and East Tintic districts.
7. One sample from main Tintic district.
8. Average of three samples from East Tintic and North Tintic districts.
9. One sample from North Tintic district.
10. Average of eight samples from East Tintic district.
11. Average of two samples from main Tintic district.

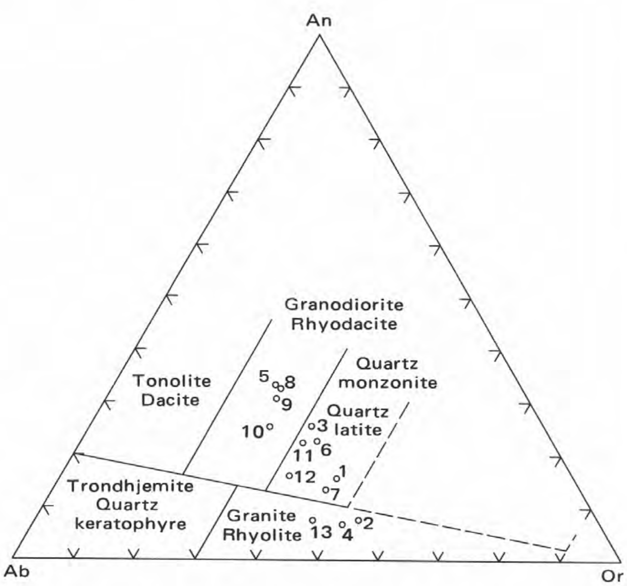



FIGURE 27. — Ternary diagram showing the normative feldspar content of averaged igneous rocks of the East Tintic Mountains. Samples 1-11 are from table 7; samples 12 and 13 are the same as samples 1 and 2 of table 6. Fields are from O'Connor (1965).

of gravity lows that are shown on a Bouguer gravity map of the western United States (Moore, 1962, p. 109).

Within the limitations imposed by the geologic and mineralogic features, the chemical compositions, and the chemical trends of the igneous rocks of the East Tintic district, some tentative conclusions may be drawn as to their origin and evolution.

Volcanism was initiated abruptly in early middle Oligocene time when the Packard Quartz Latite was deposited over a surface of mature relief that had been carved by erosion into the folded and faulted Paleozoic rocks. The uniform texture of the Packard from base to top indicates that it was emplaced nearly continuously during a short interval of time, and its thickness and the wide distribution of its correlative units further indicate that a volume approaching 15-30 cubic miles (62.6-125 $km^3$) was erupted. A caldera apparently was formed as a consequence of these eruptions. The comparatively high silica and potassium content of the Packard, and the chemical trend lines of the East Tintic volcanic rocks, indicate that it is probably a differentiate of a more basic magma that

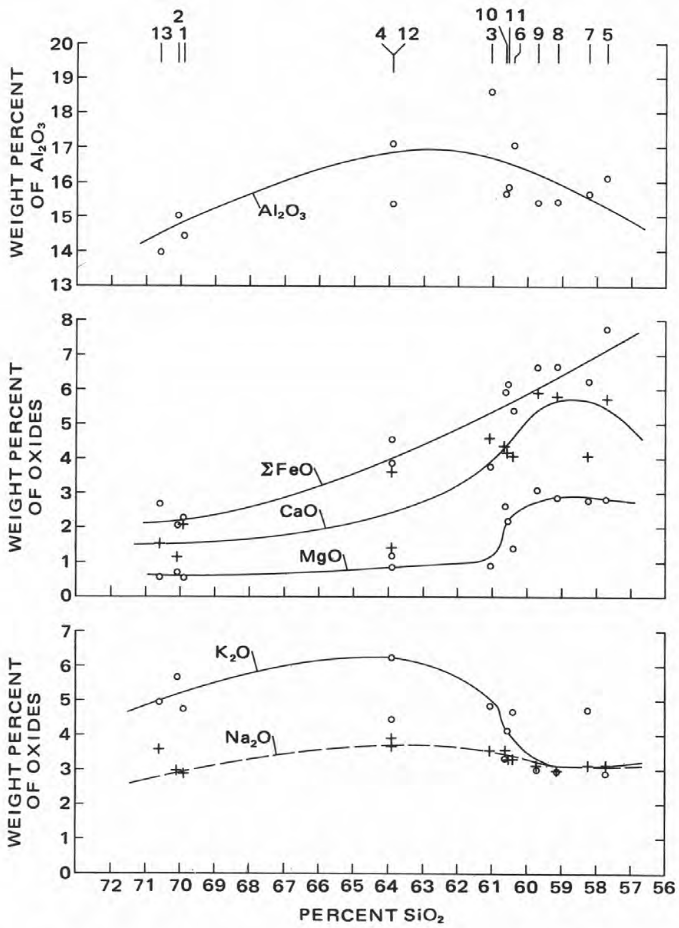



FIGURE 28. — $SiO_2$ variation diagram of averaged igneous rocks of the East Tintic Mountains; sample numbers are at top; samples 1-11 are from table 7; samples 12 and 13 are the same as samples 1 and 2 of table 6. All iron summed as FeO.

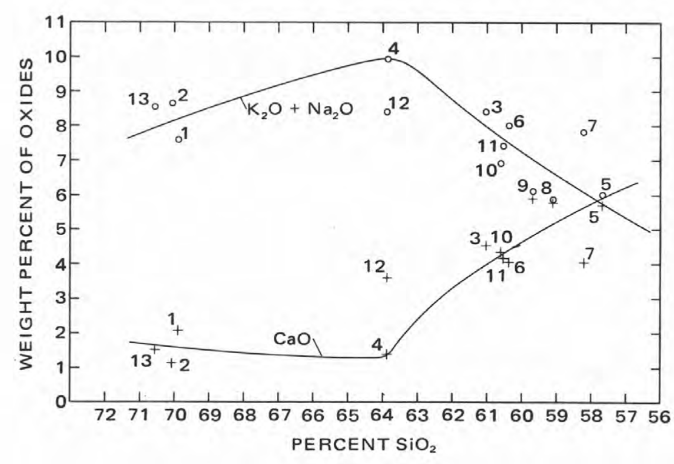



FIGURE 29. — Plot of $K_2O$ + $Na_2O$ and CaO against $SiO_2$, indicating an alkali-lime index of approximately 58 for the igneous rocks of the East Tintic Mountains. Samples 1-11 are from table 7; samples 12 and 13 are the same as samples 1 and 2 of table 6.

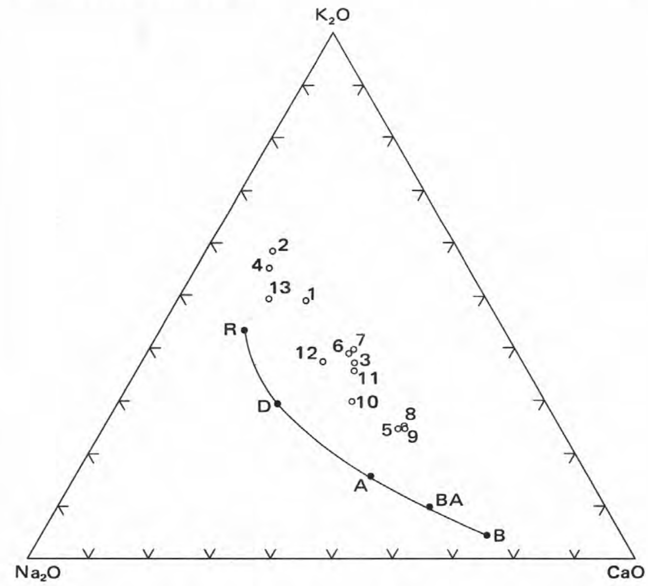



FIGURE 30. — Ternary diagram of $K_2O$, $Na_2O$, and CaO in the igneous rocks of the igneous rocks of the East Tintic Mountains. Samples 1-11 are from table 7; samples 12 and 13 are the same as samples 1 and 2 in table 6. Closed circles show rhyolite (R), dacite (D), andesite (A), basaltic andesite (BA), and basalt (B) from the Cascade province (Carmichael, 1964, p. 448).

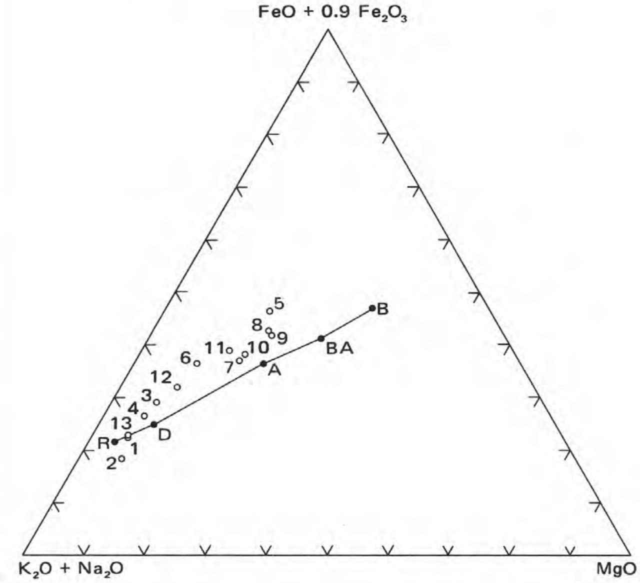



FIGURE 31. — Ternary diagram of alkalies ($K_2O + Na_2O$), iron oxide ($FeO + 0.9\ Fe_2O_3$), and magnesia in the igneous rocks of the East Tintic Mountains. Samples 1-11 from table 7; samples 12 and 13 are the same as samples 1 and 2 in table 6. Closed circles show average rhyolite (R), dacite (D), andesite (A), basaltic andesite (BA), and basalt (B) from the Cascade province (Carmichael, 1964, p. 448).

eventually gave rise to the Tintic Mountain and Laguna Springs Volcanic Groups and their related intrusive rocks. The only known intrusion that is equivalent to the Packard is the Swansea Quartz Monzonite, a stock in the Tintic district. Chemically it contains about the same amount of $SiO_2$ but somewhat more $K_2O$ than the average Packard Quartz Latite. Its emplacement apparently was not accompanied by major hydrothermal activity.

The Tintic Mountain Volcanic Group was emplaced over the Packard Quartz Latite after a period of erosion during which 25 percent or more of the Packard was removed. The principal eruptive center of the Copperopolis Latite was probably in the west-central part of the East Tintic Mountains. The initial eruptions were of spatter breccia, lapilli tuff, and fine-grained volcanic ash which were overlain by fine- to medium-grained dark lava and agglomerate that apparently filled the Packard caldera to overflowing. Of these rocks, only relatively small quantities of the volcanic ash and the fine- to medium-grained latite are exposed in the East Tintic district. The Copperopolis eruptions apparently were followed by a period of quiescence, during which time further differentiation, probably in a restricted magma chamber, produced a silica- and potassium-enriched magma that was explosively erupted as the air-fall and welded tuffs of the Latite Ridge Latite. These rocks probably were erupted from a vent in Copperopolis Canyon in the cental part of the range. Shortly after the emplacement of the Latite Ridge Latite, the silica- and potassium-poor Big Canyon Latite was erupted from an unknown vent. Assuming approximately equal volumes, the combined Latite Ridge and Big Canyon magmas are closely similar in composition to the Copperopolis magma, suggesting that they are corresponding felsic and mafic differentiates of the same magma.

The cessation of the Tintic Mountain volcanic episode was marked by the intrusion of a number of stocks, plugs, dikes, and other intrusive bodies in the central East Tintic Mountains. One of these bodies, the Sunrise Peak stock in the main Tintic district, is the feeder for the extensive Gough sill, an intrusive sheet that extends into the East Tintic district, and the Dry Canyon sill that caps Tintic Mountain, about 8 mi (13 km) south of the East Tintic district. In contrast to later intrusions, the Sunrise Peak intrusive episode was not accompanied by significant movement of late hydrothermal solutions.

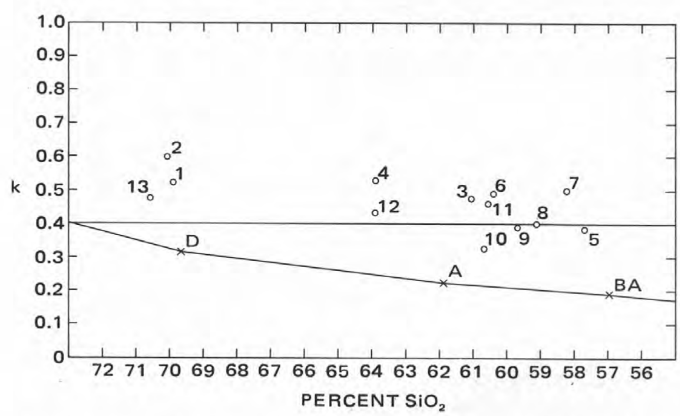



FIGURE 32. — The molecular ratio of $K_2O$ to $K_2O + Na_2O$ — Niggli "k" value — plotted against $SiO_2$ for the igneous rocks of the East Tintic Mountains. Numbers 1-11 are samples listed in table 7; numbers 12 and 13 are the same as samples 1 and 2 of table 6. Letters BA, A, and D are average basaltic andesite, andesite, and dacite of the Cascade province (Carmichael, 1964, p. 451) which are shown for comparison.

Erosion of the multiple volcano that was produced during the Tintic Mountain volcanic episode produced a thick and extensive agglomerate unit that crops out on Long Ridge and in the southern part of the Wasatch Mountains and the northern part of the Gunnison Plateau in east-central Utah.

After this second period of volcanic quiescence, the tuffs, tuff-breccias, and the coarse-grained porphyritic lavas of the Laguna Springs Volcanic Group were emplaced over the eroded northeastern flank of the Tintic volcano and the adjacent area of eroded Packard Quartz Latite. The eruptive sources appear to be some of the plugs and dikes of similar mineralogic and chemical composition that crop out in the East Tintic district. The volcano produced by the Laguna Springs eruptions was much smaller than the Tintic Mountain and Packard volcanic piles, but it apparently extended over the entire area of the East Tintic district. The Laguna Springs episode was terminated by the intrusion of the Silver City stock and its satellitic plutons in the East Tintic district. This intrusive episode was accompanied and followed by the movement of great volumes of hydrothermal fluid (Lovering, 1949) terminating in ore deposition. Chemically the rhyodacitic lavas and some of intrusive rocks of the Laguna Springs volcanic episode are the least felsic of the igneous rocks of the East Tintic Mountains. The related Silver City stock, however, is not quite as mafic, which may indicate further differentiation.

After the intrusion of the Silver City stock, a period of volcanic quiescence lasting approximately 13 m.y. preceded the intrusion of the Silver Shield dike and the eruption of the Silver Shield flow. No volcanic units of comparable age and character are known elsewhere in the East Tintic Mountains, but volcanic and intrusive units of approximately the same age have been described by Staatz and Carr (1964, p. 75-86) in the Thomas and Dugway Ranges. Slightly younger leucocratic granitic rocks are also known in the Sheeprock Mountains and in Desert Mountain.

The ages of the eruptive and intrusive rocks in the East Tintic Mountains are summarized in figure 33.

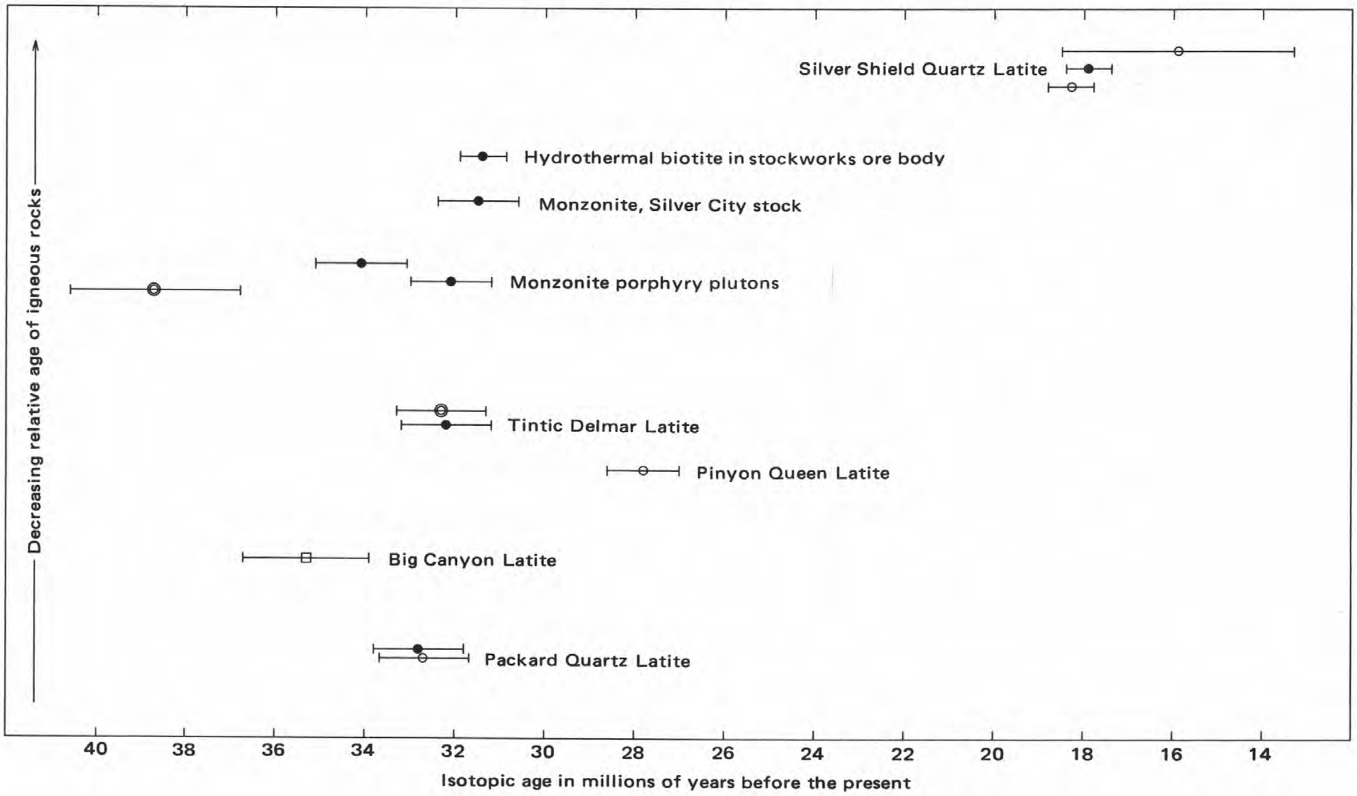



FIGURE 33. — Summary of isotopic ages of igneous rocks of East Tintic Mountains.

## POSTVOLCANIC DEPOSITS

The postvolcanic deposits in the East Tintic district and the nearby region are all younger than the Basin and Range tectonic event and consist chiefly of basin-fill deposits in Goshen Valley and alluvium, colluvium, and thin eolian deposits in the upland area. These deposits were described by Goode (in Morris and Lovering, 1961, p. 129-138) and are only briefly summarized here. Additional descriptions of the basin-fill deposits of this general area, including the lacustrine beds deposited in glacial Lake Bonneville, are presented by Bissell (1963).

### QUATERNARY SYSTEM

### OLDER ALLUVIUM

An extensive bajada, which is largely mantled by clastic sediments deposited in Lake Bonneville and by patchy thin sheets of post-Lake Bonneville alluvium, spreads eastward from the East Tintic Mountains into Goshen Valley. The gently sloping surface of these deposits is locally termed the Goshen Slope or, more descriptively, the Slant.

The component fans forming the bajada are typical of other thick Pleistocene fans in the Great Basin. Near their apexes at the mouths of the mountain canyons, they have gradients of approximately 450 ft (137 m) per mile. In the middle parts the gradient decreases to 300 ft (91 m) per mile. In their lower parts the gradient decreases even more, but in Goshen Valley the middle and lower parts of the fans are largely concealed beneath lake deposits.

Exposures showing the internal composition and structure of the fans generally are limited to a few cutbanks and drill holes. In these exposures the bedding is poorly developed to obscure, sorting is fair to poor, and the fragments are angular to subrounded. Most of the fans apparently were formed by intermittent streams that drained only volcanic terranes. Consequently, they are composed largely of blocks and fragments of latite, quartz latite, and monzonite porphyry, all embedded in a matrix of sand and silt. Exceptions are the fans at the mouths of Big Canyon and Pinyon Creek, both of which contain large and small fragments of limestone derived from the exposures of Paleozoic rocks in their headwaters areas. The angularity of many of the fragments found several miles or more from the range front indicates rapid transport by mudflows generated during the frequent cloudbursts that continue to be characteristic of the region.

In general, the fan materials are poorly consolidated except locally where caliche and hot-spring tufas have thoroughly cemented the clastic debris. The sand-size material mixed with the gravel and boulders in the fans is commonly angular and may be readily distinguished from the rounded to subrounded lacustrine sands.

The thickness of the fan deposits is not known. From physiographic evidence and sparse drill-hole data, the larger fans may be as much as 800-1,000 ft (244-305 m) thick near the mountain front, and they lense out into lacustrine deposits in the center of Goshen Valley, 4-6 mi (6.4-9.7 km) from the range front. The log of a water well drilled in the NW¼-NW¼SW¼ sec. 4, T. 10 S., R. 1 W., approximately 3.5 mi (5.6 km) northeast of the mouth of Big Canyon, indicates 90 ft (27 m) of Lake Bonneville deposits overlying 212 ft (64.6 m) of fan gravels and alluvium, which rests in turn on interlayered fan gravels and lacustrine deposits probably of the Salt Lake Formation of Pliocene age (Cordova and others, 1969, p. 20).

As described by Hunt, Varnes, and Thomas (1953, p. 15, 43-45) and others, many of the fans, as well as the upland deposits of pre-Lake Bonneville age, are mantled by deep soil. This pre-Wisconsin soil consists of an upper layer that is lime free and clayey and a lower layer that is composed of lime-enriched parent material. Locally, the soil zone may be from 20 to 30 ft (6-9 m) thick.

### Lake Bonneville Group

During the Wisconsin Glaciation, Goshen Valley was occupied by an arm of Lake Bonneville; this lake covered 20,000 square miles (51,800 km$^2$) in northern Utah at its fullest development and now is represented only by such remnants as Utah Lake and Great Salt Lake. At its highest stage, this Pleistocene lake cut a faint to moderately well developed beach terrace at an elevation of 5,120-5,150 ft (1,561-1,570 m) along the northeastern side of the East Tintic Mountains (see Crittenden, 1963, p. E4, E9); other terraces and lacustrine deposits record a complex history of fluctuation and final dessication at lower elevations in parts of northern Utah (see Hunt and others, 1953, and numerous other references).

The deposits that were laid down in Lake Bonneville are called the Lake Bonneville Group and are divided into three formations, each of which represents a major still stand of the ancient lake. These formations are the Alpine, Bonneville, and Provo Formations. Because of the relatively high elevation of the East Tintic district, only the Alpine and Bonneville Formations were deposited in the area of plate 1; however, the Provo underlies the greater parts of Goshen and Utah Valleys a few miles to the east (Bissell, 1963).

#### Alpine Formation

The oldest formation of the Lake Bonneville Group was named the Alpine Formation by Hunt (Hunt and others, 1953, p. 17) from exposures near the town of Alpine in northern Utah Valley. In Goshen Valley, as elsewhere in the Lake Bonneville basin, the Alpine Formation consists largely of silt and clay, probably derived from the erosion of the extensive pre-Wisconsin soil (Hunt and others, 1953, p. 40); sand and gravel occur in some exposures, but the overall proportions are far less than in the succeeding Bonneville and Provo Formations. The silt and clay deposits are typically thin bedded, consisting of alternating layers of clay, silt, sand, and grit ½-2 in. (1.3-5.1 cm) thick. The sand and gravel members, which are most commonly found near the mouths of the canyons and gulches that drain into the valley, are recognized by their close association with the silt and clay deposits and their occurrence immediately below an elevation of about 5,100 ft (1,554 m), which represents the maximum level to which the lake waters rose during the Alpine stage.

#### Bonneville Formation

The Bonneville Formation in the area shown on plate 1 consists of gravel deposits in deltas, bars, and other embankments, sand deposits as facies in the embankments and as bars and aprons in front of them, and less extensive deposits of silt and clay, some of which represent reworked Alpine Formation. The gravel deposits contain moderately well sorted and moderately well rounded cobbles and pebbles, many of which have been eroded to ovoid disks from wave action in a beach environment. The largest wave-rounded fragments are about 6 in. (15 cm) in diameter, and the average is about 2 in. (5 cm) in diameter. The pebbles are composed of all the rocks that are exposed in the upland areas, and many of the larger fragments in the upper part of the wave-cut beaches are partly covered with a crust of caliche as much as a quarter of an inch (0.6 cm) thick. The sand layers are 6 in. (15 cm) to 30 ft (9 m) thick; they are mostly medium to fine grained and are somewhat less iron stained than the sand layers in the Alpine Formation. The most extensive deposits extend from the mouth of Big Canyon to the vicinity of Hillside Siding. These deposits consist of a small delta and several bars and modified spits, the upper surfaces of which are at an elevation of 5,150 (1,570 m). The combined Alpine and Bonneville Formations range in thickness from 3 ft (0.9 m) to more than 50 ft (15 m), achieving its greatest thickness in the Big Canyon delta.

### Terrace gravels of Lake Bonneville age

Linear ridges and terraces that are composed of alluvium and stand 10-30 ft (3-9 m) above the flood plains of the modern streams are a characteristic feature of the larger valleys in the East Tintic Mountains that drained into Lake Bonneville. The surfaces of the flat-topped ridges slope eastward at approximately the same gradient as the modern streams and, on projection, merge with the Lake Bonneville Group. In exposures in cutbanks and in drill holes, the alluvium in these terraces is poorly sorted, moderately rounded, and strongly channeled, and except for a somewhat greater abundance of caliche veins and patches, it is indistinguishable from modern alluvium. The general relations of these terrace gravels with the Bonneville Formation, and the absence of a pre-Wisconsin soil, indicate that these gravels were deposited as a result of the decrease in stream gradients when Lake Bonneville filled to its highest level. They were dissected by streams as the original base level was reestablished on the disappearance of the lake.

### Younger Alluvium

Deposits that are younger than the strata of the Lake Bonneville Group include talus, colluvium, alluvium, fan gravels, and eolian sand and silt. Some of the talus, colluvium, alluvium and other upland deposits undoubtedly consist chiefly of materials that accumulated during both Lake Bonneville and pre-Lake Bonneville times, but no attempt was made during the present study to differentiate between them. The talus deposits include rock detritus that has accumulated as small cones, aprons, and rock slides in the higher and steeper parts of the range. The material is unsorted and unstratified and is generally devoid of vegetation. Similar deposits, resulting from landslides rather than frost action, are more common in the volcanic terrane than in the area of Paleozoic rock outcrop. These landslide deposits generally contain a high proportion of soil, clay, and other fine debris.

Colluvium has accumulated to a substantial thickness in many parts of the East Tintic Mountains, effectively obscuring the bedrock in many areas of hydrothermal alteration and structural brecciation. In some places prospect adits penetrate 50-100 ft (15-30 m) of slopewash and other debris before entering the solid bedrock. The typical colluvium also contains a high proportion of clay and silt and apparently developed mostly in pre-Lake Bonneville time.

The larger stream valleys are underlain by medium- to coarse-grained gravel that is unsorted and contains layers and lenses of grit, sand, and clay. The gradient of the larger streams ranges from 400-500 ft (122-152 m) per mile in their upper parts to 200 ft (61 m) per mile near the Lake Bonneville beach terrace. The alluvium filling the stream valley is locally 50 ft (15 m) thick or more.

The post-Lake Bonneville fan gravels consist of boulder, cobble, and pebble gravel that is characterized by poor sorting and lenticular bedding. The fragment size ranges from medium boulders to sand and clay with the predominant material ranging from coarse sand to cobbles. In most areas, the post-Lake Bonneville fan deposits have an aggregate thickness of only 10 ft (3 m) or less, emphasizing the great age of the extensive, thick bajada that underlies the Lake Bonneville deposits on the eastern flank of the range.

A short distance east of the eastern front of the East Tintic Mountains, the Lake Bonneville deposits are locally overlain by windblown sand and silt. Here and there crescent-shaped dunes have formed on the northeastern sides of deflated areas that are characterized by pebble pavements of lag gravels. The eolian sand and silt are typically medium to light brown, well sorted, and crossbedded. Recent cultivation of the lake beds has accelerated the developement and movement of the windblown material.

## STRUCTURE

The principal geologic structures of the East Tintic district include folds, thrust faults, and several types of high-angle faults. Some of these structures are of large size and are best understood and evaluated in the context of the regional setting of the East Tintic Mountains. Others are more limited in extent, including some small structures that have great economic importance in selected areas in the district where they localize major ore deposits or where they have served as conduits for hydrothermal solutions.

In general, three groups of structures are recognized. The oldest, which affect only the Paleozoic and older rocks, are compressive and postcompressive features that resulted from the late Mesozoic Sevier orogeny. The next oldest structures are considerably smaller in magnitude and are related to Oligocene volcanic activity and monzonite intrusion. The youngest structures are Basin and Range faults, which first formed in latest Oligocene or early Miocene time and which locally cut Pleistocene and Holocene deposits.

## REGIONAL SETTING

The East Tintic Mountains are located within the central part of the Sevier orogenic belt, which has been described by Billingsley and Locke (1939), Harris (1959), Roberts, Crittenden, Tooker, Morris, Hose, and Cheney (1965, p. 1944-1951), and Armstrong (1968). Although many of the structural features of this orogenic belt are obscured in the vicinity of the East Tintic district by postorogenic volcanism and intrusion and by Basin and Range faulting, paleogeologic reconstruction clearly portrays the general features of the prevolcanic structures.

In general aspect, the Sevier orogenic belt is a great linear welt that is characterized by a series of overlapping thrust plates of large breadth and displacement. It extends from California and Nevada northeasterly through Utah and into Wyoming, Montana, and Canada. In Utah, it is as much as 100 mi (161 km) wide and originated in response to broad upwarps in the area of the present borderlands of Utah and Nevada that caused large thrust plates to move eastward across central Utah and southeastern Nevada. In central Utah, as shown in figure 34, the plates broke into a series of overlapping slices, some of which locally moved into broad basins in which thick deposits of coarse conglomerate and other clastic debris were accumulating on the eastern flank of the welt. Several of these thrust plates were deformed during transport and compressed into large asymmetric folds that were cut by subsidiary thrust and tear faults contemporaneously with the folding.

As shown by Roberts, Crittenden, Tooker, Morris, Hose, and Cheney (1965, p. 1944-1948) and by Armstrong (1968, p. 437), the East Tintic Mountains lie within a segment of the orogenic belt that has been named the Nebo-Charleston sector, taking its name from the main basal thrust fault in the Wasatch Mountains where it may have a total displacement of more than 100 mi (161 km). This basal thrust is best exposed at Mount Nebo in the southern Wasatch Mountains near Nephi; here rocks of Precambrian to Jurassic age have been carried over Triassic and Jurassic units (Eardley, 1934). Farther north, near Provo, the Charleston segment of the same structure was first shown by Baker (1947) to have a basin facies of Pennsylvanian and Permian Oquirrh Formation as much as 26,000 ft (7,295 m) thick in its upper plate and a shelf facies of equivalent rocks averaging less than 3,000 ft (914 m) thick in its lower plate. Southward, the Nebo-Charleston thrust apparently terminates at the Leamington tear fault (Christiansen, 1952; Morris and Shepard, 1964); in northern Utah its counterpart appears to be the Willard thrust (Blackwelder, 1910; Crittenden, 1959, 1961), which in turn continues northward into northernmost Utah and southern Idaho as the great Bannock overthrust (Mansfield, 1927, p. 150-159), later renamed the Paris thrust.

A few miles west of the trace of the Nebo-Charleston thrust, the rocks of its upper plate are cut by the Midas thrust fault. This thrust, which has 10-20 mi (16-32 km) of displacement, underlies the great plate of folded rocks that extends from central East Tintic Mountains to the central Oquirrh Range. The Midas is apparently delimited on the south by the largely concealed Inez tear fault that is believed to extend from the East Tintic Mountains to Lake Mountain (Morris and Shepard, 1964); in the northern part of the Oquirrh Mountains, the Midas thrust is concealed by overlying the North Oquirrh thrust.

West of the East Tintic Mountains, the Midas thrust plate is overlapped by the Tintic Valley thrust plate. The Tintic Valley thrust, which may rival the Nebo-Charleston thrust in magnitude, is mostly concealed by the alluvium of Tintic and Rush Valleys, but it crops out southeast of the range in the Gilson Mountains (Morris and Kopf, 1969, p. 55; Wang, 1969), and it also underlies thin alluvium in the narrow pass between South Mountain and the Stansbury Range near Stockton, Utah (Billingsley and Locke, 1939, p. 35). North of the Stansbury Range its trace is everywhere concealed by alluvium. Along the Tintic Valley thrust, markedly dissimilar stratigraphic sequences of middle Paleozoic rocks were brought into juxtaposition, particularly sections of Lower and Middle Devonian rocks that are greatly different in lithology and thickness. Southward, the correlation of the Tintic Valley thrust has not been established, and it may terminate at the Leamington tear fault; however, it may also correspond to the Pavant thrust exposed in the Pavant Mountains near Fillmore, Utah.

The westernmost thrust of the Nebo-Charleston sector of the Sevier orogenic belt is the Sheeprock thrust, which crops out in the Sheeprock and West Tintic Mountains about 12 mi (19 km) west of the East Tintic district. It overlaps the Tintic Valley thrust plate and separates a thick section of late Precambrian and Cambrian rocks in the upper plate from beds of Late Mississippian age in the lower plate. South of the Leamington tear fault it is probably represented by the Canyon Range thrust.

As shown in earlier reports (Roberts and others, 1965, p. 1952-1953), both the Nebo-Charleston and Midas thrusts are believed to extend beneath the East Tintic district. Neither fault has yet been exposed in the district, although the concealed Inez fault, which apparently terminates both the Midas thrust and the great anticlines and synclines of its upper plate, may have been penetrated by one or more drill holes.

Detailed studies by Spieker (1946, 1949), Schoff (1951), and others indicate that the principal deformation of the Sevier orogeny took place during medial

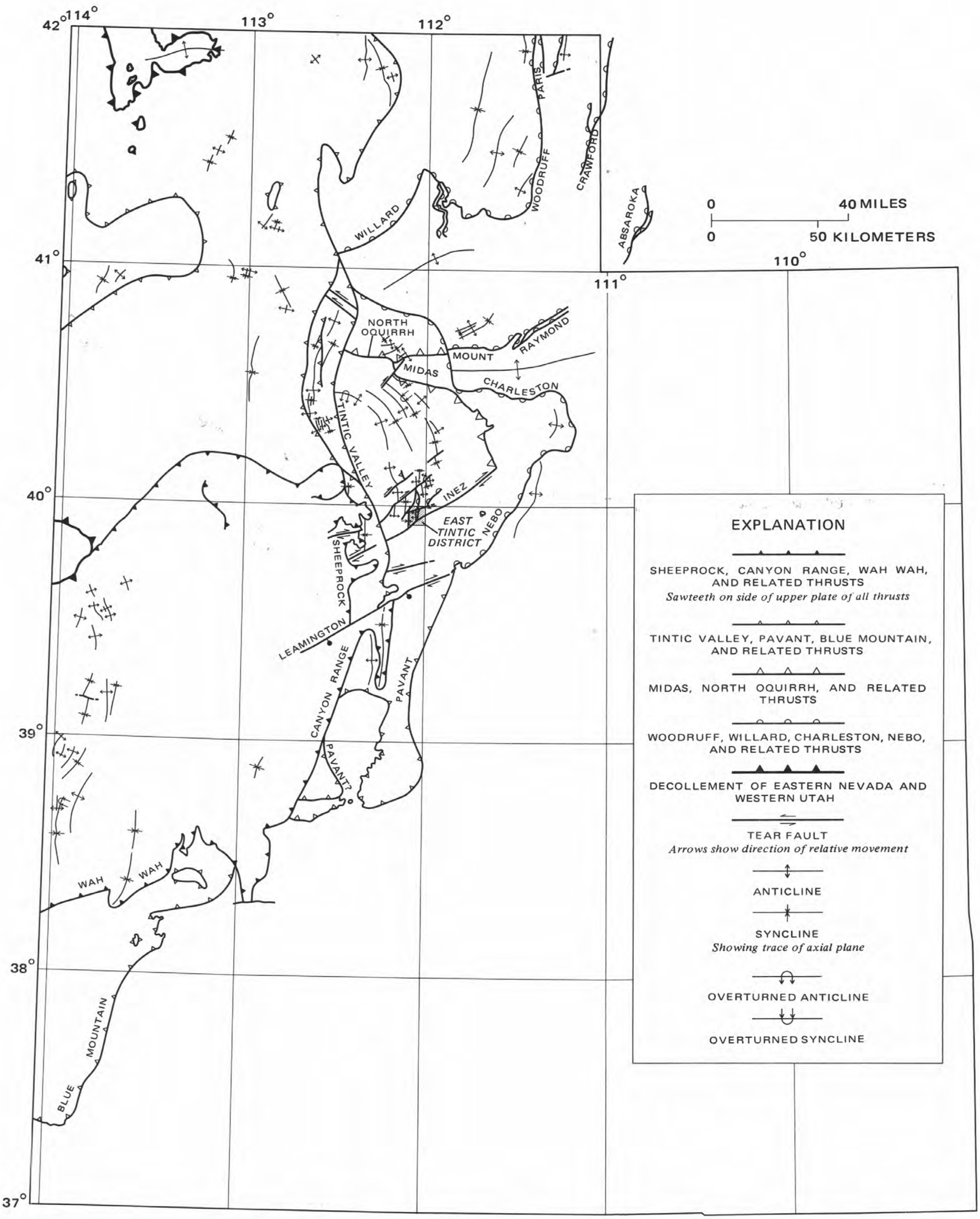



FIGURE 34. — Setting of East Tintic district in relation to the geologic structures of the central part of the Sevier orogenic belt.

and late Montana time and probably did not extend into the Paleocene.

In middle Oligocene time, long after the paroxysms of the Sevier orogeny had subsided and the deformed thrust plates had been cut by normal faults of large displacement and deeply eroded, volcanic eruptions produced the great volcanic pile that buried the folded and faulted Paleozoic rocks in the area of the East Tintic Mountains. As described earlier, this volcanic pile was as much as 50 mi (80 km) in diameter, and its center generally coincided with the central part of the East Tintic Mountains. The first eruptions of quartz latite filled many of the erosional irregularities of the prelava topography but apparently did not completely cover the higher peaks. Caldera collapse followed the eruption of the quartz latite, but only the northernmost edge of the caldera is believed to extend across the southern boundary of the East Tintic district. This caldera was filled and overtopped by latite agglomerates, tuffs, and flows, which appear to have produced a composite volcano of large size. After this second and perhaps most extensive period of volcanism, a smaller composite volcanic cone was formed on the northeast flank of the larger cone, chiefly over the area of the East Tintic district. Many of the primary structural features of these volcanic piles are preserved with little deformation.

Of somewhat greater interest than the constructional features of the volcanoes are the associated mineralized north-northeasterly trending faults and fissures that guided the emplacement of many monzonite and pebble dikes and that also served as channelways for hydrothermal solutions. In general, these faults and fissures are limited to the areas of intrusive rocks near the central part of the volcanic pile and do not extend regionally beyond the limits of the mining districts.

During the Basin and Range tectonism, which reached a climax during the late Miocene, all of the earlier structural and volcanic features were cut by northerly trending normal faults of large displacement. Movement on these faults produced elongated north-trending mountain ranges, some of which are horsts and others of which are the edges of large tilted blocks. These ranges are separated by broad grabenlike valleys that locally received as much as 7,000-12,000 ft (2,134-3,658 m) of clastic and lacustrine sediments (Cook and Berg, 1961).

In gross aspect, the East Tintic Mountains represent the western edge of a large internally faulted tilted block located near the east-central margin of the Great Basin. The northern part of the range is horstlike and appears to be bordered on both flanks by valleys that are deeply filled with alluvium. In its southern part, the range divides into several spurlike blocks that are bounded by faults of only small to moderate displacement, and it gradually merges with adjacent small hills.

## PRELAVA STRUCTURES

The prelava structures within the East Tintic district include folds of both regional and local dimensions, low-angle faults that are chiefly thrusts, and high-angle faults that include shear faults, tear faults, and normal faults. Many of these structures are concealed beneath the lavas and are known only from exposures in mine workings or from drill holes. They are confined to the Paleozoic and presumably older rocks, which had been deeply eroded before the onset of volcanism.

### FOLDS

#### EAST TINTIC ANTICLINE

The dominant structural feature in the Paleozoic rocks of the East Tintic district is the north-trending moderately plunging (north) East Tintic anticline. This fold is largely concealed by lava, but its general form and character in the central ore-producing part of the district are comparatively well known from scattered exposures of prelava rocks at the surface and in the mines, and from drill-hole data. Regionally, this fold is part of the Tintic-Oquirrh foldbelt, and its crest lies about 2 mi (3.2 km) east of the trough of the adjacent Tintic syncline, which is conspicuously exposed in the main Tintic district. Presumably, the East Tintic anticline is flanked on the east by a syncline comparable to the Tintic syncline that is totally concealed by lava. The amplitude of these folds is about 10,000 ft (3,048 m).

The axial area of the East Tintic anticline is moderately well exposed in the Trixie mine, but it is offset eastward by the Apex Standard and Eureka Standard faults to a point between the Apex Standard and Burgin No. 2 shafts. From this area it extends irregularly northward. North of the latitude of the Tintic Standard mine, and south of the Trixie mine, the axial area has not been exposed by mine workings, and its precise position is unknown. Because of the uncertainties as to the location of the axis at the base of the lavas, it is not shown on plate 1.

As shown in cross sections B-B' and D-D', the part of the anticline that lies north of the Apex Standard and Eureka Standard faults is asymmetric, with a west limb that dips about 30° W. and an east limb that is locally overturned, particularly near the East Tintic thrust. Near the North Lily and Tintic Standard mines, the asymmetric form of the developing anticline resulted in the formation of the Tintic Standard thrust fault near the contact of the Tintic Quartzite and the Ophir Formation and the subsidiary North Lily trough near the anticlinal crest. These structural features are described separately in this report, as are the contemporaneous transcurrent faults and postcompressional faults and fissures that cut and displace the anticline.

## LOW-ANGLE FAULTS

The low-angle faults of the East Tintic district are genetically related to the formation of the East Tintic anticline and include thrust faults of both large and small displacements. Like many of the structural features in the district, they are best known from exposures in mine workings, where some are important ore-localizing features and, therefore, are more fully described in the discussion of the mines later in this report. In general, the low-angle faults dip westward and show evidence that the upper plates moved relatively eastward; locally they are folded. The largest displacement that is recognized on the fold-related thrusts exposed in the East Tintic district is more than 1 mi (1.6 km). As indicated earlier, this displacement is small when compared to the major thrust faults that are believed to deeply underlie the district.

### EAST TINTIC THRUST FAULT

The East Tintic thrust is the largest thrust fault exposed in the East Tintic district. It is cut on three levels of the Burgin mine a short distance west of the Burgin No. 2 shaft and also has been intersected by several drill holes, including one drilled downward from the bottom of the Silver Shield (Independence) shaft. In the area between the Burgin and Silver Shield mines, the lava-concealed trace of the thrust zone has been reasonably well determined by drilling, and south of the Burgin mine it has been similarly followed to its intersection with the concealed Inez fault. Drill holes in the vicinity of the Inez fault suggest that the thrust either terminates at the point of intersection or that it is offset more than half a mile (0.8 km) to the southwest.

The general strike of the East Tintic thrust is almost due north, and the dip is west, ranging from 5° to 35° and averaging about 25°. The displacement is not the same in all exposures of the thrust because of the independent movement of segments of the upper plate that lie between tear faults. The maximum known displacement is in the area of the Silver Shield mine, where the Cambrian Tintic Quartzite and Ophir Formation have been thrust over the Upper Mississippian Humbug Formation, indicating a minimum throw about 7,000 ft (2,134 m), which is the stratigraphic separation of these formations.

In the Burgin mine the zone of the East Tintic thrust consists of five or more separate thrust planes. Movement on the lowest of these planes, the main footwall strand, has brought the Tintic Quartzite over the upper part of the Ajax Dolomite, indicating more than 5,000 ft (1,524 m) of stratigraphic displacement. The overlying hanging-wall strands apparently are limited to the area lying between the Apex Standard and Eureka Standard tear faults, both of which cut the upper plate of the thrust and terminate downward on the main footwall plane. In the vicinity of these tear faults, the main footwall plane is also moderately folded into two or more parallel synclinal troughs. The easternmost and largest of these troughs is an important localizing feature of the main Burgin ore body.

The Allens Ranch thrust in the southern part of the Allens Ranch quadrangle (Proctor and others, 1956) is similar to the East Tintic thrust in trend, habit, and displacement; however, the faults are not believed to be equivalent. In general, the East Tintic thrust cuts the steep east limb of the East Tintic anticline and separates strata of Cambrian age from younger carbonate rocks that range in age from Cambrian to Mississippian. In comparison, the Allens Ranch thrust, which is exposed less than 1 mile (1.6 km) north of the East Tintic district, cuts gently dipping rocks of the west limb of the anticline and separates strata of the Upper Cambrian Ajax Dolomite and adjacent units from rocks of the Mississippian Gardison and Deseret Formations.

The lava-concealed position of the East Tintic thrust north and northeast of the Silver Shield shaft is unknown. Presumably it trends northeasterly from the area of this shaft and is cut by the Homansville fault. Because of the low dip of the thrust, and the large throw on the Homansville, the faulted segment north of the Homansville fault may be displaced to a point near or even beyond the eastern boundary of the East Tintic district.

### PINYON PEAK THRUST

The second largest thrust exposed in the East Tintic district extends northeastward across the southern and eastern slopes of Pinyon Peak, from which it is named, to the area of the North Standard shaft. Its southwestward continuation is concealed by lava. A probable northward continuation of the thrust extends beneath volcanic rocks into the Allens Ranch quadrangle, where Proctor and his coworkers (1956) recognized a fault zone of similar character about 1 mi (1.6 km) west of the Allens Ranch thrust.

The net slip on the Pinyon Peak thrust is not known. The stratigraphic throw ranges from about 200 ft (61 m) to more than 1,500 ft (457 m); it is greatest near the North Standard shaft, where the upper part of the Middle Cambrian Cole Canyon Dolomite has been thrust over the lower part of the Upper Ordovician Fish Haven Dolomite. The fault in this area dips gently west, and drag folds indicate that the upper plate moved relatively eastward.

Like the East Tintic thrust plate, the upper plate of the Pinyon Peak thrust is cut by many northeasterly trending transverse faults. Unlike the East Tintic thrust, however, it is not known to localize ore, although it does localize masses of jasperoid and other zones of hydrothermally altered rocks.

### TINTIC STANDARD THRUST

The Tintic Standard thrust, which is an important ore-bearing structure at points where it is cut by steep northeasterly trending mineralized fissures, is a zone of folded low-angle faults near the contact of the Tintic Quartzite and Ophir Formation in the area of the Tintic Standard and North Lily mines. Because of the complex configuration of this folded thrust, it may best be visualized from cross sections, such as C-C' of plate 2, or from the construction of structure contour maps, first prepared by Lovering (1949) and later modified as in figure 35. In this figure, structure contours are drawn on the surface of the Tintic Quartzite, and by appropriate symbols the character of this surface is indicated. Open dip arrows indicate that the surface of the quartzite is the Tintic Standard thrust. Solid dip arrows indicate that the quartzite surface is a high-angle fault that offsets the Tintic Standard thrust. Normal contacts of the Tintic Quartzite and the Ophir Formation are indicated by a row of dots adjacent to the structural contours, and the contact of the Tintic Quartzite and the Packard Quartz Latite is stippled.

Careful examination and interpretation of the Tintic Standard thrust reveals that concurrently with the late asymmetric development of the East Tintic anticline, the west-dipping strata near the crest of this fold were locally compressed into a shallow northwest-trending syncline, locally named the North Lily trough. As the anticline began to overturn to the east, the Ophir and overlying formations decoupled from the underlying Tintic Quartzite and moved across the minor crenulations; locally they were also repeated on imbricate thrust faults (cross sec. C-C', pl. 2). The resultant structure is a low-angle fault zone that chiefly follows the contact of the Tintic and Ophir Formations and elsewhere cuts upward into the Ophir, Teutonic, and overlying formations on a series of secondary thrust planes, some of which are also folded.

As compression and overturning of the anticline intensified, the part of the Tintic Standard thrust that is north of the South tear fault was downfolded sharply along the axis of the North Lily trough, and the northeastern flank of this trough was crumpled against the South fault, producing the cross-folded Tintic Standard trough. In the final stages of compression, the South fault also was compressed and slightly crumpled.

At the east end of the Tintic Standard trough, the surface of the Tintic Quartzite rises steeply out of the generally flat lying trough and becomes overturned to the west. The area of highly broken carbonate rocks and shale, bounded below and on the north and east by the crumpled Tintic Standard thrust and on the south by the South tear fault, is known locally as the Tintic Standard pothole. During mineralization these broken rocks were largely replaced by the Central or Main ore body of the Tintic Standard mine.

The related, but only generally similar, North Lily pothole occurs northwest of the North Lily shaft where the low-plunging North Lily trough narrows and rises steeply to the northwest, and its limbs locally become steep and even overturned. As in the area of the Tintic Standard mine, the Ophir and younger formations between the limbs of the fold also were highly broken and later were partly replaced by ores.

Beyond the structurally complex area of the Tintic Standard and North Lily mines, the Tintic Standard fault probably dies out at the contact of the Ophir Formation and the Tintic Quartzite. Its continuation south of the South fault, however, may be indicated by the log of an exploration drill hole, located on the north flank of Mineral Hill, that cut less than 60 ft (18 m) of sheared, altered, and brecciated Ophir Formation between the Teutonic Limestone and the Tintic Quartzite.

### MINOR THRUST FAULTS

In addition to the larger thrust faults, other low-angle faults of more limited extent and smaller displacement are recognized in the East Tintic district. Most of them occur on the west limb of the East Tintic anticline, and many are subparallel to the strata.

On the south side of Homansville Canyon, a small thrust fault, locally called the Homansville thrust, separates the Cole Canyon and Bluebird Dolomites in the upper plate from chiefly the Herkimer Limestone in the lower plate. The thrust appears to have been folded, forming an east-trending asymmetric anticline, which has a steeply dipping north limb and a more moderately dipping south limb. The displacement on this thrust is unknown, but the maximum stratigraphic separation across it is probably no greater than 500 ft

(152 m). Like many other thrust faults in the East Tintic district, the rocks of the upper plate of the Homansville thrust are more strongly altered than those in the lower plate.

On Mineral Hill, a short distance south of the Tintic Standard mine, a low-angle thrust that is nearly parallel to the strata of the upper plate separates Teutonic Limestone in the hanging wall from Dagmar Dolomite and Herkimer Limestone in the footwall; an adjacent thrust separates parts of the Herkimer Limestone from the Dagmar Dolomite. The dips in the strata of the footwall blocks of these thrusts are notably discordant to those in the hanging wall, and the footwall rocks are much faulted and hydrothermally altered. The maximum stratigraphic separation on these thrusts is about 400-500 ft (123-152 m). Displacement on similar thrusts also is believed to have repeated the Dagmar and Herkimer Formations in the upper part of the Tintic Standard mine as discussed later in the description of this mine.

In the vicinity of the Crown Point No. 2 shaft, the basal phosphatic shale member of the Deseret Limestone is the locus of a low-angle bedding-plane thrust along which the overlying Tetro Member has been brought in contact with the Gardison Limestone. The log of a diamond-drill hole located near the Old Beck Tunnel, a short distance west of plate 1, suggests that northward this fault cuts upward into the Deseret Limestone, causing the repetition of some of the beds in the lower part of the Tetro Member. Near the Crown Point and Crown Point No. 2 shafts, the upper plate rocks adjacent to the thrust zone have been replaced by large irregular masses of dense dark-colored jasperoid.

The sedimentary rocks in the vicinity of South Apex Hill are also cut by small low-angle faults similar in many respects to those on Mineral Hill. Movement on the strongest of these faults has placed Bluebird Dolomite over faulted Herkimer and Teutonic Limestones, indicating a maximum stratigraphic separation of about 600 ft (183 m). These minor thrusts also appear to have influenced the movement of early hydrothermal solutions.

The thrust fault of moderate displacement that is cut by the Big Hill shaft (cross sec. B-B' and C-C', pl. 2) is inferred from the geology of the mine as indicated on unpublished company maps chiefly prepared by M. B. Kildale and on district-wide geologic reconstructions. This fault does not crop out and has not been followed by any mine workings, and confirmation of its existence depends on reopening of the mine or on diamond drilling.

## HIGH-ANGLE FAULTS OF PREVOLCANIC AGE

The high-angle faults that originated during the early part of the Sevier orogeny are chiefly shear and tear faults that formed concomitantly with the major north-trending folds and thrust faults. Regionally, they are part of a conjugate system of northeast- and northwest-trending fractures that cut the axes of the major folds at 25°-85°; in general, they have dips ranging from 40° to 90°, and they have dominantly horizontal displacement. Several of the northeast-trending shear faults are tears that merge with the East Tintic and other thrusts. Because of the eastward tectonic transport of the larger thrust plates and the oversteepening of the east limb of part of the East Tintic anticline, the northeastward-trending high-angle faults are more throughgoing than the northwestward-trending faults and commonly have larger breccia zones in their walls.

Other high-angle faults include normal and reverse faults that chiefly formed during the later stages of the Sevier orogeny. At least one of these faults, however, was reactivated during the period of volcanic activity and later during the Basin and Range tectonism. These faults in general trend either more easterly or more northerly than the shear faults and have somewhat steeper dips.

The following descriptions in this section cover only the larger high-angle prevolcanic faults in alphabetical order and do not include many smaller faults that have less structural or economic importance.

### APEX STANDARD FAULT

The Apex Standard fault crops out a few hundred feet south of the Apex Standard No. 1 shaft; it is also well known from exposures in the Apex Standard and Burgin mines, where it strikes approximately N. 45° E. In its exposures southwest of the Apex Standard No. 1 shaft, the straight course of the fault trace across uneven topography suggests that the dip near the surface is almost vertical. At depth, however, the fault plane apparently passes through the No. 1 shaft about 500 ft (152 m) below the surface and was intercepted on the 700- and 900-ft levels, 75 and 135 ft (23 and 41 m), respectively, north of the shaft. These relations indicate that the fault plane is irregular, ranging in dip from nearly vertical near the surface to 40° NW. at a depth of 500-1,000 ft (152-305 m).

At the surface, movement on the Apex Standard fault brought the Ophir Formation and Teutonic Limestone in the hanging wall against Herkimer Limestone in the footwall, suggesting 400 ft (123 m) or more of reverse displacement. Exposures in the Burgin mine, however, indicate that the fault has only strike-slip displacement and that the hanging-wall rocks actually have been shifted as much as 2,000 ft (610 m) or more eastward from the crestal area of the East Tintic anticline to a point that is opposite the rocks on its eastern limb. Near the Trixie shaft the Apex Standard fault appears to merge with the strike-slip Eureka Standard

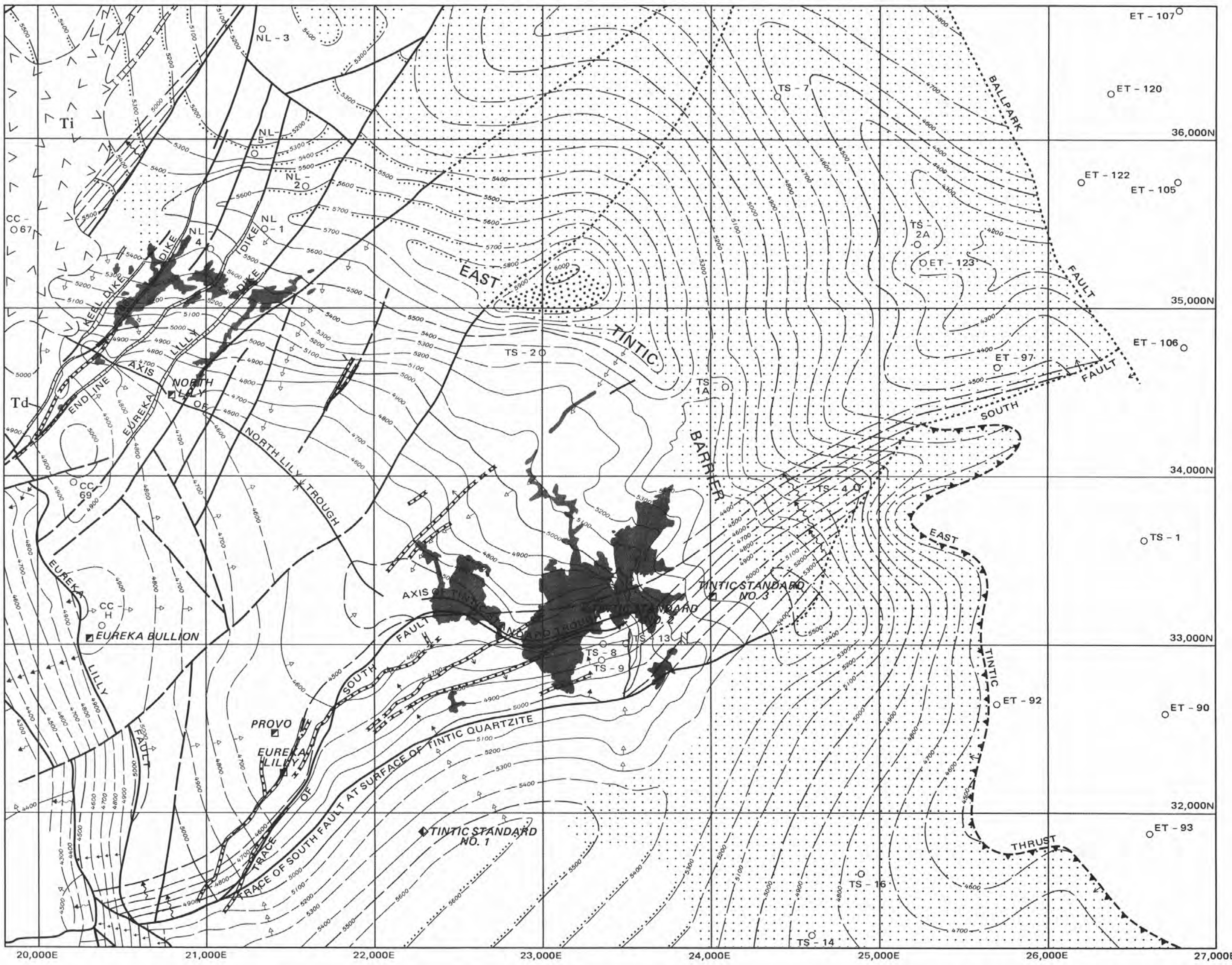
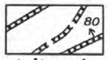


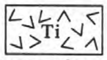

FIGURE 35. — Subsurface structure map of Tintic Standard and North Lily mine areas showing relations of Tintic Standard thrust and South fault. Explanation on facing page.

EXPLANATION

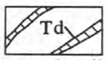
Replacement ore bodies in rocks adjacent to the Tintic Quartzite



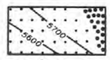

Veins cutting Tintic Quartzite; shown at the surface of the quartzite; dashed where inferred



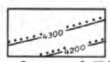

Monzonite and quartz monzonite porphyry pluton; contact shown at the surface of the Tintic Quartzite




Monzonite and quartz monzonite dikes; contacts at surface of Tintic Quartzite



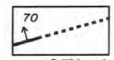
Structure contours on erosion surface of Tintic Quartzite, dashed where inferred. Dense dot pattern denotes area of quartzite outcrop; light pattern denotes prelava erosion surface



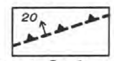
Structure contours on surface of Tintic Quartzite in normal sedimentary contact with Ophir Formation; dashed where inferred

Structure contours on fault surface where one wall is Tintic Quartzite and other wall is a post-Tintic Quartzite formation; dashed where inferred. Solid arrows denote dip of high-angle faults; open arrows denote dip of Tintic Standard thrust fault

Structure contours on fault where both walls are Tintic Quartzite; wavy arrows connect different contours on same fault surface




Position of fault at surface of Tintic Quartzite; dashed where inferred, dotted at trace on prelava surface. Arrows show direction and amount of dip




Trace of East Tintic thrust fault at prelava erosion surface. Sawteeth on side of upper plate; arrows show direction and average amount of dip

Shaft

o NL-5

Drill hole showing number. NL = North Lily, TS = Tintic Standard, CC = Chief Consolidated, ET = Kennecott Copper Corp. (East Tintic Project).

0 200 600 1000 FEET

0 50 150 300 METERS

COUNTOUR INTERVAL 100 FEET
DATUM IS MEAN SEA LEVEL

fault. Southwest of this area the combined fault, which is concealed by lava, appears to have as much as 5,000 ft (1,524 m) of largely horizontal displacement that eastward is distributed approximately equally on the Eureka Standard and Apex Standard faults.

The Apex Standard fault is an ore-localizing feature of considerable importance in the Burgin mine. Elsewhere in the district, the fault is not known to be significantly mineralized except for small stringers and pockets of lead and silver ore on the 900-ft level of the Apex Standard No. 1 mine, and for the occurrence of copper-bearing hydrous sulfate minerals where the Apex Standard fault is cut by the Apex Standard No. 1 shaft.

### BALLPARK FAULT

Surface and underground diamond-drill holes in the area of the Ballpark ore bodies about three-quarters of a mile (1.2 km) north of the Burgin No. 2 shaft indicate the presence of a fault that is not known with certainty elsewhere in the East Tintic district. This concealed structure apparently trends about N. 30° W. and dips about 75°W. Vertical displacement on the fault is estimated to be approximately 1,000 ft (305 m); this estimate is based on the inferred displacement of the East Tintic thrust, whose projected trace at 4,500-ft elevation appears to be offset by it about 3,000 ft (914 m). The dip of the thrust also changes from west-southwest in the hanging wall of the Ballpark fault to northwest in the footwall, further suggesting rotation of one of the blocks of the Ballpark fault.

The northwesterly strike of the Ballpark fault indicates that it may pass close to both the Copper Leaf and Central Standard shafts, but it has not been cut by workings from either of these mines. Diamond-drill holes that penetrate both the footwall and hanging-wall blocks of the Homansville fault a short distance northwest of the Central Standard shaft indicate that two strands of the Ballpark fault may cut and displace the Homansville fault as indicated on plates 1 and 3. Confirmation of this interpretation must await the establishment of mine workings in this area.

Because of incomplete exploration and mine development, the economic importance of the Ballpark fault as an ore-localizing structure is unknown.

### CANYON FAULT

The juxtaposition of the Herkimer Limestone and Bluebird Dolomite against the middle part of the Cole

Canyon Dolomite near the east entrance of Homansville Canyon indicates the presence of a high-angle fault that is concealed by the narrow band of alluvium in the canyon bottom. This fault is inferred to extend from the vicinity of the Homansville shaft eastward at least to the edge of the Packard Quartz Latite 1,400 ft (427 m) southwest of the Central Standard shaft, and it probably extends beneath the lava to the Ballpark fault and possibly beyond. The strike of the fault is slightly irregular, averaging due east; the dip is inferred to be moderately steep to the north.

Because of the lack of exposures, the Canyon fault is something of an enigma. It is believed to have about 500 ft (152 m) of stratigraphic throw at its west end and to diminish somewhat in displacement eastward. It appears to have dominantly vertical displacement, north side down.

The Canyon fault may have been cut by the 562-ft level of the Homansville shaft (see p. 00) and by a diamond-drill hole located 2,600 ft (792 m), N. 82° E., of the Homansville shaft. If so, it did not bear ore in these areas; it has not been explored elsewhere.

### COYOTE FAULT

The Coyote fault is known only from underground exposures on the 1,500 level of the North Lily mine in the hanging-wall block of the Eureka Lilly fault. It was first cut at a point 4,100 ft (1,250 m) N. 52° W. of the shaft and was followed west-southwest for a distance of approximately 1,500 ft (457 m). Its position in the footwall block of the Eureka Lilly fault is unknown. It may be represented by the fault that crops out 1,250 ft (381 m) north-northwest of the Copper Leaf shaft, but if so, the displacement along it is relatively insignificant as compared to the fault segment that is west of the Eureka Lilly fault.

In the mine workings, the Coyote fault trends N. 63° E. and dips 70° S. At the 1,500 level the hanging wall is composed of the Bluebird and Cole Canyon Dolomites and the footwall is Tintic Quartzite, indicating a stratigraphic throw of at least 1,500 ft (457 m). The type of displacement is unknown. Regionally, the Coyote fault is alined with the Leadville fault of the main Tintic district, which also dips southeast but has reverse displacement, indicating rotational movement about a hinge zone west of the East Tintic district if the two structures are correlative. Kildale (1957, p. 110) favored an interpretation of simple normal displacement on the Coyote fault, in part related to "collapse" of the crest of the East Tintic anticline.

Near its intersection with the Eureka Lilly fault, the breccias along the Coyote fault locally are replaced by small bodies of pyritic gold ore that contain accessory amounts of light-yellow or pale-red sphalerite (Kildale, 1957, p. 117). The production from these deposits was relatively small.

### EUREKA LILLY FAULT

The Eureka Lilly fault extends northerly through the central part of the East Tintic district, passing near the Homansville, North Lily, Eureka Lilly, Iron King No. 2, Trixie, and South Standard shafts. The surface trace of the fault is somewhat irregular, with large curving segments that locally range in strike from N. 25° E. to N. 40° W., averaging, overall, about N. 10° W. The dip is also irregular, averaging 55° W., but ranging from 40° to 70° W. North of the Homansville fault the northward continuation of the Eureka Lilly is a north-trending zone of fault slices along the western base of Pinyon and Lime Peaks that has been named the Selma fault from exposures in the Selma mine in the North Tintic district. This fault is discussed separately in the section "Selma Fault Zone." South of the Eureka Standard fault, the Eureka Lilly fault cuts lavas on the east side of Silver Pass Gulch and extends south of the East Tintic district into Ruby and Diamond Hollows, merging with the Diamond fault (Morris, 1964a, p. K21).

The Eureka Lilly fault apparently was reactivated at least twice after its origin during the waning stages of the Sevier orogeny. One period of reactivation took place after the eruption of at least part of the volcanic rocks but prior to ore deposition; probably a second reactivation took place during the Basin and Range tectonism. Kildale (1957, p. 112) reported some slightly slickensided ore in the North Lily mine that apparently was produced during this second period of reactivation. Most of the displacement is believed to be in the vertical direction.

In the North Lily and Eureka Lilly mines (Kildale, 1957, pls. 13 and 14), the Eureka Lilly fault strikes N. 10°-30° W. and dips west about 50°. Near the Coyote fault the Bluebird Dolomite is faulted against the Tintic Quartzite, indicating a minimum throw of 1,500 ft (457 m). A comparable displacement is indicated in the vicinity of the Iron King No. 2 shaft where the Ajax Dolomite is faulted against the Herkimer Limestone. Near the Eureka Lilly shaft, about 500 ft (152 m) of this total displacement is younger than the emplacement of the Packard Quartz Latite; postlava displacement apparently increases northward to about 600 ft (183 m) near the Homansville fault (Morris and Anderson, 1962, p. C4).

In the vicinity of the Trixie mine the total displacement on the southern segment of the Eureka Lilly fault is only about 550 ft (168 m), indicating that some of the movement on the Eureka Lilly terminated on the Eureka Standard and other faults north of the Trixie mine. Of the movement on this southern part of the Eureka Lilly fault, about 200 ft (61 m) is post-lava, possibly of Basin and Range age as described later.

Small ore bodies occur on or near the Eureka Lilly fault in the North Lily, Eureka Lilly, and Iron King No. 2 mines, and for this reason it has been moderately well explored, chiefly in the North Lily mine. The failure of these exploration ventures to discover additional ore bodies has led miners to consider the Eureka Lilly fault as generally unfavorable as an ore-localizing structure. Because of their late Basin and Range age, the southern segment of the Eureka Lilly fault in the area of Silver Pass Gulch and the northern segment, or Selma fault, are both believed to be unlikely ore-bearing bodies.

### EUREKA STANDARD FAULT

The Eureka Standard fault is extensively exposed in the workings of the Eureka Standard, Apex Standard No. 2, and Burgin mines, where it is an important ore-localizing feature. At the surface the fault trace is mostly concealed by lava, although it is overlain only by thin alluvium in the middle part of Silver Pass Creek three-fifths of a mile (0.97 km) north-northeast of the Trixie shaft. In this area it is about half a mile (0.8 km) southeast of the Iron King fault, and the block of ground between these faults is designated the Eureka Standard trough.

The average strike of the Eureka Standard fault is about N. 50° E., and the average dip about 45° NW. As the fault approaches and merges with the East Tintic thrust in the Burgin mine, the dip flattens, the strike abruptly swings north, and the fault plane becomes a strand of the thrust fault zone. Geologic maps based on both surface and underground exposures between the Trixie and Burgin mines show the axis of the East Tintic anticline to be displaced about 5,000 ft (1,524 m) to the northeast on the Eureka Standard and Apex Standard faults. At least half or more of this right-lateral shift is on the Eureka Standard fault. In the Eureka Standard mine, right-lateral displacement on the fault has brought the Ophir and Teutonic Formations of the west limb of the East Tintic anticline against the Tintic Quartzite of the east limb.

In the Burgin mine, the main lead-zinc-silver replacement ore body occurs in a segment of the upper plate of the East Tintic thrust that lies between the Eureka Standard and Apex Standard tear faults. In the western part of the Burgin mine, and more importantly in the Eureka Standard and Apex Standard No. 2 mines, smaller but relatively high grade pyritic gold and silver ore bodies also were mined on one or more of the footwall strands of the Eureka Standard fault and on steeply dipping fractures and pebble dikes in the footwall block close to the fault plane.

### HANSEN FAULT

The Hansen fault is the zigzag fracture that forms part of the southeast side of the troughlike structural block whose northwest boundary is the Apex Standard fault. Its principal exposure is on the ridge about 1,500 ft (457 m) N. 83° E. of the Trixie shaft. East of these exposures it probably extends northeasterly, subparallel to the Apex Standard fault, passing beneath lava and a minor thrust plate a short distance north of South Apex Hill. Some of the displacement on the Hansen fault also may have been transferred to the South Apex fault along one or more concealed southeast-trending fractures. Drill holes located 1,600 and 2,100 ft (488 and 640 m) northwest of the Trixie shaft indicate a dip in this area of 40°-50° N. West of the Eureka Lilly fault the Hansen fault may be correlative with the Trixie fault (see section "Trixie Fault"), although the faults differ somewhat in strike and attitude.

On the ridge east-northeast of the Trixie shaft the Hansen fault separates the Cole Canyon Dolomite and the upper shale member of the Ophir Formation, indicating a stratigraphic throw of about 1,000 ft (305 m). The highly irregular plane of the fault suggests an origin as a late prelava tensional fault that locally may have followed segments of northeast-trending strike-slip faults.

Minor quantities of cerussite and anglesite occur on the dump of the small shaft in the hanging wall of the Hansen fault 1,450 ft (442 m) N. 76° E. of the Trixie shaft. Mineralization of the fault breccias was indicated by a drill hole 550 ft (168 m) N. 80° W. of the small shaft, which intercepted 14 ft (4.25 m) of subeconomic lead-silver ore. A second drill hole about 600 ft (183 m) farther to the north failed to cut mineralization, and no further exploration has been attempted.

### HOMANSVILLE FAULT

The Homansville fault crops out on the north side of Homansville Canyon between the Homansville shaft and the edge of the Packard Quartz Latite about half a mile (0.8 km) to the east. Its position beneath the lavas for an additional four-fifths of a mile (1.3 km) farther to the east-northeast is indicated by a series of deep drill holes north of the Central Standard shaft that either bracket the fault or enter the fault zone. Originally its lava-concealed position in Pinyon Creek Canyon was believed to be marked by the surface termination of quartzite-bearing pebble dikes (see pl. 1), but drilling has indicated that these injected breccias were emplaced diagonally upward, and they actually extend a short distance north of the subsurface trace of the fault. West of the Homansville shaft the fault is concealed by lava, but in general it is alined with the Dead Horse fault of the Tintic district (Morris, 1964a, p. K19).

In the area north of the Central Standard shaft, the Homansville fault apparently has a somewhat sinuous trace, with a strike ranging from N. 70° to 90° E. The dip is steep, averaging about 80° N. Near Lime Peak, displacement on the fault has brought the upper part of the Fitchville Formation against the middle part of the Cole Canyon Dolomite, indicating a stratigraphic throw of about 3,000 ft (914 m). The logs of drill holes in the general area of the Central Standard shaft also confirm a comparable stratigraphic separation. The type of displacement on the Homansville fault cannot be determined with accuracy from exposures or drill hole data in the East Tintic district. The general east-northeasterly trend of the fault and its great throw suggest that it may be a right-lateral transcurrent fault related in origin to movement on the East Tintic and Midas thrust faults. However, exposures in the main Tintic district indicate that the axis of the Tintic syncline is not displaced laterally across it for any appreciable distance. In addition, the geologic relations across the Dead Horse fault indicate that this possible western segment of the Homansville has only vertical displacement. On this evidence it is concluded that the Homansville fault is a normal fault and is comparable to the Sioux-Ajax fault described later. Proposed development from the Water Lillie shaft (described in section "Water Lillie Shaft"), which will explore both the footwall and hangingwall blocks of the Homansville fault near the Central Standard shaft, may disclose definitive evidence for the type of displacement on this structure.

The intersections of the Baltimore and North Lily fissure and dike zones with the Homansville fault are considered to be prime exploration targets and in 1973-75 were being explored by the Kennecott Copper Corp. The intersection of the East Tintic thrust with the Homansville fault, which is probably about half a mile (0.8 km) east-northeast of the Bluff shaft, is also of exploration interest. All of these intersections are overlain by zones of pyritized lava, and those near the Central Standard shaft also are overlain by irregular geochemical anomalies.

### INEZ FAULT

The logs of a series of rotary and diamond-drill holes that were drilled on the Inez, Eastern, and Zenith claims and on the adjacent Tintic Utah property, two-thirds of a mile (1.1 km) southeast of the Burgin mine, indicate the presence of a totally concealed steeply dipping northeast-trending fault of large displacement (Morris and Shepard, 1964). This inferred structure has been named the Inez fault (Morris, 1964a, pl. 1). The drill holes indicate that the East Tintic thrust probably terminates against this fault at a point about 4,000 ft (1,219 m) south of the Burgin No. 1 shaft and that the Ordovician to Mississippian carbonate rocks of the lower plate of the thrust also apparently terminate against the Inez fault, which contains only Cambrian Tintic Quartzite and Ophir Formation in its southeastern block. As indicated in the earlier report (Morris and Shepard, 1964), the apparent termination of the Oquirrh-East Tintic fold system in the central East Tintic Mountains has long suggested the presence of a northeast-trending right-lateral tear fault of regional extent in the lava-covered central part of the range. This regional tear fault is inferred to be similar to the Leamington tear fault exposed in the adjacent Gilson Mountains (Morris and Shepard, 1964), and in fact, the Inez fault may be the westward continuation of a fault exposed in the southern part of West Mountain, near Santaquin, that appears to delimit the folds and strata of the upper plate of the Midas thrust fault (Roberts and others, 1965, p. 1948).

Several widely spaced drill holes, coupled with exposures of sedimentary rocks in the general area, indicate that the inferred Inez fault trends approximately N. 40° E. The dip is nearly vertical but is also believed to be sinuous. It is not possible to estimate displacement accurately, but if the fault does delimit the Oquirrh-East Tintic fold system, it would doubtless exceed several miles.

The economic importance of the inferred Inez fault would seem to be substantial inasmuch as (1) limestone is in fault contact with quartzite, both of which would probably be highly brecciated; (2) the N. 40°E. trend of the fault is close to the average trend of the mineralized fissures and faults in the district; and (3) two zones of strong pyritic alteration, one in the area of South Apex Hill and the other in the vicinity of the Inez claims, 4,000 ft (1,219 m) east of the Apex Standard No. 1 shaft, appear to be related to the fault. The principal target for exploration would be the zone of the East Tintic thrust adjacent to the plane of the Inez fault.

### IRON KING FAULT ZONE

A braided zone of east-northeast-trending faults, named from exposures in and near the Iron King No. 1 and No. 2 shafts, cuts the rocks between the Eureka Lilly fault and the 20th Century fault. The probable offset segment of this same fault zone crosses Mineral Hill and has been followed underground in the workings of the Iron King, Eureka Standard, and possibly the Apex Standard No. 1 mines. In the area of the Apex Standard No. 1 shaft, the Iron King fault apparently turns slightly southward and merges with the Eureka Standard fault; to the west, in the vicinity of the Iron King No. 1 shaft, it appears to terminate against the north-trending 20th Century fault, but it may be merely offset and concealed.

The segment of the Iron King fault between the 20th Century and Eureka Lilly faults has a curved, branching fault trace that ranges in strike from N. 80° W. to N. 30° E.; the dip is apparently sinuous but generally is steep to the south. At the surface, movement on this segment of the fault has brought the Ordovician Opohonga Limestone and Fish Haven Dolomite against the Cambrian Bluebird, Cole Canyon, Opex, and Ajax Formations, indicating a stratigraphic throw of more than 1,000 ft (305 m). At the 1,545-ft level of the Iron King No. 1 shaft, the fault separates the Tintic and Ophir Formations in the footwall from beds believed to be Herkimer Limestone in the hanging wall. The type of displacement is not known, but it is probably right lateral.

The segment of the Iron King fault zone that separates the Teutonic and Herkimer Limestones at the surface east of the Eureka Lilly fault strikes about N. 60° E. and dips about 70° S. The apparent difference in dip between the fault segments on either side of the Eureka Lilly fault may represent different parts of a sinuous fault plane.

Between the 900-and 1,300-ft levels of the Iron King No. 2 mine, small pyritic copper-gold ore bodies are localized on a subsidiary north-trending fissure in the footwall of the Eureka Lilly fault close to its intersection with the Iron King fault. Despite considerable additional exploration on both of the larger faults, no other ore bodies were discovered in the mine. Manganiferous limonite fluxing ores also have been mined from deposits localized along the 20th Century fault near the point where it is intersected by the Iron King fault.

### SIOUX-AJAX FAULT

The Sioux-Ajax fault is completely covered by lava in the East Tintic district, but it was probably intercepted by the 1,280-ft level of the Roundy mine about 900 ft (274 m) south-southwest of the shaft. Because of its possible importance as an ore-bearing structure where it cuts Paleozoic rocks in the East Tintic district, its location, altitude, and displacement are of great interest to the miners.

Where the Sioux-Ajax fault is exposed at the surface in the main Tintic district and underground in the Iron Blossom No. 3 shaft, which is 2,300 ft (701 m) west of the Roundy shaft, the fault zone consists of two or more strands, which strike about S. 85° E. and dip 80° or more north. At the crest of the East Tintic Mountains a short distance west of the Iron Blossom No. 3, nearly vertical displacement has dropped steeply dipping beds on the west limb of the Tintic syncline north of the fault about 1,600 ft (488 m) relatively downward against gently dipping beds in the trough of the syncline south of the fault, placing the Pinyon Peak Limestone against the upper part of the Deseret Limestone. The displacement appears to be entirely dip slip.

At the 1,280-ft level of the Roundy shaft, movement on the Sioux-Ajax fault apparently emplaced the upper part of the Bluebell Dolomite against highly broken and altered beds in the lower part of the Opohonga Limestone or the upper part of the Ajax Dolomite, indicating a stratigraphic throw of about 1,400 ft (305 m). Farther east, the occurrence of reeflike bodies of jasperoid near the South Standard shaft suggests that the lava-concealed trace of the fault maintains its east-southeasterly course and passes a short distance south of the South Standard shaft. Despite earlier correlations with other faults in the East Tintic district (Lovering and others, 1960; Morris, 1964a), we now believe that the movement of the Sioux-Ajax fault is probably not distributed on any of the faults that are exposed in the Eureka Standard and Trixie areas.

In the main Tintic district, large pipelike and podlike replacement ore bodies are localized in breccias on the hanging-wall side of the Sioux-Ajax fault in the Mammoth and Iron Blossom mines. Because of these occurrences, parts of the fault are considered to be prime exploration targets in the East Tintic district, particularly the areas where it is cut by north-northeasterly trending pebble-dike and mineralized fissure zones related to monzonite intrusion, and especially if these areas are overlain by hydrothermally altered lavas.

Underground exploration on the 750- and 900-ft levels of the Trixie mine has been directed toward the discovery of the Sioux-Ajax fault, but as of February, 1978, this exploration had not been successful.

### SOUTH FAULT

The South fault forms the south side of the highly mineralized Tintic Standard pothole (see p. 76, 173-175). It has a somewhat sinuous course, averaging approximately N. 50° E.; the dip is also irregular, ranging from 35° to 70° N. and averaging about 50° N. It apparently steepens east of the Tintic Standard mine area. Previously, the South fault had been interpreted to be a normal fault (Kildale, 1957, p. 110; and others) or a segment of a crumpled thrust fault (Lovering, 1949, p. 14; and others), but it is now recognized to have chiefly right-lateral displacement. (See pl. 1 and fig. 35). It is conspicuously exposed from the 900-to 1,450-ft levels of the Tintic Standard mine, on several levels of ihe Eureka Lilly mine, and in drill holes in the Ballpark section of the Burgin mine 900 ft (274 m) north-northwest of the Burgin No. 2 shaft. The fault is not exposed at the surface, but it is concealed by only a thin capping of quartz latite at a point about 800 ft (244 m) southwest of the Tintic Standard No. 1 shaft.

In the Tintic Standard and Eureka Lilly mines, the South fault is nearly coincident with a segment of the Tintic Standard thrust, and the nature of the faulting is obscure. Consequently, the part of the South fault that extends into the formations overlying the Tintic Quartzite apparently was not thoroughly explored, although it may have been cut by the 200- and 400-ft levels of the Tintic Standard No. 1 shaft.

Prior to the underground exploration of the Ballpark section of the Burgin mine by Kennecott Copper Corp. in 1968-70, the South fault was presumed to terminate a short distance east of the Tintic Standard No. 2 shaft, thus restricting the possible interpretations of its origin. Underground drilling in the Ballpark area, however, revealed that it extends east of the Tintic Standard pothole area, at least as far eastward as the lava-concealed trace of the East Tintic thrust. The drilling also reveals that this thrust is stepped down on the north side of the South fault but that at least the greater part of its displacement is taken up on the thrust.

As an ore-localizing structure, the South fault assumes great importance. It forms the south boundary of the Tintic Standard pothole, which contained replacement ore bodies estimated to be worth $80 million in gross value. In the Eureka Lilly mine tabular fissure-type ore bodies were localized in and near it, and in the Ballpark area the South fault is surrounded by much mineralized ground.

### SOUTH APEX FAULT

The South Apex fault crops out in three short exposures within half a mile (0.8 km) southwest of South Apex Hill, and also it was probably cut in the southernmost part of the Apex Standard mine at the 900-ft level. On some mining company maps this fault is named the "Teutonic fault," but that name was applied to it in error and is not used in this report. The projected trace of the South Apex fault is slightly sinuous, but in general the fault plane is believed to strike about N. 55° E., passing beneath the lava about 700 ft (231 m) south of the crest of South Apex Hill. The dip of the fault, calculated by projecting the fault cut at the Apex Standard 900-ft level to the projected position of the surface exposures southeast of South Apex Hill, is 60°-65° NW. In the limited underground exposures the fault strikes N. 63° E. and dips 55° NW.

In its surface exposures, movement on the South Apex fault has placed the Teutonic Limestone and Dagmar Dolomite against the middle limestone and upper shale members of the Ophir Formation, indicating a stratigraphic throw of 300-500 ft (91-152 m). In the Apex Standard mine the upper shale member has been emplaced against the upper part of the Tintic Quartzite, also indicating a stratigraphic throw of about 500 ft (152 m). The actual type of displacement is not known but is assumed to be right-lateral strike slip, like that on most of the other northeast-trending faults in the district. Within half a mile (0.8 km) east of South Apex Hill, the South Apex fault probably merges with the Inez fault.

No ore bodies are known to be localized by the South Apex fault; however, scattered crystals of pyrite, galena, and barite were noted in the fault zone in the Apex Standard mine. Two drill holes 300 and 750 ft (91 and 229 m) southeast of the crest of South Apex Hill both cut the fault zone, but neither cut mineralized ground. Further exploration at its intersection with the Inez fault and in the area west of the Eureka Lilly fault appears to be warranted.

### 20TH CENTURY FAULT

A north-northwesterly trending fault that crops out about 600 ft (183 m) west of the Iron King No. 1 shaft is named the 20th Century fault from exposures underground on the 20th Century group of claims. As shown on plate 1, this fault defines the western side of a graben that lies between it and the Eureka Lilly fault. It also forms the eastern side of a horstlike block between it and the steep north-trending Addie fault, which is 3,200 ft (975 m) to the west.

In its surface and underground exposures, the 20th Century fault trends approximately N. 25° W. and dips about 75° E. At the surface, the rocks of the hanging wall are weakly bleached limestone beds of the upper part of the Opohonga Limestone that have been faulted against strongly pyrometasomatized and altered beds believed to be parts of Opex Formation and Ajax Dolomite, indicating a minimum throw of about 1,500 ft (457 m). South of Burriston Canyon the fault that lies about 400 ft (123 m) east of the Zuma shaft is believed to be the southerly continuation of the 20th Century fault. In this area the beds in the footwall of the 20th Century fault were compressed into a tight anticline and subsequently were faulted, bringing the lower part of the Bluebell Dolomite against the middle part of the Opohonga Limestone.

In contrast to the large normal displacement indicated in surface exposures, the formational units on either side of the 20th Century fault in workings beneath the southeastern base of Big Hill at the 1,450-ft level of the Tintic Standard mine and at the 1,545-ft level of the Iron King No. 1 shaft indicate reverse displacement and only moderate throw. The contrast between the surface and subsurface relations across the fault is not readily understood. It may be the result of a concealed thrust fault at moderate depth on either or both sides of the 20th Century fault, or possibly it may result from the elevation of the horstlike block between the Addie and 20th Century faults as a result of a sill-like injection of monzonite above the underground workings. The answer to this problem will come only from drill hole or other subsurface exploration.

Some bodies of iron and manganese oxides and halloysite occur near the surface trace of the 20th Century fault, but otherwise it is not known to localize base metal and other ores.

### TRIXIE FAULT

The Trixie fault is exposed only in the northern part of the Trixie mine, where it localizes a replacement ore body between the 750- and 900-ft levels (see section "Trixie mine"). In these workings it consists of two parallel fault planes about 70 ft (21 m) apart that strike about N. 80° E. and dip 87° N. Movement on the fault has brought the Teutonic and Ophir Formations in the hanging wall against the upper part of the Tintic Quartzite in the footwall indicating about 650 ft (198 m) of stratigraphic throw. More than 570 ft (174 m) of this throw is on the southernmost or footwall plane of the fault.

As indicated by underground exposures, the Trixie fault apparently terminates to the east against the Eureka Lilly fault, and to the west it apparently merges with the Eureka Standard fault. As stated earlier, it may have originated concurrently with the Hansen fault, but this interpretation seems to be precluded by the shallow dip of that fault. Alternatively, it may have been formed in response to movements on either the Eureka Standard or Eureka Lilly faults.

The replacement ore body in the Trixie mine lies between the strands of the Trixie fault close to the point where it is cut by a northerly trending mineralized fissure. In addition, the Teutonic Limestone and the middle limestone member of the Ophir Formation within the triangular block of ground between the Trixie, Eureka Standard, and Eureka Lilly faults are largely replaced by jasperoid that is weakly mineralized by lead and silver.

### YANKEE AND ADDIE FAULTS

Mine workings driven eastward at the 2,000-ft level of the Yankee shaft, which is in the main Tintic district 2,300 ft (701 m) west-northwest of the Maple shaft, cut two large north-trending faults beneath the lavas in upper Burriston Canyon in the general area of the Maple claim (see pls. 1 and 3). The fault nearest the Yankee shaft has been named the Yankee fault; the other has been named the Addie fault from the Addie group of claims which lies north of the Maple shaft. Neither fault crops out at the surface.

On the Yankee 2,000-ft level, the Yankee fault strikes about N. 20° W. and dips 50°-70° SW. The type of displacement is unknown, but underground maps prepared by geologists of the International Smelting Co. show the upper part of the Bluebell Dolomite in the hanging wall to be faulted against the lower part of the Opohonga Limestone in the footwall, indicating a minimum throw of about 1,200 ft (366 m).

The Addie fault, which was followed for 1,800 ft (549 m) on the 2,000-ft level of the Yankee mine, strikes N. 10°-15° E. The dip is apparently steeply west or vertical. On the 2,000-ft level, movement on the Addie has placed the Emerald Member of the Ajax Dolomite in the hanging wall adjacent to the lower part of the Cole Canyon Dolomite in the footwall, indicating a throw of about 1,200 ft (366 m). The type of displacement is unknown, but the relations are those of a normal fault.

Little is known of the general extent and character of the Yankee and Addie faults. The relatively continuous sequence of the sedimentary rocks in the vicinity of the original Iron King and Crown Point No. 2 shafts indicates that the two faults apparently join near the Maple shaft and extend southeasterly beneath alluvium and lava in the middle part of Burriston Canyon. Much of the displacement apparently terminates at the 20th Century fault, indicating that the block that is delimited on three sides by the Addie, Yankee, and 20th Century faults is either a horst or the end of a large tilted prism of rock (pl. 2, sec. D-D'). East of the 20th Century fault, the Yankee fault is deflected or offset to the south, and the exposures on both sides of Burriston Canyon east of the Zuma shaft indicate that it apparently continues nearly due east to an intersection with the Eureka Standard fault.

Breccias weakly mineralized with copper are present on the Addie fault throughout the full distance that it was followed on the 2,000-ft level of the Yankee mine; however, no ore bodies of commercial size or grade were developed.

## FAULTS AND FISSURES ASSOCIATED WITH IGNEOUS INTRUSION AND ORE DEPOSITION

After a period of structural quiescence that included all of the Paleocene, Eocene, and part of the Oligocene Epochs, during which time the mountains produced by the Sevier orogeny were being deeply eroded, relatively minor stresses associated with volcanism and intrusion produced swarms of steep northeast-trending faults and fissures, some of which were later mineralized. The exact inception of this period of structural activity is unknown, inasmuch as the fractures are both earlier and later than the period of monzonite intrusion.

Regionally the north-northeasterly trending faults and fissures are most closely related to the Silver City stock and its satellitic intrusive bodies. The earliest of these fractures apparently guided the emplacement of the stock and also served as conduits for the emplacement of pebble dikes and of monzonite porphyry plugs and dikes. Renewed movement after intrusion fractured the Silver City stock and adjacent rocks and reopened many of the older fissures, providing the channelways for ore-depositing solutions and the breccia zones that were filled and replaced by ore. Of somewhat greater importance, the ore solutions moving along these faults and fissures passed upward into the thrust and high-angle fault zones in the carbonate rocks, where they spread laterally and vertically to produce the extensive replacement ore bodies.

As stated earlier in the descriptions of the pebble dikes and the associated dikes of monzonite porphyry, the north-northeasterly trending faults and fissures are most abundant in the area of the North Lily intrusive center and the area between the Nevada Tunnel and Trixie shafts. In both areas the main fissure zone can be subdivided into two parallel subzones in which the fissures are somewhat more abundant and more throughgoing. Other less continuous fissures occur between these main subzones. A less well defined group of similar fissures lies southeast of the North Lily fissure zone, about half a mile (0.8 km) north of the Tintic Standard shaft. Linear zones of altered rocks, both at the surface and underground, and subsurface exposures of dikes and ore-bearing veins, all indicate that the fissure zones extend a much greater distance to the northeast than is suggested by the distribution of monzonite and pebble dikes at the surface.

Within the main fissure zones and subzones the fractures most commonly are individual slip planes that form a relatively narrow en echelon pattern with other similar fractures. Some fractures, however, are linked and branching, both in plan and in section. Some of the fissures are readily followed for long distances, whereas others apparently are no more than a few tens of feet in length. The width of the fissures ranges from a mere seam to 30 ft (9.1 m) or more, and in areas away from pebble and monzonite porphyry dikes, the fissure zones typically contain markedly angular breccias and slabs of country rock.

The dominant strike of the fissures is N. 30°-35° E., and the dominant dip is 80° NW. Other scattered fissures range in strike from N. 65° W. to N. 55° E. and in dip from 55° NW. to 65° NE. The great majority are normal faults; the displacements are invariably small, rarely exceeding 200-300 ft (61-91 m), and on some mineralized fissures, they are undetectable.

As indicated in other parts of this report, the economic significance of the north-northeasterly trending faults and fissures can hardly be overstated. They commonly form veins that are the loci of rich shoots of pyritic gold, silver, copper, lead, and zinc ores. More importantly, they were the conduits for the hydrothermal solutions that deposited the extensive replacement ore bodies in the larger structures that were formed during the Sevier orogeny. They are readily mapped because of their tendency to be occupied by dikes of monzonite porphyry and pebble breccia and also because they localize zones of hydrothermal alteration and ore-related geochemical anomalies. An example of a typical mineralized fissure is the 756 vein of the Trixie mine (see p. 188).

## BASIN AND RANGE FAULTS

Beginning in late Oligocene or early Miocene time, the area of the East Tintic district was subjected to the tensional forces that produced the deep-breaking north-trending Basin and Range faults. This period of normal faulting apparently reached a climax in Pliocene time, but the presence of scarps in unconsolidated Pleistocene deposits in many areas in central and western Utah indicates continued activity to the Holocene. Displacement on one of the strongest of these faults, which crops out at the western base of the East Tintic Mountains in the main Tintic and North Tintic mining districts, has elevated the range many thousands of feet in respect to the bedrock base of Tintic Valley. The general straightness of the east edge of the East Tintic Mountains also suggests the presence of a concealed Basin and Range fault in this area, but geophysical studies indicate that any such fault does not have large displacement (Morris, 1964a, p. K22). Thus, it is believed that the East Tintic Mountains block is chiefly a tilted internally faulted prism rather than a horst. Within the range, only two structures, the Selma and Diamond fault zones, are believed to have achieved their maximum displacement during the Basin and Range tectonism.

### SELMA FAULT ZONE

The closely spaced zone of normal faults extending from the Homansville fault northward along the western base of Lime and Pinyon Peaks to the northern boundary of the district is locally termed the Selma fault zone from exposures in and near the Selma mine in the Allens Ranch quadrangle. Northward in the Allens Ranch quadrangle, the Selma fault becomes the frontal fault of the main northeasterly spur of the East Tintic Mountains, which has more than 1,200 ft (366 m) of physiographic relief, and in that locality the Selma fault has all of the characteristics of a Basin and Range fault.

In the East Tintic district, the trace of the Selma fault zone is somewhat irregular but trends, on the average, about N. 10° E. The dip is unknown but is believed to be 45°-75° W. At the northwest base of Lime Peak and the southwest base of Pinyon Peak, the upper member of the Pinyon Queen Latite is faulted against the Fitchville Formation and Gardison Limestone. Reconstructions of the prelava surface (Morris and Anderson, 1962) indicate approximately 1,400 ft (427 m) of postlava displacement, part of which is distributed on a number of subsidiary faults in the footwall block.

The apparent alinement of the Selma fault zone with the Eureka Lilly fault and the minor postlava displacement on the Eureka Lilly fault suggest that as the Selma fault zone was formed during the Basin and Range tectonic episode, the Eureka Lilly fault was reactivated as a normal fault. This postlava normal displacement is largest near Homansville Canyon and progressively diminishes to 200 ft (61 m) or less near Burriston Canyon. South of the Trixie mine the postlava displacement on the Eureka Lilly fault apparently increases again in magnitude, and in the area of Ruby Hollow in the southern part of the main Tintic district, the Eureka Lilly fault appears to join the Diamond fault of Basin and Range age. This relation suggests that during the Basin and Range tectonism, the East Tintic Mountains block was broken into two subsidiary blocks by the Selma-Diamond fault, which in part followed the preexisting plane of the Eureka Lilly fault.

## WALLROCK TEMPERATURES, UNDERGROUND WATER, AND ROCK-STRATA GASES

Beginning with the first deep-level exploration from the Tintic Standard No. 1 shaft, mining activities in the East Tintic district have been hampered by high wallrock temperatures, hot corrosive mine waters, and by excessive and even deadly concentrations of irrespirable rock-strata gases. The wallrock temperatures and thermal groundwaters have been described by Lovering and Morris (1965), and the rock-strata gases by McElroy (1921). The following discussion is largely summarized from their reports.

Lovering and Morris' study (1965) indicates that the temperatures of the wallrocks cut by the shafts and mine galleries range from approximately 52° F (11° C), which is the mean annual temperature at the surface, to 156°F (69° C), which is the temperature of one or more places on the 1,200-ft level in the western part of the Burgin mine where the inflow of ground water is heavy. Until the inception of this study, the anomalous temperatures in the district had been attributed chiefly to heat generated by the accelerated oxidation of sulfides resulting from mine development. The possibility that abnormal geothermal gradients surrounding oxidizing sulfide bodies could be used in prospecting for blind ore deposits prompted the U.S. Geological Survey to begin its broader thermal studies. As the data accumulated over the years, however, the temperatures showed less direct relation to ore bodies and closer relation to specific rock units and geologic structures.

In general, the anomalous temperatures are restricted to the area that lies east of the Eureka Lilly fault. They are higher, more uniform, and less apt to show abrupt change in the more thermally conductive Tintic Quartzite than in the less conductive shale and limestone units that overlie it. In detail, isotherms drawn at the water table from points of direct observation, or from measurements in drill holes extrapolated downward to the water table, show a pattern that is strongly influenced by the geology of the Paleozoic rocks (fig. 36).

Within the upper plate of the East Tintic thrust, the highest wallrock temperatures are found in a zone that extends north-northeasterly from the vicinity of the Apex Standard mine to the Homansville fault, forming a compound thermal ridge. This ridge is nearly coincident with the quartzite core of the East Tintic anticline, sloping somewhat gently to the west and terminating abruptly in the area of the lava-concealed trace of the thrust fault. Interrupting the general northward trend of the thermal ridge are four sharp northeast-trending thermal anomalies. Two of these anomalies are relative thermal lows that mark the general intersections of the South and Eureka Standard tear faults with the East Tintic thrust. The other two sharp anomalies are relative thermal highs, marking the potholes of the Tintic Standard and Eureka Standard mines where quartzite forms a conspicuous northeast-trending footwall for carbonate rocks and shale along

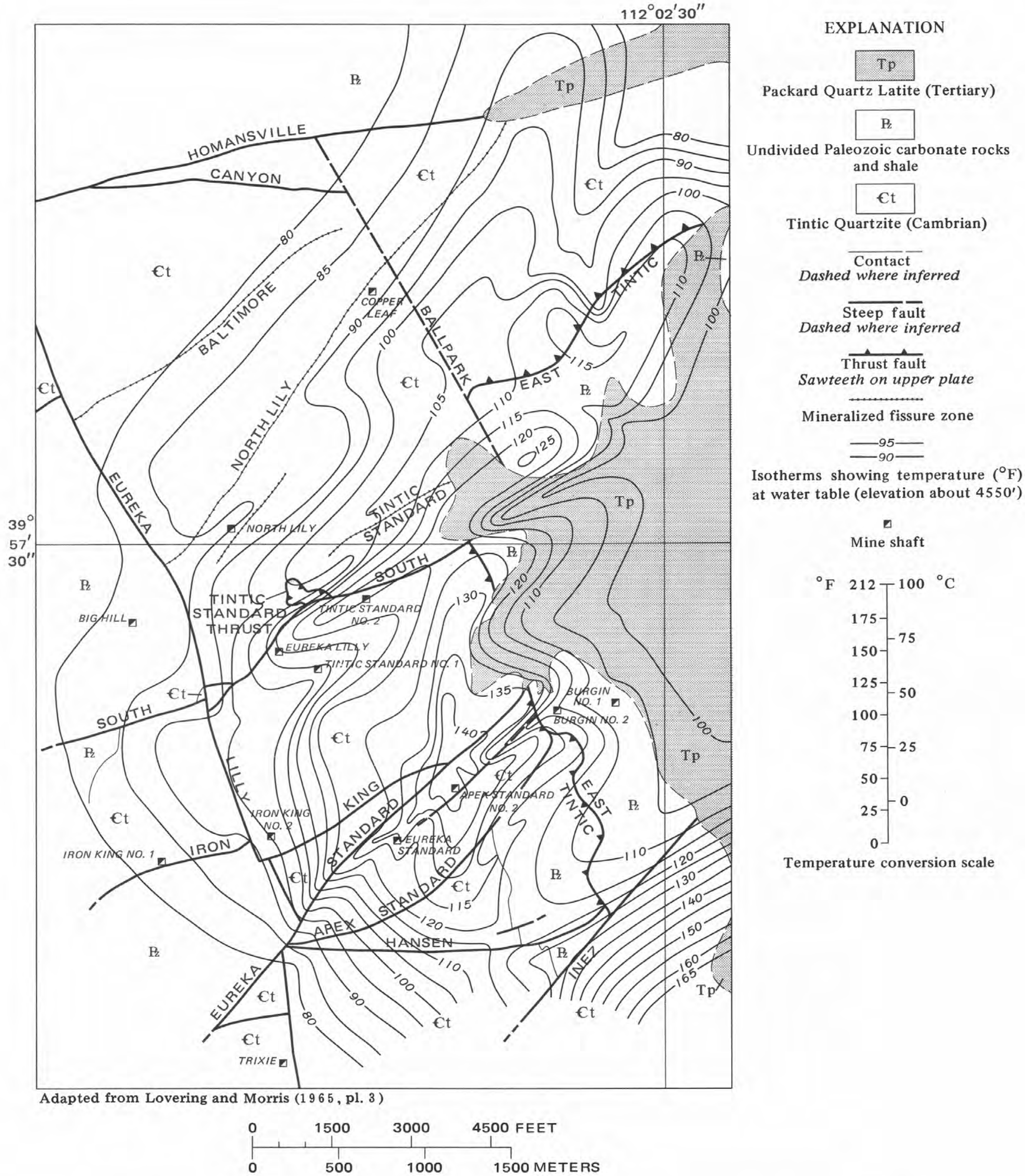



FIGURE 36. — Simplified geologic map of East Tintic thermal area showing isotherms at elevation 4,555.

parts of the same tear faults. To the southeast, the main thermal ridge terminates at a northeast-striking thermal trough that is coincident with the block of carbonate rocks and shale that lies between the Apex Standard and Inez faults.

Within the lower plate of the East Tintic thrust, relatively little is known of the general pattern of wallrock temperatures at the water table. At the 1,050-ft level of the Burgin mine near the Burgin No. 1 shaft (elevation 4,585 ft), repeated measurements show the temperature to be approximately 95° F (35° C). Westward from the shaft the temperatures gradually increase but generally do not exceed 110° F (43° C).

East and south of the mine the temperature data are chiefly known from surface drill holes. In the area south of the Inez fault, temperatures measured in drill holes increase steadily southeastward at a rate of 2.5° F (1.39° C) per 100 ft (30.5 m) horizontally, and they are extrapolated to be 163° F (72.7° C) at the water table in a drill hole that is 5,365 ft (1,635 m) S. 43½° E. of the Apex Standard No. 2 shaft. If the lateral gradient persists to the southeast at the same rate for another 1,600 ft (488 m), the temperature would reach the boiling point of water at the elevation of the groundwater surface.

Hot saline ground water is now recognized as the predominant cause of the anomalous wallrock temperature of the district. In the area west of the Eureka Lilly fault, the water table stands at an elevation of about 4,700 ft, and the ground-water surface slopes gently upward to the southwest. East of the Eureka Lilly fault, the water table is at an elevation of approximately 4,545 ft in the North Lily mine and slopes southeastward to an elevation of 4,535 ft in the Burgin mine and northward to an elevation of 4,501 ft in the Water Lillie mine. Although many local variations in the elevation of the water table are recognized, it is apparently controlled regionally by Utah Lake, about 10 mi (16 km) northeast of the district, which is maintained at an elevation of about 4,488 ft by irrigation dams and water release compacts (fig. 37).

The saline ground water apparently is derived from hot springs that are associated with an episode of Quaternary to Pliocene volcanism that is evident at several places in the east-central Great Basin. The ratios of $SiO_2$:solids, Br:Cl, K:Na, and Li:Na in the waters all suggest a magmatic origin, and the deuterium content of the water precludes its being merely heated connate water (Lovering and Morris, 1965).

The hottest ground waters thus far found in the district, which have a temperature of 156° F, are in the western part of the 1,200-ft level of the Burgin mine, where the workings are in the upper plate of the East Tintic thrust. These waters apparently are moving upward along the Eureka Standard tear fault. Inasmuch as this fault terminates downward against the East Tintic thrust zone, the waters presumably originate below the thrust and move upward and outward within the thrust zone from an unknown source to the west, southwest, or south. The total absence of thermal waters in the deep workings of mines in the main Tintic district that are west and southwest of the East Tintic district indicates a source in the southern part of this district, possibly chiefly localized by concealed Inez fault. The source of the salts contained in the waters is unknown, but it may be in Cretaceous rocks that have been overridden by the Nebo-Charleston thrust that is believed to underlie the district at great depth (Roberts and others, 1965, p. 1953).

Heavy concentrations of rock-strata gases were of great concern during the early development of the Tintic Standard mine, and occasionally during recent years they have posed a hazard to men working in unventilated stopes and galleries. The most troublesome gases are nitrogen and carbon dioxide, both of which have a suffocating effect when inhaled, even when they are considerably diluted with air. Locally, enough sulfur dioxide is also present to impart a strong odor and to cause marked irritation of the eyes and nasal passages. Careful analyses reveal that no methane or other organic or poisonous inorganic gases have been found.

The nitrogen-rich gases, being lighter than air, tend to collect in the high points of stopes, in dead end raises, and in the upper parts of unventilated and inactive galleries where air circulation is impeded. In long-disused workings, the line of demarcation between the normal air and the nitrogen-rich layer above it locally is marked by an observable difference in the degree of oxidation of the sulfide grains in the wallrocks (May, 1921).

As described by McElroy (1921), the heavy rock-strata gases are rich in carbon dioxide. All of them contain some oxygen, but when their analyses are recalculated to eliminate diffused air, they contain 60.7 to 78.7 percent of carbon dioxide and 39.3 to 21.3 percent of nitrogen. Near actively oxidizing sulfide ore, the sulfur dioxide content is also high. Most of the heavy gas that was analyzed was saturated with water vapor.

Calculations of the specific gravities of the water-saturated carbon dioxide rich gases over the range of temperatures, relative humidities, and barometric pressures existing in the mine openings, show that the gas is 1.25 to 1.40 times as heavy as water-saturated air. This difference in weight causes the carbon dioxide rich gas to collect at the bottoms of stopes and mine galleries and to migrate downward through fractures and other natural openings until it rests on the water table.

During sudden decreases in barometric pressure, the gas increases in volume according to Boyle's law. Inasmuch as the gas body is confined at the bottom and greatly restricted at the sides, the increase in volume causes upward expansion of the gas and rapid filling of the lower mine workings. Conversely, as the barometric pressure rises, the increase in pressure causes contraction of the gas body and the upper level of the gas recedes. Prior to the development of integrated ventilation systems and the installation of high-pressure fans, the mines were frequently closed during periods of low-atmospheric pressure. With time, the pockets of gas that have accumulated in the shattered wallrocks of the mine can be diluted with surface air and eliminated through up-draft shafts.

The composition of the gases and their heavy concentration in and around the larger ore bodies indicate an origin directly related to the oxidation of the sulfide ore minerals and mine timbers. The nitrogen-rich gases apparently develop through deoxygenation of dead air, with migration of the lighter gas upward and diffusion of the sulfur dioxide into the lower layer of air. The sulfur dioxide in turn produces sulfur acids that react with limestone and dolomite, generating carbon dioxide which moves downward through available openings to create pockets of heavy gas. In time, the sulfur dioxide tends to disappear from the moisture-saturated gases as a result of continuing reaction with the carbonate wallrocks.

## HISTORY AND PRODUCTION

### MINING IN THE DISTRICT

Ore was first discovered in the East Tintic district in 1899. The initial discovery was of a small partly oxidized replacement ore body in the Lilley of the West mine, the caved shaft of which is about 200 ft (61 m) west of the Eureka Lilly shaft. Prior to this discovery, the district undoubtedly had been prospected with reasonable thoroughness after the location of the Sunbeam vein of the main Tintic district in December 1869 and the staking of claims on the exposures of the replacement ore bodies in Dragon Canyon and in Mammoth and Eureka Gulches in the main Tintic district during the early months of 1870. The virtual absence of outcropping ore bodies in East Tintic, as contrasted to the conspicuous outcroppings of ore in other parts of the Tintic district, soon led to the erroneous conclusion that the area was barren, and prospecting was virtually abandoned.



In 1896 a renewed interest in the East Tintic district was suddenly generated by the sensational discoveries of the Humbug ore bodies in the eastern part of the main Tintic district. This interest was sustained by the discovery of the small Lilley of the West ore body a few years later and was further accelerated by the rich production from the large ore bodies of the nearby Beck Tunnel mine in the main Tintic district, beginning in 1904, and the Iron Blossom and Sioux mines, beginning in 1908. These latter discoveries were of blind ore bodies in an area that is only about 2 mi (3.2 km) southwest of the present center of the East Tintic district. The richness of this ore and the persistent north-trending nature of the newly discovered deposits of the Iron Blossom ore zone rekindled hope that similar concealed linear ore zones occurred farther east in the East Tintic district, and much prospecting ensued.

Among the prospectors and promoters who were active in the East Tintic district during the late 1800's and early 1900's was John Bestlemyre, and his father, August, who acquired claims east and west of the Lilley of the West shaft. In September 1907, the eastern group of the Bestlemyre claims were bonded to Emil J. Raddatz, Ira D. Travis, and their associates, who located some contiguous claims over the Packard Quartz Latite to the east and organized the Tintic Standard Mining Co. Doubtless, these men were encouraged by the discoveries in the nearby East Tintic Development (Eureka Lilly) shaft that took place about this same time (Lindgren and Loughlin, 1919, p. 247-248). After many difficulties and frustrations, Raddatz found the southwestern part of the Tintic Standard ore zone in 1916 in workings off the Tintic Standard No. 1 shaft. Approximately 1 year later while sinking the No. 2 shaft at a point 1,700 ft (518 m) northeast of the No. 1 shaft, the Main or Central ore body was penetrated; by 1925, the Tintic Standard had become one of the richest silver-lead mines in the world.

Immediately after the discovery of the main Tintic Standard ore body, a second wave of property acquisition and underground development swept the district. Much of this activity consisted of a search for the supposed northerly and southerly continuation of the Tintic Standard ore zone on the theory that another linear, Iron Blossom-type ore run had been discovered. Within 10 years, the North Standard, Pinyon Queen, Water Lillie, Central Standard, Copper Leaf, East Tintic Coalition, Eureka Bullion, Eureka Lilly, Big Hill, Montana, Iron King, Apex Standard No. 1, Eureka Standard, and other shafts had been sunk or deepened,

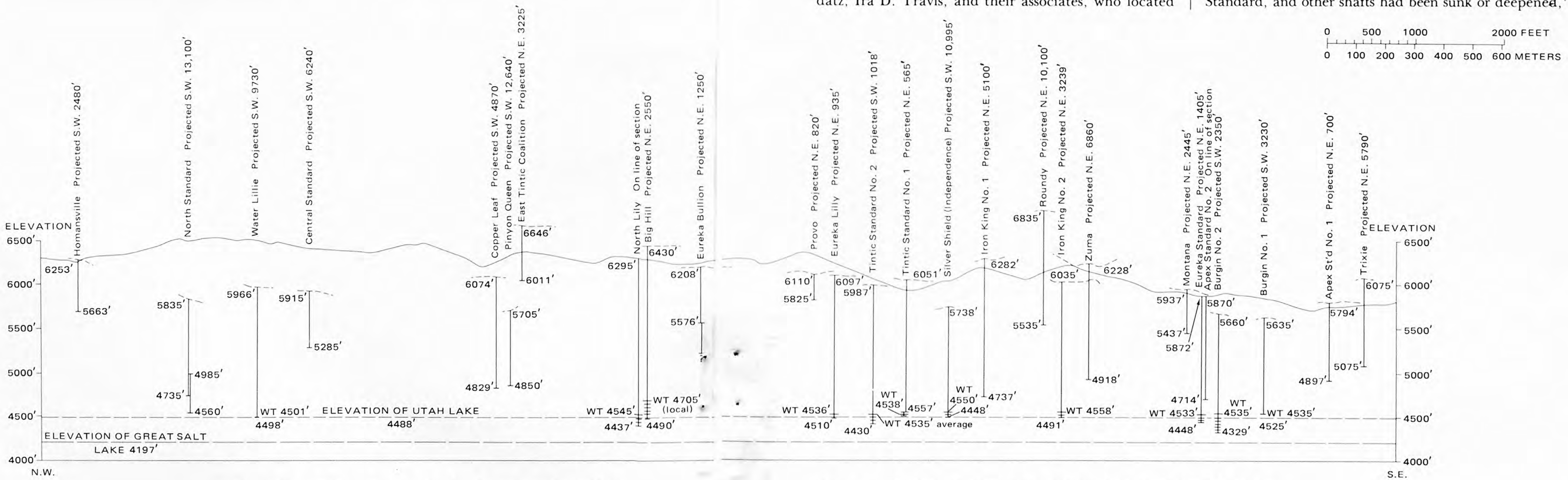



FIGURE 37. — Shafts and water table data, East Tintic district, Utah. Section runs N. 40.7° W. through Apex Standard No. 2 and North Lily shafts.

and active exploration was underway on the North Lily group of claims. Of this extensive work, only that on the Eureka Lilly, North Lily, and Eureka Standard claims resulted in the discovery of significant ore bodies.

The discovery of silver-lead ore on the Eureka Lilly and North Lily claims in December 1926 and January 1927 and of gold ore in the Eureka Standard mine in May 1928 was the second major mineral development in the East Tintic district. The North Lily-Eureka Lilly discovery resulted from the geologic studies of Paul Billingsley, who was assigned in 1922 by the International Smelting Co. to study a group of claims adjacent to the Tintic Standard mine. Billingsley's careful geologic investigations, supplemented by drilling, led him to the conclusion that the North Lily property at depth contained sedimentary host rocks and structures that were similar to those that localized ore in the Tintic Standard. This favorable target was overlain by lavas that were even more intensely altered than those that capped the Tintic Standard ore zone. On this geologic basis alone, without the interception of even traces of ore in the drill holes, an exploration crosscut was directed toward the target area from the nearest workings of the Tintic Standard mine half a mile (0.8 km) away. A few weeks later this drift cut ore on the Eureka Lilly claims and then struck the main North Lily ore body near its center. The main Eureka Lilly ore body was discovered the following year.

The Eureka Standard blind ore bodies also were discovered through geologic analysis. J. M. Snow and J. W. Wade, respectively Chief Geologist and General Manager of the Tintic Standard Mining Co., reasoned that the Ophir Formation dipping southward in the hanging wall of the Eureka Standard fault essentially duplicated the structural pothole that localized the Tintic Standard central ore body. Shaft sinking was undertaken in 1923, and although no large replacement ore bodies were discovered, vein-type ore bodies were discovered 5 years later in the footwall of the fault.

Stimulated by the North Lily-Eureka Lilly and the Eureka Standard discoveries, and the recognition of the northeast-trending fissure zones with which they are associated, considerable new work was undertaken in the late 1920's and early 1930's northeast and southwest of the North Lily mine and northeast of the Eureka Standard mine. This work resulted in the discovery of small ore bodies in the vicinity of the Apex Standard No. 2 shaft, minor ore occurrences on the 1,000-ft level of the Copper Leaf shaft, and the copper-gold ores on the Tintic Bullion and Eureka Bullion claims.

Owing to the exhaustion of ores, the Eureka Standard mine became inactive in 1940, and in 1949, the Tintic Standard, North Lily, and Eureka Lilly mines, and the adjacent properties mined from them, all ceased regular operations.

The third and most recent major mineral developments in the East Tintic district were the discovery and development of the Burgin ore center in 1958, the discovery of the Trixie ore center in 1969, and the discovery of the Ballpark mineralized area in 1970. All of these discoveries were made by the Kennecott Copper Corp. and were based in large part on the intensive geologic and alteration studies made by the U.S. Geological Survey from 1943 to 1956. These discoveries and the geologic studies that preceded them are chronicled in several reports (Bush and others, 1960; Morris, 1964b; Shepard and others, 1968).

As shown in figure 38, the East Tintic district first became a major ore-producing center in 1918, after the discovery of the Central ore body of the Tintic Standard mine. Prior to 1914 the relatively small quantities of ores reported were produced from the Lilley of the West and East Tintic Development mines and from the area of the Tintic Standard No. 1 shaft. From 1914 to 1926 the production was exclusively from the Tintic Standard, except for a few tons of ore from the Eureka Lilly mine in 1918 and the Eureka Bullion mine in 1921. Since 1963, virtually all the primary ore produced has come from the Burgin and Trixie mines.

## PRODUCTION

From the time of discovery of its first mine in 1899 through 1975, the East Tintic district has yielded 4,827,624 short tons (4,378,655 tonnes) of ore with a calculated gross value of $231,014,962 (table 8). Of the recorded production, approximately 40.1 percent of the value has been in lead, 26.7 percent in zinc, 25 percent in silver, 6.5 percent in gold, and 1.7 percent in copper. In addition, substantial but unrecorded quantities of cadmium, arsenic, and other elements have been recovered at smelters and refineries from East Tintic ores and bullion, and considerable quantities of halloysite clay and other nonmetallic commodities have been produced.

As shown by the production data, the full impact of the great depression of 1929-1934 was not felt in the district until 1931. By 1933 production had dropped to one-third of that achieved in 1929 and 1930. Although recovery was rapid after 1934, the postdepression production did not equal predepression levels until the development of the Burgin mine. Even during World War II, production continued to drop, in part because of the difficulties experienced by the mines in recruiting and retaining a competent labor force, but also because of the exhaustion of many of the larger ore bodies. The exceptionally low output in 1942 additionally reflects the inability of the relatively low grade East Tintic ores, chiefly those of the Tintic Standard mine, to qualify for significant wartime premium payments.

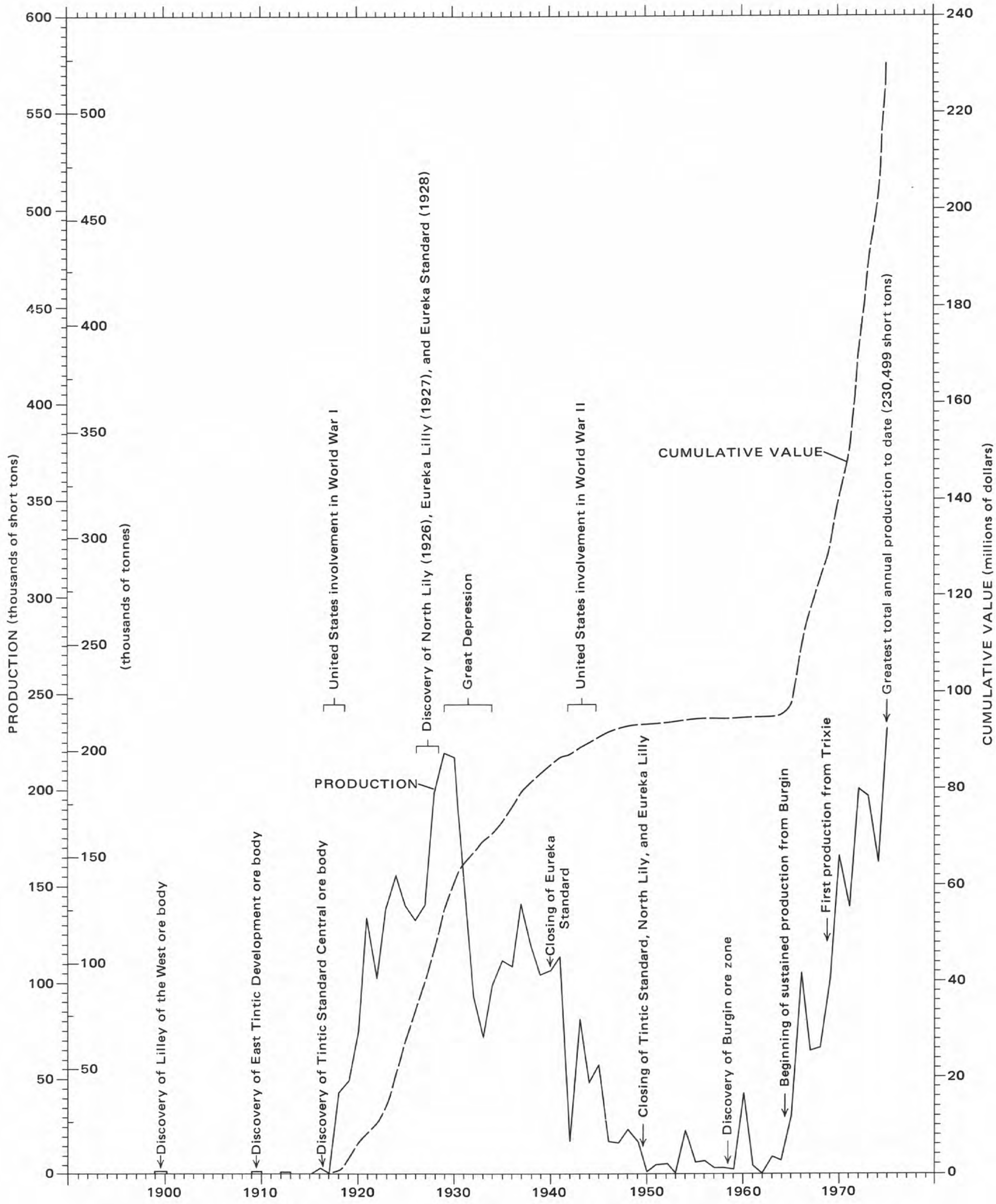



FIGURE 38. — Annual production and cumulative value of ore produced from East Tintic district 1899-1975

TABLE 8.—*Gold, silver, copper, lead, and zinc production of the East Tintic district 1899-1975*

[Production for the year 1899 estimated from data presented in Salt Lake Mining Review (June 30, 1899); production for 1909-1913 derived from Lindgren and Loughlin (1919); data for 1914-1923 from U.S. Geological Survey's Mineral Resources of the United States, and for the years 1924-1962 from the U.S. Bur. Mines Minerals Yearbook. Data for 1963-1975 furnished by Kennecott Copper Corp. Metric conversions: 1 short ton = 0.907 tonnes; 1 troy ounce = 31.10 grams; 1 pound = 0.454 kilograms.]

| Year | Ore (short tons) | Gold | | Silver | | Copper | | Lead | | Zinc | | Total value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ounces | Value | Ounces | Value | Pounds | Value | Pounds | Value | Pounds | Value | (Does not include premium payments made during 1943-1945) |
| 1899 | 50 | ... | ... | 500 | $300 | ... | ... | 30,000 | $1,200 | ... | ... | $1,500 |
| 1909<br>1910 | 1,500 | ... | ... | 4,500 | 2,376 | ... | ... | 1,250,000 | 53,750 | ... | ... | 56,126 |
| 1911 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 1912[1]<br>1913 | 1,042 | 6 | $124 | 1,063 | 640 | 24 | $4 | ... | ... | [2] 400,000 | $24,400 | 25,168 |
| 1914 | 204 | 11 | 227 | 1,092 | 598 | ... | ... | 105,665 | 4,079 | 13,580 | 762 | 5,666 |
| 1915 | 83 | 4 | 83 | 318 | 158 | 628 | 109 | 26,520 | 1,238 | 14,435 | 1,884 | 3,472 |
| 1916 | 3,414 | 279 | 5,767 | 58,596 | 38,498 | 2,116 | 576 | 1,546,422 | 106,085 | ... | ... | 150,926 |
| 1917 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 1918 | 42,193 | 1,360 | 28,114 | 147,551 | 142,829 | 669,635 | 164,931 | 3,523,792 | 261,113 | ... | ... | 596,987 |
| 1919 | 49,148 | 1,397 | 28,879 | 1,829,170 | 2,032,610 | 681,301 | 127,403 | 6,160,473 | 354,843 | ... | ... | 2,543,735 |
| 1920 | 73,550 | 1,889 | 39,049 | 2,209,339 | 2,229,223 | 778,960 | 136,006 | 13,599,295 | 1,082,504 | ... | ... | 3,486,782 |
| 1921 | 134,398 | 2,481 | 51,287 | 2,513,123 | 1,573,215 | 1,069,354 | 133,669 | 9,451,420 | 429,094 | ... | ... | 2,187,265 |
| 1922 | 102,489 | 1,078 | 22,284 | 2,045,048 | 1,381,021 | 690,000 | 95,358 | 11,367,139 | 651,337 | ... | ... | 2,150,000 |
| 1923 | 139,050 | 2,269 | 46,905 | 942,947 | 611,973 | 810,864 | 116,927 | 37,376,378 | 2,717,263 | ... | ... | 3,493,068 |
| 1924 | 156,397 | 3,413 | 70,554 | 3,928,470 | 2,624,218 | 904,198 | 117,727 | 48,531,758 | 3,931,072 | ... | ... | 6,743,571 |
| 1925 | 140,000 | 3,367 | 69,603 | 3,795,947 | 2,622,999 | 782,683 | 109,889 | 45,199,486 | 4,076,994 | ... | ... | 6,879,485 |
| 1926 | 132,182 | 5,728 | 118,409 | 3,433,264 | 2,132,057 | 747,119 | 103,028 | 45,666,455 | 3,845,116 | ... | ... | 6,198,610 |
| 1927 | 140,406 | 8,426 | 174,182 | 3,394,256 | 1,914,360 | 668,102 | 86,319 | 54,935,188 | 3,708,125 | ... | ... | 5,882,986 |
| 1928 | 199,672 | 20,789 | 429,750 | 3,885,173 | 2,261,171 | 800,589 | 116,646 | 73,356,093 | 4,628,769 | ... | ... | 7,436,336 |
| 1929 | 219,998 | 34,351 | 710,104 | 3,708,580 | 1,965,547 | 756,113 | 136,932 | 74,691,428 | 5,079,017 | 413,012 | 26,887 | 7,918,487 |
| 1930 | 217,273 | 67,683 | 1,399,143 | 3,319,772 | 1,266,493 | 888,469 | 115,323 | 53,381,457 | 2,946,656 | 304,000 | 13,682 | 5,741,477 |
| 1931 | 149,664 | 66,200 | 1,368,486 | 2,258,585 | 725,704 | 720,420 | 58,498 | 34,678,010 | 1,470,348 | 17,581 | 640 | 3,623,676 |
| 1932 | 94,920 | 42,318 | 874,798 | 2,150,149 | 599,892 | 647,016 | 35,909 | 20,138,075 | 640,391 | ... | ... | 2,150,990 |
| 1933 | 71,770 | 28,587 | 800,436 | 1,517,663 | 527,084 | 607,753 | 42,725 | 13,161,615 | 510,671 | ... | ... | 1,880,916 |
| 1934 | 98,242 | 26,716 | 993,724 | 1,353,196 | 649,128 | 696,589 | 58,722 | 10,493,891 | 405,064 | ... | ... | 2,106,638 |
| 1935 | 111,138 | 20,678 | 723,730 | 1,855,961 | 1,193,383 | 1,159,916 | 100,333 | 10,803,445 | 438,620 | ... | ... | 2,456,066 |
| 1936 | 108,342 | 23,514 | 822,990 | 1,877,454 | 846,732 | 1,078,649 | 102,148 | 12,250,317 | 576,990 | 321,156 | 15,737 | 2,364,597 |
| 1937 | 140,292 | 26,235 | 918,225 | 2,814,319 | 1,263,629 | 1,438,429 | 189,441 | 16,768,781 | 1,007,804 | 1,269,003 | 82,739 | 3,461,838 |
| 1938 | 119,353 | 11,178 | 391,230 | 2,408,564 | 1,040,500 | 1,093,413 | 109,341 | 16,116,265 | 763,911 | 1,590,666 | 73,330 | 2,378,312 |
| 1939 | 104,376 | 5,401 | 189,035 | 2,005,668 | 784,216 | 1,188,080 | 130,214 | 12,727,324 | 642,730 | 1,975,962 | 100,972 | 1,847,167 |
| 1940 | 106,857 | 5,683 | 198,905 | 1,828,703 | ,636,389 | 1,260,710 | 142,460 | 9,139,971 | 473,450 | 215,466 | 13,661 | 1,464,865 |
| 1941 | 113,652 | 5,142 | 179,970 | 1,552,726 | 540,038 | 1,201,834 | 141,816 | 12,590,071 | 728,965 | 2,728 | 204 | 1,590,993 |
| 1942 | 16,804 | 7,593 | 265,755 | 90,572 | 34,716 | 429,705 | 50,619 | 468,674 | 30,370 | 359,705 | 29,676 | 411,136 |
| 1943 | 81,500 | 14,923 | 522,305 | 816,085 | 365,198 | 1,336,508 | 157,441 | 11,771,007 | 765,115 | 634,737 | 52,366 | 1,862,425 |
| 1944 | 48,467 | 7,314 | 255,990 | 415,467 | 185,921 | 781,626 | 92,076 | 4,830,181 | 313,962 | 126,200 | 10,411 | 858,360 |
| 1945 | 56,999 | 12,093 | 423,255 | 612,294 | 274,002 | 734,787 | 86,558 | 6,357,293 | 413,224 | 247,363 | 20,407 | 1,217,446 |
| 1946 | 17,853 | 15,678 | 548,730 | 141,009 | 113,009 | 272,915 | 37,717 | 2,043,161 | 165,496 | 68,820 | 6,008 | 870,970 |
| 1947 | 16,367 | 8,771 | 306,985 | 138,383 | 99,387 | 157,551 | 33,023 | 1,268,462 | 186,083 | 11,640 | 1,222 | 626,700 |
| 1948 | 23,891 | 7,139 | 249,865 | 175,624 | 130,594 | 797,626 | 175,797 | 595,214 | 107,377 | 165,530 | 22,496 | 686,129 |
| 1949 | 17,674 | 2,651 | 92,785 | 120,825 | 86,909 | 337,755 | 64,849 | 804,222 | 123,528 | 318,919 | 38,717 | 406,788 |
| 1950 | 1,503 | 289 | 10,115 | 33,810 | 25,077 | 38,957 | 8,274 | 458,492 | 60,979 | ... | ... | 104,445 |
| 1951 | 5,024 | 369 | 12,915 | 48,146 | 43,028 | 160,102 | 38,745 | 108,653 | 19,014 | 2,569 | 462 | 114,164 |
| 1952 | 5,761 | 405 | 14,175 | 21,915 | 18,615 | 102,033 | 24,692 | 7,710 | 1,270 | ... | ... | 58,752 |
| 1953 | 353 | 7 | 245 | 3,332 | 2,838 | 1,000 | 288 | 72,560 | 9,788 | ... | ... | 13,159 |
| 1954 | 22,217 | 750 | 26,250 | 158,137 | 134,812 | 73,900 | 21,941 | 1,010,400 | 141,961 | ... | ... | 324,964 |
| 1955 | 6,420 | 221 | 7,735 | 76,592 | 68,243 | 35,000 | 13,122 | 524,400 | 82,119 | 31,000 | 3,813 | 175,032 |
| 1956 | 6,716 | 249 | 8,715 | 106,028 | 96,306 | 39,300 | 16,435 | 468,800 | 75,055 | ... | ... | 196,510 |
| 1957 | 3,564 | 77 | 2,695 | 21,000 | 10,072 | 8,900 | 2,633 | 91,900 | 13,473 | ... | ... | 37,873 |
| 1958 | 3,594 | 109 | 3,815 | 15,937 | 14,190 | 7,800 | 2,009 | 42,300 | 5,080 | ... | ... | 25,094 |
| 1959 | 2,758 | 93 | 3,255 | 3,156 | 2,878 | 8,700 | 2,713 | ... | ... | ... | ... | 8,846 |
| 1960 | 42,238 | 1,417 | 49,595 | 42,850 | 39,156 | 66,600 | 21,345 | ... | ... | ... | ... | 110,096 |
| 1961 | 4,679 | 117 | 4,095 | 4,607 | 4,259 | 5,400 | 1,616 | ... | ... | ... | ... | 9,970 |
| 1962 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 1963 | 8,258 | 72 | 2,520 | 81,961 | 104,838 | 11,300 | 3,458 | 3,158,100 | 351,812 | 492,000 | 59,040 | 521,668 |
| 1964 | 7,132 | 40 | 1,400 | 43,160 | q55,806 | 6,100 | 1,950 | 1,700,800 | 231,309 | 526,500 | 71,446 | 361,911 |
| 1965 | 29,513 | 43 | 1,505 | 342,358 | 442,669 | 4,300 | 1,506 | 7,055,100 | 1,128,816 | 2,930,900 | 424,981 | 1,999,477 |
| 1966 | 104,487 | 111 | 3,885 | 1,937,980 | 2,505,808 | 39,300 | 14,215 | 45,684,600 | 6,907,512 | 14,474,200 | 2,098,759 | 11,530,179 |
| 1967 | 63,122 | 80 | 2,800 | 893,137 | 1,384,077 | 51,400 | 19,650 | 29,771,100 | 4,167,954 | 16,148,900 | 2,235,008 | 7,809,489 |
| 1968 | 65,203 | 41 | 1,435 | 693,648 | 1,487,598 | 28,200 | 11,802 | 18,910,500 | 2,498,077 | 19,286,800 | 2,603,718 | 6,602,630 |
| 1969 | 99,327 | 735 | 25,725 | 542,932 | 972,212 | 58,200 | 27,657 | 14,464,200 | 2,153,719 | 17,786,000 | 2,596,756 | 5,776,069 |
| 1970 | 165,220 | 2,312 | 80,920 | 1,291,482 | 2,286,982 | 19,400 | 11,196 | 31,869,000 | 4,977,938 | 27,889,000 | 4,272,595 | 11,629,631 |
| 1971 | 138,952 | 591 | 20,685 | 1,010,287 | 1,561,540 | ... | ... | 24,477,800 | 3,377,936 | 19,826,800 | 3,198,063 | 8,158,224 |
| 1972 | 200,581 | 51 | 3,000 | 1,246,119 | 2,093,480 | ... | ... | 45,275,250 | 6,804,870 | 57,284,370 | 10,167,977 | 19,069,327 |
| 1973 | 197,749 | 2,697 | 263,620 | 1,227,216 | 3,138,691 | 163,993 | 97,461 | 36,160,518 | 5,888,740 | 44,091,188 | 9,105,712 | 18,494,224 |
| 1974 | 161,544 | 2,786 | 444,751 | 949,032 | 4,468,024 | 174,150 | 134,573 | 25,871,844 | 5,829,703 | 30,834,580 | 11,083,490 | 21,960,541 |
| 1975 | 230,499 | 4,997 | 805,342 | 869,087 | 3,839,122 | 177,343 | 113,782 | 19,913,323 | 4,287,139 | 33,649,845 | 13,109,643 | 22,155,028 |
| Total | 4,827,624 | 511,004 | 15,122,856 | 71,015,865 | 57,706,047 | 27,472,815 | 3,961,597 | 984,320,298 | 92,656,618 | 293,725,155 | 61,567,844 | 231,014,962 |

[1] Includes 1,000 tons of oxidized zinc ore from East Tintic Development (Eureka Lilly) mine, and 42 tons of silver-gold-copper ore from Tintic Standard No. 1 shaft.

[2] Estimated.

Revision of the standards for payment of premium bonuses is in turn reflected by the greatly increased production in 1943. During the war years and extending to 1958, the second, rather abrupt, increase in gold production resulted from the discovery of the rich gold ores of the Tintic Bullion and Eureka Bullion claims, which were developed from the North Lily shaft.

After World War II, the production from the district shows an irregular decline to the latter part of 1949 when the Tintic Standard, North Lily, and Eureka Lilly mines all ceased regular operations. From this date to 1962, the first year since 1917 that no ores were shipped from the district, the small and erratic production came chiefly from the sale of dump materials and from small leasing operations.

The production from the district since 1963 has been predominantly from the Burgin mine, except for small tonnages of ore from the Trixie mine, 1969-75, and the Ballpark area of the Burgin mine, 1970. The sharp decline in production during 1967 and 1968 chiefly reflects a strike that essentially curtailed mining operations. Caving ground near the principal stopes and the main ore haulageway in the early part of 1967 also contributed for the decline in production for that year. The output of 200,295 tons (181,668 tonnes) of ore from the Burgin mine in 1972 was the largest yield from any individual mine in the East Tintic district for a single year, substantially exceeding the previous maximum production of 156,397 (141,852 tonnes) tons of ore from the Tintic Standard mine in 1924. It is also notable that in 1968 and from 1972 through 1975 the quantity of zinc produced from the district has exceeded the quantity of lead. As mining continues in the footwall block of the East Tintic thrust in the Burgin mine, it is certain that zinc will continue to increase in importance.

The production data presented in table 8 were compiled on a mine-by-mine basis predominantly from records kept by the U.S Geological Survey and U.S. Bureau of Mines. Where necessary, these official data were supplemented by known but unrecorded small shipments of ore that were described in company reports or in contemporary newspaper and journal articles. An example is a shipment of 466 tons (422.7 tonnes) of ore from the Eureka Bullion mine in 1929 that contained 156 oz (4,851.6 g) of gold, 6,084 oz (189,212.4 g) of silver, and 20,720 lb (9,407 kg) of copper.

It should also be noted that the official government records do not always conform to the statements of production presented in the annual reports of various mining companies. This is particularly true of the Tintic Standard Mining Company, which is officially credited in 1924, for example, with the production of 156,397 tons (141,852 tonnes) of ore containing 3,413 oz (106,144 g) of gold, 3,928,470 oz (122,175 kg) of silver, 904,198 lb (410,506 kg) of copper, and 48,531,758 lb (22,033,418 kg) of lead, whereas the annual report of the company for that year lists a production of 6,147.408 oz (191,184.39 g) of gold, 4,205,463.27 oz (130,789 kg) of silver, 1,149,282.91 lb (521,774.44 kg) of copper, and 53,464,075.06 lb (24,272,690.08 kg) of lead from the same quantity of ore.

The tabulations of gross value presented in table 8 were calculated for this report by multiplying the quantity of metals produced by the average price paid during the year indicated. Thus for those years when metal prices were fluctuating rapidly and production was not uniform, the true gross value may be slightly higher or slightly lower than the figure listed. For the entire table, however, the figures are believed to be reasonably accurate. In comparison to the gross value shown in table 8, the *net* value of ores produced from the East Tintic district from 1963 through 1974, all by Kennecott Copper Corp., was $53,383,942, or about 47 percent of the gross value shown for the same interval.

## FUTURE OF THE DISTRICT

The discovery of the Burgin, Trixie, and Ballpark ore centers in areas previously considered to be underlain only by barren lava and quartzite has stimulated interest and optimism for continued new discoveries in the East Tintic district. Of major importance have been the delineation of the concealed East Tintic thrust through the eastern part of the district and the recognition of an extensive block of hospitable carbonate rocks in its lower plate. Also of potential importance is the recognition of the inferred Inez fault, which, if present, marks a large area of potential ore-bearing ground in the southern part of the district that is incompletely explored. The area of the Homansville fault, and the large block of carbonate rocks north of it, also remains incompletely tested, although ore minerals have been found in one or more drill holes. In 1978 attempts were being made to reopen the Water Lillie mine to explore an area near the Central Standard shaft.

Several specific exploration targets have been recognized, and several have been tested with encouraging results. The most attractive targets occur near the points where tear faults in the upper plate of the East Tintic thrust terminate at the lava-thrust contact. Other targets include (1) incompletely explored areas along the north-easterly trending fissure zones, particularly the areas where the fissures cross easterly and north-easterly trending faults of large displacement, as for example, the Homansville fault near the Central Standard shaft and the Sioux-Ajax fault near the South Standard shaft and (2) inadequately explored areas of the northeast-trending tear faults in the thrust plate, including the South fault east of the Tintic Standard No. 2 shaft. The number and variety of such specific exploration targets, as well as the favorable possibilities in the broad lava-covered areas in the northeastern, eastern, and southern parts of the district, are certain to insure a continuing interest in East Tintic and the eventual discovery of new ore centers.

## ORE DEPOSITS

The ore deposits[1] of the East Tintic district are all

[1] A detailed description and discussion of the mineralogy, geochemistry, and alteration relations of the ore deposits of the East Tintic district are planned for a separate report; consequently, they are only briefly reviewed here.

of hydrothermal origin and consist of (1) large and small replacement bodies in carbonate rocks, which are of principal importance, (2) fissure veins, chiefly cutting quartzite, and (3) minor disseminated deposits. Nearly all of the major ore bodies are concealed, and even the shallowest are covered by 400 ft (123 m) or more of barren rocks. The largest and richest ore bodies are confined to the Paleozoic sedimentary rocks; both structural and stratigraphic localization are important, and of the two, structural localization is of greatest importance. The minerals of the ore deposits are varied and complex and indicate an environment of ore deposition that was characterized by the moderate temperatures and pressures typical of mesothermal deposits. The minerals of the zones of wallrock alteration indicate a much greater variation in temperature and pressure, ranging from a contact-pyrometasomatic to a hot-spring environment. The dominant mineral assemblages of the altered rocks, however, are also of the mesothermal type and include clays, sericite, and cryptocrystalline silica.

## MINERALOGY

The minerals that have been identified in the ores and altered rocks of the East Tintic district are listed alphabetically below in order of their principal occurrence:

*METALLIC MINERALS OF PRIMARY ORES*

| | |
|---|---|
| Acanthite | $Ag_2S$ |
| Altaite | $PbTe$ |
| Argentite | $Ag_2S$ |
| Arsenopyrite | $FeAsS$ |
| Bismuthinite | $Bi_2S_3$ |
| Bornite | $Cu_5FeS_4$ |
| Calaverite | $(Au,Ag)Te_2$ |
| Chalcopyrite | $CuFeS_2$ |
| Enargite | $Cu_3AsS_4$ |
| Famantinite | $Cu_3SbS_4$ |
| Freibergite | $(Cu,Fe,Ag)_{12}(Sb,As)_4S_{13}$ |
| Galena | $PbS$ |
| Gold | $Au$ |
| Greenockite | $CdS$ |
| Hessite | $Ag_2Te$ |
| Jalpaite | $Ag_3CuS_2$ |
| Klaprothite | $Cu_3BiS_3 \cdot 3CuBiS_2$ |
| Krennerite | $(Au,Ag)Te_2$ |
| Luzonite | $Cu_3(As,Sb)S_4$ |
| Marcasite | $FeS_2$ |
| Matildite | $Ag_2S \cdot Bi_2S_3$ |
| Orpiment | $As_2S_3$ |
| Petzite | $Ag_3AuTe_2$ |
| Polybasite | $(Au,Cu)_{16}Sb_2S_{11}$ |
| Proustite | $Ag_3AsS_3$ |
| Pyrargyrite | $Ag_3SbS_3$ |
| Pyrite | $FeS_2$ |
| Realgar | $AsS$ |
| Sphalerite | $ZnS$ |
| Stromeyerite | $AgCuS$ |
| Sylvanite | $AgAuTe_4$ |
| Tennantite | $(Cu,Fe)_{12}As_4S_{13}$ |
| Tetradymite | $Bi_2Te_2S$ |
| Tetrahedrite | $(Cu,Fe,Zn)_{12}Sb_4S_{13}$ |

*GANGUE MINERALS OF PRIMARY ORES*

| | |
|---|---|
| Anhydrite | $CaSO_4$ |
| Ankerite | $Ca(Fe,Mg,Mn)(CO_3)_2$ |
| Barite | $BaSO_4$ |
| Calcite | $CaCO_3$ |
| Celestite | $SrSO_4$ |
| Dolomite | $Ca(Mg,Fe,Mn)(CO_3)_2$ |
| Manganosiderite | $(Fe,Mn,Mg)CO_3$ |
| Quartz, including jasperoid | $SiO_2$ |
| Rhodochrosite | $(Mn,Zn)CO_3$ |
| Siderite | $FeCO_3$ |

*MINERALS OF SECONDARY ORES*

| | |
|---|---|
| Alumian | $Al_2O_3 \cdot 2(SO_3)$ |
| Anglesite | $PbSO_4$ |
| Antlerite | $Cu_3SO_4(OH)_4$ |
| Aragonite | $CaCO_3$ |
| Argentojarosite | $AgFe_3(SO_4)_2(OH)_6$ |
| Aurichalcite | $(Zu,Cu)_5(CO_3)_2(OH)_6$ |
| Azurite | $Cu_3(CO_3)_2(OH)_2$ |
| Bayldonite | $(Pb,Cu)_3(AsO_4)_2(OH)_2$ |
| Beaverite | $Pb(Cu,Fe,Al)_3(SO_4)_2(OH)_6$ |
| Bilinite | $Fe''Fe'''_2(SO_4)_4 \cdot 22H_2O$ |
| Bindheimite | $Pb_2Sb_2O_6(O,OH)$ |
| Bournonite | $PbCu(Sb,As)S_3$ |
| Cerargyrite | $AgCl$ |
| Cerussite | $PbCO_3$ |
| Chalcanthite | $CuSO_4 \cdot 5H_2O$ |
| Chalcedony | $SiO_2$ |
| Chalcocite-digenite | $Cu_2S$ |
| Chalcophanite | $ZnMn_3O_7 \cdot 2H_2O$ |
| Chenevixite | $Cu_2Fe_2(AsO_4)_2(OH)_4 \cdot H_2O$ |
| Claudetite | $As_2O_3$ |
| Conichalcite | $CaCuAsO_4(OH)_4$ |
| Copiapite | $(Fe'',Mg)Fe'''_4(SO_4)_6(OH)_2 \cdot 2OH_2O$ |
| Copper | $Cu$ |
| Coquimbite | $Fe_{2x}\ Al_x(SO_4)_3 \cdot 9H_2O$ |
| Covellite | $CuS$ |
| Crednerite | $CuMnO_2$ |
| Cuprite | $Cu_2O$ |
| Cuprogoslarite | $(Zn,Cu)SO_4 \cdot 7H_2O$ |

Epsomite . . . $MgSO_4 \cdot 7H_2O$
Ferrogoslarite . . . $(Zn,Fe)SO_4 \cdot 7H_2O$
Goethite . . . $FeO(OH)$
Goslarite . . . $ZnSO_4 \cdot 7H_2O$
Gunningite . . . $(Zn,Fe)SO_4 \cdot H_2O$
Gypsum . . . $CaSO_4 \cdot 2H_2O$
Halotrichite . . . $Fe''AL_2(SO_4)_4 \cdot 22H_2O$
Heataerolite . . . $ZnMn_2O_4$
Hisingerite . . . $Fe'''_2Si_2O_5(OH)_4 \cdot 2H_2O$
Hydrous aluminum sulfophosphate . . . $Al_2(SO_4)_2HPO_4 \cdot 11\frac{1}{2}H_2O$
Jarosite . . . $KFe'''_3(SO_4)_2(OH)_6$
Kieserite . . . $MgSO_4 \cdot H_2O$
Kornelite . . . $Fe_4(SO_4)_6 \cdot 15H_2O$
"Lead oxide phosphate" . . . $5PbO \cdot Pb_3(PO_4)_2$
Linarite . . . $PbCu(SO_4)(OH)_2$
Malachite . . . $CuCO_3 \cdot Cu(OH)_2$
Manganocalcite . . . $(Ca,Mn'')CO_3$
Melanterite . . . $FeSO_4 \cdot 7H_2O$
Mimetite . . . $Pb_5Cl((As,P)O_4)_3$
Olivenite . . . $Cu_2(AsO_4)(OH)$
Pearceite (?) . . . $(Ag,Cu)_{16}As_2S_{11}$
Pisanite . . . $(Fe,Cu,Zn)SO_4 \cdot 7H_2O$
Plumbojarosite . . . $PbFe_6(SO_4)_4(OH)_6$
Pyrolusite . . . $MnO_2$
Quenselite . . . $PbMnO_2 \cdot OH$
Rhomboclase . . . $HFe(SO_4)_2 \cdot 4H_2O$
Roemerite . . . $Fe''Fe_2'''(SO_4)_4 \cdot 14H_2O$
Scorodite . . . $Fe'''AsO_4 \cdot 2H_2O$
Siderotile . . . $FeSO_4 \cdot 5H_2O$
Silver . . . $Ag$
"Silver plumbate" . . . $Ag_5Pb_2O_6$(?)
Smithsonite . . . $ZnCO_3$
Sulfur . . . $S$
Szomolnokite . . . $FeSO_4 \cdot H_2O$
Tenorite . . . $CuO$
Tinticite . . . $Fe'''_3(PO_4)_2(OH)_3 \cdot 3\frac{1}{2}H_2O$
Voltaite . . . $K_2Fe'''_5Fe''_4(SO_4)_{12} \cdot 18H_2O$
Wad . . . Chiefly hydrous manganese oxide
Wurtzite . . . $ZnS$

*MINERALS OF ALTERED WALLROCKS*

Adularia . . . $KAlSi_3O_8$
Allophane . . . $Al_2SiO_5 \cdot nH_2O$
Alunite . . . $(K,Na)Al_3(OH)_6(SO_4)_2$
Analcite . . . $NaAlSi_2O_6 \cdot H_2O$
Antigorite . . . $Mg_3Si_2O_5(OH)_4$
Beidellite . . . $(Na_2,K_2,Mg,Ca)_{0.33}Al_2(Si,Al_4)O_{10}(OH)_2 \cdot nH_2O$
Boehmite . . . $AlO(OH)$
Celadonite . . . $K(MgFe'')(Fe''',Al)Si_4O_{10}(OH)_2$
Cimolite . . . $Al_4Si_9O_{24} \cdot 6H_2O$
Collophane . . . $Ca_5(PO_4)_3(F,OH)$
Delessite . . . $(Mg,Fe'',Fe''',Al)_6(Si,Al)_4O_{10}(O,OH)_8$
Diaspore . . . $AlO(OH)$
Dickite . . . $Al_2Si_2O_5(OH)_4$
Endellite . . . $Al_2Si_2O_5(OH)_4 \cdot 2H_2O$
Faratsihite . . . $(Al,Fe)_2Si_2O_5(OH)_4$
Gearksutite . . . $CaAl(F,OH)_5 \cdot H_2O$
Gibbsite . . . $Al(OH)_3$
Halloysite . . . $Al_2Si_2O_5(OH)_4$
Heulandite . . . $(CaNa_2)Al_2Si_7O_{18} \cdot 6H_2O$
Hydromica (Illite) . . . $K_{1-1.5}Al_4(Si_{6.5-7}Al_{1-1.5})O_{20}(OH)_4$
Jenkinsite . . . $(Mg,Fe,Mn)_4Si_3O_{10} \cdot 3H_2O$
Kaolinite . . . $Al_2Si_2O_5(OH)_4$
Leucoxene (anatase) . . . $TiO_2$
Montmorillonite . . . $(Na_2,K_2,Mg,Ca)_{0.33}(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot nH_2O$
Mordenite . . . $(Ca,Na_2,K_2)Al_2,Si_{10}O_{24} \cdot 7H_2O$
Nontronite . . . $Na_{0.33}Fe'''_2(Al,Si)_4O_{10}(OH)_2 \cdot nH_2O$
Okenite . . . $CaSi_2O_4(OH)_2 \cdot H_2O$
Opal . . . $SiO_2 \cdot nH_2O$
Penninite . . . $(Mg,Fe'',Al)_6(Si,Al)_4O_{10}(OH)_8$
Ripidolite . . . $(Mg,Fe'',Al)_6(Si,Al)_4O_{10}(O,OH)_8$
Rutile . . . $TiO_2$
Sericite . . . $KAl_3Si_3O_{10}(OH_2)$
Thompsonite . . . $NaCa_2Al_5Si_5O_{20} \cdot 6H_2O$
Zunyite . . . $Al_{13}Si_5O_{20}(OH,F)_{18}Cl$

*MINERALS OF CONTACT AUREOLES*

Andradite . . . $Ca_3Fe'''_2Si_3O_{12}$
Augite . . . $(Ca,Na)(Mg,Fe,Al)(Si,Al)_2O_6$
Diopside . . . $MgCaSi_2O_6$
Epidote . . . $Ca_2(Al,Fe)_3Si_3O_{12}(OH)$
Forsterite . . . $Mg_2SiO_4$
Grossularite . . . $Ca_3Al_2Si_3O_{12}$
Hematite . . . $Fe_2O_3$
Idocrase . . . $Ca_{10}Mg_2Al_4(SiO_4)_5(Si_2O_7)_2(OH)_4$
Magnetite . . . $Fe_3O_4$
Saponite . . . $(Mg,Al,Fe)_3(Al,Si)_4O_{10}(OH)_2$
Serpophite . . . $H_4Mg_3Si_3O_7 \cdot 2H_2O$
Spinel . . . $MgAl_2O_4$
Zoisite . . . $Ca_2Al_3Si_3O_{12}(OH)$

The mineral components of the igneous and sedimentary host rocks not listed above are described in the appropriate sections in the early part of this report.

## REPLACEMENT DEPOSITS

Replacement ore bodies have been the source of more than 90 percent of the ores produced from the East Tintic district. They range from insignificant pods and stringers to the massive Central ore body of the Tintic Standard mine, which contained approximately 2 million tons (1,814,000 tonnes) of ore. This ore body had a pitch length of about 800 ft (244 m), and its somewhat elliptical cross section on the 900-ft level of the mine was 600 ft (183 m) long and 50-150 ft (15-46 m) wide. In general, the larger and richer replacement ore bodies occur in the hanging walls of the northerly striking westerly dipping Tintic Standard and East Tintic thrust faults, in areas where the thrusts are cut by northeasterly trending mineralized fissures and tear faults. More specifically, the greater part of the ore is also localized in deformed, brecciated, and altered limestone beds of the middle limestone member of the Middle Cambrian Ophir Formation near the planes of the thrust faults. Smaller replacement ore bodies have been mined in other carbonate beds of Middle Cambrian age in the hanging walls of the two thrust faults, particularly along the northeasterly trending fissures, and in the carbonate rocks of Ordovician, Silurian, Devonian, and possibly Mississippian ages in the footwall of the East Tintic thrust, localized in part, at least, by minor northeast-trending faults and bedding-plane thrusts. In detail, the upper surfaces of the replacement ore bodies are highly irregular with many projections, extensions, and stringers that follow minor fractures, bedding planes, and breccia zones; in general, however, the contacts between ore and the unreplaced host rocks are sharp, commonly marked only by thin rinds of manganese-stained clay and disintegrated dolomite. The occurrence of friable sanded dolomite adjacent to some ore bodies has considerably complicated the placement and maintenance of mine workings and the extraction of ore. In such areas cave-ins and sudden inflows of fluidized carbonate sand are a constant hazard.

Within the ore bodies, replacement is nearly complete, and only rarely are relict textures and structures preserved in the ore. An exception is the 260 ore body in the Burgin mine in which some ore faithfully preserves the laminations of the carbonate mud of cave deposits that were later replaced by massive fine-grained galena. Similar relict textures also are locally observed in the sulfide ores of the main Burgin ore body, but in the ore bodies above the water table, oxidation, recrystallization, and local compaction have largely obliterated the original character of the primary ore.

Oxidation of the replacement ore bodies has produced a great variety of secondary minerals including sulfates, carbonates, chlorides, phosphates, arsenates, and other minerals. Also, these ore bodies became highly porous and locally even cavernous.

## VEINS

Although the production of ore from veins of the East Tintic district is quantitatively overshadowed by production from replacement deposits, the veins have been the source of much of the moderate gold and copper production credited to the district. Almost without exception they are confined to the Tintic Quartzite and occur most commonly in the footwalls of faults that separate younger carbonate and shale beds from the Tintic Quartzite. Most of the veins strike northeasterly, the principal exception being the 756 fissure vein of the Trixie mine, which trends nearly due north. In the Eureka Standard mine, productive ore shoots in the footwall of the Eureka Standard fault have a maximum length of about 600 ft (183 m) and range in width from 4 in. (10 cm) to 5 ft (1.52 m). Individual veins and stringers less than 4 or 5 in. (10 or 13 cm) wide could not be profitably mined. In the Trixie mine the 756 vein at the 750-ft level is 520 ft (159 m) long and 1-30 ft (0.3-9.1 m) wide, averaging about 10 ft (3 m). The dip is about 75° W. The mineralized part of this vein extends vertically for at least 500-600 ft (152-183 m). Veins in the North Lily, Eureka Lilly, and Tintic Standard mines strike northeasterly, dip steeply west, and average about 4 ft (1.2 m) in width. Some have been followed for more than 1,000 ft (305 m) horizontally and 400-500 ft (123-152 m) vertically.

The East Tintic veins are localized by faults of both large and small displacement. They consist of zones of sheared and brecciated quartzite that have been mineralized by early quartz, barite, and pyrite, and by later pyrite, enargite, galena, chalcopyrite, sphalerite, copper-, lead-, and silver-bearing sulfosalt minerals, hessite and other tellurides, native gold, and other minerals. The ores are vuggy and banded; they apparently originated principally by the deposition of ore and gangue minerals in open spaces with only minor to moderate replacement of the microbreccias, wallrocks, and early sulfide and gangue minerals.

The location of the pyritic copper-gold-silver veins below or on strike with the lead-zinc-silver replacement ore bodies suggests that they occupy structures that originally served as conduits for the solutions that deposited the replacement ores. The predominance of copper and gold in the veins and lead and silver in the replacement ore bodies is chiefly attributed to selective chemical effects of the wallrocks and to some extent to the higher temperatures and greater pressures that existed in the environment of vein deposition.

## DISSEMINATED DEPOSITS

During recent exploration of the Ballpark section of the Burgin mine, disseminated zinc-lead-silver ores were found and mined in the Apex Conglomerate immediately below the Packard Quartz Latite. Prior to this discovery, no ores had been mined from the Apex, and its tight, clayey character seemed to preclude this formation as an ore host rock. The development ores consisted of scattered grains, stringers, and veinlets of galena, sphalerite, rhodochrosite, and other minerals in weakly argillized and silicified tuff, tuff-breccia, and tuff-cemented prelava rubble. The ore and gangue minerals are particularly abundant in the vicinity of the South fault and the East Tintic thrust and in areas where the Apex Conglomerate directly overlies the Tintic Quartzite. The ore and gangue minerals apparently fill isolated vugs, short narrow fractures, and other open spaces; replacement of the host rock is of minor importance. The grade of the disseminated ore is low to moderate, but in the future some of the mineralized rubble may be mined for milling ores.

## WALLROCK ALTERATION

The rocks that enclose and overlie the blind ore bodies of the East Tintic district were extensively altered by hydrothermal solutions, chiefly prior to ore deposition. These alteration zones and their relations to ore have been studied by Paul Billingsley and Norman Smith (unpub. data, International Smelting Co., Anaconda Copper Corp., 1927) and somewhat more comprehensively by Lovering and his associates (Lovering, 1949; Lovering, 1950a; Lovering and others, 1960; Lovering and Shepard, 1960a). Subsequent studies by Howd (1957) and others have been largely a reexamination and critique of Lovering's conclusions and generally have focused on one or more specific types of wallrock alteration in the district. In the studies reported on by Lovering and his coworkers, five sequential stages of alteration are recognized: (1) an early barren, or dolomitic-chloritic, stage; (2) a mid-barren, or argillic, stage; (3) a late barren, or pyritic, silicic, and calcitic, stage; (4) an early productive, or potassic-silicic-baritic, stage; and (5) a productive, or ore, stage. In brief, these stages of hydrothermal alteration have the following characteristics and effects:

### EARLY BARREN STAGE

During the initial phase of hydrothermal activity in the district, areas of limestone, ranging in size from small pods of breccia and small and large fault-bounded masses to some entire formational units, were altered to dolomite. Concurrently, parts of the basal zone of the volcanic series in the same areas were replaced by minerals of the chlorite and zeolite groups and by opaline silica. Nearly all areas of dolomitization, which extend outward for as much as 10 mi (16 km) beyond the known ore deposits, show pronounced structural localization; thus, they outline virtually all of the hydrothermal plumbing system, only a small part of which was later used by late-barren stage and ore-depositing solutions. In a recent paper, Lovering (1969) has proposed that the dolomitizing and chloritizing solutions quite possibly were convecting magnesium-bearing ground waters that had been heated by an intruding magma to temperatures sufficient to convert limestone to dolomite. Age relations of hydrothermal dolomite in East Tintic, as in various Cordilleran mining districts, show that the dolomitic alteration is earlier than the magma-related argillic alteration or the postmagmatic ore deposits.

Fault-, bedding plane-, and joint-controlled hydrothermal dolomite is particularly well exposed in Homansville Canyon 1,500 ft (457 m) northwest of the Copper Leaf shaft, and fracture-controlled chloritic alteration is also conspicuously exposed in the same general area 1,200 ft (366 m) north-northeast of the Copper Leaf. Dolomitized and chloritized rocks also crop out 1,000 ft (305 m) southwest of the Tintic Standard No. 2 shaft, 2,000 ft (610 m) northwest of the Apex Standard No. 2 shaft, and 800 ft (244 m) south of the Apex Standard No. 1 shaft.

### MID-BARREN STAGE

During the period of monzonite intrusion, which followed dolomitization but preceded jasperoidization and ore deposition, the rocks close to the monzonite stocks, plugs, and dikes in the district were invaded by hot halogen and sulfur acids. These acids bleached and argillized the igneous and other aluminous rocks and severely leached and sanded the carbonate sedimentary rocks. In the Packard Quartz Latite, which is more broadly affected than any other unit, the larger zones of argillic alteration surround groups of intrusive bodies, forming an outward-diminishing halo as much as a half a mile (0.8 km) or more wide. These zones are dazzling white and are cut by a network of fractures and joints that are stained by iron oxide and iron sulfate minerals. Within the argillic halos in the Packard Quartz Latite, detailed petrographic, X-ray, and chemical studies have revealed several locally discontinuous subzones extending outward from the contact of the intrusion and the lava, or other solution conduits. These subzones are (1) a zone in which both the phenocrysts and groundmass are altered to clay; at some places kaolinite, dickite, beidellite, and hydromica are dominant, and at other places, sericite, beidellite, and hydromica are dominant; (2) a zone within which quartz becomes increasingly abundant and the sericite gives way to hydromica; (3) a zone within which quartz and alunite are abundant; (4) a wide zone of abundant kaolinite and endellite; and (5) a fringe zone, containing montmorillonite, beidellite, pyrite, and minor amounts of a colorless chlorite, probably leuchtenbergite, that fades into fresh rock. The prevalence of pyrite in the argillic fringe zone suggests the presence of various sulfur radicals in the argillizing solutions.

In an area where a monzonite plug has invaded hydrothermal dolomite and halogen acid-rich solutions were dominant, the zonation in the dolomite is (1) hematite and quartz; (2) pyrolusite with manganite, manganapatite, and other manganese minerals; (3) fluorite, kaolinite, and diaspore; (4) diaspore, kaolinite, and fluorite; (5) kaolinite, diaspore, and fluorite; (6) kaolinite, mixed-layer montmorillonite-chlorite clay, and mixed-layer mica-montmorillonite; (7) strongly sanded and leached dolomite with some kaolinite and mica; and (8) weakly sanded hydrothermal dolomite (Lovering and Shepard, 1960b).

In the igneous rocks, the first mineral to react with the acid solutions was plagioclase feldspar, followed in sequence by the ferromagnesian minerals, potassium feldspar, and, finally, quartz, which is practically inert. In areas of intense argillization even the fine-grained intergrowth of quartz and orthoclase that forms the groundmass of both the quartz latite and the monzonite porphyry is altered to clay. The mineral products of argillization, chiefly of the plagioclase phenocrysts, in zones of decreasing order of intensity of alteration include (1) dickite, (2) kaolinite, (3) endellite, (4) beidellite, and (5) montmorillonite. Locally, sericite, alunite, and quartz occur in association with dickite, kaolinite, and beidellite.

Chemical analyses presented in other reports (Lovering, 1949; Lovering, 1950a) indicate that during moderately strong argillic alteration both the igneous and sedimentary rocks lost part or all constituents except water and substantially gained only one constituent — molecular water. The greatest proportional losses, in reference to their concentrations in fresh rock, are of CaO and $Na_2O$, reflecting the susceptibility of plagioclase to argillization. The substantial decreases in MgO and iron from many samples of argillized igneous rock similarly reflect the destruction of biotite and other ferromagnesian minerals. Some of the $K_2O$ loss can be ascribed to the argillization of biotite, but the potassium feldspars of both the phenocrysts and the groundmass also contributed. Most of the $Al_2O_3$ and $SiO_2$ that were lost were probably furnished by argillized plagioclase and biotite, although much of the alumina and silica present in these minerals reacted to form the stable clay minerals, micas, or allophane and thus were not flushed out of the rocks. Of the minor constituents, half of the $TiO_2$, chiefly contained in the biotite and magnetite, was removed, and the remainder was recrystallized to form minute grains of rutile, which are locally abundant. Similarly, half of the $P_2O_5$ was also lost, the balance presumably remaining as minute grams of apatite or as a constituent of the mixed-layer clays. The behavior of iron was less uniform. Presumably it was removed completely during the argillization of biotite and the destruction of magnetite and was partly restored in the form of pyrite.

The absence of ore-stage minerals throughout the areas of argillized igneous and sedimentary rocks, except where they are crossed by younger zones of alteration and mineralization, is strongly indicative that the argillizing solutions were barren of the ore metals. The common occurrence of the ore bodies within zones of sanded dolomite and solution breccia, however, emphasizes the importance of the argillizing solutions in preparing the sites of ore deposition and enlarging the conduits and fractures that were later followed by the late barren stage and the ore-depositing solutions.

The principal zones of argillic alteration in the district surround the groups of plugs that are located northwest of the North Lily mine and south of Big Hill. A third area of extensive argillic alteration occurs at the north side of the Silver City stock in the vicinity of the Nevada Tunnel shaft in the southwest corner of the district. The area of the Helen prospect near Highway 6-50 at the eastern portal to Homansville Canyon is well known for its conspicuous exposures of an argillized monzonite plug, an argillized contact between quartz latite and hydrothermal dolomite, and an adjacent area of strongly sanded dolomite.

## LATE BARREN STAGE

After the period of monzonite intrusion and argillic alteration, the rocks near the structural and stratigraphic features that later became the sites of ore deposition were jasperoidized, calcitized, and pyritized. The most important of these late barren types of alteration is jasperoidization, inasmuch as many of the jasperoid bodies were later sites of ore deposition. The jasperoid masses chiefly replace Paleozoic carbonate rocks, occurring along many of the fissures and in many of the breccia masses that earlier had been followed by the dolomitizing and argillizing solutions. In particular, the masses of sanded dolomite and the rubble-filled solution channels near the outer fringe of the zones of argillic alteration were readily entered by the silica-bearing solutions and extensively silicified. The jasperoid bodies range from small masses 1 ft (0.3 m) or less in diameter to huge bodies 700 ft (213 m) or more wide and high. They are highly irregular in form and commonly reflect the general shape of the conduit along which they occur. Where the breccia mass was large, the jasperoid body is podlike; elsewhere they commonly are tabular or pipe shaped, reflecting the form of bedding-plane or crosscutting faults or of fault intersections. In most ore bodies the jasperoid is incompletely replaced or filled by the ore minerals and forms an irregular envelope or casing around the ore.

Hand specimens of unweathered jasperoid are mostly light to medium gray to black. Many are banded or layered, commonly because of shrinkage during dessication and crystallization from the original gelatinous form. Most jasperoid bodies also show evidence of one or more periods of brecciation and recementation prior to the introduction of the ore stage minerals. Under the microscope the jasperoid consists of minute interlocking grains of clear quartz, some of which are peppered with minute inclusions of allophane. The youngest jasperoids, whose deposition probably extended into the early phases of ore deposition, also contain crystals of barite, pyritohedral and cubic pyrite, and minor veinlets and clumps of light-green delessite. Contemporaneous with these minerals are water-clear crystals of quartz that fill vugs and coat fractures in the early-formed jasperoid.

The fluids that deposited the jasperoids of the late barren stage are believed to have been warm nearly neutral bicarbonate solutions that were still undersaturated with the bases. The silica contained in them may have been derived from either magmatic sources or from the thick Tintic Quartzite that underlies the district, or both. A magmatic source is indicated for the Ba, $CO_3$, and $SO_3$ that was introduced along with the $SiO_2$. The most readily accessible area in the district where jasperoid bodies of the late barren stage may be observed, other than the ore bodies of the Tintic Standard, Burgin, North Lily, and other mines, is the general vicinity of the Tintic Standard No. 1 shaft, where a small mass of iron-stained baritic jasperoid crops out adjacent to the North Lily road. The massive exposures of jasperoid at the eastern and southeastern base of Pinyon Peak and elsewhere in the district apparently originated shortly after the deposition of the lavas through the agency of downward-moving meteoric waters and are not related to the jasperoids of the hydrothermal phase.

Calcitic alteration is most evident in the basal part of the Packard Quartz Latite above or uprake from the masses of jasperoid and ore. The calcite-filled fractures, vugs, and breccia zones that occur in limestone and dolomite above and outward from jasperoid may also have originated during the substage of calcitic alteration, but the ubiquitous character of such features in carbonate rocks precludes a definite correlation. The calcitized lavas are nearly identical in appearance to their unaltered counterparts and can be detected only under the microscope or by chemical techniques. This alteration type was first discovered under the microscope when the plagioclase feldspars of presumably fresh quartz latite were found to be partly to wholly replaced by calcite. Subsequent mapping of the calcitized lavas based on random closely spaced testing of the rock by conventional use of dilute hydrochloric acid, later checked by examination of thin sections, revealed rather widespread calcitization in the lavas above and uprake from jasperoid and ore (Lovering, 1949, p. 29). Characteristically, the edges of the calcitized zones are irregular and tail out along fractures, pebble dikes, and other channelways.

In thin section, the calcite is seen to replace the plagioclase feldspar, extending outward from fractures and twinning planes. Care must be taken to distinguish it from calcite veinlets, which have been introduced from downward percolating ground water from the zone of weathering. The solutions that hydrothermally calcitized the lavas are believed to be the same as those that jasperoidized the carbonate rocks at depth. As these solutions moved upward through brecciated and sanded carbonate rocks with which they reacted, they became depleted in $SiO_2$ and enriched in Ca, Mg, and $CO_2$. As they moved upward and outward through the overlying lavas, replacement of the calcium feldspars ensued. The principal areas of calcitized lavas cropping out at the surface in the district occur in the zone of pebble dikes and fractures northeast of the North Lily and Tintic Standard mines. Elsewhere the calcitic lavas are overlain by fresh lavas, or they were obliterated by the sulfur acids generated during the weathering of disseminated pyrite and are known only from drill holes and underground workings.

Pyritic alteration of the late barren stage is probably the most conspicuous and widespread of the alteration types in the East Tintic district. It is particularly common in the lavas above jasperoidized carbonate rocks and ore, and in both sedimentary rocks and lava adjacent to mineralized fractures and pebble dikes; however, it also occurs in thick masses of lava that are believed to be remote from any or bodies. Many of the pyritized zones are large, the zone near Low Lonesome Point exceeding 1 mi (1.6 km) in length and having a probable width of three-quarters of a mile (1.2 km) or more. In the vicinity of the North Lily, Tintic Standard, and Burgin mines, the pyritization strongly reflects the northeasterly trend of the pebble dikes and mineralized fractures and also broadly reflects the eccentric shape of the Tintic Standard trough and other features of the lava-concealed sedimentary rocks.

The unweathered pyritized lava appears little changed from unaltered lava except for the addition of minute cubic crystals of pale greenish-yellow pyrite. Under a strong lens or in thin section, all of this pyrite is seen to have a cubic crystal habit and to replace the indigenous grains of magnetite in the rock. Where closely spaced pyrite cubes cluster on biotite phenocrysts, it is evident that the pyrite replaces small grains of exsolved magnetite and obviously does not combine with the iron in the crystal lattice of the biotite.

At the surface and extending to a depth of 40-60 ft (12-18 m), virtually all the pyrite grains in the zones of pyritic alteration are thoroughly oxidized and are marked by minute vacuoles coated with iron oxides. The acids generated by the oxidation of the pyrite in areas where the pyrite content exceeded 2 percent have bleached the rocks, causing them to be superficially similar to the argillized lavas. The weathered pyritic lavas also are characterized by thin seams of jarosite, geothite, and other iron minerals and by only minor to incipient development of clay minerals in contrast to the extensive development of clays in the argillized zones.

Chemical analyses of the unweathered pyritized lavas indicate only the addition of sulfur to the rock and presumably the loss only of oxygen. This relation, coupled with the remarkably uniform dissemination of pyrite in the lava and the common localization of pyritic alteration on the hanging-wall side of west-dipping faults, suggests pervasive neutral gas-phase introduction of the sulfur and reaction with the magnetite of the lavas. These gas-phase reactions extended upward and outward far beyond the limits of other types of late barren stage alteration, affecting rocks that show no other changes except sulfidization of the iron oxides.

During the episodes of pyritic alteration, iron-bearing sedimentary rocks were also pyritized, particularly the Tintic Quartzite and Ophir Formation, which commonly contain 1-4 percent of iron sulfide over large areas near ore bodies and their conduits. In addition to the zones of pyritic alteration near the Tintic Standard mine and Low Lonesome Point, areas of pyritic alteration occur in the general vicinity of the North Standard, Silver Shield (Independence), Central Standard, Eureka Lilly, Burgin No. 1, and Zuma shafts, and in many other parts of the East Tintic district. Pyritic alteration in argillic fringe zones is virtually identical with the pyritic alteration of the late barren stage and may be distinguished only by its occurrence at the margins of the argillized halos.

## EARLY PRODUCTIVE STAGE

The appearance of several distinctive if not widespread minerals that are younger than the main alteration products of the late barren stage but earlier than the ore minerals marks the early productive stage of alteration. These minerals include clear quartz, barite, sericite, and hydromica, or in some areas orthoclase, and possibly rhodochrosite and other manganese minerals. Pyrite also continued to be deposited in abundance during this and the following ore stages. The intimate association of these minerals with jasperoid and ore suggests that as the main period of jasperoidization declined, the solutions became increasingly enriched in barium, potassium, iron, sulfur, and manganese. The barium and potassium were deposited with the youngest jasperoids to form abundant barite of several generations, and sparse sericite, hydromica, or orthoclase. Commonly the manganese remained in solution longer than the other elements and was deposited on the outer fringe of the mineralized area as one or more manganese carbonate minerals or as hypogene manganese oxides. The potassic alteration, which is the most characteristic feature of the early productive stage, chiefly affects clay minerals that were formed during the mid-barren stage and the chlorite of the late barren stage and so is abundant only where these minerals are abundant, as in lava or monzonite close to ore. Elsewhere potassic alteration is sparse or is lacking in areas where no prior argillic alteration occurred.

The solutions responsible for the early productive stage of alteration appear to have been relatively neutral in chemical character and with time seem to have contained decreasing amounts of potassium, barium, silica, and manganese and increasing amounts of metals, thus becoming the ore-depositing fluids. The areas of potassic alteration in the East Tintic district, as compared to other zones of alteration, are small, rarely extending more than a few feet in the wallrocks of ore shoots or more than a few hundred feet above ore along fractures and conduits. The largest areas occur in the pyritized and weakly argillized lavas uprake from the North Lily, Tintic Standard, Burgin, and Trixie ore bodies. These zones were detected only through the recognition of late-stage orthoclase and sericite in thin sections of the altered rocks.

## PRODUCTIVE STAGE

The productive, or ore-depositing, stage began with the first deposition of ore minerals. Geochemically it may be considered to be the terminal phase of hydrothermal alteration, diminishing in intensity with time until all volcanic-related hydrothermal solutions ceased to flow. Paragenetic relations indicate that during the productive stage, quartz, pyritohedral and cubic pyrite, rhodochrosite, and calcite were deposited early, followed in sequence by sphalerite, galena, tetrahedrite, enargite, proustite, and other sulfosalts, hessite and other tellurides, and gold. Recent studies in the Burgin mine indicate at least two major stages of galena deposition with an intervening episode of sphalerite deposition.The early galena tends to be finer grained than the later galena and to contain less silver and antimony in the mineral structure. The late galena clearly replaces the earlier sphalerite (Smit and Foth, 1970, p. 752-753). Intermittently during the deposition of the ore minerals, renewed deposition of pyrite, quartz, rhodochrosite, and calcite took place. At other times, these minerals were either dissolved or replaced.

Other details of the ore bodies are given elsewhere in this report.

## ZONATION OF ORE DEPOSITS

Within individual ore centers, and on a district-wide basis as well, a zonation is apparent in the bulk composition of the ores. In the Tintic Standard, North Lily, and possibly the Eureka Standard mines, the ores in the Tintic Quartzite at depth, which are believed to be on the inlet of the ore-solution conduits, are rich in barite, copper, and gold. Above these ore bodies, mostly uprake to the northeast, the replacement bodies in the carbonate rocks are rich in silver and lead. On the outlet side of the solution channelways, the tenor of silver and lead in the replacement bodies diminishes, and manganese and zinc become important constituents of the ores.

On a district-wide basis the high zinc and manganese content and the relatively low silver content of the Burgin ores, as compared to the Tintic Standard and North Lily ores, suggest that the Burgin deposits represent an outer zone of ore deposition similar to the peripheral zone of manganese and zinc ores at Butte, Mont. At East Tintic, however, the relative small number of mines and the limited vertical and horizontal range of the ore bodies preclude a pronounced display of compositional zonation.

## ORIGIN OF THE ORES

The ore deposits of the Tintic and East Tintic districts are unquestionably the final product of Oligocene volcanism and have many of the characteristics that are commonly ascribed to magma-derived ores. Relations in the East Tintic district and elsewhere in the East Tintic Mountains indicate that the wallrock-altering and the ore-depositing solutions began to flow in volume only during the terminal phases of the eruption of the Laguna Springs Volcanic Group and the intrusion of the Silver City stock and related plutons. Earlier eruptions of the extensive Packard Quartz Latite and related rocks, and voluminous eruptions and intrusions of the Tintic Mountain Volcanic Group and Sunrise Peak Monzonite Porphyry produced only insignificant quantities of hydrothermal fluids and no ore. These relations seem to preclude the possibility that the solutions of the mid- and late-barren alteration stages and the early productive and ore-depositing stages were merely local connate or ground waters that had been mobilized by volcanism and intrusion. Such a mechanism is proposed for the extensive hydrothermal dolomite in the district; however, this dolomite is demonstrably much earlier than ore, and many of the zones of most intense dolomitization are barren of even traces of the ore metals.

Additional evidence for the magmatic origin of the hydrothermal solutions is also found in the acid character of the argillizing solutions of the mid-barren stage. Such solutions are found only in volcanic terranes and are well known from studies in the Valley of Ten Thousand Smokes, Alaska (Zeis, 1929), Lassen National Park, Calif. (Anderson, 1935), Yellowstone National Park, Mont. (Allen and Day, 1935), and many other volcanic centers throughout the world (Lovering, 1950a). The neutral to alkaline brines and bicarbonate solutions that compose connate and many ground waters are highly unlikely sources for such acidic solutions.

If a volcanic origin for the mid-barren solutions is accepted, then the obvious localization of jasperoid and ore along argillized channelways and in masses of sanded dolomite and solution breccia is strong evidence that the postargillic and ore-depositing solutions were derived from the same source and escaped along the same conduits. The close regional association of all of these altered rocks and ore suggests a common origin.

Evidence for the magmatic derivation of the ore bodies is also found in the isotopic character of their contained lead and sulfur. As shown by Stacey, Zartman, and NKomo (1968, p. 808), the lead of the ore bodies is remarkably uniform in composition and is isotopically similar to the leads in the feldspars of the Silver City stock. These leads appear to be a mixture of lead derived from the intrusive magma and radiogenic lead derived from the upper crustal rocks through which the mineralizing solutions passed. As shown by Ames (1962), the isotopic composition of the sulfur of the sulfide minerals of Tintic and East Tintic ores is also compatible with a magmatic hydrothermal origin. The strongest evidence is found in the relatively narrow range of $^{34}S$ values, which has been shown by Jensen (1959) to be characteristic of magmatic hydrothermal ore deposits. In addition, the sulfides in the replacement ore deposits of the two districts are progressively enriched in $^{34}S$ outward from the Silvery City stock, suggesting that this magma body and its subsurface extensions were the principal and possibly the only source of the mineralizing solutions. Finally, the temperatures of deposition of the sulfide minerals, as estimated by the fractionation of the sulfur isotopes between primary sulfide and sulfate minerals in East Tintic ore deposits range from 230° to 480° C, characteristic of the range of temperatures of solutions of magmatic origin.

## MINES, PROSPECTS, AND PROPERTIES

In comparison with many other mining districts in the Great Basin, the East Tintic district contains only a relatively small number of productive mines and an equally small number of major prospects. The large numbers of minor mines and prospects that are characteristic of other camps are not present, chiefly owing to the limited exposures of ore-bearing sedimentary rocks in the district and to the great expense of exploring beneath the thick and barren volcanic cover. Lack of knowledge of the subsurface geology has also hampered development in the district, and it continues to impede exploration of the lava-covered areas that lie northeast of the Copperleaf shaft, north and east of the Burgin No. 1 shaft, and south and east of the Apex Standard No. 1 and Trixie shafts.

In the following section all the productive mines and most major prospects are described in alphabetical order, covering their location and history, development, production, geology, ore bodies, ores, and other features of interest. The mines and prospects not included either are unimportant, or their descriptions and records have not been preserved. Figure 39 shows the major properties of the East Tintic district in 1973.

### APEX STANDARD MINE

The Apex Standard mine is in the central part of the East Tintic district about 1 mi (1.6 km) south-southeast of Dividend and less than a quarter of a mile (0.4 km) east of the Eureka Standard mine (pl. 1). Prior to the development of the Burgin mine, the Apex Standard was the principal underground development on a block of 143 patented mining claims in the central and southeastern part of the district owned by the Chief Consolidated Mining Co. Since its acquisition by Chief Consolidated, the Apex Standard has been considered an integral part of the company and not a separate subsidiary unit.

The Apex Standard group of claims is a consolidation of several former small mining companies whose early history is not well known. According to C. A. Fitch (oral commun., 1954), a shaft, later to be renamed the Apex Standard No. 1 shaft, was sunk to a depth of 165 ft (50 m) on the Lincoln claims during the surge in mining activities that followed the discovery of the Iron Blossom ore bodies in 1908. Presumably this underground exploration was in search of the easterly continuation of the Sioux-Ajax fault. A few years later, in 1917, during the excitement that followed the discovery of the main Tintic Standard ore body 1 mi (1.6 km) to the north, control of the Lincoln claims was acquired by Lewis W. Merriman, Frank Kimball, S. S. Pond, F. W. Brock, Hugh Hefferman, and others who formed the Apex Standard Mining Co. In 1918 and 1919 the existing shaft was deepened to the 900-ft level and prospecting proceeded on the theory that the Tintic Standard ore bodies were part of a linear ore zone similar to those in the main Tintic district. Early in 1921, the original Apex Standard Mining Co. absorbed the adjacent Tintic Zenith, Tintic Eastern, and Tintic Union mining companies, and later that year, full control of the expanded company was acquired by the Chief Consolidated Mining Co., which purchased much treasury stock on the stipulation that the money be used entirely for development and exploration.

During the latter part of 1923 the Chief Consolidated Co. began to sink the Apex Standard No. 2 shaft, completing it in 1924 to a crosscut that had been driven northward at the 900-ft level of the No. 1 shaft. Eight years later the No. 2 shaft was deepened to the 1,100-ft level to intercept ore bodies that had been mined northeastward in the Eureka Standard mine toward the Apex Standard claims (see pl. 4). This exploration was only moderately successful, and the mine was inactive from 1936 through the period of World War II. From 1946 to 1949 the Apex Standard property was under lease to the Newmont Mining Co., who carried out exploration at the 900-ft level south of the No. 1 shaft, after which it again became inactive. Since 1956, the claims have been under lease to the Kennecott Copper Corp., which has developed the Burgin ore body in the north-central part of the property. (See section "Burgin Mine.")

#### DEVELOPMENT AND PRODUCTION

The Apex Standard No. 1 shaft is located about 1 mi (1.6 km) south-southeast of Dividend. It has a collar elevation of 5,794 ft and is 898 ft (273 m) deep. Two levels have been cut: the 700 level at an elevation of 5,105 ft, and the 900 level at 4,896 ft. An inclined winze, which is located 1,215 ft (370 m) south-southeast of the shaft, is about 350 ft (107 m) long and descends from the 900 level to an elevation of 4,720 ft. In the vicinity of the ore body on the Middle fault about 1,065 ft (325 m) north-northwest of the No. 1 shaft, a steep inclined winze extends to the 1,000 level, and an inclined raise extends to the 800 level. The lateral workings from the No. 1 shaft, including the 900 level crosscut to the No. 2 shaft, aggregate approximately 8,500 ft (2,591 m).

The Apex Standard No. 2 shaft is 1,550 ft (472 m) north-northwest of the No. 1 shaft (fig. 40). The collar elevation is 5,872 ft, and the shaft is about 1,158 ft (353 m) deep. Six levels have been developed; these include the 700 level at an elevation of 5,150 ft, the 800 level at 5,070 ft, the 875 level at 4,991 ft, the 900 level at 4,916 ft, the 1,000 level at 4,815 ft, and the 1,100 level at 4,732 ft. The lateral workings aggregate approximately 10,300 ft (3,139 m). A number of raises and winzes also have been developed; one winze near the No. 2 shaft is more than 100 ft (30 m) long and extends from the 900 level to the 1,000 level.

Prior to the discovery and development of the Burgin mine, the Apex Standard mine had produced 13,728 tons (12,451 tonnes) of ore with a gross value of approximately $300,000 (Bush, 1957b, p. 122). The production from the Burgin ore bodies, which are chiefly within the Apex Standard claims, is discussed separately on pages 115-116.

### GEOLOGY

The underground workings of the Apex Standard mine chiefly explore the crest and east flank of the north-trending East Tintic anticline in the area where it is cut by the Eureka Standard, Apex Standard, and other northeasterly trending tear faults (fig. 41). The Paleozoic rocks exposed in the mine range from the Tintic Quartzite to the Herkimer Limestone; the Cenozoic rocks include the Apex Conglomerate, Packard Quartz Latite, and Pleistocene and Holocene unconsolidated deposits.

The tear faults all dip moderately to the northwest and have broadly curving planes that are characteristic of faults with large lateral displacement. Although the movement on these faults is predominantly horizontal, the block between the Iron King and Eureka Standard and Apex Standard faults is relatively upraised, and the block between the Apex Standard fault and the Hansen and South Apex faults (which are south of fig. 41) is relatively depressed. The strike of the Iron King fault is somewhat more easterly than the strike of the Eureka Standard fault, and the two structures are presumed to merge at an unknown point northeast of the No. 2 shaft. The area between the converging faults has, in the past, been compared with the Tintic Standard and North Lily potholes (see p. 76 and 173-174), but diamond-drill holes and underground workings have not disclosed ore in this grabenlike structure.

The No. 1 shaft is collared in the upper part of the middle limetone member and descends into the lower shale member of the Ophir Formation at a depth of 165 ft (50 m) and into the Tintic Quartzite at 370 ft (113 m). At a depth of 485-520 ft (148-159 m), it crosses a wide breccia zone presumed to be the Apex Standard fault and then reenters the lower shale member. It recrosses the lower contact of the Ophir Formation at a depth of 825 ft (251 m) and bottoms in the Tintic Quartzite at 892 ft (272 m). Workings at the 700 level extend 85 ft (26 m) northerly from the shaft, where they intersect and follow the northeast-trending Apex Standard fault for 175 ft (53 m).

The more extensive workings at the 900 level extend chiefly north, east, and south from the shaft. The north-trending workings crosscut the Apex Standard fault at a point that is 160 ft (49 m) north of the shaft and then follow beds of the Tintic Quartzite, which generally strike N. 14° E. and dip 60° E., for 1,570 ft (479 m) to the Apex Standard No. 2 shaft. At a point 1,065 ft (325 m) north-northwest of the No. 1 shaft, this drift cuts the northeast-trending Middle fault, which is mineralized, and follows it for about 500 ft (152 m) southwest and northeast of the drift. This fault also has been stoped upward to the 800 level. The east-trending workings at the 900 level crosscut the north-striking and east-dipping Ophir, Teutonic, Dagmar, and Herkimer Formations in the footwall of the Apex Standard fault east of the shaft. Two north-trending drifts from this crosscut explore the contact zone of the Tintic and Ophir Formations and the middle limestone member of the Ophir Formation where they abut the fault. Although small quantities of galena and barite occur locally in the fault zone, no ore bodies were found. South of the No. 1 shaft, the 900 level workings extend, in general, south-southeasterly, cutting the north-trending east-dipping strata at an acute angle. The basal contact of the Ophir Formation is crossed about 1,220 ft (372 m) south-southeast of the shaft, and the greater part of the workings remain in the Ophir Formation until they intercept the east-striking north-dipping South Apex fault 2,150 ft (655 m) south-southeast of the shaft and again enter the Tintic Quartzite. The contact zone of the Tintic Quartzite and Ophir Formation where it is exposed south-southeast of the No. 1 shaft contains low values in lead, zinc, and silver and has been explored by an inclined winze to an elevation of 4,720 ft, approximately 185 ft (56 m) vertically below the level. The dolomite marker bed in the lower shale member of the Ophir in the same general area also contains low values in base metals and silver, but it has not been explored.

The Apex Standard No. 2 shaft is collared in the Packard Quartz Latite and remains in almost structureless porphyritic lava to a depth of 618 ft (188 m), where it crosses into tuffs that contain many boulders and slabs of Paleozoic limestone. At a depth of 680 ft (207 m) the shaft passes into the prevolcanic Apex Conglomerate, remaining in this formation for 107 ft

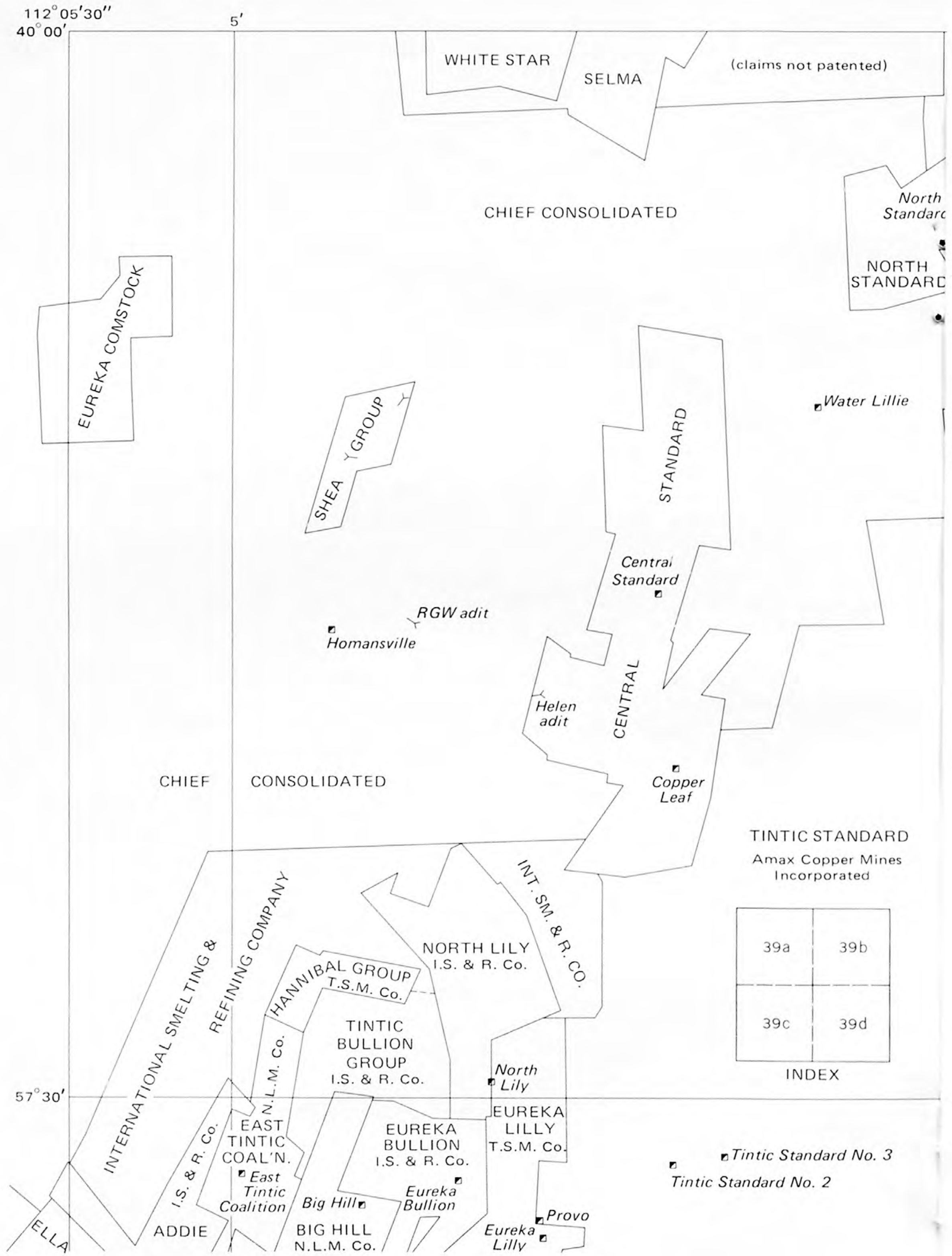



Figure 39. — Generalized property map of East Tintic district showing major blocks of patented claims.



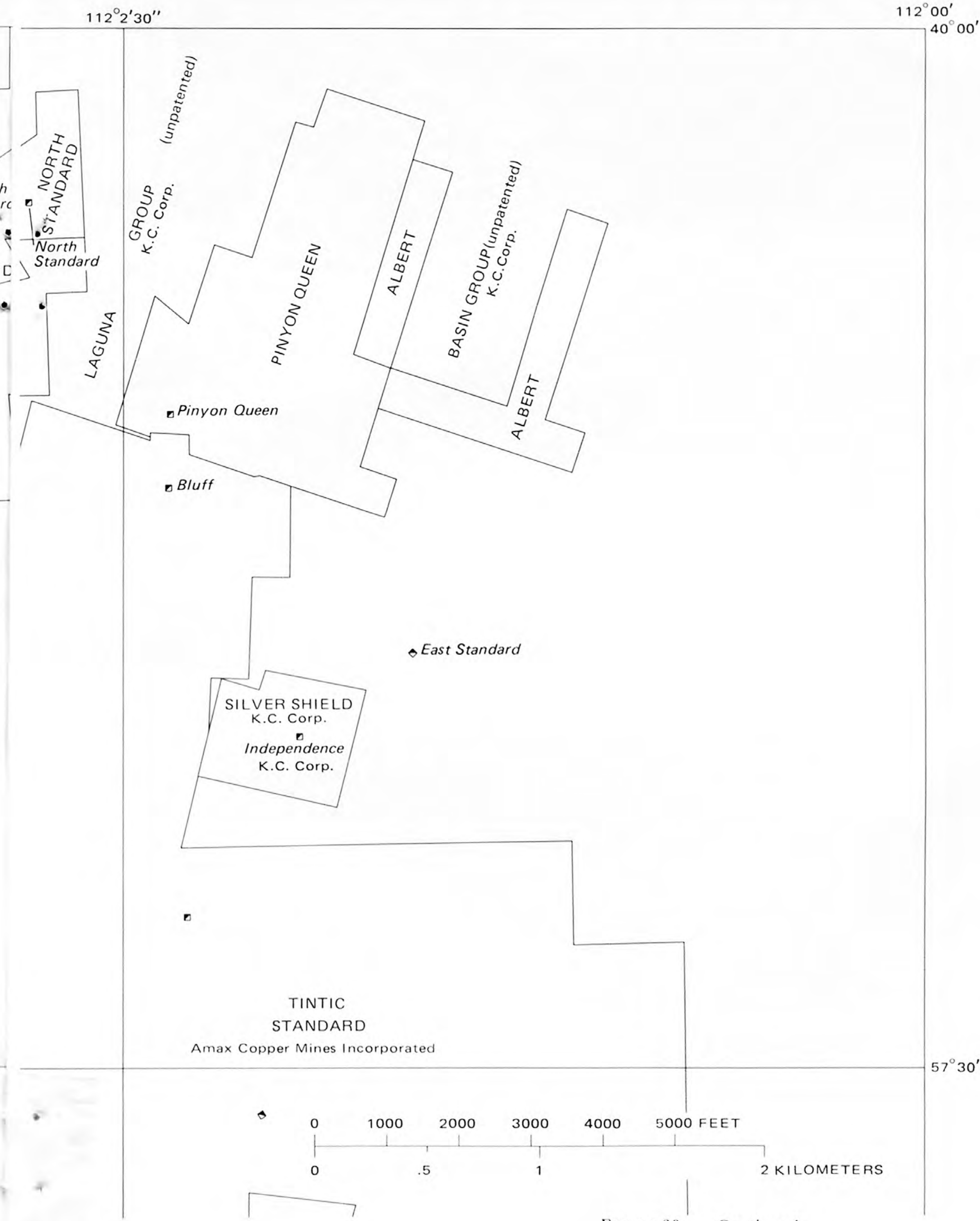



Figure 39. — Continued.

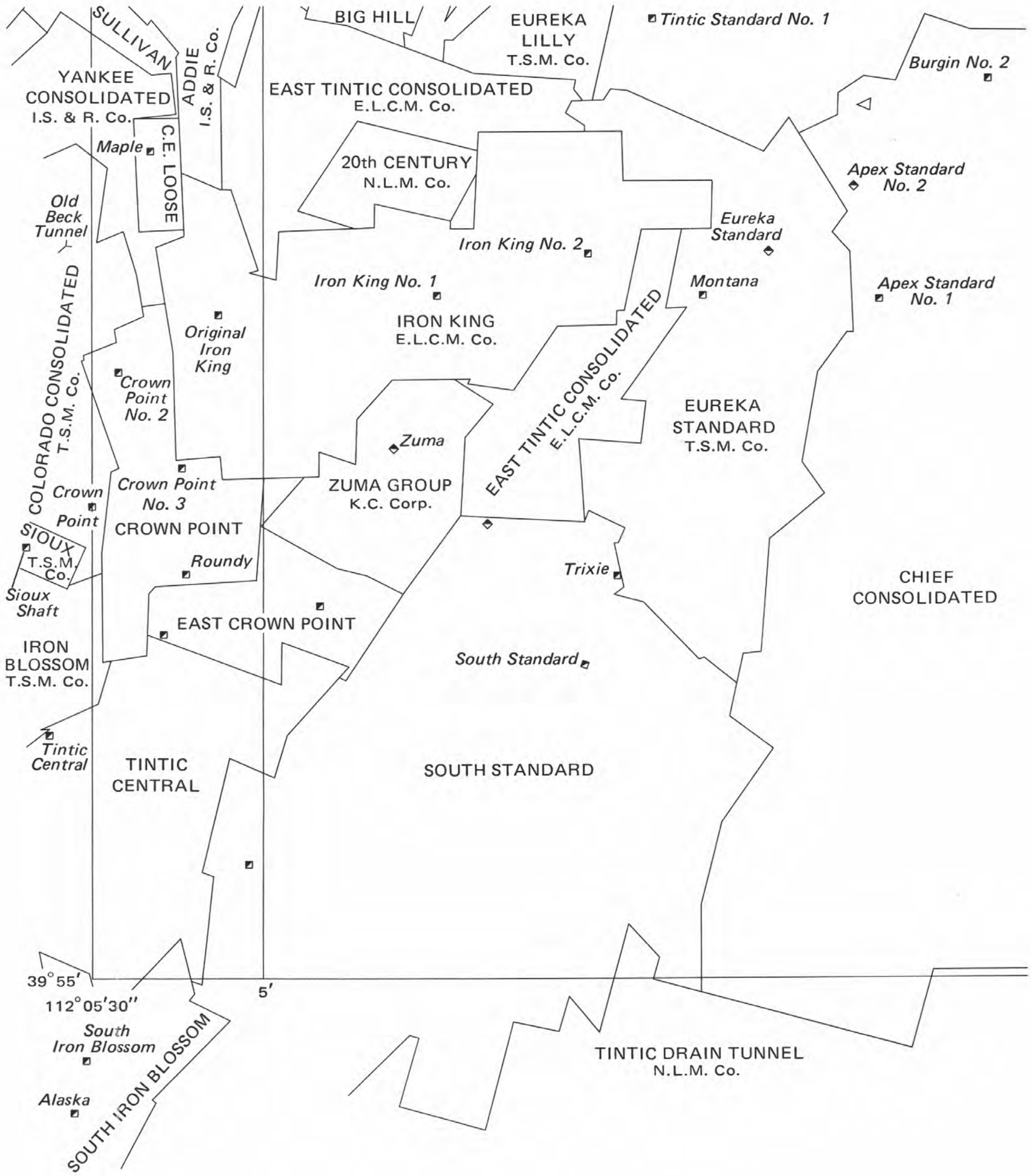



FIGURE 39. — Continued.

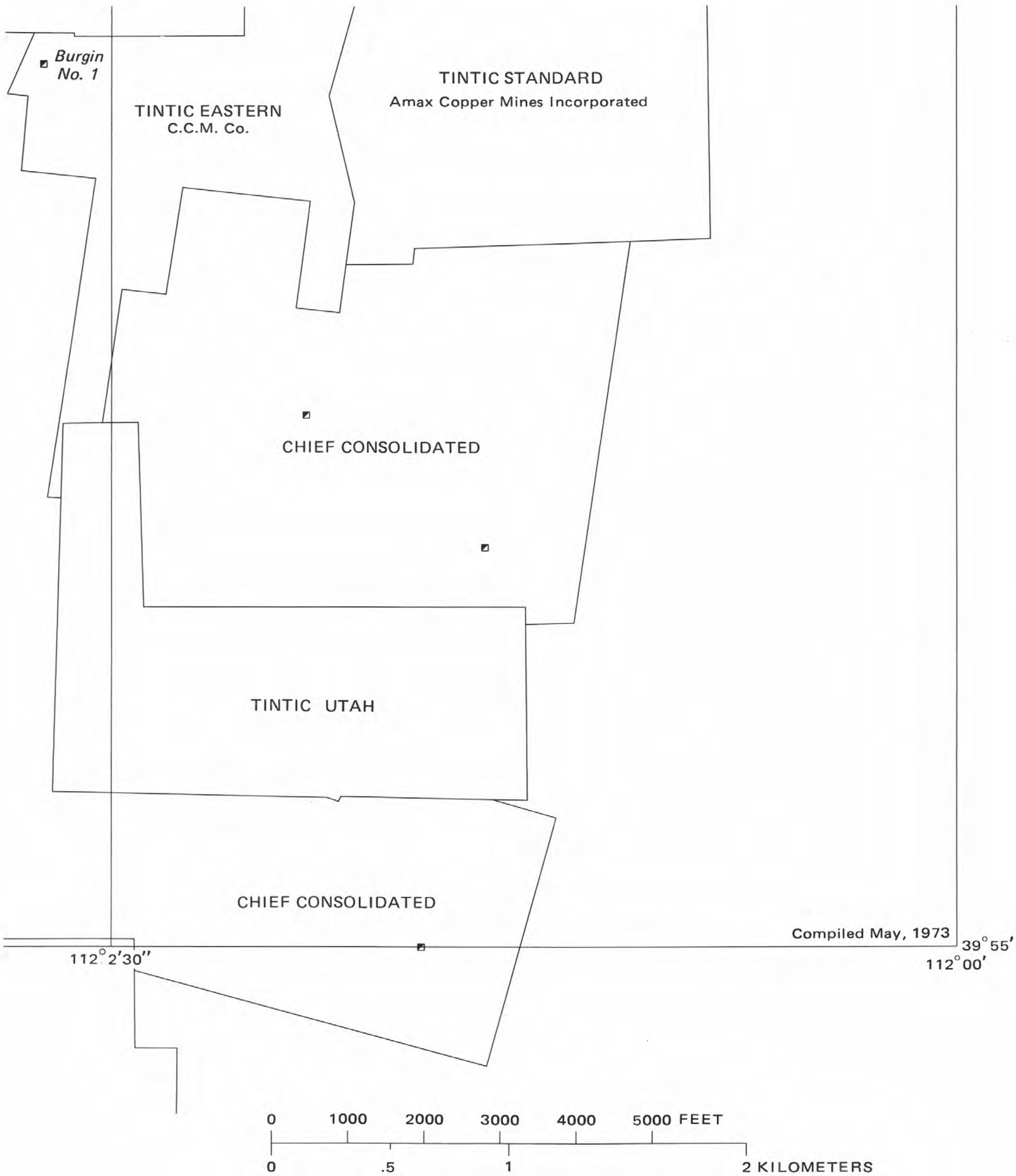



FIGURE 39. — Continued.

FIGURE 40. Apex Standard No. 2 shaft head frame and dump, looking north. Prominent ledges in background are Packard Quartz Latite.

(33 m) before it enters the Ophir Formation in the hanging wall of the Eureka Standard fault. The fault zone is penetrated by the shaft at a depth of 890-900 ft (271-274 m) below which it is in the Tintic Quartzite in the footwall of the Eureka Standard fault to its bottom at a depth of approximately 1,178 ft (359 m).

The workings at the 700 level of the Apex Standard No. 2 shaft extend for 300 ft (91 m) north and 200 ft (61 m) south of the shaft and are largely confined to the boulder-bearing tuff in the lower part of the Packard Quartz Latite. A southeast-trending crosscut, however, enters Tintic Quartzite in the footwall of the Eureka Standard fault at a point about 205 ft (62 m) southeast of the shaft. The workings at the 800 level chiefly extend southerly from the shaft, passing from the lower member of the Ophir Formation into the Tintic Quartzite across the Eureka Standard fault 112 ft (34 m) south-southeast of the shaft. These workings continue southerly, following north-trending and moderately east dipping beds of the Tintic Quartzite to the Middle fault, which is intercepted about 600 ft (183 m) south-southeast of the shaft. The workings at the 875 level enter the Eureka Standard fault zone 50 ft (15 m) south of the shaft, follow it southwesterly for approximately 50 ft (15 m), and then turn westward into the lower shale member of the Ophir of the hanging wall. A north-trending quartz vein about 6 in. (15 cm) wide was cut in the west crosscut 120 ft (37 m) southwest of the shaft. The workings at the 900 level extend northwesterly, northeasterly, and southwesterly from the shaft and, of course, connect with the workings at the 900 level of the No. 1 shaft. The northwest-trending workings were driven chiefly to crosscut and explore the Eureka Standard structural trough. They pass through the main strand of the Eureka Standard fault 37 ft (11m) northwest of the shaft and enter the lower Ophir shale, cutting the northwest-striking moderately southwest-dipping strata at an acute angle. The base of the shale is cut 548 ft (167 m) north-northwest of the shaft, and within an additional 35 ft (11 m) an east-northeast-trending steeply north dipping fault was explored by a curving drift that extends westerly from the crosscut. This fault is presumed to be the Iron King fault, or a subsidiary fault generally parallel to it. The other workings at the 900 level extend 210 ft (64 m) southwest and 620 ft (189 m) northeast of the shaft following multiple strands of the Eureka Standard fault. Small ore bodies, which are continuous with ore bodies mined upward from the 1,000 level, were found in the footwall of the fault 160-295 ft (49-90 m) north-

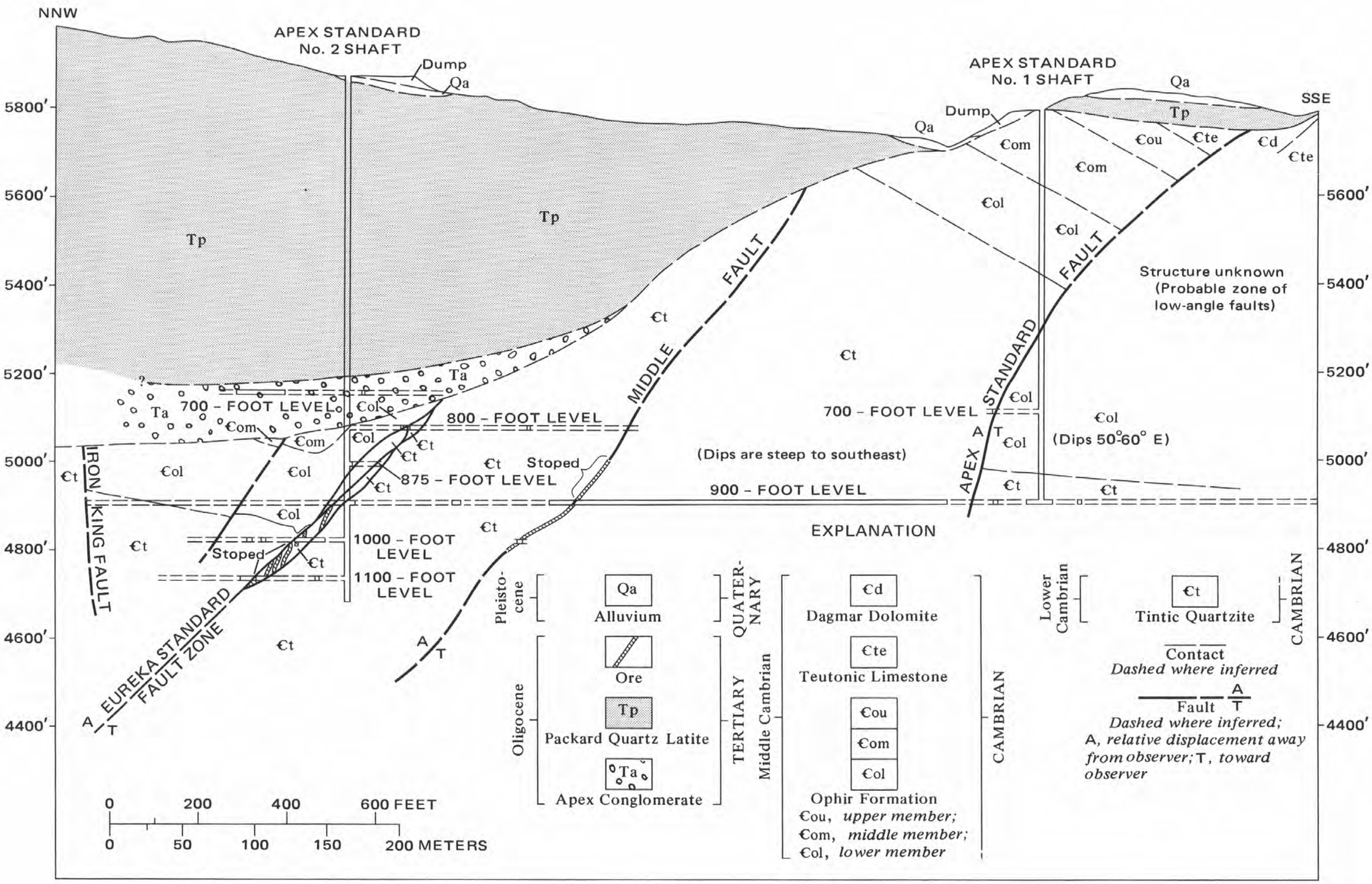



FIGURE 41. — Geologic cross section through Apex Standard No. 1 and No. 2 shafts.

east of the shaft. The workings at the 1,000 level are the most extensive of those driven from the No. 2 shaft. In general they follow the various strands of the Eureka Standard fault from a point 100 ft (30 m) west of the shaft to the Tertiary erosional surface underlying the Packard Quartz Latite more than 2,400 ft (732 m) northeast of the shaft and continue for several hundred feet into the lavas. These workings were driven chiefly to explore the Eureka Standard fault zone, and at the time they were driven in 1934-36, it was not known that they were in the hanging wall of the East Tintic thrust fault a short distance above the extensive Burgin ore body (pl. 4).

The underground workings that were driven from the Apex Standard No. 2 shaft indicate that the Eureka Standard fault is a slightly sinuous zone of linked and branching fractures that trends about N. 50° E. and dips 43° NW. Despite the considerable lateral displacement on this structure, there is surprisingly little drag folding in the shale strata of the hanging-wall block.

### ORE BODIES

Two ore bodies have yielded nearly all of the ore produced by the Apex Standard mine. These are the Middle fault ore shoot on the 900 level, and the continuation of the Eureka Standard ore shoot on the 1,000 level near the No. 2 shaft. The Middle fault ore body is localized within the fault zone between walls of Tintic Quartzite, apparently in an area where there is a greater than average amount of shearing and brecciation. It has been stoped upward from the 900 level, through a vertical distance of about 85 ft (26 m). The workings are irregular in shape but in general indicate that the ore shoot had a pitch length of about 160 ft (49 m), a maximum width of 50 ft (15 m), and a maximum thickness of 8-10 ft (2.4-3 m). The ore body plunges at a low angle due west in the northeast-trending moderately northwest dipping fault zone. It does not appear to be localized in the fault zone by any obvious secondary feature.

The Eureka Standard ore shoot is in the footwall of the Eureka Standard fault, extending from a point 30 ft (9 m) below the 1,000 level upward to the 900 level in the area immediately north and northeast of the Apex Standard No. 2 shaft. The ore body is generally restricted to fractures in the quartzite footwall of the fault, but its widest part is opposite the contact of the Tintic Quartzite and Ophir Formation in the hanging wall. Like the Middle fault ore shoot, the Eureka Standard ore shoot plunges at a low angle nearly due west in the footwall of the fault. The overall pitch length is approximately 250 ft (76 m), the maximum width is 50 ft (15 m), and the maximum thickness is 12 ft (3.7 m). The localization of the ore shoot within the fault zone apparently is not related to obvious secondary structures in the footwall of the Eureka Standard fault.

Numerous other pods, stringers, and occurrences of ore minerals have been noted elsewhere in the mine. Many of these have not been stoped.

The ores of the Middle fault and Eureka Standard fault ore shoots in the Apex Standard mine are closely similar in texture and general character to the ores of the Eureka Standard mine but are different in overall content of gold and copper. The ores in the Apex Standard consist of sheared and brecciated quartzite, the interstices of which are filled with crystalline quartz and barite, and partly oxidized pyrite, galena, enargite, sphalerite, argentite, hessite, and possibly some ruby silver, native gold, and other minerals. One lot of 136 tons produced from the Middle fault ore shoot, in January and February 1925, had an average grade of 1.25 oz per ton of gold, 14.2 oz per ton of silver, and 19.3 percent lead (Crane, 1925, p. 8). According to Cook (1957, pl. 3), the average grade of 13,728 tons produced from both ore shoots was 0.10 oz per ton gold, 13.70 oz per ton silver, 0.40 percent copper, and 2.70 percent lead. Although the Eureka Standard and Middle fault ore shoots are similar to ore bodies in the adjacent Eureka Standard mine, they contained only one-seventh the average amount of gold and one-tenth the average amount of copper, but about twice as much lead and half again more silver.

The partly oxidized ores of the Apex Standard mine contained chiefly hydrous iron oxides, cerrusite, and anglesite stained and intergrown with azurite and malachite. Fine-grained native gold was common, and cerargyrite and wire silver were fairly abundant. The degree of oxidation diminished with depth, and some narrow stringers of enargite exposed on the 1,100-ft level are virtually unaltered.

### WALLROCK TEMPERATURES

As indicated by Lovering and Morris (1965), the Apex Standard mine is located near the center of the East Tintic thermal area. Wallrock temperatures exceed 135° F (57° C) at the 1,100-ft level and 124° F (51° C) at the 900 level in the near vicinity of the No. 2 shaft. The source of this heat is a hot-spring system that apparently discharges at the water table; it is described on pages 87-89 and is more fully discussed in Lovering and Morris (1965).

## BIG HILL MINE

The Big Hill mine is in the central part of the East Tintic district approximately 1 mi (1.6 km) due west of Dividend (pl. 1). It is named from the prominent conical hill a short distance southwest of it that rises to an alititude of 7,004 ft.

The original claims in the area apparently were patented by John Bestlemyre, and a company was organized June 15, 1899. In 1919 controlling interest in this company was acquired by Jesse Knight and his associates, who enlarged the shaft that was on the property and deepened it from 200 to 600 ft (61 to 183 m). Briefly in 1926 the property was leased to the Tintic Standard Mining Co. In 1929, the North Lily-Knight Corporation assumed controlling interest, and the property was leased to the North Lily Mining Co., who extended the shaft to a total depth of 1,940 ft (588 m) in 1931. During this same year the Big HIll 1,600-ft level was connected with the North Lily 1,200 level, and the Big Hill 1,900 level was extended onto the properties of the North Lily and Eureka Bullion Mining Companies. The connection at the 1,200 level of the North Lily mine was reportedly made to improve ventilation in the Big Hill mine and to utilize the excess water-pumping capacity of the North Lily mine. All operations from the Big Hill shaft were suspended in May 1932.

### PROPERTY DEVELOPMENT AND PRODUCTION

The property of the Big Hill Mining Co. consists of all or part of five patented mining claims and an additional 1.58 acres (0.64 hectares) of patented surface rights, all totaling approximately 72 acres (29 hectares) (see fig. 39). The claims cover the north half of Big Hill and extend northerly along its north-trending spur ridge. Of the outstanding stock, 50.02 percent is owned by the North Lily-Knight Co., 95.47 percent of which company is owned by the North Lily Mining Co., 56.97 percent of which, in turn, is owned by the International Smelting and Refining Co., a wholly owned subsidiary of The Anaconda Co.

The Big Hill shaft is collared at an elevation of 6,430 ft, and lateral workings have been driven at the 200-, 600-, 1,091- (1,100), 1,600-, and 1,900-ft levels. The 200-ft level has approximately 850 ft (259 m) of workings and explores the area south and southwest of the shaft. The 600-ft level has about 790 ft (241 m) of workings and also extends southwesterly from the shaft. The 1,091-ft level is approximately equivalent to the 700 level of the North Lily shaft; it has approximately 1,070 ft (326 m) of workings and explores an area that is northwest of the shaft, including part of the Addie property. The 1,600- and 1,900-ft levels were both driven in conjunction with the exploration and development of the North Lily and Eureka Bullion properties, and within a short distance east-northeast of the shaft, extend across the boundary of the Big Hill claims.

No ores are known to have been produced from areas within the Big Hill claims, although some ores were produced from Big Hill workings that extended onto adjacent properties.

### GEOLOGY

The shaft, inaccessible in 1973, is collared in a small exposure of the middle part of the Ajax Dolomite that is nearly surrounded by alluvium on the northeast slope of Big Hill. Less than 800 ft (244 m) north, east, and south of the shaft, the carbonate rocks are overlain by highly argillized and pyritized quartz latite. Near the shaft they are cut by several northeast and east-trending pebble dikes.

Not much is known about the geology in the upper levels of the mine. Cross sections indicate that the 200-ft level probably explores the lower part of the Ajax Dolomite and that the 600-ft level explores either the Opex Formation or the upper part of the Cole Canyon Dolomite. All of the shaft, in fact, is in carbonate rocks of Cambrian age, and because of the extensive hydrothermal alteration in the Big Hill area, it is presumed that many of the normal characteristics of these rocks have been changed or obliterated.

At the 1,600-ft level (elevation 4,825 ft) the shaft passes through a steep north-trending fault that brings the Herkimer Limestone on the east side down against the Dagmar and Teutonic Formations. The occurrence of these formations at a depth of 1,600 ft (488 m) indicates that a low-angle fault lies above the 1,600-ft level on which about 400 ft (123 m) of strata has been cut out. On sections B-B' and C-C' of plate 2, this low-angle fault is inferred to be about 1,325 ft (404 m) below the surface and to have eliminated a significant part of the Cole Canyon Dolomite and all or nearly all of the Bluebird Dolomite.

The original objective of the deepened shaft was the Ophir Formation. The shaft however, was bottomed in the Teutonic Limestone above the Ophir, apparently because of strong inflows of water that first appeared at an elevation of 4,705 ft. According to contemporary newspaper accounts, both the 1,600- and 1,900-ft levels, or workings from them, penetrated the Ophir Formation and Tintic Quartzite but not on Big Hill claims.

## BLUFF SHAFT

The Bluff shaft is located in the north-central part of the district approximately a fifth of a mile (0.3 km) south of the Pinyon Queen shaft in the S½SE¼ sec. 34, T. 9 S., R. 2 W. (pl. 1 and fig. 39). The early history of the property is unknown; however, the original

Bluff claim appears to predate other claims in the area, including those in the Pinyon Queen and Tintic Standard blocks. The claim is now part of the extensive holdings of the Tintic Standard Mining Company.

According to incomplete company records, shaft sinking was first undertaken in June 1923 to satisfy assessment requirements, utilizing an existing shallow prospect pit on the property. Work was intermittently carried out during 1924, 1925, and 1926, when the shaft reached a total depth of 243 ft (74 m). One level was driven at a depth of 45 ft (13.7 m), 2 ft (0.6 m) above the water table in the lavas; an advance of 107 ft (33 m) was made in a northeasterly direction at this level in 1924.

The shaft is collared in the tuff member of the Pinyon Queen Latite but probably passes into the Packard Quartz Latite at shallow depth. Both rock units in the vicinity of the shaft are strongly pyritized and locally are replaced by opaline silica. Oxidation of the pyrite has bleached the rocks and has created abundant limonite and other hydrous iron oxides.

A churn drill hole drilled by the Tintic Standard Mining Co. 350 ft (107 m) southeast of the shaft indicates that the lavas are 390 ft (119 m) thick in the area and are underlain by the Teutonic and Ophir Formations. The Tintic Quartzite was penetrated at a depth of 873 ft (266 m) in the drill hole.

## BURGIN MINE

By A. Paul Mogensen, W. M. Shepard, H. T. Morris, L. I. Perry, and S. M. Smith

The Burgin mine is at the east edge of the productive area of the East Tintic district, about three-quarters of a mile (1.2 km) southeast of Dividend (pl. 1). The property is served by the Iron King Branch of the D. & R. G. W. Railroad and by an all-weather hard-surfaced road maintained by Utah County.

The Burgin ore center was discovered in 1958 by the Bear Creek Mining Co., exploration arm of Kennecott Copper Corp., largely on the basis of geologic studies made earlier by the U.S. Geological Survey (Bush and others, 1960, p. 1539). Many years prior to the Geological Survey's activities, the conspicuous zone of pyritized Packard Quartz Latite that characterizes the Burgin No. 1 shaft area had attracted moderate attention from prospectors, and several shallow workings were sunk on iron-stained fissures. The largest of these workings, the Chief Oxide shaft, was completed to a depth of about 75 ft (23 m) in the early 1920's. This shaft was located about 50 ft (15 m) west of the Burgin No. 1 shaft, and although no discoveries were made from it, the area of pyritized lavas surrounding it first became known as the Chief Oxide alteration halo. In later reports by Kennecott personnel and others, the alteration zone has since been termed the Burgin alteration halo.

In the late 1920's the Chief Oxide area was recommended for exploration by Paul Billingsley, geologic consultant to several of the East Tintic companies, who suggested that another structural pothole similar to those in the Tintic Standard and North Lily mines might be present beneath the lava. As a result, drifts were driven and some diamond drilling was carried out from the Apex Standard mine by the Chief Consolidated Mining Co. No commercial ore bodies were discovered, although the workings were driven into a point that lies above some of the ore bodies of the Burgin mine (see pl. 41, fig. D and p. 112). During this period a horizontal diamond-drill hole, which was collared in volcanic rocks on the Apex Standard 1,000-ft level, was drilled eastward into carbonate rocks that are now known to be in the footwall of the East Tintic thrust fault. Because of intensive alteration, however, these rocks were not recognized at that time as being the Opohonga Limestone and, therefore, in the footwall of a lava-concealed thrust. With the onset of the Great Depression in 1929, the exploration efforts stopped.

After World War II, the Newmont Mining Co. became interested in the Chief Oxide area as a result of the Geological Survey's work on alteration and structure in the East Tintic district and carried out a program of underground rehabilitation and drifting in the Apex Standard mine. Excessive heat, high operating costs, and failure to discover large ore bodies, however, led Newmont to abandon this program in 1948. As a final phase of Newmont's exploration effort, two churn-drill holes were sunk near the west edge of the Chief Oxide pyritic halo. The first of these holes, N-1, which was located near the west-central boundary of the pyritized zone, confirmed the presence of a thick sequence of carbonate rocks beneath the Packard Quartz Latite in the area. Hole N-1 also penetrated about 50 ft (15 m) of altered dolomite that contained traces of lead, zinc, and manganese. Drill hole N-2, which was located in the northwestern part of the alteration halo about 385 ft (117 m) northeast of N-1, tested a geochemical anomaly discovered by the Geological Survey (Lovering and others, 1948). This hole was drilled to a depth of 1,100 ft (335 m) and was terminated approximately at the elevation of the water table without discovering significant mineralization.

In 1949-50, drill hole N-2 was reoccupied by the Geological Survey and deepened to 1,600 ft (488 m) in an effort to identify the carbonate rocks that had been penetrated by the Newmont churn-drill holes. Soon after the drilling began, fossils of Devonian and

Mississippian age were identified in the core, eliminating the long-held interpretation that the carbonate strata were of Cambrian age. A reanalysis of the structure of the lava-concealed sedimentary rocks, therefore, suggested the existence of a completely concealed north-trending thrust fault. This interpretation was chiefly based on the presence of the Cambrian Tintic Quartzite and the Ophir Formation on the 1,000-ft level of the Apex Standard mine only 1,300 ft (396 m) west of the Devonian and Mississippian rocks that normally are about 4,500 ft (1,442 m) higher in the stratigraphic section and also by the asymmetric nature of the East Tintic anticline. Further evidence of a concealed thrust fault was provided in 1951 by the discovery of the outcropping Allens Ranch thrust fault at the north edge of the lava field about 4½ mi (7.2 km) north of the Chief Oxide area. The Geological Survey's geologists also reasoned that the only north-trending faults of large displacement in the East Tintic Mountains were thrust faults and postlava Basin and Range faults, and inasmuch as the lavas were not appreciably faulted in the Chief Oxide area, it was fairly certain that the fault indicated by the drill hole was, indeed, a thrust.

In addition to providing geologic data leading to a new interpretation of the deep structure in the Chief Oxide area, the Geological Survey's drill hole also cut a zone of sphalerite- and galena-bearing jasperoid and sanded dolomite at a depth of 1,310-1,445 ft (399-440 m). This low-grade mineralization in relatively unbroken rocks of the footwall of the postulated thrust fault not only established the presence of ore minerals in an unexplored area that was 1 mi (1.6 km) away from the nearest known ore body, but it also suggested the possibility that large ore bodies occurred in the breccias and other favorable ground adjacent to the concealed thrust.

Upon completion of a second short-hole drilling program in 1954 that tested the geochemical anomaly and alteration zone in the lava, the Geological Survey ended its activities in the Chief Oxide area, and the accumulated data were made available to interested mining companies by means of a public announcement (Lovering, 1950b). Among those examining these data was the Bear Creek Mining Co., exploration subsidiary of the Kennecott Copper Corp., which was actively pursuing an exploration program in the Main Tintic district at that time. In September 1956, a unit lease agreement was negotiated between Bear Creek and several of the principal land owners in the East Tintic district, and an active program of exploration including diamond drilling and shaft sinking was begun without delay.

The Burgin No. 1 shaft was sunk between January 30 and July 20, 1957, and was bottomed at the permanent water table at a depth of 1,110 ft (338 m). An exploration level was established 1,050 ft (320 m) below the surface; drifting and diamond drilling were then undertaken to locate and explore the inferred thrust and to evaluate the zone of zinc and lead mineralization that was cut by the Geological Survey's drill hole. By late 1958 the westward-directed mine workings had discovered the concealed East Tintic thrust fault, and in late August of that year mineralized rock of ore grade was also penetrated in drill holes directed below the 1,050 level into footwall rocks of Devonian age 460 ft (140 m) west-southwest of the shaft. Subsequent discoveries of high-grade ore along the thrust fault 1,310 ft (399 m) west-southwest of the shaft and followup drilling during the succeeding months led to the delineation of at least a million and a quarter tons (1.13 million tonnes) of lead-zinc-silver ore by early 1961 (Mining Congress Journal, 1961). Important additional discoveries of ore have been made since that time, particularly in the footwall block of the East Tintic thrust.

Beginning in 1960, an attempt to reach and sample the high-grade ore zone below the water table was undertaken by means of an inclined winze sunk from the 1,050 level. This effort was abandoned after many months of frustrating work because of highly incompetent ground and heavy flows of hot ground water. Later, in 1962, a vertical winze (No. 2 winze) and a short sublevel drift driven from it confirmed the presence of high-grade lead-zinc-silver ore and provided samples for mineralogic study and mill tests.

The Burgin No. 2 production shaft (fig. 42) was sunk during 1963-65 to a depth of 1,331 ft (406 m), where sinking was terminated because of heavy inflows of hot ground water. It has been the principal production and working shaft of the mine. Since 1968 the mine has produced 500-800 tons (454-726 tonnes) of ore per day except during periods of labor negotiations.

During the early part of 1972, the No. 1 shaft was deepened to the 1,300 level (1,260 level on some maps), and a connection was made with the No. 2 shaft. The total depth of the No. 1 shaft in 1976 was 1,278 ft (390 m). In 1975, a third vertical opening, to be chiefly used for mine ventilation, was drilled upward from the 1,300 level to the surface at a point about midway between the No. 1 and No. 2 Burgin shafts. This ventilation shaft is approximately 7 ft (2 m) in diameter.

## PRODUCTION

From 1963 through 1975 the Burgin mine has yielded a total of 1,384,655 short tons (1,255,882 tonnes) of ore containing 482 oz (14,990 g) of gold, 14,090,715 oz

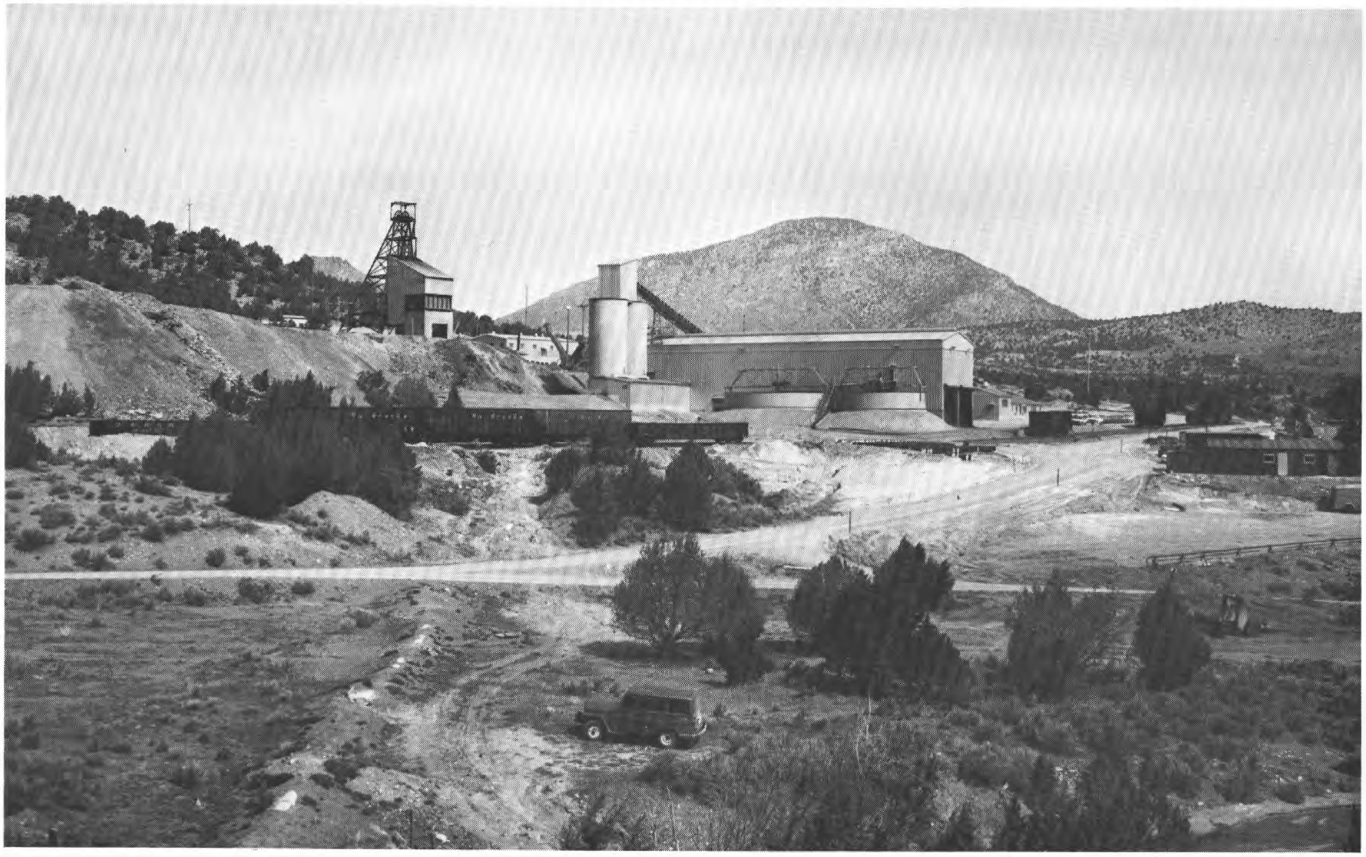


FIGURE 42. — Burgin No. 2 shaft head frame and surface installations. Large building in center is mill; Pinyon Peak in background.

(438,221 kg) of silver, 76,756 lb (34,817 kg) of copper, 303,524,472 lb (137,780,011 kg) of lead, and 285,161,083 lb (129,463,132 kg) of zinc. The calculated gross value of these metals at the prices prevailing at the time of their production is $135,928,073. In addition, a total of about 3 million lb (1.36 million kg) of cadmium, not shown in table 8, also has been produced.

## GEOLOGY

The rocks exposed at the surface in the area of the Burgin mine are porphyritic lavas of the Packard Quartz Latite, which are cut by a few dikes of medium- to coarse-grained monzonite porphyry, fine-grained latite, and pebble breccia. The lavas are from about 500 to more than 2,000 ft (152-610 m) thick and conceal the overturned and thrust-faulted east limb of the asymmetric East Tintic anticline. A major feature of the surficial geology is the Chief Oxide or Burgin pyritic area, which is approximately 1,900 ft (579 m) wide and 2,100 ft (640 m) long (Lovering and others, 1960). Near the Burgin No. 1 shaft, this pyritic zone encloses a northeast-trending area about 1,000 ft (305 m) long and 400 ft (123 m) wide containing anomalous trace quantities of copper, lead, and zinc that were introduced into the fractured and pyritized rocks during the mineralization of the sedimentary rocks at depth (Lovering and others, 1948, p. 395-398).

The Paleozoic sedimentary rocks exposed in the mine workings range from the Early Cambrian Tintic Quartzite to the Fitchville Formation of Late Devonian and Early Mississippian age (see pl. 4). In the upper plate of the East Tintic thrust fault, only highly broken and altered units of the Tintic Quartzite and Ophir Formation have been recognized, although the Teutonic Limestone may have been penetrated by the 1,000-ft level of the Apex Standard mine in the area above the main Burgin ore body (pl. 4). In the lower plate of the thrust a folded, faulted, and altered stratigraphic section ranging from the Upper Cambrian Ajax Dolomite to the Devonian and Mississippian Fitchville Formation has been exposed.

All of the sedimentary rocks exposed in the mine contain some ore. The larger ore bodies are found in the middle limestone member and the lower carbonate marker bed of the lower shale member of the Ophir Formation, in the Fish Haven and Bluebell Dolomites, Victoria Formation, Opohonga Limestone, and possibly in the Teutonic Limestone.

The Packard Quartz Latite is the predominant igneous rock in the Burgin area. It extends from the surface to depths of 705 ft (215 m) in the No.1 shaft and 875 ft (267 m) in the No. 2 shaft; from the area of the shafts it thickens abruptly to the north, northeast, and east. Drill holes and mine workings indicate that the lavas north of the shafts fill a deep east-southeast-trending valley (Morris and Anderson, 1962) whose axis extends approximately through the Ballpark area of the mine. In drill hole ET-106, which is 3,665 ft (1,117 m) nearly due north of the Burgin No. 2 shaft near the center of this prelava valley (pl. 3), the quartz latite and underlying tuffs and Apex Conglomerate together are 1,600 ft (488 m) thick. East and southeast of this hole they increase to an unknown thickness exceeding 2,700 ft (823 m).

Intrusive igneous rocks are not common in the Burgin mine. In the Ballpark crosscut 1,600-2,000 ft (488-610 m) north-northwest of the No. 2 shaft, two or more northeast-trending linear zones of highly argillized igneous rocks believed to be dikes of monzonite porphyry were intercepted in the lavas. Pebble dikes, also cut in the Ballpark workings in the general area of these argillized zones, further suggest the presence of monzonite porphyry intrusions. At the surface above this part of the mine, dikes of both pebble breccia and monzonite porphyry cut the Packard Quartz Latite, but they are not appreciably argillized.

The dominant structural feature in the Burgin mine is the East Tintic thrust fault. This fault does not crop out at the surface and is known only from underground exposures in the Burgin mine and from intercepts in drill holes. In the mine, the thrust zone consists of five or more moderately west dipping subparallel but undulatory fault planes that are from 20 to 300 ft (6 to 91 m) apart. The main footwall fault plane is the site of maximum displacement; it separates overturned parts of the Tintic Quartzite, middle limestone, and upper shale members of the Ophir Formation, and possibly the Teutonic Limestone from the underlying, similarly overturned Ajax Dolomite and Opohonga Limestone. The indicated stratigraphic separation is 3,100 ft (945 m), and the estimated total displacement on the entire fault zone probably exceeds 5,500-6,000 ft (1,676-1,829 m).

The four or more imbricate thrust planes above the main footwall thrust plane in the central part of the mine have relatively small displacements. Between two of these planes the lower and middle members of the Ophir Formation have been overfolded and compressed into a recumbent syncline; in the northwestern part of the mine this syncline underlies a large thrust slice containing Tintic Quartzite and overlying stratigraphic units.

Three or more northeast-trending tear faults, all of which apparently terminate at the main footwall thrust plane, cut the rocks of the upper plate of the East Tintic thrust in the general area of the main Burgin ore body. Two of these tear faults are provisionally correlated with the Apex Standard and Middle faults, originally recognized in the Apex Standard mine. At the 1,050 level of the Burgin mine they are about 900 ft (274 m) apart and apparently acted as the principal conduits for the hydrothermal solutions that deposited the ore body. The more fully explored Eureka Standard fault has been penetrated a short distance northwest of the Middle fault and is followed by several mine workings. It does not appear to be as important an ore-localizing feature in the Burgin mine as it is in the Eureka Standard and Apex Standard mines. As all of these tear faults approach the thrust, they gradually flatten in dip and then abruptly change strike and merge with it.

Detailed knowledge of the structural relations of the three major tear faults has been important in mine development as well as in geologic interpretation. For example, the main footwall strand of the East Tintic thrust is at a higher elevation on the south sides of both the Apex Standard and Middle faults than on the north sides. Also, several of the minor imbricate thrusts that localize ore in the mine are present only in the area between the Eureka Standard and Apex Standard faults and are not recognized elsewhere in the mining district.

In the footwall block of the East Tintic thrust, between the Burgin No. 1 and No. 2 shafts, the vertical to overturned middle Paleozoic carbonate rocks are cut by several steeply dipping strike faults, which cut out parts of the stratigraphic section, and by the 274 shear fault, a northeast-trending strike-slip fault that has had an important influence on the localization of ore. The 274 shear fault was first intercepted on the 1,050 level near the 274 drift and is believed to have been penetrated more recently in the 12-48 stope at the 1,200 level (plate 4, fig. B). It is possible that this fault is a footwall continuation of the Apex Standard fault; however, it does not appear to be alined with the Apex Standard, and in addition, it seems to dip somewhat more steeply and to have left-lateral rather than right-lateral displacement. Little is known of the rock sequence southeast of this fault.

Near the Burgin No. 1 shaft the footwall strata are completely overturned, creating a small antiform with a core of Mississippian limestone. The extent and character of this antiform in the unexplored areas north and south of the No. 1 shaft are unknown; a few hundred feet east of the shaft at the 1,050 level, the sedimentary strata terminate at the prelava surface, and nothing is known of the sedimentary strata below this point.

In the area of the South fault, in the Ballpark area, three-quarters of a mile (1.2 km) north-northwest of the No. 2 shaft, drill holes from stations on the 1,050 level and from the surface disclose that movement on the East Tintic thrust has brought Tintic Quartzite over the Fish Haven and Bluebell Dolomites with only minor imbrication. Like the other tear faults, the South fault, which cuts only quartzite in this area, appears to terminate at the thrust, but it also steps the thrust down on the north side. The thrust is about 600 ft (183 m) higher in elevation south of the projected trace of the South fault than north of it. The presence of the northwest-trending Ballpark fault in this general area is inferred chiefly from the displacement of the East Tintic thrust between ET-97 and the drill holes in the main Ballpark mineralized area to the northeast.

South of the main Burgin ore body little is known of the East Tintic thrust, in part because its displacement is greatly diminished south of the Apex Standard fault and in part because unidentified altered carbonate rocks occur in both the hanging wall and footwall. Several diamond-drill holes have penetrated the thrust in this area, but their logs are enigmatic. It seems probable that the thrust terminates at the inferred Inez fault 4,500 ft (1,372 m) south of the No. 1 shaft.

## ORE BODIES

### MAIN BURGIN ORE BODY

The most productive ore body discovered and developed to date in the Burgin mine, the main Burgin ore body, is a complex replacement deposit that lies against the main footwall plane of the East Tintic thrust between the 274 shear fault and the Middle tear fault. It is localized above an undulatory structural terrace on the west-dipping footwall plane of the East Tintic thrust and is 1,300 ft (396 m) or more long, 75-200 ft (23-61 m) wide, and as much as 100 ft (30 m) thick. The southern terminus of this ore body is in the vicinity of the 274 fault, where the ore zone turns sharply eastward and merges with the 12-48 ore body in the footwall of the thrust. From this area on the 1,200 level, the Main Burgin ore body plunges gently northwestward crossing the Apex Standard tear fault and extends to the Middle fault at and below the 1,300 level, where it spreads laterally and plunges somewhat more steeply beneath the Tintic Quartzite that forms the hanging wall of the Middle fault. Its northernmost limit is currently unknown.

Reconstructions of the premineral geology suggest that the main Burgin ore body is a massive replacement of overturned and brecciated slices of middle Ophir and possibly Teutonic Limestone that lie against the Opohonga Limestone and Ajax Dolomite. Where carbonate rocks overlie the ore body, their identifying features have largely been obliterated by intense hydrothermal alteration.

In gross aspect, the main Burgin ore body is divided into two parts by the Apex Standard tear fault. The northwestern segment, which chiefly lies between a hanging wall of shale and a footwall of argillaceous Opohonga Limestone, is generally unoxidized and is composed largely of sulfide minerals. In contrast, the southeastern segment, which lies between carbonate rocks in both the hanging wall and the footwall, is partly oxidized and contains a substantial proportion of sulfate, carbonate, and oxide minerals.

The metallic minerals of the unoxidized parts of the main Burgin ore body include pyrite, galena, sphalerite, tetrahedrite, argentite, and locally, a considerable variety of lead-, silver-, copper-, and zinc-bearing sulfosalt minerals. The nonmetallic gangue includes jasperoid, barite, abundant rhodochrosite, calcite, dolomite, and a number of residual, hydrothermal, and secondary clay minerals. Oxidation has produced a great variety of secondary ore minerals, including cerrusite, angelsite, mimetite, smithsonite, jarosite, and geothite, and many secondary manganese minerals, including chalcophanite.

The average grade of this ore body prior to mining was estimated to be 10 oz of silver per ton (342 g per tonne), 15.2 percent of lead, and 12.2 percent of zinc for approximately a million and a quarter tons (1.13 million tonnes) of ore. Subsequent data have confirmed that the ratio of zinc to lead is 2:3 in the unoxidized parts of the ore body but only 1:5 in the oxidized parts, indicating removal and migration of the zinc during oxidation. The highest silver and lead values are found near the Tintic Quartzite in the hanging wall of the Middle fault; zinc increases concomitantly as silver and lead decrease southeast of this area. The zinc content also increases with elevation, with the highest zinc values being found near the top of the ore body.

Smith's (1971) studies of the weakly mineralized manganiferous wallrocks of the partly oxidized southeastern segment of the main Burgin ore body indicate a concentric zonation of manganese oxide minerals and an outward primary dispersal of metal ions. Nearest the ore body is a zone characterized by pyrolusite ($MnO_2$) and quenselite ($PbMnO_2 \cdot OH$). Beyond this zone, nsutite ($Mn^{+4}$, $Mn^{+2}$) $(O, OH)_2$ and hetaerolite $ZnMn_2O_4$ are common; farther out nsutite diminishes, and birnessite (Na, Ca)$Mn_7O_{14} \cdot 3H_2O$ is characteristic. Concentrations of zinc and cadmium are relatively high in the nsutite-hetaerolite zone and are lower in the inner and outer manganese halos.

### 260 ORE BODY

An ore body containing approximately 75,000 tons (68,025 tonnes) of lead-zinc sulfide ore was discovered on the 1,050 level of the mine in 1963 when the 302W ventilation drift was driven in the western part of the mine. This body chiefly extended upward from the level, apparently replacing rubble and horizontally bedded calcareous sediments filling a cavern that had developed in the carbonate marker bed of the lower shale member of the Ophir. The ore body is about 450 ft (137 m) long, 100-125 ft (30-38 m) wide, and 6-20 ft (1.8-6.1 m) thick. It dips west at 20°-50° in conformity with enclosing beds of Ophir Shale. A downward extension of this ore body has been found in the 1,260 raise from the 1,200 level, but only a small amount of this ore has been mined because of its relatively low grade.

The average grade of 53,750 tons (48,751 tonnes) of ore mined from the 260 ore body was 7.8 oz per ton (267 g per tonne) of silver, 10.3 percent lead, and 5.5 percent zinc. In general, the highest lead and silver values occurred near the 1,050 level and in the southern part of the ore body, and the highest zinc values were near the top and in the northern part. Some exceptionally rich fine-grained banded argentiferous galena ore, which completely replaced thin-bedded cave-filling sediments, was mined near the 304 raise. The 260 ore body contained many octahedral crystals of galena, and near the center of the ore body, a highly siliceous zone contained many vugs and irregular openings, some of which were partly filled with unusual tabular and acicular aggregates of galena crystals.

Although the sulfide ores of the 260 ore body are located well above the permanent water table, they are largely unoxidized, averaging only about 0.25 percent nonsulfide lead and zinc. An explanation for this relation may lie in the fact that the ore body is almost completely enclosed by tight unfractured shale and thus was protected from air and oxygenated vadose water.

### 302 ORE BODY

A small ore body that is similar in some respects to the 260 ore body was discovered at the 1,050 level in the southwestern part of the mine (pl. 4, fig. A). It apparently replaces a limestone bed in the lower part of the middle limestone member of the Ophir Formation. It is completely surrounded by shale, and thus it also is relatively unoxidized although other mineralized limestone beds of the middle limestone member nearby are strongly oxidized. This ore body yielded about 18,000 tons (16,326 tonnes) of milling ore. The primary ore minerals were galena and sphalerite in association with rhodochrosite, jasperoid, and barite.

### 58-56 ORE BODY

A narrow elongated ore zone that is parallel to the main Burgin ore body occurs in the hanging wall of the thrust chiefly above the 1,200 level but locally extends downward past the 1,200 level to the 1,300 level (pl. 4, figs. B and C). The lateral persistence of the ore suggests that it replaces limy gouge and breccia along a minor thrust fault within the East Tintic thrust zone. The ore is of moderate grade and similar in composition to the other ore bodies nearby. It is unoxidized even where it lies above the oxidized parts of the main Burgin ore body.

### 12-48 ORE BODY

The second largest ore body in the Burgin mine is in the footwall block of the East Tintic thrust near the southern terminus of the main Burgin ore zone (pl. 4, figs. B and C). This ore body extends from a point above the 1,200 level to an as yet unknown point below the 1,300 level. It provided much of the ore produced from the mine in 1972 and 1973. The ore body is apparently localized by the 274 fault, but this relation cannot as yet be confirmed because of extensive alteration and mineralization. So far as is currently known, the ore chiefly replaces part of the faulted Fish Haven and Bluebell Dolomites and possibly the dolomitized Opohonga Limestone.

The principal ore minerals in the 12-48 ore body are sphalerite and galena. The content of zinc is equal to or higher than the content of lead, and the silver content of the ore body is lower than that of the main Burgin ore zone. In some of the ore, galena and sphalerite are so intimately intergrown that clean separation during milling has proved to be virtually impossible.

### 274 ORE ZONE

The first ore found in the Burgin mine workings was cut on the 1,050 level 450 ft (137 m) southwest of the No. 1 shaft in 1957. It occurred as a narrow streak of ochreous material containing cerrusite, smithsonite, and other ore minerals that replaced dolomite of the Victoria Formation proximal to a northeast-trending fault of moderate displacement. In 1958, diamond drilling from the 274N and 274S drifts disclosed a generally north-trending ore zone localized in nearly vertical beds of the Bluebell and Victoria Formations 155-225 ft (47-69 m) below the level. The ore was traced for 250 ft (76 m) north and 400 ft (123 m) south of the initial point of discovery. No further exploration or development of this ore body was undertaken until 1973, when the southern part of the ore zone, below the 274S drift of the 1,050 level, was found to be the eastern part of the northeast-plunging 12-48 ore body and was chiefly mined from the 1,200 level. Development of the northern part, below the 274N drift, was deferred until 1972, when a crosscut at the 1,300 level (pl. 4, fig. C) cut the ore zone below its exposure on the 1,050 level, and stoping was begun the following year.

Since 1973, mine development at the 1,300 level in the northern part of the 274 ore zone has disclosed many separate ore bodies within a generally north-trending area as much as 400 ft wide (123 m) and more than 1,000 ft long (305 m). The northern limit of this ore zone is yet to be determined, and it may extend an unknown distance beyond drill hole ET90 (see pl. 4, fig. A) which cut galena- and pyrite-bearing dolomite at the approximate elevation of the 1,300 level. The northerly persistence of this ore zone is similar to that of the north-trending ore runs of the main Tintic district.

The ore mined from the 274 ore zone in 1975 averaged about 2.5 oz per ton silver, 5 percent lead, and 8.5 percent zinc. The gangue is mostly rhodochrosite. In some of the ore bodies the sphalerite and galena are so intimately intergrown as to present serious difficulties in obtaining pure flotation concentrates. Rims of galena overgrowing sphalerite crystals are particularly common.

Undeveloped ore bodies, which may be similar to the 274 ore bodies, have been cut in diamond drill holes that were drilled from a station on the 1,050 level 1,000 ft (305 m) northwest of the Burgin No. 2 shaft. These ore bodies, which are in an area designated Zone A in the mine, were the objectives of mine exploration and development at the 1,300 level in 1977, but heavy inflows of hot water caused a temporary abandonment of this project.

### BALLPARK AREA

In 1961-63, an extensive zone of mineralized rocks was discovered by Bear Creek Mining Co. at depth beneath the Packard Quartz Latite in the vicinity of the old baseball park about half a mile (0.8 km) northeast of Dividend. In this area five deep diamond- and churn-drill holes within an area 2,400 ft (732 m) long and 800 ft (244 m) wide intercepted thick masses of dolomite and dolomite breccia containing scattered crystals, veinlets, and pods of galena, sphalerite, and rhodochrosite. Some of the intercepts of mineralized rock are 200-500 ft (61-152 m) thick and include zones up to 20 ft (6 m) thick that are at or close to ore grade.

After the completion of the Burgin No. 2 shaft, a long crosscut at the 1,050 level was driven toward the Ballpark area with the objectives of exploring the parts of these mineralized rocks that extended above the water table and establishing underground drilling stations from which short exploration diamond-drill holes could be drilled to points below the water table (pl. 4, fig. A). These underground drill holes also have established the position of the lava-sedimentary rock contact and the lava-concealed position of the East Tintic thrust. The drill holes also have cut several zones of ore and mineralized rocks that may be classified into three groups: (1) mineralized areas associated with the East Tintic thrust; (2) mineralized areas in the Apex Conglomerate and basal tuffs of the Packard Quartz Latite, particularly in areas near the South fault; and (3) replacement and disseminated ores in the footwall rocks of the East Tintic thrust. In addition, a fourth zone of fissure and quartzite breccia ore possibly may occur in the hanging-wall rocks of the East Tintic thrust adjacent to the South fault.

The mineralized zones associated with the East Tintic thrust fault in the area of the Ballpark crosscut are known only from intercepts in diamond-drill holes below the 1,050 level. They chiefly occur in the breccias of the fault zone and range from massive replacements to scattered crystals of sphalerite, galena, rhodochrosite, and other minerals. Many of the deposits have a spotted appearance with unreplaced quartzite fragments embedded in a matrix of relatively massive ore. The chief ore minerals are sphalerite and galena, and the chief gangue minerals are rhodochrosite, pyrite, barite, jasperoid, and kaolinitic clay minerals.

The mineralized zones in the Apex Conglomerate and the basal tuffs of the Packard Quartz Latite are near the lava-concealed trace of the South fault. They have been explored both by drill holes and by the mine workings that extend westward from a point near the north end of the Ballpark crosscut. In the mineralized tuff and rubble beds, sphalerite and galena occur both as disseminated crystals and as small veins and stringers along with nonmetallic minerals. The disseminated crystals of sphalerite and galena are most abundant in the tuff beds. Most of the crystals range in diameter from 1/8 in. (3 mm) to less than 1/32 in. (0.8 mm), and some crystals are associated with small cavity fillings of dickite and other clays. The small veins and stringers cut both the conglomeratic beds and the tuff; they generally trend northeasterly parallel to the South fault and dip steeply northwest. They are 0 to 6 in. (15 cm) wide and 6 in. (15 cm) to 10 ft (3 m) long. Partly filled cavities are locally common. The minerals filling the veinlets and cavities are sphalerite, galena, pyrite, rhodochrosite, quartz, and barite. The galena cubes and octahedrons are as much as half an inch (1.3 cm) in diameter, although most are a quarter of an inch (0.6 cm) or less. Crusts of mammilary and botryoidal sphalerite commonly occur on the galena and on cubic and pyritohedral pyrite.

The replacement ore bodies in the carbonate footwall rocks of the East Tintic thrust in the Ballpark area are known only from the intercepts in drill holes. Consequently their size and general character are imperfectly known. The meager data suggest that they generally resemble the ore bodies of the 274 ore zone in being localized by selected favorable beds and bedding-plane faults. They contain sphalerite, galena, pyrite, rhodochrosite, barite, quartz, and jasperoid. In general, their zinc content is relatively higher than that of the main Burgin ore body, and their silver content is considerably lower. On the average there is 2 or 3 percent zinc and possibly no more than 0.1 oz per ton (3.43 g per tonne) silver for each percent lead.

### WALLROCK AND GROUND-WATER TEMPERATURES

As the Burgin No. 1 shaft was being sunk and the 1,050 level was being developed, wallrock temperatures were found to range from 95° F (35° C) in the broken carbonate rocks exposed in the Burgin No. 1 shaft station to 136° F (58° C) in or near the exposures of Tintic Quartzite in the northwestern part of the mine. These abnormal temperatures compare with an expected normal wallrock temperature at the elevation of the 1,050 level of 68° F (20° C) or less.

As the mine was developed below the water table, temperatures increased with depth, reaching an average of 148° F (64° C) at the 1,300 level. The steepness of the geothermal gradient below the 1,050 level eliminated the long-favored hypothesis that the heat was derived from oxidizing sulfide minerals and in turn suggested that the heat source was a hot-spring system discharging at the water table. Analyses of the mine waters indicated a high percentage of dissolved materials, chiefly sodium chloride but also including sodium, potassium, and calcium sulfates and bicarbonates and other constituents. Continued chemical monitoring of the combined mine discharge waters indicates an average content of 3,500 ppm chloride. Individual samples collected on the 1,200 level contained about 4,500 ppm chloride and had temperatures of 156° F (69° C) in the western part of the mine in contrast to 2,200 ppm chloride and temperatures of about 95° F (35° C) in the eastern part of the mine, suggesting a local source of thermal brine inflow at depth in an undetermined area to the west of the Burgin mine.

Pumping of the saline mine waters started in 1964 and has continued at a volume ranging from 8,000 to 9,000 gallons per minute for more than 8 years without apparent decrease in the volume or temperature of the water, or in the concentration of its dissolved constituents. The thermal waters are moderately corrosive and have required the installation of special pumps and conduits, and the frequent replacement of rails and other equipment.

The oppressively high air temperatures in the mine are modified by the introduction of large volumes of surface air downward through the Burgin No. 2 shaft and the exhaustion of hot and humid mine air upward through the Burgin No. 1 and Apex Standard No. 2 shafts. This ventilation results in a skin cooling of the rocks exposed in the stopes and other mine workings; however, any interruption of the air flow results in a rapid return to the original rock and air temperatures as the enormous reservoir of heat in the wallrocks quickly raises the temperature of unventilated workings. Irrespirable rock gases have not been as troublesome as they were in area of the more completely oxidized Tintic Standard ore bodies.

The support of unstable masses of sanded dolomite and corroded breccias, particularly in areas adjacent to main haulageways and operating stopes, has required careful dewatering in advance of mining and the extensive use of mine timbers, closely spaced lagging, and yieldable sets composed of structural steel. The sanded and corroded ground apparently is more common near the East Tintic thrust fault than in the vicinity of the ore bodies in the footwall carbonate rocks.

## MINES OF THE CENTRAL STANDARD CONSOLIDATED MINING CO.

The property of the Central Standard Consolidated Mining Co. is in the central and upper parts of Pinyon Creek Canyon, extending from the southeast base of Pinyon Peak southward across Highway 6-50 (pl. 1; fig. 39). The present company is a consolidation of the Central Standard and Copper Leaf Mining Companies, which merged in May 1922 and were placed under the direction of T. F. Pierpont of Provo, Utah, and his mining superintendent, John W. Taylor. Originally both companies had been formed shortly after the discovery of the Tintic Standard ore body.

The Copper Leaf shaft was collared in December 1916 and completed in December 1920; from January

1918 to December 1920 and from May 1923 to January 1924, much drifting and crosscutting were undertaken in a search for a northerly continuation of the Tintic Standard ore zone.

The Central Standard shaft was sunk in 1920, and drifting was carried out in 1921 with the same objective as the Copper Leaf.

Beginning in March 1927, after the discovery of the North Lily and Eureka Lilly ore bodies, the Copper Leaf shaft was reopened with the assistance of the United States Smelting and Refining Co., and underground exploration was resumed at the 1,200-ft level in conjunction with surface drilling. This work was terminated in 1931.

Beginning in 1949 a small deposit of manganese ore and halloysite clay was intermittently explored by George and Dell Steele on the White Star claim, and a small lot of ore was shipped in 1950. In 1968 the Central Standard claims were leased to the Kennecott Copper Corp., which has carried out much drill-hole exploration in the vicinity of the Homansville fault.

## PROPERTY DEVELOPMENT AND PRODUCTION

The property of the Central Standard Consolidated Mining Co. consists of 20 patented claims and fractions containing approximately 300 acres (121.5 hectares). In addition to the Copper Leaf shaft, which is 1,245 ft (379 m) deep, and the Central Standard shaft, which is 630 ft (192 m) deep, two other shafts, both on the Loop No. 3 claim 1,300 ft (396 m) north of the Central Standard, have been sunk to depths of 400 ft (123 m) and 200 ft (61 m), and two short adits have been driven on the White Star claim near the mouth of Homansville Canyon. One of these adits is popularly but erroneously regarded to be on the Helen claim.

Lateral workings have been driven from the Central Standard shaft at the 600-ft level and from the Copper Leaf shaft at the 300-, 500-, 1,000-, and 1,200-ft levels. The Central Standard 600-ft level extends for 380 ft (116 m) south-southeast of the shaft and terminates at the east side line of the property. The 300-ft level of the Copper Leaf shaft has 745 ft (227 m) of lateral workings and 55 ft (17 m) of raises in the area northeast of the shaft. The 500-ft level has approximately 1,700 ft (518 m) of drifts and a 62-ft (19 m) raise from which a 5-ft (1.5 m) drift was driven, all in the west-northwestern part of the mine. The 1,000-ft level has 1,455 ft (443 m) of lateral workings and 120 ft (37 m) of raises also in the northwestern part of the mine. The 1,200-ft level has approximately 2,000 ft (610 m) of lateral workings in the area north, west, and southwest of the shaft.

With the exception of the small lots of high-grade manganese oxide ore from the area of the Helen adit, there is no recorded production of ore by the Central Standard Consolidated Mining Co. It is possible, however, that small lots of sulfide ores were hand sorted from the narrow veins that were exposed on the 1,000-ft and other levels of the Copper Leaf shaft.

## GEOLOGY

### CENTRAL STANDARD SHAFT

The Central Standard shaft is in the SW¼SW¼ sec. 3, T. 10 S., R. 2 W. It is collared in strongly pyritized Packard Quartz Latite near the northwest edge of the Baltimore fissure zone, and it is in altered lava to a depth of 380 ft (116 m). It then cuts approximately 85 ft (26 m) of the middle limestone member of the Ophir Formation, including an undetermined thickness of prelava soil and rubble, and extends to a total depth of 630 ft (192 m); it is bottomed in the lower part of the Ophir's lower shale member. According to Thomas F. Pierpont (oral commun., 1949), the shaft was abandoned in 1922 because the argillized lavas and shale continued to swell after they were exposed to damp air and frequently broke the shaft timbers. The 600-ft level extends S. 20° E. through shale for 290 ft (88 m) where it crosses a north-northeast-trending fault of small displacement and enters the Tintic Quartzite (fig. 43). At this point the drift extends S. 30° E. through quartzite for 90 ft (27 m), crossing a mineralized north-northeast-trending fissure near the end.

Although the Homansville fault was known to extend through the Central Standard property at the time the Central Standard shaft was being developed, no attempt was made to explore this structure beneath the lavas. However, this fault, both on and near the Central Standard claims, was the objective of the south crosscut of the Water Lillie mine in 1922, and also of a drilling program by the U.S. Geological Survey in 1957 and the Kennecott Copper Corp. in 1969-75. This drilling indicated that the fault passes approximately 600 ft (183 m) north-northwest of the shaft and that the fault zone is overlain by a deep, keel-like lobe of quartz latite and at depth contains much highly broken and altered ground.

### COPPER LEAF SHAFT

The rocks in the general vicinity of the Copper Leaf shaft, which is located in the W½NW¼ sec. 10, T. 10 S., R. 2 W., are lavas of the Packard Quartz Latite that locally have been chloritized, pyritized, and calcitized. Cambrian limestones are exposed a short

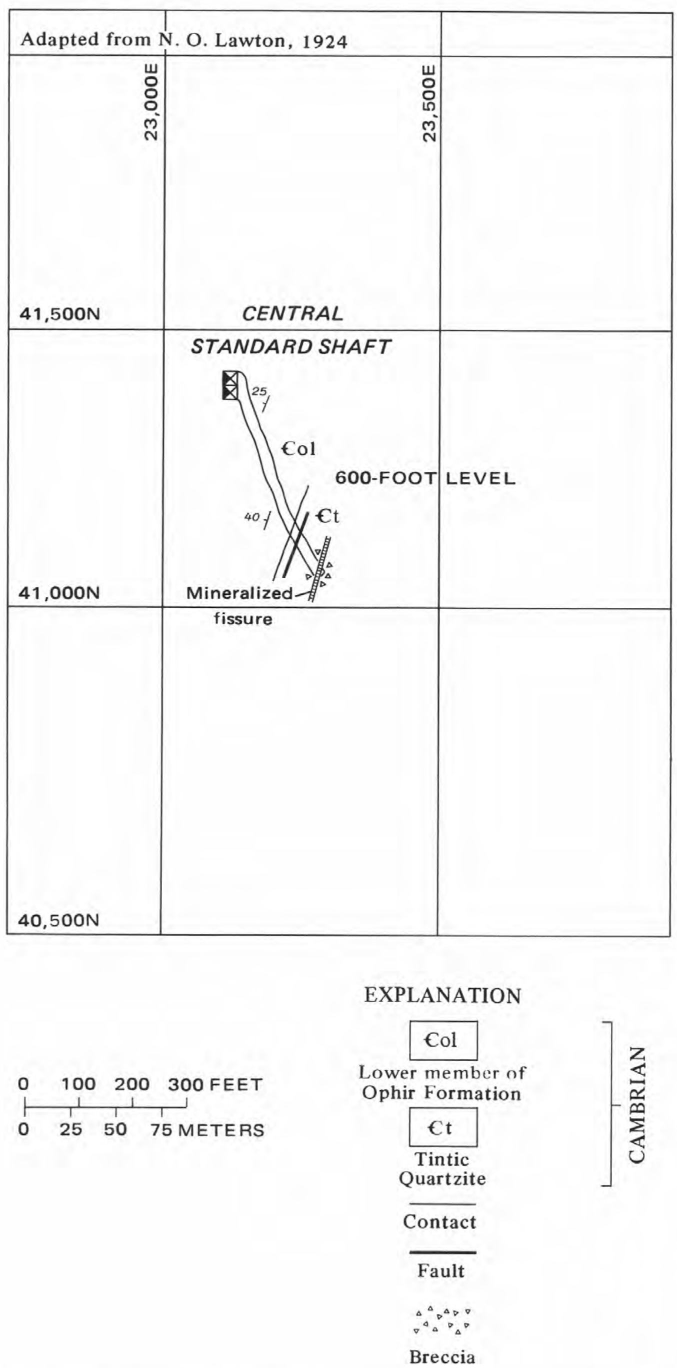



FIGURE 43. — Geologic plan of 600-ft level of Central Standard shaft.

distance north of the shaft, and both rocks are cut by fissures, faults, and pebble dikes of the North Lily and Baltimore fissure systems. According to N. O. Lawton (private report to Central Standard Mining Co., 1924), the log of the shaft from the collar down includes 155 ft (47 m) of quartz latite; 20 ft (6 m) of rubble and prelava soil; 50 ft (15 m) of blue limestone; 65 ft (20 m) of red calcareous shale; 12 ft (3.7 m) of red quartzitic sandstone; and 943 ft (289 m) of buff fine-grained quartzite, which is highly brecciated and intruded by monzonite below a depth of 1,200 ft (366 m). The section of red calcareous shale and red quartzitic sandstone between the blue limestone and the buff-colored quartzite presumably represents the lower shale member of the Ophir Formation beneath the blue limestone of the middle member, but only the lower half or so of the lower member apparently is represented and the remainder, therefore, may be cut out by an unrecorded, possibly low-angle fault at the top of the red shale and quartzite sequence.

The lateral workings of the Copper Leaf mine, most of which extend northwesterly from the shaft, chiefly explore the Tintic and Ophir Formations on the low-dipping west limb of the East Tintic anticline within an area where these formations are cut by fractures, pebble dikes, and monzonite dikes of both the North Lily and Baltimore fissure zones (fig. 44). Within a distance of 1,500 ft (457 m) from the area of the shaft, four northeast-trending faults have been recognized, and undoubtedly others have gone unnoticed. Beginning with the fault nearest the shaft, the larger faults have been named by company officials the First, Second, Third, and Fourth faults. The First fault was explored northeast of the shaft on the 300-ft level, near the shaft on the 1,000-ft level, and southwest of the shaft on the 1,200-ft level, where it localizes a discontinuous dike of monzonite porphyry. The fault strikes approximately N. 35° E., dips 82° NW., and has about 25 ft (6 m) of reverse displacement. Near the shaft on both the 1,000- and 1,200-ft levels, its breccias contain scattered grains of galena and pyrite. The Second, Third and Fourth faults define a graben and an adjacent horst. The Second fault, which marks the southeast edge of the graben, was cut 400 ft (123 m) west-northwest of the shaft on the 500-ft level, and 550 ft from the shaft on the 1,000-ft level. It strikes N. 38°-45° E., dips 73° NW., and has about 270 ft (85 m) of normal displacement. On the 500-ft level it localizes a pebble dike, and on the 1,000-ft level, where it has been termed the Iron Fissure, it is mineralized with galena and much pyrite. The Third fault, which defines the northwest side of the graben and the southwest side of the horst, was cut 775 ft (236 m) northeast of the shaft on the 500-ft level and 930 ft (283 m) from the shaft on the 1,000-ft level. It is a zone of multiple fractures, the strongest of which appears to strike N. 55°-60° E. and dip 78° NW. The displacement is reverse and is close to 480 ft (146 m). With the exception of a small amount of jasperoid noted on the 500-ft level, it is not mineralized. The Fourth fault, which marks the northwest side of the horst, has been cut only on the 500-ft level, 1,230 ft (375 m) northwest of the shaft. It apparently strikes N.

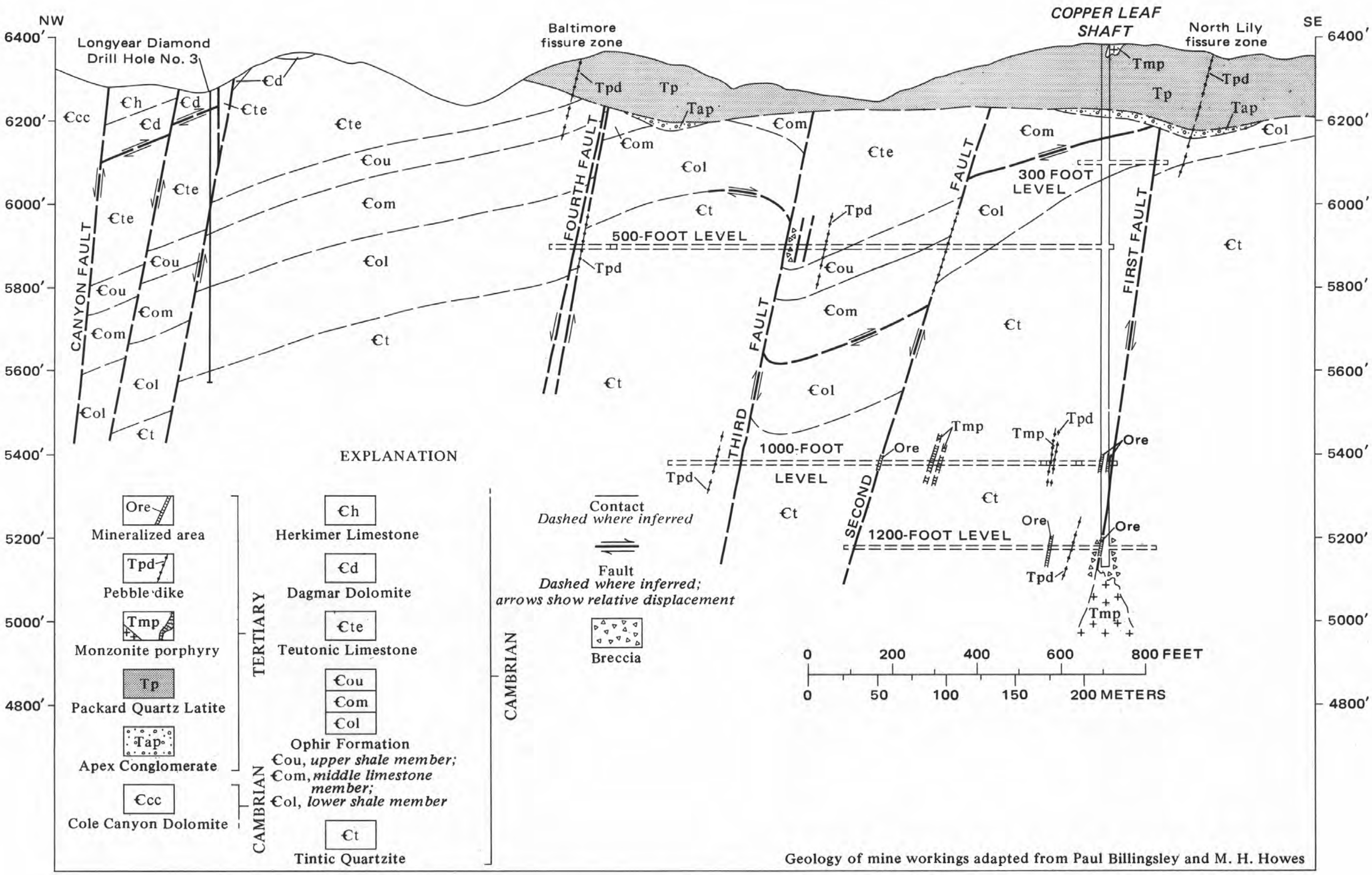



FIGURE 44. — Geologic cross section of Copper Leaf mine.

40°-45° E., dips about 78° NW., and has about 120 ft (37 m) of normal displacement.

In general, the rocks and structures show stronger mineralization and alteration on the 1,000- and 1,200-ft levels than on the 300- and 500-ft levels. Both monzonite and pebble dikes also are more abundant on the deeper levels, and occurrences of lead minerals are more common. On the upper levels the limestones of the Ophir and Teutonic Formations show relatively little dolomitization or other hydrothermal alteration.

It is notable that during the development of the Copper Leaf mine below the 900-ft level, work was intermittently suspended because of excessive gas in the mine galleries. Presumably this gas consisted chiefly of carbon dioxide, nitrogen, and sulfur dioxide produced by the accelerated oxidation of pyrite. Similar, but more serious, conditions existed in the Tintic Standard mine (see p. 171-172, 179).

### WHITE STAR ADIT

The White Star adit is on the south side of the Homansville Canyon about 2,200 ft (671 m) N. 47° W. of the Copper Leaf shaft. As shown in figure 45, it enters dolomitized, brecciated, and sanded basal Herkimer Limestone at about the canyon level and for some distance follows a sinuous pebble dike. The workings enter the Dagmar Dolomite 84 ft (26 m) from the portal, presumably across a normal contact that strikes nearly due east and dips 45° N. At 184 ft (56 m) from the portal, the adit reenters the dolomitized Herkimer Limestone across a nearly vertical north-northwest-striking fault of small displacement. Near the end of the adit the workings intersect an intrusion breccia consisting of angular fragments of dolomite embedded in an altered igneous matrix, which is probably the edge of the argillized monzonite plug that is conspicuously exposed in the roadcuts of Highway 6-50 above the adit. No ore minerals were found in the mine.

### HELEN ADIT

The Helen adit is in the west-central part of the White Star claim about 200 ft (61 m) west of the point where Highway 6-50 enters Homansville Canyon and about 2,300 ft (701 m) northwest of the Copper Leaf shaft. The workings, which are about 50 ft (15 m) above the level of the highway, extend about 30 ft (9 m) toward and through a fault-steepened contact between the basal Packard Quartz Latite and the Herkimer Limestone, both of which are highly altered at this locality.

Although it is short, the Helen adit provides a convenient, well-exposed interesting example of argillized terrane containing both igneous and carbonate rocks. According to Lovering and Shepard (1960a, b), a series of overlapping zones of hydrothermal alteration are exposed by the adit. In the lava, outward from the contact with dolomite, the zones consist of: (L1), a silicic band 1-5 in (2.5-12.7 cm) wide with some kaolinic clays, mixed-layer clay, and micaceous minerals; (L2), a strongly argillized zone about 3 ft (1 m) wide containing much montmorillonite, some micaceous minerals, and a decreasing amount of kaolinic minerals away from zone L1; and (L3), a transition zone 2-5 ft (0.6-1.5 m) wide in which montmorillonite diminishes, micaceous minerals increase, and kaolinic minerals disappear as the argillized rock grades into the chloritized country rock. The zones in the altered dolomite outward from the lava contact are: (D1), a hematite-quartz zone 5-8 ft (1.5-2.4 m) wide, which contains some minor sericite and manganese oxides; (D2), a manganiferous zone 1-2 ft (0.3-0.6 m) thick containing abundant manganese oxides and hematite, and minor clay, quartz, and kaolinic minerals; (D3), an irregular zone about 8 in. (20 cm) thick of halloysite and kaolinite; (D4), a fluorite-kaolin zone about 1 ft (0.3 m) thick with minor diaspore; (D5), a diaspore-fluorite zone about 4½ ft (1.4 m) wide in which the kaolin minerals diminish away from zone D4; (D6), a diaspore-kaolinite zone about 1 ft (0.3 m) wide with minor fluorite and mixed-layer clays; (D7), a kaolin and mixed-layer clay zone about 3 in. (7.6 cm) thick with very minor manganese oxide, fluorite, and diaspore; (D8), a zone of sanded dolomite about 10 ft (3 m) wide with minor kaolinite and mica; and (D9), hard fresh hydrothermal dolomite extending outward for several hundred feet. Zone D8 grades imperceptibly into D9. The mineral zones suggest reaction of the rocks with hot halogen-rich acid solutions carrying halides of iron, aluminum, and silicon; the zonal precipitation of the oxides of iron, manganese, silicon, and aluminum, and of fluorite is appropriate to increasing pH caused by reaction with the wallrocks.

The ores shipped by the Steele brothers from the area of the Helen adit consisted of hematic pyrolusite that occurred as small pods chiefly in the inner part of zone D2. These podlike masses were small, however, and significant unmined reserves are probably nonexistent.

## CHIEF LIME QUARRY

The formerly active limestone quarry of the Chief Consolidated Mining Co. is on the southwest flank of Lime Peak at the west entrance to Homansville Canyon. During the active period of the quarry, a

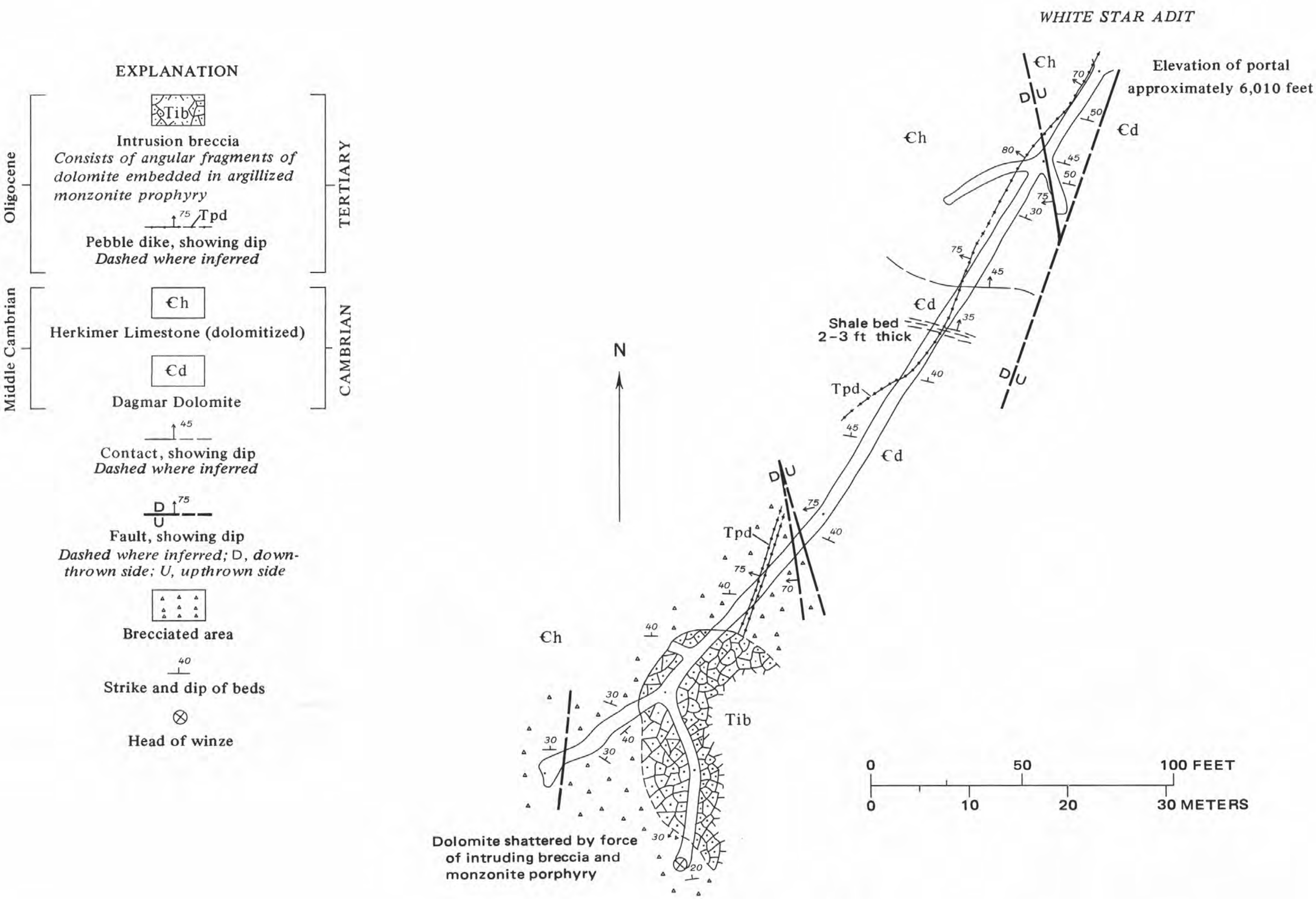



FIGURE 45. — Geologic plan of White Star adit.

hydrating, grinding, and bagging plant was also operated at a station on the Rio Grande Railroad, a third of a mile (0.54 km) to the northeast at Saddle. Except for several temporary periods of inactivity, particularly during the early 1930's, the plant was operated successfully from February 1924 to June 1954, when it was permanently closed, owing to the increasing costs of quarrying the limestone and excessive competition from larger lime plants in Tooele and Utah Counties. The total production of raw limestone and hydrated lime from this operation are not known; however, the maximum capacity of the hydrating plant was 40 tons (36.3 tonnes) per 24 hours, and the capacity of the kilns ranged from 20 to 100 (18.1-90.7 tonnes) tons per 24 hours, depending on the forced draft that was utilized from the electrically driven blowers (Keiser, 1928).

The quarry is opened in the pink sublithographic limestone unit and the laminated, curly limestone unit at the top of the Fitchville Formation in the footwall of the Selma fault. These units, as quarried, contained 97.2 percent $CaCO_3$, 0.9 percent $MgCO_3$, 0.5 percent $Al_2O_3$, and iron oxides, and 1.4 percent insoluble residue, chiefly quartz (Keiser, 1928).

At the quarry site the pink sublithographic limestone unit is 14 ft (4.3 m) thick, and the curly limestone unit is 3 ft (1 m) thick, which is more than twice the average thickness of both of the units elsewhere in the East Tintic mountains. The quarry site was selected because of this thickness and because at that point the lime-rich strata were deformed into a minor compound anticline, thus also increasing the quantity of available limestone within a limited area (see Tower and Smith, 1899, pl. 78, p. 626).

An unusual feature of the lime-burning operation was the utilization of two underground kilns, which were stoped out of the limestone of the quarry floor (Keiser, 1928, p. 298). They are circular in cross section and are spaced 21 ft (6.4 m) apart from center to center. Both are 65 ft (19.8 m) high, 12 ft (3.7 m) in diameter at their base, 18 ft (5.5 m) at half their height, and 15 ft (4.6 m) at the top, which is coincident with the quarry floor. A 65-ft (20 m) adit from the hillside to the discharge floor provided a passageway for the forced-draft tubing and access for the removal of the burned lime. Each kiln was equipped with a steel hopper at the bottom, which supported a grate consisting of railroad rails spaced on 5-in. (12.7 cm) centers. The kilns were charged from the top by use of a small scraper to move the broken limestone from the quarry face and to mix it with 13 percent of coke. Despite the fact that the underground kilns were operated intermittently for 30 years, scaling and slabbing of the kiln walls were negligible.

As the quarrying operation progressed, it became necessary to remove an increasingly greater thickness of the lower part of the Gardison Limestone to expose the high-purity limestone at the top of the Fitchville Formation, thus increasing operating costs and eventually forcing the closure of the quarry.

## CROWN POINT CONSOLIDATED MINING CO.

The property of the Crown Point Consolidated Mining Co. is near the west edge of the East Tintic district approximately 2 mi (3.2 km) southwest of Dividend. The company was organized April 9, 1907, shortly after the discovery of the Humbug and other mines in the northern part of the Iron Blossom ore zone, which lies a short distance west of the property. The Crown Point No. 1 shaft was sunk in 1908 jointly with the Colorado and Iron Blossom Mining Companies and is actually on claims owned by the Colorado Consolidated Mining Co. Relatively little exploration was carried out from the No. 1 shaft, and the main periods of exploration and development of the Crown Point claims were from 1910 to 1921, when the northern part of the property was explored to the 1,000-ft level from the Crown Point No. 2 shaft, and from 1928 to 1931, when the No. 3 shaft was sunk in the central part of the claims. Underground exploration was briefly resumed in the No. 3 mine in August 1937, but by February 1939, the property again became inactive until the recent sinking of the Roundy shaft and the drill holes that preceded it in the south-central part of the property. The exploration from the Roundy shaft is described in the section "Roundy (Larsen) Shaft."

### PROPERTY DEVELOPMENT

The holdings of the Crown Point Consolidated Mining Co. consist of all or part of nine patented claims embracing 126.367 acres (51.18 hectares). In addition to the three Crown Point shafts and the Roundy shaft, the property is opened by a short adit and several shallow prospect pits.

The No. 1 shaft is in the SE¼SE¼SW½ sec. 20, T. 10 S., R. 2 W., 1,850 ft (564 m) south-southwest of the No. 2 shaft. It is 405 ft (123 m) deep, and one level has been established near the bottom. It is collared in the lower part of the Humbug Formation and bottoms in the Deseret Limestone. The details of the geology at the 400-ft level are not known; some old maps show about 260 ft (79 m) of lateral workings that extend southeasterly from the shaft, presumably all in west-dipping beds of the Deseret.

The No. 2 shaft is located a short distance south of the center of sec. 20, T. 10 S., R. 2 W., about 1,550 ft (472 m) north-northwest of the Crown Point No. 3

shaft. It is slightly more than 1,000 ft (305 m) deep and has seven levels that were driven at the approximate depths of 250, 400, 500, 550, 725, 750, and 1,000 ft (76, 123, 152, 167, 221, 229, and 305 m) below the collar. The lateral workings chiefly extend east and west of the shaft to the property boundaries and aggregate about 6,810 lineal feet (2,076 m).

The Crown Point No. 3 shaft is in the S½SE¼ sec. 20, T. 10 S., R. 2 W., about 2,850 ft (869 m) west of the Zuma shaft. It is 700 ft (213 m) deep, and the only level was established at a depth of 680 ft (207 m). The workings at this level, including two inclined winzes and two vertical raises, total a little more than 2,000 ft (610 m) and explore the area southeast of the shaft.

The Crown Point adit is located 490 ft (149 m) southwest of the No. 3 shaft and extends N. 71° W. for 330 ft (101 m) at which point it divides into a N. 45° W.-trending fork 85 ft (26 m) long and a west-trending fork that is 35 ft (11m) long. It enters the uppermost part of the Gardison Limestone but within a short distance crosses into the basal phosphatic shale member of the Deseret Limestone, where it remains for almost its entire length.

No ores have been produced from any of these workings.

### GEOLOGY

The rocks exposed at the surface on the property of the Crown Point Consolidated Mining Co. include the Fitchville, Gardison, Deseret, and Humbug Formations, which are overlapped by tuffs and lavas of the Packard Quartz Latite and Tintic Mountain Volcanic Group and locally are cut by dikes of monzonite porphyry. The subsurface geology is best exposed in the No. 2 shaft (fig. 46), which is collared in the uppermost part of the Gardison Limestone and bottoms in the Victoria Formation. The east- and west-trending levels all cut a generally unfaulted, normal sequence of beds that strike from N. 10° W. to N. 10° E. and dip 20°-25° W. The only fractures noted in the No. 2 mine are narrow north-trending fissures, one of which was followed for some distance northeasterly on the 250-ft level about 850 ft (259 m) east of the shaft.

Igneous rocks recognized in the workings of the No. 2 mine consists of narrow northeasterly trending dikes of monzonite porphyry, one of which was cut by the 400-ft level about 280 ft (85 m) northeast of the shaft. Presumably the same dike was cut by the 1,000-ft level 190 ft (58 m) east of the shaft, indicating a nearly vertical dip. A second dike was also cut at this level 455 ft (139 m) east of the shaft. The 250-ft level apparently entered prelava rubble and Apex Conglomerate about 430 ft (131 m) south of the shaft, indicating that the prelava topography slopes southward from the mine area.

The No. 3 shaft is collared in weakly pyritized Latite Ridge Latite, but within a short distance it enters the Gardison Limestone and bottoms in the upper part of the Victoria Formation. As shown in figure 47, the workings in the northern part of the 680-ft level are in the Victoria, which generally strikes N. 20°-30° W. and dips 20°-30° SW., but at a point 560 ft (171 m) S. 26° E. of the shaft they cut the contact of the Pinyon Peak Limestone and generally follow it for about 700 ft (213 m) to the southeast. Several north-northeast-trending pebble dikes were cut 150-220 ft (48-67 m) southeast of the shaft, and a narrow north-northeast-trending quartz vein was followed for several hundred feet in the area that is 400 ft (122 m) south-southeast of the shaft. At a greater distance, 750 and 900 ft (229 and 274 m) south-southeast of the shaft, several iron-stained breccia zones were also found, but they were not sufficiently mineralized to constitute ore, although some scattered grains of galena were observed.

## EAST CROWN POINT CONSOLIDATED MINING CO.

### PROPERTY DEVELOPMENT

The property of the East Crown Point Consolidated Mining Co. is in the southwestern part of the East Tintic district about 1¾ mi (2.8 km) southwest of Dividend. The company was incorporated July 8, 1907, and in 1972 slightly more than one-third of the outstanding stock was owned by the Chief Consolidated Mining. Co. The property consists of parts of eight patented mining claims, totaling 92.324 acres (37.39 hectares). It is contiguous with property of the Crown Point Consolidated, Zuma, South Standard, and Tintic Central Mining Companies. No ore has been shipped from the claims.

Prior to the sinking of the Roundy shaft in the southern part of the adjacent Crown Point property, and the exploration attendant with this development, the East Crown Point claims had been explored only to shallow depths. Contemporary newspaper articles state that by December 1912, a shaft had been completed to a total depth of 335 ft (102 m) at the far western side of the property. Presumably this is the abandoned shaft in the center of W½NE¼ sec. 29, T. 10 S., R. 2 W., which is collared in the Latite Ridge Latite and which apparently remains in this unit for its entire depth. Also, according to other newspaper accounts, plans were made in October 1920 to sink a second shaft, presumably in the W½W½NW¼ sec. 28, T. 10 S., R. 2 W. It appears that less than 100 ft (30 m) of sinking was accomplished, however, despite the erection of a headframe, hoist house, and other improvements.

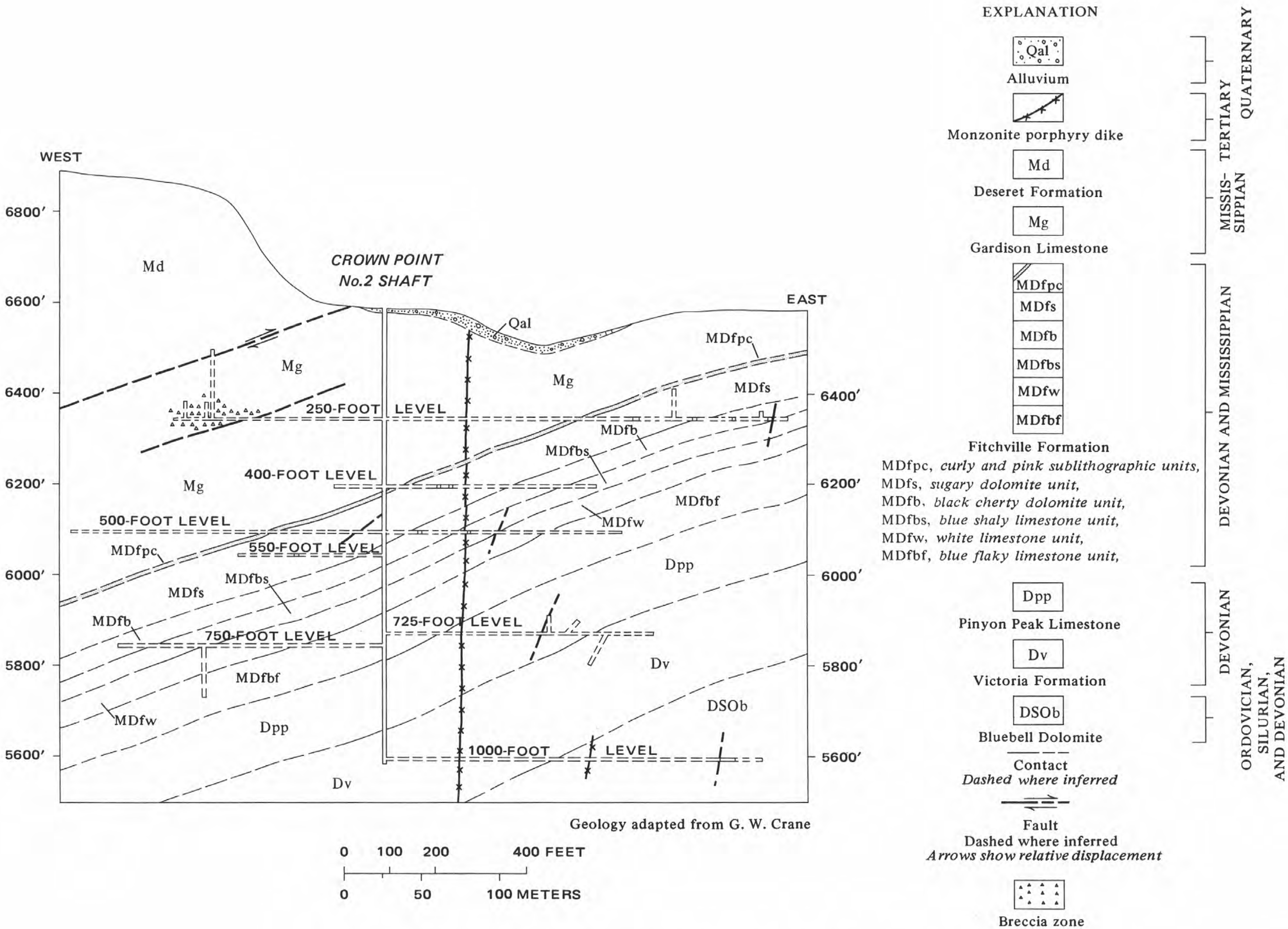



FIGURE 46. — Geologic cross section of Crown Point No. 2 mine.

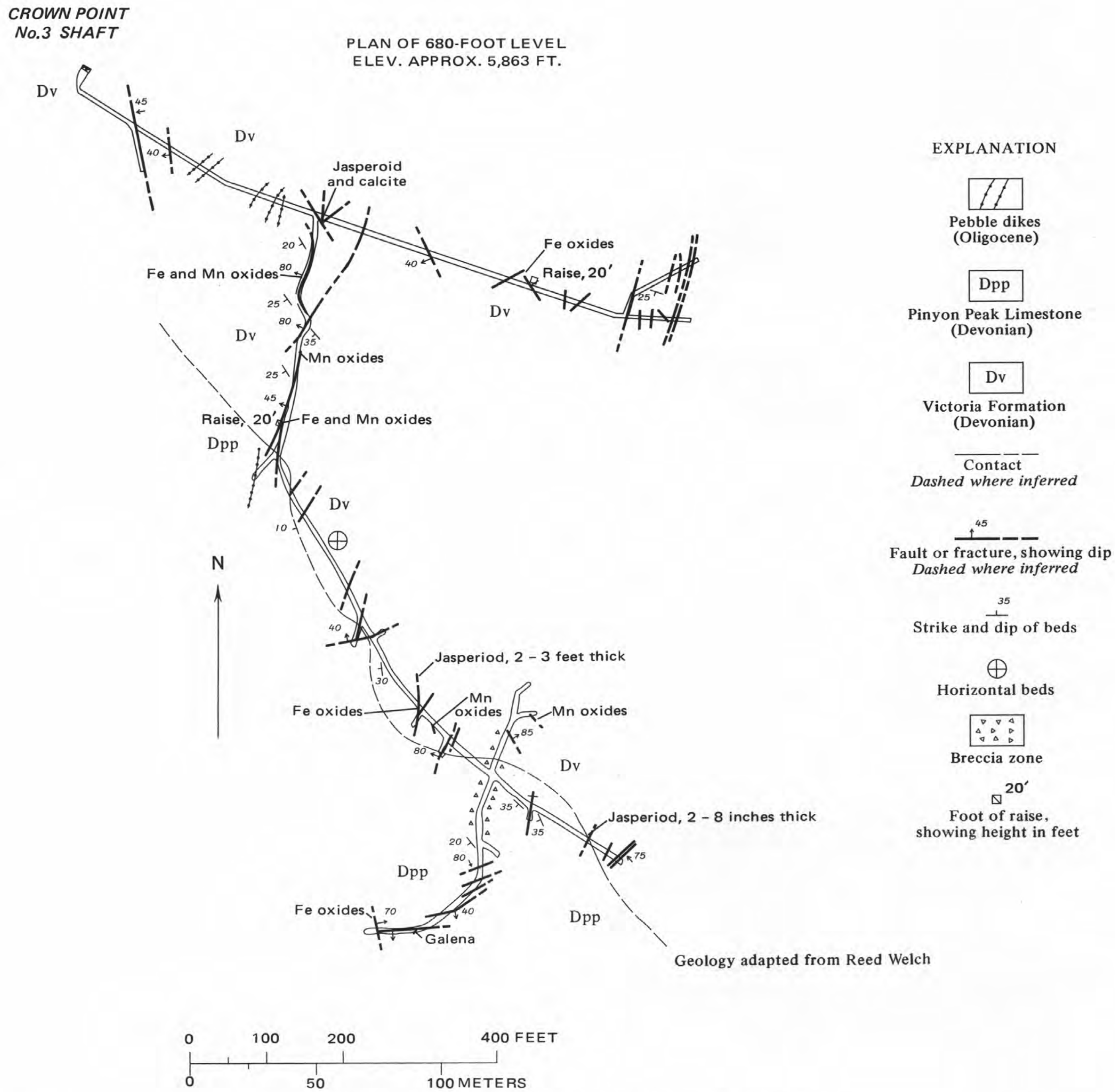



FIGURE 47. — Geologic plan of 680-ft level of Crown No. 3 mine.

## GEOLOGY

Except for a wide dike of monzonite porphyry in the southwestern part of the property and a smaller exposure of monzonite porphyry in the northeastern part of the property, the East Crown Point claims are entirely underlain by Latite Ridge Latite. Over much of the property these rocks are strongly pyritized and locally are cut by obscure northeast-trending fissures. Underground exposures in the Iron Blossom No. 3 and Roundy mines indicate that the Sioux Ajax fault extends easterly through the southernmost part of the East Crown Point property in the sedimentary rocks below thick lavas. This fault and its intersections with the Zuma and other north-northeasterly fissures were the principal objective of the Roundy shaft in 1971-72 (see section "Roundy (Larsen) Shaft").

## EAST STANDARD MINING CO.

The East Standard shaft is the principal underground opening within a block of unpatented ground in the northeastern part of the district about 2,000 ft (610 m) northeast of the Silver Shield (Independence) shaft. The East Standard Mining Co. was organized in 1919, and development of the property began soon after. Apparently the proposed targets for underground exploration were the large areas of opalized lava that crop out on the property. The shaft is reported to be 700 ft (213 m) deep and to have one level at a depth of 500 ft (152 m), which is a short distance above a perched water table in the lavas. According to newspaper accounts, the shaft was rehabilitated in 1928, and plans were made to drill from the 500-ft level to a total depth of 1,000 ft (305 m) or deeper to determine the thickness of the lava and the geology of the rocks underlying it. The results of this drilling were not reported, and it may not have been completed.

The shaft is collared in hematized vitrophyre agglomerate of the upper part of the Packard Quartz Latite 300 ft (91 m) north of the Silver Shield dike. Careful examination of the mine dump reveals that the vitrophyre agglomerate is only weakly altered near the surface but at shallow depth is argillized, silicified, and pyritized; these altered rocks apparently extend below the bottom of the shaft. The geology of the 500-ft level is unknown, but the absence of coarse-grained porphyritic quartz latite on the dump suggests that the Silver Shield dike was not cut by any of the mine workings and that the workings are entirely within the altered Packard lavas. So far as known, the opalized lavas are not associated with ore but may be related to the emplacement of the Silver Shield dike.

## EAST TINTIC COALITION SHAFT

The East Tintic Coalition shaft is in the west-central part of the East Tintic district in the E½E½ sec. 17, T. 10 S., R. 2 W., about 1½ mi (2.4 km) due west of Dividend. The first claims in the area were apparently staked by John and August Bestlemyre, and the original company was organized May 1, 1917. The property has been inactive since 1924. Of the outstanding stock, 97.7 percent is currently owned by the North Lily Mining Co., which acquired the property as a result of a stock transfer in 1926.

The property consists of six patented mining claims containing 59.63 acres (24.15 hectares) and one fractional claim of 0.35 acre (0.14 hectares) held under location. According to company records, mine workings on the property consist of two tunnels with a combined length of 500 ft (152 m) and four shafts. The main East Tintic Coalition shaft is 635 ft (194 m) deep, from which 870 ft (265 m) of lateral workings were driven at the 320-ft level. All of the workings are east and southeast of the shaft. The other shafts, now largely caved, were 127, 142, and 330 ft (39, 43, and 101 m) deep, respectively.

The main East Tintic Coalition shaft is collared in colluvium, but within a short distance, passes into the uppermost part of the Ajax Dolomite, possibly through a short interval of strongly weathered Packard Quartz Latite and Apex Conglomerate. A short distance south of the shaft the Ajax Dolomite locally is sanded and contains many pods and veinlets of iron-stained jasperoid, and presumably similar rock was cut in the mine workings. Nearby exposures of the Packard Quartz Latite are pyritized and argillized, and the lower part of the Opohonga Limestone northwest of the shaft is replaced by porous fine-grained quartz. The nearest intrusive rocks are small pipelike and dikelike bodies that cut the lavas 1,000 ft (305 m) south of the shaft. The geology exposed on the 320-ft level is unknown, although the beds are almost certainly the cherty dusky-gray dolomite of the Ajax Formation above its Emerald member. They probably dip 30°-50° W.

No ore is known to have been produced from the East Tintic Coalition claims.

## EUREKA BULLION MINE

The property of the Eureka Bullion Mining Co. is in the west-central part of the East Tintic district about half a mile (0.8 km) west of Dividend. It is bordered on the east and south by properties controlled by the Tintic Standard Mining Co. and on the north and west by other properties controlled or owned by the International Smelting and Refining Co. The Eureka Bullion Mining Co. was incorporated September 5, 1916, under the direction of John Bestlemyre and others, who had taken over the existing Grutli claims, including a shaft that was 220 ft (67 m) deep. In May 1919, after the discovery of the main Tintic Standard ore body, Bestlemyre and his associates deepened the shaft to the 800 level, which is 632 ft (193 m) below the collar. During the following 2 years, a winze was sunk from that level to the 1,150 level, and the company was active in exploring and developing an ore-bearing fissure by means of raises and winzes. In 1924 or 1925, controlling stock ownership of the Eureka Bullion Mining Co. was acquired by the Chief Consolidated Mining Co., who in turn, sold it in 1931 to the International Smelting and Refining Co. This latter company, in 1972, reportedly owned 50.4 percent of the outstanding stock. Since 1928 the Eureka Bullion claims have been developed only by workings extending from the North Lily and Big Hill shafts.

### PROPERTY DEVELOPMENT AND PRODUCTION

The property of the Eureka Bullion Mining Co. consists of all or part of nine patented claims containing 85 acres (34 hectares). The principal underground opening is the Eureka Bullion shaft, which is near the center of sec. 16, T. 10 S., R. 36 W. This shaft is 632 ft (193 m) deep, and the so-called 800 level was driven at this depth. From the 800 level a deep vertical winze was sunk on an ore-bearing fissure, and short levels, termed the 925, 1,050, and 1,150 levels, were driven from it (see fig. 48). The true elevations of these levels are not known. The 1,200, 1,350 and 1,500 levels of the North Lily mine also extend through a considerable part of the Eureka Bullion property as do the 1,600- and 1,900-ft levels of the Big Hill mine; however, none of these workings apparently connect with the Eureka Bullion workings. According to company estimates the Eureka Bullion mine openings, in addition to the shaft, include 626 ft (191 m) of winzes and 14,116 ft (4,303 m) of raises and lateral workings. There are also adits that aggregate 310 ft (94 m) in length, including the original Grutli adit, which trends northward from a point near the shaft collar and is about 85 ft (26 m) long.

Cook (1957, pl. 3) has estimated the total production of ores from the Eureka Bullion claims to be 18,589 tons (16,860 tonnes) having the average composition of 0.30 oz per ton (10.29 g per tonne) gold, 8.9 oz per ton (305.18 g per tonne) silver, 1.80 percent copper, and 0.2 percent lead. Most of this ore was mined from fissure and breccia ore bodies that extend into the northern part of Eureka Bullion property from the Tintic Bullion claims and the North Lily mine. The replacement ore bodies that were mined in the early 1920's apparently yielded less than 1,000 tons (900 tonnes) of ore. Individual carload lots of this latter ore are reported in contemporary newspaper accounts to have contained as much as 50-60 oz per ton (1,715-2,057 g per tonne) silver and 2.5-10 percent lead, and individual assays are reported to have been as high as 114 oz per ton (3,909 g per tonne) silver and 38 percent lead.

### GEOLOGY

The rocks exposed at the surface of the Eureka Bullion claims consist chiefly of fresh and altered lavas of the Packard Quartz Latite, which surround two erosional windows that expose the underlying Paleozoic rocks. In the west-central part of the claims, the Ajax Dolomite crops out in a window that extends westerly to the Big Hill shaft. In general, the beds of the Ajax strike northeast and dip 15°-40° NW. In the east-central part of the claims the Cole Canyon Dolomite forms a prominent hill that is surrounded by lava. These beds also generally strike northeast and dip 30°-40° NW. They lie in the hanging wall of the Eureka Lilly fault and are cut by several small faults of diverse strike. The Packard Quartz Latite that surrounds the erosional windows is argillized, pyritized, and calcitized, except for a few small areas that have escaped alteration.

The Eureka Bullion shaft is collared near the lava-sedimentary contact on the southwestern side of the erosional window that exposes the Cole Canyon Dolomite. According to C. N. Gerry (unpublished notes, 1920), who visited the mine on November 14, 1920, the rocks cut by the 800 level are Herkimer Limestone that strikes northerly and dips west at a low angle. A shale bed, 50 ft (15 m) thick and reportedly cut at the 1,150 level, probably is the shale member of the Herkimer Limestone, although its thickness seems excessive. No mention is made of the Dagmar Dolomite. Examination of the dump indicates that most of the limestone in and near the mine has been dolomitized. No intrusive rocks have been described from the mine, but a pebble dike, with nearly vertical striations on its walls, is reported to have been followed by the south drift at the 800 level. No notable faults or other geologic features are reported to have been found in the mine workings, although one of the major strands of the Eureka Lilly fault zone may possibly extend to the vicinity of the shaft and main winze.

### ORE BODIES

The small replacement bodies that were developed by workings driven from the Eureka Bullion shaft lie 200-350 ft (61-107 m) north and northeast of the shaft and occur in a fracture zone that trends approximately N. 67° E. and dips steeply north-northwest. Ore was first found in May 1919 about 300 ft (91 m) N. 20° W. of the shaft in a drift that was driven along an obscure north- or northwest-trending fissure. The ore zone is tabular, and where it was first cut, it was 2-3 ft (0.6-1 m) wide; small shipments returned assays of 5-38 percent lead and 12-58 oz per ton (411-1,989 g per tonne) silver. The ore-bearing zone apparently achieved its greatest size at the 925 level where it was followed for a lineal distance of 200 ft (61 m) or more and was as much as 5 ft (1.5 m) wide. One lot of 40 tons (36 tonnes) of ore shipped from the 925 level contained $2.40 per ton ($2.64 per tonne) gold, 60 oz per ton (2,057 g per tonne) silver, and 2.5 percent lead. The ore zone terminated a short distance above the 800 level, was greatly diminished in size at the 1,050 level, and was represented by only a few pockets of ore minerals at the 1,150 level.

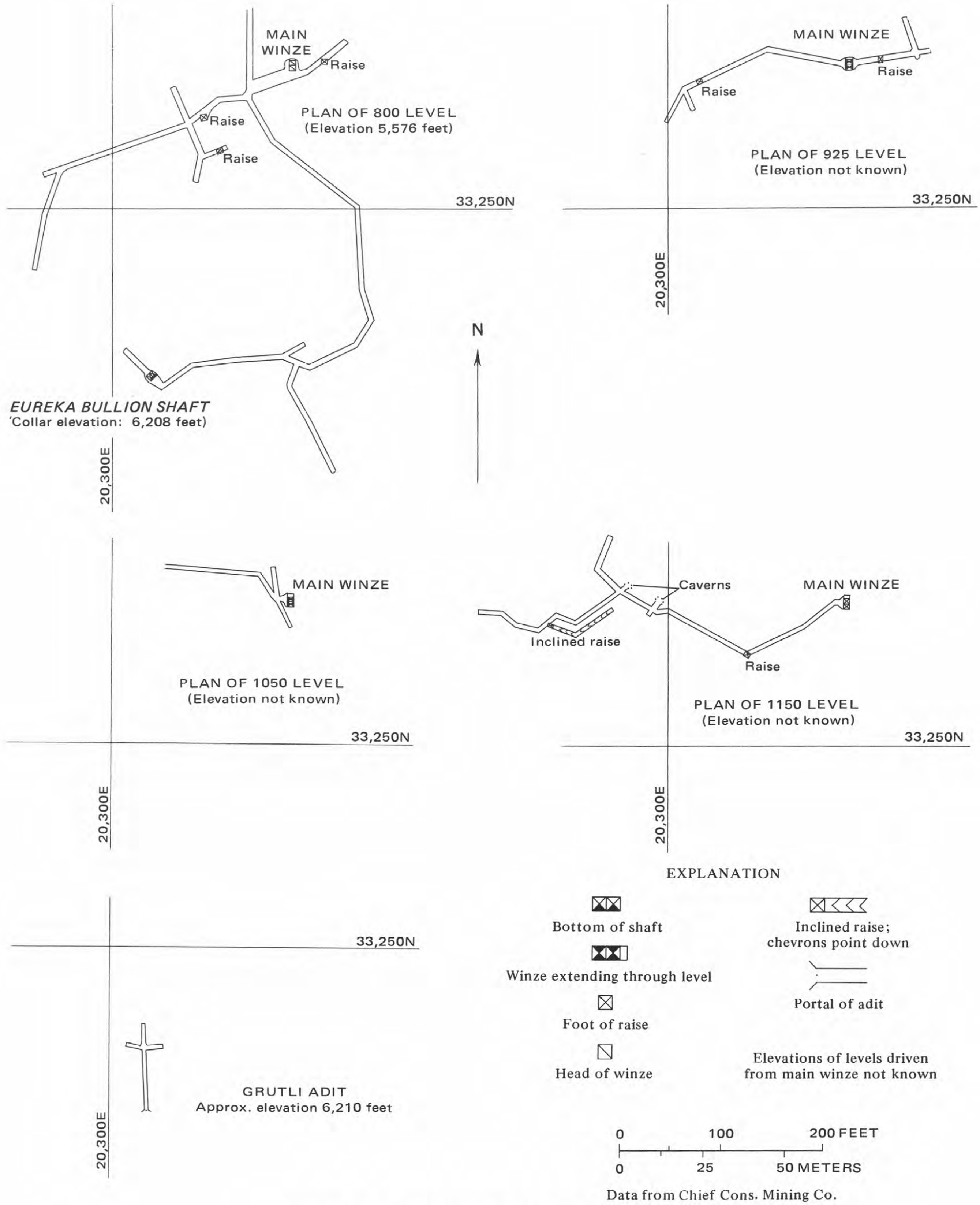



FIGURE 48. — Plan of workings of Eureka Bullion mine.

Descriptions of the Eureka Bullion replacement ores are sketchy and incomplete. Contemporary newspaper accounts indicate that they chiefly consisted of dolomite breccia incoherently cemented with quartz, calcite, and iron oxides containing pockets of cerussite, anglesite, corroded galena, and some malachite and azurite. The form of the silver is not reported, but it is probably cerargyrite.

In 1929, while the Eureka Bullion mine was under the ownership of the Chief Consolidated Mining Co., the North Lily 1,200 level explored the Tintic Quartzite in the footwall of the Eureka Lilly fault on a downward projection of the east-northeast-trending fissure that localized the Eureka Bullion replacement ore bodies in the hanging wall of the fault between the 800 and 1,050 levels. This deep exploration yielded 466 tons (423 tonnes) of ore containing 156 oz (4,851.6 g) gold, 6,084 oz (189.2 kg) silver, and 20,720 lb (9,407 kg) copper. The correlation of the two ore-localizing fissures across the fault zone was suspected but not proved.

The most productive ore bodies within the area of the Eureka Bullion claims are the southernmost extension of gold-bearing fissures that were followed in the North Lily mine south-southwesterly across the Tintic Bullion claims into the northernmost part of the Eureka Bullion property. These fissures are within the converging Keel dike and Endline dike fissure zones in the Tintic Quartzite, and their ore shoots rake downward from the southwest end of the North Lily replacement ore body and terminate against the Eureka Lilly fault on the Eureka Bullion claims (see p. 157). As described by Kildale (1957, p. 115), the ores occur in part as fissure fillings along strong steep fissures and in part as overgrowths on fragments of brecciated quartzite and monzonite. The ore shoots were irregular in shape and were mostly 2-3 in. (5-7.6 cm) to 5 ft (1.5 m) or more wide. They were most strongly developed between the 1,200 and 1,400 levels of the North Lily mine and greatly diminished in grade and became pyritic on the 1,500 level. At the intersections of the two southeasternmost fissures of the group and the Eureka Lilly fault, two small pods of mineralized breccia were mined from the 1,200 level. Additional exploration both along the fault and in the hanging-wall rocks failed to disclose other similar ore bodies.

The ores of the fissure and quartzite breccia ore bodies consisted of pyrite, enargite, tetrahedrite, galena, sphalerite, and minor chalcopyrite, in association with crystalline quartz, barite, and clay minerals. They are more fully described on page 161.

## EUREKA LILLY MINE

The Eureka Lilly mine is near the center of the SE¼ sec. 16, T. 10 S., R. 2 W., half a mile (0.8 km) west-southwest of Dividend. It was the second commercially productive mine developed in the East Tintic district, having shipped ore in 1909, 10 years after the first ore was mined and sold from the Lilley of the West shaft, which is about 200 ft (61 m) west-southwest of the Eureka Lilly shaft. Exploration from the present Eureka Lilly shaft began in 1906, having been stimulated by the proximity of the Lilley of the West ore body and the excitement that resulted from the discoveries of the rich mines of the Iron Blossom ore zone in the main Tintic district 1¾ mi (2.8 km) to the west. The shaft was sunk on the Ralph claim, a holding of less than 10 acres (4.5 hectares), in 1908 by the East Tintic Development Co. under the direction of M. M. Kellog and W. D. Bonham, and ore was first found at the 230-ft level in January 1909. Development of these shallow ore bodies was rapid, and a considerable amount of lead ore was produced from stopes between the 70-ft and 500-ft levels from 1909 to 1911. As metal demand increased during the beginning phases of World War I, these same stopes and parts of the mine dump were reworked for oxidized zinc ore; these efforts yielded more than 1,000 (907 tonnes) tons of high-grade zinc oxide ore from 1911 to 1913 and lesser amounts in the succeeding 2 or 3 years.

In 1916, the property and other assets of the East Tintic Development Co. were sold after foreclosure litigation, and the claims were then merged with other contiguous small holdings to form the Eureka Lilly Mining Co. Under the direction of this new company, an unsuccessful search was made for possible extensions of the Tintic Standard ore body, during which time an inclined winze 1,135 ft (346 m) long was sunk from the 500-ft level to the so-called 1800-ft level.

In November 1921 control of the Eureka Lilly was acquired by the Chief Consolidated Mining Co. In 1926 and 1927, during its operation by this company, a spectacular discovery of ore was made in the northern part of the property as a result of exploration efforts directed by Paul Billingsley; later, the vertical shaft was also sunk to a depth of 1,400 ft (427 m). Billingsley's contributions to the discovery of the Eureka Lilly and North Lily ore bodies is discussed on pages 154-155.

In February 1936 Chief Consolidated's controlling interest in the Eureka Lilly Mining Co. was purchased by the Tintic Standard Mining Co. for $360,000. The new holders deepened the shaft to a total depth of 1,587 ft (484 m) and developed a new ore zone on the South fault near the shaft. In January 1, 1938, the Eureka Lilly, East Tintic Consolidated, and Iron King Consolidated Mining Companies were merged into the Eureka Lilly Consolidated Mining Co., which continued under the control of Tintic Standard. The mine property has been inactive since June 1949 except for minor operations from the Eureka Lilly shaft in 1950 and 1951. In 1956 properties of the Eureka Lilly Consolidated Mining Co. were leased to the Kennecott Copper Corp. along with other properties controlled by the Tintic Standard Mining Co.

On November 22, 1974, Eureka Lilly Consolidated Mining Co. was merged into the Eureka Standard Consolidated Mining Co. whose controlling interest had been acquired by Amax Copper Mines, Inc. through its absorption of Tintic Standard Mining Co. in May 1973.

### PROPERTY DEVELOPMENT AND PRODUCTION

Prior to the merger into the Eureka Standard Consolidated Mining Co., the property of the Eureka Lilly Consolidated Mining Co. consisted of 60 patented and 1 unpatented mining claims aggregating 862 acres (349 hectares). These claims were originally bordered by the properties of the North Lily, Tintic Standard, Eureka Standard, South Standard, Zuma, Crown Point, Yankee Consolidated, and several other smaller mining companies. The original Eureka Lilly property was developed by three vertical shafts totaling 5,145 ft (1,568 m), 3,875 ft (1,181 m) of tunnels, and approximately 60,000 ft (18,288 m) of underground workings. Two of the shafts, however, and a substantial part of the tunnels and underground workings are on the Iron King group of claims and are described separately later.

The Eureka Lilly vertical shaft, as stated earlier, is 1,587 ft (484 m) deep; from it, levels were driven at approximately 70, 130, 230, 330, 500, 1,300, 1,400, and 1,545 ft (21, 40, 70, 101, 152, 396, 427, and 471 m) below the collar. The main inclined winze in the mine extends from the 500-ft level to the 1,400-ft level, and intermediate levels were driven from the winze at depths that are approximately 600, 850, and 1,150 ft (183, 259, and 351 m) below the collar elevation of the shaft. In addition, there are many workings in the northern part of the mine that do not extend from the Eureka Lilly shaft, but connect, instead, with the 500, 600, 700, 900, 1,200, and 1,350 levels of the North Lily and Tintic Standard mines. Numerous small winzes and raises extend from all of the lateral workings, and sublevels have been driven from some of them.

The ore produced from the Eureka Lilly mine, not including the production of the Iron King and East Tintic Consolidated properties, is estimated by Cook (1957, pl. 3) to be approximately 245,000 tons (222,215 tonnes), averaging 0.25 oz per ton (8.57 g per tonne) gold, 5.6 oz per ton (192 g per tonne) silver, 0.8 percent copper, 3.6 percent lead, and an unspecified percentage of zinc. Kildale (1957, p. 106), in the same report, estimated that of this total approximately 145,000 tons (131,515 tonnes) came from the ore bodies that were mined through the North Lily shaft and 100,000 tons (90,700 tonnes) came from fissure ore bodies along the South fault that were mined through the Tintic Standard and Eureka Lilly shafts. In addition, about 5,000 tons (4,535 tonnes) of lead, zinc, and silver ore was mined above the 500-ft level of the Eureka Lilly shaft, making a grand total of 250,000 tons (226,750 tonnes). Kildale (1957) further estimates that of the ore mined through the North Lily shaft, about 50,000 tons (45,350 tonnes) was classed as lead-silver ore having an average recoverable metal content of 0.187 oz per ton (6.41 g per tonne) gold, 6.5 oz per ton (222.89 g per tonne) silver, and 17.5 percent lead, and 95,000 tons (86,165 tonnes) was classed as siliceous gold-silver ore having an average recoverable metal content of 0.40 oz per ton (13.72 g per tonne) gold and 2.75 oz per ton (94.3 g per tonne) silver. The fissure ores near the South fault were chiefly siliceous gold-silver-copper ores that contained an average of about 0.15 oz per ton (5.14 g per tonne) gold, 8.0 oz per ton (274.3 g per tonne) silver, and 2 percent copper. The grade and volume of the shallow ore bodies near the Eureka Lilly shaft are not known with any degree of certainty, but these bodies are estimated to have yielded about 3,500 tons (3,174 tonnes) of lead ore that contained an overall average of about 5 oz per ton (171.5 g per tonne) silver and 30-40 percent lead, and 1,500 tons (1,361 tonnes) of oxidized zinc ore that contained 30-35 percent zinc.

### GEOLOGY

The following descriptions of the geology and ore deposits of the Eureka Lilly mine are limited to parts of the claims that are opened by the Eureka Lilly, Tintic Standard, and North Lily shafts. The parts of the property that originally were the Iron King Mining Co. and East Tintic Consolidated Mining Co. are described under those headings.

The Eureka Lilly shaft is collared at the contact of the Dagmar Dolomite and the Herkimer Limestone a short distance east of the trace of the Eureka Lilly fault. At the surface, the greater part of the general area is underlain by the Packard Quartz Latite, which in part was faulted against the sedimentary rocks by movement on the Eureka Lilly fault and in part is in depositional contact with these rocks on the flanks of a prelava hill that now forms an erosional window. In the northernmost part of the claims near the North Lily shaft, the lavas are extensively altered and are cut by many northeast-trending dikes of pebble breccia and monzonite porphyry.

The sedimentary rocks exposed at the surface are all of Cambrian age and range from the Teutonic

Limestone to the Cole Canyon Dolomite. Although they are cut by many high- and low-angle faults of small displacement, the exposed rocks provide only meager evidence of the complicated geologic structure that is concealed beneath the lavas.

The Eureka Lilly shaft penetrates the base of the Dagmar Dolomite and almost all of the Teutonic and Ophir Formations before it cuts the Tintic Standard thrust fault, which is here coincident with bedding, and enters the upper part of the Tintic Quartzite at a depth of about 1,400 ft (427 m). Approximately 185 ft (56 m) deeper, the shaft bottoms in Tintic Quartzite near the zone of the South fault. Parts of the Ophir Formation exposed in the shaft and on the 1,300- and 1,400-ft levels are strongly contorted, presumably related to drag folding that is particularly conspicuous near the Tintic Standard thrust and South tear faults. One or more low-angle faults also may have been cut higher in the shaft, particularly at a depth of 800 ft (244 m), where a strong reversal of dip is indicated on company maps (see sec. C-C', pl. 2). Near the shaft, the South fault trends in a sinuous course to the northeast and also dips sinuously to the northwest. Southwest of the Eureka Lilly shaft, the South fault is cut and shifted southward as a result of normal displacement on the Eureka Lilly fault.

In the upper workings of the Eureka Lilly and the nearby Lilley of the West shafts, the Eureka Lilly fault trends northerly and dips approximately 50° W. The base of the Packard Quartz Latite is faulted downward at least 300 ft (91 m) and perhaps as much as 500 ft (152 m); the total throw on the fault, as indicated by the vertical separation of the Tintic Standard thrust at the top of the Tintic Quartzite in the vicinity of the shaft is estimated to be 600-700 ft (183-213 m). The somewhat greater displacement of the sedimentary rocks below the lavas may indicate one or more periods of prelava movement on the fault. The strata on both sides of the Eureka Lilly fault generally trend northerly and generally dip westerly at low to moderate angles.

The limestone beds throughout the mine have been converted to hydrothermal dolomite over large areas and locally these dolomites have been sanded and replaced by manganese minerals and clay.

In the general vicinity of the replacement ore bodies in the northern part of the claims, the Tintic Quartzite rises steeply out of the North Lily trough (see fig. 35, and fig. 65) and forms a northwest-trending structural ridge, termed by Lovering (1949, p. 14) the East Tintic barrier (fig. 49). In the area of the trough, which lies west of the strucutral ridge, the Ophir and younger formations were detached from the underlying quartzite along the plane of the Tintic Standard thrust fault and are crumpled, brecciated, and locally sliced into several fault segments, particularly along the west-facing flank of the East Tintic barrier. Younger north-northeasterly trending fractures of the Eureka Lilly fissure zone, some of which are occupied by pebble dikes and dikes of monzonite porphyry, cut the folded and faulted sedimentary rocks and the overlying lavas as well. During the waning phases of igneous activity, these fractures served as conduits for the ore-depositing and other hydrothermal solutions.

## ORE BODIES

The most productive ore bodies in the Eureka Lilly mine are those in the northern part of the property that were worked through the North Lily shaft. They are part of a group of replacement bodies that are somewhat larger and more abundant on the adjacent North Lily property (see section "North Lily Mine"). The largest of the Eureka Lilly ore bodies has a pitch length of more than 800 ft (244 m) extending from the 600-ft level of the mine to a point on the 850-ft sublevel that is 225 ft (69 m) N. 38° E. of the North Lily shaft. Lower grade extensions have been followed to the 950-ft sublevel. Below the 800-ft level, the ore bodies are tabular replacement veins, mostly less than 20 ft (6 m) wide. Above this level the ores replace fault-bounded blocks of the Ophir's middle limestone member where the bodies expand to a maximum width of 200 ft (61 m); their thickness ranges from 15 to 50 ft (4.6 to 15.2 m). A similar, but smaller, ore body lying east of this main ore body extends into the North Lily property. In general, the Eureka Lilly-North Lily replacement ore bodies are localized at the intersections of steep north-northeasterly trending fissures and the Tintic Standard thrust and associated low-angle faults. Unlike the main North Lily ore body, however, the greater part of the main Eureka Lily replacement body does not lie directly against the quartzite of the lower plate but replaces blocks of the middle limestone member of the Ophir Formation above the subsidiary thrusts in the upper plate. Also unlike its counterparts in the North Lily mine, the main replacement body in the Eureka Lilly mine apparently is not underlain by ore-bearing fissures in the quartzite footwall.

The second most productive ore bodies in the Eureka Lilly mine are shoots of copper and gold ore that occurred along the South fault and in fissures cutting Tintic Quartzite in the footwall block. In general, the strike of these fissures is slightly more northerly than the strike of the South fault, and the ore shoots are limited to a zone that is a few hundred feet below the intersections of the fissures with the South fault. In general, the shoots are tabular, ranging in width from 3 in. (7.6 cm) to 10 or 20 ft (3 or 6 m); they are limited to the Tintic Quartzite between the 1,300-ft and 1,550-ft levels of the mine.

The shallow replacement ore bodies in the vicinity of the Eureka Lilly shaft have been described by Loughlin (in Lindgren and Loughlin, 1919, p. 247-248) in considerable detail. They consisted of several podlike masses of oxidized galena that replaced the Dagmar Dolomite and the adjacent Teutonic and Herkimer Limestones within the sheeted zone of the north-trending Provo fissure a short distance east of the shaft. The uppermost ore body was mined on the 70-ft level, and other ore shoots in the same zone were followed downward to a point below the 330-ft level. The largest ore body was stoped continuously from the 130- to the 230-ft level; the stope width along this part of the vein ranges from 60 to 120 ft (18-37 m) and its thickness from 4 to 10 ft (1.2 to 3 m). The vein crosses the shaft 30 ft (9 m) above the 330-ft level, and on that level it is 10 ft (3 m) west of the shaft, striking N. 15°-20° W. and dipping 70° W. According to Loughlin (in Lindgren and Loughlin, 1919, p. 248) the vein was followed on the 330-ft level for 100 ft (31 m) where it had a general thickness of 5 ft (1.5 m), though at places it bulged to 10 ft (3 m). On the 500-ft level the most prominent mineralized zone is 135 ft (41 m) west of the shaft, striking nearly due north and dipping about 60° W. Apparently little if any stoping was done at this level.

The ores of the replacement ore bodies of the northern part of the Eureka Lilly mine were closely similar to the oxidized ores of the Tintic Standard and North Lily mines. In general, they consisted of incoherent vuggy masses of ochreous material containing cerussite, anglesite, plumbojarosite, chalcocite, argentojarosite, malachite, azurite, and iron and manganese oxides mixed with lumps of honeycombed jasperoid, iron-stained dolomite breccia, pods and seams of clay, and grains and masses of residual hypogene metallic minerals. Locally smithsonite, hemimorphite, native silver, cerargyrite, bismite, native gold, and a variety of rare or uncommon minerals were relatively abundant. Pockets of ore that escaped alteration and oxidation, particularly in shaly horizons, indicate that the dominant hypogene minerals were pyrite, argentiferous galena, enargite, tetrahedrite, proustite, and native gold. Less abundant minerals included sphalerite, bismuthinite, argentite (or acanthite), jamesonite, polybasite, and, possibly, hessite, petzite and native gold. The gangue minerals included brecciated baritic jasperoid of several generations, sanded dolomite, and argillized shale. The manganese oxides were probably also derived from rhodochrosite.

The ores of the fissure veins near the South fault in the vicinity of the Eureka Lilly shaft consisted of quartzite breccia cemented or coated by crystalline and fine-grained quartz, abundant barite, cubic and pyritohedral pyrite, and greater or lesser amounts of enargite, tetrahedrite, native gold, and some galena and sphalerite. Less common minerals included chalcopyrite, bornite, hessite, petzite, and calaverite. These ores were generally unoxidized.

The replacement ore bodies that were mined on the upper levels of the Eureka Lilly shaft were described by Loughlin (in Lindgren and Loughlin, 1919, p. 247-248) as consisting of rather fine-grained galena, accompanied by anglesite and cerussite, in a gangue of partly sanded dolomite breccia. Below the 330-ft level, baritic jasperoid became abundant. The main bodies of oxidized zinc ore occurred below the lead stopes, particularly on cross-breaking fissures. Evidently the zinc ore migrated downward from the oxidizing ore bodies and replaced the unaltered limestone in dolomite below the main zones of ore deposition.

## EUREKA STANDARD MINE

The Eureka Standard mine is in the south-central part of the East Tintic district about 0.8 mi (1.3 km) south of Dividend in the lower reaches of Burriston Canyon (fig. 50). It is situated between the Apex Standard mine, on the east, and the Iron King mine, on the west; it chiefly explored and developed a segment of the Eureka Standard fault.

The Eureka Standard Mining Co. was first organized in March 1917 by Jesse Knight and his associates of Provo, Utah. Prior to that time the property had been known as the Montana Mining Co., the early history of which is discussed in the section "Montana Shaft." In May 1917, a group of 11 claims and a millsite were added to the original 14 claims and fractions of the Montana Mining Co., and plans were announced in contemporary newspapers to deepen the existing 500-ft-deep Montana shaft to a total depth of 1,000 ft (305 m). In August of the same year, however, before this work was started, the dominant control of the company was purchased by the Tintic Standard Mining Co. On November 22 of the same year the present corporation was formed through a merger with the Tintic Bonanza Mining Co., which was also controlled by Tintic Standard, to form the Eureka Standard Consolidated Mining Co.

The decision to develop the Eureka Standard claims followed geologic studies of the area by J. M. Snow, chief geologist of the Tintic Standard Mining Co., that disclosed a structural trough, believed to resemble the Tintic Standard pothole, containing faulted and altered Ophir Formation at depth and scattered exposures of argillized and pyritized Packard Quartz Latite at the surface. Additional features that con-

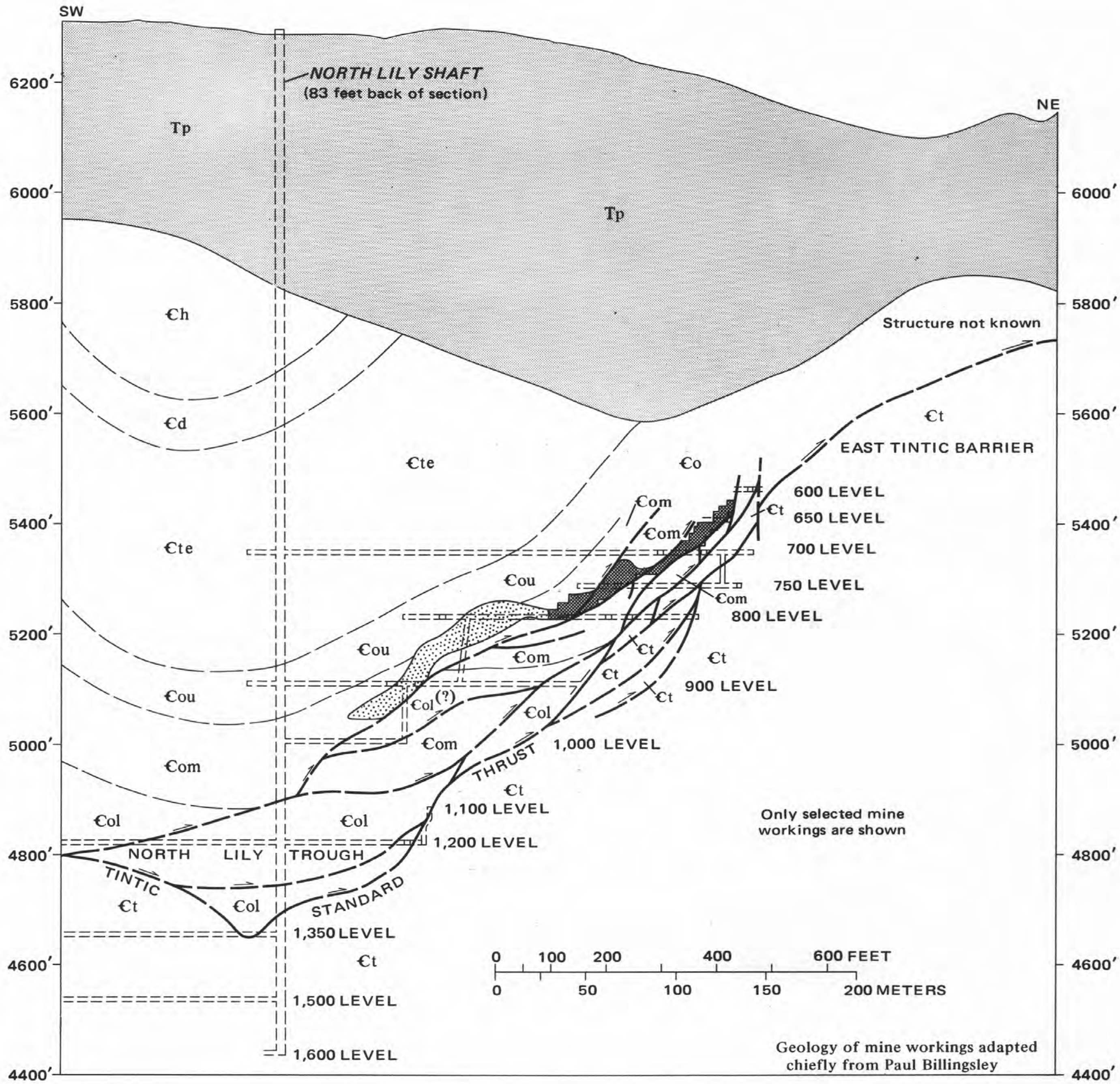



FIGURE 49. — Geologic cross section through main replacement ore body of Eureka Lilly mine in general plane of Eureka Lilly fissure zone.

tributed to the decision to develop the property included the presence of bodies of iron and manganese oxides near the Montana shaft and on the adjoining Iron King claims, and also the discovery and development of lead and zinc ores in the nearby Apex Standard mine.

In preference to deepening the existing Montana shaft, the new Eureka Standard shaft was located and collared in 1923. By May 1925 it had reached a depth of 780 ft (238 m), and a long crosscut was being driven northerly to connect with the workings of the Tintic Standard mine. The shaft was later sunk to 1,170 ft (357 m), and the initial discovery of high-grade ore was made in May 1928 on the 1,100 ft level. This ore body was 8 ft (2.4 m) wide at the point where it was first penetrated, and by December 31 of the same year it had been developed for a strike length of 450 ft (14 m)

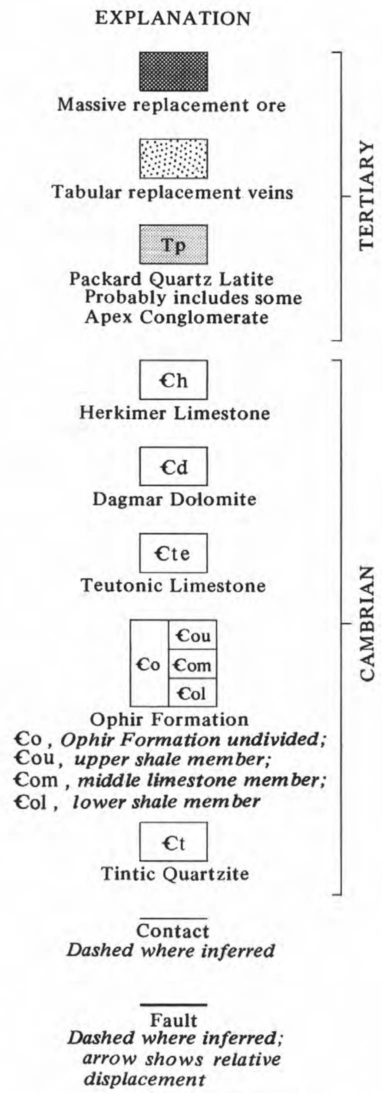



FIGURE 49. — Continued.

at the 1,100-ft level and also followed upward to the 1,000-ft level and downward to the 1,220-ft level. The overall average thickness of this ore was about 6 ft (2 m). The grade of 4,295.8 tons (3,896 tonnes) of ore that was shipped during the initial exploration and development of the discovery ore body was 0.77 oz per ton (26.40 g per tonne) gold and 10.58 oz per ton (362.79 g per tonne) silver.

Development of the mine rapidly followed the discovery of the blind ore bodies. By June 1931 the shaft had passed the 1,400-ft level, and a new headframe, hoist, and mine plant had been installed. In October 1931 the Eureka Standard Consolidated Mining Co. purchased controlling interest in the East Tintic Consolidated Mining Co. from the Chief Consolidated Mining Co. Six years later, in December 1937, this interest was exchanged for 269,048 shares of the Eureka Lilly Consolidated Mining Co., into which the East Tintic Consolidated was merged.

The Eureka Standard reached a maximum annual production of 42,963 tons (38,967 tonnes) of ore in 1934. After 1939, however, the output greatly diminished, and except for the sale of dump materials, mining and development operations were discontinued in September 1940. Since 1956, the inactive property has been under lease to the Kennecott Copper Corp.

On November 22, 1974, the Eureka Lilly Consolidated Mining Co. was merged with the Eureka Standard Consolidated Mining Co., which became the surviving company. Controlling interest in both companies was held by Amax Copper Mines, Inc. through its acquisition of Tintic Standard Mining Co. in May 1973. In April 1975 it was reported that Colorado Consolidated Mines Co. of the main Tintic district also

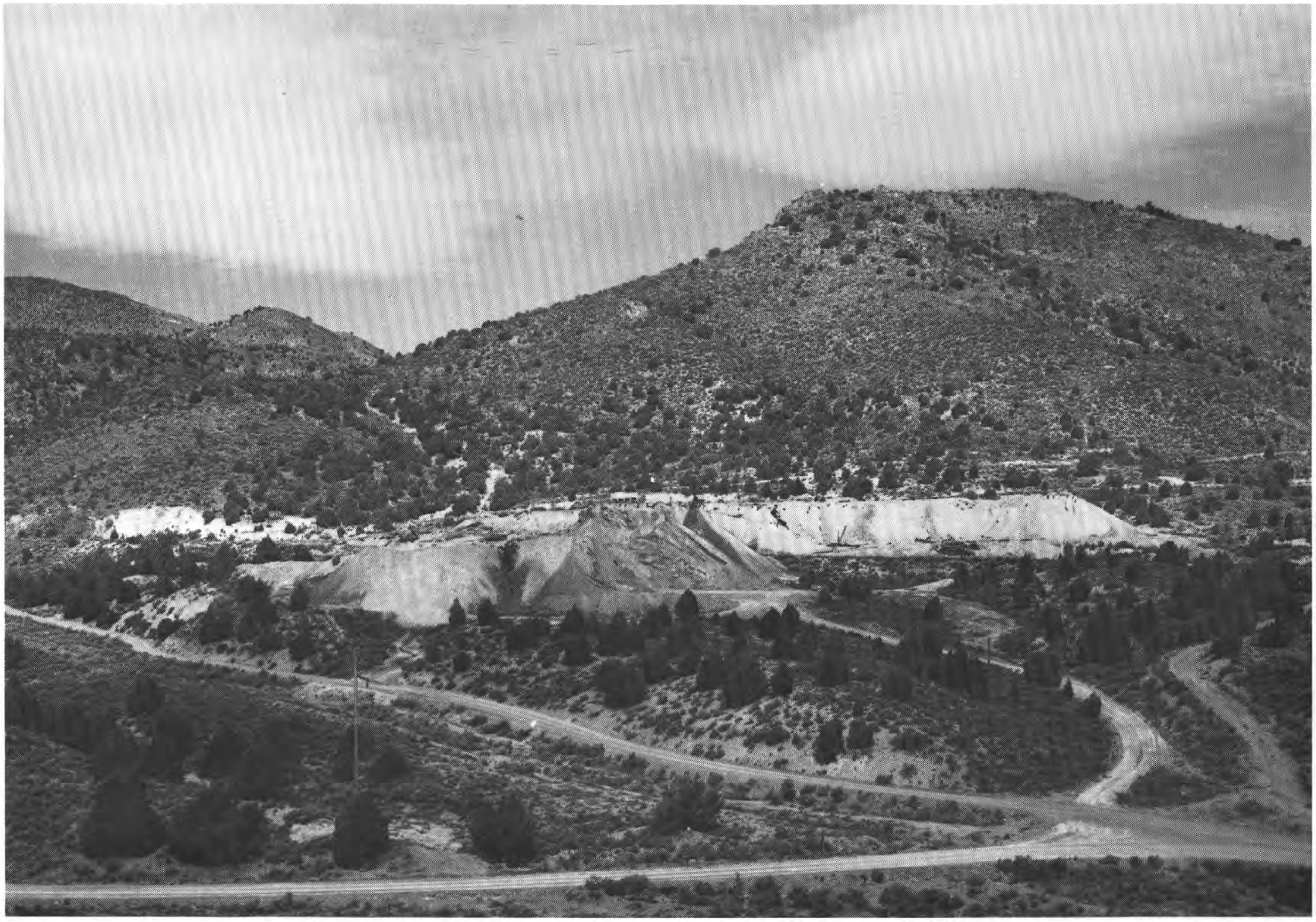


FIGURE 50. — Eureka Standard shaft site and dumps. Prominence in right background is Mineral Hill.

would be merged with Eureka Standard Consolidated.

## PROPERTY DEVELOPMENT AND PRODUCTION

Prior to the acquisition of the Eureka Lilly Consolidated Mining Co., the property of the Eureka Standard Consolidated Mining Co. consisted of 43 patented mining claims aggregating 373 acres (151 hectares) and 5 additional unpatented claims and fractions. It was opened by the four-compartment Eureka Standard shaft 1,424 ft (434 m) deep, which has five levels that are at approximate depths below the collar of 780, 900, 1,000, 1,100, and 1,300 ft (238, 274, 305, 335, and 396 m). In addition, sublevels have been driven at approximately the 1,050- and 1,200-ft levels from a vertical raise in the central part of the mine and approximately at the 1,350- and 1,400-ft levels from an inclined winze also in the central part of the mine. Horizontal workings aggregate 52,128 ft (15,889 m), and raises and winzes total 10,115 ft (3,083 m), according to company data. The Montana shaft, also on the property, is described separately in this report.

The total production from the mine and dumps of the original Eureka Standard Consolidated Mining Cc. from 1928 to 1970 was 362,832 tons (329,089 tonnes) of ore containing 242, 919 oz (7,554.8 kg) gold, 3,430,723 oz (106,695.5 kg) silver, 2,716,434 lb (1,233,261 kg) copper, 11,211,423 lb (5,089,986 kg) lead, and 3,496,852 lb (1,587,571 kg) zinc. The Eureka Standard was the first mine in the district to produce chiefly gold ores and the first to produce commercial ore from the Tintic Quartzite. Dividends totaling $1,124,692.50 have been paid by the company.

It should be noted that approximately 1,400 tons (1,270 tonnes) of ore credited to the Eureka Standard mine was actually produced from the propety of the East Tintic Consolidated Mining Co., which was under lease to the Eureka Standard and opened on the 1,350- and 1,400-ft levels. This ore contained approximately 254 oz (7,899 g) gold, 11,083 oz (344.7 kg) silver, 22,401 lb (10,170 kg) copper, and 41,336 lb (18,767 kg) lead.

## GEOLOGY

The dominant geologic feature in the vicinity of the Eureka Standard shaft is a grabenlike structural trough that is bounded on the south by the Eureka Standard fault and on the north by the Iron King fault (fig. 51). The strata preserved within the relatively downfaulted block include all of the Cambrian formations between the Tintic Quartzite and the Cole Canyon Dolomite. These formations are probably cut by two or more minor thrust faults. South of the Eureka Standard fault only the Tintic Quartzite, Ophir Formation, and Teutonic Limestone are present; north of the Iron King fault the strata range from Tintic Quartzite to the Herkimer Limestone. In the general area of the shaft, most of the sedimentary rocks are overlain by pyritized Packard Quartz Latite, which in turn is largely concealed by colluvium and other surficial deposits. The log of the shaft (Paul Billingsley, written commun., 1956) shows the lava-sedimentary rock contact at an elevation of approximately 5,260 ft, which is about 600 ft (183 m) below the collar. The pattern of outcrops suggests that the volcanic rocks fill a relatively wide prelava valley that trended east-northeast.

Intrusive igneous rocks have been found only on the 1,300-ft level, where two tabular bodies of monzonite porphyry were penetrated by the Iron King crosscut close to the hanging-wall strand of the Eureka Standard fault. A body of metabasalt that is also exposed on the 1,300-ft level in the southwestern part of the mine and reported by Kransdorf (1934, p. 23-24) to be intrusive may be faulted and folded part of the chloritized basalt flow of the Tintic Quartzite described elsewhere in the East Tintic Mountains and adjacent areas (Morris and Lovering, 1961, p. 15-16).

The Eureka Standard fault in the Eureka Standard mine is slightly sinuous in detail but in general strikes N. 44°-50° E. and dips 35°-50° NW (fig. 52). It is penetrated by the shaft about 10 ft (3 m) below the sill of the 900-ft level. Although the fault was long considered to have normal displacement, it is now known to have approximately 2,500 ft (762 m) of right-lateral horizontal displacement, bringing beds that originally were on the west limb of the East Tintic anticline adjacent to beds near the crest. As discussed below, one or more subsidiary strands are recognized in both the hanging-wall and footwall blocks of the Eureka Standard fault; however, the main fault plane is readily recognized on the 1,100-ft and higher levels where shale and (or) limestone has been displaced against quartzite.

The Iron King fault, which forms the northwest side of the Eureka Standard trough has been penetrated only at two points in the Eureka Standard mine. In the eastern part of the mine a long north-trending crosscut to the Tintic Standard mine at the Eureka Standard 780-ft level cuts the fault 1,300 ft (396 m) N. 5° E. of the shaft. In the western part of the mine a connection with the Iron King No. 2 mine at the 1,300-ft level cuts the Iron King fault 2,465 ft (751 m) S. 82° W. of the shaft. Elsewhere in the Eureka Standard mine the Iron King fault is concealed, and its position and character are known only from geologic projections. Generally it is believed to strike approximately N. 60° E. and to dip 70° or more steeply to the south-southeast. The displacement is probably also horizontal and closely related to the movement on the Eureka Standard fault.

Within the block between the Iron King and Eureka Standard faults, the beds generally strike east-northeasterly and dip southeasterly at 5°-20°; however, the dip reverses to northwesterly in the vicinity of the Eureka Standard fault. Much of the local folding and crumpling may be the result of drag folding adjacent to the fault.

In the far western part of the mine, the 1,300-ft level follows the Eureka Lilly fault for several hundred feet (about 100 m), which here strikes N. 26° E. and 60°-70° W.

Of prime importance to the occurrence of ore in the Eureka Standard mine is the Trixie system of pebble-dike fissures that intersects the Eureka Standard fault at an acute angle. These fissures and their altered selvages are best seen at the surface on the west side of Silver Pass Gulch, where they strike about N. 42° E. and dip steeply west. They probably served as the principal channelways for the ore-depositing solutions, which moved into the fractures and breccias of the Eureka Standard fault zone and into subsidiary fissures, particularly in the footwall.

The permanent water table was encountered in the mine at an elevation of 4,533 ft, approximately 30 ft (9 m) below the sill of the 1,300-ft level. This water is similar in many aspects to the ground water in the Burgin mine, containing more than 5,500 parts per million solids and reaching temperatures as high as 133° F (56° C) and possibly higher. The precipitated salts from the ground water are more than half sodium chloride; others include calcium sulfate, calcium carbonate, magnesium chloride, and potassium chloride (Kransdorf, 1934, p. 157). These waters were highly corrosive and greatly damaged mine rails and pumping equipment. The large volume of ground water, along with its high temperature and corrosive nature, prevented the development of the mine to the 1,500-ft level as originally planned.

## ORE BODIES

The principal ore bodies in the Eureka Standard mine consists of swarms of narrow closely spaced nearly vertical ore-bearing fissures that occur in the quartzite footwall of the Eureka Standard fault and of masses of brecciated quartzite that commonly lie in sheeted zones

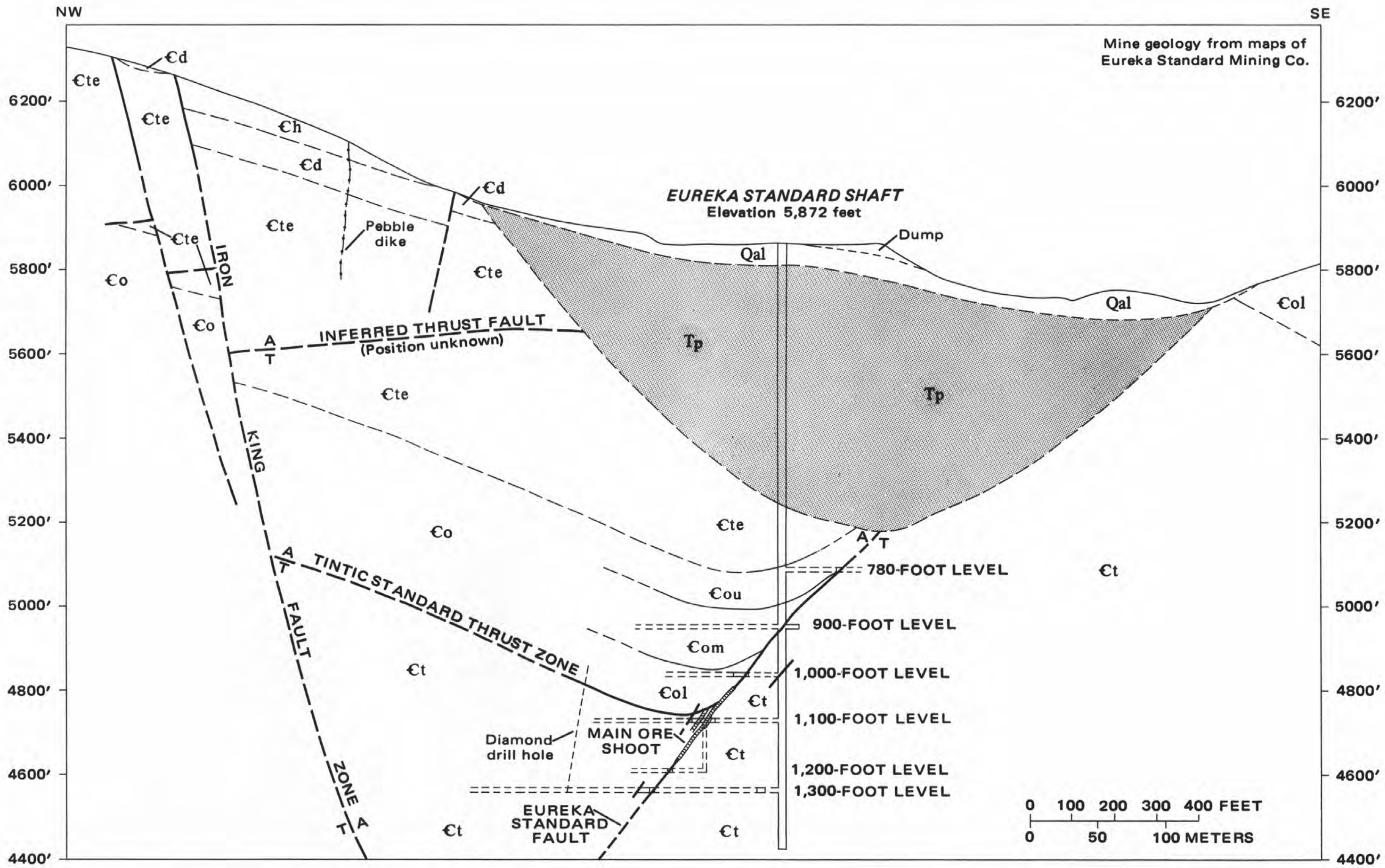



FIGURE 51. — Geologic cross section of Eureka Standard mine showing relation of ore bodies to Eureka Standard fault.

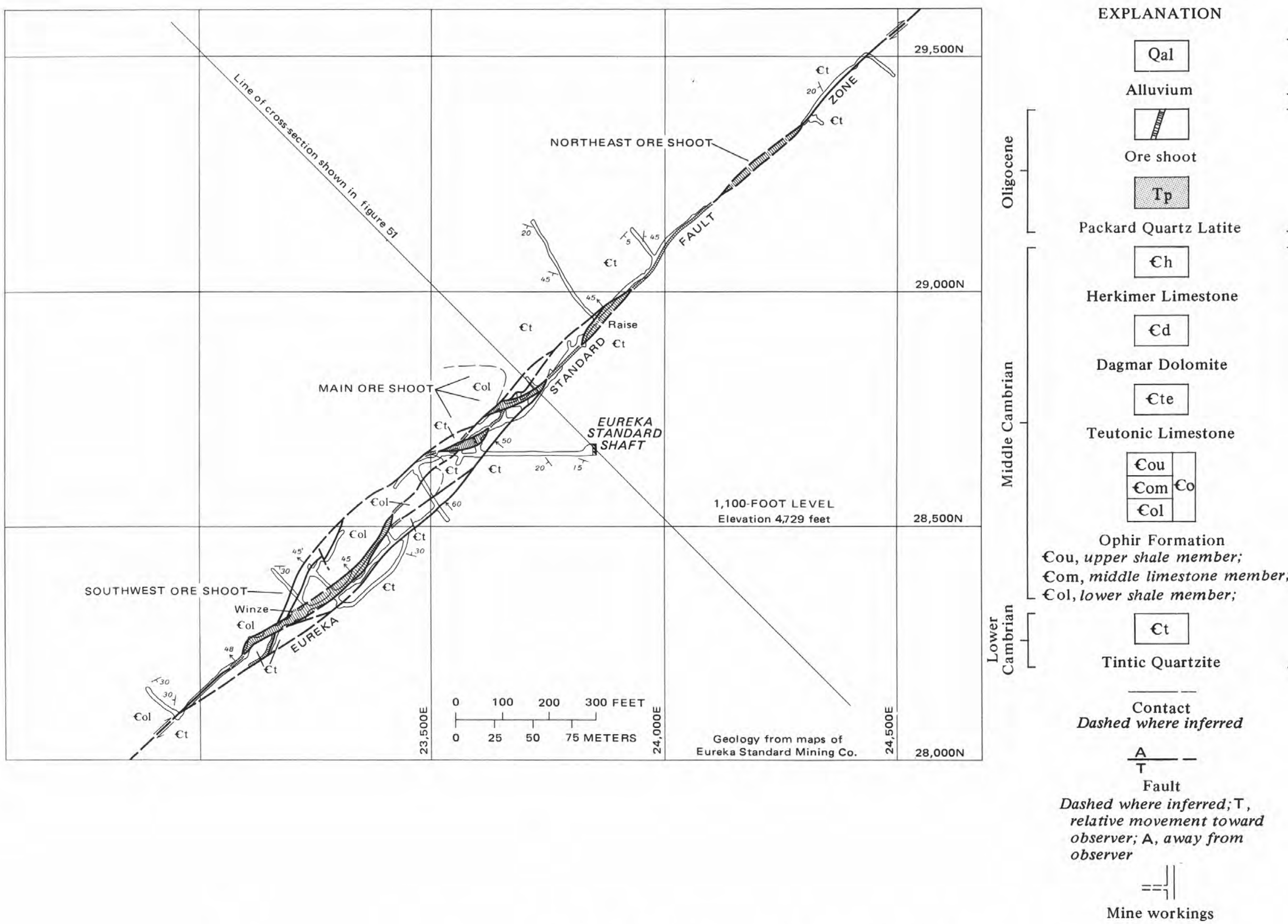



FIGURE 52. — Geologic plan of 1,100-ft level of Eureka Standard mine.

between branches of the fault. Economically less important replacement ore bodies have also been mined in the limestones of the Eureka Standard trough. The individual ore-bearing fissures in the sheeted zones range from microscopic seams to veins as much as 5 ft (1.5 m) wide, averaging, perhaps, 4 in. (10 cm) in width. The larger veins all strike somewhat more easterly than the Eureka Standard fault, ranging from N. 55° to 65° E.; the average dip is vertical. As they approach the stronger fault planes from either the footwall or hanging-wall sides of the fault, they characteristically subdivide into numerous smaller fractures forming the sheeted or horsetail zones.

Although ore and gangue minerals occur nearly ubiquitously throughout the Eureka Standard fault zone below the 1,100-ft level, the principal ore bodies form three en echelon ore zones or ore shoots that lie just below and locally within the fault zone; they are known as the Southwest, Main, and Northeast ore shoots (fig. 52). These ore shoots all strike east-northeasterly and rake to the west at 15°-20°. The Southwest ore shoot is more than 600 ft (183 m) long and 120 ft (37 m) wide on the 1,300-ft level in an area that is 1,150 ft (351 m) southwest of the shaft. This shoot has yielded development ore on the 1,400-ft level and apparently terminates upward at a point that is midway between the 1,100- and 1,000-ft levels. The Main ore shoot, which lies a few hundred feet northwest of the shaft between two important strands of the Eureka Standard fault, extends from the 1,350-ft level to a point that is a short distance below the 1,000-ft level. The Northeast ore shoot is 500-700 ft (152-213 m) northeast of the shaft, and its east edge extends into the Apex Standard No. 2 shaft area. It is less extensive than the other ore shoots and is largely confined between the 1,000- and 1,100-ft levels.

The lower and upper limits of minable ore in the fissure ore bodies were apparently determined by a combination of geologic and economic factors. Little, if any, such ore was mined above the 1,000-ft level, where the shoots diminished in size and grade, probably because of the exhaustion of ore ions in the depositing solutions. The downward termination of ore shoots was probably also the result of geochemical factors, although the exploration and development of the shoots below the 1,350-ft level was so severely hampered by inflows of hot corrosive saline ground waters that complete knowledge of the lower parts of the ore shoots was not attained.

The limestone replacement ore bodies of the Eureka Standard mine were not discovered until 1938, but for the following 2 years they were the source of substantial amounts of lead, zinc, and silver ores during the time that the fissure ore bodies were declining in productivity and grade. The replacement shoots were first found at the 900-ft level in the middle Ophir limestone; they differed from other limestone replacement ore bodies in the East Tintic district only in being early unoxidized despite their position well above the water table. This lack of oxidation is ascribed to the relatively unfractured character of the enclosing limestone and the presence of thick layers of shale of the Ophir Formation above and below the host rocks. The replacement ore deposits did not prove to be extensive, producing less than 20,000 tons (18,140 tonnes) of the 362,832 tons (329,089 tonnes) of ore credited to the mine.

The overall average grade of 345,585 tons (313,446 tonnes) of siliceous fissure ore was 0.70 oz per ton (24 g per tonne) gold, 9.27 oz per ton (317.9 g per tonne) silver, 1.02 percent lead, and 0.37 percent copper. The average grade of 17,247 tons (15,643 tonnes) of lead-zinc-silver ore from the replacement ore bodies was 0.10 oz per ton (3.43 g per tonne) gold, 13.19 oz per ton (452.3 g per tonne) silver, 12.13 percent lead, 9.11 percent zinc, and 0.37 percent copper. The average grade of 1,412 tons (1,281 tonnes) of fissure ore mined from the Southwest ore shoot on the 1,350- and 1,400-ft levels on the property of the East Tintic Consolidated Mining Co. was 0.18 oz per ton (6.17 g per tonne) gold, 7.95 oz per ton (27,261 g per tonne) silver, 1.48 percent lead, and 0.80 percent copper. The marked decrease in the tenor of gold in the deep ore bodies on the East Tintic Consolidated's claims as compared to the average gold content of the fissure ore bodies in the middle part of the mine is noteworthy and indicates substantial gold impoverishment with depth as compared to only slight impoverishment of silver and substantial increases in the average tenor of lead and copper.

The cause of the localization of the three principal shoots of fissure ore is obscure. In general, the mineralized ground lies at the intersection of the Trixie fissure zone and the Eureka Standard fault. The low southwesterly plunge of all of the ore shoots, however, seems to preclude a simple intersection of these two structures. In fact, the close similarity in the strike and plunge of the ore shoots suggests the intersection of three nearly identical geologic features with the Eureka Standard fault. In the absence of regularly repetitive changes in the strike and dip of the fault, these nearly identical features are believed to be the traces of particularly brittle beds or zones in the Tintic Quartzite against the fault within the general area of the Trixie fissure zone. The absence of important ore bodies in the rocks above the quartzite possibly may be attributed to the impervious shales of the Ophir Formation, which may have prevented the ore solutions from reaching the carbonate rocks, or to exhaustion of the ore solutions, as stated earlier.

The dominant ores of the Eureka Standard mine consist of vuggy masses of sulfides, sulfosalts, tellurides, and native gold that incompletely fill narrow fissures in the Tintic Quartzite or fill the interstices of quartzite breccias along with abundant crystalline quartz and barite. The principal hypogene metallic minerals include pyrite, marcasite, enargite (luzonite), tetrahedrite, galena, sphalerite, petzite, hessite, and native gold. Less abundant hypogene minerals include chalcopyrite, proustite, and sylvanite (or krennerite). Bornite, argentite, and calaverite are also reported by Gardner (1935). The dominant gangue minerals are quartz, barite, and kaolinite. Although the ores are relatively little oxidized because of their substantial depth below the surface, some secondary chalcocite and covellite have been reported, along with anglesite, cerussite, malachite, azurite, limonite, and, presumably, oxidized zinc minerals.

As with other fissure-filling ore bodies in the Tintic and East Tintic districts, the vein ores of the Eureka Standard mine locally were banded and crustified and contained vugs that were lined with partly terminated crystals. Except for the replacement of early pyrite by enargite and tetrahedrite, most of the younger minerals simply overgrew the older minerals and formed successively younger bands toward the center of the veins or breccia cavities. The general paragenesis of the metallic minerals is (1) pyrite, (2) enargite, (3) tetrahedrite, (4) sphalerite and chalcopyrite, (5) petzite and hessite, (6) gold and fine-grained galena, and (7) coarse-grained galena.

The ores of the replacement ore bodies of the Eureka Standard mine were similar to the zinc- and lead-bearing sulfide ores of the Tintic Standard and North Lily mines. They consisted of fine- and coarse-grained galena, dark iron-bearing sphalerite, pyrite, and minor tetrahedrite in a gangue of fine-grained gray jasperoid that contained small crystals of barite. The relatively high ratio of silver to lead in the ores suggests the presence of considerable silver in the tetrahedrite and possibly also the presence of small quantities of argentite, stromeyerite, and other silver minerals that are common to the district.

## HOMANSVILLE SHAFT

The Homansville shaft is about 550 ft (166 m) east-southeast of the common corner of secs. 4, 5, 8, and 9, T. 10 S., R. 2 W., at the west entrance to Homansville Canyon. It takes its name from the old town of Homansville, which was a short distance northeast of the shaft in the northwestern part of the district. The shaft was sunk by the Chief Consolidated Mining Co., beginning in July 1916, to explore claims that had been acquired by purchase and location in a large area centering on Pinyon Peak. Shaft sinking was completed to a total depth of 590 ft (180 m) in October 1916, and a shaft station was cut at the 562-ft level. During the ensuing few years, approximately 3,050 ft (930 m) of lateral workings was driven at the 562-ft level, chiefly north, south, and east of the shaft. Apparently no raises or winzes were driven.

The shaft is collared in alluvium and lava only a few tens of feet northwest of the surface trace of the intersection of the north-trending Selma fault, and the east-northeast-trending Homansville fault. At that point at the surface, the Selma fault, along which the Packard Quartz Latite was brought down against the Devonian and Mississippian Fitchville Formation, apparently terminates against the Homansville fault, and its late normal displacement is deflected for about 500 ft (152 m) westward on the older Homansville fault to a point where it is joined by the postlava Eureka Lilly normal fault. The beds at the surface south of the Homansville fault in the vicinity of the shaft are the unmistakable light and dark strata of the Cole Canyon Dolomite that probably overlie a folded thrust fault of moderate displacement.

For the greater part of its depth, the shaft is in the sheeted zone of the Selma fault. From the collar to a depth of about 160 ft (49 m), it cuts massive quartz latite, below which it alternately passes from limestone into lava and back into limestone to a point a short distance below 500 ft (152 m) where it probably crosses the main footwall strand of the Homansville fault and enters beds that are assumed to be dolomitized limestones of the Middle Cambrian sequence.

In figure 53, the 562-ft level is shown cutting the Homansville fault a short distance north of the shaft station and extending diagonally through the Selma fault zone until solid lava is cut 420 ft (128 m) to the north-northwest. The workings south of the Homansville fault first traverse dolomitized Herkimer Limestone (or the Bluebird Dolomite); then at a point 200 ft (61 m) south-southwest of the shaft, they penetrate a fault that is presumed to be the Canyon fault and there enter dolomitized Teutonic Limestone. North of the Homansville fault and east of the Selma fault, the dolomite strata at the 562-ft level are believed to be Bluebell Dolomite. West of the Selma and Eureka Lilly faults at this level, the rocks are downfaulted Packard Quartz Latite.

Several small pebble dikes also were cut on the 562-ft level near the Canyon fault; no ores were found in any of the workings, and there are no records of any work being done in the mine following World War I.

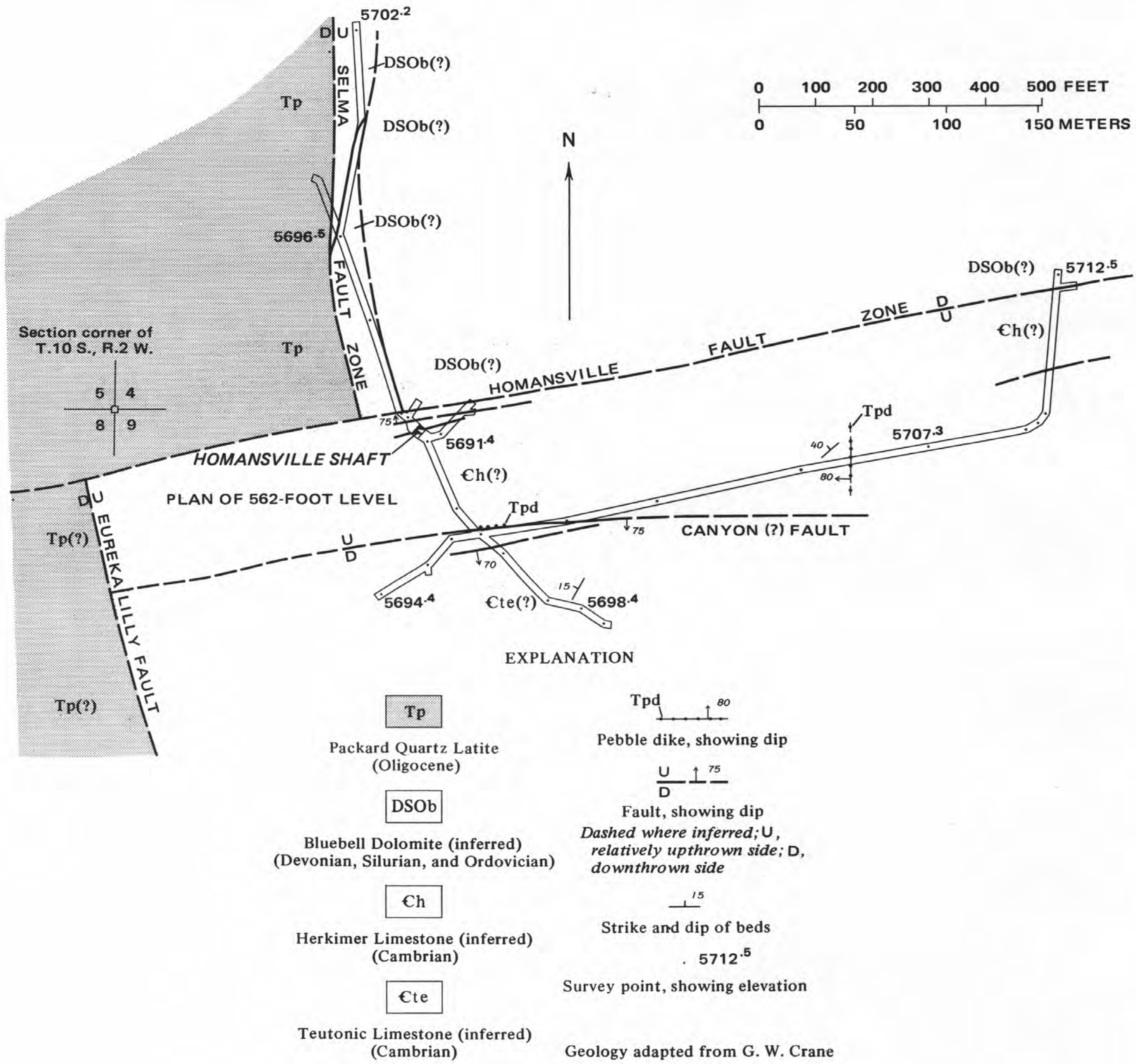



FIGURE 53. — Geologic plan of 562-ft level of Homansville shaft.

## INDEPENDENCE OR SILVER SHIELD SHAFT

The Independence or Silver Shield shaft is in the W½NE¼SW¼ sec. 2, T. 10 S., R. 2 W., in the central part of Silver Shield Gulch about 2 mi (3.2 km) northeast of Dividend. The property consists of 81 and a fraction acres (33 hectares) of patented claims that adjoin holdings of the Tintic Standard and East Standard Mining Companies; it is currently owned by the Kennecott Copper Corp., who purchased it in 1961. The claims were first developed by the Independence Mining Co., which was organized in June 1919, and who sank the shaft to a depth of 413 ft (126 m). The Independence Mining Co. was merged into the Silver Shield Mining Co. in September 1924; by December 1925 the shaft had been deepened to 915 ft (279 m) and drifting started at the 900-ft level. Shaft sinking was resumed during the early part of 1930 and was completed at a total depth of 1,250 ft (381 m) in July 1930. According to records of the Silver Shield Mining Co., large volumes of ground water below an elevation of 4,550 ft prevented the completion of the shaft to a planned depth of 1,600 ft (488 m). The only developed level of consequence is the 900-ft level, which penetrated areas that are chiefly east, north, and west of the shaft.

The shaft is collared in pyritized Packard Quartz Latite, and according to company records, it cuts the base of the volcanic sequence at a depth of 688 ft (210 m). The structure of the sedimentary rocks below the lava is enigmatic and presented much confusion at the time the shaft was being sunk. It was initially assumed that the Ophir Formation immediately underlay the volcanic rocks and that the lower part of the shaft was mostly in the Tintic Quartzite, but the common occurrence of limestone apparently interlayered with the quartzite cast much doubt on the validity of this interpretation. In an effort to solve the problem, the Silver Shield Mining Co. employed two consulting geologists, R. T. Walker and A. E. Kipps, to separately examine the property. It was the conclusion of Walker (written commun., January 3, 1929) that the "fine-grained, cross-bedded sandstones intercalated with sandy dolomitic limestones" immediately below the lavas were probably part of the Humbug Formation. Walker also reported that "silicification has in places transformed this formation into a massive quartzite, in which all traces of bedding disappear." Kipps (written commun., January 8, 1929) in general agreed with Walker and stated further that "upon drilling vertically down in the sedimentaries, alternate layers of pure and impure limestones and dolomites were exposed."

Careful examination of the dump of the Silver Shield shaft during the present survey indicated the presence of much dense fine- to medium-grained quartzite, identical to the Tintic Quartzite, and, in addition, considerable red and greenish-gray micaceous and arenaceous shale, similar to the shale or argillite that is common in the upper part of the Tintic Quartzite and the basal part of the Ophir Formation. Also present on the dump are rare fragments of porous crossbedded sandstone and of medium-gray coarse-grained sandy limestone, both of which resemble rocks of the Humbug Formation. In addition, much drill core was found on the dump, some of which is light- to medium-gray fossiliferous limetone identical to the Humbug.

All of these observations suggest that the shaft penetrates a zone of imbricate slices of the East Tintic thrust fault that apparently interleave masses of Humbug Formation and Tintic Quartzite. It is significant that dense quartzite, or a large mass of jasperoid, persists to a depth of 1,250 ft (381 m) in the shaft, but a diamond-drill hole drilled below this level cut several hundred feet (about 100 m) of fossiliferous limestone. This general interpretation is confirmed by the distribution of Cambrian and Mississippian strata beneath the lava as disclosed by surface drill holes about a quarter of a mile (0.4 km) west, southwest, and northwest of the shaft.

The workings at the 900-ft level indicate that the structure is broadly anticlinal, with bedding surfaces dipping outward from the general area of the shaft. A substantial part of the workings are in quartzite and micaceous shale typical of the Tintic Quartzite, but sandstone and limestone are present northeast of the shaft. Presumably these rocks are infaulted or inthrusted slabs of Humbug Formation, although the limestone could be part of either the Teutonic Limestone or Ophir Formation in low-angle fault contact with the Tintic Quartzite.

In the northern part of the mine, about 550 ft (168 m) north of the shaft, the main north-trending crosscut intercepts the south contact of the Silver Shield dike and follows it westward for several hundred feet. Other intrusive bodies were cut 150 and 350 ft (46 and 107 m) east-southeast of the shaft. The north-trending basal contact of the Packard Quartz Latite was also followed for a distance of several hundred feet in the northwestern part of the mine about 400 ft (123 m) northwest of the shaft.

Ore minerals were reported in several places in the mine, but so far as records reveal, no ores have been shipped. A small body of low-grade ore with streaks and bunches of higher grade ore is shown on company maps to occur in limestone and shale about 180 ft (55 m) northeast of the shaft, and a second body of low-grade ore is also shown to be adjacent to the Silver Shield dike about 500 ft (153 m) due north of the shaft. The character of this ore is not recorded.

Company temperature data indicate that the mine was very hot in areas where it was not ventilated, indicating that the East Tintic thermal area extends northward at least as far as the Independence shaft.

## IRON KING MINE

The Iron King group of claims is in the west-central part of the East Tintic district about 1 mi (1.6 km) southwest of Dividend. The original property consisted of 35 patented claims aggregating 410 acres (166 hectares); it is adjoined by the properties of the Eureka Standard, East Tintic Consolidated, Zuma, Crown Point Consolidated, and other mining companies. The Iron King Consolidated Mining Co. was first organized in June 1907 by Colonel C. E. Loose, Reed Smoot, O. J. Salisbury, Frank Knox, and A. A. Noon, and included claims that were initially located by Peter and Nick Roberts. In June 1927, control of the company was acquired by the Tintic Standard Mining Co. through the purchase of 674,000 shares of treasury stock, which cancelled an indebtedness of the Iron King Consolidated to Tintic Standard. Some 10 years later, in December 1937, the Iron King Consolidated was merged into the Eureka Lilly Consolidated Mining Co. along with the Eureka Lilly, Provo, and East Tintic Consolidated Mining Companies. In November 1974, the Eureka Lilly Consolidated Mining Co. in turn was merged into the Eureka Standard Mining Co. Underground operations were last carried out on the Iron King claims in 1931.

### PROPERTY DEVELOPMENT AND PRODUCTION

The Iron King claims are opened by three shafts, two long adits, and numerous short adits, inclined shafts, and large and small open pits. The original shaft, the Iron King, is located in the S½S½NE¼ sec. 20, T. 10 S., R. 2 W. It was sunk in 1907-08 to a depth of 500 ft (152 m); the extent of workings from it is unknown. The Iron King tunnels (actually adits) apparently were driven prior to 1918. The portal of the main Iron King tunnel is in the S½S½ sec. 21, T. 10 S., R. 2 W. It trends N. 86° W. and has a total length of 3,185 ft (971 m). A smaller adit, whose portal is in the S½S½NW¼ sec. 21, T. 10 S., R. 2 W., extends in an eastward-curving course for about 500 ft (152 m) to a point near the No. 1 shaft.

The Iron King No. 1 shaft is in the SW¼SE¼NW¼ sec. 21, T. 10 S., R. 2 W. It was sunk in 1918-19 beginning at the tunnel level and was eventually completed to a total depth of 1,545 ft (471 m). Levels were established at the 375-ft or tunnel level, and the 1,000-, 1,330-, and 1,545-ft levels. The workings aggregate approximately 6,000 lineal ft (1,829 m).

The Iron King No. 2 shaft was sunk in 1924-25 to a depth of 1,100 ft (335 m) and was deepened in 1927-28 to a total depth of 1,544 ft (470 m). The lateral workings that extend from this shaft are the 770-, 900-, 1,050-, 1,100-, 1,200-, 1,300-, 1,450-, and 1,550-ft levels. The 1,050- and 1,200-ft levels are at the same elevations, respectively, as the 1,300- and 1,545-ft levels of the No. 1 shaft and connect with them, and the 1,450-ft level of the No. 2 shaft extends southerly and then easterly to connect with the 1,300-ft level of the Eureka Standard mine. The length of the lateral workings in the area of the No. 2 shaft probably exceeds 8,350 lineal ft (2,545 m), not including several hundreds of feet of raises and winzes.

According to Cook (1957, pl. 3), the baritic sulfide ore bodies mined from the Iron King No. 2 shaft yielded 14,001 tons (12,699 tonnes) of ore with an overall average grade 0.10 oz per ton (3.43 g per tonne) gold, 1.40 oz per ton (48 g per tonne) silver, and 0.10 percent copper. The total volume of iron-oxide fluxing ores and associated deposits of manganese oxides produced from the Iron King claims near the No. 1 shaft is not known with any degree of accuracy but is here estimated to be between 50,000 tons (45,350 tonnes) and 100,000 tons (90,700 tonnes). The grade of the iron ore, which was chiefly sold to smelters in the Salt Lake Valley to aid in fluxing siliceous copper ores, was reported in 1911 to be 51.5 percent iron.

### GEOLOGY

The Iron King group of claims is on the west flank of the East Tintic anticline and in general extends over the area that is east, southeast, and south of the Iron King intrusive center. The Paleozoic rocks exposed at the surface on the claims range from the Middle Cambrian Teutonic Limestone to the Lower Mississippian Gardison Limestone. They are exposed in a large erosional window in the Packard Quartz Latite and are cut by many faults and intruded by many small pipes and plugs of hornblende-biotite monzonite porphyry. In the vicinity of the plutons, large and small masses of carbonate rock at or near the base of the lava have been strongly sanded and replaced by iron and manganese oxides and by halloysite and other clays.

The original Iron King shaft is collared in colluvium but appears to cut a thin erosional wedge of Packard Quartz Latite before entering the lower part of the Fitchville Formation. At its reported depth of 500 ft (152 m), it probably bottoms in the lower part of the Victoria Formation or the upper part of the Bluebell Dolomite.

The Iron King No. 1 shaft is also collared in colluvium but within a short distance enters the Fish Haven Dolomite in the hanging wall of the Iron King fault. At its total depth of 1,545 ft (471 m), it bottoms in the Tintic Quartzite in the footwall of the fault, apparently passing through the fault zone a short distance above the 1,330-ft level. At the 1,000-ft level, lateral workings traverse bleached carbonate rocks and then cut monzonite porphyry about 375 ft (144 m) northwest of the shaft. At the 1,330-ft level the workings extend east-northeasterly from the shaft generally following the Iron King fault zone or the subsidiary fractures that cut the Ophir Formation in the footwall of the fault. The workings at the 1,545-ft level of the No. 1 shaft extend both west-southwesterly and east-northeasterly, connecting with the 1,200-ft level of the Iron King No. 2 shaft. The general geology of these workings is shown in fig. 54.

The Iron King No. 2 shaft is collared close to the surface trace of the Iron King fault and passes through the Eureka Lilly fault at a depth of approximately 700 ft (213 m). The rocks penetrated above a depth of 700 ft (213 m) are in the footwall of the Iron King

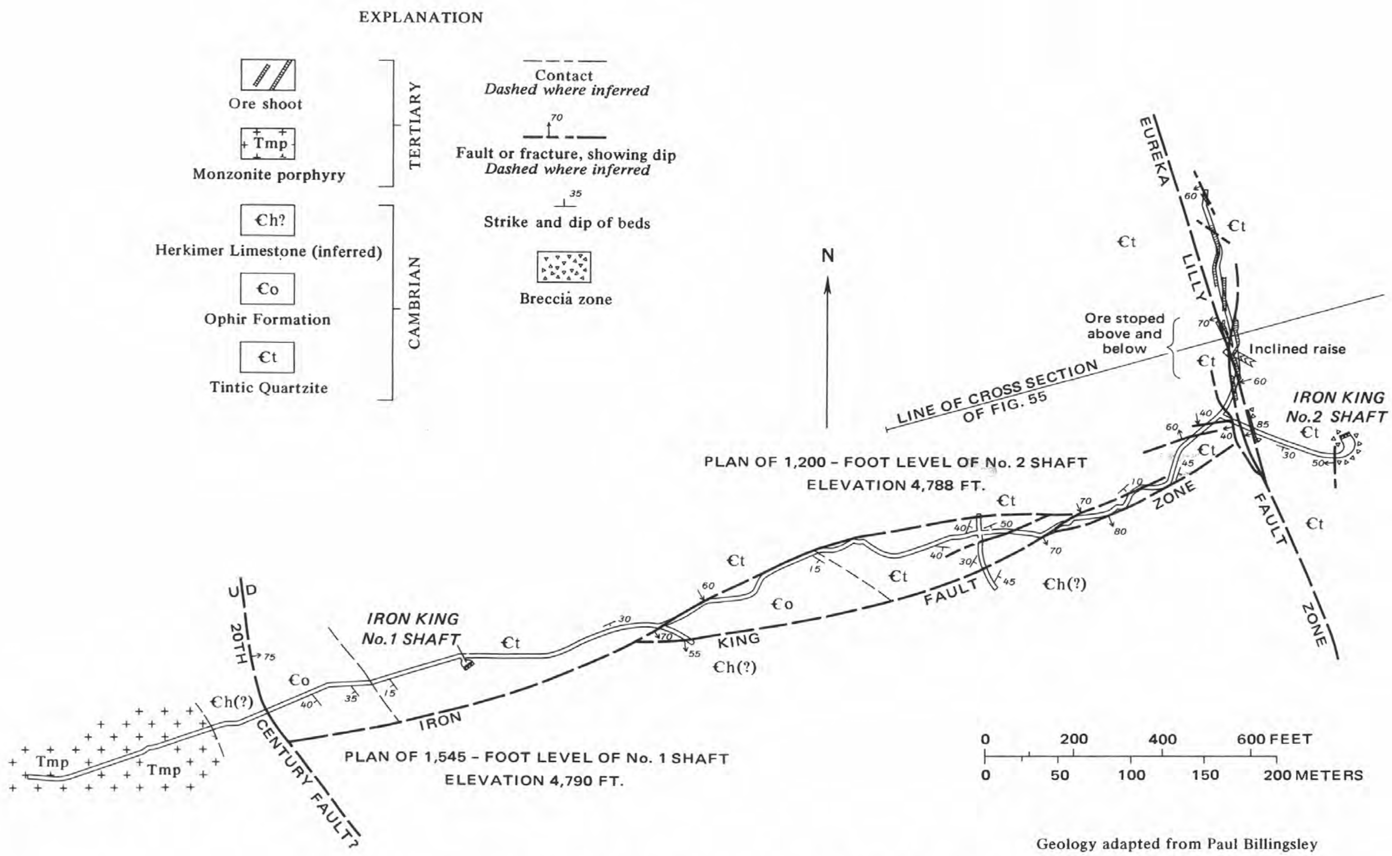



FIGURE 54. — Geologic plan of 1,545-ft level of Iron King Mine.

fault and range from the Bluebird Dolomite to the Teutonic Limestone. The rocks below 700 ft (213 m) are chiefly Tintic Quartzite, with a thin interval of the basal part of the Ophir Formation between 700 and 800 ft (213 and 244 m) of depth. The lateral workings from the No. 2 shaft chiefly explore the mineralized Eureka Lilly fault zone north of its intersection with the Iron King fault. In addition, the 770-ft level cuts the base of the Ophir Formation 275 ft (84 m) northeast of the shaft; the 1,050-ft level explores the Tintic Quartzite to a point 270 ft (82 m) southeast of the shaft; the 1,300-ft level follows the Eureka Lilly fault for several hundred feet south-southeast of the shaft area; and the 1,450-ft level explores the foot and hanging walls of the Eureka Lilly fault near the gold ore shoot and also follows the fault to a point that is more than 700 ft (213 m) south-southeast of the No. 2 shaft.

The water table in the No. 2 shaft stands at an elevation of 4,558 ft, approximately 5 ft below the 1,450-ft level.

The main Iron King tunnel enters the upper part of the Ajax Dolomite and extends through a section of undulating partly bleached carbonate rocks to a point 435 ft (133m) west-northwest of the Iron King No. 1 shaft. Because of the altered nature of the rocks, and the probable presence of bedding-plane and other faults that have not been detected at the surface, specific formational and fault contacts have not been precisely established. For example, the contact between the Ajax Dolomite and the Opohonga Limestone may cross the adit at any point within the interval that is 400-1,200 ft (122-366 m) from the portal. Similarly, the position of the Iron King fault in the adit is unknown, although it appears that the workings 2,380-2,530 ft (725-771 m) from the portal may be tangent to a lobe of the curving fault zone in an area where there are several monzonite dikes. West of the No. 1 shaft, the workings at the adit level enter the zone of the 20th Century fault and the extensive bodies of iron oxide ores adjacent to it.

## ORE BODIES

Two distinctly different, and probably unrelated, types of ore have been shipped from the Iron King claims. The original product from the property was iron oxide that was sold as smelter flux, chiefly to metallurgical reduction plants in the Salt Lake Valley. This ore was supplanted in 1923 by the discovery of a tabular shoot of baritic sulfide ore containing values in gold, silver, and copper. Although the total volume of this latter ore was small, its similarity to the high-grade gold ores of the Eureka Standard and North Lily (Tintic Bullion) mines has been the principal reason for continued interest in the claims.

The baritic gold shoot lies in the immediate footwall of the Eureka Lilly fault a short distance northwest of the Iron King No. 2 shaft (fig. 55). It was stoped from a point a short distance below the 1,300-ft level upward to a point between the 900- and 1,050-ft levels, a distance of about 430 ft (131 m). At the 1,050-ft level the stopes are about 250 ft (76 m) wide, but the ore body was nearly everywhere less than 5 ft (1.5 m) thick. The geologic reasons for the localization of the ore shoot are unknown. It occurred chiefly in the breccias of the quartzite footwall of the Eureka Lilly fault opposite the low-dipping Ophir Formation and uppermost Tintic Quartzite in the hanging wall; however, these beds are in fault contact with the Tintic Quartzite for a distance of several thousand feet to the north where no similar ore shoots have been recognized. No crossbreaking fissures have been recognized, and the nearly right-angle intersection of the Iron King fault and the Eureka Lilly fault about 200 ft (61 m) south of the ore shoot is not mineralized. On the basis of the evidence at hand, it may be concluded only that a narrow column of ore-depositing solution rose steeply up the zone of the Eureka Lilly fault depositing the ore and gangue minerals in porous quartzite breccias lying opposite the Ophir Formation, which may have induced precipitation.

The minerals of the gold ore body are reported to be pyrite, enargite, and some galena in a gangue of crystalline quartz and barite. Presumably the ores also contained tetrahedrite, argentite, hessite, and native gold, as did the similar ores of the adjacent Eureka Standard mine.

The iron ore bodies, as described earlier, occur most abundantly in the general vicinity of argillized plugs and dikes of monzonite porphyry. Many of them crop out at or near the base of the Packard Quartz Latite, although others, including the largest in the Iron King No. 1 shaft area, appear to be more specifically related to faults and intrusive contacts rather than to the rubble zone beneath the lavas. They range in size from small pods and narrow seams to the massive ore body 650 ft (198 m) west of the No. 1 shaft that has been mined in three interconnected pits extending over 400 ft (122 m) in total length and 75-125 ft (23-38 m) in width. This ore body is localized in the zone of the 20th Century fault, and reportedly it or related iron ore bodies were mined at the 375-ft level.

In general aspect, the iron deposits are typical replacement ore bodies; they are irregular in form and have many narrow extensions that follow fractures, bedding planes, and zones of breccia. They invariably replace carbonate rocks, particularly the more competent dolomite units, and commonly lie against marbleized carbonate rocks, sanded dolomite, argillized monzonite porphyry, pyritized and argillized quartz latite tuff, or massive bodies of halloysite clay. The ores range in color from brownish yellow to dusky brown, but most are yellowish red to brick red. They are highly porous, and some parts of the ore bodies are cavernous and have an irregularly banded, botryoidal aspect. Analyses indicate that they are dominantly goethite. At their contacts, many of the ore bodies contain various amounts of jasperoid, clay, or unreplaced fragments of carbonate rock.

#### ORIGIN OF THE IRON ORES

The typical occurrence of the manganiferous iron deposits in the proximity of argillized plugs of monzonite porphyry, and their close association with bodies of halloysite (or endellite), zones of sanded dolomite, and areas of argillized lavas, all suggest deposition from the hot acidic solutions of the midbarren stage of hydrothermal alteration (Lovering, 1949; 1950a). The obvious replacement textures and the common localization of the iron deposits in faults and fractures and in contact breccia zones suggest that the solutions rose from depth and spread outward in the prelava rubble zone when they were blocked by the impermeable tuffs and flow rocks.

As Lovering (1949, p. 45-55) has reported, these hot acid solutions probably contained more halogens than sulfur and vigorously attacked the intrusive rocks and their shattered wallrocks along their paths of intrusion. Decomposition of iron-bearing silicate minerals and the solution of iron compounds in the sedimentary rocks may have provided the source of iron. Similarly, decomposition of plagioclase and other minerals is believed to have provided the alumina and silica now constituting the halloysite. Reaction of the acidic solutions with the carbonate wallrocks produced large volumes of sanded dolomite and also increased the pH to 7 or higher. As the free acid was neutralized, goethite probably was precipitated by the hydrolysis of ferric chloride and ferric sulfate. This reaction was particularly intense in or near the prelava rubble zone and near fault zones where the impounded solutions spread laterally through the conglomerate or breccias incorporating abundant oxygen, cooling rapidly, and undergoing accelerated neutralization. The absence of even minor quantities of residual pyrite in even the most massive ore from depths approaching 400 ft (123 m) below the surface indicates that little if any of the

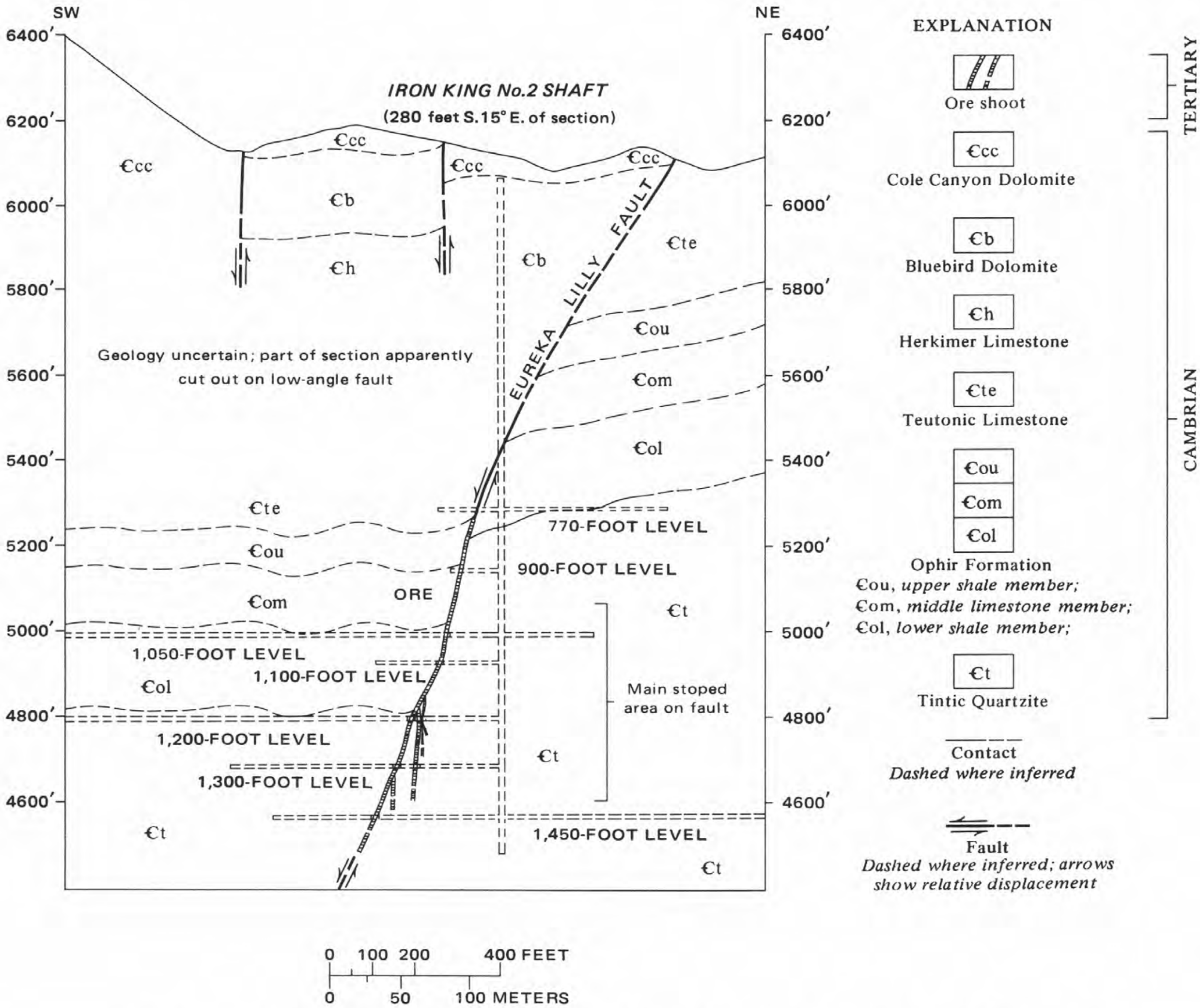



FIGURE 55. — Geologic cross section of ore shoot on Eureka Lilly fault, Iron King No. 2 shaft area.

goethite originated from the oxidation of massive replacement iron sulfide. Similarly, the deepest deposits contain no iron-rich carbonate or silicate minerals that might have been the oxidized source of the goethite deposits.

An alternative hypothesis of origin was proposed by Lindgren (in Lindgren and Loughlin, 1919, p. 262-265) for the genesis of the Dragon and other iron deposits, including the Iron King, in the Tintic district. He concluded that the iron was derived from the oxidation of pyrite in the overlying pyritized lavas and the adjacent pyritized monzonite porphyry. Presumably the iron moved downward in descending acidified meteoric solutions and was deposited as iron oxides chiefly at the base of the lavas and in fault and breccia zones. The principal objection to this hypothesis is that extensive drilling and other underground work have revealed that the disseminated pyrite in the lavas and intrusive bodies is oxidized only in relatively thin zones near the surface and that the great bulk of the pyrite remains unoxidized in the water-saturated rocks. Chemical analyses of the oxidized zones also indicate that iron derived from the disseminated pyrite has migrated only a few centimeters from its original site of deposition.

## LARSEN HALLOYSITE CLAY PITS

The Larsen halloysite clay deposits are located in the southwestern part of the district about 1,350 ft (411 m) west-southwest of the Zuma shaft and 1,600 ft (488 m) east of the Crown Point No. 3 shaft. They occur chiefly on the Zuma No. 3 claim of the Zuma Mining Co., which is owned by the Kennecott Copper Corp. and after 1971 was under lease to the U.S. Energy Corp. (formerly the Western States Mining Co.), of which Glen E. Larsen is a senior official. The clay was first exposed in 1956 during the construction of the access road to the Roundy shaft. It was not prospected further, however, until March 1972 after suspension of the initial underground phase of exploration on the 1,280-ft level of the Roundy shaft. At about this time agreements were completed with Kennecott for a lease of parts of the Zuma and Iron King properties by the Larsen interests, and contracts were negotiated with the Filtrol Corp. for the purchase of the clay. At this time production of halloysite from Filtrol's highly productive Dragon deposit in the main Tintic district had been sharply curtailed by a mine fire, and stockpiled reserves were being rapidly depleted.

Production from the Larsen pits was started in May 1972 and has continued intermittently to the present time (May 1976).

## PROPERTY DEVELOPMENT AND PRODUCTION

The halloysite clay is mined from two closely adjacent pits that in time may merge into a single excavation. The westernmost pit, which is a short distance west of the saddle of the ridge that trends southwestward toward the Roundy shaft, is approximately 220 ft (67 m) long, 170 ft (52 m) wide, and 50 ft (15 m) deep. It is entered by inclined ramps from the western side. In October 1972 when this pit had reached a depth that required extensive benching and other nonproductive development work, it was temporarily abandoned, and a second pit was opened 350 ft (107 m) to the east, about 1,000 ft (305 m) west-southwest of the Zuma shaft.

Except for the minor hand removal of iron- and manganese-rich fragments, the clay as mined is hauled by trucks to a railroad loading point near the Burgin No. 2 shaft. It is shipped to the Filtrol Corp. plant near Salt Lake City where it is processed into a filter catalyst that is used in the cracking of crude oils into gasoline and other light-petroleum derivatives.

The production of halloysite clay from the Larsen pits from May 1972 to January 1976 has amounted to 29,231 tons (26,518 tonnes) valued at approximately $1,000,000. In both 1973 and 1975 about 300 tons of the halloysite produced came from the Crown Point Extension No. 4 claim of the East Crown Point Consolidated Mining Co., which is adjacent to the Zuma No. 3 claim. The clay reserves and resources of the area of the Larsen pits are unknown but probably are not large.

## GEOLOGY

The halloysite deposits replace weakly bleached and sanded dolomite beds of the Bluebell and Victoria Formations adjacent to their contact with argillized and pyritized Packard Quartz Latite and Latite Ridge Latite. In the general area of the deposits, both the lavas and the sedimentary rocks are cut by plugs and dikes of monzonite porphyry and by pebble dikes. The carbonate rocks show weak to moderate contact pyrometasomatism, although no tactite zones have been observed. Of much greater importance are zones of hydrothermal alteration of the mid- and late-barren stages that occur in both the igneous and sedimentary rocks.

The clay bodies are closely associated with smaller deposits of iron and manganese oxide minerals, which were exploited during the period of early development of the nearby Iron King No. 1 mine in the early 1900's. The high-grade clay deposits appear to replace the carbonate rocks adjacent to a hanging wall of pyritized and argillized tuff or lava, and the iron and manganese ore bodies appear chiefly to lie between the clay and the unreplaced sedimentary rocks. The clay bodies plunge very steeply southward, possibly localized at the intersection of obscure north- or northeast-trending steep fissures and the east-striking south-dipping contact zone. It is equally possible that they are localized by irregularities or corrugations in the contact zone between lavas and sedimentary rocks. Like the Dragon halloysite deposit (Kildale and Thomas, 1957, p. 95) of the main Tintic district, which largely underlies an overhanging contact of the Silver City monzonite porphyry stock, the Larsen deposit appears to underlie an inclined contact of sedimentary and igneous rocks. Further data concerning the details of the geology of the deposit must await additional development of the clay bodies.

## MINERALOGY

The clay deposits consist predominantly of endellite, $Al_2Si_2O_5(OH)_4 \cdot 2H_2O$. It dehydrates near the surface, losing part of its nonmolecular water, and becomes halloysite. Some mineralogists, however, refer to these minerals, respectively, as halloysite and metahalloysite. The purest endellite is massive and dazzling white with a smooth lustrous surface resembling porcelain, although it can be scratched with the thumbnail. The dehydrated endellite, or halloysite, is dull chalky white and is pulverulent. Electron photomicrographs reveal that the endellite has a concentric tubular crystal structure or perhaps consists of minutely rolled sheets, which commonly become split, unrolled, or flaky on dehydration.

The lower grade clays locally contain irregular masses of gibbsite, alunite, allophane, and kaolinite and other clay minerals and in other areas may also contain scattered crystals of pyrite, seams and veins of manganese and iron-oxide minerals and quartz, and unreplaced residual masses of quartzite, chert nodules, sand grains, and altered carbonate rocks. Either alunite or iron in amounts over 0.5 percent are particularly deleterious to the efficiency of the clay as an effective catalyst, and quartz, jasperoid, and other similar types of silica seriously abrade the lead-lined pipes and valves of the sulfuric acid circuits of the activation plant. The average grade of the purest and most desirable clay probably exceeds 95 percent endellite.

### OUTLOOK

Occurrences of halloysite are widely scattered within the broad halos of argillic alteration throughout the central East Tintic district. They are particularly abundant near the contact of igneous and sedimentary rocks in the vicinity of the Iron King No. 1 shaft and adjacent areas that are cut by dikes, plugs, and small stocks of monzonite porphyry. Other than the Larsen deposits, only the deposits on the Maple claim in this general area have been seriously prospected for halloysite. One or more of these occurrences conceivably may be as large as the Dragon deposit in the main Tintic district, which probably has yielded as much as 1½ million tons of high-grade activatable halloysite (endellite) and which contains large reserves of low-grade clay. The Dragon deposit, however, is localized within the contact zone of the large Silver City stock, whereas the deposits in the East Tintic district chiefly occur adjacent to masses of argillized lavas and tuffs or to relatively small plugs of monzonite porphyry and thus may be proportionally smaller.

At the Larsen pits the halloysite deposits are known to extend for several hundred feet along the exposed contact. Only further exploration will reveal the depth to which these deposits extend and their ultimate volume.

In addition to halloysite, other substances including certain montmorillonite clays, synthetic silica-alumina gels (Milliken and others, 1955, p. 314), and natural and synthetic zeolites (Pickert and others, 1968) have also been used as oil-cracking filter catalysts. With time it seems reasonable to anticipate that the synthetic zeolites, in particular, with their greater purity and efficiency, their ability to be modified to form highly active and selective catalysts tailored for specific reactions, and their high resistance to poisoning by sulfur and nitrogen compounds will absorb an increasingly larger share of the market now held by clay-based catalysts.

## LILLEY OF THE WEST MINE

The Lilley of the West mine, whose caved and largely obliterated shaft is 200 ft (61 m) west-southwest of the Eureka Lilly shaft, has the distinction of being the first productive mine in the East Tintic district. In August 1899, its owner and developer, P.P. Hindmarsh received $1,000 for a shipment of silver-lead ore that had been mined on the 260-ft level near the Eureka Lilly fault (Salt Lake Mining Review, Aug. 15, 1899, p. 11).

Development of the mine began in 1898 on a landholding of less than 31 acres (13 hectares). In 1916 the property was merged with other adjacent properties, including the Ralph claim, into the Eureka Lilly Mining Co. Maps and cross sections provided by the Tintic Standard Mining Co. indicate that the Lilley of the West shaft reached a total depth of 370 ft (113 m). Two levels were driven from the shaft, one at 260 ft (79 m) and the other at 370 ft (113 m) below the collar. A deeper sublevel, about 50 ft (15 m) below the 370-ft level, was apparently established from a winze. A raise connects the 370-ft level to the 330-ft level of the nearby Eureka Lilly shaft.

The Lilley of the West shaft is collared in the Packard Quartz Latite but within a short depth it crosses the Eureka Lilly fault and apparently enters the Teutonic Limestone. The ore encountered in the workings consisted of galena, anglesite, and cerussite in a gangue of manganese- and iron-stained sanded dolomite. The ore body at the 260-ft level was about 6 ft (2 m) wide; the other dimensions are unknown. The original assays, presumably of picked specimens, indicated 60 percent of lead and a few ounces of silver to the ton (Salt Lake Mining Review, June 30, 1899, p. 13).

## MAPLE SHAFT

The Maple shaft, on a claim of the same name, is in the upper part of Burriston Canyon, near the west-central edge of the district (pl. 1). This claim is owned by Clarence Loose of Salt Lake City, the grandson of Colonel C.E. Loose, who was active in the organization and management of the Iron King Mining Co. in the East Tintic district and in the management of the Grand Central and other mining companies in the main Tintic district.

The Maple Mining Co. was organized in September 1899, after the discovery of the Humbug ore bodies about three-fifths of a mile (1 km) to the west-southwest. The original officers and directors were Fred A. Hoock, John Davis, and Louis Hobein. By November 1901 a shaft 200-300 ft (61-91 m) deep had been sunk, where an occurrence of fine-grained galena was reported. Control of the property apparently passed to Colonel Loose after 1901.

Except for a small exposure of the Opohonga Limestone a short distance north of the shaft, the rocks exposed near it mostly consist of tuffs and welded tuffs of the Packard Quartz Latite, which are cut in places by pebble dikes and by dikes and plugs of monzonite porphyry. Limestone on the dump of the shaft, which is located near the center of the claim, indicates that the volcanic rocks are thin, at least over the tops of irregularities in the prevolcanic surface. All of the volcanic rocks show intense argillic alteration, and shallow pits and adits northeast of the shaft expose replacement bodies of endellite and halloysite near the volcanic-sedimentary rock contact.

The subsurface geology of the Maple claim is not well known. Underground workings at the 2,000-ft level of the nearby Yankee mine (elev. 5,125 ft) pass a short distance northwest of the claim and intersect the north-northwest-trending Addie fault. This fault, which was weakly mineralized in the Yankee workings, undoubtedly extends southward into the Maple claim, probably terminating at or merging with the Yankee fault near the southern boundary of the claim.

No ores are known to have been produced from the Maple property.

## MONTANA SHAFT

The Montana shaft is in the SE¼SE¼NE¼ sec. 21, T. 10 S., R. 2 W., a little less than 1 mi (1.6 km) south-southwest of Dividend. It is located on claims that currently are part of the holdings of the Eureka Standard Mining Co. and has not been used since about 1918. The early history of exploration activities in the area of the Montana shaft is imperfectly known. Prior to 1909, the claim on which the shaft is located was part of the holdings of the Mielich Mining Co. and earlier had been part of the Missouri Group. In May 1909 the Montana Mining Co. was organized by John Roundy, Ernest R. Woolley, Fred R. Woolley, Duncan McVichie, J. C. Jensen, and E. J. Raddatz. By December 1914 underground development was reportedly underway on the property under the direction of H. G. Snyder. By March 1916 control of the property, which then consisted of 14 claims and fractions, had passed to the F. C. Richmond Machinery Co. of Salt Lake City, and shaft sinking was proceeding. In March 1917, the Jesse L. Knight interests of Provo, Utah, assumed control of the Montana Co. and reorganized it as the Eureka Standard Mining Co. At the time of its acquisition by the Knight interests, the Montana shaft had been sunk to a depth of 500 ft (152 m). Plans were announced at that time to continue sinking the shaft to a total depth of 1,000 ft (305 m) to explore for the supposed southerly extension of Tintic Standard ore body. It does not appear, however, that the shaft was deepened beyond its existing depth of 500 ft (152 m), and the property was sold in August 1917 to the Tintic Standard Mining Co. Development of the Eureka Standard ore bodies on these claims is described in the section "Eureka Standard Mine."

Interest in the area of the Montana shaft was doubtless based on the scattered deposits of iron oxides on Mineral Hill and, in particular, on the heavily iron-stained contact zone of the Packard Quartz Latite and the Bluebird Dolomite 500 ft (152 m) east-northeast of the shaft. This contact zone is shown on some maps as the Montana fissure although it is now recognized to be the normal basal contact of the volcanic series and the underlying sedimentary rocks. The three-compartment shaft is collared a short distance below the contact of the Bluebird and Cole Canyon Dolomites, which strikes nearly due east and dips 20°-25° S. At a depth of 500 ft (152 m), the workings presumably bottom in the upper part of the Herkimer Limestone. The extent of lateral openings, if any, is unknown, and no ore shipments are recorded.

The dump of the shaft is composed chiefly of dolomite, some of which is probably dolomitized Herkimer Limestone and some scattered small masses of iron oxide and iron-stained jasperoid.

## NORTH LILY MINE

The North Lily mine is located in the central part of the East Tintic district, about three-quarters of a mile (1.2 km) northwest of Dividend (fig. 56). It is owned by the North Lily Mining Co., a stock company whose controlling interest is held by the International Smelting and Refining Co., a wholly owned subsidiary of the Anaconda Co. The North Lily ore bodies are concealed by more than 500 ft (152 m) of barren lava and other rocks, and their discovery in January 1927 culminated 5 years of detailed and systematic geologic studies in the East Tintic district by Paul R. Billingsley and his associates in the International Smelting and Refining Co.

The first claims established in the North Lily area were owned by the Wicklow Mining Co. This company was organized in 1906 by J.B. Caldwell and A.J. Weber; by 1912, however, little work had been carried out, and the company was dissolved. In 1916 Caldwell and Weber sold the claims to H. G. Snyder and George Horton, who organized the North Lily Mining Co. Apparently little in the way of physical exploration and development was carried out during the ensuing few years, however, until the International Smelting and Refining Co. became interested in exploration possibilities in the East Tintic district.

Beginning in 1922, this company assigned Billingsley to undertake a detailed study of the highly productive Tintic Standard mine and its geologic setting. Particular attention was paid to the structural and stratigraphic localization of its ore bodies and their relations to the zones of hydrothermal alteration in the lavas uprake from them. After this underground study, a careful investigation was made of the surface geology of the East Tintic district, with particular emphasis on the large zone of hydrothermal alteration on the North Lily claims. In July 1924 controlling interest in the North Lily Mining Co. was purchased by the International Smelting and Refining Co. and a program of drilling exploration was undertaken from the surface. While the drilling was in progress in May 1925, other East Tintic properties, including the East Tintic Coalition Mining Co., the Standard Lily Extension, and the eastern part of the Yankee Mining Co., were added to the holdings, and the Addie group was taken under lease.

In all, five exploration holes were drilled from the surface, and although no ore was cut, it was recognized that these holes had penetrated the hydrothermally altered Ophir Formation beneath the bleached and iron-stained lavas and that it occurred in a structural setting generally similar to that of the Tintic Standard ore body.

A decision was then made to explore the favorable area by conventional mining techniques, and in August 1926 an agreement was made with Tintic Standard to extend the 700-ft level of that mine 2,400 ft (732 m) to the target area. Under this agreement the North Lily Co. paid one-third of the cost of driving through Tintic Standard ground and all of the cost of driving through the property of the Eureka Lilly Mining Co., which intervened in the most direct route to the target area.

The exploration workings was driven with great speed with the use of mechanical shoveling and loading equipment, and by December 1926 low-grade ore had been found on the Eureka Lilly claims. Shortly afterward, in January 1927, high-grade ore was penetrated in the target area on the North Lily claims. Ore shipments began immediately through the Tintic Standard No. 2 shaft, averaging about 100 tons (91 tonnes) per day during the next year and a half.

Beginning in March 1927, while this ore was being mined, the 900-ft level of the Tintic Standard was also advanced to the target area and beyond it to the west boundary of the North Lily claims. During this second drive the Eureka Lilly, North Lily, and Tintic Standard each paid one-third of the cost of driving the workings through Tintic Standard ground; Eureka Lilly also paid two-thirds of the costs through its own claims with North Lily paying the remainder. This drift also disclosed high-grade ore in both the Eureka Lilly and North Lily properties.

In May 1927 the four-compartment North Lily shaft was collared in an area that was centrally located in respect to the North Lily and Eureka Lilly ore bodies and other relatively undeveloped properties in the vicinity. It was originally sunk to a depth of 1,400 ft (427 m) and was put into service in June 1928. For many ensuing years the North Lily shaft was also used by the Chief Consolidated Mining Co. in the exploration and development of the Eureka Lilly, Tintic Bullion, Baltimore, and Eureka Bullion properties; by the Tintic Standard Mining Co. in the exploration and development of the Hannibal claim; and for the exploration of claims held by the International Smelting and Refining Co. that were not integral parts of the North Lily Mining Co.

After the discovery of the North Lily ore bodies, the North Lily and International Smelting and Refining Companies embarked on an extensive program of property acquisition in the Tintic and East Tintic district. In 1927, International purchased control of the Mountain View Mining Co. in the main Tintic district, which was an earlier consolidation of the May Day and Uncle Sam properties. In July 1929, through the establishment of the subsidiary North Lily-Knight Corp., the North Lily Mining Co. acquired operating control of many of the properties of the Knight Investment Co., including the Big Hill and 20th Century Mining Companies in the East Tintic district; the Dragon Consolidated, Empire, Swansea Extension, Middle Swansea, Swansea Consolidated, Tintic Drain Tunnel, and the New Southern Eureka Mining Companies in the main Tintic district; along with substantial stock interests in the Tintic Central, North Godiva, and Defender Mining Companies, and the Eureka Hill Railroad. In 1931 the International Smelting and Refining Co. purchased control of the Eureka Bullion Mining Co., and in 1932 also purchased the Addie claims, Tintic Bullion group, Baltimore, and other claims. At various times these and other holdings were under lease to the North Lily Mining Co. for development or exploration through the North Lily shaft. In July 1941, 95.47 percent of the stock of the North Lily-Knight Corp. passed directly to the North Lily Mining Co.

On July 1, 1949, the ore bodies and exploration possibilities in the North Lily mine were considered to be exhausted, and the mine was closed. It remained inactive until the latter part of 1973 when a deep exploration drill hole was located about 1,000 ft (305 m) north-northwest of the shaft. In August 1974 this hole was completed to a total depth of 3,769 ft (1,149 m). Two other holes also were drilled later to depths of 1,083 ft (330 m) and 1,451 ft (442 m) in the area between the North Lily shaft and U.S. Highway 6.

#### PROPERTY DEVELOPMENT AND PRODUCTION

The property holdings that are owned or controlled by the North Lily Mining Co. in both the main Tintic and East Tintic districts consist of approximately 1,100

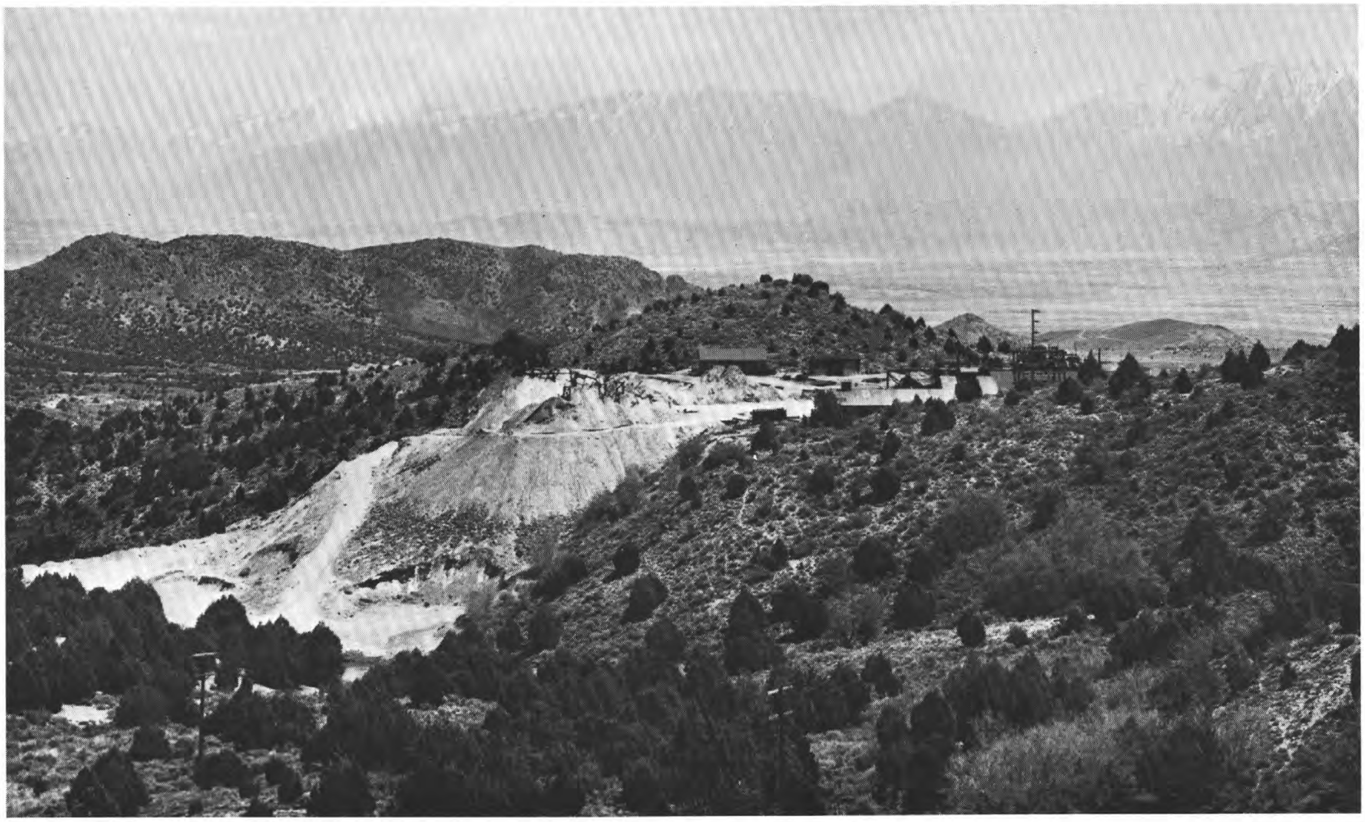


FIGURE 56. — The dump and general setting of the North Lily mine. Goshen Valley is in middle background, and the southern Wasatch Mountains are in the far background.

acres (466 hectares) of patented mining claims and agricultural lands. These holdings include a dozen or more separate parcels that are chiefly located in the central and southern parts of both districts. The productive ore bodies of the North Lily mine, however, are largely centered on the original group of seven North Lily claims, which lie three-quarters of a mile (1.2 km) northwest of Dividend. Extensions of these productive ore bodies and other separate ore bodies were mined on adjacent claims of diverse ownership.

The North Lily shaft is on the Horton claim in the SW¼NW¼NE¼ sec. 16, T. 10 S., R. 2 W. It is 1,858 ft (566 m) deep, and the 700, 900, 1,000, 1,200, 1,350, and 1,500 levels have been opened from the shaft. In addition the 400, 500, 600, 650, 750, 874, 950, 1,100 and other sublevels have been driven from numerous vertical and inclined winzes and raises. The total length of lateral workings, winzes, and raises is reported to be about 10 mi (16 km).

Inasmuch as the North Lily mine was first developed by the 700- and 900-ft levels of the Tintic Standard No. 2 shaft, the Tintic Standard level numbering system has been retained despite the fact that the collar of the North Lily shaft is about 295 ft higher in elevation than the collar of the Tintic Standard No. 2 shaft. Thus the so-called 700 and 900 levels of the North Lily mine are actually 954 and 1,189 ft (291 and 362 m) below the collar, and other levels have the same general discrepancies between their actual and their indicated depths below the surface.

The estimated total tonnages and grades of ores produced from the North Lily claims and adjacent separate land holdings are presented in table 9, which is adapted from Cook (1957, pl. 3) and other sources. In comparison, Kildale (1957, p. 105) estimated the combined production from the North Lily mine and closely associated properties to be approximately 375,000 dry tons (340,125 tonnes), which included 194,000 tons (175,958 tonnes) of lead-silver ore, 35,000 tons (31,745 tonnes) of lead-zinc ore, and 146,000 tons (132,422 tonnes) of siliceous gold-copper and gold-silver ore. The average recoverable metal content of these various ores, as estimated by Kildale, is presented on page 161 of this report.

## GEOLOGY

The North Lily ore bodies are localized in Cambrian sedimentary rocks at or near the intersections of the North Lily and Eureka Lilly fissure zones and the Tin-

TABLE 9.—*Tonnages and average grade of ore produced from various groups of claims mined through the North Lily shaft*

[............., negligible; short tons = 0.907 tonnes; 1 oz per short ton = 34.29 g per tonne]

| Property | Ore produce (dry tons) | Average grade: Gold (oz/ton) | Silver (oz/ton) | Copper (percent) | Lead (percent) | Zinc (percent) |
|---|---|---|---|---|---|---|
| North Lily group (Miller, Natrona, Caldwell, Clark, Dewey, Horton amended and Dewey claims) | 271,876 | 0.2 | 10.4 | .......... | 17.7 | 0.5 |
| Tintic Bullion group and Coyote claim. | 81,885 | 1.1 | 5.7 | 1 . 1 | 1.5 | 1.5 |
| Eureka Bullion group | 18,589 | .3 | 8.9 | 1 . 8 | .2 | .......... |
| Hannibal and Water Gulch claims | 3,691 | .2 | 4.7 | 1 . 7 | .1 | .......... |
| Baltimore claims | 1,064 | .2 | 4.7 | 1 . 7 | .1 | .......... |
| Total | 377,105 | | | | | |

tic Standard thrust fault, on the west flank of the asymmetric East Tintic anticline. The sedimentary rocks that are exposed in and near the mine range from the Tintic Quartzite to the Cole Canyon Dolomite. They are complexly folded and faulted and are overlain by as much as 500 ft (152 m) of Packard Quartz Latite. In the northwestern part of the mine both the sedimentary rocks and the lavas are cut by many small stocks and plugs of monzonite porphyry, which constitute the North Lily intrusive center, and throughout the mine many of the north-northeast-trending fissures are partly occupied by dikes of monzonite porphyry and of pebble breccia. Close to the igneous intrusions and the ore bodies, many of the rocks are strongly argillized, pyritized, or otherwise altered.

With respect to ore localization and ore deposition, the dominant structure in the North Lily mine is the folded Tintic Standard thrust fault. This fault is a relatively wide zone of braided fracture planes, movement along which has brought the Ophir, Teutonic and possibly other limestone units into fault contact with the uppermost part of the Tintic Quartzite. A cross section (fig. 57) drawn through the main North Lily ore body shows the thrust to be folded sharply downward into the northwest-converging North Lily trough and then to rise steeply up the west flank of the East Tintic anticline, forming the so-called North Lily pothole (see fig. 35). In the plane of this cross section the thrust zone is cut by the North Lily fissure, which trends N. 40° E. and dips steeply northwest. A short distance southeast of the North Lily fissure is the Endline Dike fissure, which trends N. 45° E. and apparently merges with the North Lily fissure in the general vicinity of the Eureka Lilly fault. Beyond the Endline Dike fissure to the southeast, lie the fractures of the Eureka Lilly fissure zone. Northwest of the North Lily fissure other subparallel northeast-trending fissures have been discovered, including the Keel Dike fissure, which lies about 90 ft (27 m) from the North Lily fissure (see fig. 35). Much farther to the northwest, some 3,030 ft (924 m) north-northwest of the North Lily shaft and beyond the pothole area, the N. 40-50° east-trending Baltimore fissure zone was explored at the 700 and 900 levels.

Of less economic significance but of considerable structural importance in the mine is the Eureka Lily fault. This structure is southwest of the main area of ore deposition, trending N. 37° W. in the area north of the North Lily shaft and turning to N. 10° W. south of the shaft. The dip of the fault is close to 50° SW. Displacement on the fault is normal, with the upper surface of the Tintic Quartzite faulted down about 1,000 ft (305 m) in the general area of the North Lily and Eureka Bullion shafts. Of this displacement approximately 500 ft (152 m) occurred after extrusion of the lavas.

The ground-water table stands at an elevation of 4,545 ft in the North Lily shaft, which is close to its elevation throughout the footwall block of the Eureka Lilly fault. In the hanging-wall block, however, the water table apparently rises sharply, having been cut at an elevation of 4,705 ft in the nearby Big Hill shaft.

## IGNEOUS ROCK AND HYDROTHERMAL ALTERATION

The intrusive bodies in the northwestern part of the North Lily mine consist of the small North Lily stock and many satellitic plutons and dikes of greenish-gray medium- to coarse-grained monzonite to quartz monzonite porphyry. In underground exposures these rocks are readily distinguished from the Packard Quartz Latite, which they intrude, by their coarser texture, the relative absence of quartz, and the presence of hornblende and augite. Associated with the dikes, but exceeding them in abundance, are numerous pebble dikes; this quartzite pebble breccia also forms local selvages at the contacts of some of the plutons. Other intrusive rocks include narrow dikes of fine-grained andesite or latite porphyry, some of which are also related to late-stage intrusion breccias of a different origin than the pebble dikes.

In the general proximity of the igneous intrusions, the shattered and fissured country rocks are extensively argillized and pyritized, a feature that first directed the attention of the International Smelting and Refining Co. to the exploration possibilities in the North Lily area. In the Packard Quartz Latite the argillized zone is centered on the North Lily stock; this zone is elliptical in plan, with a long axis about 4,300 ft (1,311 m) in length trending N. 25° E., generally through the center of the stock, and the short axis about 3,100 ft (945 m) in length trending S. 65° E. through the southern part of the stock (Lovering, 1949; Lovering and others, 1960). Within this aureole the lavas and the adjacent parts of some of the intrusive bodies are

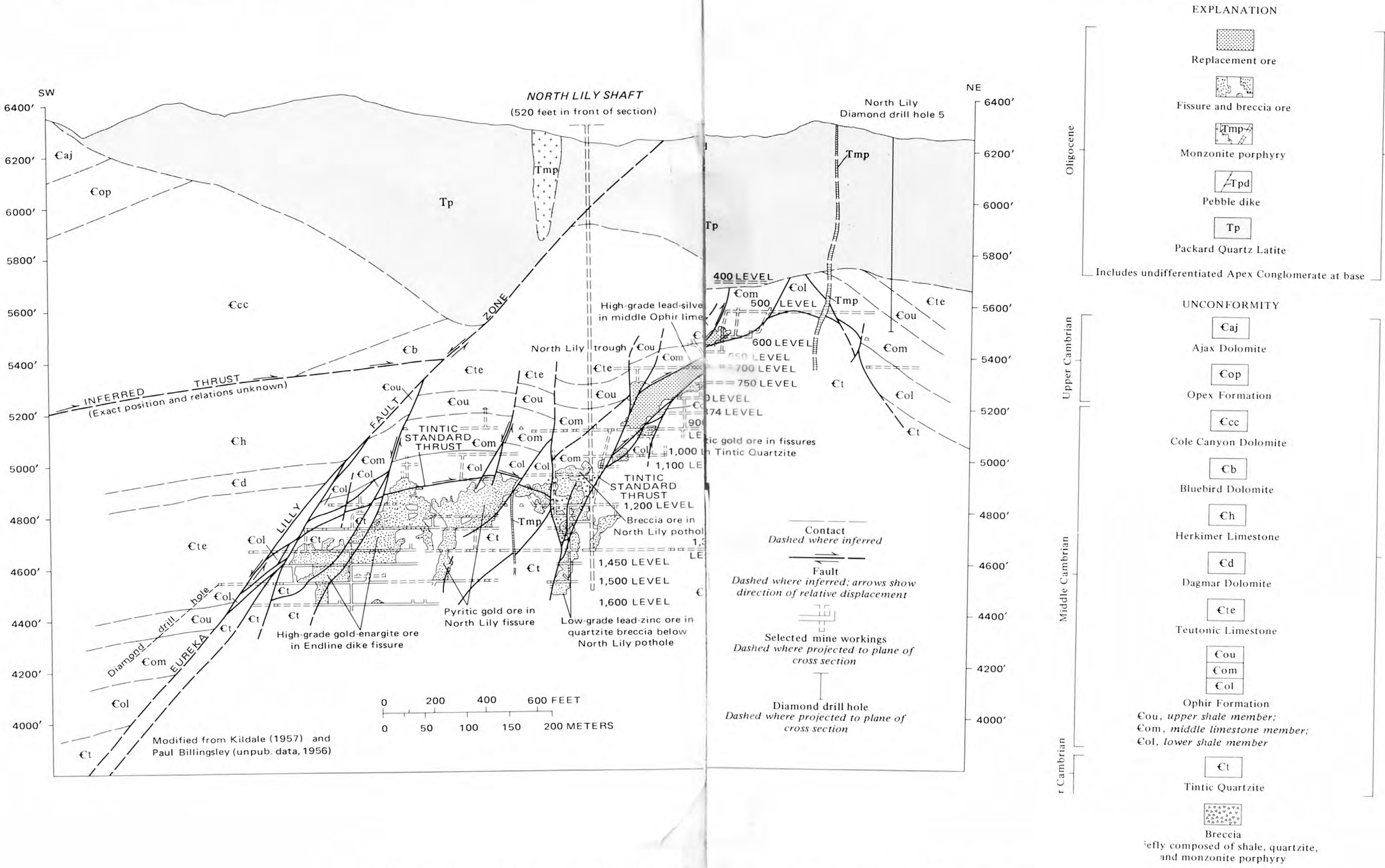



FIGURE 57. Geologic cross section of North Lily mine in the plane of the North Lily fissure zone.

bleached to a dazzling white color, the magnetite is leached away, and the plagioclase feldspar phenocrysts, the ferromagnesian minerals, and locally the groundmass constituents are converted to kaolinite, endellite, or even dickite. Near the outer borders of the aureole, montmorillonite progressively becomes the dominant replacement product, particularly in the areas where only the plagioclase and ferromagnesian minerals are altered.

At the fringe of the argillized zone, commonly adjacent to the northeasterly trending fissures, scattered patches of pyritized lava become noticeable. Some of these patches are believed to have originated from the reaction of sulfur-rich argillizing solutions that were active during the argillic phase of alteration, and other patches are believed to have originated from the reaction of other sulfur-dominant solutions that were active somewhat later, in part during the ore-depositing phase.

Beyond the main areas of argillized and pyritized lavas, the plagioclase phenocrysts of otherwise fresh appearing volcanic rocks are partly to wholly replaced by calcite within an irregular zone that extends for half a mile north-northeast of the main zones of argillic and pyritic alteration. This zone of calcitized lava grades nearly imperceptibly into fresh rock.

At depth, in the sedimentary rocks below the lavas, the limestones are pervasively altered to dolomite. Close to the intrusive bodies, and adjacent to some faults and fissures, the argillic alteration of overlying lavas has its counterpart in large and small masses of sanded dolomite and solution breccia. Because of the greater capacity of the carbonate rocks to neutralize the acid-argillizing solutions, the total volume and extent of leached and sanded carbonate rock are considerably less than the volume and extent of argillization in the overlying lavas. Disseminated pyrite, or its oxidized equivalent, is also common in the fringe areas of the sanded, argillized dolomites as it is in the lavas; however, it is abundant only in shale, quartzite, and those few carbonate rocks in which indigenous iron minerals were also abundant. Calcitization of the dolomites is insignificant as compared to calcitization of the lavas. Detailed discussion of hydrothermal alteration in the East Tintic district has been presented in earlier reports (Lovering, 1949; 1950a).

## ORE BODIES

The principal ore bodies of the North Lily mine are replacement lead-silver ores in the middle Ophir limestone and veinlike shoots of copper-gold ores in the Tintic Quartzite. Less important deposits include incomplete replacement deposits of galena, sphalerite, and pyrite in limy shale and monzonite breccias and low-grade lead-zinc-gold ores in shale and quartzite breccia in the North Lily pothole.

The main replacement ore body, in plan, is shaped somewhat like a cross: the long axis, which averages about 100 ft (30 m) wide, extends upward at a low angle for about 800 ft (244 m) from the 900 level to a point above the 600 level, and the short axis, which is about 400 ft (122 m) in total length, extends outward from the longer ore body at about the 700 level (see fig. 35). This ore body is approximately 100 ft (30 m) thick. It is localized chiefly at the intersection of the North Lily fissure and the middle Ophir limestone, with the cross axis of the ore body occurring at the trace of the ore-host beds against the Tintic Standard thrust fault. A similar but smaller replacement body also occurs at the same horizon centered on the Endline Dike fissure. Southwest of the end of the main replacement ore body a separate shoot of pyritic lead-zinc-gold ore extends downward into the breccias of the North Lily pothole.

Vertically below the replacement ore bodies, linear shoots of pyritic gold ore extend downward into the quartzite along the North Lily fissure. In the southwestern part of the mine on the Tintic Bullion and Eureka Bullion claims, similar shoots, which range in width from about 6 in. (15 cm) to 20 ft (6 m) or more, also occur along the converging Endline Dike and associated fissures. These shoots consist chiefly of ore-cemented breccias, and according to Kildale (1957, p. 115) the richer parts of the ore shoots were apparently localized by small cross fractures; the low southerly rake of the ore zone also suggests a general localization by the bedding of the quartzite.

Ore bodies in other parts of the North Lily mine are small as compared to the main North Lily replacement deposit and the veinlike bodies of the Endline Dike and other fissures. These include (1) a small tabular ore shoot of gold-copper ore in the Tintic Quartzite on the Baltimore claim 3,600 ft (1,097 m) north-northwest of the shaft, (2) a small podlike shoot along the fault contact of the Tintic Quartzite and Cole Canyon Dolomite on the Coyote No. 2 claim 4,200 ft (1,280 m) northwest of the shaft, (3) an irregular body of lead and zinc ore in the Tintic Standard thrust and the Eureka Lilly fault on the Hannibal and Coyote No. 5 claims 2,700 ft (823 m) northwest of the shaft, (4) a small body of ore adjacent to the North Lily stock on the Desert No. 5 claim 1,650 ft (503 m) northwest of the shaft, and (5) a tabular body of lead-copper-gold ore in the Tintic Quartzite that lies chiefly on the Eureka Bullion claims 1,000 ft (305 m) southwest of the North Lily shaft.

The mineralogy of the North Lily ore bodies ranged from simple to complex. The replacement deposits in the middle Ophir limestone consisted chiefly of fine- to coarse-textured galena and its oxidation products, anglesite and cerussite, considerably less abundant pyrite or iron-oxide minerals, and minor amounts of sphalerite or its alteration products, smithsonite and hemimorphite. Argentite and tetrahedrite were not abundant in these ores, which may account for the overall lower content of silver as compared to the replacement ores of the Tintic Standard mine. Nonmetallic gangue minerals were not abundant, although jasperoid and calcite were common in addition to unreplaced breccia fragments and residuals of altered country rock. According to Kildale (1957, p. 105) the average recoverable metal content of the lead-silver ore was 0.116 oz per ton (3.98 g per tonne) gold, 12.6 oz per ton (432.1 g per tonne) silver, and 24 percent lead. Somewhat similar but more sphalerite-rich ores were mined from the shale-monzonite-quartzite breccias of the North Lily pothole. Kildale (1957) reported that these lead-zinc ores contained 0.087 oz per ton (2.98 g per tonne) gold, 10 oz per ton (342.9 g per tonne) silver, 7.1 percent lead, and 6.1 percent zinc. An unusual silver-rich ore shoot occurred just below the 1,200 level. This ore consisted chiefly of pyrite, pearcite, tennantite, bismuthinite, and rare chalcopyrite. A recalculated analysis of this ore showed 16.6 percent silver (3,984 oz per ton or 136,611.4 g per tonne), 16.2 percent copper, 19.95 percent bismuth, 12.3 percent iron, 28.5 percent sulfur, 5.15 percent arsenic, and 1.3 percent antimony (Kildale, 1957, p. 118).

The fissure and quartzite breccia ores were generally coarser textured and more vuggy than the replacement ores and were characterized by abundant pyrite, crystalline and fine-grained quartz, large and small platy crystals of barite, and fine-grained to invisible gold. Two general classes of these ores were recognized from their additional content of either copper or lead and zinc minerals. The fissure ores below the lead-silver and lead-zinc replacement ore bodies in the central and northeastern part of the mine contained notable quantities of galena and sphalerite with accessory argentiferous galena. In contrast, the siliceous gold ore shoots in the Tintic Quartzite in the southwestern part of the mine contained relatively little galena and only minor sphalerite, but relatively abundant auriferous luzonite, tetrahedrite, hessite, krennerite, petzite (?), and native gold. As reported by Kildale (1957, p. 105) the average grade, in terms of recovered metal, of 65,000 tons (58,955 tonnes) of gold-copper ore mined along the Endline Dike fissure was 1.326 oz per ton (45.47 g per tonne) gold, 4.75 oz per ton (155.56 g per tonne) silver, and 1.37 percent copper. Some of this ore was exceptionally rich in native gold, with some selected samples assaying more than 2,000 oz per ton (68,580 g per tonne). Some samples of luzonite from one part of this ore shoot contained visible threadlike and pinhead-sized concentrations of native gold constituting as much as one-third of the total weight of the specimen. Kildale (1957, p. 117) reported that a picked sample of the high-grade gold-copper ore contained 9.25 percent (2,698 oz per ton or 95,514.4 g per tonne) gold, 0.72 percent (210 oz per ton or 7,200.9 g per tonne) silver, 44.14 percent copper, 27.43 percent sulfur, 13.98 percent arsenic, 3.81 percent antimony, and 0.63 percent iron.

In the small outlying fissure ore bodies in the Baltimore area at the northern end of the North Lily mine and in the Coyote area in the far northwestern part of the mine, the pyritic gold ores are characterized by accessory amounts of light-yellow to pale-red sphalerite or wurzite.

## NORTH STANDARD MINE

The North Standard mine is at the eastern base of Pinyon Peak about 2¾ mi (4.4 km) north-northeast of Dividend in the center of the N½ sec. 34, T. 9 S., R. 2 W. The property consists of nine patented claims and fractions aggregating about 115 acres (47 hectares); it adjoins the Laguna claims on the north and east, and the Chief Consolidated claims on the south, west, and northwest (see fig. 39).

The North Standard Mining Co. was organized in 1916, at which time the property was opened by a shaft 285 ft (87 m) deep and by several short adits and shallow pits that penetrated irregular bodies of manganese oxides and halloysite clay cropping out near the base of the lavas. Major shaft sinking and other underground development of the property took place between 1918 and 1922, after the Tintic Standard discovery, and again from 1927 to 1932, after the discoveries of the North Lily, Eureka Lilly, and Eureka Standard mines.

The North Standard shaft has not been used since 1932 and in 1975 was largely caved. According to company maps and contemporary newspaper accounts, it is 1,100 ft (335 m) deep, and levels have been established at depths of approximately 500, 850, and 1,100 ft (152, 259, and 335 m). As shown in figure 58, the workings at the 500-ft level exceed 690 ft (210 m), and at the 850-ft level they aggregate more than 2,700 ft (823 m). Several raises and winzes have been driven from the 850-ft level. The longest winze is in the southeastern part of the mine near station 847. It is an 80° decline approximately 535 ft (163 m) long; from it, levels have been established at approximate depths of 1,200, 1,300, and 1,400 ft (366, 396, 427 m) below the surface. Fifteen feet (4.6 m) south of this winze a vertical raise extends 100 ft (30 m) above the 850-ft level.

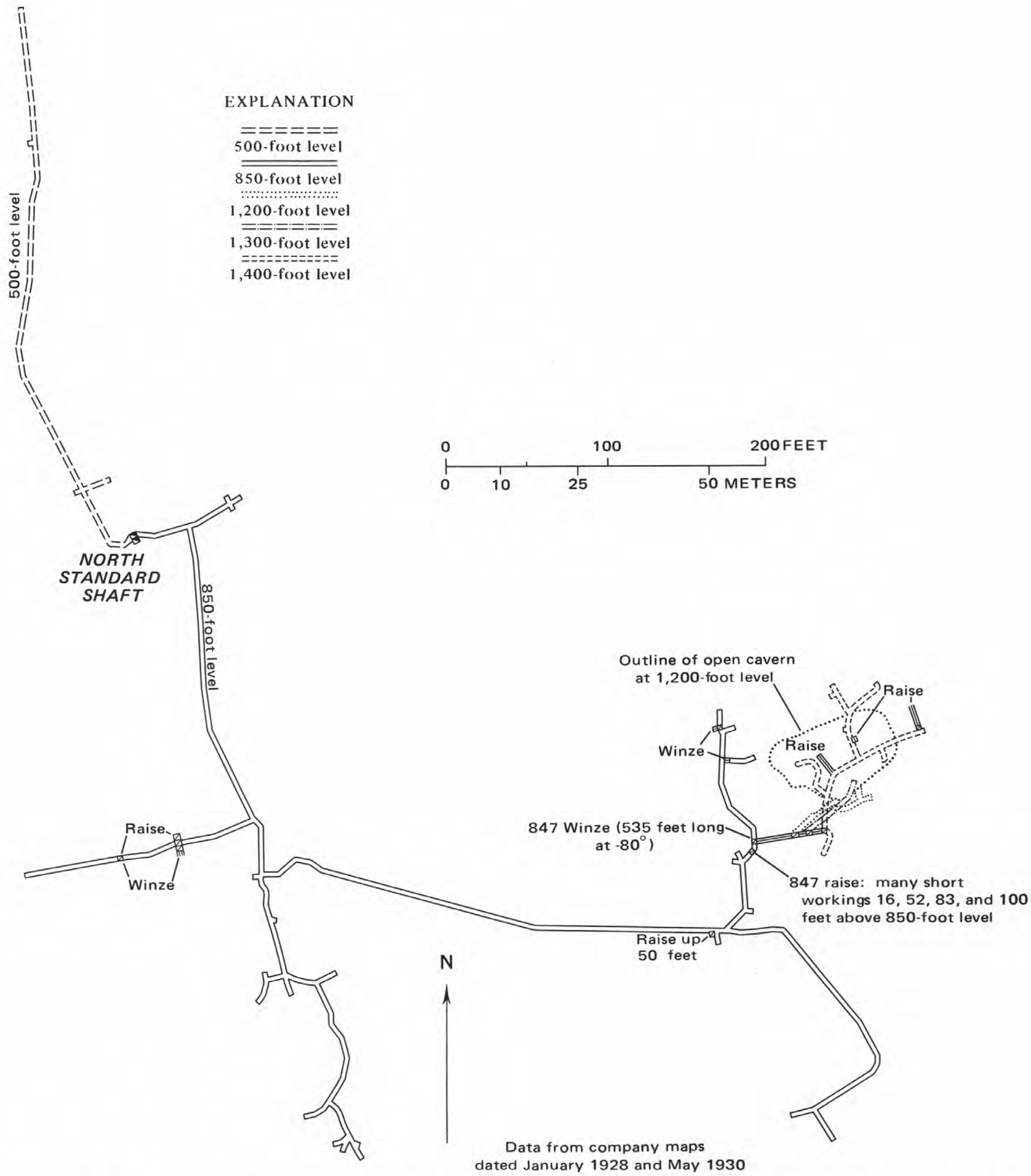



FIGURE 58. — Composite map of workings at the 500-, 850-, 1,200-, 1,300-, 1,400-ft levels of North Standard shaft.

From it, short workings have been driven at 16, 52, 83, and 100 ft (5, 16, 25, and 30 m) above the level. The extent of workings at the 1,100-ft level is unknown, but drifts and crosscuts several hundred feet in total length are reported to be in the area northeast of the shaft. Workings at the 1,200-ft level are 155 ft (47 m) long; at the 1,300 level they are 80 ft (24 m) long; and at the 1,400-ft level they are nearly 500 ft (152 m) long. Three raises also extend from the 1,400-ft level and two of them end at short sublevels 52 and 75 ft (16 and 23 m) above the 1,400-ft level.

At the surface, the immediate area of the North Standard shaft is underlain by sedimentary rocks. These include the Opohonga, Fish Haven, and

Bluebell Formations, which are in the lower plate of the nearly horizontal Pinyon Peak thrust fault. This thrust crops out about 600 ft (183 m) southwest of the shaft, and above it the Cole Canyon, Opex, and Ajax Formations dip moderately to the west (pl. 1). North, northeast, and east of the shaft the sedimentary rocks and the thrust are covered by lavas and tuffs, some of which are strongly argillized and pyritized.

Reconstructions of the subsurface geology based on surface exposures indicates that the 500- and 850-ft levels are probably in the Ajax Dolomite; the 1,100-ft level also may be in this formation, but it is equally likely that it is in the Opex Formation, or even in the Cole Canyon Dolomite.

According to J. H. Manson (oral commun., September 21, 1949), the north wall of the shaft at 700 ft (213 m) of depth intersected an open cavern that is 75 ft (23 m) long, 30 ft (9 m) wide, and 70 ft (21 m) high. This cavern was partly filled with boulders loosely cemented by skeletal silica, which, in turn, was coated with hematite.

A similar but larger cavern was also intersected at the 1,200-ft level from the 847 winze. This deeper cavern was found to be approximately 160 ft (49 m) long, 95 ft (29 m) wide, and about 50 ft (15 m) high. The 1,300-ft level below it penetrated a great mass of calcite-cemented breccia, but the still deeper 1,400-ft level from the winze penetrated only unbroken rock (see fig. 58).

Newspaper accounts published at the time the property was under development indicate that the mine workings near the 847 winze and 847 raise partly follow a contact between carbonate rocks and an igneous intrusion. A careful search of the dump, however, failed to disclose any igneous material, so its composition and texture are undetermined.

No metallic ores are known to have been shipped from the North Standard mine. J. H. Manson (oral commun., 1949) reported that a narrow vein, about 1 in. (2.54 cm) wide, was found on the 1,100-ft level about 150 ft (46 m) northwest of the shaft. A sample from this small vein reportedly returned assays of 75 oz per ton (2,572 g per tonne) of silver and 40 percent of lead.

Beginning in 1963, irregular lots of argillized tuff, from beds that probably represent the basal part of the Packard Quartz Latite, have been shipped as fire clay and as white-firing brick clay from a pit 450 ft (137 m) due west of the shaft. The total quantity of clay produced to 1970 is not known but is estimated to be about 5,000 tons (4,535 tonnes).

R. T. Walker (oral commun., October 1, 1949), who periodically visited the property during its development, reported that the entire mine, and in particular the deep winze and the 1,400-ft level, rivaled the Tintic Standard and other mines of the East Tintic district in being exceptionally hot and gassy, and that work was commonly suspended because of high concentrations of $CO_2$ in the deadend workings.

## OXEN MINE

The Oxen mine is at the ridge crest south of the central part of Homansville Canyon about 1,500 ft (457 m) west-southwest of the Tip Top mine in the N½NW¼ sec. 9, T. 10 S., R. 2 W. It can be reached by a steep, narrow road that leaves U.S. Highway 6 a short distance south of Homansville. The mine was first developed in 1944 by the Steele brothers of Nephi, Utah, who intermittently mined the deposit during the succeeding 2 or 3 years.

The workings are all confined to the Oxen claim, owned by the Chief Consolidated Mining Co. Originally the claim was part of the property of the Homansville Mining Co. and was purchased with other claims in March 1916. The Oxen mine openings consist of a curving opencut, 175 ft (53 m) long, 30-50 ft (9-15 m) wide, and 5-30 ft (1.5-9 m) deep, that terminates on the west at an irregular inclined shaft about 75 (23 m) ft deep. Several smaller pits and short adits are located nearby. The recorded production from the claim is 749 long tons (761 tonnes) of ore averaging 22.7 percent manganese, and 25.55 long tons (25.96 tonnes) averaging 36.5 percent manganese (Crittenden, 1951, p. 50). Some lots were reportedly refused by the Geneva Steel Co. because of excessive quantities of zinc (Dell Steele, oral commun., 1947).

The country rock of the Oxen ore bodies is the Cole Canyon Dolomite, which chiefly strikes northeast and dips to the northwest at a low to moderate angle. A few hundred feet north of the mine, erosion has breached the Cole Canyon Dolomite, indicating that it has been faulted against the Herkimer Limestone by movement on a small folded thrust fault (see pl. 1). Both formations and the minor thrust are cut by several steep north-trending faults of small to moderate displacement, one of the strongest of which is exposed in the shaft at the west end of the open cut. The only igneous rock exposed near the mine is the basal part of the Packard Quartz Latite, which crops out 200 ft (61 m) or so southwest of the pit.

The manganese ore bodies consist chiefly of veinlets and pods of mixed manganese oxides that have incompletely replaced the dolomite along faults, fractures, joints, and bedding planes, forming an ore stockworks. Most of the ore occurs in a single bed 4-5 ft (1.2-1.5 m) thick, but it locally extends downward along crossbreaking faults, particularly the fault exposed in the shaft, which localizes a tabular ore body 1-3 ft (0.3-0.9 m) wide containing a mixture of manganese oxides and breccia that may average 35 percent manganese. Pyrolusite is apparently the most abundant manganese mineral according to Crittenden (1951, p. 51); however, psilomelane is also present, and both minerals are intimately intermixed with pulverulent jasperoid, which ranges in particulate size from 38 to -500 mesh.

The grade of the ore that was shipped indicates that much of it was hand sorted, inasmuch as a bulk sample taken by the U.S. Bureau of Mines for mill testing contained only 19.4 percent manganese and in addition 4.5 percent iron, 40.4 percent $SiO_2$, 0.034 percent phosphorus, 7.1 percent $Al_2O_3$, a trace of zinc, and 2.8 percent CaO (Ipsen and others, 1949, p. 13). In general, the Oxen ores did prove to be amenable to concentration because of the intimate association of the pyrolusite and psilomelane with exceptionally fine grained silica (Ipsen and others, 1949, p. 13-15).

Three inclined diamond-drill holes drilled by the Chief Consolidated Mining Co. in 1947-48 to points beneath the manganese occurrences on the Oxen claim all cut relatively unaltered dolomite and limestone.

## PINYON QUEEN MINE

The Pinyon Queen mine is in the central part of Pinyon Creek Canyon, 2.3 mi (3.7 km) north-northeast of Dividend. The property consists of 17 patented claims aggregating 322.34 acres (131 hectares). The original Pinyon Queen Mining Co. was organized in 1918 or 1919 by T. F. Pierpont, J. William Knight, J. C. Deal, and William Scowcroft, with Andrew Sutherland as superintendent. By 1920 E. J. Raddatz had acquired voting control of the stock and was vigorously pressing the exploration and development of the mine. In 1972 the majority stock interest was held by the E. J. Raddatz Estate, and the property was under lease to the Kennecott Copper Corp.

The Pinyon Queen shaft is in the S½SE¼ sec. 34, T. 9 S., R. 2 W., in the southern part of the claims and was completed to a depth of 855 ft (261 m) in December 1920. A station was cut at a depth of 775 ft (236 m), and approximately 900 ft (274 m) of mine workings has driven east and northeast of the shaft (fig. 59). Active mine development was apparently terminated in 1921.

The shaft is collared in the upper vitrophyre member of the Packard Quartz Latite. It remains entirely in volcanic rocks to a point near the base, where it reportedly entered the Apex Conglomerate and met with a heavy flow of water. Examination of the dump indicates that the volcanic rocks are moderately to strongly pyritized throughout the total depth of the shaft, and company records indicate that the Apex Conglomerate is also pyritized and partly silicified. The central and northern part of the claims are underlain chiefly by tuffs and lavas of the Laguna Springs Volcanic Group and by alluvium. The conspicuous tuff and agglomerate member of the Pinyon Queen Latite crops out a short distance north of the shaft.

According to J. M. Snow, geologist for the Tintic Standard Mining Co. at the time the shaft was sunk, the northeast-trending mine workings at the 800-ft level were all in brown or green fine-grained igneous rock similar to that cut in the shaft; some of it also was reported to resemble sandstone. Presumably this rock is tuff or devitrified vitrophyre; the general strike is reported to be northwesterly and the dip northeasterly.

Other than the Apex Conglomerate, no sedimentary rocks were cut by the shaft or by the workings at the 800-ft level. However, a diamond-drill hole, which was drilled from the surface in 1970 at a point that is 450 ft (137 m) due west of the shaft, penetrated dolomite at an elevation of 4,780 ft, which is only 65 ft (20 m) below the bottom of the shaft. This and other deep holes have been drilled nearby in recent years by Kennecott Copper Corp. in a continuing program of exploration.

No ores were found in the Pinyon Queen shaft or mine workings, although the silicified Apex Conglomerate reportedly returned assays in silver. The surface drill holes similarly have not cut mineralized rock.

## PROVO SHAFT

The Provo shaft is a little less than half a mile (0.8 km) west-southwest of Dividend in the E½NW¼SE¼ sec. 16, T. 10 S., R. 2 W. It is situated on claims that are now part of the Tintic Standard Mining Co. The original Provo Mining Co. was organized in February 1887 and reorganized in 1907 under the direction of J. C. Leetham, J. W. Farrer, D. W. Conover, Delbert Roberts, and others. The original property was small, consisting of three patented mining claims aggregating about 13 acres (5.3 hectares). The shaft was sunk in 1909 by the Eureka Leasing Co., under the direction of Roberts and Leetham, to prospect for the northerly continuation of the shallow lead, silver, and zinc ore bodies then being developed along the Provo fissure in the East Tintic Development (Eureka Lilly) mine about 250 ft (76 m) to the south-southeast. According to contemporary newspaper accounts, and a few maps that have been preserved by adjacent mining companies, the shaft is 285 ft (87 m) deep and has a total of about 700 ft (213 m) of lateral workings at the 300-ft level. These workings were limited by property boundaries to an area that is northeast of the shaft. Ownership of the

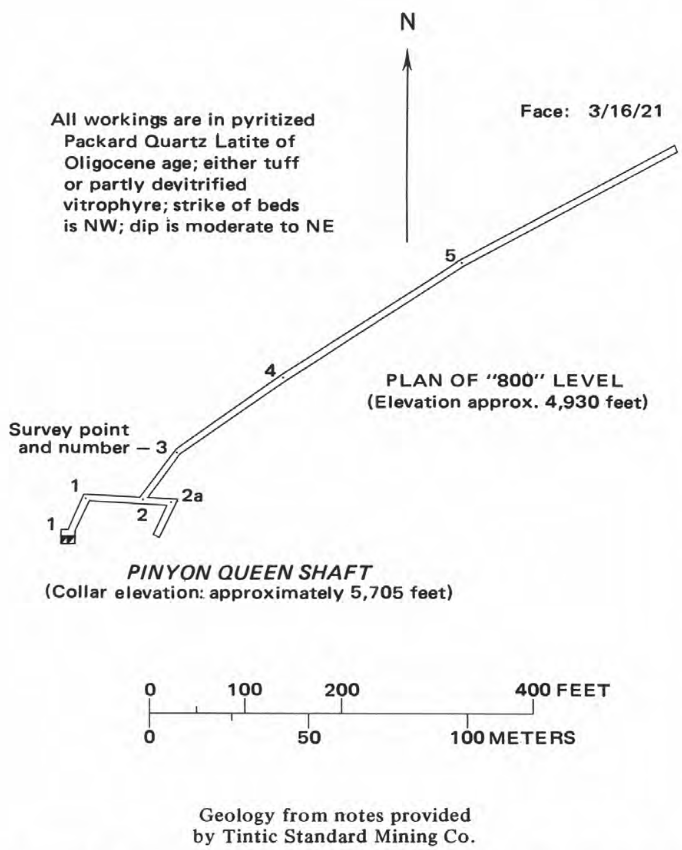



FIGURE 59.—Plan of workings at 800 level of Pinyon Queen shaft.

Provo claims passed to the Tintic Standard Mining Co. in 1919.

The Provo shaft is collared in the lower part of the Herkimer Limestone in the footwall of the Eureka Lilly fault, whose surface trace underlies shallow alluvium about 150 ft (46 m) to the west (pl. 1). Presumably the shaft passes through the Dagmar Dolomite and bottoms in the upper part of the Teutonic Limestone. It also may be inferred that all of the workings at the 300-ft level are in the Teutonic. Lead carbonate ore was first found in the mine in November 1909. The initial shipment of ore was made in March 1910 from a shallow winze sunk from the 300-ft level. Apparently two or three carloads of ore were shipped, presumably from ore bodies along the Provo fissure.

## RGW (R. G. WILSON) ADIT

The RGW, or R. G. Wilson, adit is driven into the north wall of Homansville Canyon, in the S½S½SW¼ sec. 4, T. 10 S., R. 2 W., half a mile east (0.8 km) of the old site of Homansville. Little is on record as to the early history of the workings prior to the purchase of the property, consisting of five patented claims, by the Chief Consolidated Mining Co. in May 1917. Apparently little work has been done in the adit since that time; however, the east drift at the 562-ft level of the Homansville shaft explored the area at depth directly below the adit entrance, probably in 1917 or 1918 (see fig. 53).

The workings of the RGW adit extend northwesterly under the southwest quarter of Lime Peak and aggregate 2,970 ft (905 m) of drifts and crosscuts (fig. 60). There are no raises or winzes more than a few feet long, and no ores have been shipped from the property.

The dominant geologic feature in the vicinity of the RGW adit is the Homansville fault, movement on which emplaced the Fitchville and Gardison Formations against the Cole Canyon Dolomite. The fault zone is as much as 50 ft (15 m) wide at the surface but is not particularly conspicuous because of thorough dolomitization and recrystallization of the fault breccias.

The initial objective of the adit appears to have been a small mass of iron-stained jasperoid localized at the intersection of an east-trending fissure and a north-northeast-trending pebble dike in the hanging wall of the Homansville fault. The adit enters the Cole Canyon Dolomite about 100 ft (30 m) in elevation below the jasperoid body, but 85 ft (26 m) from the portal it cuts the Homansville fault zone and extends through healed fault breccia for about 60 ft (18 m). A pebble dike is exposed about 235 ft (72 m) from the portal, but no significant amount of iron-stained jasperoid like that exposed at the surface was found. The remainder of the workings are probably in the gray sugary-grained dolomite unit of the upper part of the Fitchville Formation, inasmuch as neither the black cherty dolomite unit nor the pink sublithographic limestone unit, which respectively lie below and above the sugary-grained unit, have been recognized in the workings. The beds are undulatory but generally horizontal in the central part of the workings and dip gently northeast in the northern part. North of the healed breccias of the Homansville fault zone, the only significant fractures are northerly trending faults in the northwestern part of the workings that probably represent the east edge of the Selma fault zone. None of the workings, however, appear to cut the main fracture of the Selma fault zone and enter the lavas of the downfaulted block.

The only minerals of possible economic significance were found in the extreme northeastern part of the workings where an irregular small body of manganese- and iron-stained clay and small pods of brown scalenohedral calcite are associated with an east-trending vuggy fissure. Assays of this material by the Chief Consolidated Mining Co. indicated only traces of gold, silver, and base metals.

## ROUNDY (LARSEN) SHAFT

The Roundy shaft is in the southwestern part of the East Tintic district about 2 mi. (3.2 km) southwest of

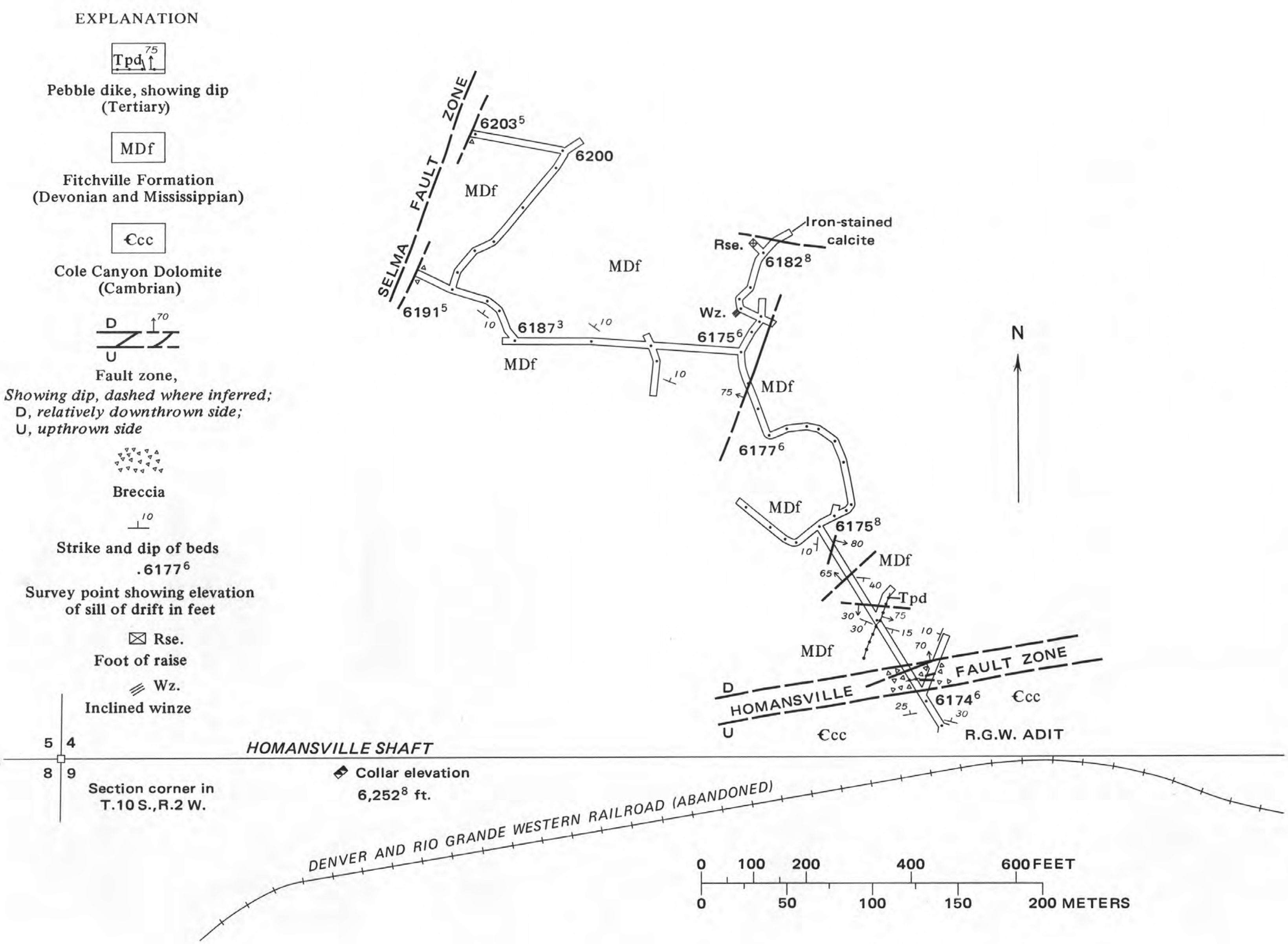



FIGURE 60. — Geologic plan of RGW adit.

Dividend in the NE¼NW¼NE¼ sec. 29, T. 10 S., R. 2 W. It is collared in the south-central part of the property of the Crown Point Consolidated Mining Co. and the lateral workings extend into the property of the East Crown Point Consolidated Mining Co., both companies which are under long-term lease to the U.S. Energy Corp. (formerly Western States Mining Co.) of Riverton, Wyo.

The decision to undertake the underground exploration on the Crown Point and East Crown Point properties that led to sinking the Roundy shaft was based on studies by Glen E. Larsen of the U.S. Energy Corp., who for many years had explored, developed, and operated parts of the adjacent Iron Blossom mine as an independent lessee. Larsen became intrigued with the exploration possibilities presented by the Sioux-Ajax fault in the area east of the Iron Blossom claims where the fault is concealed by an unknown thickness of argillized and pyritized lavas and possibly cut by north-northwest-trending fissures. During the early 1960's, he secured preliminary lease agreements with the officers of the Crown Point Consolidated and East Crown Point Consolidated Mining Companies and sank two drill holes. The Larsen No. 1 hole was drilled at a point 300 ft (91 m) N. 55° E. of the present site of the Roundy shaft and was completed in July 1964 to a total depth of 1,100 ft (335 m). It was collared in altered volcanic rocks, cut the rubble zone at the base of the volcanic sequence between 890 and 896 ft (271 and 273 m) below the collar, and then entered either the Victoria Formation or the Bluebell Dolomite, probably remaining in the Bluebell to its total depth. The carbonate rocks cut by the hole were highly fractured, moderately recrystallized, and iron stained. A narrow monzonite porphyry dike also was cut between 1,062 and 1,064 ft (323.7 and 324.3 m), and a small crystal of galena rimmed with cerussite was noted at a depth of 1,016 ft (309.7 m)

The Larsen No. 2 hole was drilled 1,060 ft (323 m) S. 78° W. of the present site of the shaft. This hole attained a total depth of 1,178 ft (359 m) and bottomed in the zone of tuff and prelava rubble at the base of the volcanic sequence. No prelava sedimentary rocks were penetrated.

The Roundy shaft, which was named for Clayton Roundy, President of the Crown Point Consolidated Mining Co., was sunk between July 1969 and January 1971 with partial financial assistance of the U.S Office of Minerals Exploration (OME). Intermittently thereafter, underground work has been directed toward the discovery of northeasterly trending fissures in the carbonate rocks below the lavas and to the exploration of a segment of the Sioux-Ajax fault in the areas where it may be cut by these fissures.

### DEVELOPMENT

As stated earlier, the Roundy shaft is 1,300 ft (396 m) deep, and one level was established at an approximate depth of 1,280 ft (390 m). As of January 31, 1972, when the OME contract was terminated, the total length of lateral workings was approximately 1,670 ft (509 m). In addition, 4,264 ft (1,300 m) of diamond-drill holes had been drilled from the shaft station, the west crosscut, and from the south drift. The mine was dormant from February 1972 to February 1973 when it was reopened by Larsen to explore the area north and northeast of the shaft at the 1,280-ft level. The principal target of the new exploration effort was the area of the galena-bearing fissures cut many years ago in the southern workings of the Crown Point No. 3 mine. This new work will require drifting about 1,100 ft (335 m), some crosscutting, and some drilling.

### GEOLOGY

The Roundy shaft is collared in the Latite Ridge Latite, which contains many patchy areas of pyritic alteration that are chiefly associated with east-northeasterly fractures and joints. The shaft cuts the base of the Latite Ridge at a depth of 440 ft (134 m) and then enters pyritized Packard Quartz Latite. At a depth of about 860 ft (262 m), it crosses into a zone of airfall tuff and prelava rubble (Apex Conglomerate) marking the base of the Packard, and at a depth of 1,066 ft (325 m), it enters the upper part of the Bluebell Dolomite. It remains in moderately brecciated Bluebell to 1,086 ft (331 m) and then penetrates a highly altered sill or dike of monzonite porphyry that is about 100 ft (30 m) thick. At 1,186 ft (362 m) it reenters the Bluebell Dolomite and remains in that formation to the shaft's total depth of 1,300 ft (396 m).

As shown in figure 61, the strata at the 1,280-ft level generally strike north-northeasterly and dip westerly at 15°-30°. Twenty ft (6 m) west of the shaft station a narrow north-northeasterly trending pebble dike was cut and followed to the south-southwest for 145 ft (44 m). In the west crosscut, which extends west-southwesterly from the southernmost exposure of the first pebble dike, four other south-trending pebble dikes, or pebble dike zones, were discovered. One of these pebble dike zones was followed intermittently for several hundred feet in the south drift, and it also has been a target for one or more underground diamond-drill holes directed below the level.

At a point 910 ft (277 m) S. 35° W. of the shaft, the south drift apparently cuts the main fracture plane of the Sioux-Ajax fault, crossing into a broken and altered dolomite unit that may be either the Ajax Dolomite or the dolomitized Opohonga Limestone.

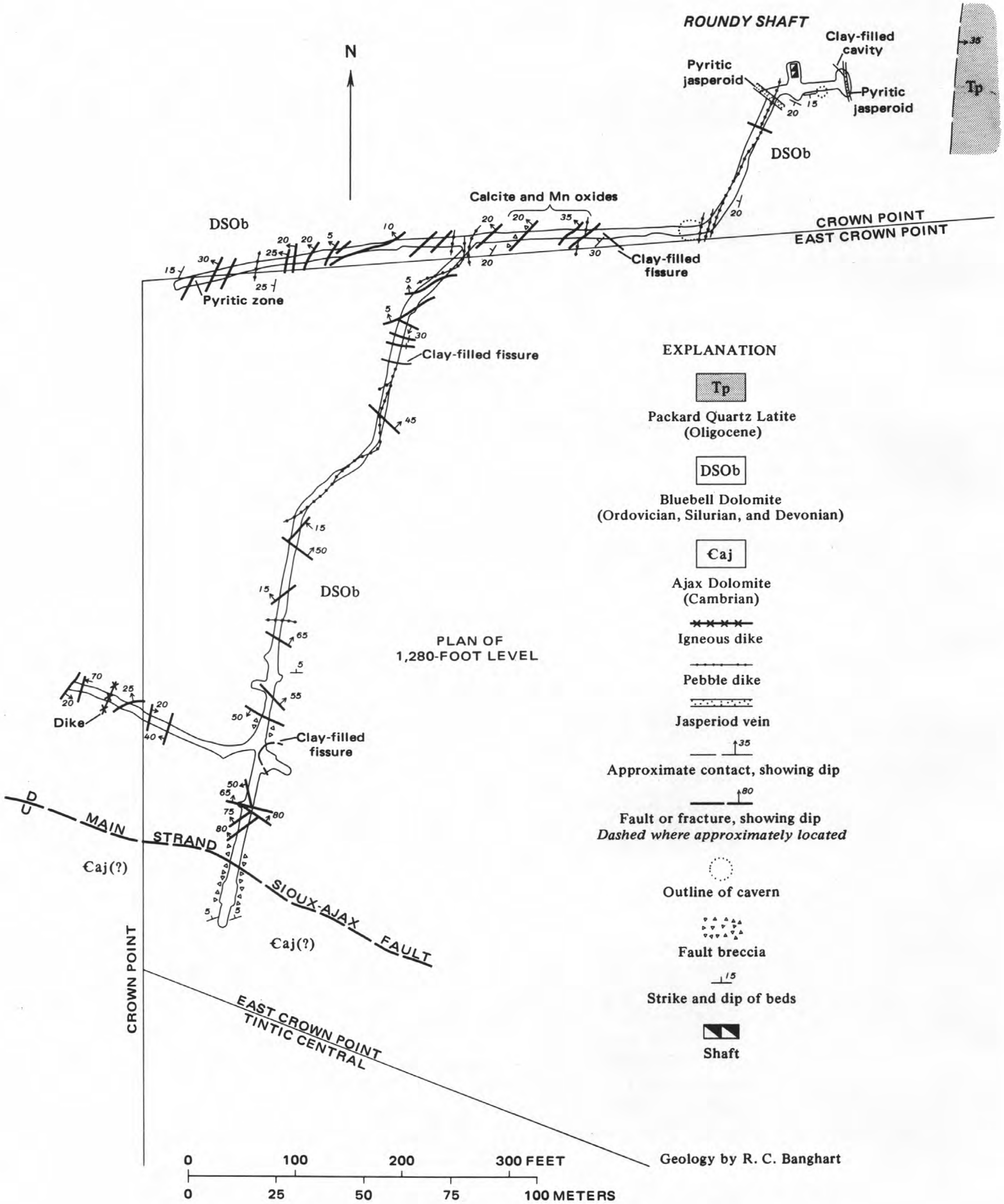



FIGURE 61. — Geologic plan of 1,280-ft level of Roundy shaft.

Little of this unit was exposed. The Bluebell Dolomite of the hanging wall is highly brecciated and sheared for a distance of 140 ft (43 m) north of the fault plane. This exposure of the Sioux-Ajax fault indicates a general strike of S. 75°-80° E. from its position in the Iron Blossom No. 3 mine in the main Tintic district, where the fault appears to strike almost due east.

In the exposures at the 1,280-ft level of the Roundy mine, the Bluebell Dolomite contains many zones of breccia, some of which are cemented by brown sparry calcite. Other parts of the Bluebell within 100-200 ft (30-61 m) north of the Sioux-Ajax fault are cut by scattered seams and narrow veins of clay and iron oxide, some of which contain trace concentrations and even assayable quantities of silver, lead, zinc, and copper. Unfortunately, however, no ore bodies have been discovered to date as a result of the extensive exploration efforts.

## SOUTH STANDARD MINING CO.

The South Standard Mining Co. owns an extensive tract of patented mining claims in the south-central part of the East Tintic district extending from the vicinity of the Trixie shaft 1½ mi (2.4 km) south-southwest of Dividend to the central part of Ruby Hollow, which is in the main Tintic district south of the south boundary of plate 1. The company was organized on November 1, 1916, and a year later it absorbed the United Tintic Mining Co., establishing a single property containing more than 1,200 acres (486 hectares). A later sale of several claims to the Tintic Drain Tunnel Co. reduced the holdings to 65 full and partial claims containing about 1,020 acres (413 hectares).

In addition to many shallow openings, the property is developed by three or more shafts and several adits. The most extensive underground workings are from the Trixie shaft, which is described separately in the section "Trixie Mine." The South Standard shaft is in the SW¼NE½ sec. 28, T. 10 S., R. 2 W.; it is 102 ft (31 m) deep and has about 325 ft (99 m) of workings at the 100-ft level, chiefly west-southwest of the shaft. The Nevada Tunnel shaft is in the SE¼SE¼ sec. 29, T. 10 S., R. 2 W.; its depth and the extent of the lateral workings, if any, are unknown. The United Tintic shaft is in S½SW¼ sec. 32, T. 10 S., R. 3 W., south of plate 1, and is considered to be in the main Tintic district. A short adit on the Horse Shoe claim about 1,550 ft (472 m) west-northwest of the South Standard shaft explores an area of pyritic jasperoid that crops out on the ridge 400-500 ft (122-152 m) east-southeast of its portal.

A small to moderate amount of ore was mined from the United Tintic workings during the early development of the main Tintic district. These workings also yielded 41.395 short tons (38 tonnes) of ore in 1935, but so far as is known, no ore has been produced from the part of the claims that is in the East Tintic district.

With the exception of some small exposures of lower Middle Cambrian limestone and shale in the northernmost part of the claims, all of the South Standard property is underlain by igneous rocks. These rocks are predominantly lavas of the Tintic Mountain Volcanic Group but also include part of the Silver City monzonite stock in the area of the claims that extends in the main Tintic district. Of prime importance from a prospecting standpoint is the Trixie-Treasure Hill fissure and dike zone, with its associated halo of strong argillic and pyritic alteration, which extends longitudinally through the central and western part of the claims.

The workings of the 100-ft level of the South Standard shaft all cut relatively unaltered tuffs and breccias of the lower member of the Latite Ridge Latite (fig. 62). Presumably these workings were directed toward the outcrops of massive jasperoid about 1,000 ft (305 m) west-southwest of the shaft. According to company records, about 15-20 gallons (57-76 l) of water per minute came into the workings at the 100-ft level as it was driven outward from the shaft, prompting a termination of drifting and a lease of the water rights to the Tintic Standard Mining Co. for a consideration of $40,000.

## TINTIC CENTRAL MINING CO.

The claims of the Tintic Central Mining Co. are partly in the southwestern corner of the East Tintic district and partly in the main Tintic district. The shaft is located in the NW¼NE¼SW¼ sec. 29, T. 10 S., R. 2 W., about half a mile (0.8 km) southwest of the Roundy (Larsen) shaft. The Tintic Central Mining Co. was originally organized in June 1907 by George M. Smoot, R. L. Anderberg, A. N. Haldaway, and others after the discovery and development of the adjacent Iron Blossom ore zone. Much exploration was carried out from the shaft from 1910 to 1918. During 1917-18 the Iron Blossom Mining Co. drove an east-trending crosscut at the 1,700-ft level through the central part of the Tintic Central claims. In February 1917, it was reported in newspaper accounts that several quartz-bearing fissures had been cut by these workings at a point about 200 ft east of the Tintic Central shaft. In 1920 an important stock interest in the Tintic Central Mining Co. was acquired by the Knight Investment Co. This interest passed to the North Lily-Knight Co. in July 1929, and thence to the North Lily Mining Co. in July 1941. Other major stockholders include the heirs of Jesse Knight.

### PROPERTY AND DEVELOPMENT

The Tintic Central property consists of 274 acres (111 hectares) of patented mining claims. These claims

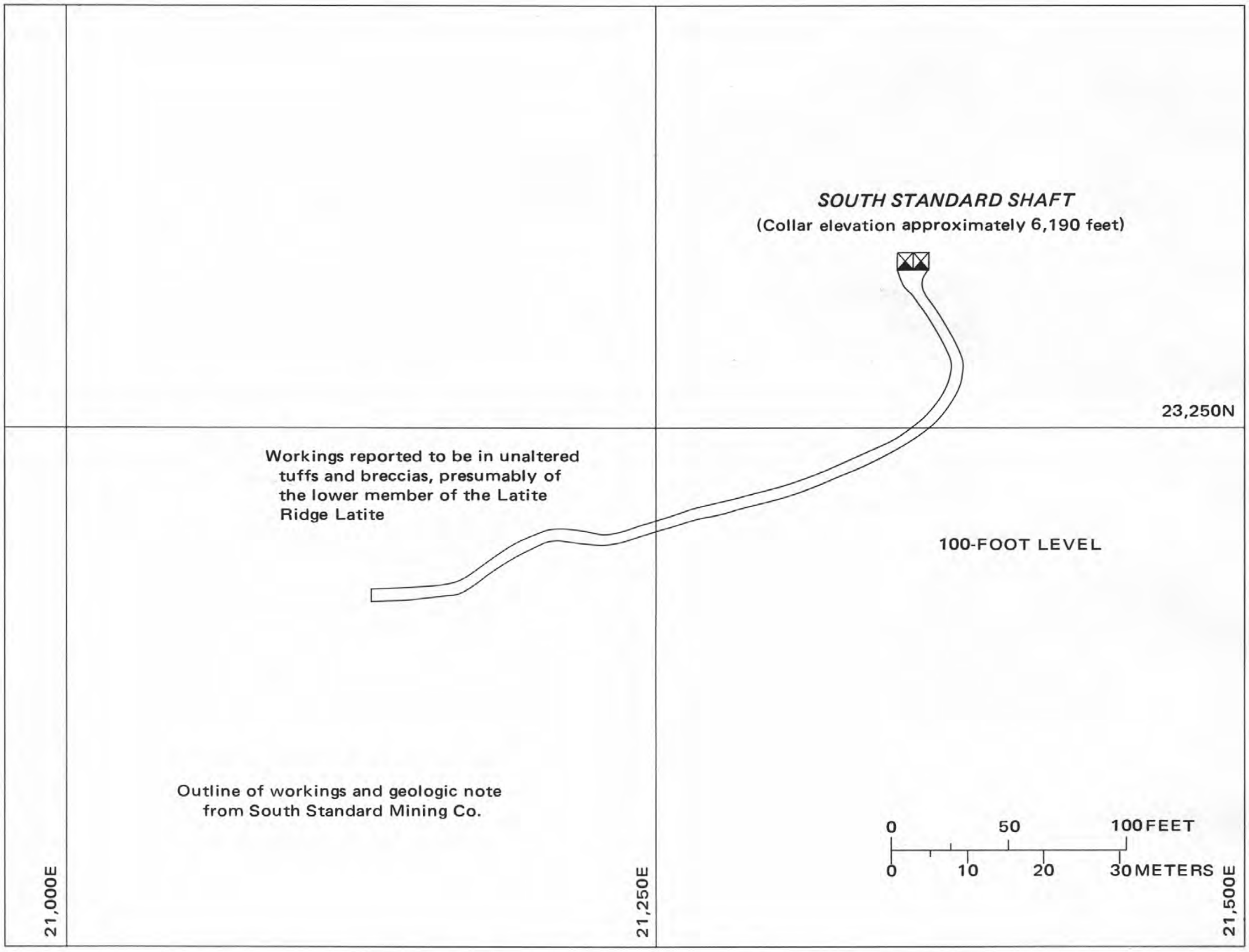



FIGURE 62. — Plan of workings at 100-ft level of South Standard shaft.

are bordered by the South Standard, South Iron Blossom, Iron Blossom, Crown Point, East Crown Point, and other properties. The shaft, which is 2,900 ft (1,189 m) S. 42° W. of the Roundy shaft, is 1,075 ft (328 m) deep, and levels were driven at depths of 870, 920, and 1,020 ft (265, 280, and 311 m) below the collar. The 1,700-ft level of the Iron Blossom No. 1 mine of the main Tintic district penetrates the property at approximately 1,500 ft (457 m) below the collar, but it is below the bottom of the shaft. The total footage of workings at the Iron Blossom 1,700-ft level on the Tintic Central property is reported to exceed 1,800 ft (549 m). The workings connected with the shaft in the upper part of the mine are reported in contemporary newspaper accounts to include "many thousands" of feet of drifts.

## GEOLOGY

At the surface, the east half or more of the Tintic Central claims are underlain largely by argillized, pyritized, silicified, and epidotized tuff of the Latite Ridge Latite. Locally some small masses of Opohonga Limestone extend through the lavas in this area. The west half or less of the claims are underlain by part of the Silver City monzonite stock, many apophyses, plugs, and dikes of which cut the tuffs. The shaft is collared in monzonite but at a depth of 690 ft (210 m) passes into bleached carbonate rocks. Even the deepest mine workings are in sedimentary rocks, indicating that the northeastern part of the stock dips southward at a relatively low angle and may have the general form of the sill. This outward flaring margin of the stock was originally noted in the Iron Blossom No. 1 mine (Lindgren and Loughlin, 1919, p. 241-242).

As indicated by the geology of the Iron Blossom No. 1 shaft and by incomplete maps of the Tintic Central mine, the rocks cut by the workings from the Tintic Central shaft are probably all in the Opohonga Limestone. The crosscut from the Iron Blossom No. 1 shaft, however, may well cross into Ajax Dolomite at some point east of the area of the Tintic Central shaft. Regional reconstructions of the geology indicate that the shaft penetrates the axial area of the Tintic syncline, and thus the strata dip west and north at low angles in the western and central parts of the claims. In the eastern part of the claims, the dips are probably moderate to the west. There is no record of large faults having been out by any of the mine workings.

Incomplete records indicate that the carbonate rocks throughout the mine are bleached and discolored owing to the proximity of the Silver City stock. However, no large masses of contact-pyrometasomatic silicate minerals have been described.

During 1912, work on the 920-ft level 990 ft (302 m) northeast of the shaft reportedly cut ore containing 1.1 percent copper and 5.5 oz per ton (188.6 g per tonne) silver. A raise was driven on this showing. In 1914, on the 870-ft level in an unspecified part of the mine, a tabular body of silicified limestone containing values in lead and silver was discovered. Presumably the production of 28 tons (25.4 tonnes) of ore credited by Cook (1957, pl. 3) to the Tintic Central mine came from either or both of these ore occurrences. The average grade of this ore was 0.1 oz per ton (3.43 g per tonne) gold, 9.2 oz per ton (315.5 g per tonne) silver, 0.3 percent copper, and 1.3 percent lead. The mine has been inactive since 1925.

## TINTIC STANDARD MINE

The Tintic Standard mine, which achieved worldwide prominence from the great volume of rich silver ores it produced from 1918 to 1949, is located in the central part of the East Tintic district adjacent to Dividend. The Tintic Standard Mining Co. was originally organized in October 1907 by Emil J. Raddatz, Ira D. Travis, and others and for 65 years operated as an independent mining company. In May 1973 it was merged into the Amax Copper Mines Incorporated, a division of American Metals Climax Incorporated, on the basis of an exchange of 9.2021 shares of Tintic Standard stock for each share of Amax series A convertible preferred stock. It was not announced whether the Tintic Standard would be operated as a separate division of Amax Copper Mines or would be discontinued as an operating entity. The disposition of the other East Tintic mining properties controlled by Tintic Standard similarly was not announced.

The initial interest in the area of the Tintic Standard mine was taken by John and August Bestlemeyre, who had staked and patented a number of claims in the East Tintic district after the discoveries of the Humbug ore bodies 2 mi (3.2 km) to the west. During the late summer of 1907, Bestlemeyre offered two of these claims, the Union B and Carbonate Queen, for sale to Raddatz, who was impressed that they included ground that was hydrothermally altered in a manner similar to that of the Honorine mine in the Stockton mining district, Utah, of which he was manager. Consequently, he bonded the Bestlemeyre claims for $60,000 and also located the adjacent Copper Queen group of four claims, on which the main ore body was discovered about 9 years later. Other adjacent and nearby parcels of land were acquired by purchase and location during the early stages of mining activity.

The initial development of the claims was by an inclined shaft located 850 ft (259 m) east-southeast of the contemporary East Tintic Development (Eureka Lilly) mine. This inclined shaft was sunk to a depth of 400 ft (123 m) in an unsuccessful effort to find commercial ore beneath a conspicuous outcrop of iron-stained baritic jasperoid containing scattered minute grains of argentiferous cerussite. Undaunted by this failure, Raddatz, in 1909, began sinking the vertical Tintic Standard No. 1 shaft, which was completed to a depth of 1,000 ft (305 m) in 1910 and connected at the 200-and 400-ft levels with the adjacent inclined shaft.

As the No. 1 shaft was being sunk, small streaks of low-grade ore were found on the 700-ft level in kaolinized shale immediately overlying the Tintic Quartzite, and much effort was then directed to the exploration of this contact, especially on the 1,000-ft level 700 ft (213 m) northeast of the shaft. The deeper work produced 42 tons (38 tonnes) of ore that netted a little more than $40 per ton. The ore was followed downward in an inclined winze to the 1,100-ft level, and further sinking revealed a separate shoot below it at the 1,200-ft level, which also yielded small ore shipments. A drift was directed northeastward along the mineralized contact of quartzite and shale at the 1,200-ft level of the winze for about 150 ft (46 m), and a second inclined winze was started. This second winze followed small shoots of siliceous copper-silver-gold ore to the 1,550-ft level, where the shale-quartzite contact steepened, and then entered a replacement body of siliceous lead-silver ore. A further extension of the winze to the 1,600-ft level disclosed a rich and extensive lead-silver ore body underlying the siliceous ore body, and in September 1916 regular ore shipments were begun. The excitement and importance of this discovery, however, were soon transferred when the main, or Central, ore body was discovered during the sinking of the No. 2 shaft.

When the workings of the No. 1 shaft entered the Tintic Quartzite below the 700-ft level, wallrock temperatures became very high and rapidly increased with depth; also, large volumes of gas commonly prevented occupation of the mine for hours or even days. To assist in alleviating the ventilation problems and to facilitate the handling of ore from the 1,600-ft level, the vertical No. 2 shaft was collared at a point

1,700 ft (518 m) northeast of the No. 1 shaft, and sinking began in December 1916. In July 1917 this shaft unexpectedly entered the main, or Central, Tintic Standard ore body at a depth of 1,174 ft (358 m) and was temporarily bottomed in high-grade ore in August 1917.

It was immediately apparent that the newly discovered ore body rivaled in size and grade the largest and richest ore bodies of any of the mines in the main Tintic district. During the following 13 months, workings were driven to evaluate the discovery, and a ventilation drift was driven to connect with the stopes at the 1,600-ft level of the No. 1 shaft. In September 1918, sinking of the No. 2 shaft was resumed, and ore of shipping and milling grade continued to be penetrated by the shaft to a point below the 1,350-ft level. The shaft was completed to a depth of 1,441 ft (439 m) in December 1918, and a second connection was made a year later with the 1,300-ft level of the No. 1 shaft, which considerably improved the ventilation in the mine. After completion of the 1,450-ft level station of the No. 2 shaft in 1920, an inclined winze was also sunk 159 ft (48 m) below this level, giving the mine a total depth at that time of 1,600 ft (488 m). Within a few years after discovery of the Central ore body in the No. 2 shaft, the Tintic Standard mine became one of the richest silver mines in the world, with an annual production that reached more than 4,200,000 oz (130,620 kg) of silver in 1924.

Late, in May 1926, the Tintic Standard No. 3 inclined shaft was raised from the 600-ft level to the surface at a point 750 ft (229 m) east of the No. 2 shaft. It was used largely for ventilation purposes.

In October 1920, work began on the wholly owned Standard Reduction Co. mill at Warm Creek, 11 mi (17.7 km) east of the mine. This mill utilized a modified Holt-Dern process, which consisted of a chloridizing roast followed by an acid-brine leach, and it operated successfully from January 1921 to November 1925, when preferential contracts with established mills and smelters in north-central Utah made continued operation of the Warm Creek mill unprofitable.

During 1940 the No. 2 shaft was deepened to the 1,570-ft level and through the period of World War II, a considerable amount of copper-gold ore was mined from fissures in the Tintic Quartzite. During this time production also was accelerated from the stopes above the 1,450-ft level that had already produced large volumes of ore in the previous two decades. At this time the first important shipments of zinc ores were made, and some manganese ores were also shipped.

In June 1949, after a period of difficult labor negotiations, the mine was considered to have reached its limits of economic production and was closed. Later, in 1952 and 1953, attempts were made to extract the pillar of ore surrounding the No. 2 shaft, but caving ground and a lower grade of ore than was anticipated forced the termination of the effort after only a moderate quantity of ore was shipped. In 1956 the company properties were leased to the Kennecott Copper Corp., and much exploration was carried out by surface drilling along the lava-concealed trace of the East Tintic thrust fault and by underground exploration of the South fault and its intersection with the thrust below the lava in the general area of the Dividend ballpark. The underground exploration resulted in the production of several thousand tons of development ore in 1970 and is described in the section "Burgin Mine — Ballpark area."

## PROPERTY DEVELOPMENT AND PRODUCTION

The original property of the Tintic Standard Mining Co. consisted of 162 patented claims aggregating more than 2,920 acres (1,183 hectares) and an additional 68 acres (28 hectares) of unpatented fractional claims and other parcels. These claims chiefly lie in the north-central and northeastern parts of the East Tintic district and include much ground that has not been fully prospected. At the time of its merger into Amax Copper Mines, Inc., the company owned the Iron Blossom Mining Co. and controlling stock interest of the Colorado Consolidated Mining Co. and the Sioux Mines Co., all in the main Tintic district; it also owned controlling interest in the Eureka Lilly Consolidated and Eureka Standard Consolidated Mining Companies, of the East Tintic district, and held important stock interests in the Empire, Dragon, and other mines in the general Tintic area. On November 2, 1974, the Eureka Lilly Consolidated was merged into the Eureka Standard Consolidated Mining Co.

The Tintic Standard mine was developed by two vertical and two inclined shafts. During the principal productive phase of mining activity that extended from 1918 to 1949, the main operating facility was the No. 2 shaft, which is in the SW¼SW¼NW¼ sec. 5, T. 10 S., R. 2 W. This three-compartment shaft is 1,557 ft (475 m) deep. Levels were established at approximately 700, 800, 900, 1,100, 1,250, 1,350, 1,450, and 1,570 ft (213, 244, 274, 335, 381, 411, 442, and 479 m) below the collar. In addition, a 600-ft level was connected by a vertical raise as well as by the No. 3 inclined shaft; the 1,570-ft level and other sublevels are also reached by the inclined winze from the 1,450-ft level. Because of badly caving ground in the vicinity of the backfilled stopes, the No. 2 shaft was abandoned in 1948.

The Tintic Standard No. 1 shaft, which is in the S¼NE¼SE¼ sec. 16, T. 10 S., R. 2 W., is 1,494 ft (455 m) deep, and levels were driven from it at depths of approximately 200, 400, 700, 1,000, and about

1,300 ft (61, 122, 213, 305, and 396 m) below the collar. As stated earlier, the 1,100, 1,200, 1,300, 1,400, 1,500, and 1,600 levels were driven from winzes. During the greater part of the active life of the mine, the No. 1 shaft was used only for ventilation and as an escapeway. In 1948, however, it was rehabilitated as an operations and production shaft and was chiefly used in this capacity when the attempts were made to extract the No. 2 shaft pillar in 1952 and 1953.

The Tintic Standard No. 3 inclined shaft extends at an angle of 70° from the 600-ft level of the mine to the surface in the SE¼SW¼NE¼ sec. 15, T. 10 S., R. 2 W. It was used only for updraft ventilation. The original Tintic Standard inclined shaft was not used after the nearby No. 1 shaft had reached the 700-ft level in 1910; exploration was then concentrated along the shale-quartzite contact at the 700-ft and lower levels.

In all, the Tintic Standard mine is reported by the company to be developed by 5,679 ft (1,731 m) of shafts of all classes, about 30,000 ft (9,144 m) of raises, and more than 230,000 ft (70,104 m) of lateral workings. It is, by far, the most extensively developed mine in the East Tintic district.

The Tintic Standard has the distinction of being not only the first major mine to be developed in the East Tintic district but also to have developed and exploited the richest and most productive deposit as well. According to data assembled by the U.S. Geological Survey and U.S. Bureau of Mines, the total production of the mine from 1913 to 1953 was 2,327,148 tons (2,110,723 tonnes) of ore containing 85,860 oz (2,670.2 kg) gold, 51,788,528 oz (1,610,623 kg) silver, 18,337,708 lb (8,325,319 kg) copper, 545,998,074 lb (247,883,126 kg) lead, and 9,547,748 lb (4,334,678 kg) zinc. The gross value of this ore is estimated to exceed $80 million and the net value — received from smelters — to be close to $50 million. Dividends paid exceed $19 million.

## GEOLOGY

The relatively simple geologic relations exposed at the surface of the Tintic Standard claims, as shown in plate 1, provide scant evidence of the complex geologic environment in which the ore bodies occur at depth. Our present knowledge of this complex subsurface environment was achieved only after extensive mine development and exploration drilling, and it seems certain that future penetrations in parts of this property still covered by lavas will require further modifications of current interpretations and conclusions.

The Tintic Standard No. 1 and No. 2 shafts are located near the east edge of an erosional window in the Packard Quartz Latite that exposes moderately faulted sedimentary rocks of Middle Cambrian age. Eastward from the mine area the volcanic rocks increase irregularly in thickness above the maturely dissected erosion surface over which they were deposited, and drill holes indicate that they are more than 1,500 ft (457 m) thick less than half a mile (0.8 km) northeast of the No. 2 shaft. Although the lavas are cut by pebble dikes and were extensively chloritized, pyritized, and calcitized by hydrothermal solutions, they do not localize any significant ore bodies near the mine, and need not be considered further in a discussion of the subsurface geology.

Within the mine the sedimentary rocks beneath the lavas include all of the formations between the Tintic Quartzite, which forms an effective basement rock in the area, and the Bluebird Dolomite, which is stratigraphically 1,500 ft (457 m) above it. All of these sedimentary strata are moderately to strongly folded, cut by low- and high-angle faults, brecciated, and altered to a greater or lesser degree. In a few areas of the mine, they are cut by dikes of fresh and altered monzonite porphyry and by pebble breccias.

As shown in figures 63 and 64, the Tintic Standard No. 2 shaft penetrates the east-central part of the Tintic Standard pothole and bottoms in the upper part of the Tintic Quartzite, near the plane of the South fault. As described in the section "Tintic Standard Thrust" and illustrated in figure 35, the Tintic Standard pothole originated during the asymmetric development of the East Tintic anticline. During the stages of maximum compression, the rocks north of the South fault were sharply down-buckled into the North Lily trough, and the Ophir and overlying formations were decoupled from the Tintic Quartzite, forming the Tintic Standard thrust fault. As compression intensified, the northeastern limb of the North Lily trough was crumpled against the South fault, producing the Tintic Standard trough — or pothole. Prior to mineralization, this structure was a mass of faulted, sheared, and brecciated limestone and shale of the upper plate of the Tintic Standard thrust bounded below, to the north, and to the east by Tintic Quartzite of the lower plate of the folded and crumpled Tintic Standard thrust and bounded on the south by Tintic Quartzite of the footwall of the South fault.

A second, much less deformed, thrust with moderate displacement is inferred to be in the undeveloped area above the 700-ft level in the western part of the mine on the basis of (1) the occurrence of the Dagmar Dolomite and adjacent formations both at the surface and on the 800- and 900-ft levels and (2) the absence of any large normal faults in the mine area.

Of particular importance in the origin of the Tintic Standard ore body is the Tintic Standard fissure zone, which extends east-northeasterly through the area of the pothole, generally in the plane of figure 63. These

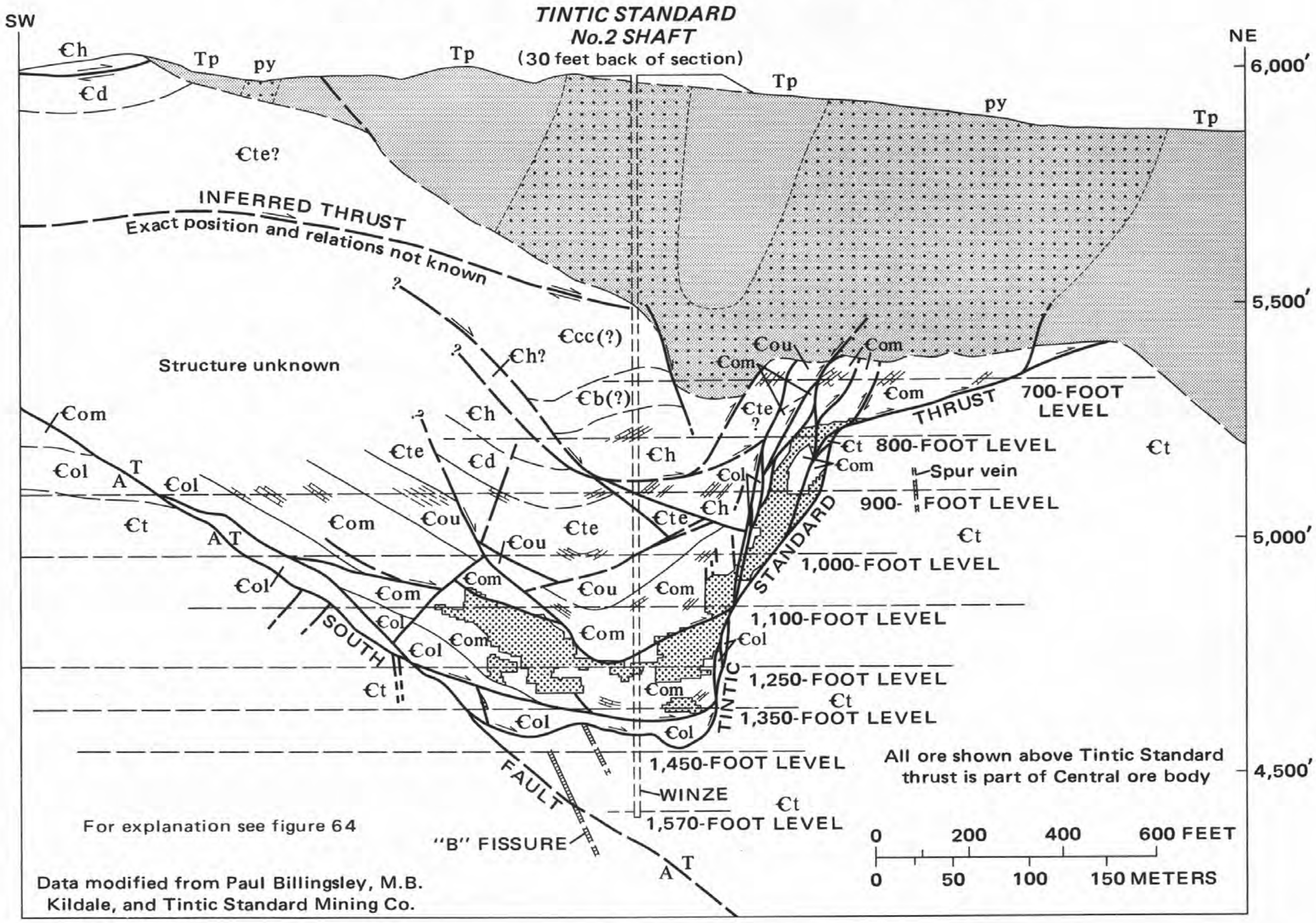



FIGURE 63. — Geologic cross section through the structural pothole and the Central ore body of Tintic Standard mine.

fissures are best known in the Tintic Quartzite below the East Tintic thrust fault where they trend approximately N. 60° E. and dip steeply northwest. Several of these fissures were mined as sources of siliceous gold-copper-silver ore; their chief geological importance, however, was not as host structures for veins but as channelways for the ore solutions that moved upward into the breccias of the pothole and formed the extensive replacement ore bodies.

The youngest faults in the Tintic Standard area are normal faults of small displacement that originated as the ore body was oxidized and collapse and compaction took place. Some of these local structures were reactivated during additional collapse of the ore body as it was being mined. This later movement damaged one or more buildings in Dividend, requiring them to be razed.

## ALTERNATIVE STRUCTURAL INTERPRETATIONS

The complex geologic structure of the Tintic Standard pothole has elicited a variety of structural interpretations. Crane (1925, p. 11-13) and J. M. Snow (in Wade, 1930, p. 3) originally interpreted the pothole structure as resulting from nearly vertical displacement on three normal faults — the northwest-trending North fault, the north-trending East fault, and the northeast-trending South fault. Billingsley (in Billingsley and Crane, 1933, p. 118-124) and Kildale (1957, p. 110-112) also favored normal faulting on the North or Standard-Lily fault, East fault, and the South fault, but both of these investigators also recognized an earlier period of local buckling or sharp downfolding that they interpreted to give rise to both the Tintic Standard and North Lily pothole structures. In addition, Billingsley (in Billingsley and Crane, 1933, figs. 19, 20, 22, and pl. 13) illustrated a breccia-filled pipe or conduit in the core of the Tintic Standard pothole that is now known not to exist.

The absence of a breccia pipe below the pothole and of definable fault zones in the Tintic Quartzite on downward projection from the so-called North and East faults led Lovering (1949, p. 14) and his coworkers to interpret these faults as being parts of the continuous but folded Tintic Standard thrust fault. For a time, the South fault also was thought to be part of this same crumpled thrust zone, but exposures in the

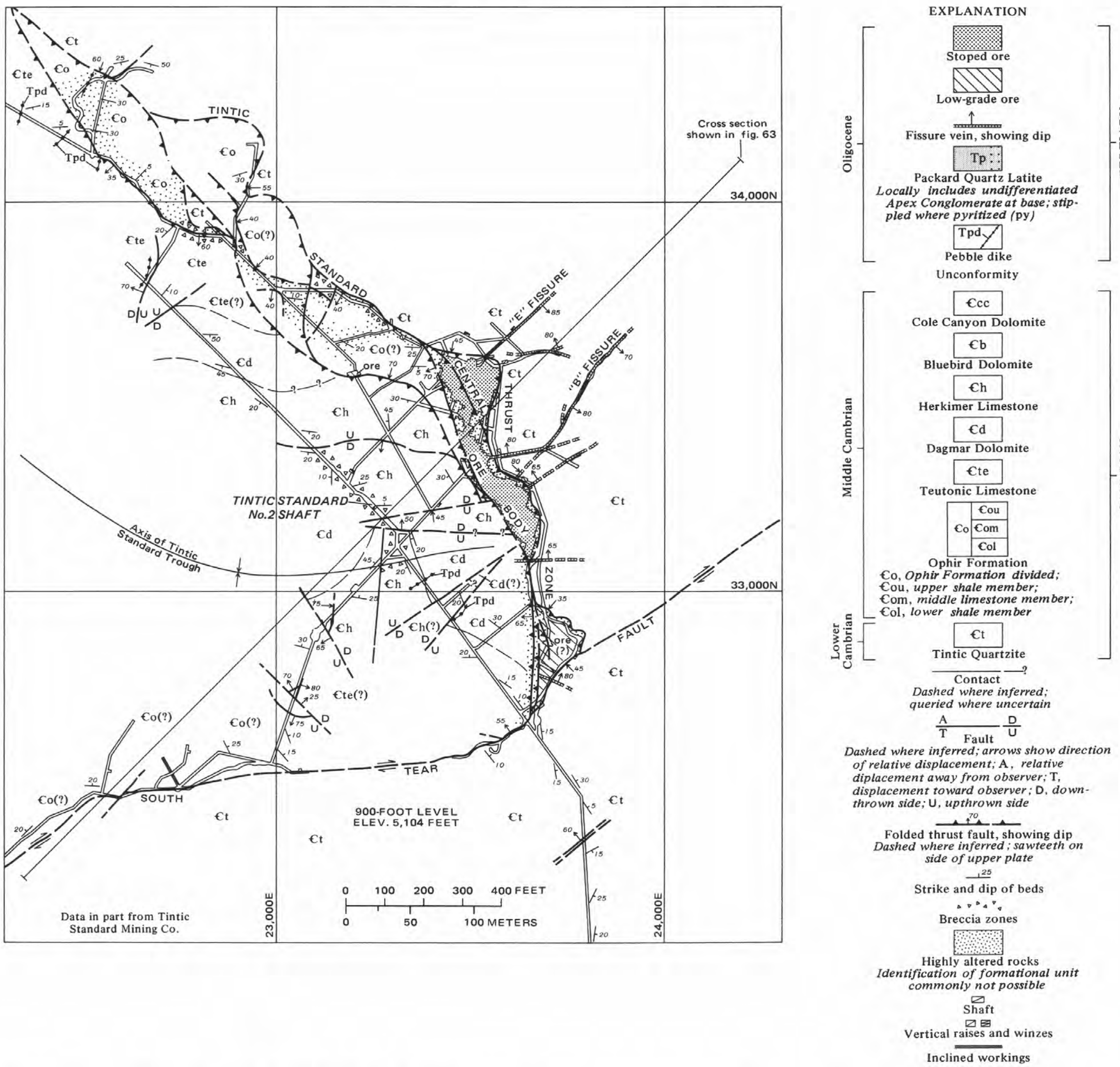



FIGURE 64. — Geologic plan of 900-ft level of Tintic Standard mine showing relation of ore bodies to Tintic Standard thrust and South fault.

Ballpark section of the Burgin mine later showed it to be a throughgoing tear fault (Shepard and others, 1968, p. 949) and indicated that it acted as a buttress against which the southern part of the North Lily trough was crumpled to produce the Tintic Standard trough and pothole.

## ORE BODIES

The ore bodies of the Tintic Standard mine consist of both replacement and fissure deposits. Of these, the replacement deposits have yielded the overwhelmingly predominant amount of ore. As shown in figure 65, which is a block diagram prepared from figure 35, and also in figures 63 and 64, these deposits replace faulted and brecciated carbonate rocks and shale of the upper plate of the Tintic Standard thrust near or adjacent to their fault contacts with the Tintic Quartzite within the Tintic Standard pothole structure. As in the adjacent North Lily and Eureka Lilly mines, the replacement deposits occur above veins and mineralized faults and fissures, through which the ore-depositing solu-

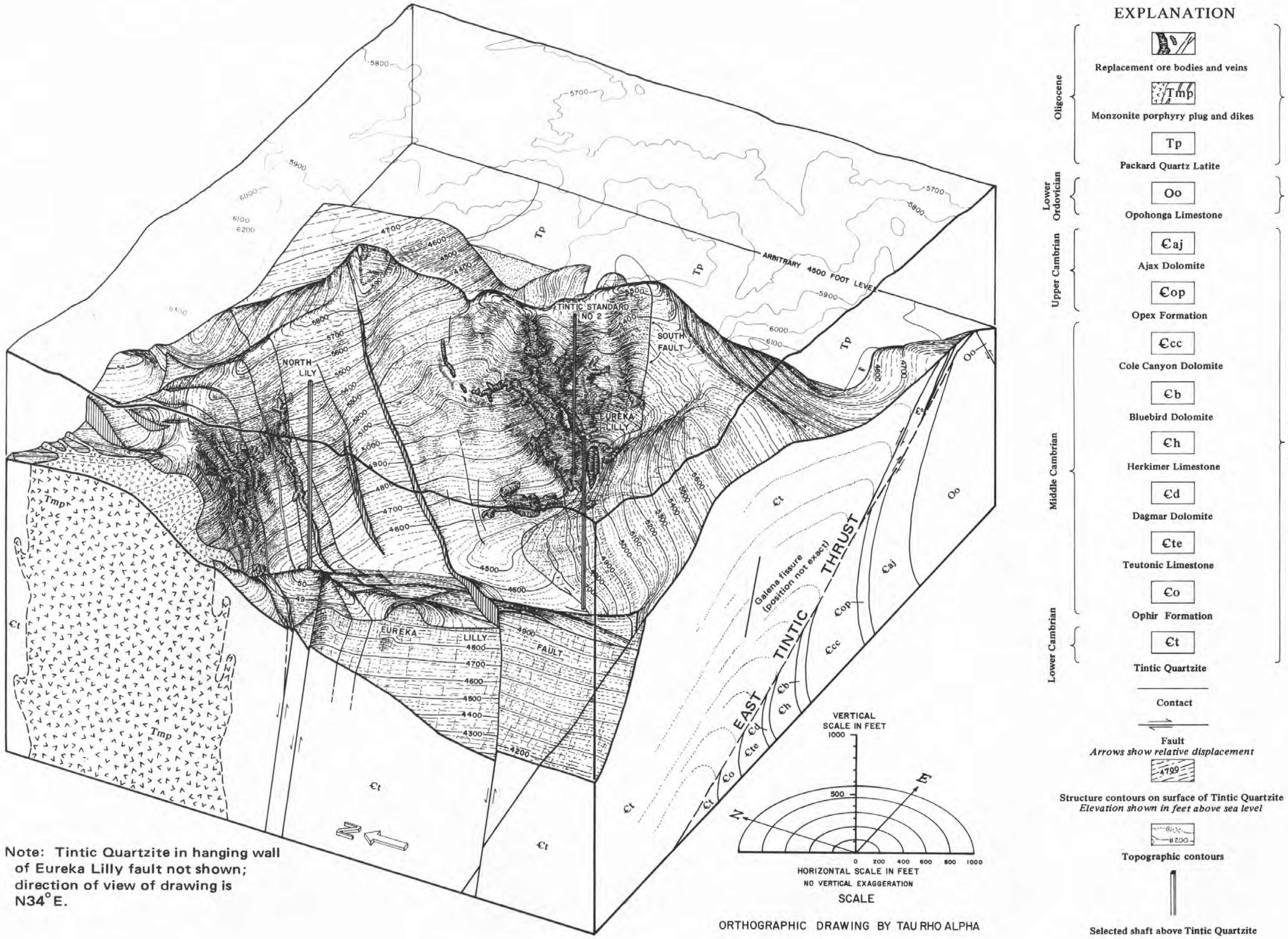



FIGURE 65. — Relation of North Lily-Eureka Lilly and Tintic Standard ore bodies to surface of Tintic Quartzite.

tions moved upward into the brecciated post-Tintic Quartzite rocks.

The largest of the replacement deposits is the great Central, or main, ore body which was the source of 75 to 80 percent or more of all the ores produced from the Tintic Standard. At the 1,100- and 1,250-ft levels, the Central ore body extends across the full width of the pothole from the South fault for 400-600 ft (123-183 m) northward to the opposing folded Tintic Standard thrust. In vertical section, it extends from points below the 1,350-ft level upward along the steeply dipping Tintic Standard thrust on the eastern and northeastern sides of the pothole, terminating in several long, narrow projections that nearly reach the rim of the East Tintic barrier above the 800-ft level. In general, it may be described as being palmate, with irregular fingerlike projections extending upward against or near the moderate to steeply dipping folded Tintic Standard thrust fault.

Geologic reconstructions indicate that the ore and gangue minerals of the Central ore body chiefly replace all or part of fault bounded blocks or slices of Cambrian limestone that were thrust against the Tintic Quartzite and later cut by northeast-trending fissures and pebble dikes. Because of the great size of this ore body, mining was difficult and was accomplished by the use of heavy timber square sets that were backfilled with mine waste supplemented by crushed limestone quarried from an exposure near the No. 2 shaft.

Other smaller replacement ore shoots were also mined near the Central ore body. One of these is an inclined pipelike shoot that was mined from the 1,000-ft level 275 ft (84 m) north of the No. 2 shaft sinuously upward to the 700-ft level, in part through carbonate and shale wallrocks containing abundant secondary manganese oxide minerals. A somewhat larger isolated replacement ore body was mined about 800 ft (244 m) west-northwest of the No. 2 shaft. This so-called West ore body is generally rectangular in plan, being about 400 ft (123 m) long, 190 ft (58 m) wide, and 30-40 ft (9-12 m) thick. It replaced the lower part of the middle Ophir limestone above a subsidiary thrust fault in an area where the beds are generally flat lying. Much of the area between the West and Central ore bodies consists of fine-grained gray jasperoid containing low values in silver and lead as well as scattered concentrations of kaolinite and sericite. Throughout the mine, but particularly near the South fault, other small replacement silver-lead ore bodies also have been mined, most of them under a system of block leasing by individual miners or leasing teams.

The fissure ore bodies were chiefly explored and mined during 1939 and 1940 after the price of gold had been revalued upward and also during World War II when premium payments were made for accelerated copper production. The fissures were designated alphabetically, and of the eight or so that were recognized, the B fissure and the E fissure were the most productive. The B fissure was cut at the 1,450-ft level 200 ft (61 m) southwest of the No. 2 shaft and was followed for 650 ft (198 m) to the south-southwest. The E fissure was also cut at the 1,450-ft level 490 ft (149 m) west-southwest of the No. 2 shaft. It trends N. 60°E. and was followed for a total distance of 1,050 ft (320 m). A short distance northwest of the E fissure, and parallel to it, is the F or gold fissure; it was drifted for 225 ft (69 m) at the 1,450-ft level. The similar, but less productive Q and R fissures were explored and mined also on the 1,450-ft level 1,100 ft (335 m) west-northwest of the No. 2 shaft. In general, all of these fissures ranged in width from a few inches to as much as 5 ft (1.5 m) and consisted of quartzite breccia locally cemented by greater or lesser amounts of quartz, barite, pyrite, and ore minerals. Some areas of highly sheared quartzite were entirely replaced by sulfides. Similar ore shoots were also mined along the South fault in the extreme southwestern part of the mine and in the adjoining Eureka Lilly mine. The E and B fissures were also explored and mined at the 1,570-ft level.

As a consequence of the highly permeable ore-host rocks and the deep water table in the East Tintic district, the ores of the Tintic Standard mine were almost completely oxidized to the 1,000-ft level and decreasingly oxidized to the 1,450-ft level, which is approximately at the elevation of the permanent water table. Supergene enrichment of the ore, however, was rare or lacking, owing in part to the relative absence of zinc and the comparatively small amounts of pyrite and copper minerals in the replacement ore bodies and in part to the highly reactive and neutralizing character of the brecciated and sanded dolomite and limestone wallrocks.

The primary ores, as indicated by the unoxidized replacement ore bodies in the lower part of the mine and by unaltered residual masses of sulfide ores above the 1,000-ft level, consisted predominantly of galena with various amounts of argentian tetrahedrite, silver sulfosalt minerals, pyrite, and some marcasite. Sphalerite was not common, except locally, and argentite, bismuthinite, stromeyerite, and some other relatively rare minerals were present but not abundant. The nonmetallic constituents of the primary ores were chiefly jasperoid, fine-grained barite, and unreplaced fragments of dolomite, many of which were highly sanded and altered. In the lower part of the mine, and in particular in the relatively unoxidized West ore body, the sulfide ores were rudely layered, containing bands of silver-rich galena and tetrahedrite ore that were separated by bands of low-grade siliceous silver ore.

Above the 1,000-ft level, and locally below it, much of the ore consisted of friable earthy mixtures of abundant anglesite, less abundant cerussite, plumbojarosite, argentojarosite, cerargyrite, and iron oxides that enclosed layers and masses of vuggy quartz and jasperoid, residuals of sulfide ore, and fragments of iron-stained sanded dolomite. The argentojarosite is of particular interest inasmuch as it not only was first recognized as a new mineral in the Tintic Standard mine but also occurred there in minable quantities. In the discovery stope, as described by Schempp (1923), it formed brilliant yellow layers as much as a quarter of an inch (0.64 cm) thick and small spherical segregations in an iron-poor ore body composed chiefly of anglesite, barite, quartz, and minor argentite (acanthite?). In an adjacent stope plumbojarosite was common, but it apparently contained no silver and could be distinguished from its silver analogue only by its darker brown color. A relatively large tonnage of argentojarosite ore was produced from the discovery stope. During February, March, and April 1923, the ores mined from this area contained more than 200,000 oz (6,220 kg) of silver, largely in the form of argentojarosite, and one carload lot of 64 tons (58 tonnes) assayed 1,018 oz per ton (34,907 g per tonne) silver. This stope and others in the mine provided argentojarosite to museums throughout the world.

The oxidation of the massive Tintic Standard ore body was accompanied by a considerable amount of shrinkage and collapse, which brecciated and granulated much of the oxidized ore and also developed a number of minor faults that extended upward through the overlying carbonate rocks and into the Packard Quartz Latite. The granulated ore was difficult to mine because of its tendency to run like dry sand. For example, in the J stope near the footwall of the ore body on the 900-ft level, a leasing team continuously produced sandlike anglesite and cerussite ore for a period of 13 months without once resorting to blasting.

The fissure ores constituted only a few percent of the total ore produced from the Tintic Standard, but they were notable for their markedly different composition and character as compared to replacement ore bodies. They consisted of pyrite, enargite, tetrahedrite, and minor galena in association with well-crystallized quartz and barite. These minerals chiefly filled the interstices of quartzite breccias and pebble dikes and locally replaced highly sheared quartzite. Gold was substantially more abundant in them than in the replacement ore bodies, but it was not as abundant as in some of the fissure ores of the North Lily mine; its form is unknown, although it is suspected that petzite and krennerite were present as well as native gold. Some of the silver probably occurred as hessite and stromeyerite as well as argentian tetrahedrite and enargite. Crustification banding was not common, but locally, vugs contained partly terminated crystals of the metallic minerals as well as well-formed crystals of quartz and barite.

During the productive life of the mine several classes of ores were mined selectively and shipped under preferential smelter schedules. Partial analyses of six classes of ore are given in table 10.

During the development and mining of the base-metal and silver ore bodies, several bodies of low- to moderate-grade limestone-replacement manganese ores were found. On the 900-ft level approximately 600 ft (183 m) north of the No. 2 shaft, an irregular pipelike deposit about 60 ft (18 m) wide, 30 ft (9 m) thick, and 100 ft (30 m) in dip length was explored by a raise and short lateral workings. A bulk sample from this body assayed 27.5 percent manganese and 21 percent iron. A second manganese body was discovered on the eighth floor of the 900-ft level about 550 ft (168 m) south of the first deposit. This ore body is 70 ft (21 m) wide, 30 ft (9 m) thick, and 50 ft (15 m) in dip length; a sample assayed 25.3 percent manganese and 9.9 percent iron. A third body was discovered on the sixth floor of the 1,100-ft level. It is 40 ft (12 m) wide, 20 ft (6 m) thick, and at least 20 ft (6 m) in dip length. A sample from it assayed 13.5 percent manganese and 37.5 percent iron. Although little if any of this ore was mined and sold, Ipsen, Snedden, and Gibbs (1949, p. 2) reported that the samples from the two higher grade ore bodies could be readily beneficiated to a product containing 48 percent or more manganese. It is probable, however, that the beneficiated product would contain more than the maximum 1 percent allowable content of zinc, as do the Burgin manganese oxide ores.

Mineralogically, the manganese ores consist mostly of psilomelane and pyrolusite, accompanied by other manganese oxides. Coronadite, chalcophanite, and other manganates probably are present also, but they have not been specifically identified. The parent manganese mineral was chiefly rhodochrosite with some manganodolomite and other mixed carbonates.

TABLE 10. — *Typical analyses of classes of Tintic Standard Ores*

[Chiefly from Parsons (1925); ........., negligible]

| Class of ore | Au | Ag | Cu | Pb | Fe | Sulfur | Silica |
|---|---|---|---|---|---|---|---|
| | (oz/ton)[1] | | (percent) | | | | |
| Lead-silver | 0.037 | 31.0 | 0.35 | 28.87 | 4.0 | ...... | 49 |
| Mill | .032 | 18.5 | .37 | 5.22 | ...... | 2.5 | 67 |
| Dry silver | .10 | 98.0 | .62 | 3.31 | ...... | ...... | ...... |
| Silver-lead | .20 | 220.0 | 1.30 | 18.00 | ...... | ...... | ...... |
| Sulfide | .033 | 19.0 | .35 | 4.00 | 10.0 | 16.0 | ...... |
| Fissure[2] | .12 | 19.0 | 2.60 | 1.00 | ...... | ...... | ...... |

[1]One oz per short ton = 34.29 grams per tonne.
[2]Kildale, 1957, p. 105.

### GROUND WATER

The permanent water table in the Tintic Standard mine stands at an elevation of 4,535 ft, which is approximately 20 ft (7 m) below the sill of the 1,450-ft level. The average wallrock temperature at this elevation is 120° F (48.8° C), and the waters are slightly to moderately saline, a fact which caused excessive corrosion to mine rails and mining equipment. During the early 1940's when the No. 2 shaft was deepened to the 1,570-ft level and copper-gold-silver ores were mined below the water table, a considerable volume of water was pumped to the surface. Analyses of this water are not available, but it is believed to be similar to the saline thermal water present in the Burgin mine (p. 121).

### WALLROCK TEMPERATURES AND MINE GASES

The Tintic Standard was the first deep mine to be established in the East Tintic district and thus was also the first to encounter the anomalous wallrock temperatures that are characteristic to the district. Concurrently, but probably coincidentally, it also encountered large quantities of nitrogen and carbon dioxide gases. As the mine shafts and their lateral workings passed through the Packard Quartz Latite and the Paleozoic carbonate rocks and shale, it was recognized that the wallrock temperatures were higher than at comparable depths below the surface in the mines of the main Tintic district; also the rate of temperature increase with depth — the geothermal gradient — was found to be greater. These anomalous temperatures caused little problem, however, until the workings passed into the siliceous ore body and into the Tintic Quartzite, where the geothermal gradient suddenly steepened and wallrock temperatures ranged from 100° to 130° (37.7°-54.4° C).

The proximity of this hot terrane to an actively oxidizing ore body initially led to the conclusion, later proved to be erroneous, that the heat was derived from the oxidation of sulfide minerals. This conclusion was also reinforced by the assumption that the pockets of nitrogen and carbon dioxide gas were the products of deoxygenated air that was most abundant in the vicinity of the oxidizing ore bodies. Later studies (Lovering and Morris, 1965), chiefly in the Burgin mine where the mine workings extended below the water table, have convincingly demonstrated that the anomalous temperatures of the East Tintic district are related predominantly to a system of hot springs that issue at the water table and only to a slight degree to oxidizing sulfide ores. This hydrothermal system is independent of the mineralized area of the East Tintic district and is evidently a manifestation of Pleistocene basalt volcanism in central and north-central Utah.

Mining activities and geologic studies in the Burgin mine have failed to disclose anomalous concentrations of nitrogen and carbon dioxide gases associated with the heavy inflows of thermal water, indicating that, indeed, these gases in the Tintic Standard were derived in part from the oxidation of the sulfide minerals and in part from the production of $CO_2$ by the reaction between sulfuric acid and limestone, and not from the hot-spring waters.

With time, an increase in the generation of these gases was noted in the Tintic Standard mine. This condition was caused by the increased development of the ore bodies, which accelerated the reaction between the sulfide ores and atmospheric oxygen, and by the decomposition of the great volume of mine timbers that were used in the square-set mining system used in the hot, dry mine. To combat the problems presented by the excessive temperatures and bad air, heavy ventilating fans, a system of upcast and downcast shafts, and many electrically operated ventilation doors were used. Blowing fans were eventually adopted in preference to exhausting fans, inasmuch as they provided better circulation control and helped to force the deoxygenated gases back into the wallrocks (Wade, 1930, p. 15).

## TINTIC UTAH MINING COMPANY

The property of the Tintic Utah Mining Co. is in the southeastern part of the East Tintic district, extending across the east-central part of Latite Ridge and the area to the southeast of it. The property consists of 496 acres (201 hectares) of patented mining claims, all in the western and southern part of sec. 23, T. 10 S., R. 2 W. The company was incorporated January 27, 1920, by W.C. Albertson, Lafayette Holbrook, George Havercamp, George C. Armstrong, A. G. Burrit, J. C. McLean, and Isabella C. Albertson. In 1971, the president of Tintic Utah Mining Co. was Chase Hoffman of Tulare, Calif. The only mine workings on the property consist of short adits and shallow prospects.

The rocks exposed at the surface on the claims are predominantly Latite Ridge Latite with some Packard Quartz Latite and boulder tuff of the Pinyon Queen Latite exposed in the far eastern part of the property. The exposures of Packard Quartz Latite exhibit weak pyritization, but otherwise the rocks on the claims are unaltered.

During 1961, the property was leased to J. J. Beeson and Charles Steen, who drilled four diamond-drill holes, chiefly in an attempt to discover the presumed southerly extension of the East Tintic thrust fault. Three of these holes are in the extreme northwesterly part of the claims about 1 mi (1.6 km) south-southeast of the Burgin ore body. They penetrated approximately 725-825 ft (221-251 m) of Packard Quartz Latite, part or all of the Ophir Formation, and then bottomed in the Tintic Quartzite. The East Tintic thrust was not found and is believed to terminate against the inferred Inez fault; likewise, no ores were found.

## TIP TOP MINE

The Tip Top mine, which is the largest producer of manganese ores in the East Tintic district, is in the center of the N½N½ sec. 9, T. 10 S., R. 2 W., near the east end of the ridge that forms the south side of Homansville Canyon. The principal underground opening, an adit, is reached by a trail that climbs about 125 ft (38 m) above U.S. Highway 6. This adit extends to the area below a large opencut, which is reached by a narrow road that climbs to the ridgetop from the small canyon on the south side of the ridge. The mine is owned by the Chief Consolidated Mining Co. Prior to the purchase of the parent Homansville Mining Co. by Chief Consolidated in 1915, the Tip Top adit tunnel had been driven to prospect for silver ores, and only "incidentally disclosed a deposit of manganese" (Pardee, 1921, p. 207). The mine was intermittently productive between 1916 and 1948. Some drill holes were sunk in the vicinity of the mine in 1950 and 1954.

### PROPERTY DEVELOPMENT AND PRODUCTION

The principal workings of the Tip Top mine consist of a curving adit and several sinuous side drifts having an aggregate length of 400-500 ft (122-152 m), a shaft that now opens to the opencut, and the opencut, or glory hole, which is about 80 ft (24 m) long, 35 ft (11 m) wide, and about 25 ft (7.6 m) deep. The extent of stopes and workings prior to the development of the opencut is shown in figure 66. Several smaller pits have been excavated along the ridge crest both east and west of the opencut. All the workings are on the Tip Top No. 1 and No. 2 mining claims.

The recorded production of the Tip Top mine (Crittenden, 1951, p. 49) is given in table 11. No significant production is shown after 1940, although some small unrecorded shipments were made by George and Dell Steele in 1947-48.

### GEOLOGY

The country rock of the Tip Top manganese deposit is the lower part of the Cambrian Herkimer Limestone, which is cut by several nearly vertical, north-trending faults of small displacement and one or more pebble dikes. The limestone is mostly fresh and unaltered in the vicinity of the opencut but shows strong dolomitization a short distance to the north and south. Reconstruction of the geology suggests that the present surface is a short distance below a small folded thrust fault, movement along which has brought the Cole Canyon Dolomite over the Herkimer Limestone in an area a few hundred feet west and north of the mine. The nearest intrusive rocks are dikes and plugs of highly argillized monzonite porphyry that crop out in highway cuts along the southeast side of Homansville Canyon 600-700 ft (183-213 m) from the mine.

In September-November 1954, the E. J. Longyear Co. drilled a vertical diamond-drill hole at a point 150 ft (46 m) west of the opencut to a total depth of 1,067 ft (325 m). This hole penetrated the lower 200 ft (61 m) or so of the Herkimer Limestone, approximately normal sections of the Dagmar, Teutonic, and Ophir Formations, and bottomed in the upper 70 ft (21 m) or so of the Tintic Quartzite. Several pebble dikes were also cut. With the exception of manganese stringers in the uppermost 95 ft (29 m) of the hole and fairly strong pyritization of the Tintic Quartzite and the shales of the Ophir Formation in the lower part of the hole, the strata were neither altered nor mineralized. An inclined drill hole, sunk in January 1950 by the Chief Consolidated Mining Co., passed under the ridge crest about 800 ft (244 m) west-southwest of the Tip Top opencut at a depth of about 600 ft (183 m). This hole also penetrated unaltered Herkimer Limestone and Dagmar Dolomite, but at 505 ft (154 m) in the inclined hole it cut a narrow zone of vuggy jasperoid that assayed 0.01 oz per ton (0.34 g per tonne) gold, 0.45 oz per ton (15.4 g per tonne) silver, and 0.07 percent manganese.

### ORE BODIES

According to Pardee (1921, p. 208), who visited the property prior to the development of the opencut, the main ore body was an irregular pod or pipelike mass at least 90 ft (27 m) long and from 3 to 40 ft (1-12 m) in diameter that plunged about 45° S. and did not extend below the adit level. This ore body cropped out at the surface as one or more small veins near the middle of a belt of scattered manganese ore occurrences that extend along the ridgetop for 500 ft (152 m) or more. In

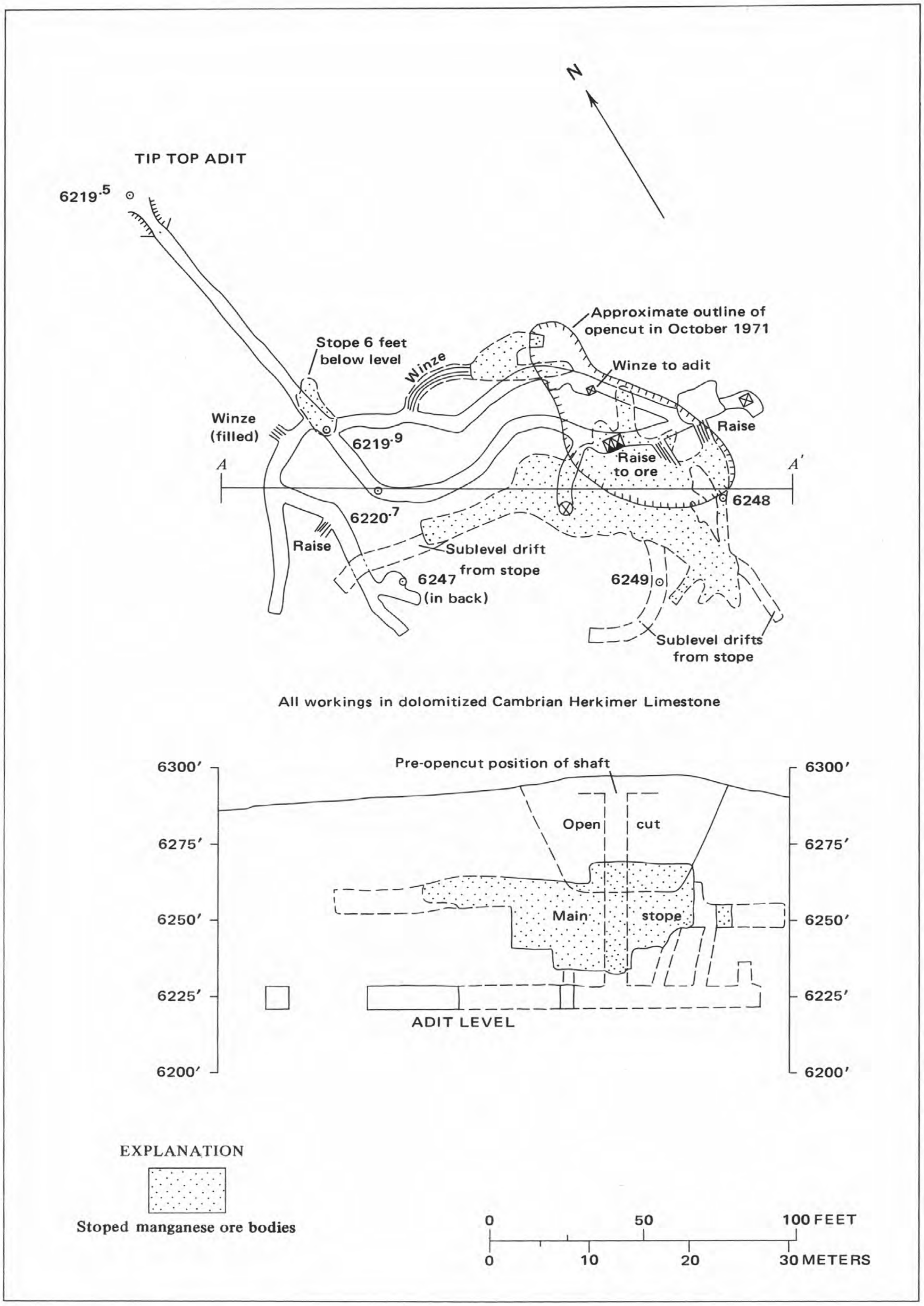



FIGURE 66. — Composite plan and cross section of main workings and stopes of Tip Top manganese mine.

TABLE 11. — *Manganese ore production, Tip Top mine*

| Year | Shipper | Ore shipped (long tons)[1] | Grade (percent Mn) |
|---|---|---|---|
| 1916 | Chief Consolidated Mining Co. | 147 | 40-44 |
| 1917 | Thomas L. McCarthy | 714 | 35+ |
| 1918 | do | 36 | 10-35 |
| 1918 | Huish and Bean | 664 | 40 |
| 1929 | Chief Consolidated Mining Co. | 1,818 | 24.48 |
| 1930 | C.W. Jenkins for unknown shipper | 338 | 20-25 |
| 1931 | do | 157 | 25(?) |
| 1940 | Steele brothers and associates | 1,373 | 24.07 |
| Total | | 5,247 | |

[1]One long ton = 1.016 tonnes.

later years the large stope examined by Pardee was cut open to the surface and subsequently has been partly filled.

The main ore body apparently was a massive replacement of limestone within and just below the minor folded thrust fault between two closely spaced parallel faults. Minor extensions of the manganese ore body follow adjacent fissures and bedding planes.

The Tip Top manganese ores are fairly soft and friable and commonly are vuggy and cavernous. They consist largely of nodules and veinlets of manganese oxides intermixed with soft brown and black clay that may be the nonlimy fraction of the original, considerably argillaceous limestone. The various manganese minerals are intimately mixed and, according to Pardee (1921, p. 207), are largely psilomelane and pyrolusite.

The pronounced structural and stratigraphic localization of the Tip Top manganese deposit indicates that it was formed by the replacement of limestone by ascending hydrothermal solutions. Minor quantities of both zinc and silver in the ore relate these solutions to the metallic ore-depositing episode. The original manganese mineral was probably rhodochrosite, as in the Burgin mine, or mangancalcite; manganosiderite is contraindicated by the relative absence of iron oxides in the deposit. The vuggy, cavernous, and friable character of the ore undoubtedly resulted from shrinkage accompanying the oxidation of the parent manganese-bearing carbonate minerals.

## TRIXIE MINE

By A. PAUL MOGENSEN, H. T. MORRIS, and S. M. SMITH

The Trixie mine is in Silver Pass Canyon approximately 1½ mi (2.4 km) southwest of the Burgin No. 2 shaft and a quarter of a mile (0.4 km) north of the South Standard shaft (fig. 67). The shaft is on the Trump claim of the South Standard Mining Co. near the property boundary with the Eureka Standard Consolidated Mining Co. Since 1956 both of these properties have been part of the East Tintic Unit Lease of the Kennecott Copper Corp.

Early prospecting interest in the area of the Trixie shaft is indicated by the presence of several prospect pits and shallow shafts, some of which were probably developed prior to 1900. The largest of these prospects was the Trump shaft, 94 ft (29 m) deep, which is now buried by the dump of the Trixie shaft. The original Trixie prospect pit is 350 ft (107 m) northeast of the Trixie shaft on the Trixie claim of the Eureka Standard Mining Co. This prospect explored the altered contact between the Teutonic Limestone and the overlying volcanic rocks near a small pebble dike.

The exploration activities leading to the discovery of the Trixie mine all postdate World War II. During the latter part of 1946, K. L. Cook, F. H. Gunnel, and W. A. Young of the U.S. Bureau of Mines made a gravimetric, spectrographic, and geologic study of the Trixie area (Cook, 1947), in part "following methods that T. S. Lovering and his coworkers of the U.S. Geological Survey had developed and used elsewhere in the East Tintic district." Shortly afterward, before the Bureau of Mines report was released for public inspection, the Trixie area was also selected for detailed geologic and geochemical studies by H. T. Morris and Hy Almond (Morris and others, 1956). This latter work indicated the presence of a concealed fault, later named the Trixie fault, which separates Cambrian carbonate rocks and Tintic Quartzite at a point where this fault is cut by the north-northeast-trending Trixie fissure system. This structural intersection is overlain by altered volcanic rocks that contain anomalous quantities of ore-stage heavy metals. This geochemical anomaly and the geology of the Paleozoic rocks beneath the volcanic rocks were investigated by the U.S. Geological Survey during the summer months of 1954 and 1955. Under this program, nine exploration holes were drilled; these holes confirmed the presence of the concealed Trixie fault and provided additional data concerning the character of the geochemical anomaly. One drill hole, U.S. 7a, also cut low-grade ore in the fault zone.

After the end of the Geological Survey's activities in 1956, additional drilling in the Trixie area was carried out by the Bear Creek Mining Co. Bear Creek completed eight additional diamond-drill holes in the target area, which precisely determined the lava-concealed position and strike and dip of the Trixie fault. Several of these holes also intercepted replacement ore at depth, and one of them cut 27 ft (8.2 m) of ore that averaged 19.6 percent lead, 0.4 percent zinc, 0.15 percent copper, and 6.0 oz per ton (205.7 g per tonne) silver. Because of the apparent presence of ore bodies of commercial interest at depth, and the disappointingly low recoveries of core and drill cuttings suitable for an economic evaluation, exploration drilling from the surface was terminated in 1957 in favor of eventual shaft sinking, drifting, and shorter range underground drilling.

Sinking of the Trixie shaft was undertaken in April

FIGURE 67. — Surface installations of Trixie mine. Dumps in left background mark mines of Iron Blossom ore zone of main Tintic district.

1968 and was completed to the 750 level in 1969. Later that year ore was discovered in the footwall rocks west of the shaft and in the Trixie fault zone. In 1971 the shaft was deepened to the 900 level, and during 1976 it was further deepened to the 1050 level. Shaft sinking was again resumed in 1977, when the 1200 level was reached and developed. By February 1978, the shaft was 1,300 ft (396 m) deep, and sinking was being continued to a projected total depth of 1,500 ft (457 m) or the permanent water table.

## DEVELOPMENT AND PRODUCTION

As of February 1978, the underground workings of the Trixie mine consisted of the main shaft, approximately 1,300 ft (396 m) deep, five main raises with a total footage of approximately 1,160 ft (354 m), approximately 450 ft (137 m) of drifts at the 600 sublevel, 5,420 ft (1,652 m) of drifts and crosscuts at the 750 level, 400 ft (122 m) of drifts at the 800 sublevel, 380 ft (116 m) of drifts at the 850 sublevel, 3,260 ft (994 m) of drifts and crosscuts at the 900 level, 1,350 ft (412 m) at the 1,050 level, and 630 ft (192 m) at the 1,200 level. In addition a large diameter drill hole, suitable as an escape shaft, had been drilled from the surface to the 750 level at a point 480 ft (146 m) south-southeast of the South Standard shaft. A large amount of diamond drilling has been carried out, chiefly from the 750 level.

The water table in the Trixie mine is believed to stand at an elevation of approximately 4,575 ft, approximately 1,500 ft (457 m) below the collar of the shaft. In the lavas in the upper part of the shaft is a small perched water table, and insignificant flows of water occur locally in the mine workings. The water issuing from the sedimentary rock is fresh and maintains a constant temperature of about 75° F (24° C) at the 750 level.

Between 1969 and January 1, 1976, the Trixie mine produced 86,929 tons (78,845 tonnes) of direct shipping ore, which contained 14,074 oz (437,701 g) gold, 966,746 oz (30,065.8 kg) silver, 530,218 lb (240,719 kg) copper, 779,083 lb (353,704 kg) lead, and approximately 60,000 lb (27,240 kg) zinc. In addition 2,450 tons (2,222 tonnes) of milling ore was mined during the early part of 1972 for metallurgical testing. This ore contained a total of 73.5 oz (2,285.9 g) gold, 14,500 oz (450,950 g) silver, 171,500 lb (77,861 kg) lead, 81,500 lb (37,001 kg) zinc, and 49,000 lb (22,246 kg) copper. The estimated gross value of all of these ores is approximately $5,268,229, not including the payments made for the high silica content of some of the direct shipping ore.

The total reserves of the mine are not yet established, and during 1976 new mine developments disclosed extensions of the 756 fissure ore shoot at depth and new ore bodies in an area about 1,600 ft (488 m) south of the Trixie shaft. This latter ore body is termed the 75-85 ore shoot, and during 1977 was brought into production.

## GEOLOGY

The Trixie mine explores the strongly faulted crestal area of the largely concealed East Tintic anticline between the Eureka Standard and Sioux-Ajax faults. The Paleozoic rocks exposed in the mine workings south of the Eureka Standard fault range from the Tintic Quartzite to the Teutonic Limestone (fig. 68). North of the Eureka Standard fault, the Cole Canyon Dolomite is believed to have been penetrated by drill holes. In general, the strata dip at low angles to the east, north, or west except near faults where steeper dips occur.

At the surface, within a short distance north, west, and south of the Trixie shaft, the sedimentary rocks are largely concealed beneath irregular thicknesses of altered tuffs and lavas (fig. 69). West and southwest of the shaft, both the sedimentary rocks and the lavas are intruded by small plugs of hornblende-augite-biotite monzonite porphyry and related pebble dikes (fig. 70). Most of the igneous rocks are either argillized or pyritized.

The principal ore-bearing units are the Tintic Quartzite, which is the host rock of the 756 and 75-85 ore shoots and the middle limestone member of the Ophir Formation, which is the host rock of the main replacement ore body within the Trixie fault zone. Large masses of weakly mineralized jasperoid also occur in the Teutonic Limestone at the 750 level in the hanging wall of the Trixie fault. All of these formations also may contain other ore bodies at depth in the hanging-wall block. Except for the traces of ore-stage metals in the altered lavas above the Trixie fault zone, none of the igneous rocks are known to be mineralized.

Five major faults are exposed in or near the Trixie mine. These include the Trixie, Apex Standard, and Eureka Standard faults north of the shaft, the Eureka Lilly fault east of the shaft, and the Sioux-Ajax fault, which may be projected with some confidence into the area about 1,700 ft (518 m) south of the shaft. Numerous smaller fractures, the most important of which are part of the north-northeast-trending pebble-dike and fissure zone, are also recognized in the mine workings.

The Trixie fault zone consists of two parallel fault strands about 70 ft (21 m) apart. The footwall strand is cut by workings at the 750 and 900 levels at points 530 and 540 ft (162 and 165 m), respectively, north of the shaft. It strikes approximately N. 80° E. and dips about 85° NNW. At the 750 level, the footwall strand separates Tintic Quartzite from the upper shale member of the Ophir Formation, and the hanging-wall strand separates the upper shale member from the highly altered Teutonic Limestone. At the 900 level the footwall strand separates the Tintic Quartzite and middle limestone member of the Ophir Formation, and the hanging-wall strand separates the middle and lower parts of the middle limestone member. These relations indicate an apparent throw of about 570 ft (174 m) on the footwall strand and about 80 ft (24 m) on the hanging-wall strand; however, the actual displacement on the fault may be chiefly right lateral like that of the nearby Eureka Standard tear fault. Correlation of the Trixie fault with faults exposed at the surface or in other mines is uncertain. It was originally believed to be the western extension of the Hansen fault, which crops out northeast of the shaft in the hanging wall of the Eureka Lilly fault. The Trixie fault, however, appears to have less throw than the Hansen and to dip at a much steeper angle (see section "Hansen Fault"). A correlation with the Apex Standard fault also is unlikely inasmuch as the strata are relatively upthrown on the north side of the Apex Standard and relatively downthrown on the same side of the Trixie fault. West of the mine area the Trixie fault apparently terminates against or merges with the Eureka Standard fault.

The lava-concealed area north of the Trixie fault zone is believed to contain both the Apex Standard and Eureka Standard faults, which are exposed at the surface half a mile (0.8 km) or more northeast of the Trix-

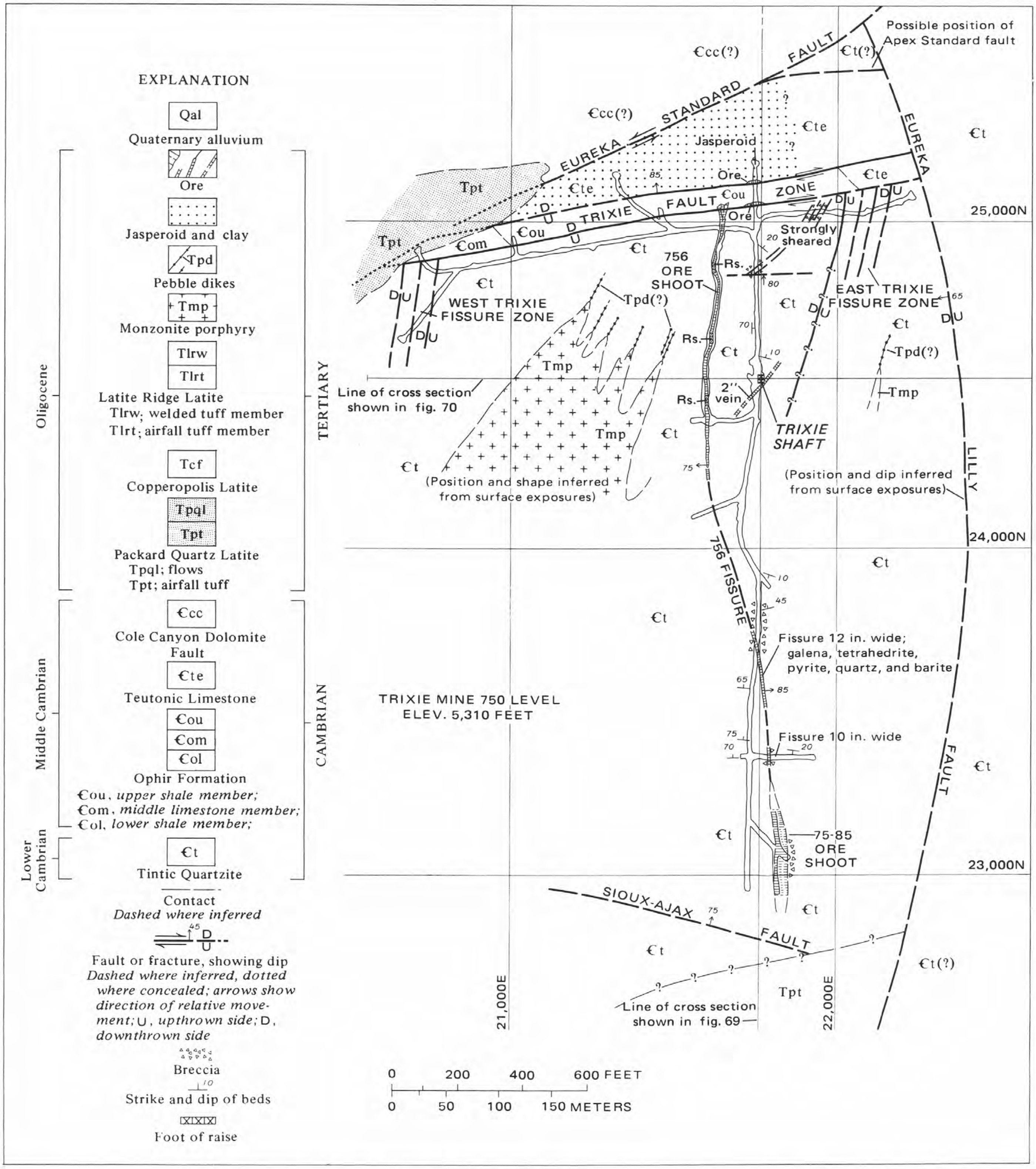



FIGURE 68. — Geologic plan of 750 level of Trixie mine.

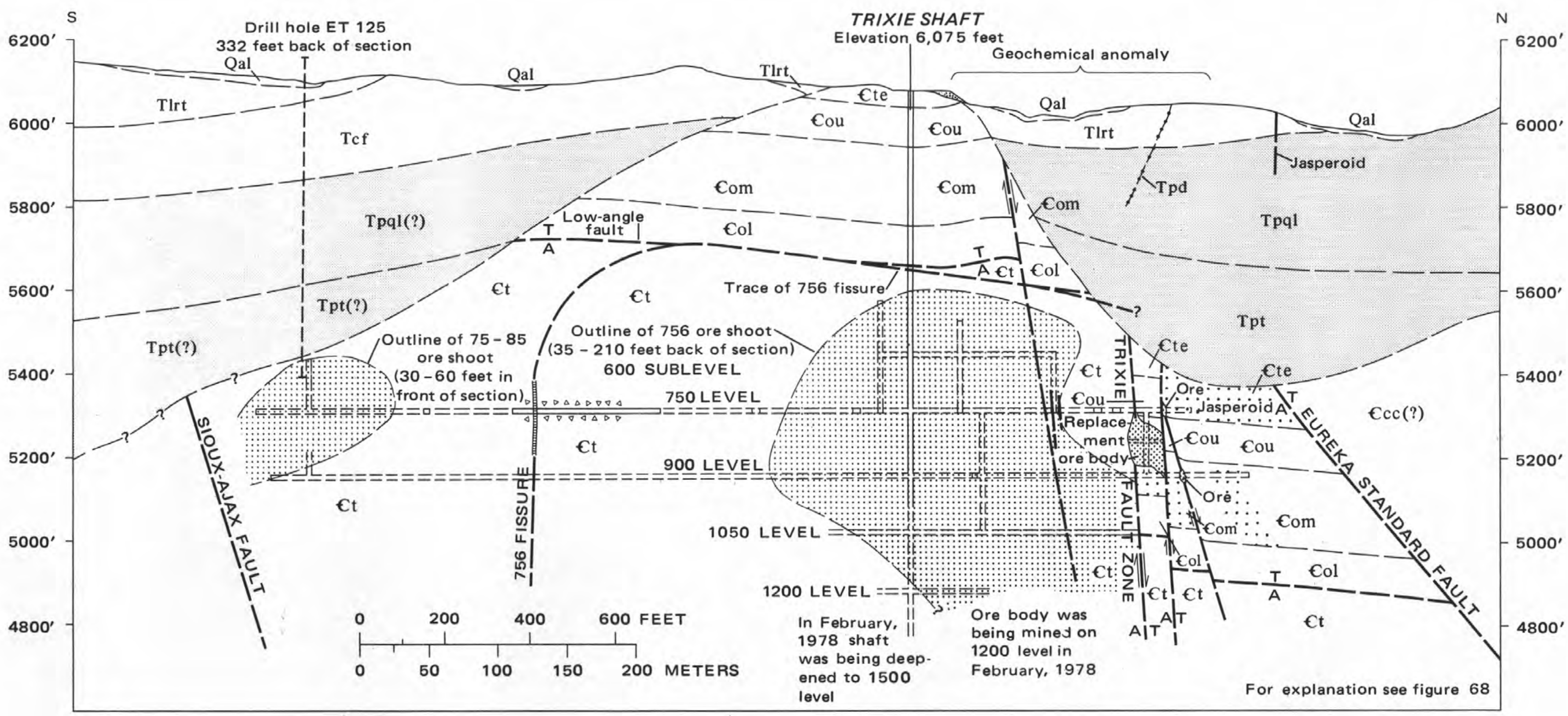



FIGURE 69. — North-south cross section through Trixie mine.

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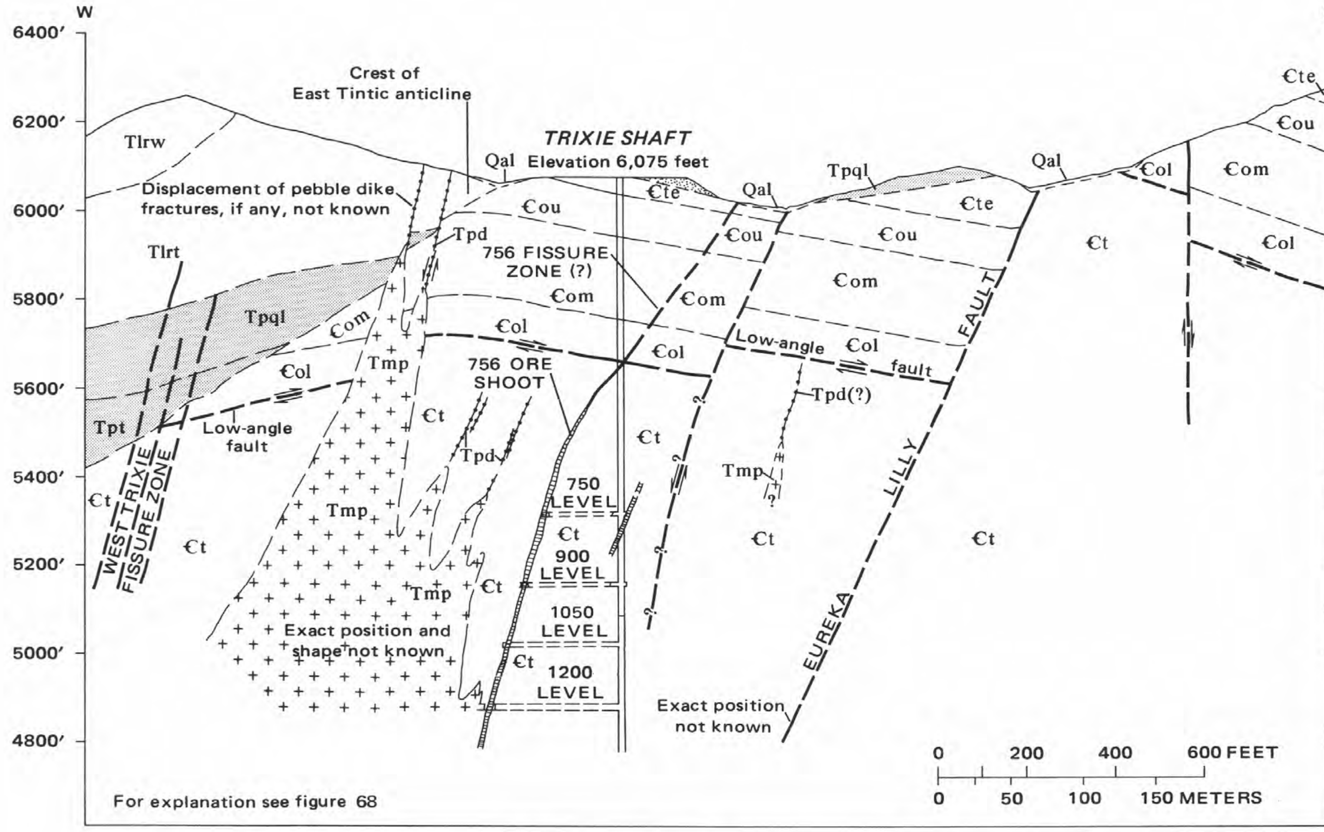


FIGURE 70. — East-west cross section through Trixie mine.

ie shaft, and in the Apex Standard and Eureka Standard mines. Neither fault has been exposed in the Trixie workings, although relatively unaltered dolomite cut by a horizontal drill hole 900 ft (274 m) north of the shaft appears to be Cole Canyon Dolomite of the hanging wall of the Eureka Standard fault. In addition, the Packard Quartz Latite that is penetrated by drifts and drill holes in the northwestern part of the 750 level probably occupies a prevolcanic gulch or canyon that was eroded along the trace of the Eureka Standard fault zone.

Surface exposures of the Eureka Lilly fault indicate that it may be projected to a point that is about 600 ft (183 m) east of the Trixie shaft at the 750 level. An east-trending crosscut in the northern part of the mine that was driven to intercept it apparently was terminated before reaching the main fault zone. Instead, these workings cut numerous fractures and possibly several small dikes of highly altered monzonite porphyry that intrude highly fractured Tintic Quartzite (see fig. 68). The fractures strike N. 10°-20° E. and dip 50° to 70° W. All are discontinuous.

The Sioux-Ajax fault has not been cut by the workings of the Trixie mine, but recent exposures of this fault at the 1,280-ft level of the nearby Roundy shaft indicate that it probably lies about 1,700 ft (518 m) south of the Trixie shaft at the 750 level.

In addition to the major faults described above, numerous north-northeast-trending fractures, which have small displacements but which localize pebble breccias and dikes of monzonite porphyry, extend through the area of the Trixie mine. These fissures form the Trixie fissure zone. In general they have sharply defined walls, strike N. 5°-40° E., and dip 70°-85° W. They range from narrow seams to breccia-filled masses 20 ft (6.1 m) wide or more, averaging about 2 ft (61 cm) in width. The gold- and silver-bearing 756 fissure is considered to be part of this fissure system.

## ORE BODIES

Exploration and development to January 1976 have disclosed two contrasting types of ore bodies in the Trixie mine. One type, characterized by the 756 and 75-85 ore shoots, occurs in tabular mineralized breccia zones that cut the Tintic Quartzite of the footwall of the Trixie fault; the other, characterized by the Trixie fault ore body, occurs as siliceous replacement deposits that are localized in the fault zone. To date most of the ore produced from the mine has come from the Trixie ore shoot, but during and after 1976 much ore has come from the 75-85 ore shoot.

Although the initial exploration in the Trixie area was directed toward the discovery and delineation of a replacement ore body, the 756 ore shoot was the first ore deposit disclosed by the underground workings from the Trixie shaft. This ore body occurs entirely within the Tintic Quartzite about 150 ft (46 m) west of the shaft. At the 750 level the shoot is about 650 ft (183 m) long and 1-30 ft (0.3-9.1 m) wide, averaging about 10 ft (3 m) in width. It terminates on the north in a series of horsetail fractures about 100 ft (30 m) south of the Trixie fault zone, and it narrows to an unminable width at a point about 300 ft (91 m) southwest of the shaft. From that point it extends to the southern part of the mine, where it localizes the comparable 75-85 ore shoot.

The 756 ore shoot has been followed upward from the 750 level in 3 raises about 250 ft (76 m) almost to the top of the Tintic Quartzite. At the 900 level the ore shoot has about the same dimensions as it does on the 750 level, although it may have a slightly greater length of exposure. The total depth to which the ore shoot persists is unknown, but by 1978 it had been followed to the 1200 level. At the 750 level the trace of the fissure is curving, the strike ranging from N. 20° W. south of the shaft to N. 5° E. west and northwest of the shaft. The average dip is about 75° W., flattening somewhat in the uppermost part of the Tintic Quartzite (see fig. 70). As far as can be determined, readily identifiable beds are displaced only about 2 ft (61 cm) across the fissure zone.

The 75-85 ore shoot was discovered in April 1976 on the 750 level at a point 1,450 ft (442 m) south of the shaft. It was first cut in a drill hole directed horizontally eastward from the 750S crosscut and was penetrated soon afterward by a mine workings, which indicated that it is a tabular breccia zone, similar to the 756 ore shoot, 8-30 ft (2.4-9.1 m) wide. By August 1976 it had been opened for a lineal distance of about 250 ft (76 m) and a height of 30 ft (9 m), yielding about 7,000 tons (6,350 tonnes) of ore. This ore averaged 0.626 oz per ton gold, 4.30 oz per ton silver, and 0.145 percent copper. Preliminary examination indicates that the ore of the 75-85 ore shoot is mineralogically similar to that of the 756 ore shoot, although it contains one-fourth to one-fifth the average amount of silver and twice to three times the average amount of gold. Most of the gold appears to be fine-grained native gold. Apparently both the 75-85 and 756 ore shoots are localized on the same sinuous fissure and occur on segments that trend northerly. In contrast, northeast-trending segments of the fissure are narrow and tight and do not contain ores of mineable width. The full dimensions of the 75-85 ore shoot have not been determined, but in the latter part of 1977 the bottom of the ore shoot had been cut by the 900 level (see fig. 69), and the top of the ore shoot had been reached at a point 130 ft (40 m) above the 750 level.

The ore of both the 756 and 75-85 ore shoots consists of mineralized quartzite breccia lying between a well-defined hanging-wall fracture and an indistinct footwall contact that grades into unbroken country rock. The breccia fragments range in size from tiny grains to large blocks as much as 12 ft (3.7 m) in diameter; however, most are roughly equidimensional blocks about 1-3 in. (2.5-7.6 cm) across. The ore and gangue minerals chiefly fill the interstices of the breccia and locally replace the fine-grained fault breccias and gouge; the larger fragments only rarely are replaced. Near masses of argillized monzonite porphyry that locally intrude the breccia, and near beds of fresh and argillized shale in the wallrocks or blocks of shale in the breccia, the grade of ore greatly diminishes as compared to areas of quartzite-rich breccia and quartzite wallrocks.

The primary ore minerals of these ore shoots include argentite, proustite, polybasite, enargite, argentian and bismuthian tetrahedrite-tennantite, chalcopyrite, galena, sphalerite, bornite, stromeyerite, pyrite, and native gold. The primary gangue minerals are crystalline quartz, barite, chalcedony, sericite, chlorite, and hydromica. Inasmuch as the ores occur in highly porous breccia above the water table, they are somewhat oxidized, giving rise to a great variety of secondary minerals, including chalcocite, covellite, azurite, malachite, cerussite, anglesite, plumbojarosite, argentojarosite, hemimorphite, hematite, scorodite, and others.

The Trixie fault replacement ore body is within the Trixie fault zone about 500 ft (152 m) north of the Trixie shaft. It is a podlike mass about 140 ft (43 m) long, 135 ft (41 m) wide, and 85 ft (26 m) thick that replaces part of the middle limestone member of the Ophir between the major strands of the fault. The upper part of the ore body, which barely reaches to the 750 level, is surrounded by an extensive halo of baritic jasperoid containing low values in silver, lead, zinc, and copper. The lower part, which extends in one area to the 900 level, is similarly cased in jasperoid, although not as massive and dense as that on the 750 level. The ore body appears to be limited to the part of the Trixie fault zone that lies between the 756 fissure and the East Trixie fissure zone. In the immediate area of the 756 fissure the ore body terminates, and no ore has been found west of it.

The replacement ore body consists of massive sulfide minerals and jasperoid that locally enclose irregular blocks of argillized shale. The principal primary ore minerals are galena, sphalerite, tetrahedrite-tennantite, enargite, pyrite, chalcopyrite, and as yet unidentified sulfosalts of several varieties. The dominant gangue minerals are quartz, barite, and kaolinite. Although the ore is generally unoxidized, such secondary minerals as azurite, malachite, jarosite, plumbojarosite, cerussite, hemimorphite, smithsonite, and limonite are present in limited quantities.

Detailed assays of the replacement ore body indicate that it has a general compositional zonation. Zinc and gold values are highest in the upper part and diminish downward. In contrast, copper and silver values are highest in the lower part and diminish upward. The lead content of the ore remains fairly constant throughout.

#### OUTLOOK

The relatively early stage of development of the Trixie mine precludes a complete evaluation of its potential as a producing mine as well as a definitive discussion of its geologic and mineralogic features. Several promising exploration targets remain to be tested. These include (1) the extension of the 756 ore shoot below the 1,200 level, particularly the area where the ore shoot appears to plunge downward into the Trixie fault zone; (2) the lower part of the Teutonic Limestone within the Trixie fault zone above the 750 level; (3) the middle Ophir limestone adjacent to the hanging-wall strand of the Trixie at and below the 900 level; (4) the upper part of the Tintic Quartzite adjacent to the hanging-wall and footwall strands of the Trixie fault at depth; (5) the Eureka Standard fault zone at depth in the northern part of the mine, particularly at its intersection with the Trixie fault; (6) the intersection of the Sioux-Ajax fault and the Trixie fissure zone south of the mine area in the vicinity of the South Standard shaft. This last-named target is marked at the surface by several masses of pyritic jasperoid and an extensive area of pyritic alteration. A particularly attractive target is obviously the intersection of the 75-85 ore shoot and the Sioux-Ajax fault, which lies a short distance south of it.

### WATER LILLIE SHAFT

The Water Lillie shaft is in the SE¼NW¼ sec. 3, T. 10 S., R. 2 W., at the southeast base of Pinyon Peak, slightly more than 2 mi (3.2 km) north of Dividend. It is situated in the northeastern part of an extensive block of mining claims owned by the Chief Consolidated Mining Co. that covers much of the northern part of the Tintic district and most of Pinyon Peak. Shaft sinking was started in June 1921 and completed to a total depth of 1,468 ft (447 m) in December 1921. The original depth objective of 1,600 ft (488 m) was not achieved because of excessive quantities of ground water that came in at 1,465 ft (447 m). During the 31-day interval from July 15 to August 15, 1921, the shaft was sunk 427.5 ft (130.3 m) establishing an international shaft-sinking record that was not exceeded until April 1951, after the introduction of mechanical shaft-sinking and mucking equipment. Only one level was driven from the shaft at a depth of 1,440 ft (439 m), and three drifts extend to points that are 1,200 ft (366 m) west of the shaft, 1,030 ft (314 m) north of the shaft, and 1,200 ft (366 m) south-southwest of the shaft (fig. 71).

The Water Lillie shaft is collared in Quaternary terrace gravel, but within 75 ft (23 m) of the surface it passes into pyritized Packard Quartz Latite, which extends to a total depth of 482.5 ft (147.1 m). The remainder of the shaft penetrates approximately 75 ft (23 m) of the Opohonga Limestone and nearly the full thicknesses of the Ajax Dolomite and the Opex Formation and bottoms in the upper part of the Cole Canyon Dolomite. In all three of the drifts the bedding is undulatory. North of the shaft it generally strikes northerly to northwesterly and dips westerly at 10°-20°; south of the shaft it is about horizontal. Two northeast-trending faults and one east-trending fault were cut in the area northwest of the shaft. These faults dip southerly and have small displacements. The south-southeasterly drift had the Homansville fault as its objective, but diamond drilling in 1969 by the Kennecott Copper Corp. indicated that the fault has a more easterly strike than was originally anticipated and that the face of the drift was approximately 775 ft (236 m) short of the fault zone when it was abandoned.

No ore bodies or mineralized ground were recognized in the Water Lillie workings, although the intersection of the North Lily and Eureka Lilly fissure systems with the Homansville fault 2,000 ft (610 m) south-southwest of the Water Lillie shaft still presents an attractive exploration target. In mid-1976 Kennecott Copper Corp. announced plans to reopen the shaft to undertake the exploration of a mineralized ore cut by drill holes about 1,000 ft (305 m) west-northwest of the Central Standard shaft.

### ZUMA MINE

The property of the Zuma Mining and Milling Co. is in the southwestern part of the East Tintic district about 1½ mi (2.4 km) southwest of Dividend. The company was organized in July 1907, but exploration and development were not vigorously pursued until after the discovery of the Tintic Standard mine. Underground work then proceeded continuously from 1917 to 1928, chiefly under the direction of P. J. Fen-

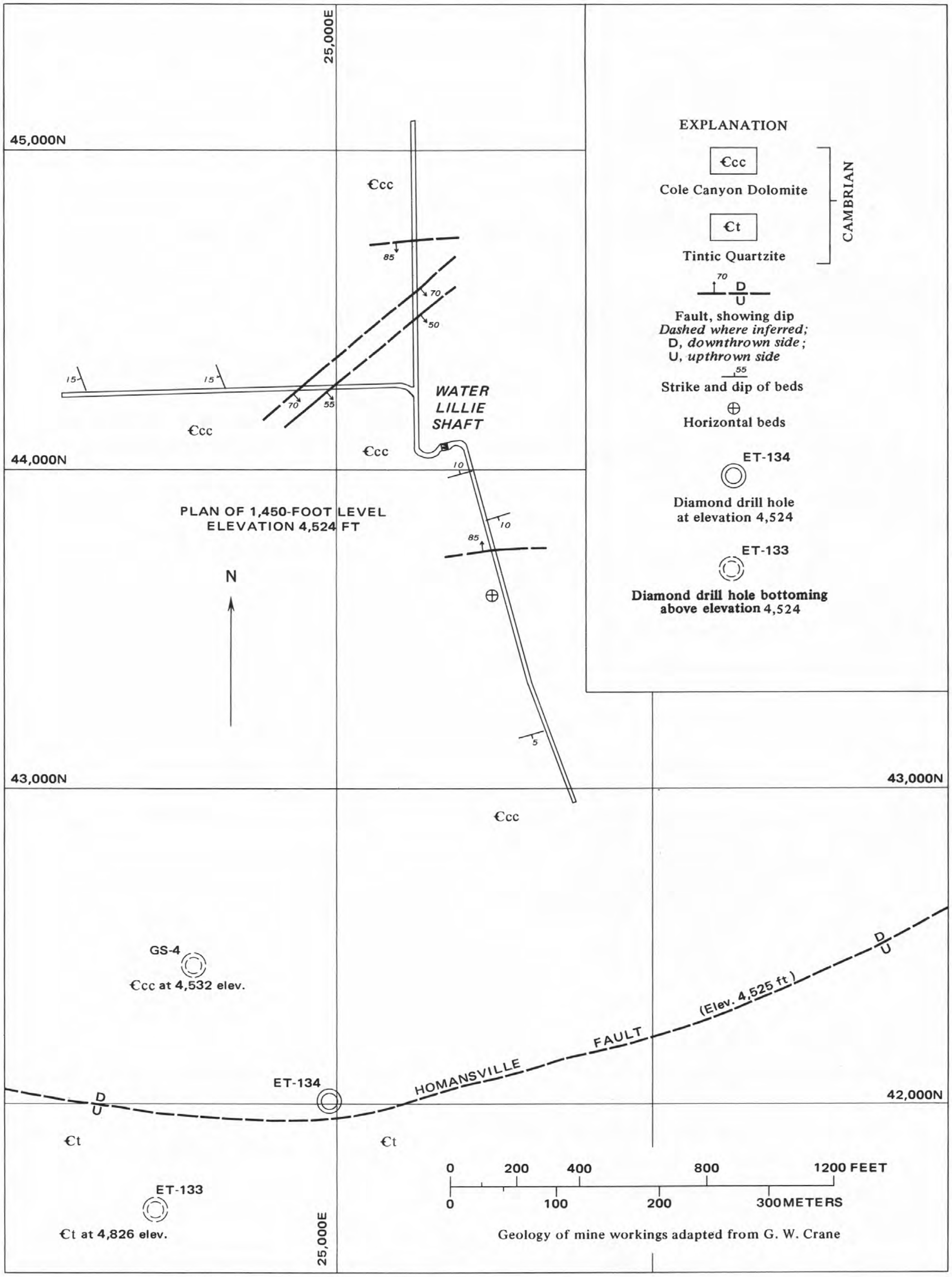


FIGURE 71. — Geologic plan of 1,450-ft level of Water Lillie shaft.

nel and A. C. Nebeker. From 1928 to 1935 the mine was idle, but it was again reactivated in February 1935 and operated continuously until January 1940. The Zuma was briefly opened in 1944 and again in 1946, when the shaft was retimbered to the 1,200-ft level. In 1957 the Zuma Mining and Milling Co. was reorganized as the Zuma Oil and Uranium Co. by Feno Tedesco and his associates, and in 1960 the East Tintic mining property and improvements were sold to the Kennecott Copper Corp.

## PROPERTY DEVELOPMENT AND PRODUCTION

The Zuma property in the East Tintic district consists of all or part of eight patented mining claims containing approximately 125 acres (51 hectares). The principal underground opening is the Zuma shaft, which is 1,310 ft (399 m) deep and is located in the NE¼SW¼SW¼ sec. 21, T. 10 S., R. 2 W. It was completed April 1922. Four levels were driven from the shaft at depths of approximately 200, 500, 1,200, and 1,300 ft (61, 152, 366, and 396 m) below the surface. In addition, the fairly extensive 800-ft level has been established from two winzes from the 500-ft level, and the 1,000-ft level has been driven from a raise connecting the 1,200- and 800-ft levels. Shorter sublevels have been established from these and other winzes and raises at approximate depths of 600, 700, 774, 875, 1,050, and 1,075 ft (183, 213, 236, 267, 320, and 328 m) below the collar, chiefly in the vicinity of the mineralized fissures. According to company data, the horizontal workings aggregate 5,015 ft (1,529 m) in length, winzes 310 ft (94 m), and raises 1,315 ft (401 m). All the underground workings are west, northwest, and southwest of the shaft. Other workings on the property include a number of shallow pits and adits, particularly in the western part of the claims.

According to published records, the Zuma mine has produced 2,208 tons (2,003 tonnes) of ore containing an average of 0.20 oz per ton (6.86 g per tonne) gold, 1.70 oz per ton (58.29 g per tonne) silver, 0.20 percent copper, and 7.80 percent lead (Cook, 1957, pl. 3). The first ore shipment was made in 1918, and other shipments were made at irregular intervals to 1944. According to J. George Jones (written commun., 1944), the gross value of 1,890 tons (1,714 tonnes) of ore produced prior to 1926 was $25,712.87. The last ore shipped in 1944 amounted to 122 tons (111 tonnes), containing a total of 2 oz (62.2 g) gold, 337 oz (10,480.7 g) silver, and 12,270 lb (5,571 kg) lead.

## GEOLOGY

The sedimentary rocks exposed at the surface on the Zuma property include the Opohonga, Fish Haven, Bluebell, and Victoria Formations, which generally strike north and dip 20°-30° W. In the south half of the claims, they are overlain by lavas and tuffs of the Packard Quartz Latite and the Tintic Mountain Volcanic Group. Near the shaft, and elsewhere on the claims, both the lavas and the Paleozoic sedimentary rocks are intruded by several small plutons and dikes of monzonite porphyry and by pebble dikes.

As shown in plate 1, the dominant structural feature on the claims is a north-trending horst within which the shaft is located. The east-bounding fault of this upraised block is believed to be the southerly continuation of the 20th Century fault. It crops out 450 ft (137 m) east of the Zuma shaft, strikes about N. 25° W., and apparently dips steeply to moderately to the east. On the west side of the 20th Century fault the strata dip moderately to steeply west. The west-bounding fault of the horstlike block crops out 320 ft (98 m) west of the shaft; it strikes N. 5° W. and dips moderately to the west. As shown in the figure 72 and in plate 1, the west-bounding fault may be one of the fissures that are mineralized at depth. Other faults exposed at the surface include two east-trending fractures that transversely cut the horst and an inferred east-trending fault underlying part of Burriston Canyon northeast of the shaft that may be the extension of the Yankee fault.

Hydrothermal solutions have altered both the lavas and the carbonate rocks. The volcanic rocks are both argillized and pyritized. The Paleozoic rocks are weakly to strongly marbleized and locally are replaced by small bunches of calc-silicate minerals and the zeolite okenite. Near some of the plugs of monzonite porphyry the Fish Haven and Bluebell Dolomites are sanded and dedolomitized, producing a porous, granular, iron-stained rock that resembles sawdust. In the Larsen clay pits, about 1,200 ft (366 m) west-southwest of the shaft, these formations are locally replaced by halloysite clay (see section "Larsen Halloysite Clay Pits").

The Zuma shaft is collared in the uppermost part of the Opohonga Limestone, and with the exception of a dike of monzonite porphyry that was penetrated at 30-150 ft (9-46 m) and four sill-like bodies of monzonite porphyry that were cut between 1,010 and 1,090 ft (308-332 m), the shaft remains in carbonate rocks to its total depth of 1,310 ft (399 m). All of the carbonate rocks penetrated by the shaft are thoroughly bleached and recrystallized, which has obliterated many of the lithologic characteristics used to distinguish formational units. The occurrence of chert nodules at about 950 ft (290 m) in the shaft, however, is believed to indicate the approximate position of the contact between the Opohonga Limestone and the Ajax Dolomite. The lateral workings penetrate a much greater volume of

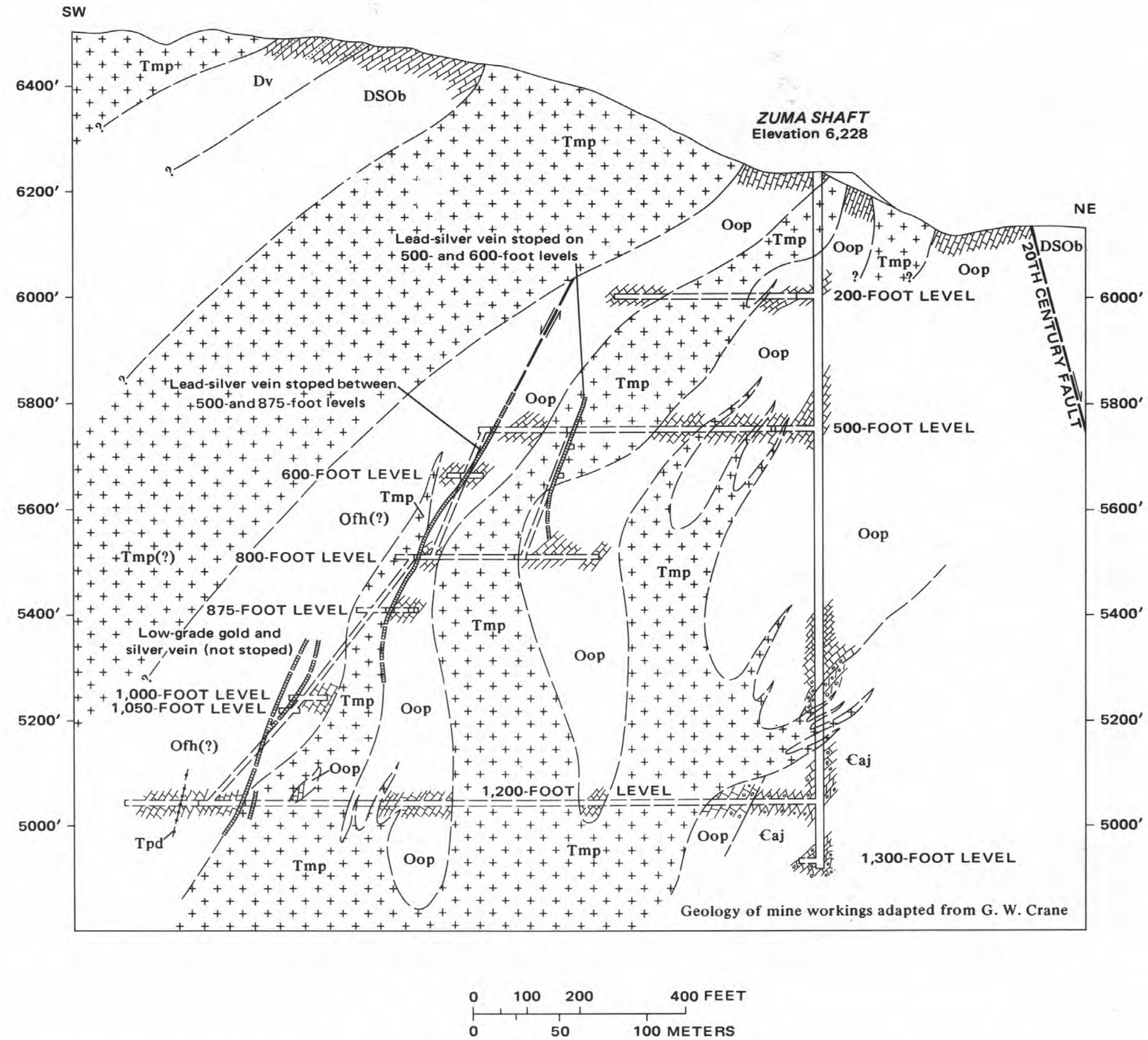


FIGURE 72. — Geologic cross section through Zuma shaft.

monzonite porphyry than would be expected from surface exposures (see fig. 72). In this area the sedimentary strata strike northerly to northwesterly and dip westerly with slightly decreasing steepness west of the shaft. Sill-like tongues of monzonite porphyry invade the carbonate rock, many of them apparently terminating upward before they reach the surface. At the 500-ft level the relative volumes of sedimentary and intrusive rocks penetrated by the workings are about equal. In contrast, the 1,200-ft level penetrates about twice as much monzonite porphyry as carbonate rock. Two or more pebble dikes were also cut by the lateral workings, and locally lenses of pebble breccias were found along the walls of the intrusive bodies, particularly on the 500-ft level 385 ft (117 m) west-northwest of the shaft.

## ORE BODIES

Three mineralized fissures or fissure zones were discovered and developed in the Zuma mine, chiefly between the 500- and 1,000-ft levels. All of them strike northerly, dip westerly, and locally merge with the contacts of the monzonite porphyry intrusions. The most

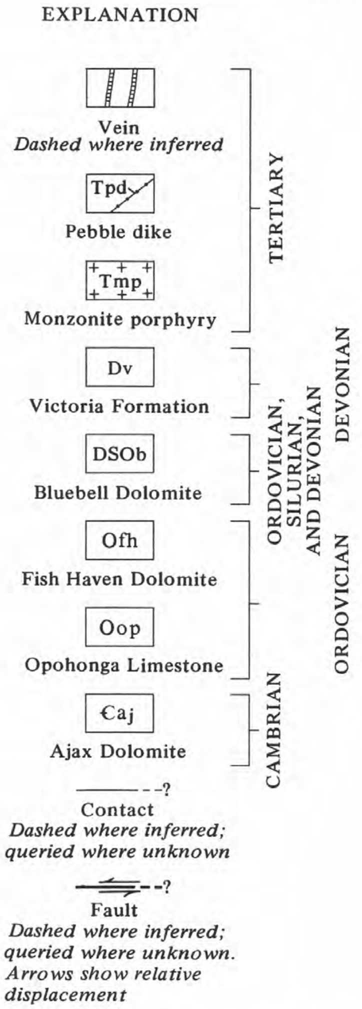


FIGURE 72. — Continued.

productive of these fissures was first encountered on the 500-ft level about 600 ft (183 m) west-southwest of the shaft and was followed downward in a series of winzes to the 1,050-ft sublevel. This fissure strikes N. 5°-10° E. and dips approximately 70° W. It cuts both limestone and monzonite porphyry and appears to be a reactivated segment of the fault that crops out at the surface 320 ft (98 m) west of the shaft. Ore occurred on this fissure in a shoot that plunges about 60° to the southwest from a point a short distance above the 500-ft level to the 875-ft level. The width of this shoot ranged from 10 to 30 ft (3 to 9 m), and its thickness ranged from 4 in. (10 cm) to 7 ft (2 m) or more.

The second most productive fissure was also first found on the 500-ft level, 460 ft (140 m) northwest of the shaft. It is somewhat sinuous in plan but in general strikes due north and dips about 60°-70° W. It was followed northward between walls of monzonite porphyry from the main west crosscut of the 500-ft level. Farther north it passes into the contact zone with porphyry on the east side and limestone on the west side. Still farther north, about 250 ft (76 m) north of the main 500-ft level crosscut, it passes entirely into bleached limestone. The main productive part of the ore shoot occurred between limestone walls. At the elevation of the 500-ft level the ore shoot was about 100 ft (30 m) wide and 2 in. (5 cm) to 2 ft (61 cm) thick. Locally it was stoped upward for 100 ft (30 m) and downward for 80 ft (24 m). Company data indicate that this ore body was selectively mined chiefly during 1937-38, yielding 483 tons (438 tonnes) of ore averaging 0.015 oz per ton (0.5 g per tonne) gold, 13.0 oz per ton (445.8 g per tonne) silver, 14.6 percent lead, 4.2 percent zinc, and 0.1 percent copper.

The third mineralized fissure, on the 1,000-ft level about 1,000 ft (305 m) west-southwest of the shaft, occurred between limestone walls, striking N. 32° W. and dipping westerly at 65°-70°. Although it was followed for more than 400 ft (123 m) to the southeast, no minable ore shoots were discovered, and at best it contained only low values in gold and silver. At the 1,200-ft level, this same fissure is believed to lie within the west contact of a monzonite porphyry pluton.

Despite the proximity of the 20th Century fault to the Zuma shaft, and strong recommendations by at least one consulting geologist to explore it (M. B. Kildale, Zuma Mining Co., unpub. data, November 1933), no exploration workings have been driven easterly to intercept and explore structure.

The minerals of the Zuma ore shoots chiefly replace marbleized limestone that was shattered by faulting and by the injection of viscous monzonite porphyry. The metallic minerals consist of partly to wholly oxidized galena, enargite, sphalerite, and abundant pyrite. Undoubtedly some of the less common metallic minerals known elsewhere in the East Tintic district also occur in the ores; however, they were not recognized in the dump materials that were examined, nor were they reported by persons who had access to the mine. The gangue minerals consist of granular quartz and jasperoid, both of which are intergrown with abundant barite, and greater or lesser amounts of iron and manganese oxides. Despite the occurrence of the ore bodies in an area of closely spaced monzonite porphyry plutons, the Zuma ores are entirely of the limestone replacement or fissure types and not of the type commonly termed contact-pyrometasomatic.

The ores were valuable chiefly for their content of silver, which ranged from 1 oz to more than 114 oz per ton (34.3-3,909 g per tonne) in selected samples. The lead content ranged from a few tenths of a percent to 35 percent, and some samples yielded as much as 1 percent copper and 0.50 oz per ton (17.2 g per tonne) gold. According to Crane (1925, p. 8) one lot of 40 tons (36.3 tonnes) of ore shipped in 1925 from the main Zuma ore body contained 0.016 oz per ton (0.55 g per tonne) gold, 19.95 oz per ton (684.1 g per tonne) silver, 0.71 percent copper, and 3.50 percent lead.

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