Geology and Ore Deposits of the Globe-Miami District, Arizona

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By N. P. PETERSON

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Within the district of known productive deposits are several large areas underlain by rocks that are younger than the period of mineralization and that may conceal other ore bodies

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By N. P. Peterson

ABSTRACT

The rocks of the Globe-Miami district range from lower Precambrian to Recent. The oldest formation, the Pinal schist, comprises several varieties of schist formed by dynamic and thermal metamorphism of shale and feldspathic sandstone during the early Precambrian Mazatzal revolution. During the later stages of this revolution, the schist was intruded by a complex of dioritic rocks and by plutons of granite and quartz monzonite. There were extensive intrusions of a biotite-quartz diorite, known as the Madera diorite, mainly south of the district. In the northern part of the mapped area, the schist was invaded by an extensive mass, the Ruin granite, which is a coarse-grained rock most commonly of quartz monzonitic composition. There are also smaller sill-like masses of slightly gneissic muscovite granite.

Upper Precambrian sedimentary rocks of the Apache group rest unconformably on the deeply eroded surface of the Pinal schist and intruded igneous rocks. The group consists of the very thin Scanlan conglomerate at the base, Pioneer formation, Barnes conglomerate, Dripping Spring quartzite, Mescal limestone, and one or more thin flows of olivine basalt at the top.

The Apache group is separated from the Troy quartzite (Middle Cambrian) by an erosional disconformity; and the Troy was completely removed by erosion from a large part of the district before the Martin limestone of Devonian age was deposited. The younger Paleozoic rocks are represented by the Escabrosa limestone (Mississippian) and the lower part of the Naco limestone (Pennsylvanian).

There are no sedimentary rocks representing the Mesozoic era, but igneous activity probably began in Late Cretaceous time and continued into the early part of the Tertiary period. The Solitude granite, Willow Spring granodiorite, and the granodiorite in Gold Gulch have been tentatively assigned to this interval, but they intrude only the Pinal schist, and their ages are therefore uncertain. They may be older than Cretaceous and may even be early Precambrian. Of more certain age are the Lost Gulch quartz monzonite, extensive sills and dikes of diabase intruded mainly into the formations of the Apache group, many small dikes and sills of diorite porphyry, the Schultze granite with its granite porphyry facies, and many small isolated bodies of granite porphyry which probably were about contemporaneous with and related to the Schultze granite.

Local accumulations of erosional detritus known as the Whitetail conglomerate and an overlying thick sheet of dacitic volcanic rocks, probably Teritary in age, rest unconformably on the extensively faulted and deeply eroded older formations. A thick blanket of the Gila conglomerate of Pliocene and early Pleistocene age, locally intercalated with thin flows of olivine basalt, filled the valley between the Pinal Mountains and Apache Peaks. In places the conglomerate is more than 4,000 feet thick and at one time, it probably mantled the entire district, but it is now being rapidly worn away by erosion.

There are strong angular unconformities at the bases of the Apache group, the Whitetail conglomerate and associated dacite, and the Gila conglomerate, and erosional disconformities occur at the bases of the Troy quartzite, the Martin limestone, and probably at the base of the Naco limestone, but the strata of the Apache group and those of Paleozoic age are essentially conformable.

The structural features of the upper Precambrian and younger formations are predominantly the results of block faulting and other displacements during the intrusion of thick dikes and sills of diabase magma. The earliest recognized faulting began at some time later than the Pennsylvanian period, and the fundamental fault pattern probably had formed by the time the diabase was intruded. Faulting continued into Quaternary time with recurrent movements on many of the major faults.

Parts of three major structural blocks are in the mapped area: the Globe Hills block, the Globe Valley block, and the Inspiration block. The Globe Hills block includes the northeastern half of the Globe quadrangle. It is bounded on the southwest side by the Pinal Creek fault system, a broad zone of step faults. Some faults in the block are older and some are younger than the diabase; the largest are the northeastward-trending faults of the Old Dominion system and the Copper Gulch, Cuprite, Budget, and McGaw faults, which strike north to northwest.

The Globe Valley block is a graben inset between the Globe Hills block to the northeast and the Inspiration block to the west. The west boundary is clearly defined by the Miami fault, which is known to have a throw of about 1,500 feet at the east end of the Miami-Inspiration ore body. Little is known concerning the structural details of the bedrock in the block, for the structural basin was filled with Gila conglomerate. The basin provides most of the water supply for domestic and industrial use in the district.

The Inspiration block includes the part of the district west of the Miami fault. The Schultze granite is the principal rock in the southern part of the block, and near it are grouped the large disseminated-copper deposits of the district. Relatively few faults have been recognized in this area, and most of the larger ones trend north to northwest. The Castle Dome and Copper Cities horsts are the most prominent structural features. In the northern part of the block, faults with northwest strikes are most numerous, and their net effect has been to depress blocks progressively to the northeast so as to repeat outcrops of rocks of similar age from southwest to northeast. The boundary between the northern and southern parts of the block, though poorly defined, appears to be a zone of major vertical displacement, probably along an intrusive contact between the Pinal schist and Ruin granite.

Mining in the Globe-Miami district began after the Globe claim was located on the Old Dominion vein in 1874, but owing to the remoteness of the region, interest centered for a time on the many small silver and gold deposits of the area. The production of copper was insignificant until 1882, when active mining was started on the Old Dominion and Buffalo veins. Development of the large, low-grade, disseminated-copper deposits began in 1904 and large-scale production in 1911. At the end of 1953, the mines of the district had produced about 6,121 million pounds of copper and minor amounts of gold, silver, lead, and zinc, having a total value of more than $1 billion.

Most of the productive deposits are of hydrothermal origin subsequently enriched by supergene processes; however, some with substantial yields of copper were deposited by cold meteoric solutions. The deposits of hydrothermal origin are of two main types: disseminated-copper or "porphyry-type" deposits and vein, or lode, deposits. There are several different kinds of vein and lode deposits, but only the simple copper-bearing veins are of major economic importance.

The large disseminated-copper deposits account for more than 80 percent of the total value of the metals credited to the district. The Miami-Inspiration ore body, by far the largest, is partly in the granite porphyry facies of the Schultze granite, but most of it is in the adjacent Pinal schist, whereas the Castle Dome and Copper Cities ore bodies are in the Lost Gulch quartz monzonite. The gangue is chiefly the original minerals of the host rocks and the minerals produced by their hydrothermal alteration, mainly quartz, sericite, and clay minerals. The protore consists chiefly of pyrite and chalcopyrite and very minor amounts of molybdenite, sphalerite, galena, and bornite. The ore bodies were formed by supergene replacement of chalcopyrite and pyrite by chalcocite and covellite. Most of the supergene enrichment in the Miami-Inspiration deposit occurred during a period of erosion and weathering that preceded the eruption of dacite. During the present cycle, erosion removed most of the cover of dacite and Gila conglomerate and also the leached capping from parts of the ore body. The copper sulfides have been extensively altered to carbonates and silicates in the exposed parts. The replacement of the Castle Dome and Copper Cities deposits has occurred during the present cycle of erosion, and the effects are not as complete as in the Miami-Inspiration deposit. The ore contains much unreplaced chalcopyrite and pyrite and very little copper in the form of oxidized minerals.

The largest vein deposits are along the Old Dominion vein system, from which metals, mainly copper, valued at about $152 million have been produced. Other similar, but smaller, deposits are the Great Eastern, Buckeye-Black Oxide, Dime, Stonewall, Big Johnnie, Maggie, Josh Billing, and Buffalo veins. All were formed by replacement of breccia and wall rock along faults and fissures that cut the upper Precambrian and Paleozoic sedimentary rocks and intruded bodies of diabase. The principal hypogene vein minerals are quartz, pyrite, chalcopyrite, bornite, and specular hematite. The upper parts of all the veins have been enriched or altered by supergene processes and contain chalcocite, covellite, cuprite, and copper carbonates and silicates. Many of the near-surface ore bodies contained only oxidized minerals.

All other types of vein deposits are of minor commercial importance and are in the areas bordering the main centers of copper mineralization. They include several small zinc-lead veins, zinc-lead-vanadium-molybdenum veins, manganese-zinc-lead-silver veins, many narrow stringers containing native silver and gold in their oxidized zones, and a group of small molybdenite-bearing veins.

Copper deposits formed by circulating ground-water include several ore bodies. The six major deposits of this type have produced copper valued at about $7 million. The ore consists of copper carbonates and silicates that replaced tuffaceous conglomerate and dacite along fracture zones or filled interstices between breccia fragments along faults in schist, diabase, or granite.

All the productive mineral deposits of the Globe-Miami district, the Pioneer district, and several smaller nearby districts to the northeast and southwest, are in a northeastward-trending belt about 6 miles wide. Within the belt several large areas underlain by Tertiary(?), Tertiary, and Quaternary rocks, younger than the period of mineralization, may include other ore bodies in the underlying older rocks.

INTRODUCTION

LOCATION, CULTURE, AND ACCESSIBILITY

The Globe-Miami mining district, in the lower foothills of the Pinal and Apache Mountains, in Gila County, Ariz., is an area of indefinite extent, most of which is included in the Globe, Inspiration, and the northern part of the Pinal Ranch 7½-minute quadrangles, as mapped by the U.S. Geological Survey in 1945. The location of the mapped area is shown on figure 1.

Globe, the county seat, and Miami are the largest towns of the district. Their populations, according to the census of 1950, are 6,419 and 4,320 respectively. Globe, Miami, and the nearby smaller settlements of Claypool, Central Heights, Midland City, and Inspiration have a total population of about 18,000. They all depend largely on the copper-mining operations of the district, but also serve many outlying ranches and are the centers of an extensive cattle-raising industry.

Globe and Miami are the hub of several main highways. U.S. Highway 60–70 connects the district with Phoenix 86 miles to the west. Northeastward from Globe U.S. 60 crosses the Salt River to Show Low and Springerville, and southeastward U.S. 70 to Safford connects with U.S. 80 at Lordsburg, N. Mex. State Route 77 runs south to Winkelman and Tucson, and the Apache Trail (State Route 88) runs northwest to Roosevelt Dam and thence to Apache Junction where it joins U.S. 60–70.

The Gila Valley, Globe, and Northwestern Railroad, a branch of the Southern Pacific system, has its terminus at Globe and connects with the main line of the system at Bowie. From Globe a branch line serves the copper mines and smelter at Miami.

Electric power for domestic and commercial use is supplied by diesel plants of the Arizona Public Service Co., and power for industrial use is produced by steam plants of the Miami Copper Co. and the Inspiration Consolidated Copper Co. and by the hydroelectric plant

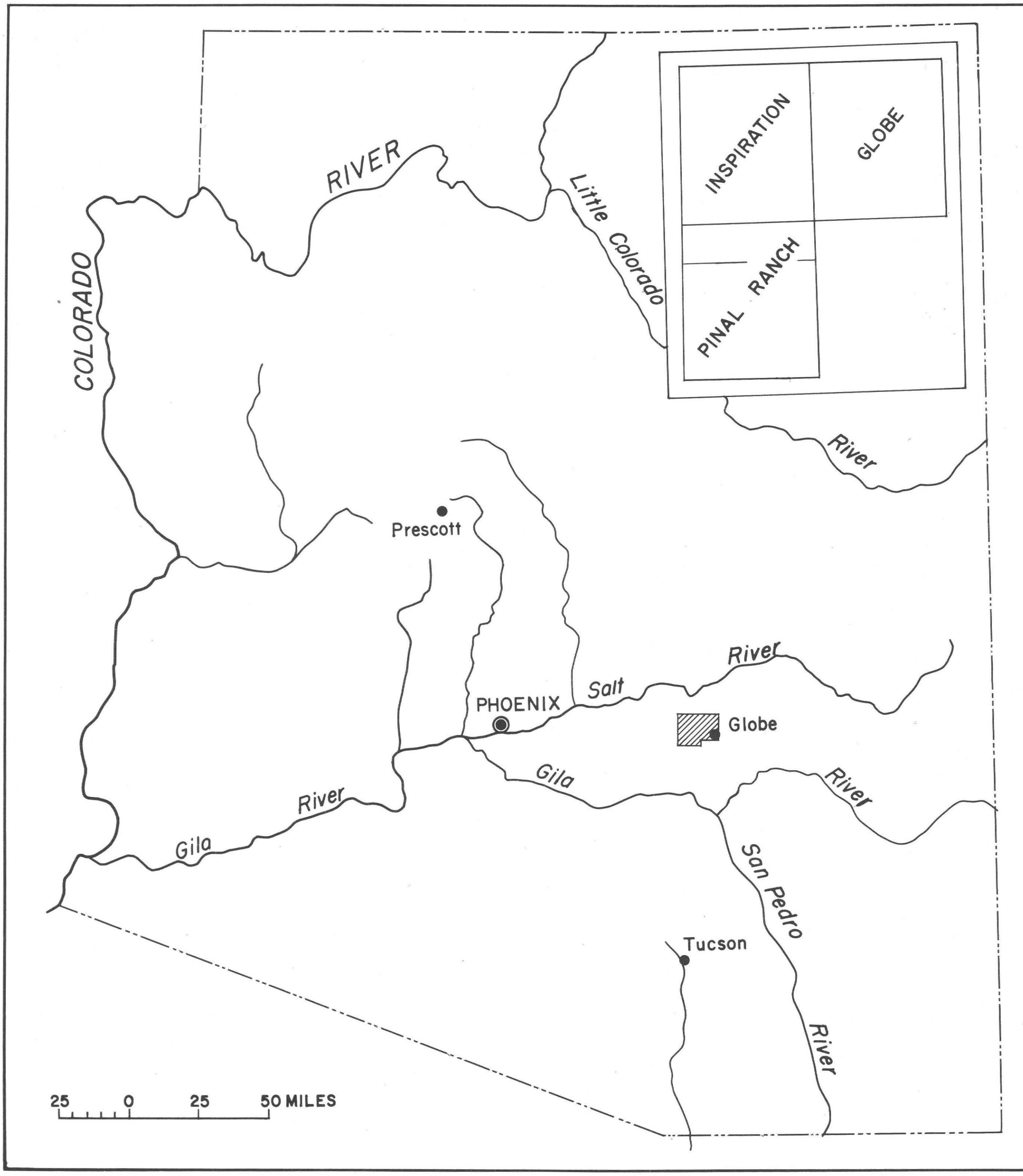


FIGURE 1.—Index map of Arizona showing the location of the mapped areas of plate 1.

of the Salt River Water Users Association at Roosevelt Dam. Natural gas for domestic and industrial fuel is brought to the district by a 6-inch and an 8-inch pipe line owned and operated by El Paso Natural Gas Co.

Water for domestic use is obtained from wells in the Gila conglomerate and from the inflow from the Gila conglomerate into the southwestern end of the Old Dominion mine at Globe. The Miami Copper Co. obtains water for industrial use from drainage into the northeastern part of the Old Dominion mine and from wells on Pinal Creek at Burch siding; and Inspiration Consolidated Copper Co. from wells at Pringle Ranch on Pinal Creek, 15 miles north of Globe.

CLIMATE AND VEGETATION

The climate of the Globe-Miami district is mild and dry. The maximum temperature ranges from 104° F. to 108° F., and generally the hottest days are in June and July; the coldest days are usually in December and January, when the minimum temperature may range from 11° F. to 22° F. during the early morning hours. The mean annual temperature at Globe is about 61.3° F.

The mean annual precipitation at Globe is about 17 inches, but usually amounts to several inches more in the western part of the district. Most of the precipitation occurs during two periods: one, in July and August is characterized by sudden, short, heavy showers or cloudbursts, the other, from December to February, by light, steady rains that may continue for several days. May and June are the driest months of the year and commonly pass without appreciable rainfall. During the winter months light snowfalls occur occasionally in Globe and Miami, and commonly in the vicinity of Castle Dome and Pinal Ranch. The higher parts of the Pinal Mountains, 10 miles south of Globe, are generally snow covered from December to March.

The vegetation of the district is typical of the transition zone between the mountains of central Arizona and the hot, arid desert region of the southwestern part of the State. There are many varieties of thorny shrubs and bushes: cacti, ranging from miniature plants to the giant saguaros; ocotillo; maguey; and yucca. Manzanita, scrub oak, cedar, and piñon cover many of the higher slopes. Large sycamores commonly grow along the beds of intermittent streams, and clumps of cottonwood mark the position of springs and permanent water.

GENERAL PHYSIOGRAPHIC SETTING

Ransome (1903, p. 14–16) divided the State of Arizona into three physiographic provinces: the plateau region, the desert region, and the mountain region. The Globe-Miami district lies in the middle part of the mountain region, which Ransome described as a broad zone of short, nearly parallel mountain ranges extending diagonally across Arizona from the southeast corner northwestward to the Colorado River. The mountain region separates the Colorado Plateau to the northeast from the desert region, characterized by typical basin and range structure to the southwest. It is 60 to 100 miles wide and contains most of the large base-metal deposits of Arizona. It is the southwestern segment of the peripheral zone of the Colorado Plateau. This zone, as Butler has pointed out (1929, p. 23), contains most of the important ore deposits of the southern Rocky Mountain region.

The district is divided into two parts by the broad Globe Valley. That part southwest of the valley is in the foothills of the Pinal Mountains, whereas the part northeast of the valley, the Globe Hills, is in the lower foothills of the Apache Mountains.

The Pinal Mountains are but one unit of a chain of northwestward-trending ranges that characterize the larger topographic features of the region. Southwest of the Pinal Mountains and parallel to them are the Dripping Spring and Tortilla Ranges. The southeastward continuation of this chain is made by the Mescal, Pinlaeno, and Galiuro Mountains. All are typical desert ranges with intervening valleys filled by fluviatile and lacustrine deposits.

The main part of the Pinal Mountains, which is south of the mapped area, is characterized by rugged peaks and steep, narrow canyons carved in schist and granitic intrusive rocks. The highest point, Pinal Peak, is 8 miles south of Globe and rises to 7,850 feet above sea level, about 4,500 feet above the lowest part of Globe Valley. Toward the northwest, elevations decrease abruptly to a rugged valley underlain by the mass of Schultze granite that is seen along U.S. Highway 60–70 west of Miami to Pinal Ranch.

The mountainous area north of this valley and lying between Pinto and Pinal Creeks (pl. 1) is generally considered to be the northwestward continuation of the Pinal Mountains. It covers most of the Inspiration quadrangle. The topography of this area is extremely irregular and varied, owing to the effect of erosion on complexly faulted structure and diverse rock formations.

Porphyry Mountain in the southern part of this area owes its prominence to a horst and to the resistance of the uplifted granitic block to erosion. Many of the hills are capped by quartzite overlying masses of less resistant diabase. Outcrops of dacite form some of the highest hills, such as Webster and Flat Top Mountains and Sleeping Beauty Peak. In broad aspect, they are flattopped and mesalike, but in detail they are seen to be strewn with large rounded boulderlike masses and are extremely rough, generally being bounded by steep cliffs flanked by streams of coarse talus.

In the northern part of the Inspiration quadrangle, the deeply weathered outcrops of Precambrian granite form broad valleys and low rounded hills. These areas, typified by Ruin and Granite Basins, are surrounded by ridges carved from complexly faulted blocks of sedimentary rocks and intrusive diabase in which erosion develops no regular pattern and its effects are governed almost completely by the relative resistance of the various formations.

The Globe Hills area, lying east of Pinal Creek in the northeastern half of the Globe quadrangle, can be considered as the lower foothills of the Apache Peaks, of which Apache Peak, about 6 miles north of the northeastern corner of the quadrangle, is the highest point. Near the northeast corner of the Globe quadrangle, the topography is characterized by a series of northwestward-trending ridges that coincide with step-faulted blocks of quartzite underlain at least in part by diabase. Farther southwest toward Pinal Creek, erosion has largely stripped off the quartzite, forming a broad hilly slope carved in diabase. Many of the hills are cuestas formed by southwestward-tilting blocks of quartzite that were engulfed by intruded diabase. The southern part of the Globe Hills area is like that west of Pinal Creek. It is complexly faulted, and the very irregular topography reflects the structural pattern.

The broad valley between the Pinal Mountains and Apache Peaks is filled by thick fluviatile deposits, the Gila conglomerate of Pliocene and early Pleistocene age, composed of detritus washed down from the bordering highlands. Toward the south, the conglomerate overlaps the northeastern flanks of the Pinal Mountains to an altitude of about 4,500 feet, where there is a marked change in the topographic pattern. Toward the northeast, the conglomerate overlaps the southern part of the Globe Hills area along Pinal Creek; and north of the junction of Pinal Creek and Miami Wash, it extends northeastward, covering the terrain formed on diabase, to high up on the southwestern flanks of the Apache Peaks.

The topography of the areas underlain by the Gila conglomerate is characteristic of that formed in the destruction of a gently sloping plain of a nearly homogeneous rock. The surface is intricately dissected by a uniform, dendritic pattern of arroyos separated by smooth rounded ridges and spurs (fig. 2). The lower reaches of the main channels have broad gravelly beds of nearly uniform gradient.

DRAINAGE

Almost all the mapped area drains northward into the Salt River by way of Pinto and Pinal Creeks. Small areas along the east edge of the Globe quadrangle drain eastward by way of Aliso Creek and San Carlos River into the Gila River. The Salt River and Gila River drainage systems are separated by a low divide from the southeastern corner of the Globe quadrangle at Pinal siding, whence it follows an irregular course northward across Buckeye Mountain, Black Peak, Ramboz Peak, and Nugget Mountain.

The divide between the drainage system of Pinto Creek and that of Pinal Creek is across the central part of the Inspiration quadrangle. It extends northward approximately along the Castle Dome road to Jewel Hill, across Webster Mountain, and along the crest of the ridge that forms the west rim of Granite Basin. The main tributaries draining westward into Pinto Creek are Gold Gulch, Eastwater and Ripper Spring Canyons, and Scanlan and Barnes Washes. Bloody Tanks Wash, Russell Gulch, Webster Gulch, Tinhorn Wash, and Gerald Wash are the main tributaries draining eastward into Pinal Creek.

Pinto Creek heads in the Pinal Mountains and generally flows steadily during the winter and spring months and for short intervals after heavy summer rains. The surface flow in Pinal Creek within the bounds of the mapped area is intermittent throughout the year. Gold Gulch usually shows seepage or slight flow that persists most of the year during periods of average or more than average annual precipitation. All other tributaries are dry except during short intervals after heavy rain or snow.

Pinal Creek has a substantial permanent underground flow that rises to the surface at the narrows near Pringle Ranch, 15 miles downstream from Globe. On March 28, 1945, when there was no surface flow for about 10 miles below Globe, G. E. Hazen and S. F. Turner (written communication, 1946) estimated the flow at the pumping plant 3 miles above the narrows to be 6,000 to 7,000 gallons per minute, of which 1,500 to 2,000 gallons per minute is pumped throughout the year for metallurgical use at Inspiration.

PREVIOUS WORK

The first geologic study of the Globe-Miami district was made in 1901 and 1902 by F. L. Ransome (1903 and 1904a) of the U.S. Geological Survey. He mapped the geology of the original 15-minute Globe quadrangle on a scale of 1 : 62,500 and described the Old Dominion, United Globe mines in the Globe Hills area and several

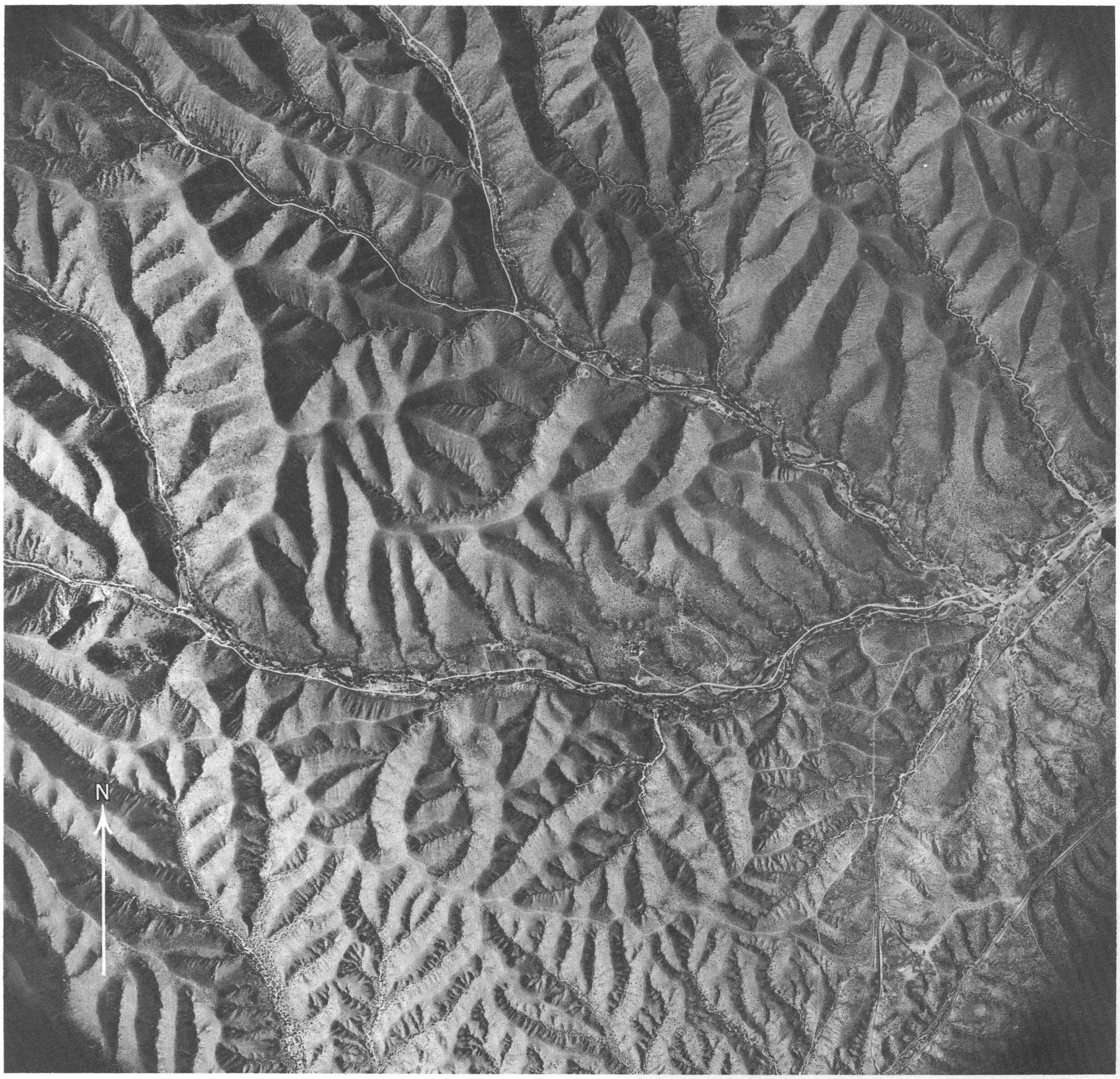


FIGURE 2.—Aerial photograph illustrating typical drainage pattern developed in areas underlain by Gila conglomerate.

other smaller properties that were being worked at that time.

Ransome began mapping the geology of the adjacent Ray quadrangle in October 1910; and in the course of this work, he remapped on a scale of 1: 12,000 the area west of Miami, which was then the object of considerable attention because of the discovery of large low-grade bodies of disseminated copper minerals. The fieldwork was continued intermittently until 1916, and the results were published by the U.S. Geological Survey in 1919 as Professional Paper 115.

Many short papers about the geology, mineralogy, mining methods, and metallurgy of the district have been written by members of the staffs of the various operating companies and published in technical journals. The titles of most of the works concerned with the geology of the district appear in the bibliography at the end of this report.

FIELDWORK AND ACKNOWLEDGMENTS

The fieldwork in the Globe-Miami district began in July 1943, when the Geological Survey undertook a detailed study of the Castle Dome area in connection with the development of the Castle Dome copper deposit. An area of about 6 square miles was mapped at a scale of 1:2,400 on a photogrammetric base map supplied by the Castle Dome Copper Co. The fieldwork was completed in September 1944, and maps and descriptions of the copper deposit were published in 1951 (Peterson, Gilbert, and Quick).

When this project had been completed, it was decided to extend the detailed study to include the entire Globe-Miami district. Areal mapping was done on a scale of 1:12,000 on a photogrammetric base prepared by the Geological Survey. Fieldwork continued at various intervals until June 1953. C. M. Gilbert, G. L. Quick, J. P. Albers, J. V. N. Dorr, 2d, Waldemere Bejnar, D. W. Peterson, Leonid Bryner, H. C. Rainey, and J. C. McKallor assisted with the fieldwork and preparation of reports at various times.

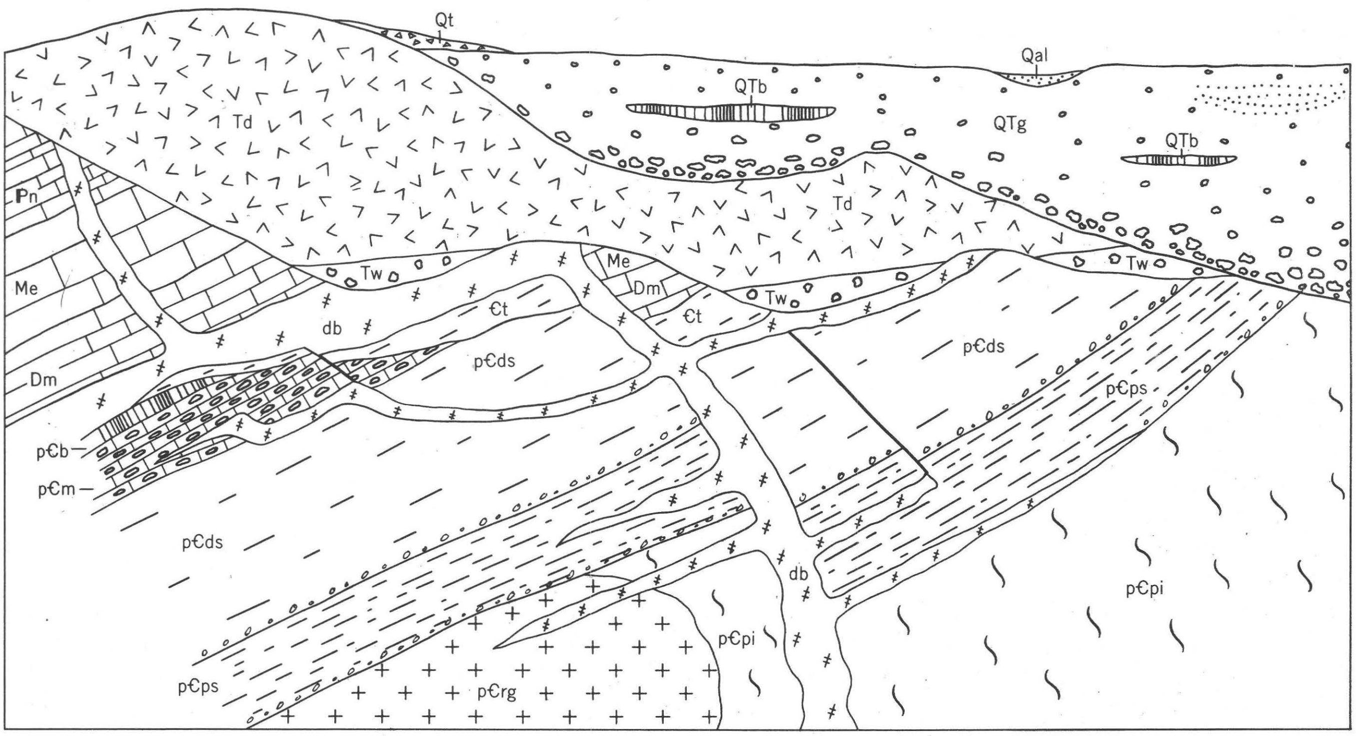
It is a pleasure to acknowledge the cordial cooperation of the local executives of the various operating companies and their technical staffs. Special acknowledgment is due Mr. R. W. Hughes, general manager, and Mr. B. R. Coil, assistant manager, of the Miami Copper Co.; Mr. P. D. I. Honeyman, general manager, Mr. H. C. Weed, general superintendent, and Mr. E. F. Reed, geologist, of the Inspiration Consolidated Copper Co.

The early work of F. L. Ransome, of the Geological Survey, was of great assistance, furnishing many data on mines and areas now inaccessible. The discussion of the Old Dominion property is based mainly on the meticulous detailed mapping of the underground workings by Guy N. Bjorge and A. H. Shoemaker. Maps and records of the Iron Cap mine were supplied by F. P. Knight and Sam Knight. Much of the history of mining development during the early days of the district was taken from unpublished notes compiled by J. B. Tenney, of the Arizona Bureau of Mines.

GENERAL GEOLOGY

PRELIMINARY SUMMARY

The rocks of the Globe-Miami district range from lower Precambrian to Recent. They are shown on the geologic map (pl. 1). Figure 3 is a diagram show-



EXPLANATION

Alluvium, Qal; talus, Qt; basalt, QTb; Gila conglomerate, QTg; dacite, Td; Whitetail conglomerate, Tw; diabase, db; Naco limestone, Pn; Escabrosa limestone, Me; Martin limestone, Dm; Troy quartzite, €t; basalt, p€b; Mescal limestone, p€m; Dripping Spring quartzite, Barnes conglomerate at the base, p€ds; Pioneer formation, Scanlan conglomerate at the base, p€ps; Ruin granite, p€rg; and Pinal schist, p€pi

FIGURE 3.—Diagram showing the hypothetical general relationships of the sedimentary and volcanic rocks and the intruded diabase.

ing the hypothetical general relationships of the sedimentary and volcanic rocks and the intruded diabase.

The oldest rocks are lower Precambrian crystalline schists, mainly of sedimentary origin, that had been highly deformed, invaded by various igneous rocks, and deeply eroded before the upper Precambrian sedimentary sequence known as the Apache group was deposited. The rocks of the Paleozoic era consist of the Troy quartzite of Cambrian age, the Martin limestone of Devonian age, the Escabrosa limestone of Mississippian age, and the Naco limestone of Pennsylvanian age. No sedimentary rocks of the Mesozoic era are represented, but a series of igneous intrusions probably began in Late Cretaceous and continued into early Tertiary time. The intrusions were accompanied by extensive faulting and deformation of the rocks and were climaxed by widespread copper mineralization in the district. Probably also in Tertiary time, the Whitetail conglomerate was deposited, and a vast sheet of tuff and dacite was erupted over the eroded surface of the fault-block mosaic of sedimentary and igneous rocks. Faulting continued and later in Pliocene and Pleistocene time, alluvial deposits that form the Gila conglomerate were laid down unconformably on the deeply eroded surface of dacite and older formations. Mild volcanic activity accompanied deposition of the Gila conglomerate, and further faulting and uplift followed, resulting in the current erosion cycle that is wearing away the conglomerate and depositing talus on the slopes and alluvium along the beds of intermittent streams.

LOWER PRECAMBRIAN ROCKS

PINAL SCHIST AND INTRUDED COMPLEX OF DIORITIC ROCKS

The Pinal schist and the large bodies of igneous rock intruded into it in early Precambrian time constitute the basement complex of the Globe-Miami district and surrounding region. Ransome's (1903, p. 23–28) type locality for the Pinal schist is in the Pinal Mountains south of Globe and Miami. Later he (1904b, p. 24) applied the name to the basal schistose rock of the Bisbee quadrangle near the southeastern corner of Arizona, and the name is now applied to the basal schists throughout the southeastern part of the state. The Pinal schist is generally correlated in age with the Yavapai series of central Arizona and with the Vishnu schist of the Grand Canyon Region of northern Arizona.

There are extensive outcrops of Pinal schist in the Pinal Mountains south of the Globe-Miami district, and the several relatively small outcrops in the southwestern part of the district are separated from the main outcrops in the Pinal Mountains by the extensive intrusive body of Schultze granite. The largest outcrops within the mapped area are in the southeastern part of the Inspiration quadrangle from Bloody Tanks Wash northward to the mass of quartz monzonite south of Sleeping Beauty Peak. A large body crops out in the Castle Dome horst block south of Gold Gulch, and others crop out west of Pinto Creek near the southwest corner of the quadrangle.

In the Globe Hills area in the eastern part of the district, Pinal schist is reached by the bottom levels of the Old Dominion, Iron Cap, and Superior and Boston mines, but there is only one small outcrop, a mile north of Black Peak. Throughout the rest of the northern part of the district, the upper Precambrian and Paleozoic sedimentary rocks rest on the truncated surface of Ruin granite, which probably intruded the schist, although direct proof is lacking.

The Pinal schist exposed in the district comprises a gradational variety of rocks that range from very fine grained quartz-sericite schist to rather coarse feldspathic sandstone. A few small bodies of amphibolite are known, and in a few places the schist appears to have been formed from rhyolite or fine-grained granite. Most of the schist, however, was formed by dynamic and thermal metamorphism of interbedded shale and feldspathic sandstone. Relict bedding is recognizable in most outcrops and is generally parallel with the foliation.

In most of the larger outcrops, the schist can be divided into fairly distinct units that could be separately mapped. No detailed stratigraphic study of the schist has been undertaken, however because the results do not seem to justify the necessary time and labor. The outcrops within the mapped area are relatively small, and the units have been displaced by faults and igneous intrusions and are not sufficiently characteristic to permit correlation from one outcrop to another. The larger outcrops show that beds are lenticular and are interfingered on a relatively small scale.

The Pinal schist comprises such a wide range of gradational varieties of rocks whose stratigraphic relationships are not known that detailed descriptions would have little significance. The most common varieties have approximately the same mineral composition. They are essentially quartz and muscovite, which generally compose at least 75 percent of the rock. They range from fine-grained quartz-sericite-chlorite schist to coarse-grained quartz-muscovite schist. Nearly all contain some fine-grained flaky biotite or chlorite, or both. Magnetite and ilmenite are present in variable amounts, either as fine disseminated grains or segregated in thin layers with grains of quartz.

The schist ranges from a highly foliated rock to a coarsely granular rock having only slight or no apparent foliation. The foliation results from thin layers composed almost entirely of quartz grains, alternating with thin layers composed mostly of muscovite. Flaky biotite, partly or wholly altered to chlorite, is more abundant in some layers than in others and is commonly segregated in small clots or larger knots as much as a centimeter in diameter. The proportion of biotite to chlorite differs greatly from place to place, and generally, schists containing a large amount of biotite also contain abundant magnetite. The microscope shows scattered stubby prisms of blue tourmaline, which are most abundant in areas containing abundant biotite or chlorite. Occasional prisms of zircon, clusters of rutile, and clinozoisite also are visible in most thin sections.

The highly foliated varieties of schist are light gray to greenish gray; some are dull, and others have a bright silver-gray, satiny sheen. In general, the luster increases with the coarseness of the muscovite, probably the result of a higher degree of metamorphism.

The coarsely granular or sandy varieties of schist are composed largely of quartz and feldspar grains, with subordinate amounts of muscovite. They are generally grayish yellow and contain very little or no biotite or magnetite. They are not noticeably foliated but have a faint gneissic texture caused by coarse layers of quartz and feldspar grains alternating with layers or thin lenses rich in muscovite.

A distinctive and rather common variety is a highly contorted fine-grained quartz-sericite-chlorite schist. It contains abundant short veins and small lenticular masses of glassy quartz, the latter localized along the crests of small close folds. Another variety common in the vicinity of the Miami-Inspiration ore body is spotted with dark-colored knots that are local segregations of biotite or chlorite. Less common is a grayish-black fine-grained rock with slaty cleavage.

The differences in the physical characteristics of the rocks included in the Pinal schist are due partly to differences in the texture and mineral composition of the original sediments and partly to differences in the degree and type of metamorphism to which they were subjected. Tectonic deformation of the sediments during the early stages of the Mazatzal revolution undoubtedly accounts for the initial, generally low-grade, regional metamorphism that characterizes the Pinal schist throughout most of southeastern Arizona. Igneous intrusions, both early Precambrian and those of Mesozoic and Tertiary age, also affected the schist and probably account to a large extent for the local differences in the degree of metamorphism and crystallinity. But even the earliest intrusive bodies contain many unoriented inclusions of schist in many places along their borders, suggesting perhaps that metamorphism was well advanced before the first intrusions.

Between Webster Gulch and the mass of Lost Gulch quartz monzonite south of Sleeping Beauty Peak, the schist has been intricately intruded by a complex of dioritic rocks. These rocks are not differentiated from the Pinal schist on the map (pl. 1) because their relationships with the schist are so complex and the exposures are so poor in this area that attempts to map them separately have proved unsatisfactory. A line drawn northeastward through the southern part of the two main outcrops of Willow Spring granodiorite is approximately the southern boundary of the area in which these igneous rocks predominate.

The schist intruded by these rocks is mainly a coarse-grained sandy variety composed largely of quartz and feldspar grains. It contains very little mica and is but slightly foliated. The dioritic rocks, also slightly foliated, occur as small sills, dikes, and irregular bodies. Both the schist and the dioritic rocks disintegrate readily, and in weathered outcrops it is often difficult to differentiate them. In some places where the exposures are good, numerous variously oriented inclusions of schist can be seen in the igneous rocks.

The dioritic rocks are of several types but are mostly equigranular, medium- to fine-grained, biotite-quartz diorite or granodiorite. A variety that occurs as small dikes and masses is medium to coarse grained and locally consists largely of biotite. It commonly contains abundant sphene and, in some places, a little hornblende.

The dioritic rocks are clearly older than the period of erosion that produced the level surface on which the upper Precambrian Apache group rests, for the basal formation, the Scanlan conglomerate, lies on the truncated surfaces of the small intrusive bodies and, in places, contains fragments of these rocks. Probably they should be correlated with the Madera diorite of the Pinal Mountains to the south.

The small isolated outcrop of Pinal schist a mile north of Black Peak is intruded by a complex of dioritic rocks that also probably should be correlated with the Madera diorite.

MADERA DIORITE

Extensive outcrops of granodiorite in the Pinal Mountains, south of the Globe-Miami area, have been described by Ransome (1903, p. 58–65), who named the rock Madera diorite from its exposures on Mount Madera, a prominent peak of the Pinal Mountains. Although the rock differs slightly in composition and character from place to place, the general characteristics are so similar that the various masses exposed undoubtedly belong to the same period of intrusion.

The Madera diorite intrudes only the Pinal schist, and in some places it includes abundant fragments of schist. The smaller bodies are slightly foliated, and the larger masses are generally foliated near their contacts with the schist.

A rock petrographically identical with the Madera diorite of the Mount Madera mass crops out in Copper Gulch just north of Globe, southwest of the Old Dominion "A" shaft, and in several places along the east side of Pinal Creek. The rock is highly shattered and might easily be mistaken for coarse detritus but for the fact that it is clearly intruded by four small bodies of granite porphyry. It is underlain by dacite and is overlapped by Gila conglomerate. The outcrops are those of a wedge-shaped remnant of a plate of Madera diorite that has been thrust over the dacite from the southwest.

The rock in the overthrust plate is a medium-grained granodiorite. White feldspar, quartz, black biotite, and greenish-yellow specks of epidote can be recognized in hand specimens. Clots of black biotite are evenly distributed through the rock, giving the outcrops a uniform bright-gray color.

In thin section, the rock is seen to have a subhedral, nonporphyritic granular texture. Andesine, approximately An_{40}; quartz; and olive-brown biotite, in grains 1 to 3 mm in diameter, are the most abundant minerals. Microcline and muscovite are present in subordinate amounts. The grains of andesine and biotite are generally subhedral, whereas all those of quartz and microcline are anhedral. The accessory minerals are apatite, magnetite, and zircon. Epidote, chlorite, and a little sericite and calcite occur as alteration products of the biotite and plagioclase.

Within the Globe-Miami area, no relationships have been observed whereby the age of the Madera diorite can be established. The granite porphyry intruding the shattered granodiorite of the thrust plate north of Globe may be related to the Schultze granite; and south of the map area in the Pinal Ranch quadrangle, several dikes, probably offshoots of the Schultze granite mass, cut both the Pinal schist and the Madera diorite. In the northeastern part of the Ray quadrangle (Ransome, 1923), 12 miles south of Globe, the Madera diorite is overlain by the Scanlan conglomerate, the basal formation of the upper Precambrian Apache group. On the basis of this evidence, all the similar granodiorite masses of the Pinal Mountains are believed to be lower Precambrian. The facts that the Madera diorite has undergone some dynamic metamorphism and that it does not intrude any of the younger rocks also suggest that it is lower Precambrian.

GRANITE ON MANITOU HILL

A number of irregular elongate masses of granite crop out along a zone that extends northeastward from near the head of Powers Gulch in the northwestern part of the Pinal Ranch quadrangle through Manitou Hill to a point south of Jewel Hill in the Inspiration quadrangle. All intrude the Pinal schist, are elongate parallel to the general foliation of the schist, and are probably thick sills.

The granite is yellowish gray and is fine to medium grained. It is composed essentially of quartz, orthoclase, muscovite, and a little plagioclase and biotite. The plagioclase is sodic oligoclase. Magnetite and zircon are accessory, and both are rare.

Crude foliation has been developed in the granite by the crushing and elongation of the quartz and feldspar and by the orientation of mica. This foliation is clearly of metamorphic origin, as it is everywhere parallel to the regional schistosity and is not related to discordant contacts of the granite bodies. However, most of the metamorphism of the Pinal schist preceded the intrusion of the granite, for on Manitou Hill, unoriented inclusions of schist occur in the granite.

The field relationships show that this granite, though younger than the Pinal schist, is older than the Schultze granite for the latter intrudes it at several places. It is believed to be of early Precambrian age because it has undergone some metamorphism and, in places, contains numerous quartz veins which appear to have been produced during the same period of mineralization that produced the glassy-quartz veins in the Pinal schist which undoubtedly were the source of the quartz pebbles of the Scanlan conglomerate (p. 13).

RUIN GRANITE

Ransome (1903, p. 73–75) gave the name Ruin granite to the coarse-grained porphyritic rock that crops out in the northern part of the Globe and Inspiration quadrangles. Ruin granite probably underlies most of the northern half of the Inspiration quadrangle. It crops out almost continuously from the southern end of Granite Basin to the northwest corner of the quadrangle, and it underlies Ruin Basin. Farther east several small outcrops occur near the northern boundary of the Globe quadrangle. All these outcrops are probably parts of the much larger mass of petrographically similar rock that crops out north of the map area. Similar granitic rocks occur throughout the mountain region of Arizona.

In Granite and Ruin Basins, the granite outcrops form broad, relatively flat valleys surrounded by hills in which the younger sedimentary rocks crop out. In most places the contacts of the granite with the younger rocks are faults, many with diabase intruded along them.

In these flat valleys, the granite is deeply weathered and uniformly light brown. The outcrops are almost completely mantled by a layer of coarse arkosic debris ranging from a few inches to more than 50 feet in thickness. The plagioclase grains of the granite are the first to be affected by weathering, and when they decompose the rock crumbles to a loose aggregate of quartz grains, fragments and whole phenocrysts of orthoclase, and flakes of biotite. In its upper few feet, the arkosic mantle is composed almostly entirely of quartz and orthoclase and shows some evidence of transportation by surface waters. Toward the base it contains increasing amounts of granite fragments, plagioclase, and biotite, and the decomposed rock grades so perfectly into the underlying granite that it is difficult to locate the contact between them. Even where the solid granite crops out, the rock crumbles so readily that it is almost impossible to break out a hand specimen.

The Ruin granite is typically of coarse-grained porphyritic texture, having large phenocrysts of pale-pink orthoclase from 10 to 50 mm long and smaller phenocrysts of quartz. The orthoclase phenocrysts poikilitically enclose grains of white plagioclase; some are rounded and have rims that include numerous small plagioclase grains. In the coarse-grained groundmass, quartz, pale-pink orthoclase, chalky-white plagioclase, books of black biotite, and magnetite can be recognized without aid of a hand lens. Although the bulk composition of the rock appears to be fairly uniform throughout the map area, there are local differences in the relative proportions of the constituent minerals. There is noticeable difference in the relative abundance of the large orthoclase phenocrysts; and in some areas there appears to be more biotite than elsewhere. The rock is usually too much altered to permit making an accurate estimate of the relative proportions of orthoclase and plagioclase; but in most places orthoclase appears to predominate. The average composition of the rock probably places it near the division point between granite and quartz monzonite.

Under the microscope the pale-pink feldspar of the groundmass and phenocrysts is seen to be microcline microperthite. The plagioclase ranges in composition from albite to andesine. In facies of the granite containing albite, microcline greatly exceeds albite; whereas, in facies containing andesine, microcline is subordinate to andesine. The biotite is pleochroic, ranging from pale olive to dark yellowish brown. Magnetite is fairly abundant and occurs with biotite. Apatite, zircon, and sphene are accessory. Sphene is abundant in some sections lacking in others, and much of it is altered to leucoxene. The texture of the groundmass is subhedral granular in which plagioclase most commonly occurs as subhedral grains.

In the northern part of the Inspiration quadrangle, there are many small irregular outcrops of a light-brown medium-grained rock that probably is an aplitic facies of the typical coarse-grained granite. The rock is a nearly equigranular aggregate of quartz, orthoclase, plagioclase, and a little muscovite. Most of the outcrops contain narrow discontinuous veins or lenses of pegmatite, generally not more than a foot wide and from 5 to 10 feet long. They are a graphic intergrowth of pale-red orthoclase and quartz and contain many irregular masses of quartz ranging from a quarter of an inch to 2 inches across.

That the Ruin granite is clearly lower Precambrian is shown by its relationship with the younger sedimentary rocks. Wherever the contacts between the Ruin granite and these younger rocks are not faults, the granite or its cover of arkosic debris is overlain by the Scanlan conglomerate, the basal formation of the upper Precambrian Apache group, which elsewhere rests on the Pinal schist or on igneous rocks that intrude the schist. The surface on which the Scanlan conglomerate was deposited truncates the steeply dipping beds of the Pinal schist and the masses of Ruin granite and is a profound unconformity that was formed during the period of erosion that followed the Mazatzal revolution at the close of the lower Precambrian.

The contact between the Ruin granite and the Pinal schist is not exposed anywhere in the mapped area; hence, there is no direct evidence that the granite intrudes the schist, though the assumption that it does appears to be the most probable one. In some places the granite contains many rounded xenoliths, 2 to 12 inches in diameter, of a fine-grained gray rock that may be inclusions of schist, completely recrystallized and with all evidence of foliation obliterated.

UPPER PRECAMBRIAN ROCKS

APACHE GROUP

REGIONAL RELATIONSHIPS AND AGE

The Apache group contains five distinct but conformable sedimentary formations: Scanlan conglomerate at the base, the Pioneer formation, the Barnes conglomerate, the Dripping Spring quartzite, and the Mescal limestone at the top. One or more flows of vesicular basalt overlie the Mescal limestone and are usually regarded as forming a unit of the group. As first described by Ransome (1903, p. 28–39) in the original

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Globe quadrangle, the group included only the first four of these formations. He inadvertently included the Troy quartzite as part of the Dripping Spring quartzite and assumed the Mescal limestone to be somewhat metamorphosed portions of the thin-bedded Devonian limestone in the lower part of his Globe limestone. Because the Apache group rests unconformably on the Pinal schist and intrusive Precambrian(?) rocks and is overlain by limestone containing Devonian fossils, Ransome suggested that the age of the group might be late Precambrian, Cambrian, or Silurian and tentatively chose Cambrian as being the most probable.

About 9 years later while mapping the Ray quadrangle, where the outcrops present much more complete sections than in the Globe quadrangle, Ransome (1919, p. 39) discovered that two quartzite units underlie the Devonian limestones, separated by about 200 feet of cherty limestone and a flow of basalt lava. He restricted the use of the name, Dripping Spring quartzite, to the lower of the quartzite units and named the intervening cherty limestone and the upper quartzite units the Mescal limestone and the Troy quartzite, respectively. He continued to favor a Cambrian age for the Apache group because of the lithologic similarity of the Mescal limestone and Abrigo limestone, which contained Upper Cambrian fossils and which he had mapped in the Bisbee quadrangle. Ransome (1919, p. 31) suggested, however, that some of the beds near the top of the group might be of Ordovician or Silurian age.

Later Darton (1925, p. 36) recognized that there was a disconformity between the Mescal limestone and the overlying Troy quartzite. He also found that the Troy quartzite lies stratigraphically between the unfossiliferous Mescal limestone and the Abrigo limestone. Cambrian fossils had been found in what is probably the upper part of the Troy quartzite in Ash Creek Canyon, northeast of Winkelman (Campbell, 1904, p. 243). Darton (1932) therefore excluded the Troy quartzite from the unfossiliferous formations of the Apache group which he assigned to the Algonkian (younger Precambrian) system because of their strong lithologic resemblance to the formations of the Grand Canyon series. He correlated the Mescal limestone with the Bass limestone and the Scanlan, Pioneer, and Barnes formations with the basal shales and conglomerates of the Grand Canyon series.

The Apache group and the Grand Canyon series probably are approximately the same age, but in view of the difficulties pointed out by Stoyanow (1936, p. 473) correlation of individual members appears too uncertain to be of value. They were deposited on opposite sides of an older Precambrian land mass, which Stoyanow (1939, p. 462) named Mazatzal land. Probable uplift of this land mass near the close of the Mazatzal revolution is indicated by a profound unconformity that separates the older Precambrian rocks from those of the younger Precambrian Apache group. Mazatzal land persisted as a positive element separating the two areas of deposition in Arizona at least during the early part of the Paleozoic era (Ransome, 1916, p. 165–166).

The Apache group lies unconformably on the deeply eroded surface of the Pinal schist and intruded rocks and, at the north, overlaps the Mazatzal quartzite (Wilson, 1939, p. 1151), which Wilson (1939, p. 1161) considers younger than the Pinal schist but older than the granitic rocks. Similarly the Grand Canyon series unconformably overlies the Vishnu schist of northern Arizona, which is generally regarded as the equivalent of the Pinal schist of southeastern Arizona. The Apache group is discomformably overlain by Troy quartzite of Middle Cambrian age, whereas the Grand Canyon series is unconformably overlain by the Tapeats sandstone, of Early Cambrian age.

SCANLAN CONGLOMERATE

The Scanlan conglomerate is the basal formation of the Apache group. In the Globe-Miami district it is rarely more than 6 feet thick and generally much less. It is too thin to be shown on the map (pl. 1) but is present wherever the map shows the Pioneer formation to be in normal contact with the older Precambrian rocks. The composition and character of the conglomerate differs from the formation it overlies, but with few exceptions it contains angular or subrounded fragments of white vein quartz and generally a few bits of schist. It appears to have been formed during the relatively rapid transgression of the Apache sea by a slight reworking of a thin mantle of local detritus that lay on the ancient peneplain.

The old peneplain must have been traversed by a few stream channels, for in some places the Scanlan conglomerate is 15 to 30 feet thick and is composed of water-worn fragments. About 10 miles south of Globe, in the northeastern part of the Ray quadrangle between Pioneer Mountain and Old Baldy Peak, the Scanlan overlies Madera diorite and is 15 feet thick. It is composed of closely packed ellipsoidal pebbles and cobbles of quartzite in a loosely cemented matrix of coarse arkosic sand. The Scanlan is of similar character at Roosevelt Dam, 30 miles northwest of Globe, where it ranges in thickness from 10 feet or less to 30 feet and overlies the irregular, channeled surface of a deeply weathered coarse-grained granite much like the Ruin granite. At both localities the pebbles and cobbles are of a hard vitreous quartzite like that of the pebbles and cobbles of the younger Barnes conglomerate; in fact, the Scanlan in these areas could not be distinguished from the Barnes except by its stratigraphic position under the Pioneer formation. Scanlan conglomerate of this type does not crop out in the map area.

There are many exposures of Scanlan conglomerate in the northern half of the Inspiration quadrangle, along the borders of the granite outcrops in Ruin and Granite Basins and in the vicinity of Barnes Peak. However, the exposures are not as extensive as might be expected, because in many places the Pioneer formation is in fault contact with the Ruin granite, which it normally overlies.

Although the Scanlan conglomerate is usually referred to as resting on the Ruin granite, actually in most places, it is separated from the granite by a layer of coarse arkose resembling the cover of arkosic detritus that mantles much of the outcrops of the Ruin granite in low-lying areas but is more firmly compacted and indurated and commonly is almost as resistant to erosion as the granite itself. In some places near normal contacts with the Scanlan, the arkose grades imperceptibly into the younger loosely consolidated arkosic detritus.

The typical Scanlan conglomerate, where it overlies granite, is a thin bed of dark-gray to black siltstone containing a few pebbles of white vein quartz, a few chips of schist, and many small grains of pale-red orthoclase and quartz. This dark bed may grade upward into a thin layer of hard coarse arkose, but in some places, where it is absent, the conglomerate is very much like the underlying arkose, except that it is crudely stratified and contains a few quartz pebbles and occasional bits of schist.

In the vicinity of Barnes Peak in the northwestern part of the Inspiration quadrangle (pl. 1), the Scanlan rests directly on coarse-grained Ruin granite or on a very thin layer of coarse arkose and is generally from 6 inches to 2 feet thick. In a few places that probably represent channels or slight depressions in the old land surface, the conglomerate thickens abruptly to as much as 10 feet. It is composed of closely packed pebbles and cobbles of white quartz, ½ inch to 4 inches in diameter, in a coarse matrix of quartz grains and cleavage fragments of orthoclase. The surface of the cobbles is characterized by peculiar knobs and indentations resembling those commonly formed by solution on the surface of limestone.

At the northern end of Ruin Basin, the Scanlan contains occasional cobbles of a grayish-red vitreous quartzite having the same surface irregularities as those near Barnes Peak. The quartzite is lithologically identical with that of the pebbles of the younger Barnes conglomerate and undoubtedly was derived from the same formation.

Scanlan conglomerate crops out on the east side of Moonshine Hill, near the west boundary of the Globe quadrangle (pl. 1), and there are a few short outcrops underlying small patches of Pioneer formation in the area west of Moonshine Hill just north of Webster Gulch (pl. 1). In this general area the Scanlan, overlain by a few feet of Pioneer formation, lies on Pinal schist or its intruded dioritic rocks. Sills of diabase intrude the Pioneer formation a few feet above the conglomerate.

The Scanlan in this area ranges from a few inches to 15 feet in thickness but is generally from 1 to 6 feet thick. It is composed of angular fragments of white vein quartz and small chips of schist in a matrix of dark-gray to black shale or siltstone that grades abruptly into dark reddish-brown or black arkosic quartzite of the Pioneer formation. Where the conglomerate overlies rocks of the dioritic complex, it generally contains a few fragments of igneous rock, in addition to those of quartz and schist, and it commonly contains small lenses of arkose.

Three miles west of the northeast corner of the Globe quadrangle, an outcrop of Precambrian Ruin granite is overlain by several small remnants of the Pioneer formation. These are blocks, largely bounded by faults, but most have depositional contacts on at least one side, along which a coarse reddish-orange arkose that is the equivalent of the Scanlan conglomerate crops out. It is a bed 1 to 5 feet thick that grades downward into reddened Ruin granite. The uppermost few inches of the bed contains a few angular fragments of white or gray quartz. The reddish-orange matrix of the arkose grades abruptly into hard fine-grained arkosic quartzite of the Pioneer formation.

The most extensive outcrops of Scanlan conglomerate in the district are in Castle Dome subarea, where the conglomerate occurs in many places along the north and west boundaries of the mass of quartz monzonite that crops out on Porphyry Mountain. The conglomerate probably was formed on a surface underlain by arkose mantling Ruin granite, but later, quartz monzonite was intruded between the granite and the conglomerate, for in most places along the intrusive contact, there is a layer of a peculiar red granitic rock that is the metamorphosed equivalent of the arkose that originally lay between the Scanlan conglomerate and the Ruin granite. The quartz monzonite magma, rising through a channel in the massive, crystalline basement rocks, found the layer of decomposed granite so weak that it spread horizontally, forming a thick sill-like mass under the cover of stratified sedimentary rocks.

The Scanlan conglomerate in the Castle Dome area and its relationship with the quartz monzonite has been described in detail in an earlier published report that deals with the Castle Dome area (Peterson, Gilbert, and Quick, 1951, p. 27–32).

PIONEER FORMATION

Outcrops of incomplete sections of the Pioneer formation are widely distributed throughout the area of sedimentary rocks and diabase in the northern part of the district. The Pioneer formation was extensively intruded by diabase sills and dikes; and in most outcrops, diabase either underlies or overlies the portion of the section that is present. The only outcrops of complete sections are in the vicinity of Barnes Peak, in the northwestern part of the Inspiration quadrangle. In the type section of the Apache group, on the east side of Barnes Peak, Ransome (1903, p. 31–33) estimated the thickness of the Pioneer formation to be about 200 feet. Exposures in underground workings in the Old Dominion and other mines indicate that the maximum thickness of the formation in the eastern part of the district is about 270 feet.

Although outcrops of Pioneer formation differ greatly in appearance, as a result of weathering and the effects of the intrusion of diabase, the prevailing finer grained texture and arkosic composition of the rock serve to distinguish it from the other quartzitic formations of the district. Throughout most of the mapped area, the Pioneer formation is a fine- to medium-grained arkosic quartzite. In most places, the lower 15 to 25 feet of the formation is especially arkosic and contains many granules of pale-red orthoclase; and in the northwestern part of the district, a coarse, dark, pebbly sandstone or grit, about 10 feet thick, commonly lies about 50 feet above the base. The Pioneer is generally thinly banded as a result partly of slight differences in grain size and partly of differences in mineral composition of the bands. The laminations commonly show low-angle crossbedding. Beds are 1 to 6 feet thick and are separated by soft shaly partings or thin layers of siltstone, some showing well-developed ripple marks. The rock is hard and brittle, and in most outcrops is prominently jointed and blocky.

The color of the rock differs greatly from place to place and to some extent in individual outcrops. Shades of red and brown predominate and range from grayish red purple to pale red and from light brown to light brownish gray. The darkest beds are generally near the top or base of the formation.

A characteristic feature of most beds is the presence of abundant greenish or gray spots, 1 to 4 mm in diameter, caused by clots of chlorite and magnetite or ilmenite. On partings parallel to the bedding, the rock breaks around these clots giving the surface a pimpled appearance. In some sections of the formation, gradation in texture from medium grained at the base to fine grained at the top is recognizable, and the upper part appears to be a little less arkosic than the lower part.

Thin sections of the typical Pioneer formation are composed of angular grains of quartz and feldspar with dimensions ranging from 0.025 to 0.5 mm in a very fine grained matrix, chiefly of clay minerals. The feldspar grains are highly altered and nearly opaque. Fine-grains of magnetite and ilmenite, largely replaced by leucoxene are sparsely disseminated throughout the rock and occur in the small clots, associated with chlorite. The matrix also contains occasional fine flakes of sericite.

In Ransome's (1903, p. 31) type section of the Apache group on the east side of Barnes Peak and in nearby outcrops, the Pioneer formation is not typical of the rest of the district but is a soft grayish-red arenaceous shale, with some intercalated thin beds of hard dark-colored siltstone. The shale commonly shows many light-colored, round, oval, or ring-shaped spots caused by local reduction of the ferruginous pigment. The lower 25 feet contains abundant cleavage fragments of pale-red orthoclase.

Gastil (1954) recently studied the Pioneer formation in the Diamond Butte quadrangle, about 50 miles north of Globe, and at other localities as far south as Old Baldy Peak, 12 miles south of Globe. He concluded that the Pioneer in 9 of the 12 sections that he studied consists entirely or predominantly of rhyolite tuff and tuffaceous siltstone. One of the sections, in which Gastil considers the Pioneer to be composed entirely of tuff, is in Gerald Wash, near the northeast corner of the Inspiration quadrangle.

BARNES CONGLOMERATE

The Barnes conglomerate lies between the Pioneer formation and the overlying Dripping Spring quartzite and might be considered to be the basal conglomerate of the Dripping Spring quartzite, but its unique charatcter suggests an origin far more complex than that of a typical basal conglomerate (p. 64). The Barnes is remarkably uniform in character and is present throughout the district wherever the Dripping Spring quartzite is in normal contact with the underlying Pioneer formation. In fact, this uniformity is characteristic of the Barnes wherever the Apache group is exposed over a large part of southeastern Arizona from the Little Dragoon Mountains on the south to the Mogollon Rim on the north, a distance of about 165 miles.

In the Globe-Miami district, the Barnes conglomerate ranges from about 6 inches to 50 feet in thickness but is most commonly 10 to 20 feet thick. It is composed of smooth, well-rounded, ellipsoidal pebbles in a matrix of coarse arkosic sand, so firmly cemented by silica that fractures generally cut through pebbles and matrix alike.

Most of the pebbles are of hard vitreous quartzite that ranges from very light gray to brownish gray. A much smaller proportion are of white glassy vein quartz, and generally there are a few small pebbles of red jasper or chert. The relative proportions of the three types of pebbles differ only slightly from place to place. The quartzitic rocks from which most of the pebbles were derived do not occur in the Globe-Miami district, but Wilson (1939, p. 1139) states that the quartzite of the pebbles is lithologically identical with the Mazatzal quartzite which crops out in the Mazatzal Mountains about 35 miles northwest of Globe.

The matrix is composed of coarse rounded quartz grains and pink orthoclase. Ferruginous pigment gives it a light-brown color. The contact of the Barnes conglomerate with the underlying fine-grained quartzite formation of the Pioneer is sharp; and although it is wavy, it is regular and conforms with the laminations in the quartzite. The upper surface of the Pioneer is commonly marked by a thin layer of siltstone, which is not indented by the pebbles. The pebbles, almost invariably, lie with their longest axes roughly parallel to the bedding.

The proportions of matrix and pebbles in the formation are not uniform in all exposures. In many places the pebbles are in contact, and there is only enough matrix to fill the interstices. Elsewhere, the matrix predominates, and the pebbles are more loosely packed or are distributed hapazardly. The conglomerate commonly contains lenses of matrix, from a few inches to several feet thick, interbedded with lenses of closely packed pebbles. In a few places the formation is but a thin bed of matrix containing only a few scattered pebbles or none at all, but even where no pebbles are present, the coarse arkosic matrix is readily distinguishable from the fine-grained Pioneer formation below it.

The matrix of the conglomerate is very similar in composition and texture to the lower beds of the Dripping Spring quartzite, and, in many places, the contact between the two formations is gradational and ill defined. In some places the contact is sharp and is marked by a thin layer of silt that forms the matrix around the uppermost pebbles.

DRIPPING SPRING QUARTZITE

Ransome assigned the name Dripping Spring to the quartzite that lies conformably above the Barnes conglomerate and under the Mescal limestone. The only place in the Globe-Miami district where a complete section of the formation can be studied with any assurance of its continuity is on the east side of Barnes Peak, where Ransome (1903, p. 30–32) measured his original type section of the Apache group. He estimated the thickness of the Dripping Spring quartzite in this section to be 425 feet. Other measured sections within the district that may be approximately complete range in thickness from 350 to 650 feet. There is undoubtedly considerable variation in the thickness of the formation, and its magnitude may be approximately as indicated by these measurements. Short and others (1943, p. 21) measured 820 feet of Dripping Spring quartzite in a section that crops out on the east side of Potts Canyon, about 4 miles west-northwest of Superior.

The general characteristics of the Dripping Spring quartzite are similar throughout the district, but the outcrops in various parts of the district differ somewhat in detail, chiefly in the prominence of the bedding and crossbedding and in the firmness of the rocks. The formation is divisible into two members.

The lower half to one-third of the formation is a light-gray to light-brownish-gray coarse- to medium-grained quartzite. Although it contains feldspar, no part of it is as arkosic as the Pioneer formation. The basal part of this member is very similar to the matrix of the Barnes conglomerate, but a few feet above their contact the quartzite becomes less arkosic and its grain size smaller. The lower part of the member generally shows distinct separation into beds that are thinly laminated and crossbedded. Higher in the section, the laminations and crossbedding become less distinct, and the quartzite becomes more massive in appearance. In some places the upper part of this member grades into a massive bed of white, nearly pure quartzite, 10 to 30 feet thick, that forms a prominent cliff. Wherever present, this massive bed forms the division between the upper and lower members.

The uppper half to two-thirds of the formation is thin bedded and flaggy. It is composed of beds of varicolored quartzite, 1 to 12 inches thick, alternating with beds of soft fissile arenaceous shale. The colors of the quartzite beds range from brownish black to pale yellowish orange; the shale is generally brownish gray. The variegated colors of the thin beds give the outcrops a characteristic banded appearance that is accentuated by the differential weathering of the hard quartzite and the soft shale. In the lower part of this member, the shale beds are as thick or thicker than the quartzite beds, whereas the upper part consists largely of quartzite beds separated by shaly partings only an inch or two thick.

MESCAL LIMESTONE

The Mescal limestone overlies the Dripping Spring quartzite and is the uppermost sedimentary formation of the Apache group. Most of the outcrops of the Mescal limestone in the Globe-Miami district are of small faulted blocks that are extensively intruded by diabase or completely surrounded by it. Many outcrops are inclusions, whose dimensions range from 10 feet to a few hundred feet, that have been isolated by the invading magma.

In the Globe quadrangle, the Mescal limestone is exposed in the mine workings along the Old Dominion vein system, and it crops out east of Black Peak, along the east boundary of the quadrangle; but is absent 2 miles farther north, in the northeastern part of the quadrangle, for the Troy quartzite lies directly on the Dripping Spring quartzite. There are many exposures of Mescal limestone in the northern half of the Inspiration quadrangle. Throughout the rest of the district the Mescal limestone and all but a few small remnants of Troy quartzite were removed during the erosional intervals that preceded and followed the Cambrian period.

Although its general characteristics are distinctive, the Mescal limestone is the most variable formation of the Apache group. It is composed of thin beds that have a great diversity in character and composition. No complete section crops out in the Globe-Miami district, and no sequence of beds has been established that permits correlation of beds from one outcrop to another. Ransome (1923, p. 3) estimated the thickness of the Mescal limestone in the Ray quarangle to the south to be 225 feet, and Darton (1925, p. 30) reported a section 300 feet thick at Roosevelt Dam to the north. A complete section, said to be about 360 feet thick (C. W. Bostford, written communication, 1919), is exposed in the Superior and Boston mine, east of Black Peak.

When viewed from a distance, outcrops of Mescal limestone have a distinctive chalky white appearance, but at close range the beds are seen to be white, light greenish gray, or light gray. Weathered surfaces of some of the cherty beds are various shades of brown. Individual beds range from a few inches to 2 feet in thickness. A few beds are of nearly pure, crystalline limestone, but most of them are of silicic and magnesian limestone. Some of the most silicic beds are a fine-grained aggregate of calcite and chalcedony; others are thinly laminated by layers of calcite alternating with layers of silicic material. On weathered surfaces, the laminated beds are prominently banded as a result of differential weathering of the layers. Some beds are composed largely of irregular segregations of chert or quartz, which commonly form crude bands parallel with the bedding and stand out in relief on weathered surfaces.

Concentric structures that are generally regarded as being a form of fossil algae are present in a few places but not so abundantly as to form entire beds as they do in the Mescal limestone exposed in the canyon of Salt River, 35 miles north of Globe.

In a few outcrops around the northern and eastern sides of Granite Basin in the Inspiration quadrangle (pl. 1), the limestone is commonly replaced by grayish-yellow-green serpentine that occurs in irregular masses or bands along fractures or bedding planes; in a few places the serpentine contains narrow discontinuous bands of cross-fibered chrysotile asbestos. All the asbestos seen in the outcrops is of the semibrittle, or harsh, variety that has little commercial value. The alteration of the limestone to serpentine is undoubtedly related in some way to the intrusion of diabase, but there are other as yet unrecognized conditions that limited it to certain definite areas.

BASALT OF THE APACHE GROUP

Soon after deposition in the Apache basin ceased, basaltic lava was erupted, and one or more flows were poured out over the Mescal limestone. Some erosion of the limestone may have preceded the eruption. The original extent and thickness of the flows are not known because in many places the basalt, the Mescal limestone, and part of the Dripping Spring quartzite were removed during an interval of erosion that preceded deposition of the Troy quartzite. In the Superior area, about 15 miles to the southwest, Harshman (Short and others, 1943, p. 34) measured a section of this basalt that is 220 feet thick and contains at least four separate flows. To the south, in the Ray quadrangle, Ransome (1923, p. 6) estimated the maximum present thickness of the basalt to be 75 to 100 feet.

In the Globe-Miami district, erosion has removed the basalt except in two small widely separated areas, much of it before deposition of the Troy in Middle Cambrian time. The basalt is exposed in the workings of the Old Dominion and other mines along the Old

Dominion vein system, but the only outcrops are southeast of Black Peak, near the east boundary of the Globe quadrangle, and about a mile south of Barnes Peak in the northwestern part of the Inspiration quadrangle.

In the outcrops southeast of Black Peak, the basalt overlies the Mescal limestone in several small faulted blocks, some of which are completely surrounded by diabase. A thick sill of diabase has been intruded between the basalt and the overlying Troy quartzite; but at the northeast end of Buckeye Mountain, a thin layer of basalt lies between the top of the sill and the base of the Troy. The basalt appears to have been altered or partly assimilated by the diabase magma; in weathered outcrops, it is difficult to determine where the basalt ends and diabase begins. More than one flow may be represented, but the exposures are so poor that the appearance of a multiple flow may well be the result of repetition caused by the minor faults that are abundant in this area.

In the area south of Barnes Peak, the occurrence is much the same. A thick diabase sill has been so intruded in the basalt as to split the flow and leave thin blocks of basalt under the Troy quartzite above the sill and others on the Mescal limestone below the sill. Other blocks were dislodged and completely engulfed by diabase.

The basalt of the outcrops is brownish gray to brownish black and is highly altered and decomposed. It was originally a rather coarse-grained olivine basalt but is now composed largely of serpentine, calcite, and iron oxides. Much of the basalt is vesicular, and the vesicles contain amygdules of calcite and chlorite.

CAMBRIAN SYSTEM

TROY QUARTZITE

The most extensive outcrops of Troy quartzite in the district are in the Globe quadrangle, northeast of Globe and near the northeast corner. The Troy also crops out in the gorge of Pinto Creek, near the west boundary of the Inspiration quadrangle; on the west side of Gold Gulch, 4,000 feet west of Porphyry Mountain; and in several small outcrops about a mile and a quarter south of Barnes Peak. Elsewhere in the district, the Troy was completely removed during an interval of erosion that preceded the deposition of the Martin limestone of Late Devonian age.

An erosional disconformity separates the Troy quartzite from the underlying rocks of the Apache group, and there may be some angular discordance of the strata where the Troy has been deposited as a blanket on an erosion surface of considerable relief. The Troy exposed in the gorge of Pinto Creek was deposited on the eroded surface of Dripping Spring quartzite, and in one place, the basal conglomerate fills a channel that cuts through the Barnes conglomerate into the Pioneer formation. In the area southeast of Black Peak, in the Globe quadrangle, the Troy was deposited on the basalt that overlies the Mescal limestone, but in the northeastern part of the quadrangle, it rests on Dripping Spring quartzite.

Wherever the base of the Troy is exposed, it is marked by conglomeratic beds that differ greatly in character from place to place. In the exposures along Gold Gulch and Pinto Creek in the western part of the district, the basal part is a massive coarse conglomerate as much as 40 feet thick. It is composed of large angular blocks from the Pioneer formation, Barnes conglomerate, and Dripping Spring quartzite and many small rounded pebbles derived from the Barnes conglomerate in a matrix of dark reddish-brown sandstone. The rock is so firmly cemented that the outcrops form prominent cliffs.

The coarse basal conglomerate grades upward into dark reddish-brown pebbly sandstone and slabby argillaceous sandstone containing round elongate forms that resemble worm borings. These upper beds resemble the uppermost part of the Troy in other areas of Arizona, in which the section is more complete. Along Pinto Creek, the Troy is from 160 to 200 feet thick. It lies on the eroded surface cut on Dripping Spring quartzite and Pioneer formation and is overlain by the basal beds of the Martin limestone.

In the mineralized area north of Globe, the basal conglomerate of the Troy quartzite is known as the Buffalo conglomerate, so named from the prominent exposures of the conglomerate along the west side of Buffalo Hill. It was a well-known marker zone in the underground mine workings.

The Troy quartzite on Buffalo Hill overlies a thick diabase sill that was intruded into the basal conglomerate. At the north end of the hill, the conglomerate is about 80 feet thick and probably represents a complete section. At the south end, only the upper 10 to 20 feet of the conglomerate is present, and along the middle part of the west side the conglomerate is entirely cut out by the diabase.

The basal bed of the conglomerate at the north end of the hill is a coarse rubble, 7 to 10 feet thick, of angular and subangular blocks of quartzite and chert breccia intermixed with rounded pebbles and cobbles of quartzite and chips of gray, black, and red chert. Some of the quartzite blocks at the bottom of the bed are as much as 5 feet in diameter.

Overlying this basal bed of very coarse unsorted fragments is a unit, 35 feet thick, composed of lenticular beds of conglomerate interfingering with layers of coarse-grained grayish-red argillaceous sandstone. The sandstone layers are generally pebbly and commonly crossbedded; the conglomerate beds have no distinct matrix and consist of a heterogenous aggregate of materials ranging in size from coarse sand to cobbles and subangular fragments as much as 10 inches in diameter. Toward the top of this unit the rock fragments become progressively smaller and more rounded, and the sandstone layers are thicker and more homogeneous.

The uppermost 35 feet forms a unit of well-stratified grayish-red conglomeratic sandstone interbedded with layers of grayish-red quartzite, 6 to 12 inches thick. The conglomeratic beds have a distinct matrix, and the pebbles and fragments are generally less than an inch in diameter. At the top, this unit grades abruptly into crossbedded quartz sandstone that is typical of the Troy quartzite.

Many of the fragments in the conglomerate beds are of very coarse grained quartzite unlike any of the rocks of the older sedimentary formations. Some of the fragments are of breccia or conglomerate composed largely of flat chips of light-gray to black chert resembling some that weather out of the cherty beds of the Mescal limestone. The presence of these fragments, whose source is uncertain, suggests that there may have been some, probably local, accumulation of sediments during Early and early Middle Cambrian time. It is quite possible that remnants of these early sediments are represented by some of the conglomeratic beds at the base of the Troy in the northeastern part of the Globe quadrangle.

In the northeastern part of the Globe quadrangle, where the most extensive outcrops of Troy quartzite occur, the conglomeratic basal beds show greater evidence of sorting and wave action than elsewhere in the district. The first material deposited was mainly reworked debris derived from the basalt flows of the Apache group and the Mescal limestone. Fragments derived from the quartzite units of the Apache group are relatively rare in the lowest beds, but they become progessively more abundant toward the top of the conglomerate. Although sections differ somewhat in detail, the general characteristics of the conglomerate are similar. The following section was measured at the top of a hill, just west of the road that is 9,000 feet south of the northeast corner of the Globe quadrangle. It is fairly typical of the basal part of the Troy quartzite in this area.

Section of basal part of Troy quartzite, 9,000 feet south of northeast corner of the Globe quadrangle

	Thickness feet
Erosion surface.	
6. Quartzite, very coarse grained, light-brown, pebbly, some thin lenticular beds of pebble conglomerate	100±
5. Sandstone, coarse-grained, light-brown, some crossbedded and ripple-marked coarse grits; and conglomerate similar to that in unit 4; in thin beds	39
4. Conglomerate; small, well-rounded pebbles of light-gray to pinkish-gray quartzite and a few water-worn chips of chert in a matrix of very coarse sandstone.	
3. Conglomerate; beds 6 to 12 in. thick: angular fragments of chert and light-gray to light brownish-gray banded quartzite and a few rounded quartzite pebbles; fragments in lower beds generally not more than 2 in. long and the matrix is fine grained; the fragments become progressively larger and the matrix coarser grained, in the higher beds; uppermost beds contain angular blocks of banded quartzite as much as 10 in. long; rounded pebbles more numerous in upper beds	27
2. Conglomerate; massive bed of flat chips and small angular fragments of light-gray to grayish-black chert in a matrix of hard, fine-grained, grayish-purple siltstone	33
1. Conglomerate, very hard; beds 6 to 18 in. thick; flat chips of dark-gray to black chert firmly cemented in a fine-grained pale-brown to grayish-brown quartzitic matrix; conglomeratic beds alternate with thinner beds of light-gray to pale-brown siltstone with fine wavy laminations	9
Erosional disconformity.	
Dripping Spring quartzite.	

The unit at the base of the section shows the greatest local differences in composition and character. In most outcrops it contains numerous fragments of vesicular basalt and generally a few pieces of Mescal limestone. Some fragments of Dripping Spring quartzite are generally present. In some outcrops the basal bed is composed largely of flat pieces of light-gray to black chert, ranging from a quarter to three-quarters of an inch in thickness, that lie in a sandy matrix with their flat sides parallel to the bedding. On the surfaces of weathered outcrops the chert fragments stand out in bold relief, as do the chert fragments on the weathered surfaces of certain cherty beds of the Mescal limestone from which these fragments undoubtedly were derived.

With the exception of the basal conglomeratic beds, the Troy quartzite is rather uniform in character and composition throughout the eastern part of the district. The lower part is typically brownish-gray medium- to coase-grained crossbedded sandstone or quartzite composed of closely packed rounded grains of glassy quartz. Locally it may contain a small amount of arkosic or argillaceous material, but rarely as much as the Dripping Spring quartzite, which it resembles more closely than any other rock in the district.

Beds are from 3 to 6 feet thick but are distinct only near the base of the formation. Some beds are separated by a single layer of pebbles, others by thin layers of siltstone that commonly show ripple marks or rain marks. A few scattered pebbles are found in most beds, and lenses of pebbly sandstone are fairly common. Upward in the section, bedding and crossbedding become less distinct or are entirely absent.

In the upper parts of the thickest sections, layers of thin-bedded slabby quartzite from 25 to 50 feet thick alternate with the layers of typical massive quartzite. Medium shades of brown, gray, or green are characteristic of the thin-bedded layers.

The Troy quartzite was deposited on an erosion surface of at least moderate relief. The underlying strata may have been slightly warped, but if so, the deformation was too slight to produce a recognizable angular unconformity. An interval of erosion occurred after deposition of the Troy quartzite, and by the time the Martin limestone was laid down in Late Devonian time, all the Troy had been removed from a large part of the district. Therefore, the total original thickness of the formation is not known. The maximum thickness of the Troy that remains cannot be determined with certainty because the amount of faulting that affected the continuity of the outcrop is not known. Undoubtedly there are many more faults that displace the outcrops than are shown on the map. Areas of quartzite breccia that probably indicate faults are common, but the continuity of these zones cannot be established because of the thin mantles of talus that obscure most outcrops of quartzite. Thicknesses of at least 400 feet of Troy quartzite can be determined with reasonable certainty, and the maximum thickness may well be as much as 700 feet.

As yet, no fossils have been found in the Troy quartzite of the Globe-Miami district, but in the Mescal Mountains, 14 miles south of Globe, Stoyanow (1936, p. 475) found Middle Cambrian brachiopods near its top. Still farther south, the Troy is overlain by the strata which he named the Santa Catalina formation and which he (1936, p. 480) correlates with the Marjum formation, of upper Middle Cambrian age, of the House Range section in Utah. Stoyanow's Santa Catalina formation is in turn overlain by the Abrigo formation which is of Late Cambrian age, according to Stoyanow. Thus on the basis of Stoyanow's work, no part of the Troy quartzite is younger than Middle Cambrian.

DEVONIAN SYSTEM

MARTIN LIMESTONE

During his first work in the Globe-Miami district, Ransome (1903, p. 39–46) included all the limestone units that apparently were younger than the Dripping Spring quartzite in a formation he named the Globe limestone. He recognized that this formation included strata of both Devonian and Carboniferous ages. The following year, while mapping in the Bisbee quadrangle, he gave the name Martin limestone to a limestone formation containing Upper Devonian fossils (1904b, p. 33–42). During his later work in the Ray quadrangle, which borders the original Globe quadrangle on the south, Ransome (1919, p. 45–48) divided the Paleozoic parts of the Globe limestone into two formations and extended use of the name Martin limestone to the lower part, which contains much the same assemblage of Upper Devonian fossils as the Martin limestone in the Bisbee quadrangle. He gave the name Tornado limestone to the upper formation, of Carboniferous age, and discarded the name Globe limestone. The use of the name Martin limestone has been extended by other geologists to include all limestone beds of Upper Devonian age throughout southeastern and central Arizona.

In the Globe-Miami district, the Martin limestone can be separated into five major members that usually can be readily recognized in most sections. There is, however, a great deal of variation in the minor units of these major members, especially in the lower members.

The total thickness of the Martin limestone ranges from about 150 feet to 350 feet. Thinning of as much as 150 feet may occur within a distance of 1,000 feet along the strike. This great difference in thickness appears to be due to the uneven erosion surface on which the Martin was laid down. Thus, within relatively small areas, the relief must have been at least 200 feet; and the total relief within the map area, estimated from the position of the base of the Martin, which ranges from well down in the Dripping Spring quartzite to some distance above the maximum section of Troy quartzite, may have been much greater, possibly as much as 1,200 feet.

A generalized and somewhat idealized section of the Martin limestone is illustrated by figure 4. The five major members are, a basal conglomerate member, a lower limestone member, a middle quartzite member, an upper limestone member, and the paper shale member at the top. Where the formation is thickest, the members are thickest and all are represented. Where the formation is thin, generally the basal conglomerate

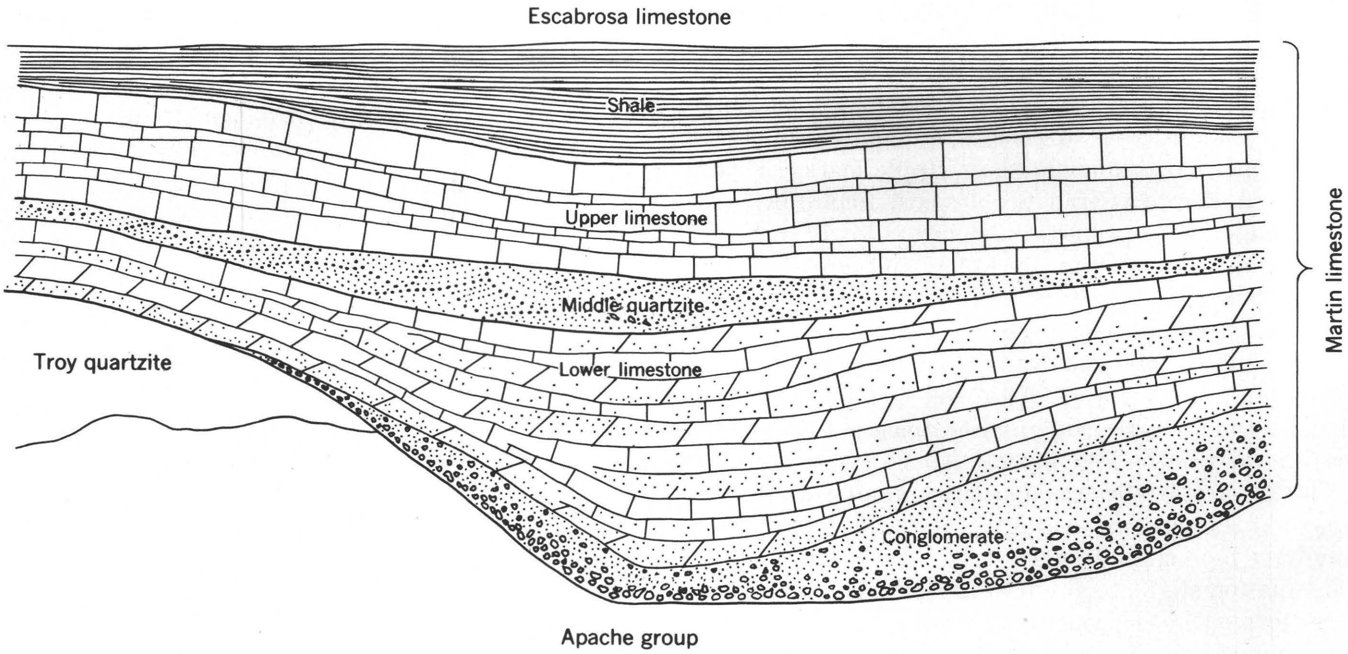

FIGURE 4.—Idealized section of the Martin limestone showing the effect of the uneven pre-Devonian erosion surface on the thickness of the Martin limestone.

member is lacking and the other members are thinner, but most of the thinning is in the lower limestone member.

The basal conglomerate ranges from 1 or 2 feet to as much as 40 feet in thickness. It is most commonly composed of angular fragments of quartzite, Pioneer formation, Barnes conglomerate, and smooth, rounded pebbles from the Barnes in a matrix of coarse dark-reddish-brown sandstone or quartzite; but locally it may include fragments of any of the older rocks. Generally the conglomerate is interbedded with lenticular layers of quartzite. In a thick section on Sleeping Beauty Peak, the conglomerate is 28 feet thick and is overlain by 46 feet of massive coarse quartz sandstone.

The only fossils found in the conglomerate are a few plates of arthrodiran fishes.

The lower limestone member probably shows the most variation of all the members. Its most persistent and characteristic beds are of very fine grained and hard gray dolomitic limestone that weathers to rough sandy surfaces. Also characteristic of this member are beds of limestone containing well-rounded grains or granules of quartz whose surfaces are frosted as if by wind action. Both limestone and dolomite are commonly interbedded with layers of coarse crossbedded sandstone or quartzite, 6 inches to 6 feet thick, and, in some places, with lenticular beds of conglomerate. Some beds are grits composed largely of frosted quartz granules.

In the thick section on the south side of Dime Gulch, just east of the Copper Gulch road, the lower limetone member is composed of hard, dense light-gray to black dolomite interbedded with soft limy shale or sandstone and a few beds of quartzite, 2 to 10 inches thick.

Fossils are generally uncommon or lacking in the lower limestone, but some sections contain one or more thin beds of white limestone composed entirely of crinoid and brachiopod fragments. In a small downfaulted block 8,000 feet east of the Old Dominion "A" shaft, the lower limestone contains abundant fragments of arthrodiran fish plates.

The middle quartzite member is the only quartzite unit that is consistently represented in all sections. It is 10 to 35 feet thick, coarse grained, gray to brown, generally crossbedded, and commonly includes lenses of pebbly sandstone. However, in the Dime Gulch section it is represented by beds of quartzite 2 to 10 inches thick alternating with beds of soft limy sandstone or marl.

The upper limestone member is rather uniform in character and is medium to thick bedded. Weathered outcrops are grayish orange or various shades of gray. Unlike the lower limestone, it is fossiliferous and contains a large assemblage of brachiopods and corals. At the top is a bed, 2 to 6 feet thick, that contains abundant shells of *Atrypa* spp. In many places this bed is composed largely of shell fragments (generally identified as those of *Atrypa reticularis* in nearly all sections describing the Martin limestone but probably they are of several species).

The uppermost member of the Martin limestone is a bed of gray calcareous shale and marl that ranges from 20 to 75 feet in thickness. On weathering, the shale breaks up into paper-thin grayish-orange flakes, and outcrops generally have been covered by soil and debris from overlying formations. The typical shale grades upward into soft marl or thin-bedded marly limestone, generally 6 to 12 feet thick but in some very thick sections as much as 45 feet.

The paper shale member is very uniform in character throughtout the Globe-Miami district. The principal variation is in the thickness of individual sections or in the relative proportions of shale and marl. At a few localities, as on the south side of Jewel Hill in the Castle Dome area, the shale member is divided by a thin bed of limestone.

CARBONIFEROUS SYSTEMS

The Carboniferous strata of the Globe-Miami district are placed in the Escabrosa limestone, of Mississippian age, and the Naco limestone, of Pennsylvanian age. Like the Martin limestone, the Escabrosa and Naco limestones were named by Ransome (1904b, p. 42–44) in the Bisbee quadrangle. The Escabrosa limestone is correlated with the lower part, and the Naco limestone with the upper part of the Tornado limestone, as described by Ransome in the Ray quadrangle (1919, p. 47–49). However, the use of the names Escabrosa and Naco has been extended to designate limestones of similar ages throughout southeastern Arizona.

The Naco limestone as defined by Ransome (1904b, p. 44–54) includes strata of Pennsylvanian and Permian ages; but if rocks of Permian age ever were present in the district, they and an unknown thickness of Pennsylvanian strata have been removed by erosion. The maximum thickness of Pennsylvanian rocks, as represented by the Naco limestone, in the district is about 500 feet, a thickness that probably represents no more than a half or third of the original thickness.

MISSISSIPPIAN SYSTEM

ESCABROSA LIMESTONE

There was no apparent break in deposition at the end of Devonian time. The massive cliff-forming beds of gray limestone that make up the lower part of the Escabrosa lie conformably on the marly beds at the top of the Martin limestone. Girty (Ransome, 1904b, p. 46–50) placed the Escabrosa in the Kinderhook and Osage series of the lower part of the Mississippian system, on the basis of fossils collected by Ransome in the Bisbee quadrangle. Fossils of Burlington age occur in the uppermost part of the Escabrosa in the Santa Catalina Mountains, 35 miles north of Tucson, (Stoyanow, 1936, p. 507). In 1942 the author collected fossils of Burlington age from the upper part of the Escabrosa in the Vekol Mountains, 60 miles south of Phoenix, which were identified by A. A. Stoyanow as *Orophocrinus stelliformis* and *Pentremites* sp.

The maximum thickness of the Escabrosa limestone in the Globe-Miami area is 365 feet; in some places its thickness is no more than 260 feet.

The basal 50 to 90 feet of the formation is a massive limestone that crops out as prominent cliffs forming a feature of the landscape recognizable from great distances. Examined at close range, this unit shows rather indistinct separation into beds, 6 to 10 feet thick. The limestone is gray: medium light gray to medium dark gray on fresh surfaces and light brownish gray to brownish gray on weathered surfaces. It is coarse grained and contains abundant small fossil fragments and probably some oolites. Irregular masses of chert alined parallel to the bedding are common.

The rest of the Escabrosa shows distinct separation into beds, 1½ to 6 feet thick, commonly separated by thin shaly partings. The bedded limestone can be readily quarried in the form of large building blocks. Many of the beds are of oolitic limestone, some are of very fine grained lithographic limestone, others of coarsely crystalline limestone, and a few are composed entirely of crinoid fragments. Lenses of red shale occur sporadically but are usually not apparent except in excavations. In some localities, chert nodules are abundant; in others, they are rare or absent. Weathered rock of the outcrops is uniformly light gray, but the fresh rock is generally somewhat darker.

The limestone beds of the Escabrosa are predominantly nearly pure calcite, but in some localities, a few beds of coarsely crystalline light-gray dolomite occur between the massive basal member and the overlying thinner bedded sequence.

PENNSYLVANIAN SYSTEM

NACO LIMESTONE

The Escabrosa limestone, of Mississippian age, is overlain by Naco limestone, which in the Globe-Miami district is of Pennsylvanian age but elsewhere in Arizona ranges in age from Pennsylvanian to Permian(?). Absence of stata of Late Mississippian age probably indicates an interval of no deposition and of subaqueous solution and oxidation rather than one of erosion during which Upper Mississippian strata were removed.

The base of the Naco limestone was mapped as the base of a bed of red shale. The underlying Mississippian limestone beds are lithologically similar up to the base of the shale. No fossils have been found in the shale, but Pennsylvanian fusulinids appear in the overlying limestone beds 25 to 75 feet above the top of the shale.

The red shale is considered to represent an accumulation of oxidized residual clay formed from limestone undergoing chemical decomposition but little or no mechanical erosion. A special environment seems necessary for the formation of such a deposit. The addition of lime by inflowing streams would have to be greatly reduced or cease completely and the water of the sea would have to be able to dissolve sufficient atmospheric carbon dioxide and oxygen to decompose limestone and to oxidize the ferruginous minerals of the residual clay. The sea must have been relatively shallow, yet deep enough that waves and tldes would not cause much transportation or sorting. Chert fragments and small lenses of chert conglomerate in the red shale probably were derived from the chert bands and nodules in the Escabrosa limestone. The fragments are angular and are abundant only in local areas, as are the nodules in the limestone.

In contrast to the underlying Escabrosa, the Naco limestone is thin bedded. Some beds are as much as 3 feet thick, but most are thinner and are separated by thin layers of gray marl or calcareous shale. Fragmental beds that consist of nodules of limestone surrounded by a matrix of darker gray argillaceous limestone are common and characteristic of the formation. Some beds contain abundant chert, and a few are of alternating thin layers of gray limestone and red shale. Beds of red shale much like the basal red shale are interbedded with the limestone at various horizons, but they are lenticular and generally do not persist for more than a few hundred feet.

Many of the beds contain abundant well-preserved silicified macrofossils. Fusulinids occur in so many beds that small isolated outcrops usually can be identified without difficulty.

The Naco limestone is not extensively exposed in the Globe-Miami district. Much of it had been removed before the eruption of dacite, and the remnants have been further reduced in size after that event and also during the present cycle of erosion. The largest outcrops and thickest sections are in the Castle Dome area, along Pinto Creek and Gold Gulch. There are a few outcrops, just north of Globe, in the down-faulted hanging-wall block on the east side of the Old Dominion vein fault. The few other outcrops in the district are those of relatively small blocks that have been faulted down between blocks of older strata. The maximum thickness of Naco limestone exposed in the district is about 500 feet.

CRETACEOUS OR TERTIARY SYSTEMS

SOLITUDE GRANITE

A distinctive light-colored granite of Late Cretaceous or Early Tertiary age crops out 3 miles south of Miami, near the head of Solitude Gulch, for which the rock was named (Ransome, 1903, p. 65). Only the northwest end of the mass lies within the mapped area (pl. 1). The outcrop of the Solitude granite is almost white, with a faint yellowish tinge; it is so much lighter in color than the neighboring, grayish-yellow Schultze granite, that the two rocks are readily distinguishable, even when viewed from several miles away.

The Solitude granite within the mapped area is largely muscovite granite. Southeastward it grades into true granite, containing about as much biotite as muscovite. Surfaces of the broken rock are rough and granular. Quartz, feldspar, and silvery white muscovite are readily recognized with the unaided eye. Brownish alteration halos commonly surround the muscovite grains. The texture is characteristically nonporphyritic, medium grained, and equigranular.

The minerals seen in thin sections are quartz, turbid orthoclase, albite, muscovite, and a little microcline. The feldspars tend to be intergrown in anhedral clusters, which are interspersed with clusters of anhedral quartz grains. Muscovite occurs as aggregates of large ragged flakes and also as minute flakes scattered through the feldspar clusters. The very sparse accessory minerals are rutile, sphene, bluish prisms of tourmaline, and occasional grains of limonite that probably are pseudomorphs after pyrite. The rock south of the mapped area contains biotite in addition to muscovite. In general, the minerals of the rock show very little or no alteration by weathering.

An outcrop of intrusive rock, whose maximum dimensions are about 1,200 by 1,800 feet, is separated from the northwest end of the outcrop of Solitude granite by a band of schist about 600 feet wide. In hand specimens the rock appears to be a fine-grained aggregate of quartz, feldspar, and biotite. It has a nondescript yellowish-gray color, much darker than that of the neighboring outcrop of Solitude granite. It includes very abundant, large and small fragments of schist, many of which have been partly assimilated by the magma. Thin sections show clusters of quartz grains, mostly 0.2 to 0.5 mm. in diameter and ragged flakes of muscovite in a groundmass apparently composed of microcrystalline orthoclase, minute flakes of muscovite, and abundant larger flakes of biotite. A few grains of andalusite were recognized in a heavy-minerals concentrate of the rock.

The rock of this small outcrop is unlike any of the other intrusive rocks of the district but has some characteristics in common with the nearby Solitude granite. The abundant schist inclusions throughout the mass and the presence of andalusite suggest that it may be a hybrid rock resulting from the assimilation of schist by magma, probably by some of the parent magma of the Solitude granite. It is therefore tentatively correlated with the Solitude granite.

There are very few data from which the age of the Solitude granite can be determined. The main mass intrudes the Pinal schist, and Ransome (1903, pl. 1) showed it in normal contact with Madera diorite for about a quarter of a mile along its southern boundary but apparently was unable to determine the relationships at this place, because exposures are poor. At the time, Ransome (1903, p. 78) described the Solitude granite he regarded all the granitic rocks of the Globe area as Precambrian in age but thought the Solitude granite to be younger than the Madera diorite, because it lacks the foliated texture of the latter.

The small outcrop near the northwestern end of the main mass is intruded by diabase, probably of the same age as the other bodies of diabase in the district, and along its northwest side, it is in contact with the Schultze granite, but the exposures are so poor that the relationships are not clear. However, it is cut by narrow porphyry dikes that seem to be offshoots of the Schultze granite, and if the rocks and the Solitude granite are of the same age, the Solitude granite is thus older than the diabase and the Schultze granite. The Solitude granite could have been intruded at any time from early Precambrian to early Tertiary, but it lacks the gneissic or foliated texture that is evident in all the lower Precambrian rocks except the Ruin granite. For this reason only, it is regarded as one of the early intrusions of the series assigned to the Late Cretaceous or early Tertiary orogeny.

WILLOW SPRING GRANODIORITE

Ransome (1903, p. 78) gave the name Willow Spring granite to a small body of intrusive rock that crops out in Willow Spring Gulch, 1½ miles west of Inspiration post office. A much larger body of similar rock crops out a mile to the northeast in the vicinity of Lost Gulch. This outcrop has an area of about a square mile, whereas the area of the outcrop in Willow Spring Gulch is less than a quarter of a square mile. Both areas are roughly oval in shape, but that in Willow Spring Gulch is partly bounded by faults.

A third body crops out along the north side of Cottonwood Gulch 1¼ miles southeast of Porphyry Mountain. Its outcrop has maximum dimensions of about 1,500 feet by 7,000 feet and is elongated northeastward. All three outcrops are on a line that trends east-northeast.

The rocks of the major part of each of the three intrusive bodies are lithologically and petrographically identical, and this is the sole basis for their correlation.

Except for a granite border facies described later, the rock is actually a biotite granodiorite porphyry rather than a granite. The fine-grained groundmass is composed of quartz, feldspar, and finely disseminated biotite that gives the rock a uniform medium-gray color. The most conspicuous phenocrysts are large crystals of orthoclase, most are 10 to 30 mm long. Some are rounded and have rims of plagioclase. Smaller phenocrysts of quartz, biotite, and plagioclase are 4 to 10 mm in diameter. The groundmass is uniform, but the number and relative proportions of the various phenocrystic minerals differ greatly from place to place. The proportion of orthoclase phenocrysts is the most variable; they generally form 5 to 15 percent of the rock. Where orthoclase phenocrysts are most abundant, the rock probably has the composition of quartz monzonite.

Thin sections show the groundmass to be of zoned oligoclase, quartz, microcline, orthoclase, and biotite in grains averaging about 0.4 mm in diameter. Almost two-thirds of the feldspar is oligoclase. The accessory minerals are apatite, magnetite, and sphene.

The granodiorite porphyry weathers rapidly. The deeply decomposed outcrops occupy basinlike areas surrounded by ridges of the more resistant formations.

A rock believed to be a younger intrusion of the Willow Spring granodiorite intrusions occurs in the Willow Spring Gulch and Lost Gulch areas. It is clearly a separate intrusion that was injected along the borders of the two granodiorite masses and does not completely surround either. It is not present in the Cottonwood Gulch area.

The contacts between the older and younger intrusions are irregular but sharp and generally appear to dip outward from the centers of the outcrops. Along the northeast side of the Lost Gulch mass, the border intrusion overlies the granodiorite porphyry like a roof, and the contact dips very gently. In several places along the south and east sides of the Lost Gulch outcrop, the two intrusions are separated by tongues of schist. Many small inclusions of schist occur in the granodiorite porphyry, but they are most numerous near its contact with the border facies. In a few places, the border facies contains small inclusions of granodiorite.

The border facies is a biotite-muscovite granite. It is light gray to pinkish gray and fine grained and appears to be almost equigranular. The minerals distinguishable with the aid of a hand lens are quartz, feldspar, biotite, and muscovite.

In thin sections, microcline, orthoclase, and quartz, in grains averaging about 0.5 mm in diameter, are the predominating minerals. Microcline and orthoclase compose 40 to 50 percent of the section, and oligoclase less than 15 percent. Muscovite occurs as large plates, the biotite as small ragged flakes. Apatite and magnetite are very sparse.

The Willow Spring granodiorite and granite border facies intrude only the Pinal schist and its intruded lower Precambrian dioritic complex. In the Cottonwood Gulch area, the body of the Willow Spring granodiorite lies between two bodies of Lost Gulch quartz monzonite. Its contacts with the two are sharp, but the quartz monzonite includes numerous blocks of what seems to be granodiorite. Although the blocks cannot be definitely identified as granodiorite, the dikelike tongues of quartz monzonite that extend into the granodiorite at several places along its northern border strongly suggest that the quartz monzonite was intruded between the schist and the granodiorite body. Near the southwestern end of its outcrop, the granodiorite is intruded by Schultze granite, which also intrudes the quartz monzonite. This relationship is clear because many thin dikes of Schultze granite extend into the Willow Spring granodiorite.

South of the outcrop at Lost Gulch, a fault that displaces the Pioneer formation and diabase can be followed to within a hundred feet of the contact of the granite border facies of the Willow Spring granodiorite with the schist, but the contact does not appear to be displaced. If this criterion could be relied on, it would indicate that the granite border at least is younger than the diabase and the rocks of the Apache group. However, the actual intersection of the fault with the contact between the granite and schist has not been seen, and the throw of the fault need not have exceeded 100 feet.

On its northeastern side, the Willow Spring Gulch mass is in contact with diabase along a fault that displaces dacite, whereas the fault to the south of the outcrop is older than the dacite.

No fragments of the Willow Spring granodiorite or of its border facies have yet been found in the Scanlan conglomerate that crops out in several places near the south boundary of the Lost Gulch mass.

Thus the Willow Spring granodiorite and its border granite facies are probably older than the Lost Gulch quartz monzonite and Schultze granite. On the basis of the very meager and uncertain evidence presented by the relationships of the two faults and on the absence of fragments from the Willow Spring in the Scanlan conglomerate, it may be younger than the rocks of the Apache group and the diabase.

GRANODIORITE IN GOLD GULCH

A long narrow body of biotite granodiorite crops out along Gold Gulch, south of the Castle Dome mine. It is bounded by Pinal schist on the south and by a large mass of Lost Gulch quartz monzonite and small bodies of granite porphyry on the north. At the east end it tapers to a dike, ending about 1,500 feet east of the Castle Dome concentrator. The west end is an intrusive breccia composed of small blocks of granodiorite included in quartz monzonite porphyry. The character of the breccia seems adequate proof that the granodiorite is older than the Lost Gulch quartz monzonite.

Several bodies of granite porphyry have been intruded along the contact between the granodiorite and the Lost Gulch quartz monzonite, and the intrusive breccia has been intruded by a small body and several thin dikes of granite porphyry. During the study of the Castle Dome area, the granodiorite was assigned to the Tertiary intrusive rocks, but its age is uncertain. It may be of early Precambrian age and related to the Madera diorite or to the complex of dioritic rocks intruding the Pinal schist.

In hand specimens, the typical granodiorite is a light-gray medium-grained almost equigranular rock. Plagioclase, quartz, and black biotite are the only minerals that can be recognized. A facies with noticeably porphyritic texture occurs in some places near the margins of the body.

In thin section the plagioclase grains are seen to be subhedral and range from 0.5 to 3 mm in diameter. They are generally zoned and have the composition of oligoclase (An_{20} to An_{30}). Some orthoclase is present, but it is always subordinate to plagioclase and nowhere composes more than 20 percent of the rock. Biotite, in small ragged books generally less than 1 mm across, forms about 5 percent of the sections. The accessory minerals are apatite, magnetite, zircon, and sphene. Although in hand specimens the rock looks to be perfectly fresh, most of the biotite is partly altered to chlorite, and the central part of some plagioclase grains is replaced by sericite and calcite.

LOST GULCH QUARTZ MONZONITE

Ransome (1903, p. 75–78) gave the name Lost Gulch monzonite to a complex of intrusive rocks cropping out in the vicinity of Lost Gulch, south of Sleeping Beauty Peak and west of Pinal Creek (pl. 1). Only in the northern part of the area mapped by Ransome (1903, pl. 1) as Lost Gulch monzonite does the rock, which actually is a quartz monzonite, conform to his description. Approximately all the southern half of the area is underlain by Pinal schist, Willow Spring granodiorite, and the rocks of the Precambrian dioritic complex. In the present report, the name Lost Gulch quartz monzonite is applied to the body of quartz monzonite near Lost Gulch and to other bodies of petrographically similar rocks of the same age elsewhere in the district.

The quartz monzonite of the Lost Gulch area forms a roughly triangular outcrop having an extent of a little less than 2 square miles. On the northwest, northeast, and east sides this outcrop is bounded by faults; the south boundary is an intrusive contact with Pinal schist and its intruded dioritic complex.

Other areas of similar rocks occur 5 miles to the southwest in the Porphyry Mountain area (pl. 1). The largest measures about 1 mile from east to west and about 1½ miles from north to south. Porphyry Mountain is in the south-central part of this outcrop. Two smaller outcrops, separated by an elongate mass of Willow Spring granodiorite, are about 1½ miles southeast of Porphyry Mountain.

The main mass on Porphyry Mountain is a northwestward-trending horst bounded on the west, north, and east sides by normal faults. The south boundary is in part a fault contact with Pinal schist and in part an intrusive contact with the older granodiorite and younger granite porphyry.

In both the Porphyry Mountain and Lost Gulch areas, there are two widespread textural varieties of the quartz monzonite that were separately mapped (pl. 7 and Peterson, Gilbert, and Quick, 1951, pl. 1). One variety is a porphyritic quartz monzonite composed of large phenocrysts of pale-red orthoclase, 25 to 80 mm long, in a coarse-grained groundmass of quartz, plagioclase, orthoclase, and biotite; the other is quartz monzonite porphyry, composed of large phenocrysts of orthoclase and smaller ones of plagioclase, quartz, and biotite in a fine-grained groundmass of quartz, orthoclase, and a little plagioclase. The contacts between the two varieties are sharp in some places and gradational in others. Quartz monzonite porphyry forms the central part of the Porphyry Mountain mass and is almost surrounded by porphyritic quartz monzonite.

The quartz monzonite porphyry shows considerable variation in texture. For example, in the central part of the Porphyry Mountain mass, phenocrysts compose no more than 25 percent of the rock, and the groundmass is very fine grained and distinct, whereas, near the margin of the mass, the phenocrysts predominate, and the groundmass is fine or medium grained and not readily apparent in every specimen. Thus, the quartz monzonite porphyry is crudely zoned, having relatively few phenocrysts and a very fine groundmass near the center and many more phenocrysts and slightly coarser groundmass near the margins.

In thin section under the microscope, the pale-red feldspar is seen to be microperthitic orthoclase clouded by indeterminate dustlike inclusions. A little microcline is present in most thin sections. Many of the large orthoclase phenocrysts poikilitically enclose small crystals of oligoclase in a zonal arrangement. Some have round or oval cross-sections and have rims of oligoclase. Titaniferous magnetite, apatite, zircon, and sphene are accessory minerals. Most of the plagioclase is oligoclase, but a little of it is andesine.

The porphyritic quartz monzonite and quartz monzonite porphyry appear to have practically the same mineral composition. They are essentially 30 to 35 percent quartz, 20 to 25 percent orthoclase, 30 percent oligoclase, and about 8 percent biotite. The groundmass of the porphyritic quartz monzonite ranges in grain size from 2 to 10 mm, whereas that of the quartz monzonite porphyry ranges from 0.1 to 0.8 mm; the most common range is from 0.2 to 0.4 mm.

The original biotite of the quartz monzonite occurs as dark-brown subhedral books; but in the southern part of the Porphyry Mountain mass, much of it is recrystallized to aggregates of small biotite plates, a few being intergrown with muscovite. The aggregates are about the same size (2.5 to 8 mm in diameter) as the books. They have about the same distribution in the rock, and, like the books, invariably they are associated with small crystals of apatite, magnetite, and sphene. Thin sections show various stages in the change from books to aggregates; some aggregates have cores composed of remnants of the original books surrounded by numerous small biotite crystals having random orientations. From some biotite aggregates, small trains of tiny biotite crystals extend as much as 2.5 mm into the surrounding quartz and feldspar. In the quartz monzonite near some of its contacts with granite porphyry, aggregates of biotite can be seen, and in addition fine-grained biotite is scattered throughout the rock in veinlets that cut through all the other minerals.

The composition of the biotite in books may differ slightly from that in aggregates, but the optical properties of the two are essentially the same. Both show pleochroism in which X is pale olive, and Y and Z are light olive brown. The optic angle ($2V$) ranges from 5° to 20°; and the index of refraction for the slow ray (gamma) ranges between 1.615 and 1.630; the low values tend to be those of the aggregates. Most of the books contain needlelike rutile inclusions oriented in 3 directions at 60° in the basal plane (001). Such inclusions have not been seen in the aggregates.

The cause of the recrystallization of the biotite is uncertain. Secondary biotite very similar to that in the Lost Gulch quartz monzonite has been described by various authors as a product of hydrothermal alteration associated with formation of mineral deposits. Hydrothermal alteration related to disseminated copper deposits is widespread in the quartz monzonite in both the Lost Gulch and Porphyry Mountain areas, and appears to be the most probable cause of the recrystallization. However, biotite is recrystallized in some specimens of the quartz monzonite that show no other evidence of hydrothermal alteration; and the distribution of aggregate biotite does not conform with the zoning pattern in the hypogene copper mineralization or associated hydrothermal alteration (Peterson, Gilbert, and Quick, 1951, p. 26–27), although it is limited entirely to mineralized areas. Furthermore, both types of biotite are similarly affected by hydrothermal alteration. The recrystallization of biotite may be a metamorphic effect produced by the intrusion of the granite porphyry bodies for it appears to be most complete in their vicinity. Near Gold Gulch, in the southern part of the Porphyry Mountain mass, all the biotite of the quartz monzonite occurs as aggregates, although the biotite in the granodiorite and granite porphyry in that area has not been recrystallized. The aggregate biotite decreases in abundance toward the north and is absent in the rock north of Porphyry Mountain. If the source of the quartz monzonite was south of Porphyry Mountain, as is likely, the recrystallization of biotite may be a deuteric change.

Dikes and small masses that range from aplite to alaskite porphyry have been intruded into both varieties of quartz monzonite and are most abundant near contacts between the two. The aplite is fine to medium grained and is nearly equigranular. It is composed of orthoclase, oligoclase, quartz, and, in some places, a little muscovite or biotite. The alaskite porphyry has approximately the same texture and mineral composition, but it contains a few phenocrysts. Most of the phenocrysts are oligoclase and quartz, but there are some large phenocrysts of orthoclase and smaller ones of biotite. Except that it has fewer phenocrysts and biotite is less abundant, the alaskite porphyry is not clearly distinct from the quartz monzonite porphyry; and in some places the two are gradational.

Next to the fault that forms the northwest boundary of the mass of Lost Gulch quartz monzonite southeast of Sleeping Beauty Peak, a relatively large outcrop of aplite appears to grade perfectly into the surrounding quartz monzonite porphyry. The central part of the outcrop is fine grained and contains no phenocrysts, but toward the margin, phenocrysts become progressively more abundant. Although the fine-grained aplite looks exactly like and contains the minerals of the groundmass of the quartz monzonite porphyry, thin sections show that it also contains muscovite.

No dikes or masses of pegmatite related to the quartz monzonite have been recognized. Although pegmatites are numerous in the two small outcrops of quartz monzonite south of Porphyry Mountain, they also intrude the younger Schultze granite, to which they probably are related.

Little is certain about the manner of intrusion and original shape of the quartz monzonite masses. The present rectilinear outcrop pattern of the Porphyry Mountain mass may not indicate the original shape of the mass, for the mass is now limited to a horst trending in a north-northwest direction. Diabase was later intruded along the east and west boundary faults of the horst and also along the north side of the outcrop, so that the quartz monzonite is now nearly surrounded by younger diabase. Part of the original roof of the complex remains north of Porphyry Mountain, where gently tilted beds of the Apache group cover the quartz monzonite (p. 58). Along the northern part of the west side of the complex, the original contact also remains, but there it is steep, although concordant. In Gold Gulch, west of Porphyry Mountain, quartz monzonite is in discordant intrusive contact with a small block of Pioneer formation; and south of Porphyry Mountain it is intruded into the granodiorite of Gold Gulch and Pinal schist along contacts dipping steeply sonthward. The steep contacts at the south and the concordant, gently-dipping roof to the north suggest that the quartz monzonite was intruded from a channel near and south of Porphyry Mountain and spread northward beneath the Scanlan conglomerate of the Apache group as a thick sill. The intrusion was a multiple process and consisted of intrusion of the porphyritic quartz monzonite phase, which was followed by that of the quartz monzonite-porphyry phase and later by injection of dikes of alaskite porphyry and aplite. The main mass of quartz monzonite porphyry is centered around Porphyry Mountain and, except where it has been intruded by younger diabase east of Porphyry Mountain, is surrounded by porphyritic quartz monzonite and older rocks. The original porphyry mass could not have been much larger than that now exposed, and it may be described as a chonolith, or irregular stock, within the quartz monzonite complex. Its southern contact has a steep southward dip outward from the center of the intrusion. The relation to the topography of many other parts of the contact suggests that the contact generally dips outward from the center, but because of its irregularity and the complications introduced by later faulting, the actual attitude of the contact is uncertain.

The locus of several intrusions was south of Porphyry Mountain and north of the Pinal schist exposed there. The first, a mass of granodiorite elongated in a general east direction, was intruded along what is now the north boundary of the schist in Gold Gulch. Later, both porphyritic quartz monzonite and quartz monzonite porphyry were intruded north and west of the granodiorite, and, although both of these rocks extend for more than a mile to the north, at least the intrusion of quartz monzonite porphyry seems to have been centered near the southern end of the area. Still later, the dikes and small bodies of granite porphyry, elongated and alined in a general eastern direction, were intruded along the northern boundary of the granodiorite and into the adjacent quartz monzonite and diabase. Because this has been a zone of repeated intrusive activity, it seems likely that the connection of the quartz monzonite with its deep-seated magma reservoir is in this area. If so, the mass of porphyritic quartz monzonite north of Porphyry Mountain, which was intruded concordantly beneath the Scanlan conglomerate, is probably a sill at least 500 feet thick that was fed by a discordant root near or south of Porphyry Mountain.

Less can be surmised concerning the manner of intrusion of the quartz monzonite complex in the Lost Gulch area. The main mass is not in contact with any of the younger sedimentary rocks except along the faults that form its northwest, northeast, and east boundaries. However, inclusions that are probably from the Scanlan conglomerate have been found at one place near the middle of the south boundary. The southern boundary is a steep intrusive contact with the Pinal schist and the rocks of the early Precambrian dioritic complex which intrude the schist. As in the Porphyry Mountain mass, a line of granite porphyry bodies trending generally eastward occur in the southern part of the outcrop in the Lost Gulch area roughly parallel to the south contact.

A block of quartz monzonite 1,600 feet northeast of the fault that forms the northeast boundary of the outcrop is overlain by small remnants of Pioneer formation. The block is completely surrounded by diabase, and it is uncertain whether the rock should be correlated with the Lost Gulch quartz monzonite or with the Ruin granite. The remnants of Pioneer formation are underlain by a thin layer of arkose, but no typical Scanlan conglomerate is present, and the arkose does not show the usual evidence of metamorphism resulting from the intrusion of quartz monzonite beneath it.

The steep intrusive contact with the lower Precambrian rocks along the south boundary is the only suggestion that the quartz monzonite at Lost Gulch may have been intruded in much the same manner as the Porphyry Mountain mass. The two main outcrops may even be continous under the cover of younger formations that separate them. A line connecting the southern boundaries of the two outcrops strikes east-northeast, the general trend of the zone that was the locus of several igneous intrusions in the Globe-Miami district.

The Lost Gulch quartz monzonite is clearly younger than the upper Precambrian rocks of the Apache group. The rocks of the Apache group have been metamorphosed near their contacts with the quartz monzonite, and a discordant intrusive contact between quartz monzonite and the Pioneer formation is exposed in Gold Gulch west of Porphyry Mountain. Blocks of the granitic arkose below the Scanlan conglomerate are included in the quartz monzonite, and inclusions that are probably from the Scanlan conglomerate have been found in the southern part of the mass in the Lost Gulch area. The only contact between quartz monzonite and Paleozoic rocks is along a fault near the north end of the mass at Lost Gulch, and it seems unlikely that such an intrusion occurred during the Paleozoic era.

The quartz monzonite has been intruded by diabase and by granite porphyry that is younger than the diabase (p. 36). The two small masses $1\frac{1}{2}$ miles south of Porphyry Mountain intrude Willow Spring granodiorite but are intruded by Schultze granite.

Therefore, the Lost Gulch quartz monzonite is younger than the rocks of the Apache group and the Willow Spring granodiorite but is older than the diabase, Schultze granite and granite porphyry. It could be of Paleozoic, Mesozoic, or early Tertiary age; however, since no intrusions of Paleozoic age have as yet been recognized anywhere in Arizona, it is tentatively regarded as one of the earlier intrusions that accompanied the Late Cretaceous or early Tertiary orogeny. Ransome (1919, p. 51–52) suggested early Mesozoic(?) age for the Lost Gulch quartz monzonite.

DIABASE

GENERAL FEATURES

Outcrops of diabase are widespread throughout the Globe-Miami district. They have had a very important influence in shaping the topography and drainage pattern of the region. The diabase is relatively soft and weathers readily. The larger outcrops generally occur

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in relatively low-lying areas in which the diabase is largely covered by talus and debris of the more resistant rocks. The smaller outcrops commonly determine the courses followed by gulches and washes. Undoubtedly many small outcrops on gentle slopes have not been mapped as such because the diabase is completely concealed by talus; many of the areas mapped as talus probably are, at least in part, underlain by diabase.

Before the intrusion of diabase, the region was intricately broken by faults. The diabase magma forced its way into many of the faults to form dikes and between the strata of sedimentary rocks to form sills, some of which are several hundred feet thick. It was intruded at shallow depths, with probably no more than the thickness of the Paleozoic limestones separating the largest masses from the surface. Space for the invading magma was provided by the lifting and pushing apart of the faulted blocks, so that the crust was dilated without a great deal of distortion of the strata, except in some local areas. It is possible that some of the diabase magma reached the surface and poured out to form basalt flows; but if so, none of the flows are known.

The igneous and metamorphic rocks were not as extensively invaded by the diabase as the sedimentary formations. In the area between Webster Gulch and Lost Gulch, north of Inspiration (pl. 1), some dikes, sills, and small masses were intruded into Pinal schist. Ransome (1903, p. 81) described a sill in the Pinal schist and Madera diorite on the south side of the Pinal Mountains southeast of Pinal Peak and another, possibly a continuation of the first, southwest of Pinal Peak. Dikes both steep and flat have been intruded into the Ruin granite in the northern part of the Inspiration quadrangle. The low-dipping dikes appear to be roughly parallel to the pre-Apache erosion surface. Many small, irregular bodies of diabase occur in the Lost Gulch quartz monzonite southeast of Sleeping Beauty Peak. Several thin sheets of fine-grained diabase have been intruded into the quartz monzonite of Porphyry Mountain, but they cannot be definitely correlated with the main intrusions of diabase (Peterson, Gilbert, and Quick, 1951, p. 36).

The largest bodies of diabase were intruded into the upper Precambrian formations of the Apache group. In some parts of the district, such as the area north of Globe, where the largest outcrops of diabase occur, the section is predominantly diabase. If considered in detail, the diabase bodies in the sedimentary rocks are dikes intruded along faults and sills intruded between the strata; but if considered on a broader scale, the blocks of sedimentary rocks are largely inclusions completely enveloped by diabase. This relationship is evident in the extensive outcrops of diabase in the northern part of the Globe quadrangle. Several small blocks of Pioneer formation, such as the thin septum that crops out about 6,000 feet west-northwest of Black Peak are clearly inclusions far removed from the strata from which they were detached. Some of the small blocks of Pioneer formation and Dripping Spring quartzite west of Ramboz Peak are erosional remnants underlain by diabase, but all probably were completely enveloped by diabase. The strata in the blocks dip 20° to 50° SW. Along the north sides of the blocks, the contacts are mostly steep and apparently are faults along which diabase was intruded, whereas the dips of contacts on the south sides conform with the bedding, and the quartzite strata are now overlapped by diabase.

No doubt the diabase outcrops are those of several southwestward-dipping sills because, in general, the strata invaded by diabase are progressively higher in the stratigraphic section from north to south. The present attitude of the sedimentary beds may be partly the result of block faulting before the intrusion of diabase, as is suggested by the northwest alinement of the blocks, but undoubtedly considerable displacement occurred as a result of the injection of such a great volume of diabase magma.

In several places thick sills have been intruded at the base of the Martin limestone, and in a few places diabase is in normal contact with Escabrosa limestone. Only four short normal contacts between the diabase and Naco limestone are shown on the maps (pl. 1), and three of these are questionable because of poor exposures. Southeast of Sleeping Beauty Peak, diabase has been intruded along the Sleeping Beauty fault, a major fault between quartz monzonite on the south and Paleozoic and upper Precambrian sedimentary rocks on the north. In several places along the fault, the diabase intruded the Escabrosa and Naco limestones and caused recrystallization in them for a few feet from the contact. However, these limestones have been removed by erosion except in a few small areas, and the original extent to which they had been intruded by diabase is not known.

Although diabase sills occur at almost every horizon in the stratigraphic section below the base of the Martin limestone, certain horizons appear to have been especially favorable as channels of intrusion. Sills are especially common in the lower part of the Pioneer formation, and a few were intruded under the Scanlan conglomerate. The Mescal limestone is invariably split by diabase sills, and many of the smaller outcrops are completely surrounded by diabase. Thick sills occur at or near the base of the Martin limestone.

However, even at the most favorable horizons, the sills are not continuous nor are they of uniform thickness. On Buffalo Hill and on Buckeye Mountain a thick sill was intruded at or near the base of the Troy quartzite, but a few miles farther north, in the northeast corner of the Globe quadrangle, the Troy quartzite rests directly on Dripping Spring quartzite. On the other hand, it is not unusual to find a sill that crosses a fault and continues uninterrupted through the adjacent block at a different stratigraphic horizon.

That minor bodies of diabase magma were intruded after the main bodies had solidified is shown by dikes and small masses of fine-grained rock. These minor bodies have been recognized only in places where the exposures are especially good, as in road cuts and similar excavations, and there may be many such late intrusions that have escaped notice.

DESCRIPTION

The diabase is typically dark gray or dark greenish gray. It ranges from aphanitic to coarse grained, and the coarser grained diabase has ophitic texture. In some places, the plagioclase laths are 25 mm or more in length; but in the average rock, they range from 1 to 5 mm long. In general, the fine-grained rocks are characteristic of the smaller bodies. The diabase is aphanitic or fine grained for a few inches adjacent to intrusive contacts with quartzite or crystalline rocks, and at some contacts a progressive decrease in grain size is noticeable for several feet.

Although the diabase appears to be fairly uniform when examined in the field, it actually differs considerably in composition, even within the limits of relatively small outcrops. The most common types range from augite diabase having no hornblende to hornblende diabase containing little or no augite, but most specimens contain both augite and hornblende that poikilitically enclose the plagioclase laths. Much of the hornblende is uralite, and in most specimens augite shows some degree of alteration to uralite. The poikilitic augite and hornblende occur in rounded masses, as much as 20 mm in diameter, which weather out as spheroidal kernels or form rounded knots on weathered surfaces of the rock. In most outcrops, the plagioclase falls within the composition range of labradorite and forms 50 to 60 percent of the rock, but in a few it is andesine or bytownite. Biotite in amounts of less than 5 percent probably is present in all the diabase; but in many specimens, it is altered beyond recognition. Magnetite of high titanium content is abundant in all the diabase. The magnetite masses are commonly surrounded by rims of biotite. Apatite is fairly abundant in most specimens and is sparse in some.

In some small local areas, the diabase contains a little quartz and orthoclase, either micrographically intergrown or in discrete grains. It is probably the same rock described by Short and others (1943, p. 36) as the quartz-orthoclase diabase in the Superior area west of the Globe-Miami district.

Some of the diabase contains as much as 10 percent olivine or pseudomorphs of serpentine after olivine, which are generally poikilitically enclosed by augite and hornblende. This rock cannot be distinguished in the field from the normal augite-hornblende diabase, and the extent to which it occurs is not known. It probably is fairly common in the northern and eastern part of the district, but olivine was not recognized in any of the diabase in the Castle Dome area. Olivine diabase similar to that in the Globe-Miami district occurs in the Superior area (Short and others, 1943, p. 36).

In many places within the larger bodies of diabase are small irregular masses of a reddish, generally coarse-grained rock that has the composition of hornblende syenite. Apparently the rock was formed from a differentiate of the diabase magma and perhaps should be called diabase pegmatite. It is composed essentially of pale reddish-brown feldspar and black hornblende. Under the microscope, the feldspar is seen to be orthoclase, heavily clouded by inclusions, and a little plagioclase, probably oligoclase. The rock contains a little magnetite and many large needles of apatite. Some of it contains a little quartz. Noble (1914), p. 57) described an identical facies in the diabase of the Shinumo quadrangle of the Grand Canyon district, where it occurs at the top of a diabase sill and appears to grade downward into normal diabase that is very similar to the olivine diabase of the Globe-Miami district.

On Porphyry Mountain, in the vicinity of the Castle Dome mine, several sheets of fine-grained diabase from 1 to 10 feet thick have been intruded into the quartz monzonite complex. They are minor rock bodies but were an important control in the localization of mineral deposition (Peterson, Gilbert, and Quick, 1951, p. 103). None can be traced as far as the edge of the quartz monzonite, and their relations to the main diabase intrusion are uncertain. A comparison of the petrographic character of the sheets with that of the main diabase bodies is not possible because the sheets are greatly altered. The diabase in the sheets contained tabular crystals of plagioclase, which are commonly visible in hand specimens as small white laths that suggest ophitic texture, but thin sections show that all the feldspar has been replaced by clay minerals and sericite. The other constituents of the rock include scattered flakes of green biotite, much of which has been altered; abundant small grains of titaniferous magnetite; some apatite; and a little quartz. Some of the quartz may be primary, but much of it may have been introduced by mineralizing solutions. None of the minerals or textures visible in the sheets clearly distinguish the rock from the main diabase, but neither does any of them definitely indicate a relationship between the two rocks. The rock of the sheets most closely resembles that of the late-formed dikes of fine-grained diabase that were intruded into the main mass in some places.

A small body of diabase crops out 1¾ miles east of Schultze ranch and about 3 miles distant from any other outcrop of diabase. It intrudes the Pinal schist and the small body of intrusive igneous rock tentatively correlated with the Solitude granite. Its original extent is unknown because the outcrop is bounded on the northeast side by the Miami fault, which brings Gila conglomerate into contact with the diabase.

Ransome (1903, p. 79–80) called the rock "metadiabase" and considered it to be of Precambrian age. The only apparent reason for this classification is that this small body of diabase is cut by dikes of granite porphyry that are obviously related to the Schultze granite, a rock which, at that time, he believed to be of Precambrian age. Thus, a rock intruded by the granite must also be of Precambrian age and much older than the diabase in other parts of the district. Along the west side of the outcrop, the diabase is in intrusive contact with the Schultze granite, but the contact is too poorly exposed to show definite age relationships.

The rock in the small mass is typical hornblende diabase with ophitic texture ranging from medium grained to very coarse grained. It is neither foliated nor perceptibly metamorphosed, except near the borders of the granite porphyry dikes. The minerals are not much altered; actually the diabase is less altered by weathering than most of the diabase elsewhere in the district. In the absence of any contrary evidence, this small isolated outcrop is now regarded as being of the same age as the main bodies of diabase.

The only characteristic that distinguishes this outcrop from the typical diabase of the district is the presence of many small inclusions of white vein quartz in some parts of the mass. The quartz fragments are corroded and are surrounded by shells of cross-oriented hornblende, as much as 5 mm thick. A few inclusions were found that are fine-grained granular aggregates of quartz and epidote; these, too, are surrounded by shells of hornblende. They probably are fragments of Pinal schist altered by reaction with the diabase magma. The quartz fragments were probably derived from quartz veins in the schist.

A similar phenomenon is commonly seen in the northwestern part of the Inspiration quadrangle where diabase has intruded the Ruin granite. In some places along the contacts, the granite appears to have been partly assimilated by diabase and all its minerals resorbed, except the quartz phenocrysts and some of the orthoclase. The resulting hybrid has a fine-grained matrix of hornblende, quartz, altered feldspar, and magnetite or ilmenite that includes abundant xenoliths of quartz and a few of orthoclase. Those of quartz, 2 to 10 mm in diameter, are rimmed and veined by hornblende; smaller xenoliths of orthoclase are completely altered to cryptocrystalline clay or sericite but are not rimmed by hornblende. In the matrix, micrographic intergrowths of quartz and orthoclase or albite are interstitial to highly altered and strongly zoned euhedral plagioclase grains; they also partly replace the plagioclase. In thin sections long needles of apatite are seen to be abundant in the areas where hornblende is sparse or absent. The matrix grades into the adjacent normal diabase. In a few places the hybrid rock contains xenoliths of orthoclase that are about the same size and shape as the orthoclase phenocrysts of the granite.

AGE OF THE DIABASE

The diabase intrudes the lower Precambrian Pinal schist and Ruin granite, the upper Precambrian formations of the Apache group, and the Troy quartzite of Cambrian age. Near Gold Gulch, southwest of Porphyry Mountain, blocks of Martin limestone and Pioneer formation are enveloped by the diabase; and farther north, about due west of Porphyry Mountain, diabase has been intruded under the Martin limestone and along faults that displace the overlying Escabrosa and Naco limestones. In a few places southeast of Sleeping Beauty Peak, diabase intrudes the Escabrosa and Naco limestones. It also intrudes the Lost Gulch quartz monzonite.

The only diabase in normal contact with the Schultze granite is the small mass 1¾ miles east of the Schultze ranch. Its relations at this place, described above, indicate that the Schultze granite is younger than this diabase which probably is the same age as the main intrusion of diabase. West and also southeast of Jewel Hill, in the Castle Dome area, diabase has been intruded by granite porphyry that is believed to be a late facies of the Schultze granite.

In the Castle Dome area, hypogene copper minerals were sparsely deposited in the diabase east of the Lost Gulch quartz monzonite, as much as 1,000 feet from the contact (Peterson, Gilbert, and Quick, 1951, p. 69–70). Vein deposits of copper, zinc, and lead occur in the diabase in the Globe Hills area and in many other places throughout the district.

Thus, if all the diabase in the map area is of one age, it is younger than the Naco limestone of Pennsylvanian age but older than the copper deposits, the granite porphyry, and, very probably, the Schultze granite. However, similar types of diabase in the region surrounding the Globe-Miami district are said to be older than the rocks of Devonian age. A. F. Shride (oral communication) regards the diabase in the Salt River area, 40 miles north of Globe, as pre-Devonian in age, and Short (Short and others, 1943, p. 38) considered the diabase in the Superior area 12 miles southwest of Miami as being younger than Middle Cambrian and older than Late Devonian in age but said (oral communication) that, on the basis of the available information, it might well be much younger. Darton (1925, p. 255–257) described an area in the Mescal Mountains, about 15 miles south-southeast of Globe, in which Martin limestone that contains large blocks of Troy quartzite lies on the eroded surface of a thick sill of diabase intruded into or above the Mescal limestone. In the Tortilla Range and on Steamboat Mountain in the Ray quadrangle, Ransome (1923, p. 10) found small bodies and dikes cutting the Martin and Tornado (Escabrosa and Naco) limestones.

On the basis of the observed relations, much of the diabase in the Globe-Miami district could be older than the Martin limestone of Devonian age, and some of it could be older that the Troy quartzite of Middle Cambrian age; but except for a few aphanitic dikes that cut the normal diabase in two places, no direct evidence has been found that more than one period of intrusion of diabase is represented. The aphanitic dikes may be feeders of the basalt flows of Tertiary or or Quaternary age, for all but one are in the vicinity of Porphyry Mountain, where all the remnants of the late basalt flows also are found. All the diabase in the Globe-Miami district is therefore regarded as being of the same age and as being emplaced during one of the several intrusions of igneous rocks that accompanied the Late Cretaceous or early Tertiary orogeny.

DIORITE PORPHYRY

Diorite porphyry occurs as thin sills, dikes, and small irregular masses in nearly every part of the map area, but is most common in the western part of the Inspiration quadrangle. The rock is generally deeply weathered and crops out only in the most favorable places. The most extensive outcrops are in the lower part of the Pioneer formation or along the base of the Scanlan conglomerate. A small dike that cuts Troy quartzite and Martin limestone crops out on Buffalo Hill in the Globe quadrangle, and other small dikes and sills cut Troy quartzite and diabase in the area north of Globe. West of Porphyry Mountain an irregular mass near the west boundary of the inspiration quadrangle invades Martin and Escabros limestones, and farther north there are many thin sills intruded between the Pioneer formation and Ruin granite, either above or below the Scanlan conglomerate. Contacts between diabase and the Pioneer formation are a common locus of diorite porphyry intrusions.

The general color of the diorite porphyry is that of the very light-gray to medium-gray, microcrystalline groundmass. The phenocrysts are crystals of white or yellowish-gray plagioclase, as much as 5 mm long. The only other mineral recognizable in hand specimens is hornblende, in minute greenish-black prisms.

In thin section, the rock is seen to be highly altered. The euhedral and subedral phenocrysts are probably of oligoclase, but are much altered to aggregates of calcite, sericite, chlorite, and clay. The hornblende phenocrysts are almost completely replaced by chlorite, calcite, and limonite. The accessory minerals are apatite, sphene, magetite, and probably biotite. The microcrystalline groundmass appears to be largely sodic plagioclase but may possibly contain quartz and orthoclase. Some of the diorite porphyry contains small phenocrysts of quartz.

The dike that crops out on Buffalo Hill contains many embayed quartz grains and euhedral phenocrysts of orthoclase as much as 10 mm long. This rock may be a facies of granite porphyry rather than diorite porphyry.

The diorite porphyry is clearly younger than the diabase. Several fragments of it have been found in the Whitetail conglomerate northwest of Continental Spring. The dike in diabase north of the Old Dominion "A" shaft is mineralized with pyrite and chalcopyrite on the tenth level of the mine. The diorite porphyry is tentatively regarded as having been intruded soon after the diabase.

SCHULTZE GRANITE

The Schultze granite was named by Ransome (1903, p. 67) for Schultze ranch on U.S. Highway 70, about 3 miles southwest of Miami. The granite mass has the form of an irregular stock and crops out along the southern boundary of the Inspiration quadrangle and in the northern part of the adjacent Pinal Ranch quadrangle. The rugged, prominently jointed granite outcrops are an impressive feature of the landscape along

U.S. Highway 70 from Miami westward to Pinal ranch, a distance of about 7 miles.

The outcrop area covers about 20 square miles and is roughly crescent shaped, with the convex side to the north. Around the greater portion of its boundary, the granite is in contact with Pinal schist. In detail the contact is generally irregular. Where the general trend of the boundary is parallel to the bedding of foliation of the schist, the contact is very irregular; many short tongues of granite extend into the schist, and there are commonly septa of schist included in the granite along the contact. Where the general trend of the boundary crosscuts the bedding of the schist, the contact may be regular, as if controlled by an old fault, or it may have angular irregularities and form serrations whose alternate sides are roughly parallel to the bedding of the schist.

The topography of the granite areas from a distance appears to be characterized by broad valleys and rounded hills, but at close range it is seen to be extremely rugged. The illusion is largely due to the very uniform light color of the rock and to the lack of sufficient vegetation to accentuate the topographic details. Generally, the granite is not deeply weathered. Except on the flatter slopes and in the bottoms of valleys and washes, the outcrops are swept almost free of detritus, and consequently they support only scanty vegetation. The prominent joint system of the granite mass, which is conspicuous along U.S. Highway 70 through Bloody Tanks Wash, causes a rough blocky surface to form by a process of natural quarrying.

The joint system comprises two major sets of fractures, which are remarkably uniform in attitude throughout the granite outcrops, and several minor sets of more local prominence.

The fractures of the most prominent set strike northeast and dip southeast. Many of them can be followed continuously for 40 or 50 feet; and nearly every one contains a veinlet, from 1 to 3 mm wide, of cross-oriented muscovite generally accompanied by a little quartz. The strikes range from N. 25° E. to due east, but most are within the range from N. 55° to N. 75° E. The dips range from 50° to 75° SE., but are most commonly about 65° SE. A very minor set of fractures, which also contain muscovite veinlets, strikes N. 65° to 85° W. and most commonly dips 55° to 75° SW.

Of secondary prominence is a set of open fractures without muscovite veinlets that strike north to northwest and dip 60° NE. to vertical. A less prominent set of open fractures strikes northwest and dips steeply southwest. Northeastward-trending fractures having northwest dips are rare but may be prominent in local areas. In some places, there are a few northeastward-trending fractures with low northwesterly dips, generally less than 40°.

The average strikes and dips of the various sets of joint fractures differ slightly from place to place. For example, in the western part of the granite mass the average strike of the muscovite veinlets is probably about N. 70° E., whereas in the eastern part, the average strike is noticeably more northerly, probably about N. 50° E.

Fractures of the various sets are not uniformly spaced throughout the granite mass; zones in which the fractures are so closely spaced as to resemble sheeting alternate with parallel zones in which the fractures are widely spaced. Thus, no single small area is likely to show a true composite of the joint system. For example, at a given point of observation, joints of a minor set may be abnormally abundant and those of a major set poorly represented or entirely lacking. The spacing of the joints ranges between wide limits, but the common range is probably from 1 inch to 3 feet.

Joints of the various sets of fractures intersect one another and cut pegmatites, aplite dikes, and quartz veins without causing noticeable offsets; and they commonly bisect the mineral grains of the granite without displacing the two halves.

The joint pattern apparent in the Schultze granite is clearly a regional feature and has been recognized in all the massive rocks of the district. It is well developed in the quartz monzonite of the Porphyry Mountain mass (Peterson, Gilbert, and Quick, 1951, p. 55–61) and the dominant set of fractures that contain the mineralized veinlets of the Castle Dome copper deposit is essentially parallel to the muscovite veinlets in the Schultze granite. There are also unmineralized fractures in the Castle Dome area that are similar in attitude to the open fractures in the Schultze granite, but it is difficult to determine which fractures of this set were formed at the same time as the mineralized fractures and which are related to younger faults of similar trend. The same joint system can be recognized in the diabase east of the quartz monzonite and in the granite porphyry and granodiorite bodies south of Porphyry Mountain. Some outcrops of the Precambrian granite on Manitou Hill show a system of joints like the most prominant set in the Schultze granite; and where the two rocks are in contact, muscovite veinlets continue from one into the other.

The dominant set of fractures, which contains muscovite veinlets in the Schultze granite and the mineralized veinlets in the quartz monzonite of the Castle Dome area, is essentially parallel to the dominant structural trend of the Globe-Miami district.

Outcrops of Schultze granite are generally grayish yellow. The rock is porphyritic with large orthoclase phenocrysts ranging from 10 to 80 mm in length. The proportion of orthoclase phenocrysts differs greatly from place to place, forming as much as 15 percent of the rock locally but generally less than 2 percent. Hand specimens of the rock are nearly white and speckled with flakes of black biotite. White feldspar, quartz, and biotite can be recognized in the groundmass with the unaided eye. The mineral grains of the groundmass range mostly from 0.2 to 2 mm in diameter, but some quartz and orthoclase grains are as much as 6 mm in diameter.

In thin section under the microscope, the texture of the groundmass is seen to be subhedral, although some of the plagioclase grains show euhedral form. The plagioclase is oligoclase, about An_{25} in most specimens. Many oligoclase crystals are zoned, but the composition differs within a very narrow range. Some have rims of orthoclase or albite. Much of the orthoclase is slightly perthitic, and some of the larger grains of the groundmass are poikilitic with enclosed grains of quartz, oligoclase, and biotite. The biotite is pleochroic, from dark olive-brown to pale olive, and occurs as ragged books and flakes. The accessory minerals are muscovite, magnetite, ilmenite, zircon, and apatite. They are usually included in or associated with biotite and are never abundant. Except in mineralized areas, the granite shows remarkably little alteration.

A chemical analysis of a typical sample of the coarse, porphyritic Schultze granite collected by Ransome about a mile west of Schultze ranch is given in the first column of analyses in table 1. The approximate mineral composition of the sample as computed by Ransome (1903, p. 70), is as follows:

	Percent
Quartz	24.09
Orthoclase molecule	16.82
Albite molecule	43.83
Anorthite molecule	8.41
Biotite	4.50
Muscovite	1.28
Titanite (sphene)	.43
Iron ore	.64

If 8.41 grams of material having the composition of anorthite molecule is combined with 23.8 grams of material having the composition of albite molecule to form oligoclase of composition An_{25}, 100 grams of this rock will contain an excess of 20 grams having the composition of albite molecule that must be contained in the orthoclase. Microscopic examination shows that this excess cannot be accounted for by the albite inclusions in the perthitic orthoclase; hence, a large proportion of the excess must be combined with material having the composition of orthoclase molecule to form

TABLE 1.—*Chemical analyses of the granite and granite porphyry of the Schultze granite*

[E. T. Allen, analyst; samples collected by F. L. Ransome (1903, p. 69)]

	1	2	3
SiO_2	70.95	69.35	68.95
Al_2O_3	16.30	15.71	15.84
Fe_2O_3	1.01	1.18	1.14
FeO	.36	.43	.56
MgO	.23	.36	.24
CaO	1.85	1.79	1.96
Na_2O	5.16	4.78	4.56
K_2O	3.34	3.63	3.69
H_2O+	.26	1.17	.86
H_2O-	.37	.97	1.49
TiO_2	.23	.19	.22
ZrO_2	Trace	Trace	.01
CO_2	0	0	0
P_2O_5	Trace	.08	.08
SO_3	Trace	----	----
Cl	Undet.	----	----
F	Undet.	----	0
S	Trace	Trace	0
Cr_2O_3	0	0	0
MnO	Trace	Trace	Trace
BaO	.04	.07	.07
Total	100.10	99.71	99.67

1. Granite, 1 mile west of Schultze ranch.
2. Granite porphyry, marginal facies of the granite, 2 miles south of Schultze ranch.
3. Granite porphyry dike, 4 miles south of Schultze ranch.

a high-sodium orthoclase. The rock would then contain 36.8 percent perthitic, high-sodium orthoclase and 32.2 percent oligoclase, An_{25}. Thus, as was pointed out by Ransome (1903, p. 71), the Schultze granite is difficult to classify, for chemically it is a sodium-rich granite, but mineralogically it is a quartz monzonite.

GRANITE PORPHYRY FACIES

The Schultze granite includes several bodies of a granite porphyry that is clearly a marginal facies of the rock of the main mass. In most places the boundaries between the porhyry and the normal granite are gradational and the two facies have not been mapped separately. The granite porphyry of other bodies isolated from the main mass but probably related to it has been given a separate symbol on the geologic maps. These bodies cannot be proved to be parts of the main mass, although the rock is similar in texture and mineral composition to the granite porphyry facies of the Schultze granite and is approximately of the same age.

Rock of the large lobe of Schultze granite extending northeastward from the main mass just north of Bloody Tanks Wash (pl. 1) has several characteristics that distinguish it from the typical rock of the main mass. For convenience in description, rock of this mass will be called granite porphyry, although it includes varieties that range from rock that cannot be distinguished from that of the main body to typical quartz porphyry. In contrast with the prominently jointed, blocky outcrops that are characteristic of the main mass, the rock in this lobe is thoroughly shattered and forms smooth rounded outcrops that look very much like those of the adjacent Pinal schist.

On the southeast side of the lobe, along Bloody Tanks Wash, the contact with the schist is approximately concordant with the schistosity, which dips from 70° NW. to vertical. In the northwestern part of the lobe, the porphyry is underlain by schist and has the form of a sill-like tongue intruded into the schist (pl. 7, sec. *A′–A′*). This relationship, not apparent from a study of the outcrops, was disclosed by churn-drill exploration of the Miami-Inspiration copper deposit, which occurs along the north side of the lobe. East of the Bulldog fault, the north contact is generally steep (pl. 7, secs. *D–D′* and *E–E′*). Along the west side of the lobe, south of the Sulphide fault, the contact with the schist is very irregular; its relationship to the topography does not indicate low-angle dips. However, in this area, there are no subsurface data to confirm this interpretation.

The rock composing this lobe includes a wide range of textural varieties that are gradational from a typical quartz porphyry facies with aphanitic groundmass to medium- or coarse-grained porphyritic rock that is identical with that of the main mass of Schultze granite. Intermediate varieties have the same mineral composition and texture as typical Schultze granite but generally are finer grained.

The northern part of the lobe is predominantly granite porphyry, whereas to the south, toward the main mass, the proportion of coarser grained rock increases. The relationships between the facies are very complex, and it would be difficult and perhaps impossible to delineate satisfactorily definite bodies of either facies. In many places, there are sharp, well-defined contacts between granite porphyry and the coarser grained granite, but along the strike of these contacts the textures of the rocks change and become so similar that all semblance of a contact disappears.

Southwest of this lobe is a smaller outcrop of similar highly shattered rock that also contains ill-defined areas of granite porphyry. The block containing the body has been relatively depressed by displacement on the Barney fault, which cuts northwestward between the two outcrops, and the two outcrops probably represent different depth zones in a mass of granite and granite porphyry that was once continuous. Toward the south, the smaller body extends like a tongue into the main stock of Schultze granite and the outcrop ends in a small alluvium-covered flat that is crossed by U.S. Highway 70 at the Schultze ranch (pl. 1).

At least part of this flat is underlain by Pinal schist, which apparently separates the shattered rock from the normal blocky granite to the south. The alluvial cover obscures the relationships, and it is not known whether the small body of schist is a roof pendant or an inclusion. A drill hole sunk in 1912 by the South Live Oak Development Co. at the Schultze ranch, 250 feet northwest of the schist outcrop, is reported to have been in granite for the length of the hole, 825 feet.

On the east and west sides, the shattered rock is separated from the normal Schultze granite by zones of white clay, from 10 to 50 feet wide, which are shown on the map (pl. 1) as faults, although their true nature is uncertain. The clay zone on the east side strikes approximately north in the interval from the highway to a point 2,500 feet to the north, whence it changes in strike a full 90° to the east and apparently joins a late Tertiary or Quaternary fault that forms the northeast boundary of the outcrop. The southern part of the clay zone on the west side also strikes approximately north but dips 45° to 60° W. Farther to the north it changes in strike to west and dips south. Westward, as the Castle Dome road is approached, the clay zone becomes indistinct, and the two facies of the granite cannot be distinguished.

The origin of the clay is not known. In a few places along the west zone, the clay is foliated and shows some evidence of slippage that suggests a fault zone; however, no relationships that indicate appreciable displacement have been observed. In most places the appearance of the clay suggests a zone of argillic hydrothermal alteration formed along a fracture or igneous contact, but no other minerals characteristic of hydrothermal alteration are present. In the central part of the clay zone, all the minerals of the granite and granite porphyry have been altered to clay except quartz. The change from clay containing quartz grains to unaltered rock is gradational but generally takes place within a distance of only a few feet. The clay mineral is of the montmorillonite type and has a mean index of refraction of about 1.547.

The northwest boundary of this outcrop of shattered rock is an intrusive contact with Pinal schist. It is very irregular but seems to be steep. There are numerous apophyses extending into the schist and abundant large and small inclusions of schist near the contact. Some inclusions have been partly assimilated by the magma, but most of them have sharp angular contacts and show little if any evidence of alteration.

The normal Schultze granite grades into granite porphyry in the southern part of a large lobe that projects into the schist at the southeastern end of the main outcrop, and small bodies occur at a few other places along the margins of the mass. Many of the dikelike apophyses of the stock are granite porphyry or are distinctly finer grained than the normal granite. Along the greater part of the contact, however, there is no marked change in the general texture of the rock.

The granite porphyry facies probably is slightly younger that the main intrusion, although no proof of age difference can be given. The complex relations of the several textural varieties that can be seen in the outcrops of the northeastern lobe may well be the result of successive pulses of magma injected somewhat later than the main intrusion. The several pulses were injected in such close succession that the magma of one pulse had not completely consolidated before it was invaded by a succeeding pulse.

The presence of deeply rooted channels leading to the magma chamber is suggested by the extensive mineralized areas associated with the larger bodies of granite porphyry. The great Miami-Inspiration disseminated-copper deposit is along the north side of the northeastern lobe of granite porphyry. A broad zone of disseminated pyrite and very sparse chalcopyrite occurs in the schist bordering the granite porphyry at the southern end of the southeastern end of the outcrop of Schultze granite.

The true granite porphyry is readily recognized in hand specimens by the many euhedral quartz phenocrysts, 1 to 8 mm in diameter, scattered through the microcrystalline groundmass. The quartz phenocrysts are especially conspicuous in the porphyry near the Miami-Inspiration ore body and in other places where the rock is hydrothermally altered; the alteration has clouded numerous small plagioclase phenocrysts, giving strong contrast to the clear glassy quartz grains. Where the rock is disintegrated by weathering, the loose quartz grains are seen to be stubby, bipyramidal forms. Euhedral phenocrysts of yellowish-gray to pinkish-gray orthoclase as much as 20 mm long are also conspicuous. Abundant phenocrysts of plagioclase and a few of biotite are generally less than 2 mm across.

In thin section the rock is seen to have typical porphyritic texture. The plagioclase is medium to calcic albite and more sodic than that of the granite of the main mass. The orthoclase phenocrysts are untwinned and but slightly perthitic. Most of the euhedral quartz grains are more or less corroded and embayed by the groundmass. Very sparse accessory minerals include magnitite, apatite, zircon, and rare sphene. The groundmass is a microcrystalline aggregate of quartz and orthoclase, with perhaps a little albite, whose grain size most commonly ranges from 0.01 to 0.05 mm.

Thin sections of the intermediate varieties of the rock show areas of medium-grained groundmass, like that of the typical granite interspersed with patches of fine-grained quartz and orthoclase like that of the groundmass of the porphyry but generally a little coarser grained. In some thin sections, the grains are as much as half a millimeter in diameter. Although in the field, the gradation from medium-grained porphyritic granite to granite porphyry appears to be complete, none of the thin sections that showed both kinds of ground mass contained the euhedral quartz phenocrysts characteristic of the typical granite porphyry.

Small bodies of granite porphyry not connected with the granite stock occur in several places in the Globe-Miami district. One of the largest was intruded between quartz monzonite and granodiorite southeast of the Castle Dome mine (pl. 1). It is a narrow, steep-walled body having a general eastward trend. Its east end extends into diabase as a dike. About 1,000 feet farther west, another smaller body also was intruded between the quartz monzonite and the granodiorite. The westward extension of this zone of granite porphyry intrusions is indicated by numerous small dikes and irregular masses in the quartz monzonite and by two small plugs in the diabase near Gold Gulch. Several other masses in this zone do not crop out but were cut by exploratory drill holes. These apparently disconnected bodies probably represent the top of a larger mass which has not yet been exposed by erosion. Several other small masses have been intruded into diabase east of Porphyry Mountain. Two small bodies intruded into Pinal schist crop out on the Cactus property northwest of Manitou Hill (pl. 7).

Many dikes and small irregular masses of granite porphyry intrude the quartz monzonite south of Sleeping Beauty Peak. In this area, as in the Porphyry Mountain area, the granite porphyry occurs in a series of small intrusive masses alined in an eastward-trending zone through the quartz monzonite.

West of Powers Gulch, near the northwest corner of the Pinal Ranch quadrangle, granite porphyry crops out along the edge of the dacite that conceals all the older formations from Pinal Ranch southwestward to Superior. The porphyry in these outcrops includes a medium-grained variety identical with the typical Schultze granite. It is probably connected with the main mass of Schultze granite under the intervening tongue of schist that may well be a roof pendant. In each of the four localities described above, disseminated copper minerals are associated with the granite porphyry.

Four small intrusive bodies of granite porphyry occur in the overthrust block of Madera diorite that crops out south of the Old Dominion A shaft. These are the only granite porphyry outcrops east of Pinal Creek.

Ransome (1903, p. 73) described several dikes intruded into the Pinal schist and Madera diorite south of the Schultze granite stock that he considered to be offshoots of the main intrusion. He based his correlation on the essentially identical composition of the typical Schultze granite, the granite porphyry, and the dike rock. The analysis of a sample collected by Ransome from one of these dikes, 4 miles south of Schultze ranch, is given in column 3 of table 1. Analyses of typical medium-grained Schultze granite and the granite porphyry of the marginal facies, 2 miles south of Schultze ranch, are given in columns 1 and 2, respectively. It seems highly improbable that rocks of so similar and characteristic compositions should not be related.

Although there is no direct field evidence that any of the small outlying bodies of granite porphyry are related to the Schultze granite, they are similar in mineral composition and texture to the granite porphyry facies of the Schultze granite, and they are at least approximately of the same age.

The rocks adjacent to the south side of the Schultze granite stock contain many small dikes of light-colored rock from a few inches to several feet wide. A few of the dikes are clearly apophyses of the main granite mass; many of them have no visible connection with the granite but are generally near the contact. Some cannot be distinguished from small aplitic dikes that cut the granite itself.

The rocks of all these small dikes are very similar and apparently evolved from a common parent magma. They are composed chiefly of quartz, orthoclase, and albite. All contain a little muscovite, and many contain biotite. They generally have fine equigranular texture; some are porphyritic and have phenocrysts of albite and quartz.

A very minor phase of the granite porphyry in which all the phenocrysts are albite occurs in several small dikes that intrude the Lost Gulch quartz monzonite south of Sleeping Beauty Peak.

AGE OF GRANITE AND GRANITE PORPHYRY OF THE SCHULTZE GRANITE

The stock of Schultze granite invaded the Pinal schist, and some of the older igneous rocks intruded into the schist. It was intruded into the Precambrian granite on the south flank of Manitou Hill and also east of Powers Gulch. Southeast of Porphyry Mountain Schultze granite shows intrusive relationships with a body of Willow Spring granodiorite and also with the southern, separate mass of the Lost Gulch quartz monzonite. About 2 miles east of Schultze Ranch, it intrudes a small body of igneous rock that has been tentatively correlated with the Solitude granite (p. 23). In the same locality Schultze granite is in contact with a small body of diabase, but the contacts are poorly exposed, and the relationships are not clear. However, both the diabase and the adjacent small mass of Solitude(?) granite are cut by several small dikes which almost certainly are offshoots of the Schultze granite. This is the only place where the stock is in contact with diabase, and it is uncertain that this small isolated mass is of the same age as the main intrusion of diabase (p. 30).

In the Castle Dome area, the granite porphyry is younger than the main intrusion of the diabase. In the largest of the several small bodies that crop out northwest of Jewel Hill the groundmass of specimens of the granite porphyry near the contact with the diabase is distinctly finer grained than the groundmass of specimens farther from the contact. Furthermore, there are tiny inclusions of altered diabase in the porphyry near contact. The narrow dikes southwest of Jewel Hill surely must have been intruded into the diabase.

Thus, the granite porphyry and probably also the Schultze granite are younger than the main intrusion of diabase, which occurred in post-Pennsylvanian time. Both antedate the period of hypogene copper mineralization. The close association of mineral deposits of hydrothermal origin with intrusions of granite porphyry suggests that the granite porphyry and the mineralizing solutions ascended along the same channels, which in turn, suggests that the granite porphyry may be slightly younger than the main intrusion of granite. The Schultze granite and its related porphyry facies seem to be the youngest rocks emplaced during the series of intrusions that culminated in the extensive mineralization that produced the great copper ore bodies of the district. This period of igneous activity may have begun in Late Cretaceous and continued into early Tertiary time.

TERTIARY(?) SYSTEM

WHITETAIL CONGLOMERATE

The Whitetail conglomerate is a deposit of detrital material of local origin that accumulated in low-lying areas and along stream channels during the period of erosion that preceded the eruption of dacite. It is very similar in character to the younger Gila conglomerate, from which it can be distinguished only where its stratigraphic position beneath the dacite can be established. The type locality of the Whitetail conglomerate is 2 miles north-northwest of Porphyry Mountain in Eastwater Canyon, which was known as Whitetail Gulch at the time Ransome (1903, p. 46–47) named and described the formation (pl. 1).

The most extensive outcrops of Whitetail conglomerate are in the western part of the Inspiration quadrangle, in the area south of Eastwater Canyon and west of Porphyry Mountain. In this area the maximum thickness of the formation is at least 200 feet and probably much more. The top of the formation is well exposed, but the contacts with the older rocks are chiefly steep normal faults. In one outcrop, 7,500 feet west southwest of Porphyry Mountain, where both top and base of the Whitetail can be seen, the formation is thin and overlies Naco limestone in a down-faulted block. A few small remnants of dacite occur along the fault that forms the west boundary of the depressed block.

Several outcrops of Whitetail conglomerate occur along the zone of faults on the east side of Porphyry Mountain. In the faulted block northwest of Jewel Hill, a drill hole passed through nearly 500 feet of conglomerate before it reached the northeastward-dipping fault that forms the west boundary of the block. At this point the original thickness of the Whitetail may have been considerably more than 500 feet.

A few small outcrops of Whitetail conglomerate occur in the area along the northwest side of the mass of Lost Gulch quartz monzonite west of Pinal Creek. In the area east of Pinal Creek, no outcrops of Whitetail conglomerate have been recognized. However, according to the geologic records of the underground mine workings, some Whitetail conglomerate underlies the dacite at the southwest end of the Old Dominion mine.

In the western part of the district, where the thickest sections occur, the Whitetail conglomerate is composed of coarse, bouldery detritus derived largely from diabase and is generally dark reddish brown from oxidation of the iron-bearing minerals. Commonly, fragments derived from the Pinal schist, the Apache group, and limestones of Paleozoic age are also present in variable but always subordinate proportions. The lower part is wholly unsorted and unstratified. Higher in the section crude stratification can be recognized, and lenses of poorly sorted gravel occur that undoubtedly represent temporary stream channels. Approximately the upper 50 feet of the formation is well stratified and is composed by layers of dark sand and gravel interbedded with layers of white tuffaceous sand.

The Whitetail conglomerate in the small faulted blocks along the Warrior fault zone in the vicinity of Inspiration (pl. 7) apparently is a very local accumulation of detritus in an old channel on the erosion surface on which the dacite was deposited; because elsewhere in this general area, the dacite and basal vitrophyre and tuff rest directly on the older rocks. The lower part of Whitetail deposited in this channel is a breccia of fragments obviously derived from local outcrops, chiefly Pinal schist, diabase, and Pioneer formation. In the upper part, the breccia is interbedded with water-laid tuffaceous sand. The preponderance of tuffaceous material in some places makes it difficult to decide whether the outcrops should be mapped as Whitetail conglomerate or as a part of the dacite sequence.

VOLCANIC ROCKS

The Tertiary(?) volcanic rocks of the district represent two distinct periods of eruption that were separated by an interval during which some erosion of the rocks of the first eruption occurred. The extent of this erosion is not yet known. Almost all the rocks of the earlier eruption are beyond the map area of this report, and they are as yet only partly mapped. They crop out in a belt, possibly 5 miles wide, that extends from the west boundary of the Inspiration quadrangle to the vicinity of Picketpost Mountain, southwest of Superior. These volcanic rocks are a complex of bedded tuffs, felsitic and glassy lavas that solidified from an extremely viscous magma, and perlite glass. The presence of thin discontinuous strata that obviously were water laid suggests that in some places or at intervals the volcanic material fell or was in part extruded into shallow bodies of water.

The rocks of the second eruption unconformably overlie the earlier volcanic rocks and have far greater areal extent; beyond the limits of the rocks of the earlier eruption they may rest on any of the older formations. They consist essentially of two members. The lower member, generally too thin to be shown on the geologic maps, is a bed of white to yellowish-gray crystal tuff that grades upward into a layer of black vitrophyre. The upper member is a thick sheet of light brownish-gray rock that, in accordance with Ransome's (1903, p. 88–95) nomenclature, is called dacite. As commonly used in later discussion in this report the name "dacite" refers to both members of the second eruption.

EARLIER VOLCANIC ROCKS

Within the map area, the rocks of the earlier eruption are found only in two small outcrops, chiefly of perlite, on the west boundary of the Inspiration quadrangle. The perlite rests on limestone of Paleozoic age or on the Whitetail conglomerate and is overlain by water-laid tuff. The age of the tuff is uncertain; it may have been deposited during the second eruption.

The lower part of the tuff is grayish orange pink firmly consolidated, and is interbedded with thin layers of pink or red mudstone. The upper part is crudely bedded and contains fragments of quartz, feldspar, biotite, pumice, and foreign material in a fine-grained matrix of clay and partly devitrified glass. The matrix is made almost opaque by very fine limonitic dust. The pumice fragments are as much as an inch in diameter and are altered to a grayish-yellow montmorillonite-type clay. This tuff is overlain by the massive upper member of the younger eruption. The white crystal tuff and vitrophyre are absent but are present a short distance away where the younger volcanic rocks rest on Paleozoic limestone or Whitetail conglomerate.

The fresh perlite is black, has vitreous luster and conchoidal fracture, and is speckled with phenocrysts of glassy feldspar. On weathered surfaces, it is dull medium gray.

In thin sections, the glass is clear and almost colorless. Perlitic structure is well developed, and there has been slight devitrification along many of the cracks. Globulites are sparsely disseminated throughout the glass and are also concentrated in roughly parallel curved flow bands. Some of the flow bands are made by trichites and longulites oriented roughly parallel to to the bands or forming swirls around the phenocrysts. The feldspar phenocrysts are clusters composed of euhedral or subhedral albite-oligoclase and anhedral clear sanidine. Olive-brown biotite occurs as thin books 0.3 to 1.5 mm across. An average thin section contains less than a dozen phenocrysts. Apatite, zircon, magnetite, and minute grains of a mineral resembling epidote are rare and are generally within the phenocrystic clusters.

The index of refraction of the glass is slightly less than 1.50. When heated above the softening temperature, the glass expands, or "pops," to a white frothlike aggregate. Much of the perlite is suitable for the manufacturer of light-weight concrete aggregate, insulation material, and other industrial products.

Within the porphyritic perlite are many masses of yellowish-gray felsite that appear to have formed by local devitrification of the glass. They contain the same assemblage of phenocryst minerals, and flakes of biotite can be seen with the aid of a hand lens. Microscopic examination of the thin sections shows that the glass is only partly devitrified. The perlitic structure is well preserved by more complete alteration along the cracks. Alteration began at the cracks and worked outward, producing a cryptocrystalline felt that surrounds small islands of unaltered glass. In some areas, bands of cross-fibered or spherulitic alkalic feldspar formed along cracks, producing a mosaic of polygons of cryptocrystalline devitrified glass. Some of the polygons have a concentric structure with cryptocrystalline bands alternating with bands of isotropic glass. The feldspar crystals in the phenocrysts are generally shattered. Most of the biotite is altered, at least in part, to a reddish-brown variety. Minute rounded grains of a yellowish mineral resembling epidote are scattered through the altered glass and are especially abundant in the bands that formed along the perlitic cracks.

LATER VOLCANIC ROCKS

The second eruption laid down a thin layer of vitric-crystal tuff and over it a massive sheet of rock that Ransome (1903, p. 88) called dacite. Many large and small remnants of the sheet occur throughout the Globe-Miami district. The largest has an area of about 5 square miles and is in the central part of the Inspiration quadrangle. To the north and east the dacite sheet extended beyond the limits of the map area, and it extended for at least 40 miles west of Globe. On the south, it probably overlapped the northern flanks of the Pinal Mountains, but its original extent in that direction is unknown, because the southern part of the sheet is buried beneath a thick alluvial fan that was washed down from the mountains. The dacite extends around the north and west sides of the Pinal Mountains as far south as Ray.

The thickness of the dacite in the outcrops that have been mapped is uncertain because of the lack of knowledge concerning the surface on which it rests. It is known, however, that this surface was one of considerable relief. In a drill hole 1,500 feet west of the southwest corner of the Inspiration quadrangle 1,215 feet of dacite was penetrated. In a second drill hole, 1 mile southwest of the Old Dominion "A" shaft, 1,050 feet of dacite was intersected. At both localities the dacite undoubtedly has undergone considerable erosion. Short (Short and others, 1943, p. 45) stated that the dacite sequence is 1,300 feet thick on Picketpost Mountain, 4 miles southwest of Superior, and 2,500 feet thick in the Superstition Mountains northwest of Superior.

Although the dacite is fairly resistant to erosion and caps many of the highest hills in the district, most of the outcrops are in down-faulted blocks. Characteristic of the rugged outcrops are large rounded masses of dacite formed by weathering back from widely spaced joints. Columnar jointing is prominent in some outcrops, and in others jointing is inconspicuous. In the area between Miami and Superior the outcrops are studded with spectacular knobby pinnacles resulting from weathering controlled by vertical columnar joints and eutaxitic structure. In most outcrops of the Globe-Miami area, the lower 100 feet or more of the dacite appears to be harder and more closely jointed than the upper part. It forms steep cliffs generally flanked by streams of coarse angular talus. Ten miles southwest of Miami, where the dacite is deeply incised by Devils Canyon, columnar jointing is well developed in the upper walls of the canyon, whereas in the lower walls the rock is more massive; but here the basal part of the formation is not exposed.

In some outcrops, coarse agglomeratic structure is suggested by what appear to be large relict fragments of dacite that is slightly lighter in color than the matrix rock. In other outcrops, the dacite includes abundant lenticular fragments belived to be flattened pumice bombs. Throughout the Globe and Inspiration quadrangles and most of the Haunted Canyon quadrangle to the west, the dacite outcrops contain some local zones in which these lenticular fragments are fairly abundant, but southwest of Miami, toward Superior, such fragments become increasingly abundant and widespread, until in the canyon of Queen Creek, east of Superior, very thick sections of dacite can be seen, in which they compose as much as 50 percent of the rock.

As seen in fresh excavations, the fragments are commonly altered to a soft cellular aggregate of needlelike feldspar crystals, clay, and spherulitic growths that are probably cristobalite. On weathered surfaces, the fragments are represented by lenticular cavities that resemble large vesicles, 2 to 10 inches long. Wherever examinations can be made, the coarse eutaxitic structure, believed to be caused by the flattening of pumice bombs, is roughly parallel to the lower surface of the sheet.

Rock fragments are common throughout the dacite, but they also differ greatly in abundance from place to place. The fragments are from all the older formations, but those of reddish-brown or gray felsite apparently derived from the earlier volcanic rocks, are the most common.

The dacite outcrops are uniformly light brownish gray. The fresh rock has the same color, but it may differ in intensity slightly from place to place. When broken, surfaces feel sharply granular. The groundmass is aphanitic and includes abundant small phenocrysts, most less than 2 mm in diameter, of feldspar, quartz, and glistening black biotite. Faint flow banding is seen in some places, but generally the rock is massive and uniform throughout.

As seen in thin sections, the quartz phenocrysts are deeply embayed and rarely show crystal boundaries. Plagioclase is by far the most abundant feldspar and is also more abundant than quartz, it differs slightly in composition, and some crystals are zoned, but most of it is andesine containing about 35 percent of the anorthite molecule. The potash feldspar is sanidine and, like the quartz, has been resorbed. Much of the biotite is in ragged and corroded books and is partly or wholly altered to a reddish-brown variety that is strongly pleochroic—from yellowish brown to dark reddish brown or opaque. The few books that appear to be unaltered are uniform in color and pleochroic, from greenish yellow to olive gray. A little green hornblende is present in most specimens. Magnetite occurs as scattered grains and along the corroded edges of the altered biotite. Other accessory minerals are apatite and occasional grains of zircon in the biotite.

The glassy groundmass is made semiopaque by brownish dustlike inclusions that probably are hydrated iron oxides and give the rock its color. Microscopic flow banding is conspicuous in the groundmass and is accentuated by the inclusions. The flow bands show a general uniform orientation but in detail form intricate swirls and mold themselves around the phenocrysts. Some of the bands are clearly due to flowage of a viscous glass, but the origin of others is not so clear, and the apparent banding may be the result of compaction of pumice fragments and glass shards. Unquestionable evidence of such compaction has not been recognized in the groundmass of the typical massive dacite. In some specimens, the phenocrysts are highly shattered and the fragments displaced. In these the banding is irregular, discontinuous, and generally more obscure than in specimens that show only minor fracturing of the phenocrysts. Areas of incipient crystallization characterized by spherulites and trichites are seen in all thin sections of the dacite. Much of the groundmass is at least slightly birefringent as a result of devitrification. Some areas are microspherulitic, and some are cryptocrystalline. Coarse spherulitic structures formed by radial clusters of branching and plumose crystals are promient in some sections.

A chemical analysis, made by E. T. Allen, of a typical specimen of the dacite collected by Ransome (1903, p. 92–93) a quarter of a mile north of the Old Dominion mine is given in table 2. The norm calculated from this analysis shows that the rock contains about

TABLE 2.—*Chemical analysis of dacite from the Globe-Miami district.*

[E. T. Allen, analyst. Sample collected by F. L. Ransome (1903, p. 92–93) from outcrop one-fourth mile north of Old Dominion mine.]

SiO_2	68.76	P_2O_5	.06
Al_2O_3	15.48	SO_3	0
Fe_2O_3	2.50	Cl	.03
FeO	.44	F	0
MgO	.56	S	0
CaO	2.23	Cr_2O_3	.06
Na_2O	3.89	NiO	0
K_2O	3.88	MnO	.02
H_2O-	.79	BaO	.08
H_2O+	.57	SrO	0
TiO_2	.50		
ZnO	.03	Total	99.82
CO_2	0		

twice as much plagioclase as orthoclase. The normative composition of the plagioclase is $Ab_{77}An_{23}$.

In most parts of the district, the massive brownish-gray dacite is underlain by a bed of white to yellowish-gray vitric-crystal tuff, 10 to 100 feet thick. Toward the top, the tuff commonly contains increasingly abundant lenses or schlierenlike streaks of black glass and grades into a layer of black vitrophyre on which the dacite rests. The vitrophyre ranges from 5 to 25 feet in thickness but is generally less than 10 feet thick.

Thin sections show the same assemblage of phenocrysts in the vitric-crystal tuff as in the dacite. The principal differences are that the tuff has a greater number of hornblende phenocrysts and that its quartz and feldspar phenocrysts are more shattered and the fragments more widely dislocated than those in the dacite. Even the biotite and hornblende are unaltered except near the base of the tuff. The minor constituents are magnetite and apatite. The groundmass appears to be composed of pumice fragments of clear, colorless glass that are crushed and flattened and squeezed between the phenocrysts. The glass is partly devitrified and shows a fibrous or felted texture between crossed nicols. Toward the top of the tuff layer, the groundmass contains increasing amounts of clear glass, and the banding looks more like flow structure.

In thin section, the black vitrophyre looks exactly like the tuff except for the groundmass in which the banding more closely resembles flow structure than that of the groundmass of the tuff. The groundmass of the vitrophyre is faintly brownish but is almost clear glass. It shows bands containing abundant globulites and some trichites that alternate with bands of clear glass, which, in turn, are banded with streaks of light-colored and darker colored glass. The index of refraction of the glass is slightly higher than 1.495.

Thin sections of intermediate specimens show progressive change in the character of the groundmass from tuff to vitrophyre. This gradation from white vitric-crystal tuff at the base to black porphyritic vitrophyre at the top suggests that the vitrophyre was formed by compaction and welding of the pumiceous tuff by the heat and pressure of the overlying dacite sheet. In order to determine whether compaction had occurred, the porosities of specimens collected from various levels above the base of a typical section were measured and are shown in table 3.

The porosity decreases from 26.39 percent in the white vitric-crystal tuff near the base to 1.6 percent in the black vitrophyre at the top, just below the base of the dacite. The bulk specific gravities of the same specimens increase from 1.79 for the tuff to 2.47 for the vitrophyre.

TABLE 3.—*Porosity and bulk specific gravity of the tuff, vitrophyre, and dacite, Globe-Miami district*

Sample	Rock type	Distance above base of tuff (feet)	Porosity (percent)	Bulk (specific gravity)
9	Dacite	245	10.04	2.26
8	do	195	10.90	2.23
7	do	120	7.17	2.38
6	do	70	12.08	2.26
5	do	22	6.27	2.41
4	Vitrophyre	12	1.60	2.47
3	Tuff	7	4.35	2.38
2	do	5	6.62	2.29
1	do	2	26.39	1.79

The white basal tuff is clearly of pyroclastic origin and probably was deposited from incandescent clouds of ash or as ash flows. The thickest deposits accumulated in valleys and low-lying areas. Only in a few small areas is the tuff entirely absent beneath the dacite. In areas that were low at the time of the eruption, for example, the area northwest of Porphyry Mountain, the pyroclastic material undoubtedly was deposited in shallow bodies of water. In such areas, the tuff is generally yellowish gray, soft, and sandy and may be crudely stratified. It is composed of fragments of the same minerals that occur as phenocrysts in the normal vitric-crystal tuff, abundant small fragments derived from older rocks, and bits of glass in a claylike matrix of devitrified pumice. The lower part is stratified and is commonly interbedded with the underlying Whitetail conglomerate. The upper part is unstratified and appears to grade into the overlying dacite, and only small irregular lenses of the black vitrophyre are interbedded in a few places. In the transition zone, the rock becomes firmly indurated, and toward the top the rock fragments become less abundant, and the color of the groundmass changes to grayish brown.

Apparently the black vitrophyre formed mainly in those areas where the tuff settled on dry land, and in these areas the tuff may still have been very hot and near the softening temperature of the glass at the time the dacite covered it. Where the tuff is thickest and clearly water laid, very little of the black vitrophyre was formed.

Ransome (1903, p. 88–95) and many other geologists familiar with the Globe-Miami district and the surrounding region have regarded the dacite as a thick lava flow. However the dacite sheet must have been at least 1,200 feet thick in the Globe-Miami area and in the outcrops is massive throughout, showing no recognizable breaks or changes in lithologic character on which to base separation of the dacite into thinner units. A single flow of such a thickness is inconceivable. Furthermore, no large-scale flow structures have been recognized; and the suggestion of agglomeratic structure, which was mentioned earlier is far too indistinct to class the rock as a flow breccia. On the other hand, the broad characteristics of the dacite sheet, together with the presence of flattened pumice fragments of bomb size in many places, and the very obvious clastic character of the rock in some local areas strongly suggest a pyroclastic origin. The microscopic texture of the groundmass does not clearly indicate a pyroclastic origin, but neither is it typical of the common flow rocks. The incandescent clouds or ash flows that could have deposited the dacite must have been extremely dense and must have contained a large proportion of liquid or plastic material that did not expand into pumice before coming to rest.

Several petrographers with broad experience in the study of pyroclastic rocks now consider the dacite to be a welded tuff. C. S. Ross (1955, p. 431) refers to the great thickness of welded tuffs in the Globe-Superior region of Arizona. G. J. Neuerburg (written communication, 1953), of the U.S. Geological Survey, studied specimens of the dacite from near Superior and describes the rock as an ill-sorted crystal lapilli tuff, most probably a welded tuff. R. L. Smith (oral communication, 1956), also of the Geological Survey, considers the structural features of the dacite outcrops along the canyon of Queen Creek east of Superior, to be typical of some deposits of welded tuff.

TERTIARY AND QUATERNARY SYSTEMS

GILA CONGLOMERATE

The name Gila conglomerate was given by Gilbert (1875, p. 540–541) to deposits of valley fill in the region drained by the upper Gila River and its tributaries. He described the deposits as bouldery conglomerate of local origin interbedded with layers of slightly coherent sand, tuff, and sheets of basalt. In contrast to the Recent valley deposits, the Gila is being eroded rather than accumulating. Ransome (1903, p. 47) extended the use of the name to include the deposits in the Globe and Ray quadrangles that appeared to be identical in character and origin and in part continuous with those described by Gilbert. The Gila includes deposits of Pliocene and early Pleistocene age. (Gidley, 1922, p. 120–121, and Knechtel, 1936, p. 81–92). As used in this report, the Gila conglomerate includes alluvial deposits that are younger than the dacite but older than the latest orogenic disturbances that affected the region.

The deposition of the Gila conglomerate in the Globe-Miami area was preceded by a period of faulting and vigorous erosion. The Gila overlies all the older formations, resting on an erosion surface of considerable relief. Pronounced angular unconformities with the underlying strata are common, and in many places, its stratified gravels abut steep slopes at the erosion surface. Faulting probably continued during accumulation of the deposits that are now exposed, and most outcrops show evidence of later faulting and deformation. Some of the largest faults in the district displace Gila conglomerate.

The broader features of the deposits are typical of broad coalescing alluvial fans laid down by periodic floods and intermittent streams. The character and composition differ greatly, according to the source of the constituent materials and the amount of transportation and sorting they have undergone, the deposits ranging from completely unsorted and unconsolidated rubble of angular blocks as much as 15 feet in diameter to well-stratified deposits of firmly cemented sand, silt, and gravel containing well-rounded pebbles and cobbles.

The largest deposit of Gila conglomerate in the district is in Globe Valley. Its southern boundary is 4 to 5 miles south of Globe and Miami, and it extends northward along Miami Wash and Pinal Creek beyond the limits of the district. The southwestern part of the deposit is part of a broad alluvial fan that formed on the northeast flank of the Pinal Mountains. The lower part of the fan is composed entirely of unsorted angular fragments of Pinal schist. Toward the top, there is a progressively increasing admixture of fragments of Madera diorite, and crude stratification can be recognized in some places. During the later stages in the building of this fan, the Schultze granite was uncovered, and much granite detritus was washed down from the west. Exploratory drilling a mile south of Bloody Tanks Wash shows that this fan was built up to thicknesses exceeding 4,000 feet.

A fan of entirely different character and composition formed on the opposite side of the Globe Valley, from detritus washed down from the mountains to the north and northeast. The parts of this fan that can be seen or have been penetrated by drill holes are composed of interfingering lenticular beds of gravel, sand, and silt, many of them firmly indurated by calcareous cement. Although formations from which the constituent materials could have been derived undoubtedly underlie much of this deposit, and outcrops of those formations are everywhere close at hand, nevertheless, most of the fragments are well rounded and apparently were transported considerable distances.

The fragments are mostly of rocks of the Apache group, Troy quartzite, limestone of Paleozoic age, dacite, and diabase. The relative proportions of the various types of fragments differ greatly from place to place. The sand is mostly dacitic or decomposed diabase, but grains from other rocks are generally present. Excellent exposures of this conglomerate can be seen along U.S. Highway 60–70, between Globe and Miami Wash and in the cliffs along the east side of Miami Wash, from the junction of the Apache Trail with U.S. Highway 60–70 to Burch siding.

In most areas the detailed character of the fan is obscured by a thin mantle of younger gravels that were formed largely by reworking of the original deposits. The streams that redistributed the surface material apparently flowed from the west for the gravels contain many fragments of mineralized schist and granite porphyry that must be from the leached capping of the Miami-Inspiration ore body.

The materials that compose the two major fans are blended in a broad, ill-defined zone that extends approximately along the east side of Russell Gulch and about under the Inspiration tailings dumps in Lost Gulch. On the west and northeast, the deposit is bounded by normal faults along which the conglomerate has been depressed. There is also a strong fault near the southern edge of the deposit, along which at least the older beds have been displaced. Wherever the attitudes of the bedding can be observed, the beds are seen to be nearly horizontal or dip gently to the southwest, except along the boundary faults, where the beds may be steeply inclined. It is doubtful, however, that any of the present attitudes represent initial dips. Very few dips can be measured in the very crudely stratified deposits of the southwestern fan.

It is possible that part of the alluvial deposit that occupies Globe Valley is not actually Gila conglomerate. It is not known how far southward the dacite extended. The lower part of the fan on the northeast flank of the Pinal Mountains may well be of Whitetail age and may have been overlapped by the southern edge of the dacite sheet.

The outcrop southeast of Porphyry mountain (pl. 1) is of special interest because it illustrates on a relatively small scale the manner in which the Gila conglomerate was deposited. The outcrop was mapped in detail by C. M. Gilbert during the study of the Castle Dome area. He recognized eleven mappable units, differentiated on the basis of the composition of their rock fragments.

This body of Gila conglomerate probably is somewhat younger that the major portion of the deposit that occupies Globe Valley, and its material is of more local origin. Fragments of Schultze granite are in all but the oldest unit, whereas in the thick deposit to the east, they occur only in the upper, or younger, part. The conglomerate accumulated in a small structural basin formed during the final stage in the uplift of the Castle Dome horst. The relationships of the various units indicate that the deposit was built up of a number of overlapping and coalescing alluvial fans that were washed into the basin from various directions.

The oldest fan was formed from detritus washed into the basin from the north and composed of fragments of dacite with very sparse local admixture of fragments off rocks of the Apache group. It is almost buried by younger fans that overlap it from the east, west, and south. The fan overlapping from the east is composed largely of mineralized schist and granite porphyry undoubtedly derived from the leached capping of the Miami-Inspiration ore body to the east. At approximately the same time this fan was forming at the east end of the basin, other fans were forming on the west and northwest sides. These fans are composed largely of dacite with some admixture of various other rocks. The oldest of the fans, at the west end, contains only dacite and schist. It interfingers with and is overlapped by the fan on the northwest side, which contains some fragments of schist, diabase, limestone, and rocks of the Apache group. Farther south it is overlapped by a composite of successively younger small fans that contain increasing proportions of schist and fragments of the granite on Manitou Hill, of which all the known outcrops are west and southwest of the basin. The youngest deposits probably at one time covered all the older units that are now exposed. They consist of two distinct units; the older of which is composed largely of dacite but contains appreciable amounts of Schultze granite, schist, diabase, rocks of the Apache group, and some fragments of flow-banded felsite derived from the earlier Tertiary(?) volcanic rocks. The fragments of Schultze granite and felsite indicate that the sources of the debris composing this unit were south and west of the basin. From 50 to 95 percent of the youngest unit is derived from Schultze granite; the rest is schist and a minor amount of dacite. The granite fragments average about 1 foot in diameter, but there are many blocks with dimensions of 6 to 10 feet; they undoubtedly were derived from the granite outcrops near the southern boundary of the conglomerate.

An interesting facies of this unit forms the pinnacles on the top of Needle Mountain. It is composed of angular blocks of Schultze granite and dacite embedded in a matrix of dacite sand so firmly cemented that a coarse boxwork of the matrix remains in place after the granite boulders have weathered out. The average diameter of the granite blocks is about one foot, but some blocks are as much as 30 feet in diameter.

Another large deposit of Gila conglomerate is south of Porphyry Mountain and east of Pinto Creek. This deposit and the one just described southeast of Porphyry Mountain, probably are remnants of the lower part of a much thicker mass that once covered all the surrounding area; they are in downfaulted blocks on opposite sides of the Porphyry Mountain horst block.

The conglomerate of the northern part of the outcrop west of the Porphyry Mountain horst is composed mainly of unmineralized Schultze granite, schist, and dacite in about equal proportions; the conglomerate is intercalated with two or more basalt flows, which are described on page 44. Several exploratory drill holes in the area north of the Castle Dome tailings dump show that the conglomerate accumulated in a narrow northwestward-trending valley. In the central part of the valley, the conglomerate underlying the most extensive basalt flow is at least 700 feet thick. The part of the conglomerate deposit south of the tailings dump is surrounded by outcrops of Schultze granite, and it is composed almost entirely of coarse angular granitic detritus.

The deposit of conglomerate near the western boundary of the Inspiration quadrangle, and just north of the road to Horrel ranch was mapped as Gila conglomerate because it is a well-consolidated detrital deposit that overlies dacite. It is composed of dacite boulders, many of them several feet in diameter and so firmly cemented that, in some places along the Horrel Ranch road, cliffs of the conglomerate are being undermined by the more rapid erosion of the underlying dacite. Wherever the attitude of the contact between the conglomerate and the surrounding dacite can be observed, the dips are toward the center of the conglomerate body, indicating that the dacitic debris accumulated in the bottom of a narrow northwestward trending valley.

Many other small remnants of Gila conglomerate occur throughout the district. Most of them have been preserved because they are in depressed fault blocks. In general, they represent the older parts of the formation and differ greatly in character and composition, partly because of differences in the topography of the surface on which the conglomerate accumulated and partly because of the diverse sources of the detrital material.

During the latest stages of deposition of the Gila, the Globe-Miami district was a part of a broad, nearly flat intermountain basin. A shallow body of water fed by intermittent streams from the west, southwest, and probably other directions occupied at least the eastern part of the basin. Typical lacustrine deposits of sandstone, clay, and marl that represent the youngest beds of the Gila conglomerate occur a few miles east of Globe.

The present topography bears little relationship to that of the erosion surface on which the Gila was deposited. In a few places, as in the Globe Valley, the outcrops are in the present valleys; but in other places, as on Needle Mountain, Gila conglomerate underlies areas that are now relatively high. The present outcrops are being reduced by present-day erosion. They are characterized by an intricately furcated drainage pattern unlike that developed on any of the older formations (fig. 2).

GROUND WATER IN THE GILA CONGLOMERATE

The Gila conglomerate has considerable economic importance because it contains the aquifers that provide the principal water supply for the district. The largest reserve of ground water has been contained in the conglomerate deposits of the Globe Valley area; but after a decade of deficient precipitation and greatly increased domestic usage, this source of water is being rapidly depleted.

The Gila conglomerate in the southwestern part of the Globe Valley area, south of Lost Gulch and west of Russell Gulch, is a part of the alluvial fan composed wholly of unsorted detrital material derived from the rocks of the Pinal Mountains. Its storage capacity for ground water and its transmissibility are very low. The only wells in this area that yield more than a few hundred gallons a day are near Bloody Tanks Wash. These wells are shallow and probably tap buried channel deposits fed by Bloody Tanks Wash and its tributaries.

In contrast, the Gila conglomerate of the alluvial fan washed down from the northeast contained abundant water, which apparently was stored in lenticular beds of sand and gravel and in countless sand and gravel channels that characterize this fan. Wells 500 to 800 feet deep drilled in this conglomerate commonly yield 50 to 150 gallons of water per minute. However, not all parts of the formation are equally productive, and a certain element of chance is involved in the selection of well sites. Thus it is possible that a well may be so situated that it does not find any of the buried channels and therefore receives little if any inflow, whereas a well a short distance away may provide water in substantial volumes.

A supply of potable water adequate for the needs of the various housing units of the Miami Copper Co. is obtained on the 12th level of the Old Dominion mine. This water enters the mine through faults and fractures related to the Pinal Creek fault system. These fractures traverse the dacite that underlies the low-angle thrust fault southwest of the "A" shaft (sec. *D–D′*, pl. 2), and they are intersected by the 12th level workings.

Surface water from Pinal Creek probably enters the Pinal Creek fault zone in the reach of the stream 1 to 4 miles south of Globe, whence the flow is entirely underground except during periods of heavy precipitation or of melting snow in the Pinal Mountains. G. E. Hazen and S. F. Turner (written communication, 1946) measured the surface flow of Pinal Creek in the spring of 1945 and found that the main loss occurred between the mouth of Sixshooter Canyon and the mouth of Icehouse Canyon south of Globe. According to P. G. Beckett (1917), the amount of water entering the Old Dominion mine from the west increases only after the ground becomes thoroughly saturated following periods of frequent slow rains and then varies with the amount ol local precipitation but shows a lag of 6 to 7 weeks after the rains. The underground flow in the Pinal Creek fault zone probably is restricted largely to the segments that are below the thrust fault, which may be a nearly impervious barrier, because withdrawal of water from the mine is not known to affect appreciably the general water table in the Gila conglomerate west of Globe. In 1917, an attempt was made to alleviate the water problem in the mine by collecting the entire surface flow of Pinal Creek by means of a concrete dam set on bedrock, whence the water was carried downstream in a flume for a distance of about 9,000 feet, thus preventing seepage from the stream bed in the mine area. The effect on the inflow was negligible as far as could be determined, and the practice was soon discontinued.

The mine water from the east contains about 2,300 ppm (parts per million) dissolved solids, mainly calcium sulfates, and is used by the Miami Copper Co. for metallurgical purposes. The water enters the mine through the Old Dominion vein fault and other intersecting faults and joints that tap the drainage of the Globe Hills area. Contamination of the domestic water supply is prevented by keeping the general water level in the mine well below the 12th-level workings.

Domestic water for the settlement of Inspiration is obtained from wells in the Gila conglomerate that crops out southeast of Porphyry Mountain. A well in the Gila conglomerate 1½ miles southwest of Porphyry Mountain provided an ample supply of domestic water for residences at Castle Dome. In both of these areas the Gila occupies enclosed basins that form small but excellent storage reservoirs for ground water, which are readily recharged by local runoff during the rainy seasons.

BASALT

Scattered small outcrops of olivine basalt occur in the western part of the district. Most are in a relatively narrow zone that trends north-northwestward along the west side of the Castle Dome horst block. Several flows are intercalated with Gila conglomerate southwest of Porphyry Mountain (pl. 1). The largest flow has a maximum thickness of about 200 feet (pl. 2, sec. *D–D′*). Along its northeastern margin, it is underlain by only a few feet of conglomerate or rests directly on dacite; but farther southwest, the conglomerate beneath it is as much as 700 feet thick. Apparently the basalt poured into the small valley in which the conglomerate was accumulating, and probably the flow did not have much greater extent than the present outcrop.

About 1,000 feet north of Pinal Ranch and near the western boundary of the Pinal Ranch quadrangle, a small remnant of basalt overlies Pinal schist (pl. 1). A small remnant of a basalt flow overlies dacite on a high ridge 2½ miles northwest of Porphyry Mountain and there are two small remnants of a basalt flow near the center of the large outcrop of dacite northeast of Porphyry Mountain. The larger of the two is underlain by a thin bed of Gila conglomerate, the other lies directly on dacite. On the top of Manitou Hill, near the south boundary of the Inspiration quadrangle, a small patch of basalt overlies Pinal schist and Precambrian granite.

These various small bodies of basalt probably represent several minor flows extruded from local vents. The flows intercalated with the Gila conglomerate southwest of Porphyry Mountain and the flow represented by the remnant on Manitou Hill may have been extruded from a vent on the south flank of Manitou Hill, just east of Pinto Creek. The vent is a dikelike plug of basalt, intruded into Pinal schist and Precambrian granite. Its outcrop is about 100 by 250 feet, and is surrounded by a rim, 5 to 20 feet thick, of brecciated schist and granite. The breccia fragments are highly altered and firmly cemented, apparently as a result of reaction with gases that escaped from the magma. The basalt adjacent to the breccia rim is vesicular and contains many inclusions of basalt, schist, and granite. There are very few vesicles in the basalt of the inner part of the plug. Other smaller vents may be represented by several narrow steep-walled bodies of basalt that crop out along the east side of the largest flow and appear to be small dikes intruding the Gila conglomerate.

A probable vent is a small dike of vesicular basalt that crops out 6,000 feet due east of Porphyry Mountain. The dike was intruded along a major fault along which dacite has been dropped into contact with diabase.

Two miles northwest of Porphyry Mountain, several masses of basalt crop out that clearly underlie the tuff at the base of the dacite sheet. Probably all the outcrops are parts of the same body that has been repeated by late faults, but it is uncertain whether they represent a flow poured out during the time the Whitetail conglomerate was being deposited or a sill-like body intruded into the Whitetail. Thin irregular lenses of Whitetail conglomerate occur between the basalt and the base of the dacite sheet and farther northwest, two bodies of basalt crop out in the Whitetail conglomerate. The contacts between the basalt and conglomerate are very poorly exposed, but the general shape of the basalt outcrops is not suggestive of surface flows.

As no other basalt flows older than the dacite but younger than the Precambrian basalt are known to be present in this region, these bodies are regarded as being intrusive into the Whitetail conglomerate. The presence of vents in this general area is suggested by the thin remnant of a basalt flow resting on dacite on the crest of a ridge half a mile to the northeast.

The rocks composing these several flows and intrusive masses are so similar that they are most likely related to the same period of igneous activity in late Tertiary or early Quaternary time. In the upper parts of the flows, the basalt is highly cellular and reddened by oxidation. Many of the vesicles contain amygdules composed of a shell of drusy quartz inclosing white crystalline calcite. The fresh basalt is dark gray and contains a few scattered phenocrysts of plagioclase, olivine, and augite, from 1 to 10 mm in diameter. Abundant needlelike phenocrysts of plagioclase are barely visible to the unaided eye. The microcrystalline groundmass is composed of plagioclase, augite, and olivine interspersed with abundant titanian magnetite. The olivine phenocrysts are partly altered to iddingsite, and some are completely replaced. The plagioclase is calcic labradorite.

QUATERNARY SYSTEM

ALLUVIUM, TALUS, AND LANDSLIDE

Recent deposits of soil, gravel, slope wash, and detritus mantle the bedrock in many places, but only the largest accumulations and those that conceal critical outcrops of the older formations are shown on the geologic maps (pl. 1). Many of the larger areas underlain by diabase are partly covered by soil, slope wash, and talus composed largely of diabase in various stages of decomposition.

The oldest alluvium mantles most of the area mapped as Gila conglomerate in the Globe quadrangle. It was deposited by flood waters and intermittent streams that swept eastward across the district toward the Gila River basin, mainly before the local drainage was diverted by way of Pinal Creek into the Salt River basin. The alluvium is composed largely of reworked detritus of the Gila conglomerate, partly of local origin and partly of material in transit from the western part of the district. It contains much brown clay and a large proportion of fragments, cobbles, and pebbles composed of Schultze granite, mineralized schist, and granite porphyry. The deposits range from a few feet to perhaps 50 feet in thickness. They are well exposed along Bloody Tanks Wash through Miami, Lower Miami, and Claypool and along Pinal Creek through the Globe townsite. Recent erosion is dissecting these deposits and the underlying Gila conglomerate with canyons and arroyos that are tributaries of the Pinal Creek drainage system. The alluvium forms slope wash along the sides of the canyons and arroyos, and the contact between it and the underlying Gila is rarely exposed.

Near the disseminated-copper deposits, the dry washes are commonly bordered by terraces of coarse gravel firmly cemented by iron oxides and, in some places, by copper carbonates and silicates. These deposits are older than the present stream gravels and indicate slight entrenchment of the drainage.

Alluvium composed of gravel, sand, and silt is in part, accumulating and in part, in transit along the beds of the main washes and intermittent streams and in the lower reaches of their tributaries.

The talus deposits are accumulations of angular fragments of bedrock on steep hillsides and include slope wash and soil in some areas in which the bedrock probably is diabase.

On the west flank of Webster Mountain in the Inspiration quadrangle, there are local deposits composed chiefly of huge blocks of dacite that have slumped and slid down steep slopes by riding on a thin layer of soft Whitetail conglomerate on which the dacite rested. These deposits have the characteristics of very coarse talus and are considered to be landslides.

STRUCTURE

Parts of three major structural blocks are found in the Globe-Miami district. They will be referred to as the Globe Hills block, the Globe Valley block and the Inspiration block.

GLOBE HILLS BLOCK

The Globe Hills block forms approximately the northeastern half of the Globe quadrangle. Its southwestern boundary is regarded as being formed by the Pinal Creek fault zone, which is exposed in the underground workings of the Old Dominion mine and probably extends southward approximately along the course of Pinal Creek and northwestward through a point near the junction of Pinal Creek and Miami Wash. It is rarely exposed because detritus mantles the Gila conglomerate along the inferred course of the zone. The zone exposed in the mine workings is at least a mile wide and is made up of a system of southwestward-dipping, branching and subparallel, step faults along which the blocks on the west have been relatively depressed. The total throw probably is not more than 600 feet.

The outcrops within the Globe Hills block are predominantly of diabase that forms a complex of interlaced dikes and sills intruded at various horizons in the section from the base of the Apache group to the top of the Troy quartzite.

The geologic map (pl. 1) shows a distinct difference in the structural pattern on opposite sides of a line trending N. 60° E. approximately through Black Peak. In the area south of this line, the largest diabase sill, which in some places is as much as 1,200 feet thick, has been intruded at or near the base of the Troy quartzite; whereas, in the area to the north of the line, the Troy quartzite rests directly on the eroded surface of Dripping Spring quartzite, and a thick complex of diabase sills and dikes that forms the most extensive outcrops has been intruded into the lower part of the Pioneer formation.

In the area north of the line the strata dip 10° to 45° SW., and beds are repeated several times along a traverse from southwest to northeast, suggesting that there is a series of northwestward-trending step faults along which the blocks are progressively depressed to the northeast. In the southwestern part of this northern area, very few faults have been recognized and mapped; but steep contacts with igneous rock along either the northeast or southwest sides of almost every outcrop of sedimentary rock probably represent northwestward-trending faults older than the diabase. Farther northeast, where the outcrops are mainly of the Apache group and Troy quartzite, several major northwestward-striking faults have been mapped, some of which show movement after the intrusion of diabase. At least two of them displace dacite and Gila conglomerate. They probably are faults older than the diabase along which, movement was renewed after the eruption of the dacite.

Northeastward-trending faults along which movement occurred after intrusion of the diabase are relatively abundant in the southeastern part of the northern area but become progressively less common toward the northwest. They appear to have caused minor displacements. Most are mineralized to some extent, and a few that have been explored by mine workings proved to be old faults with a little movement after the intrusion of the diabase. For example, the Irene vein fault a mile west of Black Peak is clearly an old fault along which diabase was intruded. The fault was reopened before the period of mineralization, but the renewed displacement was too small to form a well-marked break where the fault continues into the diabase beyond the limits of the quartzite block that forms the footwall of the vein.

In the southern area of the Globe Hills block, the outcrops of sedimentary rocks are almost entirely of the Troy quartzite and younger formations. The strata dip from south to southeast, in contrast to the southwestward dips prevailing in the northern area. The structure is dominated by northeast-striking faults that show a general tendency to converge toward the southwest. Most dip moderately southeast; a few are vertical or dip northwest. They are generally believed to be old faults having relatively small displacement after intrusion of diabase. Many are mineralized; and a few, notably the Old Dominion fault, contained rich veins that have yielded metals valued at nearly $166 million. Because of the economic importance of the Old Dominion vein, the structure along it will be discussed in detail.

The McGaw fault near the east boundary of the quadrangle and the Pinal Creek fault zone are the only northwest-striking faults of any consequence in this area. A few north-striking faults—the Copper Gulch, Cuprite, and Budget faults in particular—are structurally significant and will be discussed in connection with the Old Dominion vein fault.

STRUCTURE ALONG OLD DOMINION VEIN FAULT

The Old Dominion vein fault can be traced on the surface for about 8,000 feet. Its general strike is east-northeast, and its dip ranges from 40° SE. to vertical. About 200 feet south of the Old Dominion A shaft, the outcrop is terminated by a normal fault along which a mass of shattered Madera diorite is dropped into contact with the diabase and Paleozoic limestone that form the walls of the Old Dominion vein. Northeastward from this point, the outcrop extends across the southern end of Buffalo Hill and the upper end of Alice Gulch to the Grey shaft in Copper Gulch. Beyond the Grey shaft, it trends northward along the west side of Copper Gulch past the Cuprite and Copper Hill shafts to a point about 1,000 feet west of the Iron Cap shaft, where it is cut off by the Budget fault. Identification of the Old Dominion fault east of the Budget fault is uncertain, but the Iron Cap vein, whose apex is its intersection with the Black Hawk vein fault, is generally considered to be the continuation. A weakly mineralized fault known as the North vein, which is exposed along the west side of Copper Gulch, is often regarded as the displaced upper segment of the Iron Cap vein.

The outcrop of the North vein can be followed northeastward to the McGaw fault, whence the outcrop of an offset segment can be traced for an additional 2,000 feet, beyond which it becomes too inconspicuous for positive identification. The Iron Cap vein was productive for about 3,800 feet northeast of the Budget fault, but no commercial ore bodies have been found in the North vein between the Budget and McGaw faults. A little ore has been produced from the North vein east of the McGaw fault in the Superior and Boston mine.

Southwestward from the A shaft, the Old Dominion vein has been developed by underground workings for a strike distance of 4,200 feet beyond the cross fault that terminates the outcrop of the vein in that direction. Thus the Old Dominion and Iron Cap vein faults have been developed for about 3 miles and have been highly productive for at least 2½ miles.

The Old Dominion vein fault was formed before the intrusion of the diabase, and movement continued at intervals until after the eruption of dacite. The initial faulting that preceded the intrusion of the diabase is assume to have been of the normal type. The amount of the displacement cannot be estimated because of the complications caused by emplacement of sills of diabase between the sedimentary strata and by subsequent displacement on the fault. The apparent vertical separation of strata on opposite sides of the fault ranges from 50 feet or less to as much as 680 feet. If the relative positions of the tops or bottoms of diabase sills in opposite walls of the fault could be taken as an indication of the displacement after the intrusion of the diabase, the initial displacement would be very small in many places; however, estimates of the fault movements on this basis are uncertain because of differences in the number and thicknesses of the sills on opposite sides of the fault.

In a few places, displacement occurred largely along a single fault, but in general it was distributed among several subparallel, diverging, and converging auxiliary faults. The surface expression of the minor faults is generally obscure, and in most places the mine workings do not explore a sufficient width of the fault zone to expose all the minor breaks along which movement occurred. It is therefore difficult or impossible to determine with any degree of certainty the amount of displacement at a given point.

The fault is clearly caused by tension, for in many places, particularly along the southwestern part of the fault, wedge-shaped or lenticular graben blocks have moved down considerably more than the general downward displacement of the hanging wall block. Some of these graben blocks are less than 100 feet long, others have dimensions of several hundred feet. In places where mine workings enter these depressed blocks but do not continue through them into the hanging wall, erroneously large estimates of displacement are obtained.

Many other faults and fractures probably were formed at the same time as the Old Dominion fault, particularly in the hanging-wall block.

Later, when the diabase was intruded, some portions of the Old Dominion and other faults served as conduits for the magma and are now occupied by dikes. Small diabase dikes have been exposed by mine workings in both walls of the vein fault, and some small, probably lenticular, dikes have been intruded along fractures in the main zone of displacement. Most of the larger bodies of diabase are clearly sills that have been intruded between the sedimentary strata, but some may be thick dikes.

In plate 3, an attempt has been made to show the geology of the footwall and hanging wall of the Old Dominion fault zone. In both sections, features in the walls of the fault have been projected perpendicularly to a vertical plane that strikes N. 58° E. The structure and stratigraphy are of necessity greatly simplified, and stratigraphic anomalies are obvious for which no attempt has been made to depict structural solutions. Remnants of the upper Precambrian basalt commonly overlie the Mescal limestone, particularly east of the "A" shaft, but are not shown on the sections because of incomplete data.

Space for the emplacement of the diabase dikes and sills was provided by uplifting and pushing aside blocks of sedimentary strata. Parts of some sedimentary formations are missing in the sections (pls. 3 and 4), indicating either that blocks of strata have been fractured and the fragments carried away by the stream of diabase magma, or that the blocks have been pushed aside beyond the limits of the mine workings. Although small inclusions of sedimentary rocks in the diabase are extremely rare, large inclusions, whose dimensions range from a few tens of feet to several hundred feet, are fairly common. Several blocks of quartzite and Mescal limestone that apparently are inclusions have been exposed by mine workings in the thick diabase sill in the vicinity of the "A" shaft. It is obvious from the relationships shown on plate 4*A* that the block of Mescal limestone cut by the shaft has been displaced by the intrusion of the diabase, for no faults shown on the mine maps can account for its present position.

Although sills have been intruded at approximately the same stratigraphic horizons on both sides of the vein fault, some of the thickest sills must have been, at least in part, continuous across the fault; however, the overlying strata did not yield to the same extent on both sides of the fault so that sills are commonly thicker in one wall than in the other. Similar relationships occur on opposite sides of cross faults. In these places, either normal or reverse displacement occurred in the segments of the faults that traverse the sedimentary strata overlying the sills, depending on which block was intruded by the greater total thickness of diabase sills.

The number and thicknesses of the intruded diabase sills differ from place to place. Generally the smaller sills are not continuous, some are lenticular, and others abut the sedimentary beds with steep contacts. The most persistent sills were intruded at the contact between the Mescal limestone and the Troy quartzite. On the hanging-wall side of the fault, there is a sill intruded at this horizon throughout the explored extent of the fault. There is also a sill at this horizon on the footwall side; but near the "A" shaft it breaks through the Mecal limestone down to the upper part of the Dripping Spring quartzite. The two sills appear to be at least 1,300 feet thick in the vicinity of the "A" shaft but only 700 feet thick at the Kingdon shaft about half a mile to the northeast. The sill in the hanging wall is about 1,000 feet thick at the Copper Hill shaft and 600 to 700 feet thick at the Copper Hill No. 2 shaft which is just east of the Budget fault. In the Superior and Boston mine near the east boundary of the Globe quadrangle, this sill is reported (C. W. Bostford, 1919, written communication) to be from 520 to 560 feet thick.

On the upper levels of the Old Dominion mine, a thick block of Troy quartzite in the footwall of the vein fault is cut off a short distance east of the "B" shaft by a crosscutting body of diabase (pl. 3*A*). The discordant contact between the Troy quartzite and the diabase is believed to represent a wall of the Buffalo vein fault, along which the block of quartzite was displaced downward before the intrusion of diabase or else the block on the hanging wall (northwest) side was raised by the intrusion of the diabase under it. The apparent upward displacement of the hanging-wall block makes the latter explanation seem the more probable.

The relationships of the blocks of Troy quartzite in the hanging wall of the Old Dominion fault (pl. 3*B*) cannot be explained by faulting after the intrusion of diabase and must be the result of displacement attending the emplacement of the diabase magma. Further study of the sections reveals other similar examples.

After the intrusion of diabase but before the period of mineralization, further displacement took place which reopened the old fault. In many places, the walls of the fault had become igneous contacts between diabase and sedimentary rocks, as a result of the diabase intrusion; and for wide intervals, the old fault was interrupted by sills and dikes that had been intruded across it. With renewed movement, displacement took place along remnants of the old fault that cut through the blocks of sedimentary strata and along the igneous contacts that had been walls of the original fault. New connecting fractures were formed through the diabase sills and dikes. In some places the connecting breaks through the diabase consisted of one or two fairly regular fractures. In other places, probably where the remnants of the old fault had been pushed out of alinement, a wide zone of irregular and branching fractures was formed.

The displacement that occurred at this time probably was relatively small, but it was sufficient to provide fairly continuous channels for the mineralizing solutions. The most permeable channels appear to have been along remnants of the old fault and along igneous contacts. The newly formed fractures through the diabase itself were, in general, less favorable channels, and commonly they appear to have been almost impervious.

Further displacement along the vein fault occurred after the eruption of dacite, as is shown by the cross section through the "A" shaft (pl 4*A*). This displacement probably was little more than 100 feet, at the most 300 feet. The extent of the faulting cannot be determined because the dacite over the vein has been removed by erosion except in one small area near the "A" shaft and over the part of the vein southwest of the "A" shaft where the dacite is concealed by the overthrust plate of Madera diorite and by deposits of Gila conglomerate (pl. 2, sec. *D–D'*). It is possible that this displacement was local, being confined to the southwestern part of the fault and related to a system of younger cross faults southwest of the "A" shaft along which all the formations, including the Gila conglomerate, have been downfaulted.

From the "A" shaft to the southwestern limits of the Old Dominion mine, the structure along the vein fault is extremely complex. From very thorough personal observations, one might be able to make a few fairly accurate generalizations; but since only data collected and recorded by others are available for study, it is not feasible to attempt a detailed description or an explanation of the complex structure. A number of factors contributed to the complexity of this area and to the difficulties in interpretation. This area appears to be near a center toward which many of the outlying structures converge.

The outcrops southwest of the "A" shaft are almost entirely of Gila conglomerate, which is much younger than the period of mineralization and the structures that controlled mineralization. Some of the faults that cut the vein fault are younger than the Gila conglomerate, but they are obscured by a mantle of transient material which overlies the formation, except in small local areas where it is undergoing very rapid erosion.

The stratigraphy is erratic because all the disconformities and unconformities of the local stratigraphic column are represented in this area. The early Precambrian unconformity between the Pinal schist and the Apache group is reached near the bottom of the "A" shaft, but because of its southwesterly dip and its depression by a number of normal faults, it is below the present mine workings to the southwest. It was, however, a favorable horizon for intrusion of diabase sills, whose emplacement undoubtedly disturbed the overlying strata.

During the interval represented by the disconformity between the rocks of the Apache group and the Troy quartzite, erosion cut a little deeper in this area than elsewhere along the vein fault. The basalt of the Apache group was completely removed and probably a few channels were cut into the Mescal limestone. So far as is known, there are no places exposed in the mines where diabase sills have not been intruded between the formations of the Apache group and the overlying Troy quartzite. Generally the thickest sills were intruded at this horizon.

Erosion was again active in this area during the interval after the deposition of the Troy quartzite. West of the "A" shaft, the Troy thins rapidly and appears to have been completely removed in the southwestern part of the Old Dominion mine.

After deposition of the limestones of Paleozoic age, extensive faulting and intrusion of diabase added further to the complexity of the geology of this area. The diabase sill intruded at the base of the Troy quartzite becomes thinner toward the southwest; and the relationship of the sill to the sedimentary rocks suggests that the thinning takes place in steps by differential elevation of the overlying blocks rather than by simple flexing of the strata.

In the same general area, a number of minor faults striking northeast intersect the Old Dominion fault zone at very acute angles. Most have approximately the same dip as the Old Dominion fault, but a few of them dip steeply northwest. They probably were formed at about the same time as the Old Dominion fault, and most of them are mineralized to some extent. The Maggie, Josh Billings, and Buffalo veins were deposited along faults of this group; and a relatively large body of low-grade disseminated copper ore was formed in the brecciated diabase at the intersection of the two systems.

After the period of mineralization, erosion was renewed, and again the area southwest of the "A" shaft was cut deeper than elsewhere along the vein fault. The Paleozoic limestones become thinner toward the southwest and probably are absent beyond the present limits of the mine. The veins were exposed to weathering, and copper carbonates and silicates were deposited by supergene solutions along many fractures that had formed after the period of hypogene mineralization, particularly in the limestones.

Before the eruption of dacite which ended this period of erosion, the outcrops southwest of the "A" shaft must have formed a mosaic of small faulted blocks of the various limestones of Paleozoic age, Troy quartzite, Mescal limestone, Dripping Spring quartzite, and diabase. Blocks of older formations probably were exposed in the area beyond the present limits of the mine.

After the eruption of dacite and probably after erosion had been renewed, a plate of Madera diorite was thrust over the dacite from the west or southwest. It is not known how far the thrust plate extended to the northeast. It crops out in the hanging wall of the cross fault just west of the "A" shaft, but northeast of the fault it has been completely removed by erosion. It is about 400 feet thick under Pinal Creek (pl. 2, sec. *D–D′*), but two drill holes about 3,500 feet farther southwest show that erosion has reduced it to a thickness of 50 to 225 feet and that it is overlain by more than 1,000 feet of Gila conglomerate. The underlying dacite probably is not more than 100 feet thick at the fault near the "A" shaft, but a drill hole 5,000 feet to the southwest passed through 1,050 feet of dacite.

The portion of the Old Dominion fault southwest of the "A" shaft is crossed by the Pinal Creek fault zone, a broad zone of normal faults striking northwest that borders the great mass of Gila conglomerate of the Globe Valley. These faults were probably formed before or during the intrusion of diabase, but later movement along some of them displaced the dacite, Madera diorite, and Gila conglomerate. Although several of the faults can be traced across the Old Dominion fault system in the mine workings as fairly regular and continuous major breaks, much of the displacement, both early and late, probably occurred along numerous small interlacing fractures.

The structure west of the "A" shaft as depicted in plate 3 is greatly simplified and generalized. In detail,

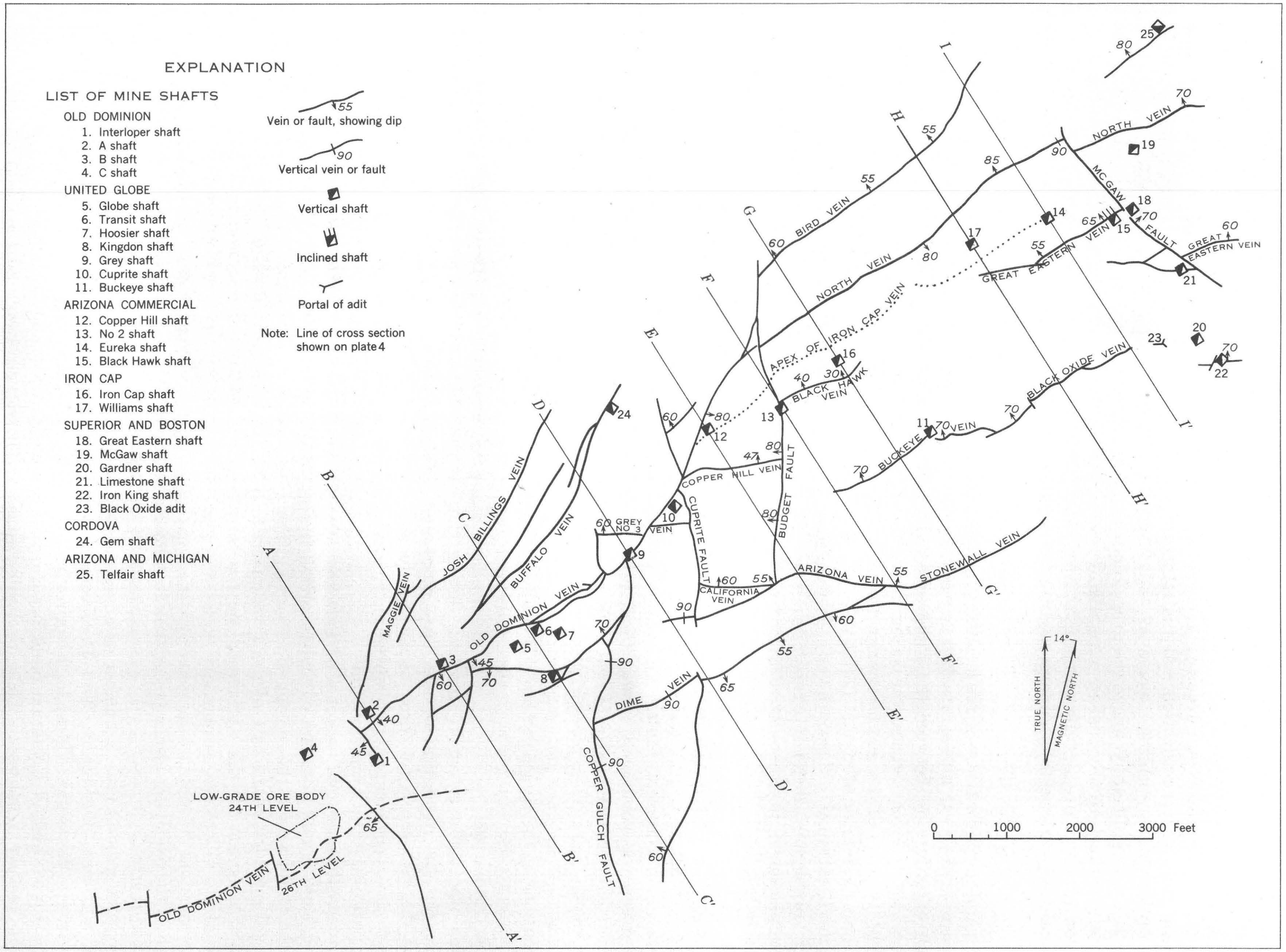

FIGURE 5.—Skeletal plan of the main veins and faults of the Old Dominion system.

many of the blocks of sedimentary rocks shown are really jumbles of smaller irregular blocks bounded by an intricate system of interlacing minor faults. Plate 5 is a plan of the west end of the 12th level of the Old Dominion mine. It is a fairly typical representation of the intricately faulted structure along the western part of the Old Dominion fault.

Figure 5 is a map showing the skeletal structural pattern along the Old Dominion vein system. It shows the outcrops of the principal veins and the traces of the major faults. Most of the pattern predated intrusion of the diabase, but some of the faults may have formed as a result of the intrusion. Many of the faults, particularly those that are mineralized, show evidence of but slight movement after the intrusion, and some faults along blocks of sedimentary rock have fine-grained diabase next to the zone of slippage, suggesting that they are reopened faults along igneous contacts.

The displacement that occurred after the intrusion of diabase but before the period of mineralization must have been restricted mainly to the faults striking northeast. Most of the faults with this strike that have been recognized and mapped in the Globe area are mineralized to some extent, many very slightly, but the proportion of mineralized faults may be somewhat exaggerated, because even slight hydrothermal alteration along faults makes them readily recognizable, whereas unmineralized faults that do not materially affect the outcrop pattern may easily escape notice. The large proportion of mineralized faults and fractures, however, indicates that the dominant trend of the structural pattern before the period of mineralization was northeast.

A few northward-striking faults are slightly mineralized, but apparently none of them contained ore bodies worthy of record. It is uncertain whether the Copper Gulch and Cuprite faults were mineralized by hypogene solutions, but if so, the mineralization was too meager to justify exploration. The Budget fault, which also strikes approximately north, is slightly mineralized, and a little oxidized ore probably was mined from a series of open pits along its outcrop south of its intersection with the Copper Hill vein. So far as can be determined, the McGaw fault was not mineralized during the hypogene period, but it did contain some copper carbonate in the segment along which the Great Eastern vein was offset.

Of the many faults that intersect the Old Dominion vein fault, most of which are too small to be recognized in outcrops, only a few, mostly west of the "A" shaft, caused appreciable offsets in the vein. They appear to have formed independently on opposite sides of the Old Dominion fault, and few of those on one side have recognizable counterparts on the other.

The Copper Gulch fault strikes approximately north and dips vertical to steeply west. Its trace intersects that of the Old Dominion fault under the dump of the Grey shaft. The relationships of the diabase in opposite walls (pl. 3*B*) suggests that the fault was formed before the diabase was intruded, but evidence of late movement is shown along the southern part of its trace, where the Gila conglomerate has been displaced. Movement on the Copper Gulch must have been simultaneous with renewed movement on the Old Dominion fault, causing greater apparent displacement on the latter west of its intersection with the Copper Gulch fault. The throw of the Copper Gulch fault if measured by the displacement of the Mescal limestone is about 400 feet, but is less than 200 feet, if measured by the displacement of the Troy quartzite. This difference is belived to be caused by the difference in the thickness of diabase sills on opposite sides of the fault.

A fault of similar strike and dip intersects the footwall of the Old Dominion fault about 400 feet west of the Grey shaft, it may be the offset segment of the Copper Gulch fault. It displaces the Troy quartzite about the same amount as the Copper Gulch fault, but it has not been identified on the lower levels of the mine, and there is no appreciable displacement of the Mescal limestone near the projected course of the fault.

Farther southwest, other smaller faults that trend north to northwest cut the hanging-wall block of the Old Dominion fault and probably account for at least part of the increase in the apparent throw of the Old Dominion fault to about 650 feet at the "A" shaft. Ransome (1903, p. 144–148) studied the structure in the upper levels of the Old Dominion mine in the vicinity of the "A" shaft and found considerable evidence of postmineralization displacement, particularly along faults in the hanging-wall block of the Old Dominion fault zone. Southwest of the "A" shaft, late movement on northwest-trending faults in the hanging-wall block of the Old Dominion fault is shown by small displacements of the base of the dacite.

Like the Copper Gulch fault, the Cuprite fault strikes approximately north; its dip is vertical or steeply west. Its throw on the hanging-wall side of the Old Dominion fault, as measured by the displacement of the Mescal limestone, is about 250 feet. Its trace is not prominent north of the Old Dominion fault, and the fault is recognized by an ill-defined breccia zone in the quartzite and in places by very thin discontinuous stringers of diabase. If any movement occurred after the intrusion of diabase, it was very slight.

In the interval between the Copper Gulch and Cuprite faults, the Old Dominion fault is poorly mineralized, and the mine workings are too limited in extent to reveal more than the broadest features of the structure and stratigraphy. The dip of the fault steepens, and on the lower levels of the mine, the dip is to the northwest. However, there are so few mine workings in this interval that it is not certain whether the northward-dipping part actually is the Old Dominion fault; it may be intersecting fault. The throw of the Old Dominion fault in this interval, as measured by the displacement of the Mescal limestone, ranges from practically zero at the west to about 200 feet at the intersection with the Cuprite fault. The small displacement, of which only a fractional part may postdate the intrusion of the diabase and precede mineralization in age, probably was too slight to open a permeable channel through the diabase sill that overlies the Mescal limestone and thus accounts for the poor mineralization of the fault. There are a few stopes on the Old Dominion vein below the 14th level of the Grey mine; but on the higher levels, stoping was chiefly along the Grey No. 3 vein. The Grey No. 3 vein, which Ransome (1903, p. 150) described as the Nevada vein, occupies a minor fault that strikes east and dips 50° to 60° N. It intersects the footwall of the Old Dominion fault and the north segment of the Copper Gulch(?) fault. A mineralized fault of similar strike but much less steep dip crops out on the hanging wall side of the Old Dominion fault. This mineralized fault also was designated as the Grey No. 3 vein and was productive on the upper levels of the Grey mine.

Between the Cuprite and Budget faults, the trace of the Old Dominion fault turns to the north and trends about N. 30° E. To a depth of about 800 feet, the fault dips steeply southeastward; and on the lower levels of the mine, it dips steeply northwestward. The throw, as determined by the displacement of the Mescal limestone, ranges from about 100 feet, near the Copper Hill shaft, to about 200 feet, near the Budget fault; but just west of the Budget fault, the basal conglomeratic beds of the Troy quartzite crop out on both sides of the Old Dominion fault, indicating a throw not greater than about 50 feet. The cross section through the Copper Hill shaft (pl. 4*E*) indicates that the quartzite in the hanging-wall block has moved up in relation to the footwall; however, the position of the base of the quartzite in the footwall block is somewhat uncertain, but any error in its location may be such that actual displacement is greater.

In the interval between the Cuprite and Budget faults, the upper part of the Old Dominion fault has been offset to the north by the Copper Hill fault, which strikes about N. 60° E. and dips 45° to 50° NW. The trace of the Copper Hill fault trends about due east; it intersects the trace of the Old Dominion fault under the southern end of the dump of the Copper Hill shaft and that of the Budget fault about 700 feet south of No. 2 shaft (fig. 5). At the Copper Hill shaft the segment of the Old Dominion fault in the hanging-wall block of the Copper Hill fault has been offset about 100 feet toward the north and 200 to 250 feet just west of the Budget fault. At the intersection of the traces of the two faults, which is concealed by the mine dump, the offset is probably very small or nil. The intersection of lower segment with the footwall of the Copper Hill fault is shown by a dotted line on figure 5.

East of the Budget fault, the Iron Cap vein is generally regarded as being the northeastward continuation of the Old Dominion vein; it does not crop out. From the Budget fault to the Iron Cap shaft, its apex is its intersection with the footwall of the Black Hawk vein fault; and from the Williams shaft into the western part of the Eureka mine, the Iron Cap vein intersects the footwall of the Great Eastern vein. From the 1,000-foot level to the 1,300-foot level of the Arizona Commercial Copper Hill shaft, stopes on the Old Dominion vein are continuous across the Budget fault. The offset caused by the fault cannot be determined from the mine records, but apparently it is very small.

The Black Hawk vein fault crops out 200 feet south of the Iron Cap shaft, it strikes about N. 60° E. and dips 30°–40° NW. Its relationships with the Iron Cap and North vein faults are similar to those of the Copper Hill fault with the lower and upper segments of the Old Dominion fault west of the Budget fault. The Copper Hill fault is commonly referred to as the Black Hawk fault and has been considered to be a segment of the latter that has been offset by the Budget fault. The name "Copper Hill fault" is used in this report to avoid confusion and the direct implication that the two faults were once continuous. The trace of the Black Hawk fault abuts the footwall of the Budget fault just north of No. 2 shaft, whence it can be followed for about 1,300 feet to the bottom of a small gulch east of the Iron Cap shaft. Northeastward from this gulch, its course along the projected strike of the fault is masked by detritus for 2,000 feet.

The North vein is a weakly mineralized fracture that crops out along the north side of Copper Gulch (pl. 1) and forms the contact between diabase and Dripping Spring quartzite for about 3,000 feet. It strikes N.

55° E., nearly parallel with the Iron Cap and Black Hawk veins, and dips 80° SE. to 85° NW. To the northeast, it ends at, or is offset by, the McGaw fault. In an apex suit of the Arizona Commercial Mining Co. versus the Iron Cap Copper Co., the North vein was alleged to be the upper segment of the Iron Cap vein that had been offset by the Black Hawk vein fault.

The relationships of the Old Dominion, Iron Cap, Black Hawk, and Copper Hill faults suggest a simple sequence of structural events: first, displacement along the Old Dominion-Iron Cap fault; then, displacement on the Copper Hill-Black Hawk fault; and, finally, displacement on the Budget fault. However, the relationships of the rock formations in the various blocks are incompatible with such a simple interpretation. It appears more probable that the displacement on the main fault, of which the Old Dominion, Iron Cap, and North vein faults are segments, was followed by the initial displacement on the Budget fault, and that the Copper Hill and Black Hawk faults were formed later. Probably all the faults had been formed before the intrusion of the diabase. The sills intruded between the sedimentary strata do not appear to be of uniform thickness from block to block, and some are not present in all the blocks. For example, a long crosscut driven northwestward on the 800-foot level of the Iron Cap mine passed through the Black Hawk fault into a diabase sill intruded at the base of the Dripping Spring quartzite or possibly into the Pioneer formation, in the hanging-wall block of the fault, whereas in the footwall block, there is no sill near this position (pl. 4*G*).

A diabase sill between the Troy quartzite and Mescal limestone in the hanging-wall block of the Old Dominion and Budget faults appears to be about 400 feet thicker than a sill intruded at the same stratigraphic position in the footwall block of the Budget fault, as shown by the cross sections through the Copper Hill and No. 2 shaft (pl. 4). Although the available subsurface data are not sufficient to show conclusively that the difference in thickness of the two sills occurs at the Budget fault, the general attitude of the sedimentary strata in the interval between the two shafts does not suggest a progressive change in the thickness of either sill.

Movements on the Budget, Copper Hill, and Black Hawk faults after the intrusion of diabase but before the period of mineralization caused sufficient readjustment of the blocks to open minor fractures through the diabase sills approximately along the projected courses of the faults. The most intense mineralization occurred in the segments of the Old Dominion-Iron Cap fault below the Copper Hill and Black Hawk faults. These segments traverse the sedimentary formations and therefore remained open to the mineralizing solutions; whereas the Copper Hill, Black Hawk, and Budget faults above their intersections with the Old Dominion-Iron Cap fault are comparatively minor fractures that are chiefly in diabase. They receive but slight leakage of mineralizing solutions from the main channels.

The Budget fault shows evidence of the largest postmineralization displacement, though it probably was one of the weakest faults before mineralization. The throw of the Budget fault, as measured by the displacement of the Barnes conglomerate on the south side of the Old Dominion fault, is about 300 feet. The alinement of the Old Dominion and Iron Cap segments indicates little if any strike slip.

At the place where the Budget fault crosses the north end of Buffalo Hill (pl. 1), the basal conglomerate beds of the Troy quartzite crop out on the west, or hanging-wall, side of the fault in contact with thin beds of quartzite and shale, which are characteristic of the upper part of the Dripping Spring quartzite, on the footwall side. Thus, the stratigraphic throw at this point would be approximately indicated by the present thickness of the Mescal limestone and the overlying basalt plus the thickness of the diabase sill intruded at the base of the Troy quartzite. It could be 800 to 1,300 feet, but a throw of that magnitude is improbable. This difference in the apparent throw may be due partly to the diabase sill intruded under the Dripping Spring quartzite in the footwall block and partly to relief on the old erosion surface at the top of the Apache group.

The intersection of the Copper Hill and the Old Dominion faults and that of the Black Hawk and Iron Cap faults at the points where they abut the Budget fault have a vertical separation of about 600 feet, or about double the throw of the Budget fault, as measured on the Barnes conglomerate. Thus it seems probable that the Copper Hill and Black Hawk faults were formed independently on opposite sides of the Budget fault.

At the northeast end of Buffalo Hill, a weakly mineralized fault known as the Bird vein intersects the Budget fault. The Bird vein strikes about N.50°E. and dips 55°–60°NW. Its trace froms the boundary between diabase on the northwest side and Dripping Spring quartzite and Pioneer formation on the southeast side.

The Budget fault has not been recognized north of of its intersection with the Bird vein; it probably intersects the Big Johnnie vein fault, or the Big Johnnie may be its continuation. If so, the trace of the connecting segment is obscured by detritus from the adjacent diabase.

Approximately on the northeast projection of the outcrop of the Black Hawk vein is the outcrop of the Great Eastern vein, which strikes about parallel to the Black Hawk vein but dips more steeply, 55° to 65° NW. Whether or not the Great Eastern vein fault is the continuation of the Black Hawk vein fault cannot be determined, owing to the poor exposures between the two outcrops.

Between the Iron Cap and the Eureka mines is an interval of 2,500 feet (fig. 5) in which neither the Black Hawk nor the Great Eastern fault is known to be exposed in the underground workings, but the fact that the Iron Cap vein also does not crop out in this interval strongly suggests that the Black Hawk and Great Eastern vein faults are continuous and actually one fault or, at least, are intersecting faults. The Great Eastern vein fault probably was cut by the Williams shaft at a point about 650 feet below the collar (pl. 4*H*), a little below the first level, but this shaft was sunk at a very early stage of the operation, and the intersection was not recorded on the mine maps that are now available.

Near the middle of the interval, there is a gap in which the Iron Cap fault is obscure and very poorly mineralized. On the 800-, 900-, and 1,000-foot levels of the Iron Cap mine, this gap appears to be at least partly the result of a zone of steeply dipping cross faults that strike about N. 20° E. The outcrop of this fault zone has not been recognized, and there are no workings on the upper levels of the mines in which the fault zone could be exposed; hence its effect on the continuity of the Black Hawk and Great Eastern faults is unknown. Southwest of this fault zone, the throw on the Iron Cap fault ranges from 220 to 365 feet; whereas on the northeast side, the throw is less than 100 feet.

A drift on the first (667-foot) level of the Williams mine follows the Iron Cap vein northeastward into the Eureka mine to a point at which it intersects the footwall of the Great Eastern vein. The intersection plunges northeastward below the deepest mine workings. The development in the Eureka mine was chiefly along the Great Eastern vein. Crosscuts to the northwest on the 701-foot and 1,005-foot levels reached what is probably the North vein (pl. 4 *I*), but no ore was found and little drifting was done.

About 1,000 feet east of the Eureka shaft, the Great Eastern vein is cut off by the McGaw fault, which strikes about N. 45° W. and, unlike the cross faults to the west, dips northeast. A vein that has generally been assumed to be the offset east segment of the Great Eastern vein was discovered by underground workings east of the McGaw fault. On the 6th (545-foot) level of the Superior and Boston mine, the segments are offset 500 feet (pl. 6) and on the 12th (1,150-foot) level only about 340 feet. The outcrop of the east segment is concealed by talus, but probably it is offset about 750 feet to the southeast. The Great Eastern vein fault dips about 55° NE. in the mine workings west of the McGaw fault, whereas the east segment dips about 42° NE. Thus it would appear that the hanging-wall block of the McGaw fault has been tilted to the southeast. The outcrop of the North vein has been offset 200 feet to the southeast by the McGaw fault.

The relationships of the segments of the two vein faults on opposite sides of the McGaw fault can roughly be explained by postulating that they are the result of a hinge movement on the McGaw fault and a strike slip of about 200 feet. The hinge point would be north of the North vein; and the throw, measured at the Great Eastern shaft, would have to be 500 to 600 feet. The hinge movement alone is not enough to cause the 200-foot offset in the outcrop of the nearly vertical North vein, and it is necessary to assume a strike slip that moved the hanging-wall block to the southeast. The steep northward dip of the segment of the North vein east of the McGaw fault, which is indicated by crosscuts driven to intersect the vein on every level of the Superior and Boston mine, is in keeping with this interpretation. However, as nearly as can be determined, the point of intersection of the hanging wall of the Mescal limestone, the Great Eastern vein, and the McGaw fault in the footwall block and the corresponding point in the hanging-wall block have a vertical separation of only about 250 feet. Thus, although the postulated movement on the McGaw fault will account for relative positions of the two segments of the Great Eastern vein, it does not appear to explain the stratigraphic relationships in opposite walls, and there is evidence for doubting that the two segments actually are the same fault. The relationship of the two segments is very similar to that of the Copper Hill and Black Hawk faults.

The throw of the Great Eastern vein fault is about 300 feet, as measured by the displacement of the Mescal limestone at the Eureka shaft; it is of approximately the same magnitude just east of the McGaw fault in the Superior and Boston mine.

The east segment of the Great Eastern fault was well mineralized and has been stoped for 1,200 to 1,800 feet east of the McGaw fault. So far as can be determined, the McGaw fault does not contain hypogene minerals.

GLOBE VALLEY BLOCK

The Globe Valley block is a graben lying between the Globe Hills block on the east and the Inspiration block on the west. It is roughly triangular and extends about 3 miles beyond the south boundary of the Globe quadrangle. The west boundary is clearly defined by the Miami fault. The east boundary is regarded as being formed by the Pinal Creek fault zone, whose location along most of its course is uncertain. The southern boundary has not yet been mapped but it appears to be an eastward-trending fault zone exposed in several of the gulches that drain the north flanks of the Pinal Mountains. This fault zone may be the continuation of the Miami fault, which, near the southern limits of the map area, trends eastward along the north side of the mass of Solitude granite. The Globe Valley block has been relatively depressed with respect to all the adjacent blocks.

The outcrops within the limits of the block are entirely of Gila conglomerate. The detailed structure of the conglomerate is not well known because the nature of the formation does not favor good exposures and most of the outcrops are mantled by terrace gravels or transient debris. The best exposures are generally along the margins of the block, where the beds have been locally much disturbed by late faulting. Much of the formation is composed of unsorted detritus and shows no evidence of stratification.

Most of the available subsurface data concerning the structure of the Globe Valley block were obtained in the vicinity of the Miami-Inspiration and Old Dominion ore bodies, where mine workings and drill holes explore the formations that underlie the Gila conglomerate. Interpretation of the data is shown on section *D–D′* (pl. 2).

The most easterly fault of the Pinal Creek fault zone crops out about 250 feet southwest of the Old Dominion "A" shaft; other faults of the system are exposed in the mine workings that extend southwestward from the "A" shaft for about a mile. The structure illustrated by section *D–D′* is, of necessity, a greatly generalized interpretation, because no vertical section can be chosen for which data for continuous control are available. The mine workings are limited to a relatively narrow zone along the Old Dominion vein that dips southeastward approximately at right angles to the strike of the section. Only the major faults are illustrated, and some of them have been projected beyond the limits of accurate location. There are many minor branching and subparallel faults that are not shown on the section.

The location of the base of the dacite is known in several places. The contacts between the dacite and Madera diorite and between the diorite and overlying Gila conglomerate are accurately located in drill holes a mile southwest of the "A" shaft, and the top of the dacite is located in a drill hole just southwest of Pinal Creek.

Remnants of the dacite sheet apparently underlie the Gila conglomerate along much of the east side of the block. The sheet is 1,000 feet thick at the southwest end of the Old Dominion mine, and it may be even thicker farther to the southwest. It was cut off at some point to the south or southwest by a thrust fault, but its present limit may be the result of either pre-Gila erosion or normal faulting.

The thin wedge of Madera diorite that overlies the dacite above the thrust fault is a remnant of the plate that has been thrust over the dacite from the south or southwest; it crops out in several places along Pinal Creek for a mile northwest of the section *D–D′* (pl. 2) and also for about 4,000 feet southeast of the section. The rock is highly shattered quartz diorite and might easily be mistaken for coarse detritus—as Ransome (1903, p. 49–50) did during his first study of the district—but for the fact that it contains four small bodies of granite porphyry, also highly shattered that were clearly intruded into the quartz diorite before it was thrust into its present position. When Ransome revisited the district about 8 years later, the thrust fault had been exposed in several places. He (1910, p. 257 and 1919, p. 119–120) described it as follows:

> Wherever a shaft has gone through the quartz diorite it is found to be separated from the dacite by a zone of trituration and slickensiding that is plainly due to fault movement. One of the best exposures of this fault plane is to be seen in a small prospect tunnel about 2000 feet northeast of the Old Dominion smelter. This tunnel runs N. 15° E. for about 150 feet through shattered Madera diorite and then passes for 20 feet through a fault breccia in which rounded polished fragments of the quartz diorite are embedded in a sheared gouge composed of triturated quartz diorite and dacite. This is separated from the solid underlying dacite by a smooth slip plane dipping 37° SW.

Section *D–D′* indicates that the general dip of the thrust fault is much less than 37°, probably less than 10°. The mine workings in which Ransome saw the thrust fault are now inaccessible, and the fault has not been recognized at the surface.

Most of the overthrust plate had been removed by erosion before the overlying Gila conglomerate was deposited. At the southwest end of the Old Dominion mine, it is 50 to 225 feet thick, but farther southwest probably all of it has been removed and the Gila conglomerate rests directly on the dacite.

The dacite, underlain locally by Whitetail conglomerate, rests on the eroded surface of the upper Precambrian and Paleozoic sedimentary rocks and intruded sills of diabase that overlie Pinal schist. In the line of section *D–D′*, which is in the footwall block of the Old Dominion vein, the section of sedimentary rocks and diabase is 2,000 feet thick at the "A" shaft but only about 1,000 feet thick a mile to the southwest. The thinning of the section is due partly to thinning of the diabase sills and partly to deeper erosion to the southwest before the eruption of dacite. These rocks are several hundred feet thicker in the hanging-wall block south of the section.

On the west side, the Globe Valley block is bounded by the Miami fault. The general strike of the fault across the map area is about N. 20° E.; the dip probably ranges from 35° E. to vertical.

The position of the Miami fault appears to have been controlled by the several masses of granitic rocks intruded into the Pinal schist. Near the southeast corner of the Inspiration quadrangle, the fault trends eastward along the northeast side of the mass of Solitude granite, whence it may continue southeastward and join or may actually be the fault zone that forms the south boundary of the Globe Valley block. Its course in the southeastern part of the Inspiration quadrangle seems clearly to have been controlled by the mass of Schultze granite. It is mainly in the schist along the east side of the granite outcrop, and only minor apophyses of granite are known to be present in the block east of the fault. Farther northeast, the Miami fault probably displaces Lost Gulch quartz monzonite, but the outcrops east of the fault and along the fault zone suggest that the Gila conglomerate in the depressed Globe Valley blocks rests on diabase or on remnants of dacite overlying diabase and that the fault formed near the east side of the quartz monzonite body. Near the northeast corner of the quartz monzonite outcrop, the fault trends more westward; and a little farther north its identity is lost in a complex network of normal faults, some of which depress the blocks to the west and probably are related to the Pinal Creek system.

At several places short segments of the Miami fault strike northwest and apparently dip northeast. These northwest segments probably are related to a system of step faults that affected mainly the depressed Globe Valley block and formed simultaneously with displacement on the Miami fault. In the small area east of the fault that has been explored by mine workings, a series of northwestward-striking faults have been exposed, all of which appear to have depressed the blocks to the north.

The blocks also must have been tilted southward, for the greatest throw on the Miami fault is in the southern part of the map area. Thus the displacement along the Miami fault probably involved complex rotational movements whereby the Globe Valley block and the individual minor blocks that compose it have been tilted to the southwest.

In the vicinity of the Miami-Inspiration ore body, where information on the subsurface is most complete, the sedimentary formations had been completely removed by erosion before the eruption of dacite, and the dacite, was laid down on outcrops of Pinal schist. However, most of the dacite was removed from this area before the Gila conglomerate was deposited and before most of the displacement on the Miami fault. Near the fault, in the depressed, or hanging-wall block, thin remnants of dacite underlie the Gila conglomerate in a few places; but farther to the east, several drill holes found no dacite between the schist and the overlying conglomerate. West of the fault, remnants of dacite are present, despite considerable erosion that must have occurred after displacement on the fault. The slope of the contact between the Gila and the Pinal east of the fault suggests deeper erosion to the east. The fault apparently formed near the west side of a channel that had been cut through the dacite in this area.

Near section line *D–D′* (pl. 1) the relationship of remnants of dacite on opposite sides of the fault indicate a throw of about 1,500 feet. For at least 2,000 feet north of the section, the throw increases somewhat, owing to the minor step faults in the depressed Globe Valley block that progressively depress the blocks to the north. Farther north and also south of the section the amount of displacement cannot be accurately determined.

Between the points on section *D–D′* (pl. 2), beyond which no information on the subsurface is available, is a gap of about 12,000 feet. At the west end of the gap, the Gila conglomerate is more than 4,000 feet thick and rests directly on Pinal schist. It is a fanglomerate that accumulated on the steep northern flanks of the Pinal Mountains and is composed of angular fragments of schist and Madera diorite, many several feet in diameter, with some admixture of fragments from Schultze granite in the upper part. The material is generally unsorted and unstratified; but in the few places where crude stratification can be seen, the beds appear to be nearly horizontal or dip southwestward at very low angles, generally less than 5°. As the initial dips must have been fairly steep to the northeast, the beds have been tilted to the south or southwest. The top of the schist at the western end of the gap, as determined by drilling, is about 200 feet below sea level.

At the east end of the gap, the Gila conglomerate is 1,000 to 1,200 feet thick and is part of a fanglomerate deposit that accumulated on the lower slopes of the Apache Peaks to the northeast. It consists of interbedded sand and gravel containing pebbles and cobbles of quartzite, limestone, diabase, dacite, granite, and schist. It rests on thin remnants of the Madera diorite thrust plate or on the eroded surface of the underlying dacite, which is about 1,000 feet thick at the southwest end of the Old Dominion mine workings. The dacite, except where underlain locally by Whitetail conglomerate, in turn, rests on the eroded surface of the Apache group and intruded bodies of diabase. The Pioneer formation was reached at 240 and at 440 feet below the 26th level of the Old Dominion mine by two drill holes that entered the footwall block of the Old Dominion vein about 2,900 feet southwest of the "A" shaft. The thickness of the diabase sill under the Pioneer formation is not known, but assuming that the sill is the same thickness at the position of the drill holes as at the "A" shaft, the top of the Pinal schist at the southwestern end of the mine workings may be roughly 400 feet above sea level. Thus, before the eruption of dacite, erosion had completely removed the sedimentary formations and exposed the Pinal schist, at least in the western half of the gap. This could have been accomplished during the cutting of an ancient stream valley whose course was around the north side of the Pinal Mountains and southeastward into the Gila River basin.

After the eruption of dacite and after the block of Madera diorite had been thrust over the dacite, renewed erosion along the same general course of the postulated ancient stream valley removed the dacite and again exposed the Pinal schist. The Globe Valley block began to sink as a result of displacement on the Miami fault and probably also on the fault zone that forms the south boundary of the block. An alluvial fan formed on the steep northern flanks of the Pinal Mountains and another on the more gentle southern slopes of the Apache Peaks filling the depression resulting from the sinking of the block.

The nature of the boundary between the two fans is unknown, but an interfingering relationship appears to be most probable. The gradational boundary between the outcrops of the two fanglomerates extends southeastward from a point near the confluence of Bloody Tanks Wash and Russell Gulch, across the southern boundary of the Globe quadrangle and westward along the course of Lost Gulch.

INSPIRATION BLOCK

The Inspiration block includes the rest of the Globe-Miami district. It is bounded on the east side by the Miami fault, in the other directions its boundaries are beyond the limits of the map area.

The bedrock ranges from the Pinal schist of early Precambrian age to Recent alluvium. Every formation of the local stratigraphic column crops out, as well as each of the intrusive and volcanic rocks known in the district. The block is of great economic importance because it contains all the disseminated-copper deposits of the district.

Within the map area, the block can be divided into two distinct geologic provinces by a northeastward-trending line drawn through the head of Gold Gulch, south of Porphyry Mountain, and across the outcrop of Lost Gulch quartz monzonite, south of Sleeping Beauty Peak. North of this line, the outcrops are predominantly of upper Precambrian and Paleozoic sedimentary rocks and intruded diabase. Wherever the basement rocks are exposed, they are the lower Precambrian Ruin granite. In the area south of the line, the outcrops are predominantly of Pinal schist and the several types of intrusive rocks in the schist. There are a few small outcrops of upper Precambrian Scanlan conglomerate and Pioneer formation which here rest on Pinal schist or on small truncated bodies of the lower Precambrian intrusive dioritic rocks. There are a few outcrops of diabase which has been intruded as sills near the base of the Pioneer formation or less commonly into the schist. Outcrops of the younger formations, including Whitetail conglomerate, dacite, and Gila conglomerate occur in both areas entirely unaffected by the assumed boundary between them.

The difference in ages of rocks of the outcrops in the two areas suggests that the northern area constitutes a relatively depressed block. In the intervals along the Sleeping Beauty fault and west of the Castle Dome horst, there has been vertical displacement of at least 1,200 feet. Across the Castle Dome horst, the evidence of displacement is uncertain but not entirely lacking. Elsewhere the boundary crosses rocks that are younger than the displacement. It is quite probable that the fundamental control of the boundary is a segment of the original intrusive contact between Pinal schist and the extensive mass of Ruin granite to the north. The Castle Dome horst and possibly the Copper Cities horst are the only major structural features that are common to both areas; the latter, because of the alinement of the granite porphyry intrusions in the quartz monzonite, is believed to have been controlled by the structural break between the two areas.

If the boundary between the two geologic provinces is projected southwestward to the west boundary of the Inspiration quadrangle, it will cross an area that is largely underlain by Tertiary and Quaternary rocks. To the south, these rocks overlie Pinal schist or diabase, probably of a sill intruded between the schist and the Apache group, whereas to the north, they overlap Naco limestone. At one place along the west side of Pinto Creek, the interval of younger rocks is only about 2,000 feet wide. The Naco limestone dips toward the schist, and there is no indication of the presence of at least 1,200 feet of the older sedimentary rocks or diabase sills whose aggregate thickness may amount to several hundred feet more. The structures that would account for the large vertical displacement are entirely concealed by the Tertiary and Quaternary rocks, but the principal break must coincide very closely with the hypothetical boundary between the two provinces. It would lie across the west boundary of the Inspiration quadrangle at about the same point as the Kelly fault.

The geologic history of this area is very complex and includes thrust faults (p. 96) that occurred between the time the Whitetail conglomerate was accumulating and the dacite was erupted. Erosion of the dacite west of Pinto Creek has revealed a fault dipping 25° to 30° W., along which Pinal schist is thrust over Whitetail conglomerate.

The southern boundary of the outcrops of Tertiary(?) rocks in this area is the Kelly fault, which strikes N. 60° W. and dips moderately northeast. The block to the southwest has been relatively elevated. At the Carlota mine (pl. 7), the throw of the Kelly fault after the eruption of the dacite is at least 1,200 feet. Farther to the east the fault appears to offset the outcrop of a dikelike body of lower Precambrian granite about 1,800 feet; however, like the Gold Gulch and Jewel Hill faults, it cannot be traced across the Schultze granite outcrop. It does not displace the outcrop of Gila conglomerate that lies across its projected course; but this fact indicates only that if the fault continues eastward, the displacement was earlier than the accumulation of Gila conglomerate in this area. The Gila here is regarded as being a very young part of the formation.

The Castle Dome horst is the most prominent structural feature in the western part of the district. It is an elevated block of Lost Gulch quartz monzonite that forms Porphyry Mountain and contains the Castle Dome copper deposit. The horst is about a mile wide at Porphyry Mountain and trends north-northwestward. It is bounded on the east by the Jewel Hill fault system, which dips steeply eastward and on the west by the Gold Gulch fault system which dips westward.

The elevation of the horst began before the intrusion of diabase and the early marginal faults have diabase intruded along them. Further elevation occurred in Tertiary and perhaps continued into Quaternary time. The late marginal faults displaced dacite and Gila conglomerate.

Near the north edge of the quartz monzonite outcrop, a fault older than the diabase cuts across the horst, and along the fault the part of the horst to the north is relatively depressed. This transverse fault probably is a branch from the Jewel Hill fault system bounding the horst on the east and joins the main fault about 1,000 feet north of the Continental mine.

North of Porphyry Mountain, the Scanlan conglomerate and the Pioneer formation overlying the quartz monzonite dip very gently toward the southwest, whereas the sedimentary rocks west of the quartz monzonite have much steeper westward dips. Along the northwest margin of the quartz monzonite, the Scanlan conglomerate and Pioneer formation are vertical or dip very steeply and, in a few places, are slightly overturned. The dip of the limestones of Paleozoic age along the west side of Gold Gulch is generally between 45° and 50° SW. The steeper dips in this area probably are the result of doming caused by the intrusion of the quartz monzonite or the diabase rather than the result of tilting due to faulting. East of Porphyry Mountain, a northeastward-trending syncline is exposed in a narrow segment of the Apache group and rocks of Paleozoic age that crop out between two parallel marginal faults (Peterson, Gilbert, and Quick, 1951, pl. 2, sec. *H–H'*). Although the marginal faults of the Castle Dome horst displace the Schultze granite, they cannot be traced across the granite outcrop.

Within the Castle Dome horst block is a smaller horst that trends nearly due north. It is bounded on the west by an east branch of the Gold Gulch fault, which dips west, and on the east by the eastward-dipping Dome fault system and a group of eastward-dipping faults in the quartz monzonite north of the Castle Dome mine. Between the Dome fault system and the east boundary of the quartz monzonite, mining excavations have disclosed a series of minor northwestward-striking faults that progressively depress the blocks to the east. The throw of individual faults is generally less than 25 feet.

From the northwestern corner of the quartz monzonite outcrop, the west branch of the Gold Gulch fault extends northward to Eastwater Canyon; it then continues northwestward to a point near the northwest corner of the quadrangle, beyond which it has not yet been mapped. Along this segment of the fault, only post-Gila displacement can be recognized. The outcrops on the west or hanging wall side are of Whitetail conglomerate, dacite, and Gila conglomerate, which have been dropped into contact with the older formations on the east or footwall side of the fault.

East of Porphyry Mountain, the Jewel Hill fault system consists of two nearly parallel faults between which a narrow block of sedimentary formations crops out. The west fault of the system displaces Whitetail conglomerate; yet it cannot be traced in the diabase that crops out across its projected course. Farther south a fault regarded as the continuation of the west fault forms the boundary of Gila conglomerate for short intervals in two places, but it is uncertain whether it actually displaces the conglomerate. The east fault displaces Whitetail conglomerate and dacite down into contact with older sedimentary units and diabase.

The Jewel Hill fault system can be readily followed north to Eastwater Canyon, where it is covered by talus and alluvium. North of Eastwater Canyon, there are large areas of talus and landslides, and the bedrock geology cannot be mapped in detail. In this area the Jewel Hill fault system has not been recognized with certainty. It probably turns westward; its displacement, which appears to decrease, may die out along an ill-defined zone of faults about 2,000 feet east of the northward continuation of the Gold Gulch fault and roughly parallel to it.

The general structure of the body of quartz monzonite, discussed on pages 25 to 27, suggests that the magma came up along a channel south of Porphyry Mountain and a tongue spread northward beneath the formations of the Apache group as a thick sill-like body. The presence of thin beds of metamorphosed granite arkose between the quartz monzonite and the Scanlan conglomerate indicates that the magma was intruded along a depositional contact or in the detrital arkose between the Ruin granite and the Scanlan conglomerate of the Apache group. Another tongue spread southward into the schist, and the two outcrops of quartz monzonite are separated by a belt of Pinal schist that appears to have the form of a roof pendant. Because no Ruin granite is exposed south of the quartz monzonite, it is logical to infer that the magma channel was along a contact between Ruin granite and Pinal schist south of Porphyry Mountain.

The area south of Porphyry Mountain was the locus of several other intrusions: the body of biotite granodiorite and the chain of granite porphyry bodies along Gold Gulch, the Precambrian granite in the roof pendant of the Pinal schist, and the Willow Spring granodiorite south of the schist. All these intrusions are dikelike bodies, trending northeastward in the general direction of the inferred strike of the contact of the granite and schist.

The Lost Gulch quartz monzonite mass in the Copper Cities area south of Sleeping Beauty Peak is also part of a relatively elevated block that is bounded on three sides by faults, however; this block trends northeastward.

Along the east side, the boundary is made by the eastward-dipping Miami fault zone (pl. 7), which drops Gila conglomerate into contact with the quartz monzonite. The throw on the fault along the quartz monzonite is not known, but it may be as much as 1,000 feet or even more.

The Ben Hur fault, which forms the northeast boundary of the block, strikes N. 45° W. and dips 60° to 65° NE. The block to the northeast has been dropped so as to bring diabase, in part overlain by dacite, into contact with the quartz monzonite porphyry. This diabase probably is a sill intruded between Lost Gulch quartz monzonite or Ruin granite and the sedimentary formations of the Apache group. It includes many blocks of Pioneer formation and Scanlan conglomerate, two having smaller blocks of quartz monzonite or Ruin granite, faulted into them (pl. 7).

On the northwest side, the block is bounded by the Sleeping Beauty fault, along which the adjacent block to the north has been relatively depressed. The Sleeping Beauty fault strikes northeast; its dip is uncertain, but probably is about vertical or steeply southeast. Probably the major part of the displacement along the fault occurred before the intrusion of diabase, for a thick diabase dike has been intruded along it. Later displacement occurred along the diabase-quartz monzonite contact. To the northeast, the outcrop of the fault ends at the Ben Hur fault, against dacite in the opposite wall. However, northeast of the dacite outcrop and on the projected strike of the Sleeping Beauty fault, a short segment of a fault brings Naco limestone in contact with the diabase sill in hanging wall of the Ben Hur fault (pl. 1). Five hundred feet southeast of this fault segment is an inclusion of quartz monzonite overlain by a small remnant of Scanlan conglomerate. On the basis of these relationships the fault segment could have a throw of approximately 1,000 to 1,500 feet. If this short fault segment, which is overlapped by dacite on the south and cut off by a fault on the north, is the continuation of the Sleeping Beauty fault, then all the displacement on the latter occurred before the eruption of dacite. Near the west end of the quartz monzonite outcrop another remnant of the dacite apparently overlaps the Sleeping Beauty fault.

Along the south side, the quartz monzonite is in normal intrusive contact with Pinal schist and the various intrusive rocks of the lower Precambrian dioritic complex. The contact is very irregular and generally appears to be steep. It is not displaced by any major faults.

This quartz monzonite mass in the Copper Cities area cannot be as closely related to intrusion along the inferred contact between Ruin granite and Pinal schist as the Porphyry Mountain mass. At the westernmost

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limit of the outcrop, the quartz monzonite is in contact with schist to the south, and the nearest outcrop of Ruin granite is in the south end of Ruin Basin, 4,000 feet to the northwest. The only indication that the Copper Cities mass extended northward between the Ruin granite and the Apache group is furnished by the small blocks included in the diabase northeast of the Ben Hur fault. The field of observation is so limited in these small blocks, that intrusive relationships between the Pioneer formation and granitic rock cannot be confirmed, and the granitic rock cannot be identified by any methods available because of the petrographic similarity of the Ruin granite and Lost Gulch quartz monzonite. However, the fact that the quartz monzonite is in contact with schist along the south side and that the only basement rock exposed north of the mass is Ruin granite suggest that the relationships may be the same as those in the Castle Dome area. The chain of small granite porphyry bodies that extends eastward across the Copper Cities outcrop suggests a linear channel of intrusion which would represent the eastward continuation of the channel inferred in the Castle Dome area. Further evidence of a deeply rooted channel along this trend is supplied by the mineral deposits at Castle Dome and Copper Cities, which show clear evidence of control of the primary mineralization by northeastward-trending structure.

Between the Castle Dome and Copper Cities areas, outcrops of dacite and Gila conglomerate straddle the boundary between the two geologic provinces and conceal all the older rocks in an area of about 8 square miles. The west and south boundaries of these outcrops are made largely by the Jewel Hill fault system and by the Williamson fault 3,000 feet northeast of Needle Mountain. Around the north and east sides, the boundary is a very irregular normal contact with the underlying older rocks.

Dacite is the rock in approximately the northern two-thirds of these outcrops. Gila conglomerate forms the rocks in the southern part and overlaps the dacite along the valley of Webster Gulch. Subsurface exploration indicates that the dacite probably extends as far south as the Williamson fault, which drops Gila conglomerate against Pinal schist on the south or foot-wall side. Near its east end, this fault has a throw of at least 400 feet and possibly as much as 1,200 feet. It may be the southward continuation of the east fault of the Jewel Hill fault system. Both faults displace the lower beds of the Gila conglomerate, and both are overlapped by younger beds of the Gila that would conceal the trace of the connecting segment. The Williamson fault terminates on the east against the Barney fault, which has a general northward strike and dips eastward. The block on the east side has been relatively depressed and tilted to the west.

Largely as a result of displacement on the Williamson fault, the conglomerate to the north occupies an enclosed basin, which is ideal for the accumulation of ground-water. It is known locally as Barney Basin and is the source of the domestic water supply for the settlement of Inspiration.

Between the Barney and Miami faults, the Pinal schist is intruded by a lobe of Schultze granite extending northward from the main stock. The lobe is largely granite porphyry that shows very complex gradational relationships with the normal Schultze granite (pp. 33–34).

A mineralized zone of disseminated pyrite and chalcopyrite, from 2,000 to 3,000 feet wide, extends along the north margin of the lobe, partly in the granite porphyry but mainly in the adjacent schist. The great Miami-Inspiration ore body, formed by supergene enrichment of the disseminated minerals, is along the central axis of the zone (pl. 7).

Generally the contact between the granite porphyry and schist appears to be steep, except around that part of the lobe north of the Sulphide fault and west of the Bulldog fault. Drilling clearly shows that this part of the mass is the lower part of a sill-like body that overlies the schist and that the contact is irregular but has a general dip of 15° to 30° SW. (pl. 7, sections *A–A′*, *B–B′*, *and C–C′*). To the south, the underlying schist crops out on the north side of Liveoak Gulch near the portal of the Sulphide adit of the Inspiration mine. For about 1,500 feet, the southern boundary between the schist outcrop and the main mass of Schultze granite is made by the so-called Sulphide fault, which strikes about east and is nearly vertical. In places the contact has the appearance of a fault but evidence of appreciable displacement has not been found. It probably is a part of the contact where the magma followed an old fault.

The Barney fault is the westernmost of a series of generally northward trending eastward-dipping step faults. All those recognized are clearly younger than the dacite; and some, if not all, are younger than the Gila conglomerate. Along a traverse about N. 80° E. through the Live Oak shaft, small remnants of the dacite sheet that crops out west of the Barney fault are repeated seven times on the hanging-wall sides of these faults. The blocks of dacite and Gila conglomerate show dips of as much as 50° W., which must be at least partly the result of tilting that accompanied the step faulting.

The western part of the Miami-Inspiration ore body shows a similar tilt to the west (pl. 7, section *A–A′*). The top of the west end of the ore body is about 1,000 feet below the present surface, but 2,000 feet to the northeast the ore body cropped out.

About 2,000 feet south of the Live Oak shaft, the fault structure becomes very complex and defies attempts at interpretation. Exposures are poor. Several exploratory holes have been drilled in this area, and the logs show schist overlying dacite. Ransome (1919, p. 115–119) discussed the structure in this area at some length and favored an explanation that involves thrust faulting. However, it is questionable whether schist actually does overlie dacite. The drill logs are of uncertain accuracy, owing to the difficulty in using churn-drill sludges to distinguish between semiconsolidated detritus and rock in place. There has been no further subsurface exploration in this area, and the exposures are now much poorer than when Ransome saw them, for the ground has been greatly disturbed by subsidence that is a result of the caving method employed in the extraction of the underlying ore body. The anomalous relationships of the dacite and schist could have been caused by normal faulting.

The Number 5 fault forms the contact between granite porphyry and Gila conglomerate 600 feet east of the Live Oak shaft, whence the fault can be traced southward for about 3,800 feet. The fault strikes irregularly northward and dips 30° to 40° E. Section *A–A′* (pl. 7) indicates that the fault displaces the contact between the granite porphyry and the underlying schist and displaces the ore body to some extent. The relationships of the dacite outcrops on opposite sides of the fault suggest that the dip slip was at least 500 feet, but many cross sections, which are based largely on interpretations of churn-drill logs, show that the displacement of the porphyry-schist contact can be accounted for by a dip slip of 250 to 350 feet. The top of the ore body appears to be a little higher on the footwall side than on the hanging-wall side of the fault, but offsets in the ore body tend to become less accentuated, owing to the effects of subsequent supergene action.

The Bulldog fault is exposed on Inspiration Ridge about 3,500 feet east of the Live Oak shaft. It strikes approximately north and dips 30° to 40° E. Its curved trace is a consequence of the topography and low dip. A small block of dacite that dips steeply to the west is inset on the hanging-wall side where the fault crosses the top of the ridge.

As a result of the low dip, displacement on the Bulldog fault has caused complete separation of the ore body resulting in a gap of about 1,000 feet between the east end of the ore body in the Keystone division of the Inspiration mine and the west end of the ore body in the Inspiration division east of the fault.

West of the fault, the ore body crops out and has been partly eroded. The exposed ore is brightly colored, owing to almost complete oxidation of the copper minerals. The top of the ore body east of the fault is about 500 feet lower in elevation than the top of the ore body west of the fault, and it is overlain by as much as 600 feet of leached capping.

The Joe Bush fault is about 3,300 feet east of the point at which the Bulldog fault crosses the top of Inspiration Ridge. Unlike most of the other faults in this series, it dips southwest about 85°. It can be traced from a point southeast of the Scorpion shaft southeastward into the caved area, where it cannot be accurately located. At the surface (pl. 7) the Joe Bush fault forms the contact between the granite porphyry facies of Schultze granite and schist for about 1,500 feet; Ransome (1919, p. 114) states that it separates barren porphyry on the southwest from ore-bearing schist on the northeast for about 1,500 feet on the third level of the Inspiration mine. The granite porphyry outcrop southwest of the fault is also practically barren.

About 500 feet northwest of the Joe Bush shaft, the contact of the granite porphyry and the schist curves to the west; the fault continues northwestward into the schist, and underground it passes into the ore body.

A fault that also forms the contact between granite porphyry and schist and may be the southeast continuation of the Joe Bush fault is 1,500 feet southeast of the Joe Bush shaft. At one point where it is well exposed, it dips 65° SW. To the northwest, the fault passes into the caved area so that its possible continuity with the Joe Bush fault cannot be confirmed.

There is little to indicate any substantial amount of displacement along the Joe Bush fault. The fault probably represents an igneous contact, possibly related to a fault formed before intrusion of granite along which there has been slight movement that was at least partly contemporaneous with that of the other faults of this series.

The Pinto fault is a few hundred feet northeast of the Joe Bush fault, and its general strike of N. 55° W. is roughly parallel to that of the Joe Bush, but the Pinto fault dips about 55° NE.

At the surface over the ore body, the Pinto fault forms the contact between an irregular apophysis of Schultze granite on its south or footwall side and schist on its hanging-wall side. The granite is thin along the line of section *A–A′* (pl. 7), but its lower surface dips toward the southeast. For about 1,400 feet northwestward from its intersection with the Miami fault, the Pinto fault separates a narrow block of schist in the footwall from granite in the hanging wall. At the northern end, the schist is thin, and its form is suggestive of a roof pendant, but south of No. 1 shaft the contact of the granite and schist dips toward the Pinto fault and intersects the fault below the 420-foot level of the Miami mine. The granite body northeast of the fault also is thin in the northern part, and its lower surface dips toward the fault. In the southwestern part of the Miami mine, a prominent fault zone considered to be the Pinto fault separates granite from schist on the 420-foot level between the lines of sections *G–G′* and *H–H′* (pl. 7). In the eastern part of the Inspiration mine the fault has not been recognized, but here both walls would be of schist.

The Pinto fault crosses Webster Gulch near the south end of the Inspiration leaching plant, but the trace is obscured by fill. It probably is the same fault that forms the contact between the dacite and schist northwest of the Inspiration mine's main shafts and joins a fault considered to be the continuation of the Bulldog fault north of Webster Gulch. To the southeast the Pinto fault joins the Miami fault about 300 feet from the Sullivan shaft.

The mine workings have exposed no key horizon cut by the Pinto fault whereby the displacement can be determined. The ore body has been mined as much as 350 feet deeper on the northeast side, or hanging-wall side, of the fault than on the footwall side, but this difference does not necessarily indicate a throw of 350 feet, because the depth of mining is governed to some extent by certain physical requirements of the mining method particularly the location of existing mine levels. The elevation of the top of the ore body is not appreciably different on opposite sides of the fault, but differences in the elevation of the top of the ore body tend to disappear through the action of supergene processes. Ransome (1919, p. 152–153) was able to examine the mine workings traversed by the fault and stated that the throw probably is 250 to 300 feet. He suggested that the displacement occurred in steps along a number of northwestward trending fissures.

The Warrior fault zone extends along the north flank of Inspiration Ridge about half a mile north of the Pinto fault. It is described on pages 135–137 in its relation to the supergene copper deposits that occur along it. The Warrior fault zone is not a major structural feature, but it is noteworthy because of its apparent age relation to the dacite. It displaces tuffaceous conglomerate that is regarded as being a very late phase of the Whitetail conglomerate, but it is doubtful that it displaces the overlying dacite.

The tuffaceous conglomerate, in places as much as 100 feet thick, is a local accumulation in the form of a narrow eastward-trending band along the fault zone. In the adjacent areas north and south of the fault zone, remnants of dacite rest directly on the older formations, mainly schist and diabase. Probably the Warrior is an old fault zone along which a deep narrow valley was eroded. Volcanic ash that fell on the surrounding area, together with some detritus of schist was washed into the valley before the main eruption of dacite. Later, displacement occurred, probably immediately preceding the eruption, and a long narrow graben settled between two nearly parallel faults of the zone. It is this tuffaceous material inset between walls of schist and overlain by dacite that the supergene copper minerals were deposited.

In the northern area of the Inspiration block the outcrops form a complex mosaic of small faulted blocks of upper Precambrian and Paleozoic sedimentary rocks and intruded diabase that rest on a basement of lower Precambrian Ruin granite. Although there are faults with every conceivable strike, the dominant trend is north to northwest. Most of these faults are older than the intrusion of diabase or were contemporaneous with it. The earliest faults served as channels for the invading magma and have diabase intruded along them in many places. Existence of such faults is inferred where outcrops of formations or strata of different ages are separated by steep-walled bodies of diabase. Examples of this relationship can be seen in many places along the margins of Ruin and Granite Basins and around the northern part of the quartz monzonite in the Castle Dome area. Many of the faults that displace sedimentary formations end at their contacts with diabase bodies but commonly reappear on the opposite sides of the diabase bodies. Examples of faults that end abruptly at igneous contacts are numerous throughout the northern area wherever the sedimentary formations have been intruded by diabase. Zones of displacement interrupted by intruded bodies of diabase can often be traced for considerable distances, although no faults through the diabase bodies or along their boundaries can be found. Most of the diabase bodies are irregular in shape, but their general trends are northwest like those of the faults. Faults that displace the diabase generally follow the trends of old faults and commonly are along igneous contacts or in the diabase close to the contacts.

The small number of faults and diabase bodies that have been mapped in the large areas of Ruin granite is evidence that many of the faults were caused by the emplacement of the diabase magma under and between the sedimentary strata. However, this evidence is not as conclusive as it appears, because faults in the granite are often hard to recognize, owing to the mantle of decomposed rock that covers much of the outcrops. The shapes of diabase bodies intruded into the granite probably were controlled largely by faults in the granite. Most of them have distinct northwestward trends; and although some of the outcrops have the topographic expression of gently dipping bodies, most of the contacts of diabase with the granite are steep wherever their attitudes can be measured.

The predominant dip of the sedimentary strata throughout the northern area is 10° to 45° SW, although many local exceptions to this general attitude are to be expected in rocks that are so complexly deformed. The general effect of the northward- to northwestward-trending faults and zones of displacement that have been invaded by diabase is to depress the blocks progressively to the northeast so that formations of similar age are repeated many times along a traverse from southwest to northeast. It is not known whether the southwest tilting of the strata in the faulted blocks is the result of the step faults or of a regional homoclinal structure that is older than these step faults.

Deformation by folding was of very local and minor importance. The attitudes of the beds indicate a small anticline near the eastern edge of the Inspiration quadrangle. Its axis can be traced from a point about 2,000 feet east of Sleeping Beauty Peak to the north boundary of the quadrangle. Another minor anticline extends northwestward from the north end of Granite Basin.

The large outcrops of Ruin granite that underlie Ruin and Granite Basins represent horsts from which the sedimentary rocks deposited on the granite have been stripped. The Granite Basin horst is almost surrounded by diabase intruded along the marginal fault zones. There has been some later displacement along parts of the boundary faults, which may have been younger than the dacite or even younger than the Gila conglomerate.

Along the west side of Ruin Basin, the displacement occurred at intervals, the earliest was before intrusion of diabase, the latest is younger at least than the basal beds of the Gila conglomerate. Along the southern part of the west side, a narrow block of Gila conglomerate has been inset between older formations along two roughly parallel faults. The conglomerate appears to have been deposited in a narrow trough that coincides approximately with the outcrop so that the present relationships could have resulted from relatively slight displacement. On the east side of Ruin Basin, all the displacement along the marginal fault zone is older than the intrusion of diabase.

The apparent displacement along the marginal fault zones of these two uplifted blocks differs widely from place to place. It ranges from a few feet or a few tens of feet to at least 800 to 1,000 feet, in places where Martin limestone is in fault contact with the granite or crops out along marginal bodies of diabase. A precise estimate of the amount of the displacement is not possible because the depth of erosion in the granite of the blocks cannot be determined and because erosional disconformities and intercalated diabase sills affect the thickness of local stratigraphic sections.

There are a few prospects in this northern area, but mineralization was very weak, and no ore bodies have been found. The strongest mineralization was along the Money Metals vein, at the south end of Granite Basin, near the south boundary of the area. The hypogene minerals are chiefly those of lead, zinc, and silver and are characteristic of the outlying deposits.

GEOLOGIC HISTORY

EARLY PRECAMBRIAN

The earliest geologic event recorded by the rocks of the Globe-Miami district is the deposition of great thicknesses of clastic sediments derived from older rocks of which we have no knowledge whatever. The total thickness of these sediments, which are now represented by the Pinal schist, is unknown, for nowhere is the base of the schist exposed.

After many thousands of feet of sediments had accumulated, deposition was interrupted by the Mazatzal revolution (Wilson, 1939, p. 1113–1163). The mountain-building forces that accompanied this revolution were largely compressive and were active from southeast or northwest. The ancient sedimentary formations were thrust and folded into mountain ranges that extended northeastward across the state. The deformation was accompanied by recrystallization of the rocks to form the Pinal schist and was followed by extensive intrusion of granitic rocks. Sites of these mountain ranges are represented by remnants of an ancient highland of lower Precambrian rocks known as Mazatzal land (Stoyanow, 1936, p. 462), the buried granitic Holbrook ridge (fig. 15), and the Defiance and Zuni uplifts to the northeast. Mazatzal land remained as a barrier between a northern and a southern sedimentary basin in Arizona during late Precambrian time and during at least the early part of the Paleozoic era.

The earliest of the igneous intrusions in the district are represented by the granite on Manitou Hill and the complex of dioritic rocks in the Pinal schist north of Inspiration, in the vicinity of Lost Gulch. In the Pinal Mountains to the south, there were extensive intrusions of Madera diorite. These rocks are generally slightly foliated and contain fragments of schist, which would indicate that the metamorphism of the sediments was well advanced before the intrusions occurred. This early Precambrian revolution culminated with the intrusion of the great mass of Ruin granite that underlies the northern part of the district and extends for a considerable distance to the north. Apparently, the Ruin granite represents one of many intrusions of magmas of similar composition that invaded the lower Precambrian rocks of Arizona at this time and crop out along the border zone of the Colorado Plateau.

The only products of mineralization that can be definitely related to this period is the many small veins of white, glassy quartz in the Pinal schist. No evidence of related metallization has been recognized, but possibly the small quartz-tourmaline and quartz-wolframite veins that occur in the Pinal schist in a few places may belong to this period.

Toward the end of the Mazatzal revolution, the topography of the region must have been characterized by extremely rugged mountains made up of folded and faulted blocks of Pinal schist and the intruded bodies of igneous rocks. There followed a long period of erosion during which the Globe-Miami area and most of the surrounding region were worn down to an almost featureless peneplain sparsely strewn with small fragments of vein quartz and other resistant rocks, few of which had been transported for more than short distances from their parent outcrops. The outcrops of Ruin granite were deeply weathered and were covered by a loose mantle of decomposed rock derived almost entirely from the granite itself.

LATE PRECAMBRIAN

Advance of the sea forming a basin over the baseleveled terrain initiated deposition of the upper Precambrian sedimentary sequence of the Apache group. The Apache basin probably was a shallow arm of the sea that entered Arizona across the southern boundary of the State and extended northward to the vicinity of Haigler Creek, north of the village of Young.

The advance of the sea must have been relatively rapid because the thin Scanlan conglomerate apparently was formed by very slight reworking of the sparse debris that lay on the land surface. The few included pebbles are angular or subrounded, and the matrix is composed largely of material from local outcrops. The streams flowing into the basin must have drained areas already reduced almost to base level, and the their loads were light and composed of fine sand and silt. There was no marked change in the conditions of erosion and deposition during this time, in which the Pioneer formation was being laid down.

A sudden change in such conditions is marked by the Barnes conglomerate, a thin bed of closely packed, well-rounded pebbles and cobbles of quartzite derived from rocks unknown in the Globe-Miami district or in the region to the south. Wilson (1939, p. 1139) states that the quartzite of the pebbles of the Barnes conglomerate is lithologically identical to the Mazatzal quartzite that crops out in the Mazatzal Mountains, about 35 miles northwest of Globe. Such a thin bed of such nearly uniform character and thickness and persisting throughout the area of the Apache group is difficult to explain by direct deposition. It undoubtedly represents a significant structural disturbance and a unique sequence of events, whose reconstruction must necessarily be largely conjectural.

One may explain the formation of the Barnes conglomerate by postulating a cycle that began with a sudden elevation of the region to the north relative to the Apache basin, thus causing a sharp increase in the rate of erosion. Undoubtedly the basin itself was elevated, causing the sea to withdraw southward, its retreat being accompanied by a regressive deposition southward of stream-laid gravels and coarse detritus similar in character to the much younger Gila conglomerate. The advance southward of these continental deposits was so well coordinated with the retreat of the sea that there was no appreciable erosion of the Pioneer formation, which, at this stage, probably was still a soft shale. The accumulation of continental gravels, sand, and boulders filled the entire basin and probably extend somewhat beyond the limits of the Pioneer formation.

The relative elevation of the region occupied by the basin was followed by subsidence, and again the sea began to advance northward. The waves beat against cliffs of the soft, poorly consolidated, detrital deposits. The larger cobbles and boulders of the most resistant rocks were worn and rounded by wave action and accumulated as a thin bed of closely packed pebbles near the advancing shoreline. The finer materials were carried seaward by tides and undercurrents and accumulated farther from the shore, forming the coarse- or medium-grained, commonly crossbedded sandstone that became the lower part of the Dripping Spring quartzite. The sandstone was in turn buried by the thin-bedded sequence of fine-grained feldspathic quartzite and shale that characterizes the upper part of the formation. Later there was only chemical deposition of calcium and magnesium carbonates and chert that formed the thin-bedded and impure Mescal limestone.

The revolution that marks the end of Precambrian deposition did not greatly affect the Globe-Miami area. It is represented only by an erosional disconformity; the sedimentary beds of the Apache group were not faulted or recognizably warped during their emergence from the sea. The only evidences of igneous activity are one or more thin but extensive flows of vesicular basalt that overlie the Mescal limestone. The basalt may have been poured out before the sea had completely withdrawn for there is no evidence of erosion at the base of the flows.

During the period of erosion that followed eruption of the basalt and the withdrawal of the sea, the basalt flows and the Mescal limestone were completely removed from a large part of the district. It is known than in some places channels were cut through the Barnes conglomerate and into the Pioneer formation, but the extent of such channeling is not known. Nowhere in the district can rocks of Paleozonic age be seen in normal contact with the older Precambrian formations.

PALEOZOIC

When the sea advanced again, in late Middle Cambrian time, it encroached in about the same direction as that taken by the earlier Apache sea (Stoyanow, 1942, pl. 56). Unlike the peneplain over which the Apache sea spread, the surface transgressed by the Cambrian sea was one of at least moderate relief. The valleys and lower slopes of the hills were covered by a mantle of coarse detritus of angular blocks of quartzite and Mescal limestone, nodules of chert, and rounded pebbles from the Barnes conglomerate. These detrital deposits were slightly reworked by the advancing sea to form the thick basal conglomerate of the Troy quartzite.

Deposition of the pebbly, cross bedded, nearly pure, quartz sand that was later firmly cemented by silica to form the Troy quartzite proceeded rapidly, probably in relatively shallow water. In late Middle Cambrian time the sea withdrew southward; deposition ceased in the Globe-Miami area, but continued in southeastern Arizona, at least through most of Late Cambrian time.

There is no record that sedimentation was renewed in the Globe-Miami area until the Late Devonian epoch. There are practically no clues to what transpired during Late Cambrian, Ordovician, Silurian, and Early and Middle Devonian time. No evidence of faulting during this interval has been found, and the strata were not noticeably warped. Some erosion took place, but no more than could have been accomplished during a small fraction of the time represented by this hiatus in the geologic column. The Troy quartzite was completely stripped from the greater part of the district, and undoubtedly some of the underlying rocks of the Apache group were removed but so far as can be determined from a study of the present outcrops, erosion did not cut deeply enough to expose the lower Precambrian rocks. The thickness of the stratigraphic section exposed by pre-Devonian erosion indicates that the relief within the mapped area may have been as much as 1,200 feet, but it seems unlikely that the strata are perfectly conformable, and a part of this apparent relief may be due to a slight, unapparent angular unconformity between the Apache group and the Troy quartzite.

In Late Devonian time, the sea again advanced and submerged the region. It was still shallow and may not have completely inundated the higher parts of the terrain while the basal conglomeratic and arenaceous beds of the Martin limestone were being deposited in the lower areas. There probably was a broad littoral zone covered by windblown sands not far to north of the Globe-Miami district at the time the lower dolomitic limestone was deposited. Later, the shore line advanced farther northward and the limestone of the upper part was laid down as continuous strata over the entire region. The fine-grained, paper shale at the top of the Martin probably marks a period during which the shore line was practically stationary, or it may represent a period during which the water was so deep that calcite precipitated from the warm surface waters was redissolved at deeper levels, and only a little very fine silt settled to the bottom.

There is no structural or erosional break between the paper shale at the top of the Martin limestone and the overlying Escabrosa limestone of Mississippian age. The massive beds of nearly pure limestone of the Escabrosa were laid down conformably on the Devonian strata. When deposition ceased is not known, but it was probably before Late Mississippian time, for no strata of Late Mississippian age are now in the Globe-Miami area.

After deposition of the Escabrosa limestone and until the beginning of the Pennsylvanian period, the waters must have been very shallow; and at times, local areas of land may have emerged from the sea, but erosion was not extensive and probably was accomplished mainly by solution of calcium carbonate. The evidence of such erosion is a thin bed of red shale containing fragments of chert and small lenses of chert conglomerate, which is interpreted as an accumulation of oxidized residual clay on the old limestone surface. The chert was derived from the chert nodules that are common in the Escabrosa limestone.

During as much of the Pennsylvanian period, as is represented by the strata of existing outcrops, the sea probably was fairly shallow. Conditions of sedimentation changed frequently, resulting in deposition of thin beds of limestone alternating with thinner layers of limy shale. A few thin, lenticular beds of red shale like that of the basal bed probably indicate short intervals in which there was emergence and erosion of local areas. That the Pennsylvanian sea supported a large marine fauna is indicated by the abundant fossils of brachiopods, fusulinids, crinoids, and corals. The earlier Paleozoic formations are not especially fossiliferous.

From the time when the upper Precambrian formations of the Apache group were being deposited through the Paleozoic era, structural forces were practically inactive, and the sedimentary formations succeeded one another without apparent angular discordance. The four recognizable disconformities resulted from alternating uplift and subsidence of the land or sea level so regional in scope that no apparent angular unconformities were formed between the several sedimentary systems.

MESOZOIC AND CENOZOIC

There is no record of sedimentation in the Globe-Miami area between Carboniferous and the time represented by the Whitetail conglomerate. Whether rocks of Permian, Triassic, Jurassic, and Cretaceous age were ever deposited is not known. It is quite probable, however, that sedimentation continued, at least through the Paleozoic era, and that all the Permian formations and a considerable thickness of the Pennsylvanian were removed by erosion during the interval that preceded the eruption of dacite. The maximum section of Pennsylvanian rocks in the district is about 500 feet thick. This thickness probably represents no more than a half or a third of the original thickness.

We have no clues whatever as to what took place during Triassic, Jurassic, and Early Cretaceous time. Sedimentary formations of Triassic and Jurassic age are present in the plateau region of northeastern Arizona but are not known in the rest of the State, south of the Mogollon Rim. Strata of Early Cretaceous age occur in the southeastern part of the State, but they extend only a little north of the latitude of Tucson. In the Reed Basin, east of Christmas, sedimentary rocks of Late Cretaceous age crop out at the base of a thick sequence of andesitic volcanic rocks, and some sedimentary conglomerate is interbedded with the volcanic rocks. (Campbell, 1904, p. 246); west of Christmas, 22 miles due south of Globe, these same andesitic rocks overlie Carboniferous limestone, whose upper part contains strata of Permian age. The volcanic rocks may have extended as far north as the Globe-Miami district; but if so, all evidence of them has been obliterated.

It is possible that some of the older igneous rocks were intruded during the Triassic and Jurassic periods. Igneous intrusions of this age have been recognized in the Bisbee district (Ransome, 1904b, p. 84; Trischka, 1938, p. 35–36). However, it appears more probable that igneous activity in the Globe-Miami area did not begin until Late Cretaceous time, as in the more closely related area in the vicinity of Christmas. The intrusions are probably younger than the volcanic rocks.

Among the earliest intrusions that have been assigned to this period are the Solitude granite, the Willow Spring granodiorite, the biotite granodiorite in Gold Gulch, and the Lost Gulch quartz monzonite. All but the Solitude granite show the same tendency toward northeastward elongation and alinement as the early Precambrian intrusions. Their spacial relationships suggest a controlling, northeastward-trending zone of weakness probably inherited from the early Precambrian structure.

Considerable crustal adjustment must have accompanied and followed these early igneous intrusions. The zone of igneous intrusions and the region to the north of it were well dissected by faults and fractures before the next event, namely the intrusion of many bodies of diabase that crosscut the older formations.

The diabase magma was intruded at relatively shallow depths. Probably no more than the thickness of the rocks of Paleozoic age separated the largest masses from the surface. Much of the magma was intruded into the formations of the Apache group; but in a few places, it rose into the Paleozoic limestone beds. Space for the large volumes of intruded magma was provided by dilation of the crust, with consequent rupture and displacement of the sedimentary strata. Some of the magma may have reached the surface and poured out as basalt lava; if so, none of the lava is now evident.

After the intrusion of diabase, many small dikes, sills, and irregular masses of diorite porphyry were injected, most near the base of the Apache group.

As a result of the intrusion of diabase, many of the old faults became igneous contacts between diabase and older rocks. Later, but before the period of mineralization, some of the old faults followed by these contacts were reopened, and additional displacement occurred. Although there was but minor displacement at this time, the reopened faults are of great importance in the economic geology of the district because many of them became channels for mineralizing solutions, particularly in the area north of Globe.

The elevation of the Pinal Mountains probably took place after the intrusion of diabase but before the intrusion of the Schultze granite. The uplift was accomplished partly by broad folding of the sedimentary strata over the crystalline rocks of the Pinal Mountains in a great anticlinal arch and partly by displacement along a major fault on the north side of the range. Although no trace of the fault is visible, the structural relationships require its existence. In the eastern part of the district, the fault zone could be overlapped by the Gila conglomerate; but in the western part, the failure to find any evidence of the fault across the outcrops of crystalline rocks suggests that magma of the Schultze granite arose along a portion of the fault zone.

The main body of Schultze granite underlies most of the southwestern part of the district. Later pulses of the magma formed lobes of granite porphyry at several places along the margins of the main mass and invaded the surrounding formations as dikes and small irregular masses.

The extensive copper metallization of the district occurred soon after the intrusions of Schultze granite and granite porphyry. It appears to have been the culminating event in this long period of igneous activity.

The rocks of the district must have been throughly broken by faults and fractures by the time the igneous activity ceased, as is evidenced by the many faults that were older than or were contemporaneous with the intrusion of diabase and also by those that became channels for mineralizing solutions.

Erosion probably occurred at various times during the Mesozoic era, and it continued for some time after the period of mineralization. In the vicinity of the Miami-Inspiration ore body, the cover of sedimentary rocks was completely removed, and the mineralized schist and granite porphyry were exposed to weathering. The greater part of the detritus was transported from the district, but a little of it accumulated in low-lying areas, forming the Whitetail conglomerate.

While erosion was going on in the Miami-Inspiration area, there was a basin of deposition in the vicinity of Porphyry Mountain to the west as shown by the distribution and thickness of the Whitetail conglomerate. The Whitetail is either very thin or absent both in the Miami-Inspiration area and in the area along the western edge of the district, but it thickens to 500 feet or more in the vicinity of Porphyry Mountain. The upper part of this thick section of Whitetail is well stratified, and grades upward into waterlaid tuff, an indication that a shallow body of water occupied a basin, at least during the later stages of deposition. Thus, while the Miami-Inspiration copper deposit was being exposed and enriched, the sedimentary cover over the Castle Dome deposit was being increased. The mineralized quartz monzonite probably was well below the groundwater level and thus was protected from oxidation.

The topography of the district was still characterized by moderate relief when erosion was interrupted by volcanic eruption. The first stage of the eruption probably occurred while the Whitetail conglomerate was being deposited in the vicinity of Porphyry Mountain and was the source of the tuffaceous material that is interbedded with the upper part of the Whitetail in that area. There were repeated ejections of tuff and small extrusions of very viscous rhyolitic lava and perlitic glass, whose outcrops are found mainly in the area lying southwest of the district and extending in that direction beyond Superior.

The eruption apparently ceased for a brief interval, during which some erosion of the volcanic rocks occurred. A second stage followed, whose effects are far more extensive than those of the first. It began with explosive ejection of pumiceous material that showered down on the Globe-Miami area and surrounding region forming a thin blanket of white vitric-crystal tuff. Then the character of the ejected material changed very abruptly, as the eruption continued, probably as showers of flows or incandescent bombs, lapilli, and molten glass of dacitic composition. The older volcanic rocks and great areas of the surrounding region were buried beneath a deposit of hot pyroclastic material that became compacted and welded to form a massive sheet, which in some places was at least 1,000 feet thick and possibly as much as 2,000 feet.

Faulting on a large scale was resumed after the eruption and continued at intervals into Pleistocene time. The faulting was mainly of the normal type and resulted in the tilting of the faulted blocks toward the southwest or west. A few minor folds were formed; and at the southwest end of the Old Dominion mine, a plate of Madera diorite was thrust over dacite along a low-angle southward-dipping fault. Somewhat earlier, probably about the time the volcanic activity began, a plate of Pinal schist was thrust over Whitetail conglomerate along a low-angle fault that crops out in Pinto Creek southwest of Porphyry Mountain.

Erosion was renewed immediately after the eruption of dacite and began to wear away the elevated blocks. The dacite cover was completely removed from some areas, and debris from the dacite and underlying formations began to accumulate in low-lying areas as the great coalescing alluvial fans which make up the major part of the Gila conglomerate. As time went on, they were built up to thicknesses exceeding 4,000 feet of coarse, bouldery detritus, gravel, sand, and silt washed into the valleys by intermittent streams.

Very minor igneous activity occurred during the time the Gila conglomerate was being deposited, as is shown by thin flows of olivine basalt intercalated with the conglomerate southwest of Porphyry Mountain and by a major part of the enrichment that formed the Copper part of the Inspiration quadrangle.

The thickest accumulation of Gila conglomerate was in a roughly triangular area, within and extending southward for 3 miles beyond the limits of the Globe quadrangle which is bounded by normal faults. The block between the faults appears to have been continuously depressed as the deposits of conglomerate were built up. At the time of its greatest extent, the Gila conglomerate probably mantled the entire district and extended considerably higher up the slope of the Pinal Mountains to the south than does the present outcrop.

During the final stages of deposition of the Gila conglomerate, the region was a broad, nearly flat, intermountain valley whose central part was occupied, at least intermittently, by a shallow body of water in which typical lacustrine sediments were deposited. The period of deposition was succeeded by a period of crustal disturbance during which the region was relatively uplifted, and extensive faulting occurred. A new drainage system developed, and erosion began to wear away the Gila conglomerate.

The events, described in the foregoing pages as having taken place since the beginning of the Mesozoic era, cannot be accurately dated in the calendar of geologic time, but the order in which they occurred can be determined with reasonable accuracy. The age of the Gila conglomerate, based on fossils collected in the San Pedro Valley from beds near the top of the formation, has been determined to be Pliocene and probably in part early Pleistocene. Thus, the latest crustal disturbance affecting the region probably occurred in early Pleistocene time.

After this latest period of faulting and regional uplift, erosion again began to wear away the elevated blocks. One of the highest blocks in the district at this time and probably among the first to be stripped of its cover of lava and sedimentary rocks was the quartz monzonite horst block of the Porphyry Mountain area. The mineralized quartz monzonite was uncovered for the first time, and weathering agents began the work of enrichment that was largely responsible for the formation of the Castle Dome ore body.

The mineralized quartz monzonite in the Lost Gulch area was uncovered before the eruption of dacite at least in part, and undoubtedly some weathering of the mineralized rock occurred, but whether any part of the Copper Cities chalcocite ore body was formed at that time is uncertain. Here, too, the quartz monzonite outcrop is in a relatively elevated horst block which probably was stripped of its cover of dacite and Gila conglomerate about the same time the quartz monzonite on Porphyry Mountain was uncovered. At least a major partof the enrichment that formed the Copper Cities ore body was about contemporaneous with the enrichment of the Castle Dome deposit and is related to the present erosion cycle.

The Miami-Inspiration ore body was covered by dacite and Gila conglomerate after the mineralized schist and granite porphyry had been enriched to form that ore body during the interval of exposure preceding the eruption of dacite, and it remained covered until very recent time. The western end of the ore body is still covered, and small remnants of the dacite and Gila conglomerate overlie the eastern part in several places. The ore body has been only slightly modified by recent supergene action.

Erosion has continued uninterrupted to the present day. Most of the resulting debris has been carried away by intermittent streams, but some of it remains as talus, terrace gravels, and alluvium. A few terraces of older cemented gravels perched along the sides of Gold Gulch and Tinhorn Wash are the only evidence that relative uplift of the area may have continued into Recent time.

MINERALOGY

The minerals that have been identified in the Globe-Miami district are listed below in alphabetical order. The mode of occurrence and common habitat are described in the order followed in Dana's "System of Mineralogy" (Palache, Berman, and Frondel, 1944, 1951) in the section that follows:

Mineral	*Formula*
Aikinite	$PbCuBiS_3$
Alunite	$KAl_3(SO_4)_2(OH)_6$
Amphibole	Silicate of Ca,Mg,Fe,Na,Al,H_2O
Anglesite	$PbSO_4$
Ankerite	$Ca(Fe'',Mg,Mn)(CO_3)_2$
Apatite	Complex calcium phosphate
Argentite	Ag_2S
Azurite	$Cu_3(OH)_2(CO_3)_2$
Barite	$BaSO_4$
Biotite	$H_2K(Mg,Fe)_3Al(SiO_4)_3$
Bornite	Cu_5FeS_4
Calcite	$CaCO_3$
Canbyite	$H_4Fe_2Si_2O_9 \cdot 2H_2O$
Cerargyrite	$AgCl$
Cerussite	$PbCO_3$
Chalcanthite	$CuSO_4 \cdot 5H_2O$
Chalcedony	SiO_2
Chalcocite	Cu_2S
Chalcopyrite	$CuFeS_2$
Chlorite	Silicate of Al,Mg,Fe,H
Chrysocolla	$CuSiO_3 \cdot 2H_2O$
Clinozoisite	$HCa_2Al_3Si_3O_{13}$
Copper (native)	Cu
Covellite	CuS
Cuprite	Cu_2O
Descloizite	$(Zn,Cu)Pb(VO_4)(OH)$
Dolomite	$CaMg(CO_3)_2$
Enargite	Cu_3AsS_4
Endellite	$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$
Epidote	$HCa_2(Al,Fe)_3Si_3O_{18}$
Feldspar	Silicate of Ca,Na,K
Ferrimolybdite	$Fe_2(MoO_4)_3 \cdot 8H_2O$
Fluorite	CaF_2
Galena	PbS

Mineral	*Formula*
Garnet	Silicate of Ca, Mg, Fe, Mn, Al
Gold (native)	Au
Goslarite	$ZnSO_4 \cdot 7H_2O$
Gypsum	$CaSO_4 \cdot 2H_2O$
Halloysite	$Al_2O_3 \cdot 2SiO_2 \cdot nH_2O$
Hematite	Fe_2O_3
Hemimorphite	$H_2Zn_2SiO_5$
Hydrous mica	Hydrous silicate of Al, Mg, K
Iddingsite	$MgO \cdot Fe_2O_3 \cdot SiO_2 \cdot 4H_2O$
Ilmenite	$FeTiO_3$
Jarosite	$KFe_3(SO_4)_2(OH)_6$
Kaolinite	$H_4Al_2Si_2O_9$
Libethenite	$Cu_2(PO_4)(OH)$
Limonite	hydrous iron oxide
Lindgrenite	$Cu_3(MoO_4)_2(OH)_2$
Magnetite	Fe_3O_4
Malachite	$Cu_2(OH)_2(CO_3)$
Manganite	$MnO(OH)$
Massicot	PbO
Metatorbernite	$Cu(UO_2)_2(PO_4)_2 \cdot 8H_2O$
Molybdenite	MoS_2
Montmorillonite	Silicate of Mg, Ca, Al, H_2O
Mottramite	$(Cu,Zn)Pb(VO_4)(OH)$
Muscovite	$H_2KAl(SiO_4)_3$
Olivine	$(Mg,Fe)_2SiO_4$
Opal	$SiO_2 \cdot nH_2O$
Pyrite	FeS_2
Pyrolusite	MnO_2
Pyroxene	Silicate of Ca, Mg, Fe, Mn, Zn
Quartz	SiO_2
Rhodocrosite	$MnCO_3$
Rutile	TiO_2
Serpentine	Silicate of Mg, Fe
Sillimanite	Al_2SiO_5
Silver (native)	Ag
Sphalerite	ZnS
Sphene	$CaTiSiO_5$
Stilbite	$(Na_2,Ca)Al_2Si_6O_{16} \cdot 6H_2O$
Sulfur (native)	S
Tennantite	$(Cu,Fe)_{12}As_4S_{13}$
Tenorite	CuO
Tetrahedrite	$(Cu,Fe)_{12}Sb_4S_{13}$
Turquoise	$CuAl_6(PO_4)_4(OH)_8 \cdot 4H_2O$
Tourmaline	Complex silicate of B, Al, Mg, Fe
Vanadinite	$Pb_5(VO_4)_3Cl$
Wavellite	$Al_3(OH)_3(PO_4)_2 \cdot 5H_2O$
Willemite	Zn_2SiO_4
Wolframite	$(Fe,Mn)WO_4$
Wulfenite	$PbMoO_4$
Zircon	$ZrSiO_4$

NATIVE ELEMENTS

Gold.—Fine specimens of native gold in the form of short wires and thin leaves were commonly found embedded in an ocherous dark-red mixture of cuprite and iron oxides in the Original Old Dominion, or Keystone deposit, on Pinal Creek (Ransome, 1903, p. 154). Appreciable amounts of native gold occurred in the gossans and near surface ore of many of the vein copper deposits, and some of the small deposits were mined for gold. The gold content of the ores of the Old Dominion mine averaged 0.014 ounce to the ton, and the ores of the Iron Cap mine, 0.006 ounce to the ton. The gold content of the disseminated deposits is very small. Gold recovered from the Castle Dome mine ranged from 0.00032 ounce to the ton during the first 4 years of operation to about 0.00012 ounce for the final year; the average was about 0.00021 ounce to the ton. Gold is not recovered by the leaching process used to treat the Inspiration ore, and annual reports of Miami Copper Co. do not state the gold and silver recovered, but the amount is very small.

Silver.—Ransome (1903, p. 124) reported minute flakes of native silver in calcite associated with cuprite in the Continental mine. Many of the small silver deposits mined during the early days of the district are said to have contained native silver; and rich bunches of ore containing native silver were mined from deposits at McMillanville and in Richmond Basin, just north of the Globe quadrangle. Many nuggets of native silver were found in the surficial deposits of the floor of Richmond Basin. A large nugget recently found in a wash north of Globe weighs about 60 pounds.

Copper.—Small amounts of native copper are present in the oxidized zones of both the disseminated- and the vein-copper deposits of the district. The copper apparently formed as a product of oxidation of chalcocite and covellite in the absence of pyrite or acid ground water. It is commonly associated with cuprite, which forms under similar conditions. Graton and Murdoch (1914, p. 56) state that native copper formed directly from chalcocite in some of the ore of the Old Dominion mine.

Minute grains and wires of native copper were commonly seen in concentrates panned from the sludges of four holes bored in the Gila conglomerate south of Miami. Occasional rock fragments brought up by the drill included minute grains of native copper. Ransome (1919, p. 132) mentioned similar occurrences of native copper in material from other drill holes in the Gila conglomerate. Fragments of schist from a hole bored for water in the town of Miami were traversed by fractures containing thin films of copper. Probably all the native copper found in the drill sludges was formed by oxidation of chalcocite grains in fragments of mineralized schist and granite contained in the Gila conglomerate.

Sulfur.—Native sulfur was noted in several places in the Castle Dome mine, where sphalerite and galena are undergoing oxidation. It occurs as well-formed orthorhombic crystals in open spaces in veins and also as thin films in fractures in sphalerite.

SULFIDES

Argentite.—An occurrence of argentite replacing galena has been reported by John A. Legge in his unpublished thesis, Paragenesis of the ore minerals of the Miami mine, Arizona (M.A. thesis 1939, Arizona Univ., 48 p.).

Chalcocite.—Chalcocite is the principal ore mineral of the disseminated copper ore bodies and in the enriched zones of the copper veins. All of it is secondary and formed by supergene replacement of primary sulfides. Chalcocite selectively replaces chalcopyrite, and not until nearly all the chalcopyrite has been used up does the replacement of pyrite begin. Much of the pyrite has been replaced in the Miami-Inspiration ore body and in the enriched zones of the Old Dominion vein, but in the Castle Dome and Copper Cities deposits only occasional grains of pyrite show slight peripheral replacement by chalcocite. Wherever galena, sphalerite, or bornite were within the reach of copper-bearing supergene solutions, most were largely replaced by chalcocite. No evidence has been found that suggests hypogene origin of any of the chalcocite.

Bornite.—Ransome (1903) does not mention bornite as one of the sulfide ores of the Old Dominion mine, which had been opened to the 12th level at the time of his examinations. Only oxidized ore had been mined to that time and the 11th and 12th levels were in the upper part of the secondary sulfide zone, where most of the sulfides had been replaced by chalcocite. Schwartz (1921, p. 325) states that bornite is abundant on the lower levels of the Old Dominion and other mines along the Old Dominion vein system. It commonly replaces chalcopyrite along grain boundaries with quartz or specular hematite. The replacement, according to Schwartz, appears to have been hypogene. In his unpublished thesis, Geology of the Old Dominion mine, Globe, Ariz. (M.A. thesis, 1923, Arizona Univ., 91 p.), Carl Lausen states that bornite is especially abundant in the rich ore bodies that replace Mescal limestone. Bornite as blades replacing chalcopyrite is reported by John A. Legge in his unpublished thesis, Paragenesis of the ore minerals of the Miami mine, Arizona (M.A. thesis, 1939, Arizona Univ., 48 p.). Although he ranks it next in abundance to chalcopyrite, it is nevertheless a relatively rare mineral. A little bornite replacing chalcopyrite and perhaps sphalerite was seen in polished sections of sulfide minerals from the Ramboz vein and from the dump of a shaft on the Mineral Farms group. Bornite was not recognized in the Castle Dome deposit or in the sulfide concentrate from churn-drill sludges of the Copper Cities deposit.

Galena.—Occasional small masses of galena and sphalerite occur in all the copper deposits of the district. In the Castle Dome deposit, veins containing galena and sphalerite cut across and are clearly younger than the veinlets containing pyrite, chalcopyrite, and molybdenite. These veins, some 4 inches wide, are crudely banded with quartz and pyrite next to the walls, intermediate bands of sphalerite and chalcopyrite and coarsely crystalline galena in the middle part of the veins. (Peterson, Gilbert, and Quick, 1951, p. 92).

Galena and sphalerite are the chief primary sulfides in all the lead and zinc deposits of the district. Few of these deposits have been explored below the oxidized zone, but small residual masses of galena surrounded by shells of anglesite and cerussite are common in the oxidized vein matter. In the few places where the unoxidized parts of the veins can be observed, the galena appears to be essentially contemporaneous with the sphalerite or is the younger mineral.

Sphalerite.—Sphalerite is everywhere associated with galena, but the relative proportions of the two minerals differ greatly from place to place. Generally the amount of sphalerite greatly exceeds that of galena, and in some places the sphalerite contains only traces of galena, as on the bottom level of the Irene mine. Most of the sphalerite includes small grains of chalcopyrite but rarely shows exsolution blebs. With few exceptions the sphalerite throughout the Globe-Miami district is very light in color; some in the Money Metals lode is almost white.

Chalcopyrite.—Chalcopyrite is the most abundant hypogene copper mineral in all the deposits of the Globe-Miami district; and, except in the Old Dominion vein, accounts for all but a very minute amount of the copper contained in the deposits. Yet it is not a conspicuous mineral and is always subordinate to pyrite. In the protore of the large "porphyry type" deposits, chalcopyrite occurs in thin quartz veinlets associated with pyrite and commonly with a little molybdenite; and it accurs also as minute disseminated grains between the rock minerals.

In the vein-copper deposits, chalcopyrite occurs with pyrite in quartz gangue. The veins are commonly a stockwork of narrow veinlets of quartz, pyrite, chalcopyrite, and specular hematite. It is present also as fine, inconspicuous grains in masses of coarse, granular pyrite.

Polished surfaces of the ore show plates of specular hematite projecting into grains of chalcopyrite, as if the chalcopyrite had been deposited in cavities lined with projecting crystals of specular hematite. In contact with molybdenite, the relationships are identical with those between chalcopyrite and specular hematite. The contacts are sharp and straight and show no evidence of replacement by chalcopyrite. The contacts between pyrite and chalcopyrite are generally smooth and regular, and show no clearcut evidence of replacement or difference in age. At least some of the chalcopyrite is younger than some of the pyrite, however, for occasional grains of pyrite are seen in which chalcopyrite fills fractures or a network of fractures as in "exploded-bomb" structures. The filled fractures have matching walls, and evidence of replacement is entirely lacking.

Pyrite.—Pyrite is the most abundant sulfide mineral in the protore of all the disseminated copper deposits, and pyritic rock containing very little or only traces of chalcopyrite, extends far beyond the limits of rock that can be considered protore. Pyrite occurs with quartz in veinlets that are generally less than inch wide. Many veinlets contain only quartz and pyrite; in others, the pyrite is intergrown with chalcopyrite; and some veinlets contain small amounts of molybdenite. Pyrite is abundant in the chalcocite zones of the Castle Dome and Copper Cities deposits, where it has not been appreciably replaced by chalcocite, but in the Miami-Inspiration ore body most of it has been replaced.

Pyrite is also the most abundant hypogene sulfide of the vein copper deposits, in which it occurs in the vein matter as coarse, granular masses or in many thin stringers with quartz and small amounts of chalcopyrite. Pyrite is a very subordinate mineral or is entirely lacking in all the other types of vein deposits.

Wherever age relations can be determined, pyrite is older than chalcopyrite but does not appear to have been appreciably replaced by chalcopyrite. Plates of molybdenite and specular hematite do not penetrate the pyrite grains, as they do chalcopyrite; both form foliated masses of thin plates along the margins of the pyrite grains or fill spaces between the grains. The boundaries are sharp and smooth, and the plates of molybdenite or specular hematite are commonly bent to conform with the outlines of the pyrite grains.

Euhedral pyrite is not common in the district but small oxidized veinlets in outlying areas of slightly mineralized schist contain many cubic limonite pseudomorphs after pyrite.

Molybdenite.—A little molybdenite is present in all the disseminated-copper deposits, but none has been reported from any of the copper veins. Miami Copper Co. has been recovering molybdenite as a byproduct since 1945 at an annual rate of about 600,000 pounds of molybdenum.

The most common occurrence of molybdenite is as thin selvages along the borders of quartz veinlets, but a little occurs in the quartz and also as minute flakes or rosettes between the rock minerals. Molybdenite is the chief sulfide of the deposits on the Bronx property (p. 133), and small scattered knots of molybdenite occur in veins of glassy quartz near the head of Powers Gulch near the northwest corner of the Pinal Ranch quadrangle.

Covellite.—Covellite is a widespread but minor mineral in the disseminated-copper deposits and in the enriched sulfide zones of the copper veins. A little covellite undoubtedly formed by direct replacement of chalcopyrite and it also commonly formed by direct replacement of sphalerite. Most of the covellite, however, is an alteration product of chalcocite, probably formed as a result of reaction with descending, acid ferric sulfate solutions. The greatest concentration of covellite is at the top of the secondary-sulfide zone or adjacent to faults and fractures that have permitted deep penetration of oxidizing solutions. Covellite forms as the first step in the oxidation and leaching of chalocite, and being more resistant to weathering, lags behind in the progressive downward migration of the chalcocite zone by solution and redeposition. Alteration of the chalcocite proceeds inward from the rims of the chalcocite grains or from fractures.

SULFOSALTS

John A. Legge in his unpublished thesis, Paragenesis of the ore minerals of the Miami mine, Arizona (M.A. thesis 1939, Arizona Univ., 48 p) reported very rare occurrences of tennantite, enargite, and aikinite in veinlets cutting chalcopyrite. Carl Lausen in his unpublished thesis, Geology of the Old Dominion mine, Globe, Ariz. (M.A. thesis, 1923, Arizona Univ., 91 p), reported finding crystals of tetrahedrite in cavities in a specimen of ore from the 17th level of the Old Dominion mine and also in a specimen from the Josh Billings vein on the 19th level.

OXIDES

Cuprite.—A little cuprite is present in the oxidized zones of all the copper deposits. It is commonly associated with native copper and generally with copper carbonates; it apparently formed by oxidation of chalcocite or covellite.

Cuprite was an important ore mineral in the Old Dominion vein and in other, smaller veins in the Globe Hills area. In some places it occurred as very fine-grained aggregates with specular hematite, earthy hematite or limonite, and copper carbonates in massive bodies rich enough in copper to be mined. Examination of the aggregates shows no evidence that the cuprite and copper carbonates formed from sulfides originally deposited with the specular hematite; yet so far as can be determined, this type of ore was found only in the oxidized zones of the veins. The cuprite may have formed by reaction of acid copper-bearing supergene solutions with specular hematite.

Quartz.—Quartz is one of the most common and abundant minerals in the Globe-Miami district. It is a primary constituent of at least some facies of all the igneous rocks. It makes up 50 percent or more of the Pinal schist and it is an important constituent of all the clastic sedimentary rocks.

Quartz also is the most abundant hypogene mineral in the metalliferous deposits except in the few in which manganese-bearing carbonates probably predominate. In the disseminated-copper deposits, nearly all the pyrite and at least 50 percent of the chalcopyrite occur in quartz veinlets. There are several large veins and replacement bodies of barren quartz in the Pinal schist, and some types of schist contain abundant short veins of barren quartz ranging from ½ to 3 inches in width. One variety of highly contorted schist contains many lenticular stringers of quartz deposited along the crests and troughs of minor folds.

Thin, drusy crusts of supergene quartz are common in leached capping and oxidized mineral deposits but represent a very small proportion of the total volume of quartz.

Chalcedony.—Chalcedony occurs chiefly in various forms of chert, such as the nodules that are so abundant in some of the limestones of Paleozoic age, especially in the Escabrosa limestone and in the cherty beds of the Mescal limestone, which are aphanitic aggregates of chalcedony and calcite. Veinlets and masses of chalcedony and opal are very common in the tuffs and in the lower part of the dacite and appear to have been deposited by silicic colloidal suspensions, possibly while the rocks were still hot.

Chalcedony is a common associate of chrysocolla especially in the supergene deposits that replace dacite and tuff. It is present in minor amounts in the oxidized parts of all the mineral deposits of the district.

Tenorite.—Tenorite, the black oxide of copper, is not a common mineral, and much of the material called tenorite in the district is a black variety of chrysocolla or a soft, earthy, indeterminate mixture commonly designated as copper pitch ore. A few specimens that could definitely be identified as tenorite were found in the ores of the Carlota and Van Dyke deposits, both formed by circulating ground water.

Massicot.—Massicot was seen only in the Albert Lea mine, where it occurs as a bright-yellow powdery deposit in cerussite.

Hematite.—Specular hematite is present to some extent in nearly all the vein deposits of the district, but it is conspicuously rare or absent in the disseminated-copper deposits. Massive bodies of fine-grained specular hematite are common along the veins of the Old Dominion fault system, where they formed by replacement of limestone or diabase. Some of the ore bodies that replaced limestones of Paleozoic age in the upper parts of the Old Dominion vein are fine-grained aggregates of specular hematite, earthy hematite and limonite, and cuprite. The massive oxides contain small bunches and veinlets of copper carbonates, and many of them were rich enough in copper to be regarded as high-grade ore, even in the early days of the district.

The Buckeye-Black Oxide, Big Johnnie, Stonewall, and many other smaller veins contain abundant specular hematite, some intergrown with cuprite that was mined for copper. The exposed parts of the veins are in highly shattered quartzite that forms a loose open breccia. Specular hematite occurs as incrustations on the breccia fragments, and the quartzite is bleached and partly altered to sericite for $\frac{1}{16}$ to ¼ inch adjacent to the hematite crusts. Tovote (1914, p. 488) states that veinlets of solid micaceous hematite cut through solid diabase away from the prominent veins in the Old Dominion mine; and where dikes or sills of diabase have penetrated limestone, huge masses of micaceous hematite are commonly present.

The relationships of specular hematite with the sulfides have been described in another part of this report (pp. 70–71). They are similar to those of other platy minerals, such as sericite or molybdenite, in contact with sulfides and suggest that specular hematite is younger than pyrite but older than chalcopyrite. However, the hematite shows no evidence whatever of the reducing action that would be expected to result from contact with sulfur-bearing solutions.

Specular hematite is the most widely distributed of all the vein minerals. It is present to some extent in all parts of the veins, and is commonly found in otherwise barren stretches of the vein faults. It has been deposited far beyond the limits of the area of quartz and sulfide mineralization, and many outlying fractures and breccia zones contain only specular hematite.

Some hematite is undoubtedly present in most of the mixtures of iron oxides that have been generally designated as limonite.

Ilmenite.—Ilmenite is a common accessory mineral of the diabase, Lost Gulch quartz monzonite, and Schultze granite. Most of the Pinal schist contains some finely disseminated ilmenite. Some varieties of schist are characterized by thin alternating light and dark bands; the dark bands are composed chiefly of fine grains of ilmenite, magnetite, and quartz. The black sand concentrate that accumulates in the stream bend throughout the district generally contains much more ilmenite than magnetite.

Rutile.—Rutile is an accessory mineral of the Pinal schist, Solitude granite, Ruin granite, and Madera diorite. Many of the biotite books in the Lost Gulch quartz monzonite contain oriented needles of rutile. In the hydrothermally altered rocks of the disseminated-copper deposits, all the original titanian minerals are altered to fine-grained aggregates of rutile or leucoxene that commonly preserve the outlines of the altered mineral. Rutile appears to be stable even in the most severely altered rocks.

Manganese oxides.—Powdery pyrolusite, crystalline manganite, and hard psilomelanelike oxides comprise the bulk of the vein matter in the oxidized zones of the manganese-zinc-lead-silver deposits. They are generally associated with limonite, calcite, and clay in pockets between ribs of stony quartz. The manganese oxides apparently formed by weathering and oxidation of rhodochrosite and manganian ankerite contained in the hypogene vein-filling. Small amounts of pulverulent and botryoidal pyrolusite and "psilomelane" minerals occur in the leached and oxidized zones of all the other types of vein deposits.

Limonite.—Mixtures of hydrated iron oxides, generally referred to as limonite, are widespread and were formed by oxidation of practically all the iron-bearing minerals. Limonite is most abundant in the leached capping of the disseminated-copper deposits and in the gossans of the copper veins, where it formed by oxidation of pyrite and chalcopyrite and, to some extent, by alteration of specular hematite.

In the leached capping of the most pyritic parts of the Castle Dome and Copper Cities deposits, the iron liberated by the decomposition of the sulfides has been transported to some extent in solution and redeposited as botryoidal and sintery crusts of limonite in open fractures and in veinlets from which the sulfides have been leached. Indigenous limonite after pyrite, chalcopyrite, and chalcocite is common in the leached capping but is not abundant, owing to the high proportion of pyrite in the protore.

Magnetite.—Magnetite is an accessory mineral in all the igneous rocks of the district, and it is especially abundant in some facies of the diabase. It is not a common hydrothermal mineral; and in most of the mineral deposits, the only magnetite present is a primary constituent of the host rocks.

A little magnetite occurs in the pyrometasomatic deposits in the Martin limestone on Jewel Hill in the Castle Dome area; and in a small area near the northeast corner of the Pinal Ranch quadrangle, the Pinal schist has been metasomatically replaced by magnetite that is intimately intergrown with sillimanite and quartz.

HALIDES

Cerargyrite.—Thin, waxlike coatings of grayish-olive cerargyrite were recognized in the oxidized vein matter of the Ramboz deposit, which has produced some high-grade silver ore. Cerargyrite probably is the chief silver mineral in the small, shallow deposits that were worked for silver during the early days of the district.

Fluorite.—A few crusts and small clusters of fluorite crystals are associated with barite and comb quartz in the southern part of the Castle Dome mine in fractures related to the Dome fault system (Peterson, Gilbert, and Quick, 1951, p. 93). Minute crystals and small masses of fluorite are disseminated in greisen associated with quartz-molybdenite veins on the Bronx property, in the northwestern part of the Pinal Ranch quadrangle. West of Barnes Peak, in the northwestern part of the Inspiration quadrangle, masses of white fluorite occur in minor shear zones in the Ruin granite. The crushed granite is stained by light-brown limonite but no other introduced minerals could be recognized.

CARBONATES

Calcite.—Calcite is a fairly common but not abundant mineral in the oxidized parts of nearly all types of vein deposits in the district. It occurs most commonly as thin, platelike rhombohedrons attached to the walls of open fractures. Calcite is a constant associate of wulfenite and vanadium minerals. Crystals of calcite are attached to crusts of vanadium minerals or are intergrown with crystals of vanadinite. Calcite is most abundant in the near-surface manganese ores where it forms coarsely crystalline masses embedded in soft, earthy mixtures of manganese oxides, limonite, and clay.

Some faults that traverse the Schultze granite contain veins of coarsely crystalline calcite that range from a few inches to 10 feet in width. Some of these faults are loci of springs, and the calcite veins may have been deposited by ground water. Faults that cut the Gila conglomerate commonly contain veins or deposits of calcite.

Calcite formed as a product of very feeble hydrothermal alteration in the outermost parts of the mineralized quartz monzonite in the Castle Dome (Peterson, Gilbert, and Quick, 1951, p. 72–73) and Copper Cities areas. It occurs as microscopic grains and, with chlorite, epidote, clinozoisite, and sericite, replaces biotite and plagioclase. Calcite is also common in the epidotized Madera diorite and diorite porphyry in the Old Dominion area.

Dolomite.—Dolomite is the chief carbonate in some beds of the Martin and Escabrosa limestones. Much of the Mescal limestone also is magnesian but it is uncertain whether the rock is a very fine grained aggregate of calcite and dolomite, or of calcite and magnesite.

Dolomite has not been recognized as a hydrothermal-alteration mineral or hypogene vein mineral in any of the deposits.

Rhodochrosite and ankerite.—Rhodochrosite and manganian ankerite are the principal hypogene gangue minerals associated with sphalerite and galena in the Ramboz deposit. Similar vein matter was found on the dump of a 215-foot shaft on the Mineral Farms claims. These carbonates probably will be found below the oxide ores in all the manganese deposits of the district. The manganese oxides in all these deposits contain a little zinc, lead, and copper, and some have been mined for their silver content.

Cerussite.—Practically all the lead ore produced in the district has been mined from the oxidized zones of veins, and cerussite was the predominant lead mineral of the ore. Most of the cerussite formed by oxidation of galena, and the lead remained essentially in place. Many nodules of cerussite have residual cores of galena that are commonly surrounded by thin shells of anglesite. A little cerussite was deposited from solution, for small well-formed crystals of cerussite line vugs or are attached to rock fragments or to the walls of open fractures. Most of the cerussite, however, occurs as granular masses or compact nodules ranging from the size of peas to 5 inches in diameter. Small amounts of oxidized zinc minerals are generally associated with the cerussite.

Malachite.—Malachite is the most abundant copper mineral in the oxidized zones of all the copper deposits. It accounts for most of the small amount of copper that remains in the leached capping of the disseminated deposits. Malachite was formed chiefly by oxidation of chalcocite and covellite, but it also formed to some extent by alteration of all the common copper minerals, even native copper.

In the weathering of the copper protore, enough pyrite is generally present to produce acid ferric sulfate that attacks chalcopyrite, and copper is liberated and carried away in acid solution. Under normal conditions, most of the copper is redeposited as chalcocite, by reaction with chalcopyrite and pyrite; but some of the copper-bearing solution collects in fractures, where the copper is precipitated, probably as a hydrate. It is then converted to malachite or silicate by reaction with carbonated surface waters or colloidal silica formed by action of acid waters on the rock minerals. Large veins of copper carbonates and silicates such as the Live Oak and Keystone veins and supergene deposits, such as the Van Dyke, Warrior, and Carlota, were formed in this manner.

When supergene enrichment has progressed to such a stage that nearly all the chalcopyrite and pyrite has been replaced by chalcocite and covellite, further oxidation produces insufficient acid to carry away all the liberated copper. The chalcocite and covellite are then altered practically in place to carbonates and silicates. Where the rate of oxidation has been accelerated by uplift and more rapid erosion of the leached capping, as in the uplifted block west of the Bulldog fault and at some other places along the top of the Miami-Inspiration ore body, the enriched chalcocite ore was converted to carbonate-silicate ore, with little if any decrease in the copper content.

Most of the malachite occurs as thin films or stains, massive incrustations, or fibrous aggregates. In the supergene deposits, it forms botryoidal or mammillary masses coating breccia fragments or filling the interstices between fragments. Concentric banded structures with chrysocolla and azurite are common. Well-crystallized malachite is very rare.

Azurite.—Azurite is generally associated with malachite but is far less abundant. It commonly occurs in crystalline masses, and well-formed crystals are occasionally seen. Some of the azurite appears to have formed by alteration of malachite.

SULFATES

Barite.—Barite is locally abundant in the southern part of the Castle Dome mine, where it forms incrustations and clusters of simple pinacoidal crystals on the walls of fractures related to the Dome fault system. Many of the crystals are coated with fine-grained drusy quartz; and in some places the barite is coated with jarosite. Also in the Castle Dome mine, minute crystals of barite are disseminated in dense masses of halloysite clay. In other mineral deposits of the district, barite is extremely rare or absent.

Massive quartz containing a little disseminated pyrite and intergrown with many thin plates of barite forms veins as much as 18 inches wide along some of the faults related to the Gold Gulch system northwest of the Castle Dome mine.

Anglesite.—Anglesite occurs only as thin shells surrounding residual cores of galena in nodules of cerussite. Some of the galena cores are cut by minute veinlets of gray substance that probably is anglesite, for, it is not lead carbonate. Lead sulfate may always be an intermediate product in the alteration of galena to cerussite, although some nodules show no intermediate layer of anglesite and look as if the galena had altered directly to cerussite. However, it is not difficult to imagine normal conditions, particularly above the water table, under which the sulfate would be altered to carbonate as quickly as it formed.

Gypsum.—Selenite is abundant in fractures in diabase and granite porphyry along the Coronado fault zone on 4,050-foot and 4,005-foot levels of the Copper Cities mine. In the diabase, it forms masses of large crystals 1 to 2 inches thick. Occasional crystals or small masses of crystals occur in the oxidized zones of many pyritic vein deposits, particularly those in diabase.

Goslarite.—Ransome (1903, p. 1-60) noted the presence of goslarite as a fluffy efflorescence of acicular crystals coating some of the drifts in the Continental mine; he thought this occurrence to be peculiar, because he found no zinc-bearing minerals in the ore. Efflorescent coatings of goslarite are common on the weathered dumps of mine workings that explore zinc-bearing deposits and on sphalerite outcrops that have been exposed to weathering agents; for example, the mass of quartz and sphalerite that is exposed on the 4,590-foot bench of the Castle Dome mine.

Chalcanthite.—Abundant chalcanthite is being deposited in the open-pit mines where ground water supplied by current rains seeps to the surface and evaporates. The walls of old adits driven to explore the Miami-Inspiration and Castle Dome deposits are covered by efflorescent crusts of chalcanthite and water-soluble iron sulfates. Most of the underground workings of the copper deposits that are within the vadose zone show some chalcanthite deposited since mining began.

Alunite.—In his unpublished thesis, Geology of the Old Dominion mine, Globe, Ariz. (M.A. thesis, 1923, Arizona Univ., 91 p.), Carl Lausen states that alunite occurs in the Old Dominion mine in veins as much as 6 inches wide in altered diabase but gives no further details.

Jarosite.—Jarosite is abundant in the leached capping and oxidized zones of the Castle Dome and Copper Cities deposits, particularly in those parts that contained a high proportion of pyrite. It occurs as brownish-yellow pulverulent masses in open spaces in limonite-crusted fractures from which pyrite has been leached. Most of the jarosite appears to have been deposited from solution at some distance from the oxidizing pyrite that supplied the iron sulfate. It is commonly deposited in the sericitic borders of pyritic veinlets that crop out; later it is altered to limonite, after most of the pyrite has been destroyed.

PHOSPHATES AND VANADATES

Descloizite.—Descloizite occurs as thin incrustations on breccia fragments and walls of open fractures in the Defiance, Albert Lea, Irene, and other smaller deposits. It is commonly attached to crystals of vanadinite, some of which show evidence of corrosion, suggesting that vanadinite may not be stable under conditions favoring deposition of descloizite.

Mottramite.—Mottramite is far less common than descloizite but is found in the same deposits. The mode of occurrence of the two minerals is the same.

Libethenite.—Libethenite has been found only along the Dome fault zone and related fractures in the Castle Dome mine (Peterson, Gilbert, and Quick, 1951, p. 94–95). Tufts of small, emerald-green prisms or drusy mats of acicular crystals are attached to walls of open fractures. In some places, crystals as much as 1.5 mm long lie flat on rock surfaces. Libethenite is probably of supergene origin, but it is generally older than most of the common supergene minerals associated with it. The libethenite of the Castle Dome has inclined extinction like dihydrite (Peterson, Gilbert, and Quick, 1951, p. 95) but its indices of refraction correspond with those of libethenite. Jewell J. Glass, of the U.S. Geological Survey, who determined the optical properties, suggested that the mineral should probably be designated as clinolibethenite.

Apatite.—Apatite is a common accessory mineral in all the igneous rocks of the district. The only other occurrence of apatite is in the Scanlan conglomerate and the arkose at the base of the Pioneer formation where these rocks have been metamorphosed as a result of intrusion of Lost Gulch quartz monzonite in the Castle Dome area (Peterson, Gilbert, and Quick, 1951, p. 28). This apatite, which occurs in clusters of crystals and in tiny veinlets that cut quartz and orthoclase, apparently was formed by hydrothermal action.

Vanadinite.—Vanadinite is the most abundant of the vanadium minerals in the Defiance and Albert Lea deposits, and it is sparse in the Irene vein and in many other smaller deposits of the same general type. Its usual habitat is in the more open parts of the veins and in fractures in the wall rock adjacent to the veins. Vanadinite formed after the period of quartz-sulfide mineralization, but it appears to have been deposited by solutions that were distinctly different from those that caused the typical supergene alteration of the deposits; wherever relationships can be observed, the common supergene minerals are clearly younger than any of the vanadium minerals.

Vanadinite occurs as bright-yellow crusts of almost hairlike crystals that are commonly arranged in rounded tufts of radiating crystals and as coarse-grained crusts and clusters of stubby red prisms as much as 5 mm long. Fine-grained descloizite is commonly deposited between the prisms and, in places, partly covers the vanadinite prisms. Descloizite is invariably the younger mineral. The only other minerals that are intimately associated with the vanadium minerals are calcite, generally as thin platelike rhombohedrons, and powdery pyrolusite.

Turquoise.—Small quantities of turquoise are present in many places in the leached capping and chalcocite zones of the Castle Dome and Copper Cities deposits. Some of the mineral is hard enough to be of gem quality, but most of it is soft and chalky. The hard turquoise is light blue or light blue green; when dry the color of the soft variety ranges from very pale blue or very pale green to almost white, but assumes deeper shades of blue or green when moist. The optical properties of the hard and soft blue varieties are identical, the intensity of the color depends entirely on the degree of comminution. The mineral in the Castle Dome deposit is almost exclusively the blue variety, which is normal turquoise, whereas that in the Copper Cities deposit is mostly greenish and is an iron-bearing variety with higher but variable indices of refraction.

The turquoise occurs in small discontinuous veinlets as much as a quarter of an inch thick and also as concretionlike masses as much as a half an inch thick and several inches across. It is clear that the mineral did not form by alteration or replacement of the wall rock but appears to be a fracture-filling of material transported in solution or in suspension in groundwater. Turquoise is associated with sericite and clay minerals and commonly contains small inclusions of clay and sericite.

It is noteworthy that in the disseminated-copper deposits of the Globe-Miami district turquoise and copper silicates appear to be mutually exclusive. Chrysocolla has not yet been identified in either the Castle Dome or Copper Cities deposits, whereas in the Miami-Inspiration deposit, chrysocolla is very common but no turquoise has been found. Although analyses show that the Lost Gulch quartz monzonite contains a little more than 0.2 percent P_2O_5 and the Pinal schist and Schultze granite generally less than 0.1 percent, this difference in composition of the host rocks would not seem to be a satisfactory explanation for the presence or absence of turquoise in the copper deposits.

Wavellite.—Wavellite has found only in the Castle Dome deposit (Peterson, Gilbert, and Quick, 1951, p. 93–96), where it occurs as incrustations on the walls of fractures within the chalcocite zone. It is older than metatorbernite with which it is commonly associated. Its relationships suggest that it may be a late hydrothermal mineral.

Metatorbernite.—Small amounts of metatorbernite were found on a few benches of the Castle Dome mine in a relatively small area in the central part of the copper deposit. It was closely associated with wavellite and generally occurred as clumps of very thin, platy crystals attached to crusts of wavellite that lined the walls of open fractures in the secondary-sulfide zone. Metatorbernite appears to have been unstable in the oxidized zone and was not recognized in the leached capping over the ore body. Apparently it is attacked by acid ferric sulfate solutions and alters superficially to a brown fibrous mineral which dissolves, leaving a very small residue of a yellowish material resembling kaolinite.

A few flakes of metatorbernite were seen in some of the churn-drill sludges during exploration of the Copper Cities deposit, and a few specimens have been found in the broken rock along the Coronado fault zone since mining operations began. In this deposit, the metatorbernite crystals are attached directly to fracture surfaces in the quartz monzonite, and as yet, have not been found associated with wavellite.

On the King group of mining claims, about a mile south of the northeast corner of the Pinal Ranch quandrangle, metatorbernite occurs in a narrow quartz vein between walls of Solitude granite. Clusters of minute crystals are attached to the walls of vugs and tiny fractures throughout the quartz vein filling. The walls of some of the larger fractures are completely coated by a mat of fine crystals, and commonly the intervening space has been filled with thinly banded, cross-fibered malachite. The vein contains much limonite and small masses and veinlets of malachite that apparently formed by oxidation of sulfides originally deposited with the quartz.

MOLYBDATES AND TUNGSTATES

Wolframite.—A few widely scattered grains of wolframite and small masses of hematite and black tourmaline occur in several narrow quartz veins near the head of Powers Gulch, about 1 mile north of Pinal Ranch in the Pinal Ranch quadrangle. One vein of massive white glassy quartz, 1 to 10 feet wide, contains occasional small masses of wolframite and tourmaline and also small isolated masses of molybdenite.

Wulfenite.—Small amounts of wulfenite are associated with lead and vanadium minerals on the Crown Point No. 6 claim, also in veinlets cut by the Doughboy shaft, and in several other small veins in the area northwest of Globe, and also in the Lost Gulch area south of Sleeping Beauty Peak. A little wulfenite is in the Dome fault zone in the Castle Dome mine (Peterson, Gilbert, and Quick, 1951, p. 95–98).

An unusual variety of wulfenite is present in several short weakly mineralized fracture zones on the east flank of Day Peaks in the Lost Gulch area about 3 miles northwest of Miami. During the early days of the district the fractures were explored for the gold and silver of the oxidized outcrops. An analysis of hand-picked material made by F. G. Hawley, of the U.S. Bureau of Mines, Tucson, Ariz., is as follows:

	Percent
PbO	56.27
WO_3	25.40
MoO_3	8.62
As_2O_5	4.56
P_2O_5	2.14
CaO	.80
Fe_2O_3	.28
Total	98.07

In the view of its high tungsten content, the mineral should properly be termed molybdian stolzite rather than wulfenite.

Lindgrenite.—Lindgrenite, the rare copper molybdate, was found in a shallow road cut near the outcrop of the Sulphide fault zone on the 3,700-foot level in the Live Oak pit of the Inspiration mine. It occurs as platy aggregates on the walls of small fractures in shattered, hydrothermally altered schist. The hypogene sulfides have been oxidized and leached, and the schist is slightly stained by malachite and copper silicate.

The physical and optical properties of the mineral were determined by Richard Erd, of the Geological Survey, as follows:

It occurs as thin lamellar crystals, which are light apple green but appear dark green when viewed on edge or in thick masses. Cleavage is perfect parallel to the clinopinacoid; very fine striae are present on the clinopinacoid; crystals are generally fresh and free of inclusions, some have slight peripheral alteration.

Optically, the mineral is biaxial negative, 2V estimated about 50 degrees; it is nonpleochroic. Dispersion is slight $r>v$; $X \wedge c=9$ degrees. Indices of refraction measured in white light with the Meyerowitz-Larsen high-index immersion media are: $\alpha=1.920$, $\beta=1.986$, $\gamma'=1.995$.

Compared with lindgrenite from Chuquicamata, Chile, the Inspiration mineral has lower indices of refraction, lower birefringence, and is much lighter green. The microchemical tests indicated that there was more nickel and iron in the lindgrenite from Chile. X-ray patterns of the Inspiration and Chilean lindgrenite are identical.

Ferrimolybdite.—The bright-yellow, pulverulent mineral ferrimolybdite was identified in a few places within a foot or two of the surface in the leached capping of the Castle Dome deposit. A little of the mineral was also identified in rock on the dump of the Louis d'Or shaft in the Copper Cities deposit, in the Bronx deposit, and in a large quartz vein near the head of Powers Gulch. In each of these locations, the ferrimolybdite obviously formed by oxidation of molybdenite in place.

SILICATES

Feldspars.—Orthoclase, microcline, sanidine, and plagioclase ranging in composition from albite to labradorite are abundant constituents of the various igneous rocks of the district. Orthoclase is a constituent of the Pinal schist and occurs in varable amounts in all the clastic sedimentary rocks.

Secondary orthoclase occurs in the hydrothermally altered host rocks of the disseminated-copper deposits but is not abundant. It occurs in the Castle Dome deposit as minute crystals in some of the quartz veinlets containing chalcopyrite and molybdenite and in the sericitic altered borders zones of some quartz-pyrite veinlets. The metamorphosed Scanlan conglomerate and arkose intruded by quartz monzonite in the Castle Dome area (Peterson, Gilbert, and Quick, 1951, p. 27–29) contains veinlets of secondary orthoclase, and much of the original orthoclase of the arkose has been recrystallized.

Pyroxene.—Augite is an abundant constituent of the diabase, in which it forms large poikilitic crystals with plagioclase. Augite is also present in the Tertiary and Quaternary basalt.

Amphibole.—Much of the diabase contains abundant hornblende, some of which may be a primary mineral but most appears to result from the alteration of augite. The diorite porphyry contains thin laths of hornblende. Hornblende is a very minor constituent of the dacite but is a little more common in the dacite tuffs and in the perlite.

Garnet.—The pyrometasomatic-type of mineralized rock in the Martin limestone on Jewel Hill just east of the Castle Dome mine is mainly garnet associated with magnetite and hematite. Irregular masses of greenish-yellow garnet replace Mescal limestone along a few minor fractures on the east side of Granite Basin. The only associated mineral is antigorite, which forms a thin sheath around the garnet masses.

Olivine.—Olivine is a primary constituent of some facies of the diabase and also of the upper Precambrian basalt and the Tertiary and Quaternary basalt.

Willemite.—Willemite is a common but inconspicuous mineral in the oxidized vein matter of the Defiance and Irene deposits. It occurs as granular aggregates of small hexagonal prisms that are rarely more than 0.04 inch long.

Zircon.—Zircon is a very minor accessory mineral of all the granitic intrusive rocks of the district. It is common in some specimens of the Pinal schist and absent in others. Zircon survives even the most intense hydrothermal alteration.

Sillimanite.—In a small area that borders the Solitude granite in the northeastern part of the Pinal Ranch quadrangle, the Pinal schist has been replaced by an intimate intergrowth of sillimanite, magnetite, and a little quartz. The replacement of the schist is regarded as being the result of a type of pyrometasomatic mineralization probably related to the intrusion of the Solitude granite.

Epidote and clinozoisite.—In the outermost zone of very feeble hydrothermal alteration, associated with the Castle Dome and the Copper Cities copper deposits, plagioclase of the quartz monzonite host rock is partly replaced by sericite accompanied by the minute stringers and scattered grains of epidote and clinozoisite. Biotite is partly replaced by chlorite, epidote, and clinozoisite. Epidote is more common in the biotite, whereas clinozoisite predominates in the altered plagioclase. Clinozoisite is also a common mineral in the altered schist along the north side of the Miami-Inspiration ore body, but here it cannot be clearly related to the copper mineralization.

The Madera diorite of the thrust plate at the southwest end of the Old Dominion mine contains abundant epidote that formed mainly by alteration of biotite and to a lesser extent of plagioclase. The quartz diorite porphyry of the dikes in the vicinity of the Old Dominion and Buffalo veins contain masses of epidote, as much as half an inch across, that formed by replacement of plagioclase phenocrysts, and smaller grains that replaced biotite or hornblende.

Hemimorphite.—Hemimorphite is the most common zinc mineral in the oxidized vein matter of the Irene, Albert Lea, and Defiance deposits, and in many other similar smaller deposits. It probably is the principal zinc mineral in all the managnese oxide deposits. When the zinc-lead deposits weathered, most of the zinc liberated by decomposition of sphalerite was carried away in solution and dissipated, but some of it was redeposited as hemimorphite and willemite widely dispersed through the oxidized vein matter. Hemimorphite occurs typically as drusy incrustations in open cavities and on the walls of open fractures; the incrustations are composed of radiating clusters of lathlike crystals as much as a millimeter thick or tufts of hairlike crystals.

Tourmaline.—Most of the Pinal schist contains occasional grains of bluish-gray tourmaline and in some localities tourmaline is abundant. A few quartz veinlets in the Pinal schist contain scattered small masses of black tourmaline, hematite, or wolframite, but the three minerals are not generally associated. A little tourmaline occurs with quartz in the gold-vanadium veins in the Lost Gulch area and also in a large quartz vein near the head of Powers Gulch.

Clusters of apatite crystals and radiating aggregates of pale-blue tourmaline occur in quartz and orthoclase pebbles in Scanlan conglomerate and in granite arkose that have been metamorphosed by intruded quartz monzonite in the Castle Dome area. Occasional prisms of tourmaline are seen in thin sections of argillized plagioclase phenocrysts in the Castle Dome copper deposit.

Stilbite.—Stilbite, the calcium-sodium zeolite, was identified in a few places in altered quartz monzonite that had been broken by blasting in the Castle Dome mine.

Muscovite.—Muscovite is an essential constituent of the Solitude granite and the granite on Manitou Hill, and it is accessory in the Madera diorite and Schultze granite. Muscovite, including the fine scaly variety sericite, forms 20 percent or more of the most common types of the Pinal schist.

Sericite is very abundant and was formed during hydrothermal alteration of the host rocks in all the disseminated-copper deposits, largely at the expense of plagioclase; but where alteration is most intense, all the rock minerals except original quartz are replaced by sericite. Although sericite is present throughout the deposits, even in the most feebly altered rock, it is most abundant wherever pyrite also is most abundant. Each quartz-pyrite veinlet is bordered by an altered zone in which all the essential minerals of the rock except original quartz are replaced by sericite and quartz. Less intense sericitization of plagioclase and, generally, of some of the biotite persists farther from the veinlets. The field relations indicate that sericite also replaces hydrothermal clay minerals, although some sericite appears to have formed at the same time as the hydrothermal clay minerals in the argillized rock between the veinlets. Some of the mineral designated as sericite actually is hydrous mica, but sericite appears to be by far the more abundant.

Sericitic alteration also accompanied the formation of the copper-bearing veins; but in the deposits that can be observed, the effects of alteration generally do not extend for more than a few inches into the wallrock.

The most prominent set of joints throughout the Schultze granite contains thin veinlets of cross-oriented muscovite associated with a little quartz and occasional grains of pyrite. The veinlets are regarded as being produced by deuteric alteration of the granite. Another occurrence of somewhat similar origin is in the coarse-grained greisen associated with the molybdenite-bearing areas of the Schultze granite on the Bronx property.

Biotite.—Biotite is the chief ferromagnesian mineral in all the granitic intrusive rocks of the district and also in the dacite and the associated tuffs. In most of these rocks it occurs as book phenocrysts; but in the Willow Spring granodiorite, the groundmass contains abundant fine-grained flake biotite. It is a minor constituent of the diabase, basalts, and diorite porphyry. Flake biotite is present in most types of Pinal schist, and it is almost as abundant as sericite in some types.

Biotite has not been identified as a secondary or hydrothermal alteration mineral; but in the Lost Gulch quartz monzonite in the Castle Dome area and also in the Copper Cities area, books of biotite in parts of the mineralized area have been reconstituted into irregular aggregates of small biotite flakes (Peterson, Gilbert, and Quick, 1951, p. 26–27). Although these aggregates are found only in rock that has been affected by hydrothermal alteration related to the copper mineralization, the areal distribution of both book and aggregate biotite bears no recognizable relationship to the character or intensity of the alteration, and both are similarly affected by hydrothermal alteration.

Chlorite.—Chlorite is a widespread secondary mineral formed both by weathering and by hydrothermal alteration. In the vicinity of mineral deposits, the mode of origin is often uncertain. Chlorite is abundant in some varieties of Pinal schist, and at least some of it appears to be an alteration product of biotite. It is relatively uncommon in the hydrothermally altered schist associated with the copper deposits, although biotite may be abundant in some of the schist that has been only moderately affected by hydrothermal alteration. The original character of the schist differs so greatly from place to place that it is difficult to determine which minerals were formed as a result of hydrothermal alteration related to the copper mineralization. In schist that appears to be most intensely altered both chlorite and biotite are generally absent.

Chlorite associated with calcite and epidote is an alteration product of biotite in the feebly altered quartz monzonite surrounding the Castle Dome and Copper Cities deposits and also in the diorite porphyry near vein-copper deposits. It is abundant in altered and partly replaced fragments of diabase in vein deposits and in diabase adjacent to the veins, where it formed from hornblende or biotite. Chlorite does not replace augite directly. In the slightly altered diabase, the formation of chlorite generally begins in minerals that are adjacent to grains of magnetite or ilmenite. As the alteration progresses, the diabase is replaced by an aggregate of chlorite and quartz. In the oxidized zones of the veins, chlorite alters to brown limonite.

Kaolin group.—Minerals of the kaolin group are not abundant in the Globe-Miami district and, except for those present in small amounts in the mineral deposits, little is known concerning their occurrence and distribution.

Although small amounts of kaolinite probably are widespread, the mineral has not been definitely identified in any of the rocks that have been studied.

A dense white to yellowish-gray clay with porcelain-like texture and conchoidal fracture was common in the leached capping and in the upper part of the chalcocite zone in the Castle Dome copper deposit. The mineral is isotropic or very weakly anisotropic, and its index of refraction is slightly higher than 1.55. These properties correspond to those of halloysite. A small proportion of the clay with slightly higher birefringence may indicate a small admixture of kaolinite.

This halloysitelike clay occurs in thin seams or as irregular masses that are commonly several inches thick. It seems to have been transported into the fractures or open spaces and shows no evidence that it formed in place by replacement of the rock minerals. Some of the masses include tiny crystals of barite, and in one place the clay contains finely divided particles of a zinc mineral that probably is hemimorphite.

A similar clay mineral that occurs in the same manner but has a lower index of refraction may be endellite; it is comparatively rare. These clays appear to have been deposited by supergene solutions, probably acid sulfate solutions as has been suggested by Ross and Kerr (1934, p. 143) for halloysite.

Montmorillonite.—Clay minerals of the isomorphous montmorillonite group are common in the Globe-Miami district. They are abundant in the host rocks of the Castle Dome and Copper Cities deposits, where they formed from plagioclase and biotite as a result of hydrothermal alteration (Peterson, Gilbert, and Quick, 1951, p. 73–76). They are common but not abundant in the granite porphyry host rock of the Miami-Inspiration deposit but are rarely seen in the mineralized schist. In some parts of the Copper Cities deposit that have been exposed by stripping operations, mainly near the Coronado and Sleeping Beauty fault zones, soft aggregates of this clay fill fractures and coat breccia fragments in the leached quartz monzonite and granite porphyry capping. The appearance and mode of occurrence of these aggregates suggest they were formed by action of supergene rather than hydrothermal solutions.

Montmorillonite-type clay occurs as fault gouge in the Schultze granite and its granite porphyry facies.

Along some faults and fractures, it replaces all the rock minerals except quartz and forms veinlike bodies, several feet thick, of pure clay with embedded quartz grains. In a few places the crystal tuff that generally underlies the dacite has been altered to montmorillonite-type clay, and most outcrops of the tuff contain some clay.

The appearance and physical character of the clay are similar throughout the district. The optical properties are fairly constant for each occurrence but differ somewhat for clays of different origin. The birefringence is rather strong, about 0.02; and the beta index ranges from about 1.52 to 1.55.

Serpentine.—The flaky variety of serpentine, antigorite, is a common alteration product of the Mescal limestone near its contacts with diabase. It occurs as yellowish-gray masses or bands that are a fine-grained aggregate of flakey crystals. At one place, coarser flakes form thin envelopes around masses of garnet, at another, around masses of magnetite that replace Mescal limestone along faults.

Narrow, cross-fibered veinlets or bands of chrysotile occur in the Mescal limestone in a few places. The chrysotile exposed in outcrops or in shallow pits is all of the brittle or harsh variety.

Iddingsite.—In all outcrops of the Tertiary and Quaternary basalt, the rounded phenocrysts of olivine have been wholly or partly replaced by lamellar aggregates of brown iddingsite.

Chrysocolla.—Hydrated copper silicate minerals generally referred to as chrysocolla, are common and often abundant in the oxidized zones of all the copper deposits of the district except the Castle Dome and Copper Cities deposits, in which they are conspicuously absent. Chrysocolla was the chief copper mineral in the Black Warrior, Black Copper and Geneva mines, where the ore bodies formed by replacement of dacite tuff, and also in the Live Oak and Keystone veins, which were in the leached-granite capping of the western part of the Miami-Inspiration ore body. These deposits were described by Ransome (1903, p. 123; 1919, p. 138–140). Chrysocolla is the principal ore mineral in all the other deposits of exotic copper in which ground water was the mineralizing agent. Those in which the host rock is schist, diabase, or granite also contain abundant copper carbonates, whereas those in dacite or tuff contain little or no copper carbonate, and the copper silicates are associated with chalcedony.

Thin sections of Schultze granite from the Blue Bird and Schultze properties show minute spheroidal aggregates of copper silicate that appear to have formed by replacement of plagioclase, but in other respects the rock minerals look to be entirely free of alteration of any kind. Hand specimens of the rock that have broken along minute joints or fractures show very slight surficial alteration, probably to a clay mineral that has adsorbed enough copper salts to give the rock a slight bluish tinge.

Undoubtedly the chrysocolla includes many species, which differ greatly in physical and optical properties. Colors range from pale to deep shades of blue, green, and blue green. Some species have vitreous luster and break with conchoidal fracture, but most are dull or even earthy. Structure is massive, banded, botryoidal, commonly with concentric banding, or it is finely jointed or crackled, as if formed from a colloidal gel. Thin sections show the texture may be microcrystalline, fibrous, or amorphous. Most specimens are anisotropic, with strong birefringence; some are weakly birefringent; and a few are isotropic. The indices of refraction range from about 1.55 to 1.60; the isotropic varieties tend to have the lower indices.

Canbyite (?).—Canbyite, the claylike hydrous ferric silicate, was abundant in the oxidized and leached zone of the Castle Dome deposit. It is chocolate brown and has a waxy luster. It coats the walls of fractures and has the appearance of a dried slimy mud. Under the microscope it is seen to consist of very thin, amber-yellow flakes. Its indices of refraction vary but are near α, 1.56; γ, 1.58. Its optical character is negative, and the angle (2V) is very small.

Sphene.—Sphene is a common accessory mineral of all the granitic rocks of the district and usually occurs associated with biotite. It is abundant locally in the Willow Spring granodiorite. In the hydrothermally altered rock, sphene is replaced by aggregates of minute prisms of rutile that retain the characteristic crystal outlines of the original grains.

MINERAL DEPOSITS

Based on the mode of origin, the mineral deposits of the district can be classified into two major groups: deposits formed by hydrothermal agencies related to igneous activity and deposits formed by circulating ground water. The hydrothermal deposits can be broadly classified according to mode of occurrence into two groups: disseminated or "porphyry-type" deposits and vein or lode deposits.

The hydrothermal vein deposits can be further subdivided on the basis of the predominant metals or minerals into several types. The seven principal types are copper veins, zinc-lead veins, zinc-lead-vanadium-molybdenum veins, manganese-zinc-lead-silver veins, gold-silver veins, molybdenite veins, and pyrometasomatic deposits. The mineralogical characteristics of the various types are to some extent gradational, and a few deposits are difficult to classify, particularly those for which good representative samples of the vein matter are not available, owing to inaccessibility of the mine workings.

With possibly a few minor exceptions, the mineral deposits of hydrothermal origin in the Globe-Miami district appear to be related to a single period of mineralization. Nearly all are clearly younger than the diabase and older than the Whitetail conglomerate and the dacite. Most of the major deposits are definitely younger than the Schultze granite and the associated granite porphyry intrusions, to which they are believed to be genetically related. A few minor deposits that are entirely within the lower Precambrian rocks, for example, the gold-silver veins in the Lost Gulch area, cannot be dated with certainty, but, there are similar deposits in diabase, and it is probable that all are of approximately the same age.

Some of the pyrometasomatic-type deposits may be related to the Lost Gulch quartz monzonite and Solitude granite intrusions and therefore may be older than the main period of mineralization.

METAL PRODUCTION OF THE GLOBE-MIAMI DISTRICT

The total value of metals produced from the mines of the Globe-Miami district recently exceeded the billion-dollar mark which qualifies the district as one of the first order. Copper accounts for more than 98 percent of the total value.

For the first 33 years of operation from 1878 to 1910, the records are incomplete, but an estimate compiled by J. B. Tenney (Elsing and Heineman, 1936) from all available sources shows total production for this period to be 27,718 ounces of gold, 5,664,431 ounces of silver, and 311,199,664 pounds of copper, with an estimated total value of $51,051,570, a total based on the average yearly prices of metals as published in "Mineral Resources of the United States". Most of the copper produced during these years came from the Old Dominion mine, for which the records of production are believed to be reasonably accurate. The production from other mines was relatively small, and lack of accurate records does not appreciably affect the total value for the district.

During the period from 1911, the year in which production from the large disseminated-copper deposits began, to the end of 1953, the metal production of the district, as published in "Mineral Resources of the United States" and "Minerals Yearbook", amounted to 158,630 ounces of gold, 10,671,978 ounces of silver, 6,120,996,830 pounds of copper, 4,511,860 pounds of lead, and 334,586 pounds of zinc with a total value of $1,031,968,666.

The amount of lead reported in the published records does not accurately represent production of that metal from mines in the Globe-Miami district. Of the total of 4,511,860 pounds reported, 3,698,875 pounds represents the production from the mines, and 812,985 pounds represents lead reclaimed from wornout linings of leaching tanks and the residue from lead anodes used in the electrolytic-precipitation process of Inspiration Consolidated Copper Co.

The yearly and total production of gold, silver, copper, lead, and zinc for the district are shown in table 4. In addition to these metals, molybdenum has been recovered by Miami Copper Co. since 1938. The total amount and the value of the molybdenum produced are not available; but during the past 7 years, the company's published annual reports record an average yearly production of about 523,000 pounds of molybdenum. Approximately 300 million tons of ore had been mined in the district to the end of 1953.

TABLE 4.—*Gold, silver, copper, lead, and zinc production in the Globe-Miami district, 1878–1953*

[Data for the years 1878 to 1910 were compiled by J. B. Tenney and are included in totals for the district published by the Arizona Bureau of Mines (Elsing and Heineman, 1936, p. 92. Data for the years 1911–23 are taken from the U.S. Geol. Survey's Mineral Resources of the United States and for the years 1924–53 from the U.S. Bur. Mines Minerals Yearbook]

Year	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)	Total value
1878	----------	260,870	----------	----------	----------	$300,000
1879	----------	446,430	----------	----------	----------	500,000
1880	----------	782,600	----------	----------	----------	900,000
1881	----------	619,470	----------	----------	----------	700,000
1882	----------	263,150	2,854,680	----------	----------	845,245
1883	----------	121,620	3,000,000	----------	----------	630,000
1884	----------	99,100	5,125,000	----------	----------	776,250
1885	----------	93,450	4,688,640	----------	----------	606,375
1886	----------	80,800	4,567,665	----------	----------	587,010
1887	----------	142,850	1,441,770	----------	----------	338,965
1888	----------	138,300	4,870,000	----------	----------	948,160
1889	----------	138,300	5,923,289	----------	----------	929,645
1890	----------	123,800	7,890,455	----------	----------	1,321,025
1891	----------	131,300	6,982,306	----------	----------	1,023,735
1892	----------	57,470	7,666,274	----------	----------	939,290
1893	----------	----------	7,665,293	----------	----------	827,850
1894	----------	----------	4,839,386	----------	----------	459,740
1895	----------	----------	----------	----------	----------	----------
1896	900	55,000	7,670,565	----------	----------	878,220
1897	500	25,000	3,241,975	----------	----------	444,370
1898	700	35,000	4,647,460	----------	----------	611,400
1899	1,400	52,000	10,751,180	----------	----------	1,894,450
1900	700	50,000	7,155,000	----------	----------	1,233,195
1901	1,400	90,000	11,351,200	----------	----------	1,979,010
1902	700	50,000	7,992,550	----------	----------	1,016,060
1903	700	50,000	7,479,721	----------	----------	1,066,090
1904	1,200	80,000	11,676,695	----------	----------	1,565,815
1905	2,000	75,000	18,475,452	----------	----------	2,969,255
1906	7,075	1,146,885	22,541,000	----------	----------	5,263,180
1907	----------	83,093	30,447,686	----------	----------	6,194,125
1908	2,330	131,228	35,746,169	----------	----------	4,810,785
1909	613	131,715	35,381,038	----------	----------	4,620,595
1910	7,500	110,000	29,137,215	----------	----------	3,871,730
1911	2,304	247,720	49,010,241	10,466	----------	6,332,684
1912	1,618	259,411	61,412,180	47,349	----------	10,328,137
1913	1,981	343,433	71,250,212	13,247	----------	11,293,115
1914	2,111	269,083	72,857,026	21,575	----------	9,883,274
1915	3,229	321,588	102,914,433	23,365	----------	19,331,142
1916	4,256	475,945	220,038,737	85,308	59,646	54,536,558
1917	5,067	454,203	169,417,110	65,010	----------	46,735,465
1918	5,966	447,395	201,806,396	15,570	----------	50,418,010
1919	7,095	402,530	171,106,182	67,078	----------	32,426,802
1920	6,389	557,608	176,215,409	212,744	----------	33,180,519
1921	1,664	229,303	76,488,211	152,770	----------	10,137,567
1922	6,447	534,855	170,035,442	64,834	----------	23,626,470
1923	8,976	673,686	198,426,127	26,531	----------	29,908,456
1924	8,331	650,139	190,451,888	88,366	----------	25,564,078

TABLE 4.—*Gold, silver, copper, lead, and zinc production in the Globe-Miami district, 1878–1953—Continued*

Year	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)	Total value
1925	8, 919	626, 184	175, 272, 327	179, 145	189, 440	$25, 537, 599
1926	9, 955	558, 165	175, 385, 817	142, 146	------------	25, 119, 465
1927	8, 015	351, 628	171, 167, 225	429, 924	------------	22, 815, 045
1928	5, 399	213, 504	160, 430, 341	374, 078	------------	23, 360, 157
1929	5, 617	219, 646	191, 596, 337	73, 061	------------	33, 958, 735
1930	4, 376	143, 003	158, 119, 898	32, 836	------------	20, 702, 756
1931	2, 461	77, 670	126, 443, 616	47, 065	------------	11, 581, 503
1932	595	14, 858	28, 448, 222	32, 700	------------	1, 809, 717
1933	365	5, 086	258, 703	56, 486	------------	27, 977
1934	316	6, 876	14, 321, 700	26, 135	------------	1, 162, 209
1935	723	61, 280	37, 359, 120	223, 075	------------	3, 179, 100
1936	1, 069	150, 891	111, 336, 391	98, 522	------------	10, 401, 760
1937	2, 884	190, 468	177, 018, 025	46, 322	13, 000	21, 671, 026
1938	1, 180	57, 666	89, 055, 123	20, 305	------------	8, 806, 915
1939	3, 106	127, 190	124, 800, 154	45, 107	------------	13, 176, 381
1940	3, 165	128, 818	140, 811, 637	86, 440	------------	16, 118, 416
1941	1, 997	83, 534	164, 837, 300	142, 400	46, 800	19, 591, 725
1942	1, 924	81, 644	188, 529, 000	193, 700	11, 400	22, 951, 445
1943	2, 341	107, 131	201, 026, 600	147, 800	------------	26, 302, 660
1944	4, 242	187, 612	190, 609, 200	197, 000	------------	26, 029, 885
1945	3, 160	183, 794	157, 291, 400	214, 500	------------	21, 494, 084
1946	3, 403	172, 115	177, 111, 500	141, 000	------------	28, 965, 606
1947	2, 761	190, 242	182, 064, 100	413, 000	------------	38, 561, 737
1948	2, 564	143, 887	176, 956, 200	87, 200	------------	38, 635, 069
1949	2, 505	126, 826	160, 377, 000	61, 600	------------	31, 806, 461
1950	2, 102	134, 767	169, 376, 600	83, 600	------------	35, 437, 160
1951	3, 138	164, 899	180, 449, 700	3, 000	2, 300	43, 928, 837
1952	2, 717	156, 484	186, 158, 000	16, 000	10, 000	45, 291, 297
1953	2, 197	139, 211	172, 956, 000	3, 500	2, 000	49, 841, 662
Total	186, 348	16, 336, 409	6, 432, 196, 494	4, 511, 860	334, 586	1,083,020,236

DEPOSITS OF HYDROTHERMAL ORIGIN

DISSEMINATED-COPPER DEPOSITS

The large low-grade, disseminated or "porphyry-type" deposits have been by far the most productive and account for more than 80 percent of the total value of metals mined in the Globe-Miami district. They include the Miami-Inspiration, Castle Dome, Copper Cities, and Cactus deposits. A relatively small disseminated-copper deposit in diabase between the 22d and 24th levels in the southwestern part of the Old Dominion mine probably also should be included in this group; it is an anomalous form of deposit along the Old Dominion fault system.

The Miami-Inspiration deposit has been described in detail by Ransome (1919, p. 132–176), and the Castle Dome deposit by Peterson, Gilbert, and Quick (1951, p. 66–127). The Copper Cities and Cactus deposits will be described later in this report.

The disseminated copper deposits of the district are very similar in character. All have been exploited chiefly for their copper content, but they also contain small amounts of molybdenite, gold, and silver.

The chief hypogene minerals are quartz, pyrite, chalcopyrite, and molybdenite. Sphalerite, galena, barite, and fluorite are present locally in very small amounts. The host rocks are Pinal schist and granite porphyry for the Miami-Inspiration and Cactus deposits, Lost Gulch quartz monzonite and granite porphyry for the Castle Dome and Copper Cities deposits, and diabase for the small deposit in the Old Dominion mine. In the mineralized areas these rocks are highly shattered or sheeted by closely spaced steeply dipping fractures. Pyrite and chalcopyrite occur with quartz in veinlets along fractures or disseminated as discrete grains between the grains of the host rock between the veinlets, so that commonly they appear to be primary constituents of the rock. However the sulfide grains are generally associated with minute flakes of sericite and are commonly connected by irregular discontinuous chains of sericite flakes. Most of the molybdenite forms selvages along the borders of quartz-pyrite veinlets, but some of it occurs as disseminated flakes.

In the Miami-Inspiration and Castle Dome deposits, there is a distinct zonal pattern, both in intensity of mineralization and in the distribution of minerals. The zones have a general east-northeastward trend, suggesting control by a linear structure of similar trend. Pyrite occurs throughout the mineralized areas, but is most abundant in a broad elongate zone along the north side of each deposit.

Only a relatively small portion of the mineralized rock contains enough chalcopyrite to be protore or rock that is sufficiently rich in copper to become ore through supergene enrichment. In the Miami-Inspiration and Castle Dome deposits the protore forms elongate zones adjacent to the south sides of the pyritic zones. At Copper Cities the protore is confined between two faults that cross the broad elongate pyritic zone aproximately at right angles.

The hydrothermal alteration of the host rocks appears to have been related to the pyritic metallization. The intensity of the alteration was roughly proportional to that of the pyritic metallization. At Castle Dome, the chalcopyrite is mainly in a zone of moderate alteration. The same relationship probably is true for the Miami-Inspiration deposit but is not so obvious because variations in the intensity of alteration and in the amount of pyrite in the protore are not readily determinable. Much of the pyrite has been replaced by chalcocite, and most of the host rock is schist, which is not greatly changed by hydrothermal alteration. At Copper Cities the protore is strongly altered and contains abundant pyrite.

Bordering each quartz-pyrite veinlet cutting the granite host rocks is a zone in which all original rock minerals except quartz are replaced by sericite or hydrous mica. The altered borders appear to vary in width roughly in proportion to the amount of pyrite in the veinlet. Rock in which argillic alteration affected chiefly the plagioclase lies between the veinlets beyond their sericite border zones. The intensity of argillic alteration probably varies in proportion with that of the sericitic alteration. Some sericite is present in all the argillized grains; and where quartz-pyrite veinlets are largest and most numerous, the altered zones along the veinlets coalesce, and the rock is completely replaced by sericite and quartz.

The schist host rock is not so greatly affected by hydrothermal alteration because it is composed largely of quartz and sericite. There is some recrystallization of original quartz and sericite, and the rock is bleached as a result of the destruction of the dark minerals, magnetite, biotite, and chlorite. It is difficult or impossible to gauge the relative intensity of the alteration.

The disseminated-copper ore bodies are largely the result of supergene enrichment. They are irregular tabular ore bodies that coincide in plan approximately with the copper-bearing zones formed by the hypogene metallization. They are overlain by nearly barren capping ranging in thickness from a few feet to 800 feet. The hypogene sulfides originally in the capping have been oxidized, and their copper has been leached by downward percolating ground water and redeposited as chalcocite and covellite, replacing the hypogene sulfides in the underlying rock.

The boundary between leached capping and the body of chalcocite ore is generally sharp and fairly regular. It is roughly parallel to the land surface at the time of enrichment, that is, either the present land surface or that which existed during the interval of erosion that preceded the eruption of dacite. The amount of chalcocite decreases gradually with depth. In the Castle Dome and Copper Cities ore bodies only a part of the chalcopyrite has been replaced; whereas in the Miami-Inspiration ore body, nearly all the chalcopyrite and much of the pyrite has been replaced by chalcocite and covellite. The bottom limits of the ore bodies and, to a large extent, the lateral limits are arbitrary boundaries based on the prevailing price of copper and the cost of production.

MIAMI-INSPIRATION DEPOSIT

HISTORY OF DEVELOPMENT AND MINING

In his early report on the Globe copper district Ransome (1903, p. 119) stated that the porphyritic facies of the Schultze granite in the vicinity of Live Oak Gulch had been much fissured and shattered, and is conspicuously stained with carbonates and silicate of copper. At this early date, the only mining in this part of the district was at the old Live Oak and Keystone mines, where high-grade chrysocolla ore was being mined on a small scale from veins in the porphyry In the course of these small operations, the presence of large quantities of rock containing 2 to 3 percent copper became known. Methods of mining and treatment were being continually improved, and soon this low-grade material began to attract considerable attention.

The Inspiration Mining Co. was organized in 1904 to develop a group of claims adjoining the Keystone property. The Woodson and Mercer adits were driven from a ravine that opens into Webster Gulch just west of the present site of the general office building of Inspiration Consolidated Copper Co. Low-grade chalcocite ore was found at a depth of 130 feet, and in 1906 a 50-ton concentrator was erected to treat the ore. The venture was not a financial success, but it confirmed the presence of large reserves of low-grade disseminated chalcocite ore.

In 1905, the General Development Co., controlled by the Lewisohn interests, sent F. C. Alsdorf to examine the Keystone property, which was then offered for sale. Alsdorf called the district to the attention of J. Park Channing, consulting engineer for the General Development Co. Alsdorf was conmissioned to obtain options on the most promising ground available. A group of 13 claims, known as the Oaks-Newman group, was optioned from John B. Newman. These options were transferred to the General Development Co. and work was begun on the Captain (No. 1) shaft about a mile east of the Keystone property at a point where the rocks were brilliantly stained by oxidized copper minerals. No ore was found, and a second shaft, known as the No. 2 shaft, was sunk 800 feet farther east near the Miami fault and reached ore at a depth of 220 feet, in April 1907; and on November 30, 1907, the Miami Copper Co. was organized. An extensive campaign of churn drilling and underground development was laid out under the direction of J. Park Channing; by 1908 ore reserves were estimated at 5 million tons containing 3 percent copper.

Miami Copper Co. started to formulate plans for production in January 1909. The extension of the railroad from Globe to Miami was completed in September, and by the end of the year Channing reported that 14 million tons of ore containing 2.75 percent copper had been blocked out. A working shaft known as No. 4 shaft was started and construction of a power plant and concentrator was begun.

Operation of the first unit of the concentrator was begun in March 1911. A contract was made with Cananea Consolidated Copper Co. to smelt the concentrates; the first shipment was made April 4. The sixth and final unit of the concentrator was completed in March 1912, bringing the total capacity to 3,000 tons of ore a day.

In the meantime, the other companies were not idle. In January 1909, the Live Oak Copper Mining and Smelting Co. property was optioned by Hoval A Smith, Henry B. Hovland, and associates, who organized the Live Oak Development Co. The original Live Oak shaft (No. 1) was deepened to prospect below the copper silicate ore body. This shaft passed through 150 feet of chalcocite ore. A drilling campaign was started in 1910. The Live Oak No. 2 shaft, begun in 1911, found ore at 705 feet that continued to a depth of 890 feet. By the end of the year, when the property was optioned to John D. Ryan, 15 million tons of ore had been developed by drilling and mine workings.

In 1909, the Keystone Copper Co. property passed into control of John B. Newman, who then sold the property to the General Development Co. New Keystone Copper Co. was organized to continue the development of the property.

Inspiration Copper Co. was organized in December 1908, with William Boyce Thompson as president. Work was begun on the Joe Bush, Scorpion, and Bull Dog shafts and also in the Woodson, Columbia, Taylor, Clipper, and Bull Dog adits. In September 1909, Thompson sold his interest in the company to the Cole-Ryan interests, and Thomas R. Drummond became manager. At this time work on the Colorado shaft began. In December 1910 Drummond reported reserves of about 18 million tons of 2 percent ore. A test mill was built at the Joe Bush shaft to treat 20 tons of ore a day.

In January 1912, the Live Oak Development Co. and the Inspiration Copper Co. were consolidated, and the new company, known as Inspiration Consolidated Copper Co., was capitalized at $30 million. At the time of consolidation, the engineers of the two companies reported that the Inspiration ore reserves were 30.3 million tons averaging 1.95 percent copper and the Live Oak reserves were 15 million tons averaging 2.11 percent copper, or a total of 45.3 million tons averaging about 2 percent copper.

The task of equipping the property for production was placed under supervision of H. Kenyon Burch. The main hoisting shafts were started, and construction of a power line from Roosevelt Dam was begun. Mineral Separation Co. began experimental work on the use of the flotation process for the treatment of the ore. A 600-ton experimental flotation plant was completed in January 1913.

Early in 1914, International Smelting and Refining Co. began construction of a smelter and Inspiration Consolidated Copper Co. started work on an 18-unit concentrator with a capacity of 14,400 tons of ore a day. The 600-ton experimental unit was operated continuously until completion of the first unit of the permanent plant in July 1915. The last unit of the concentrator was put in service February 21, 1916. Later, two additional units were added, bringing the capacity to 18,000 tons a day. The smelter was blown in on May 8, 1915.

In January 1915, the property of the New Keystone Copper Co., which separated the Inspiration and Live Oak properties, was purchased after prolonged negotiations that began early in 1912, thus making possible direct underground connection between the two divisions of the consolidated property.

A group of claims adjoining the Live Oak property on the southwest was held by the Southwestern Miami Development Co. Anticipating that any ore found in this area would be deep, the company purchased a heavy rig capable of drilling to a depth of 1,500 feet and began prospecting in 1911. The first hole found ore from 1,110 feet to 1,285 feet. From 1911 to 1914, 18 holes averaging 1,200 feet in depth were drilled, and an estimated 2 million tons of ore averaging 1.25 percent copper was blocked out. No attempt was made to develop this ore, and the property was unworked until 1929, when it was purchased by Inspiration Consolidated Copper Co.

The Barney Copper Co. was organized in 1910 by J. D. Coplan of Globe to work a group of claims adjoining the northwest side of the Live Oak property. Early in 1912, the property was optioned to General Development Co. Three holes were drilled, none of which found ore, and the option was surrendered. In 1917 the eastern portion of the Barney property was sold, and the Porphyry Copper Co. was organized to prospect it. The Porphyry shaft, sunk in 1917, penetrated 65 feet of oxidized ore and 85 feet of sulfide ore. Considerable development work was done from the shaft, and in June 1919 the Barney Copper Co. and the Porphyry Copper Co. were consolidated, the new organization being known as the Porphyry Consolidated Copper Co. In 1921 the property was sold to Inspiration Consolidated Copper Co.

Except for 7 weeks during a strike in the summer of 1917, Inspiration Consolidated Copper Co. operated continuously until the break in the copper market after World War I. Operations ceased March 31, 1921, and were not resumed until February 11, 1922.

Experiments were begun in 1922 on a leaching process to treat large reserves of mixed oxide and sulfide ore in the Keystone and Live Oak divisions of the property. The experiments were successful and a process of leaching with acid ferric sulfate solution and subsequent precipitation of the copper by electrolysis was developed. Construction of a 9,000-ton leaching plant was begun in 1925 and was completed in November 1926. The plant proved so successful that the concentrator was closed down permanently in 1930.

The decline in the price of copper during the worldwide business depression forced Inspiration to cease operations in May 1932. They were not resumed until September 1936.

In order to cope with continuously mounting costs of production, the Inspiration company began in 1946 to develop a plan to mine a part of its remaining reserves from an open pit. Construction of roads into the caved areas overlying the ore body and preparation of other facilities was begun the following year. In 1948 production of ore from the open pit, began in April of that year, was 1,338,440 tons, or about 33 percent of the total ore mined; by 1953, production from the open-pit amounted to 3,000,400 tons, or about 77 percent.

Miami Copper Co. continued uninterrupted operation except for 7 weeks during a strike in the summer of 1917. A new hoisting shaft, No. 5, was sunk in 1918, and additional drilling explored the large reserves of low-grade ore that extended beyond the limits of the relatively high-grade ore that had been mined until this time. During the general shut-down of all the major copper mines in 1920, operations were continued at a rate of about 80 percent of normal, and concentrate was stacked at the International smelter.

At the end of 1923, reserves of high-grade mixed oxide and sulfide ore for only 2 years of operation remained. In order to mine and treat the low-grade ore at a profit, it was necessary to increase the scale of operation and effect every possible economy. Plans to meet these conditions were made. The capacity of the plant was increased to 12,000 tons a day, and development of the low-grade ore was begun in 1924. The costs of production were even lower than anticipated and at the end of 1926 the reserves were recalculated in line with the reduced costs. They were reported as 84.5 million tons of sulfide ore averaging 0.93 percent copper and 7 million tons of mixed ore averaging 1.83 percent copper.

Further reductions in costs were made in 1927, and concentrator capacity was increased to 18,000 tons a day, with the result that the cut-off-grade could be decreased even more. At the end of 1927, reserves of 99.6 million tons of sulfide ore averaging 0.88 percent copper and 7 million tons of mixed ore averaging 1.83 percent copper were reported.

Mining ceased May 15, 1932, owing to the decline in copper prices, and was not resumed until July 1, 1934. Production then continued uninterrupted at an average annual rate of approximately 50 million pounds of copper a year till, by the end of 1951, the ore reserves had been reduced to about 12 million tons, only enough for three more years of normal operation. However, there remained large tonnages of submarginal material containing less than 0.5 percent copper along the southeastern edge of the ore body, largely below the old stopes of high-grade, mixed ore in the Captain division of the mine. A minable body of about 23 million tons estimated to average slightly more than 0.5 percent copper was blocked out.

In February 1952, a contract was made with Defense Materials Procurement Administration, under which General Services Administration would purchase 230 million pounds of copper produced from this block of low-grade ore at a guaranteed price of 27.35 cents per pound (subject to escalation) and would option the molybdenum concentrates. Preparations for mining this block of ore began in 1953, and production from it began in March 1954.

In the block-caving system of mining, rock is drawn from the stopes until its copper content falls below the economic grade. There remain large amounts of broken rock too low in grade to be treated in the conventional manner but nevertheless containing a large amount of copper. In 1941, Miami Copper Co. began leaching this rock in place by spraying a dilute solution of sulfuric acid on the surface over mined-out areas. After percolating through the caved ground, the solution is collected in the underground mine workings, and the copper is precipitated by means of iron scrap. A similar operation was begun by the Inspiration company in 1950. In 1952, the copper recovered by this process on the two properties amounted to about 17.5 million pounds, or about 13 percent of the total copper production of the district for that year. To the end of 1953, about 89 million pounds had been recovered by leaching in place.

In 1947, the Amico Mining Corp. was organized by Anaconda Copper Mining Co., Miami Copper Co., and Inspiration Consolidated Copper Co. to explore undeveloped lands in the Globe-Miami district. The holdings controlled by the Amico Corp. included the mining claims of the Van Dyke Copper Co. and the Sho Me Copper Co. and certain properties contracted to Amico by Miami Copper Co. and Inspiration Consolidated Copper Co. An intensive geologic study of the Amico holdings was undertaken by geologists of Anaconda Copper Mining Co.; and four churn-drill holes were sunk southeast of Miami to prospect the schist underlying a thick cover of Gila conglomerate. No ore was found, and the company was dissolved in 1949.

PRODUCTION

The copper production of the Miami-Inspiration deposit since the mining of the disseminated-copper ore body began in 1911, as given in the published annual reports of the companies is shown below.

	Ore mined (tons)	*Copper (pounds)*
Miami, mine, 1911–53	135, 416, 000	2, 129, 180, 600
Inspiration, mine, 1914–53	139, 930, 000	2, 695, 289, 400
Totals	275, 346, 000	4, 824, 470, 000

The gold and silver content of the ore is very small, and data on production of these metals, if any, are not available. The figure for total production of molyd-denum concentrate by Miami Copper Co. from 1938 to 1946 is not available, but from 1947 to 1953 the concentrate contained 3,661,482 pounds of molybdenum.

DESCRIPTION

The Miami-Inspiration deposit has been described in detail by Ransome (1919). During the present study of the district there was little opportunity to make a complete study of the deposit. The original surface over the ore body is greatly disturbed and is largely inaccessible, owing to the caving that results from mining operations. Most of the main haulage arteries of the mine workings are accessible, but are heavily timbered. The workings on the extraction levels are generally not maintained after the block of ore that they serve has been removed. Detailed geologic records of the mine workings have not been kept up, because the mineralized area was considered thoroughly explored by drilling, and the limits of the ore body had been determined accurately enough for practical purposes. The past operations have been based on the original drilling data, which have proved to be essentially accurate. Detailed sample maps of the mine workings showing some of the major geologic features have been carefully maintained.

The geologic structure of the mineralized area has been discussed on pages 60–62.

The limits of the ore body have been greatly enlarged since Ransome's study by continually including blocks of lower grade rock that could be mined and treated at a profit, owing to improved techniques of mining and metallurgy. A vertical projection of the present ore body on a horizontal plane, and a longitudinal section and several typical cross sections are shown on plate 7.

In these sections the top of the ore body was determined by exploratory drill holes that are generally spaced 200 feet apart at the intersections of rectangular coordinates. The top coincides with the boundary between the leached capping, which rarely contains more than 0.2 percent copper and commonly much less, and the enriched zone. This boundary is well defined, and its position is not subject to the changes caused by fluctuations in the price of copper and cost of mining. The boundary between ore and protore is gradational and very irregular. Its location is determined to a large extent by the prevailing price of copper and cost of production and to some extent by the vertical spacing of the extraction levels of the mines.

The lateral and lower boundaries of the ore body shown on the sections are in most places the limits of mining and therefore do not accurately portray the geologic limits. The block-caving system of mining is not as flexible as most small-scale methods and cannot be adapted to small irregularities in the shape of the ore bodies either vertically or horizontally. Thus many of the mined blocks include some rock that is lower in grade than the prevailing economic cutoff, and, conversely, projecting bodies of ore that are too small to bear the expense of the development work necesary for their extraction are left unmined. The drill holes are too widely spaced to reveal small irregularities in the shape of the ore body, and many of the holes bottomed in slightly enriched protore, whose copper content is higher than the current cutoff grade. If more complete data were available, the rectangular boundaries of the ore shown on sections *G–G′* and *H–H′* would be changed somewhat, but it is doubtful that the other sections would be appreciably affected.

The ore shown in the footwall of the Pinto fault on section *H–H′* and extending below the main ore body on section *G–G′* is slightly enriched protore that Miami Copper Co. has developed on the expectation of realizing a small profit on its extraction (p. 85).

The Miami-Inspiration ore body is 12,000 feet in length and has a maximum width of about 2,500 feet. In some places the ore is as much as 900 feet thick, but the average thickness is probably between 200 and 250 feet. The total ore mined plus the reserves reported by the companies at the end of 1953 amounts to about 380 million tons, which will have a total yield of about 5½ billion pounds of copper.

Although the deposit is commonly referred to as consisting of the Live Oak, Keystone, Inspiration, Captain, Pinto, and Miami ore bodies, these are divisions made mostly on the basis of property lines. The deposit was originally continuous, and the only complete separation is that caused by the low-angle Bulldog fault, which cuts across near the middle of the ore body between the Keystone and Inspiration divisions.

In the western part, the long axis of the ore body strikes N. 55° E., but in the eastern part the strike trends nearly east. The Bulldog fault depressed the block to the east more than 500 feet. The western segment of the ore body crops out just west of the Bulldog fault and plunges southwestward, so that the top of the ore at the west end is about 1,000 feet below the original surface. The eastern segment is undulating but is nearly horizontal. Just east of the Bulldog fault, the eastern segment is overlain by about 500 feet of leached capping, but it crops out in an area northeast of the Pinto fault. At the eastern end, the ore body is terminated by the Miami fault along which the Globe Valley block to the east has been dropped at least 1,500 feet, bringing Gila conglomerate into contact with the mineralized schist and granite.

The long axis of the ore body appears to coincide approximately with the axis of the zone of most intense hypogene copper metallization, which is along the contact between Pinal schist and a lobe on the northeast side of the stock of Schultze granite. This zone of richer protore is probably fairly well defined by the limits of the ore body at the inception of mining operations (Ransome, 1919, pl. 31), when only rock containing 2 percent or more copper was considered to be ore. Along the central part of the zone, at the level of the principal mine workings, the protore probably contained as much as 0.5 to 0.6 percent copper and in some places even more. Ransome (1919, p. 157) refers to 126 assays of diamond-drill cores from rock under the Miami ore body, as outlined at the time of his examination, that averaged 1.18 percent copper and, according to records, showed no chalcocite. Outward from this central zone, the copper content of the protore decreases; near the margins of the present ore body, it is probably about 0.3 percent.

The ore body as mined to date (1953) is the result of supergene enrichment of protore consisting mainly of pyrite and chalcopyrite. Within the limits of the ore body, practically all the chalcopyrite and much of the pyrite have been replaced by chalcocite and covellite. Ransome (1919, p. 147–148, 173–174) pointed out the lack of conformity of the top of the chalcocite zone with the present topography and the water table, and he has presented very convincing evidence that a major part of the enrichment occurred while the mineralized schist and granite were exposed to weathering during the interval of erosion that preceded the eruption of dacite. It is also clear that much of the enrichment occurred before most of the faulting and the westward tilting of the blocks in the mineralized area.

Most of the dacite covering the deposit had been stripped off, and in places there had been some erosion of the leached capping before the mineralized area was again buried, this time by the younger parts of the Gila conglomerate. In some places east of the Miami fault the Gila has a thickness of more than 4,000 feet, but it very doubtful that it was ever that thick in the area west of the fault. Displacement on the Miami fault probably occurred at intervals during the time that the conglomerate was accumulating. Other faults that displaced the chalcocite body also displaced the dacite; and some, if not all of them, displaced at least the lower beds of the Gila conglomerate in the mineralized area.

After the general uplift of the region that initiated the present erosion cycle, the Gila conglomerate and all but a few small remmants of the dacite were stripped off, except over the western end of the ore body, which had been tilted to the west, probably as a result of the faulting. The mineralized schist and granite were again exposed to weathering agents whose action has continued to the present day, and recent supergene activity has slightly modified the shape of the ore body and has partly obliterated the effects of faulting on the continuity of the ore body. Just west of the Bulldog fault, in the elevated block, erosion stripped off the leached capping and exposed the underlying chalcocite body. The chalcocite was oxidized, but too little pyrite was left in the enriched body to permit much transportation of copper by ground water. The liberated copper became fixed nearly in place as carbonate and silicate. The same condition prevails wherever the original chalcocite body has been exposed or where the capping is thin and, to a lesser degree, in many places along the top of the ore body.

A study of the outcrops of mineralized rock that are still intact and accessible, mainly along the northern and southern sides of the caved area over the ore body, shows that the ratio of pyrite to chalcopyrite was much greater on the north side than on the south side. This conclusion is based on the character and relative quantity of residual limonite and the structure of the skeletal boxwork that remains in the outcrops after the sulfides have been oxidized and leached. Along the north side of the caved area, the outcrops are more deeply colored by limonite stain that floods the rock, and there are abundant crusts of transported limonite. The silicic boxwork has the character of that resulting from leached pyrite or mixtures of sulfides that contain a high proportion of pyrite. The total copper content of the rock was low because enriched protore of commercial grade and volume was not found below the leached rock.

Along the south side erosion has cut more deeply, and in places, sulfides are found within a few inches of the surface. They are far less abundant than they were on the north side, and chalcopyrite predominates. Obviously, however, the rock contains too little chalcopyrite to have been protore that would become ore by through enrichment, even under the most favorable conditions.

The details of the transition from rock highly mineralized with pyrite on the north side to rock weakly mineralized with chalcopyrite on the south side could not be observed. Only in one very small area southeast of the Live Oak shaft could the original outcrop of mineralized rock over the ore body be examined. The rock in this area is granite, which contains many blebs and small masses of indigenous dark reddish-brown pulverulent limonite characteristic of the residue of leached chalcocite, but it is not conspicuously iron stained.

CASTLE DOME DEPOSIT

The geology of the Castle Dome disseminated-copper deposit was studied during 1943 and 1944 as a part of the Globe-Miami project of the Geological Survey. A detailed description of the deposit and adjacent area was published in 1951 (Peterson, Gilbert, and Quick). There have been no significant disclosures during the mining operations that add materially to the published data or that necessitate any changes in the views expressed. The structure sections of the ore body, compiled as mining proceeded, differ slightly in minor details but are essentially the same as the published sections (Peterson, Gilbert, and Quick, 1951, pl. 4).

During 1945 and 1946, the small ore body underlying South Hill (Peterson, Gilbert, and Quick, 1951, p. 81, 99) was explored. On the basis of 43 churn-drill holes, company engineers estimated about 6 million tons of additional reserves averaging 0.7 percent copper. Stripping operations to uncover this ore body were started in 1948.

Production of copper began in 1943. The ore reserves were exhausted and the mine closed down in December 1953. Dismantling of the plant for removal to the Copper Cities deposit, which was already in process of development, was begun immediately. Preparations have been completed for recovering to some extent the small percentage of copper contained in the waste dumps by a process of leaching in place. These dumps contain about 48 million tons of broken rock.

PRODUCTION

During the 10½ years of operation, the mine produced copper at a constant rate of about 50 million pounds a year. The total production amounts to 514,390,317 pounds of copper, 8,291 ounces of gold, and 554,138 ounces of silver obtained from 41,442,617 tons of ore. The total value of the produced metals is about $103 million. The average yield per ton of ore treated during the life of the mine is 12.4 pounds of copper, 0.0002 ounce of gold, and 0.013 ounce of silver to the ton.

The actual production by years as published in the annual reports of Miami Copper Co. is shown in table 5.

TABLE 5.—*Copper, gold, and silver produced from the Castle Dome mine, Arizona, 1943–53*

Year	Ore (tons)	Copper (pounds)	Gold (ounces)	Silver (ounces)
1943	1, 714, 205	18, 020, 066	1, 871	95, 975
1944	4, 107, 975	49, 743, 367		
1945	4, 183, 769	53, 324, 969	1, 306	86, 851
1946	4, 102, 566	56, 590, 107	1, 571	84, 210
1947	3, 890, 627	52, 840, 237	658	73, 653
1948	3, 890, 126	49, 585, 565	288	37, 557
1949	3, 744, 922	46, 306, 057	396	45, 233
1950	3, 690, 465	44, 795, 706	254	33, 350
1951	3, 864, 250	49, 712, 786	992	36, 694
1952	4, 300, 937	52, 655, 859	504	24, 707
1953	3, 952, 775	40, 815, 598	451	35, 908
Total	41, 442, 617	514, 390, 317	8, 291	554, 138

COPPER CITIES DEPOSIT

The Copper Cities disseminated-copper deposit is on the south flank of Sleeping Beauty Peak, 3½ miles due north of Miami. The ore body straddles the middle part of the common boundary between the Globe and Inspiration quadrangles.

HISTORY OF DEVELOPMENT

Small gold and silver deposits in the Pinal schist attracted the first attention to the Lost Gulch area. Development work was begun in 1896 by the Girard Mining Co., which was reincorporated the same year as the Lost Gulch Mining Co. A 10-stamp treatment plant was erected, but lack of an adequate supply of water soon forced suspension of the operation. During the ensuing years, small pockets of relatively high-grade gold ore were mined and treated in crudely constructed arastras.

The Lost Gulch United Mines Co. was organized in 1909 to operate the properties of the Lost Gulch Mining Co. and several other claims in the area. Little is known concerning the activities that followed. The company was reorganized as the Louis d'Or Gold Mining Co. in 1912 and produced a little gold-silver-lead ore from the Bonanza, Badger, and Cedar Tree claims.

In 1913, Charles E. Hart was sent by Baldwin Syndicate of Chicago to examine the gold deposits in Lost Gulch. In the course of his examination he was greatly impressed by the similarity of the porphyry outcrops south of Sleeping Beauty Peak to the leached outcrops of the disseminated-copper deposits of the Ely district in Nevada. As a result of his examination, the Louis d'Or Gold Mining Co. was reorganized as the Louis d'Or Mining and Milling Co., on the strength of the possibility that a part of the holdings might be developed into a "porphyry" copper mine. In addition to 12 claims owned by the company, the Gila Monster, Bessie, and Sarah groups of claims covering the porphyry outcrops were optioned from J. W. Bennet. The terms of the option called for a payment of $150 a month during the exploration period and specified a price that would be paid if the drilling disclosed ore.

Exploration by churn drilling was begun in 1917; and by the end of 1922, the Louis d'Or shaft, 360 feet deep, and 12 drill holes, totaling nearly 9,000 feet, had been sunk. The work proved the presence of disseminated copper minerals, and the property under option was purchased. The Bradley group of five patented claims was acquired in February 1923. The deposit, however, was too low grade to justify exploitation at that time.

Louis d'Or Mining and Milling Co. became insolvent, and in 1928 the noteholders protective committee entered into an arrangement with Pinto Valley Co., then exploring the Castle Dome and Cactus deposits, whereby the latter company advanced funds to the committee for the purchase of the Louis d'Or property at a bankruptcy sale. A new company, Porphyry Reserve Copper Co., was then organized jointly by Pinto Valley Co. and the noteholders, and the properties were transferred to it. Porphyry Reserve Copper Co. issued bonds in the amount of $500,000. Adjacent properties of Inspiration-Miami Copper Co. were acquired, and, during 1929 and 1930, 13 test holes were drilled under the supervision of T. R. Drummond. Also during these years, 350,000 pounds of copper was produced from stream gravel cemented by copper carbonates and silicate in Tinhorn Wash east of Sleeping Beauty Peak.

Interest payments on the bonds were defaulted in 1934, and many of the unpatented claims had been allowed to lapse for failure to do the annual assessment work. These claims were relocated by various individuals, and many of them were acquired by J. R. Heron of Globe. The bondholders foreclosed on the small group of claims that the company still retained, and these claims were purchased at a sheriff's sale by Copper Cities Mining Co., a newly organized subsidiary of Miami Copper Co. Copper Cities Mining Co. then purchased most of the rest of the original claims from Mr. Heron and other locators. Systematic exploration by churn drilling was begun in 1943 and completed in 1948. A low-grade ore body reported by the company to contain 33 million tons amenable to open-pit mining methods had been blocked out.

An agreement was executed under which a loan of $7.5 million was obtained from Reconstruction Finance Corporation to assist in financing the development of the property. General Services Administration contracted to purchase, at 23 cents a pound, a maximum of 170 million pounds of the first 192 million pounds of copper produced, should the company be unable to sell the copper for domestic use at a price equal to or greater than the contract price.

Development work preparatory to exploitation of the ore body was begun in the latter part of 1950; and by the end of 1953, 14,101,000 tons of leached capping had beeen removed from over the ore body. The development program has been so planned that after the depletion of the Castle Dome deposit, production from the Copper Cities deposit could begin as soon as the concentrator and other facilities at Castle Dome had been moved to prepared sites at Copper Cities. The transfer of buildings and equipment began in December 1953; and in the early part of August 1954, production of copper concentrate had begun in several units of the concentrator.

ROCKS EXPOSED IN THE MINE AREA

The Copper Cities deposit is in a body of Lost Gulch quartz monzonite that has been intruded by several smaller bodies of granite porphyry. These rocks are identical petrographically with the quartz monzonite and to the granite porphyry of the Castle Dome area, 5 miles to the southwest, and have been correlated with them. The quartz monzonite in both areas includes the same two textural facies, coarse-grained, porphyritic quartz monzonite and quartz monzonite porphyry (p. 25). Small bodies of fine-grained diabase exposed in the mine area at Copper Cities are similar to the thin dikes of diabase exposed in the Castle Dome mine and undoubtedly should be correlated with them. In neither area can these small bodies of diabase be definitely correlated with the main intrusion of diabase, although all the diabase is considered to be approximately the same age.

STRUCTURE

The outcrop of Lost Gulch quartz monzonite is a northeastward-trending horst block that is bounded on three sides by faults (pl. 7), the Sleeping Beauty fault on the northwest side, the Ben Hur fault on the northeast side, and the Miami fault on the east side. These faults have been described on page 59. As at Castle Dome (Peterson, Gilbert, and Quick, 1951, p. 30) the south boundary of the mass is a steep intrusive contact with Pinal schist and the various rocks of the lower Precambrian dioritic complex.

The structures that are most important in their relation to the ore body are the Coronado and Drummond fault zones, which limit the copper ore body on the west and east sides respectively. The Coronado fault which strikes north and dips steeply west for a distance of 2,000 feet along the west side of the ore body, is a sheared, brecciated, and silicified zone, 100 to 300 feet wide. At the north and south ends of this broad part, the zone, trends westward and, in a distance of a few hundred feet, appears to contract to such a minor fissure that its outcrop is scarcely recognizable, but recent stripping operations at the north end have exposed a strong gouge zone that extends to the Sleeping Beauty fault. Where the fault zone is widest and most prominent, it is the boundary between the two facies of the quartz monzonite, the porphyritic quartz monzonite on the east, or footwall side, and the quartz monzonite porphyry on the west side (pl. 8). Whether this relationship continues at depth is uncertain. Small lenticular bodies of fine-grained diabase have been intruded along the fault zone. Outcrops of granite porphyry within the fault zone did not appear to be appreciably sheared or displaced, but recent excavations along the fault have revealed many slip planes in the granite porphyry, many of which are younger than the period of mineralization.

The Drummond fault zone is much less prominent than the Coronado, but in other respects the two faults are similar. The outcrop is a narrow zone of silicified breccia generally less than 25 feet wide. It strikes N. 45° W. and dips 60° NE. Like the Coronado fault zone, it forms the boundary between the two facies of the quartz monzonite along most of its recognizable extent. On the 4,005-foot level of the mine, the northwestern portion of the fault zone is marked by black gouge about 6 feet wide that continues to the Sleeping Beauty fault. To the southeast, beyond the mine limits, the fault zone becomes too indistinct to identify.

Northeast of the Drummond fault zone, the quartz monzonite is traversed by many faults that strike north to northwest and dip 50° E. to vertical. The surface expressions of these faults are narrow zones of silicified breccia that commonly protrude a little above the surface of the adjacent quartz monzonite. The absence of gouge zones along the faults suggests that the displacement was relatively small. Most of these faults are older than the diabase, and many of them have thin discontinuous stringers or small irregular bodies of diabase intruded along them, particularly at the intersections of faults.

The mineralized quartz monzonite is intricately dissected by joints, fractures, and minor faults, some older and some younger than the period of mineralization. The older, or premineralization, fractures are now occupied by quartz-pyrite and chalcopyrite veinlets; in many places, it is difficult to find a hand-sized fragment of rock that is not bounded on one or more sides by walls of veinlets. Within the mine area east of the Coronado fault, no dominant pattern of veinlets and joints has yet been recognized. Postmineralization fractures and minor faults are abundant, and some are so recent that they seem to displace the boundary between leaching capping and the top of the ore zone.

The mine benches that have been excavated into the rock west of the Coronado fault expose a prominent system of closely spaced fractures and veinlets that strike N. 30° to 70° E. and dip steeply southeast. There also are many minor faults of similar strike and dip. Wherever the direction of movement can be determined, the blocks to the southeast are depressed, generally less than 20 feet.

MINERALOGY

The mineralogy of the Copper Cities deposit is fairly simple and in most respects is like that of the other disseminated deposits of the district. The principal hypogene minerals are quartz, pyrite, chalcopyrite, and molybdenite. Pyrite is by far the most abundant hypogene sulfide. The relative proportion of pyrite to other sulfides is probably greater than in the copper-bearing zones of the other disseminated deposits of the district. Pyrite occurs in veinlets with quartz and a little chalcopyrite and is associated with rocks showing much sericitic alteration.

Chalcopyrite is next in abundance but is not as widely distributed as pyrite. It is found mainly in the block between the Coronado and the Drummond fault zones. In addition to that in the quartz-pyrite veinlets, some chalcopyrite occurs in quartz veinlets containing little or no pyrite, and some occurs as discrete grains disseminated in the host rock between the veinlets. The relative importance of the three modes of occurrence is as yet unknown, but it appears likely that more than half of the chalcopyrite is in the form of disseminated grains. The chalcopyrite in the quartz-pyrite veinlets is intergrown with pyrite, but no clearcut evidence of replacement of either mineral by the other has been found.

Neither molybdenite nor its oxidation products were recognized in the leached capping over the ore body, but occasional flakes were seen in the concentrate panned from drill sludges. The molybdenum content of the rock within the limits of the ore body has been estimated by company engineers to be about 0.004 percent, which is much less than that of the other disseminated-copper deposits of the district.

Rock fragments cut by quartz veinlets containing molybdenite are common in the dump of the Louis d'Or shaft, which was sunk at the eastern edge of the copper-bearing area near the outcrop of the Drummond fault zone (pl. 8). In the place from which the rock of the dump was mined, probably within the Drummond fault zone, quartz-molybdenite veinlets must have been abnormally abundant and apparently traversed rocks affected by strong pyritic metallization and strong silicic and sericitic alteration.

Sphalerite and galena have not been recognized in the drill sludges, but a few specimens have been found in the broken rock from stripping operations along the Coronado fault zone. No veins showing evidence of having contained sphalerite or galena were recognized in the outcrops in the mine area. A small shoot of sphalerite and argentiferous galena has been mined from a short vein in the schist a few feet from its contact with the quartz monzonite on the Cedar Tree claim, 4,000 feet southwest of the Copper Cities mine (p. 123). Other small sphalerite and galena veins occur in the schist farther southwest.

Chalcocite and covellite are the only supergene sulfide minerals in the deposit. Chalcocite formed by replacement of chalcopyrite in the enriched zone and to a very minor extent as a replacement of pyrite. Its occurrence, therefore, is the same as that of the replaced minerals. A little covellite may have formed by direct replacement of chalcopyrite, but most of it is an alteration product of chalcocite. It is largely limited to the upper part of the chalcocite zone.

Malachite, azurite, and turquoise account for most of the acid-soluble copper in the ore body and for the small amount of copper that remains in the leached capping. Turquoise was commonly seen in drill sludges, and it is abundant in and around small prongs of the ore body that have been found during the current stripping operations. Most of it is the soft chalky variety, but some of it is hard enough to be of gem quality. Much of the hard turquoise is the greenish ferrian variety.

A few flakes of metatorbernite have been seen in the drill sludges, and a little has already been uncovered in the mine. It occurs as the usual tiny rosettes on the walls of minute fractures in the granite porphyry along the Coronado fault zone.

Probably most of the mineralogic details of the Castle Dome deposit will also be found to characterize the Copper Cities deposit owing to the great similarity of the broader geologic features of the two deposits.

HYPOGENE MINERALIZATION

Hypogene metallization and accompanying hydrothermal alteration were limited to the quartz monzonite and its intruded bodies of granite porphyry and diabase, except in a few places along the south side of the deposit where the effects of weak hydrothermal alteration can be detected in the adjacent schist and dioritic rocks. The outcrop of mineralized rock measures about 10,000 feet from southwest to northeast and is about 3,000 feet wide. Its long axis trends N. 60° E., approximately parallel to the Sleeping Beauty fault. Its general outline is represented by the limit of moderate hydrothermal alteration as shown in plate 7. This outline was plotted by use of arbitrary standards and therefore is subject to considerable variation, owing to personal factors.

Along the northwest side, hypogene mineralization was generally strong as far as the Sleeping Beauty fault, but the diabase north of the fault shows no evidence of it. In other directions, the effects of mineralization gradually disappear. Throughout this area, the rocks contain many steeply-dipping, quartz-pyrite veinlets. In outcrops, the pyrite is completely oxidized and mostly leached. The resulting voids are partly filled by powdery or granular limonite or by sintery crusts of dark-brown transported limonite.

Pyritic metallization was strongest along the Sleeping Beauty fault and along the Coronado and Drummond fault zones as shown by the bright red and yellow color of the outcrops there, in contrast to the light-brown color of outcrops elsewhere in the mineralized area.

Copper metallization was confined largely to the block lying between the Coronado and Drummond fault zones, which is in the northeastern part of the mineralized area. It appears to have been strongest in the quartz monzonite bordering the granite porphyry intrusive bodies and locally in the granite porphyry itself. The estimated copper content of the protore within the limits of the ore body as determined by detailed studies of several exploratory drill holes, ranged from about 0.25 to 0.6 percent; the average was about 0.4 percent. In general, the protore in the granite porphyry appears to have been somewhat lower in grade and probably contained from 0.15 to 0.35 percent copper. Near the southern edge of the ore body, the tenor of the protore is 0.15 to 0.25 percent copper, and farther south the copper content gradually decreases as the outer limit of the mineralized zone is reached.

Although the mineralized rock was raised to ore grade as a result of supergene enrichment, the copper content of the protore within the vertical limits of the ore body appears to have been greater than that of the unenriched or slightly enriched protore below the ore body. There appears to be a progressive decrease in the copper content of the protore with increasing depth.

Much more pronounced is the increase in the ratio of pyrite to chalcopyrite with depth. Within the limits of the ore body, the ratio ranged from 1.2 to 9, the average being about 3.6, whereas below the ore body the radio ranges from 4 to 16, the average being about

10. Because the low ratios are those of rock that has undergone considerable supergene enrichment and the high ratios are those of rock showing but slight or no enrichment, it might be inferred that the difference is the result of supergene processes. However, study of the sulfide concentrate from exploratory drill holes shows clearly that replacement of pyrite by chalcocite or covellite is negligible.

The smaller proportion of pyrite to chalcopyrite within the limits of the ore body may be partly due to replacement of pyrite by chalcopyrite during hypogene metallization, but this process could only be a minor cause. The sulfide concentrate contained few grains in which pyrite and chalcopyrite are in contact. The boundaries between the two minerals are smooth and regular and give no conclusive evidence of replacement or difference in age. The protore clearly shows a substantial increase in the proportion of pyrite with depth.

The thickest and richest part of the ore body is in the quartz monzonite along the south side of the granite porphyry mass that crops out across the central part of the block between the Coronado and Drummond fault zones (pl. 8). In places, rock averaging 0.5 percent copper continues to depths of 600 feet or more below the leached capping. The ore is thick, mainly because the hypogene copper metallization was more intense here than elsewhere in the deposit. In the upper part of this thick part of the ore body the copper content has been approximately doubled through supergene enrichment. In the lower part, very slight enrichment was sufficient to raise the copper content above the cut-off grade. There has been very slight or no enrichment below a depth of about 300 feet.

HYDROTHERMAL ALTERATION

A complete and detailed study of the effects of the hydrothermal alteration that accompanied the metallization at Copper Cities has not been undertaken. However, the general characteristics of the altered rock appear to be similar in most respects to those observed in the Castle Dome area (Peterson, Gilbert, and Quick, 1951, p. 71–88). The host rocks of the two deposits are petrographically identical, and the metallization was of the same general character. In both deposits the same three alteration phases are represented, a quartz-sericite phase, an argillic or clay phase, and a very feeble border phase of the propylitic type. The most apparent difference is in the areal distribution of the alteration products in relation to the copper ore body.

After reviewing most of the southwestern "porphyry-copper" deposits, Schwartz (1947, p. 351) concluded that chalcopyrite was introduced largely during the quartz-sericitic alteration. At Copper Cities, as at Castle Dome, some sericitic alteration undoubtedly took place during deposition of chalcopyrite, but the major part of the quartz-sericite alteration was clearly related to the pyritic metallization. Each quartz-pyrite veinlet is bordered by a narrow zone in which the original texture of the rock has been completely destroyed, and all rock minerals except quartz have been replaced by sericite or hydrous mica and quartz. The width of each alterated border zone is roughly proportional to the amount of pyrite in the veinlet. Where the pyritic metallization was most intense and the veinlets most numerous, most of the plagioclase of the intervening rock also has been replaced by sericite. In some places the alterated border zones coalesce, and the wallrock is completely replaced by sericite and quartz.

Complete silicification, the ultimate result of the alteration, is far more common than in the Castle Dome area. Silicic replacement was strong along some faults and breccia zones, and in a few places the quartz monzonite and granite porphyry have been completely replaced by quartz and disseminated pyrite.

Argillic alteration, in which the plagioclase of the rocks was replaced by a colorless or slightly yellowish clay mineral of the montmorillonite type, pervaded the rock between the veinlets throughout the area that has been appreciably mineralized. The rocks affected by this alteration appear almost fresh, but the effect of alteration can be detected by chalky appearance of the plagioclase and in some places by bleaching and replacement of biotite. The relative intensity of the argillic alteration can be gauged roughly by the hardness of the plagioclase and by the ease with which the grains disintegrate in water. A little fine-grained sericite or hydrous mica is present in all the argillized grains.

A rock showing very feeble but entirely different type of alteration in the outer fringes of the mineralized area extends beyond the limits to which appreciable evidence of the other types of alteration can be recognized in the field. The minerals developed are those characteristic of propylitization, namely chlorite, epidote, pyrite, a little sericite, and probably calcite and clinozoisite, as at Castle Dome (Peterson, Gilbert, and Quick, 1951, p. 72–73). This alteration was so feeble that it is difficult to detect its effects except by microscopic examination. The only megascopic evidence of its effects on the quartz monzonite are slight chloritic alteration of biotite and the presence of occasional grains of pyrite near biotite books.

The quartz-sericite alteration was superimposed on the argillic alteration in the sense that the argillic-alteration front reached a given point somewhat earlier than did the quartz-sericitic-alteration front. Except in the areas of strongest alteration, in which much of the clay is assumed to have been replaced by sericite, the intensity of one phase appears to be roughly proportional to that of the other. Thus both phases are regarded as the result of a single process related chiefly to the quartz-pyrite mineralization.

ZONING

In the Copper Cities deposit, there is no clear evidence of lateral zoning in the distribution of minerals comparable with that displayed in the Castle Dome deposit (Peterson, Gilbert, and Quick, 1951, p. 98–101). The copper-bearing area occupies a more central position with respect to the pyritic rock than in the other disseminated-copper deposits of the district. There is, however, some evidence of vertical zoning as shown by the increase in the ratio of pyrite–chalcopyrite with depth.

Practically all the exploratory drill holes show a definite decrease in the copper content of the rock with increasing depth below the base of the leached capping. Within the vertical limits of the ore body, this decrease is largely the result of a decrease in the degree of enrichment with depth, but most of the drill holes that extend well below the limits of enrichment, bottomed in rock that carries from 0.2 to 0.35 percent copper. For example, a deep hole drilled in the southwestern part of the ore body near the granite porphyry contact, where mineralization was relatively strong, showed intersections ranging from 0.3 to 0.6 percent copper to a depth of 1,225 feet. Rock in the interval from 1,225 feet to the bottom of the hole at 1,500 feet averaged 0.23 percent copper. Computations of the original grade of the protore in a few selected holes, which are based on the amount of chalcopyrite replaced by chalcocite, show a small but definite decrease in the copper content of the protore with increasing depth.

Vertical zoning may possibly be the controlling factor in the localization of copper in the Copper Cities deposit. The copper-bearing area may be the outcrop of a block that has been relatively depressed by postmineralization displacement between the Coronado and Drummond fault zones and so represents a shallower zone of mineralized rock than that represented by the pyritic rock cropping out in the blocks to the east and west. If this is true, at least the postmineralization displacement on these faults is reverse, as the copper-bearing block forms the footwall of both faults.

AGE OF HYPOGENE MINERALIZATION

The hypogene mineral deposit at Copper Cities shows the same age relationships as the other copper deposits of the district. It is younger than the quartz monzonite, the granite porphyry, and the diabase that intrudes the quartz monzonite, all of which are mineralized. It is older than the dacite which is not mineralized, and whose few remnants rest on the eroded surface of mineralized granite porphyry. The hypogene mineralization probably was related to the intrusion of the granite porphyry, a rock that is regarded as a late facies of the Schultze granite intruded during late Mesozoic or early Tertiary time.

GROUND-WATER LEVEL

The mine area lies across the upper reaches of Tinhorn Wash, a tributary of Pinal Creek 2 miles to the east. The topography and drainage pattern are governed to a large extent by the relatively resistant outcrops of granite porphyry. The surface has a general southeastward slope in the direction of the gradient of the main wash, The maximum relief is about 450 feet. Altitudes range from 4,250 feet, on the top of the highest hill in the northwestern part of the mine area, to 3,800 feet, in the bed of Tinhorn Wash where it crosses the southeastern limits of the mine.

The ground-water level, as determined during the exploratory drilling of the copper deposit, also has a general southeastward slope (pl. 8), approximately the same as the bed of Tinhorn Wash. It ranges in elevation from 4,000 feet in the northwestern part of the mine area to 3,7000 feet in the southeastern part. In detail, it reflects most of the major topographic features and also is influenced by geologic structure and rock formations. It is higher in the granite porphyry bodies than in the surrounding quartz monzonite.

The main circulation of ground water appears to follow the course of Tinhorn Wash and probably is controlled by the same gap in the eastward-trending barrier formed by the granite porphyry bodies that controlled the course of the wash. That there is a secondary channel of underground flow along the Coronado fault is shown by the prominent deepening of the water table in a narrow zone that is approximately parallel to the strike of the fault.

At some time, probably before the latest movement on the Miami fault and before the oxidation of the sulfides had penetrated to the present levels, enough ground water drained from the quartz monzonite and was discharged into Tinhorn Wash to cause at least semipermanent flow southeast of the mine area. This is indicated by terraces of alluvial gravel along the sides of the channel that are firmly cemented by iron oxides and copper carbonates and contain many limestone fragments coated with replacement shells of malachite.

SUPERGENE ENRICHMENT

Although supergene enrichment was a very important process in the formation of the ore body, its effects are relatively superficial and incomplete. In the few drill holes that have been studied in detail, the depths to which appreciable amounts of chalcocite are present range from 175 to 335 feet, or 100 to 220 feet below the leached capping. Even at the top of the chalcocite zone, replacement of chalcopyrite by chalcocite is not complete. Only a few samples showed any replacement of pyrite by chalcocite, and these few contained only an occasional grain of pyrite that showed slight peripheral replacement. Only the smallest grains of chalcopyrite, 0.1 millimeter in diameter or smaller, are completely replaced. All others have cores of unreplaced chalcopyrite that form as much as 80 percent of their sectional area.

From the top of the chalcocite zone, the degree of replacement decreases progressively with depth. There is generally little or no covellite except in the upper part of the enriched zone, where chalcocite is being decomposed by acid ferric sulfate solutions formed by action of oxygenated surface waters on residual pyrite. Pyrite is so abundant throughout the deposit that a little remains in the lower part of the leached capping after all the copper sulfide minerals have been destroyed.

Throughout most of the ore body, the amount of acid-soluble copper[1] is generally less than 0.1 percent and rarely exceeds 0.2 percent. The most common occurrence of the minerals containing acid-soluble copper is in the relatively thin chalcocite zone in the granite porphyry bodies.

The top of the chalcocite zone also is the top of the ore body, except in a few places where too great a proportion of the copper minerals are oxidized and hence are not recovered by the flotation process. The top of the zone is clearly related to the present land surface and reflects most of the topographic details.

The leached capping, which generally contains less than 0.1 percent copper, ranges from 20 to 115 feet in thickness; the average thickness over the ore body is about 65 feet. It is thickest under hills and ridges and is thin under the gulches. The boundary between chalcocite ore and capping is rather sharply defined and shows on the faces of the mine benches as an abrupt change in the color of the rock from light brown to gray.

In most parts of the mine area, the top of the chalcocite zone is well above the present water table (pl. 8). It approximately coincides with the water table under the bed of Tinhorn Wash, where the ground-water level probably is least affected by seasonal and cyclical differences in the amount of precipitation. Much chalcocite occurs below the water table. The decrease in the proportion of chalcocite in depth is gradual, and nowhere at the water table does there appear to have been an increase in the degree of enrichment.

Undoubtedly the base of the chalcocite zone is very irregular because various conditions affect the circulation of supergene solutions. For example, the degree of enrichment is greatly affected by the host rock. The enriched zone is consistently thinner in the granite porphyry than in quartz monzonite. This condition and the generally smaller amount of the hypogene minerals in the granite porphyry keeps much of this rock within the mine area from being classed as ore. The result is a hump of marginal or waste material in the central part of the ore body. The same condition is true for the granite porphyry at Castle Dome (Peterson, Gilbert, and Quick, 1951, p. 70) but there, fortunately, this rock was so situated that it did not materially affect mining operations.

The finer texture of the granite porphyry renders it less pervious to circulation of ground water than the quartz monzonite, particularly the coarse-grained facies of the latter, and thus accounts for the relative thinning of the chalcocite zone. This conclusion is confirmed by the higher-than-normal position of the water table in the granite porphyry bodies and the rock's greater resistance to weathering.

In contrast, the quartz monzonite directly adjacent to the granite porphyry masses seems to have been especially pervious, probably as a result of fracturing and metamorphism attending the intrusion of the latter. What little movement of ground water took place in the granite porphyry was chiefly lateral, toward the margins of the bodies, as is indicated by the slope of the water table. Probably a large proportion of the copper leached from mineralized granite porphyry was redeposited in the adjacent quartz monzonite.

As nearly as can be determined by the exploratory drilling, faults caused no prominent irregularities in the base of the oxidized zone or in the shape of the chalcocite ore body. The drill sludges of most of the holes were light brown through the leached capping and uniformly gray through the chalcocite zone and in the protore below. Below the capping there were very few recurrences of brown sludge to indicate deep oxidation or leaching along faults or fractured zones. Marked changes in the assay patterns of the drill hole could generally be related to a projected igneous contact rather than to faults that could be recognized by

[1] Acid-soluble copper and oxide copper" are terms used by engineers to denote copper that is not generally recoverable by flotation and must be determined by a special procedure in the assay of copper ores.

intersections of gouge or clay. This condition is in keeping with the fact that no major faults other than the three boundary faults were found on the surface over the ore body. As would be expected, however, stripping operations revealed many small irregularities in the boundary between capping and ore resulting from differences in permeability caused by minor faults and fractures.

AGE OF SUPERGENE ENRICHMENT

In the western part of the quartz monzonite outcrop, remnants of the dacite lie directly on quartz monzonite and granite porphyry (pl. 7). Farther northeast, in the vicinity of the ore body, remnants of dacite overlie the adjacent sedimentary rocks within 400 feet of the Sleeping Beauty fault, which forms the northwest boundary of the quartz monzonite mass. On the northeast margin of the quartz monzonite outcrop, near the Miami fault, a patch of dacite overlaps a small outcrop of diabase that intrudes the quartz monzonite. These relationships indicate that at least a part of the quartz monzonite mass had been uncovered before the eruption of dacite, and they strongly suggest that the uncovered area may have been approximately equal to that of the present outcrop.

However, the chalcocite zone of the ore body is clearly related to the present topography carved during the present erosion cycle, and its relative youth is also shown by the superficial extent of the enriched zone and by the incomplete replacement of hypogene sulfides by chalcocite.

That the quartz monzonite outcrop stood relatively high during the interval of erosion that directly preceded the eruption of dacite is shown by the absence of Whitetail conglomerate under the dacite in the vicinity of the copper deposit. It appears likely that the mineralized quartz monzonite was undergoing too rapid erosion during this interval of exposure to allow enrichment to proceed.

Furthermore, there is nothing to indicate that the quartz monzonite was again uncovered during the interval between the eruption of dacite and the deposition of the Gila conglomerate in this area. The lenses of dacite that crop out along the Miami fault zone and the outcrops of dacite that underlie the conglomerate along the west side of Pinal Creek farther to the east suggest that dacite underlies the Gila conglomerate east of the Miami fault.

Thus we may conclude that the enrichment that produced the chalcocite ore of the Copper Cities deposit occurred after the block containing the outcrop of quartz monzonite had been elevated by displacement along the Miami fault and after the cover of Gila conglomerate and the dacite beneath the Gila had been removed during the present cycle of erosion.

ORE BODY

The shape and size of the Copper Cities ore body is determined to a large extent by economic factors; that is, the tonnage of ore included within the planned limits of the mine is that which can be profitably mined and treated at certain anticipated costs and price of copper. These factors arbitrarily determine the ultimate limits of the mine illustrated on the cross sections through the mine (pl. 8). The outline of the proposed open-pit mine is shown in plates 7 and 8.

Excluding the leached capping, most of the rock within the limits of the mine has been affected to some extent by supergene enrichment, and therefore, the mine limits roughly delineate the chalcocite ore. The ore is thin in the granite porphyry bodies, where the chalcocite zone is thin and the copper content of the protore below the economic cut-off grade. The ore is generally thick in the quartz monzonite adjacent to the granite porphyry bodies, where the copper content of the protore ranged from slightly below to well above the cut-off grade and where the vertical range of supergene enrichment was much greater than in the granite porphyry bodies. Some of the ore near the bottom of the mine contains very little chalcocite or none at all, it is ore because the primary copper content of the rock made it ore grade or was so high that the rock was raised to ore grade by very slight enrichment.

CACTUS DEPOSIT

The Cactus property on Pinto Creek near the southwest corner of the Inspiration quadrangle contains a relatively small disseminated-copper deposit that attracted considerable attention as early as 1905. From 1908 to 1910, Cactus Copper Co. sunk 15 churn-drill holes ranging from 170 to 700 feet in depth. The Pinto and Hamilton shafts were sunk, and about 6,500 feet of lateral workings were driven on the 300-, 400-, and 500-foot levels of the Hamilton shaft. In 1921, Pinto Valley Co. took over the properties of Cactus Copper Co. and during the ensuing years sunk at least 15 churn-drill holes to further explore the Cactus deposit and contiguous areas. As a result of this exploration a small body of mineralized schist had been blocked out. Work was discontinued in 1929 and has never been resumed. The property was acquired by Castle Dome Copper Co. in 1940.

The deposit is considered as too small and too low in copper content to permit economic exploitation under present conditions. All the underground workings except a few shallow adits are now inaccessible.

The available records are lacking in firsthand descriptions but do give some information concerning the general structure of the deposit.

The copper deposit is in a mass of highly shattered and hydrothermally altered Pinal schist that crops out on the north side of Pinto Creek just west of Manitou Hill (pl. 7). The shafts and drill holes in the mineralized area are described as entering unaltered or "black" schist after passing through a fault zone that directly underlies the chalcocite deposit. This fault zone, known as the Cactus fault, dips 20° to 30° SW. The mineralized schist appears to have been a plate thrust over the normal schist on the Cactus fault, probably from the south or southwest (section *B–B′*, pl. 7). The deposit is a gently dipping, partly oxidized chalcocite blanket formed by supergene enrichment. On the west and north sides, its outcrop is overlapped by dacite and Gila conglomerate. The south boundary is formed by the Kelly fault along which the altered schist has been dropped into contact with an unaltered, coarse-grained quartz-sericite schist, Precambrian granite, and diabase in the south or footwall, side of the fault.

The chalcocite deposit is overlain by 100 to 300 feet of highly silicified schist from which all but a trace of copper has been leached.

The east boundary between mineralized and unmineralized schist is largely covered by talus, but in the few places where it can be seen, it is marked by a zone of intense brecciation that probably is the outcrop of the Cactus fault. The breccia fragments show random orientation as a result of rotation, and they are bound together by a matrix of finely ground rock that is firmly cemented by silica and limonite. Large and small fragments of apparently unaltered schist are common in the breccia. The best exposure is in an opencut from which 50 to 100 tons of oxidized ore has been mined. At this point, the breccia zone appears to have a westward dip of 30° to 40°

In the northern part of the schist outcrop, there is a small area of unmineralized schist that is bounded on the north, west, and south sides by steep faults. It apparently is the outcrop of an up-faulted block of the schist that underlies the Cactus fault. At the eastern side the block is overlapped by a mass of schist breccia that is no doubt a small remnant of the thrust plate.

A thrust fault that probably is an offset segment of the Cactus fault strikes north along the west side of Pinto Creek, 3,000 feet northwest of the Hamilton shaft. This fault is well exposed for about 2,000 feet, and strikes approximately north and dips 20°–30° W. The hanging-wall block is of unaltered schist which has been thrust over the Whitetail conglomerate and the diabase. To the north, the outcrop of the fault is overlapped by dacite; and at the south, the fault is cut off by a normal fault, although the inferred intersection of the two faults is concealed by alluvium in the bed of Pinto Creek. The normal fault is roughly parallel with the Kelly fault, and the block between has been relatively depressed so as to bring dacite into contact with schist of the thrust plate above the Cactus fault.

The copper-bearing rock that forms the Cactus deposit is reported to contain chalcocite, a little pyrite, and copper carbonates and silicates. Some of the carbonates, particularly in the upper part of the deposit, undoubtedly were formed by alteration of chalcocite. The most metallized rock is generally in the lower part of the deposit, just above the Cactus fault, which itself is richly metallized with copper carbonates and silicates that coat breccia fragments or fill interstices between them. These minerals are regarded as a direct deposit from supergene solutions that percolated downward through the shattered mineralized schist into the gently-dipping fault zone where much of their dissolved copper was deposited.

The protore of the deposit has not been described, and probably it was not found in the course of exploration. No doubt it is similar to that of the other disseminated deposits of the district, in which the hypogene sulfides consist mainly of pyrite and chalcopyrite.

The host rock, as seen in the outcrop, is highly silicified schist containing some sericite but generally much less than in most local varieties of unaltered Pinal schist. It is stained light brown by residual limonite; the color is generally a little deeper than the leached-schist capping that overlies the Miami-Inspiration ore body. In the most highly altered schist, all semblance of foliation has been destroyed.

The major brecciation clearly occurred after the hypogene metallization. Veinlets have been offset by fractures; and where brecciation was most intense, fragments have been rotated and veinlets do not continue into the matrix. Fragments of relatively unaltered schist commonly are completely surrounded by fragments of altered rock.

It is uncertain whether the supergene enrichment of the deposit took place before or after the plate had been thrust into its present position. If, as appears probable, the Cactus fault and the fault that crops out west of Pinto Creek are one fault, its age can be established very closely. It is younger than the Whitetail conglomerate but is older than the dacite, and therefore was formed during the interval of erosion that preceded the eruption of dacite. Much of the supergene enrichment in the district took place during this interval. The drilling logs record that altered schist underlies dacite in the depressed block in the hanging wall of the Kelly fault, but there is no mention that copper was present either as sulfide or carbonate in the altered rock. If copper is really absent, this condition suggests that the plate of altered schist had been at least partly oxidized and leached before it was thrust into its present position. However, the information contained in the logs is too meager and incomplete to constitute more than suggestive evidence. Criteria based on the relationship of the top of the chalcocite zone to present topography or to that preceding the deposition of the dacite are not conclusive. It is certain, however, that much of the oxidation, leaching, and deposition of copper carbonates and silicates was accomplished during the present cycle of erosion after the plate had been thrust to its present position.

The source of the mineralized schist is purely a matter of speculation. If it can be assumed that the overriding plate has been thrust up the dip of the fault surface, the present attitude would indicate that the mineralized block had been thrust from the west or southwest; but the rocks in this general area have been much faulted and tilted, and the present attitude does not necessarily represent the initial attitude of the fault. A possible source is suggested by a small body of altered schist having the characteristics of leached capping that crops out under the dacite cliffs on the west side of Powers Gulch 1¼ miles west-southwest of the Cactus deposit, but there is no direct evidence that the two bodies of schist are in any way related (p. 140).

COPPER VEINS

The copper-bearing veins of the Globe Hills area have yielded less than 20 percent of the total metal produced from the district, but nevertheless, their contribution amounts to nearly a billion pounds of copper and more than $9 million in gold and silver. The major part of the production came from the Old Dominion, United Globe, Arizona Commercial, and Iron Cap mines, all on the Old Dominion vein system. Similar deposits of considerably less importance are the Great Eastern, Buckeye-Black Oxide, Dime-Stonewall, Big Johnnie, Maggie, Josh Billings, Buffalo, Original Old Dominion, I.X.L., and Highline veins.

In all these veins, the principal hypogene minerals are quartz, pyrite, chalcopyrite, bornite, and specular hematite. Cuprite that is intergrown with specular hematite may also be hypogene. Sphalerite and galena occur locally in very small amounts, and a little tetrahedrite and enargite have been reported (Adams, S. F., written communication 1917), in the ores of the Old Dominion mine.

The veins were formed by replacement of breccia and wall rock along faults and fissures that cut upper Precambrian and Paleozoic sedimentary rocks and bodies of diabase intruded into them. Undoubtedly the veins continue downward into the underlying Pinal-schist, but the few that have been followed down to the schist were found to be poorly mineralized. Some of the veins, the Old Dominion for example, are along faults that have displacements of several hundred feet, whereas others follow fissures with little or no displacement. The largest and most continuous ore bodies are along faults or segments of faults having relatively large displacements.

In general, the ore does not appear to be limited to definite shoots of great vertical extent but rather seems to be localized in areas of the fault zones that show a definite relationship to the formations traversed by the faults; that is, the character and volume of the vein matter differ from place to place, according to the type of wall rock. Except for limestones of the Paleozoic age, the differences are due mainly to the physical characteristics of the rocks that affect the permeability of the fault zones rather than to the chemical character of the rocks.

Very abrupt changes occur where veins pass from one type of rock to another. The Paleozoic limestones were the most readily replaced and commonly contain thick lenses of very rich ore. In some places, flat tabular ore bodies extend outward along certain especially favorable beds as far as a hundred feet from the vein fault. Extensive ore bodies have been mined between walls of Mescal limestone and between walls of the various quartzite and sandstone formations or any combination of these formations. Good ore bodies may be found also where diabase forms one wall and any of the sedimentary formations the other; but where both walls are of diabase, the vein fault is likely to be tight and poorly mineralized or entirely barren.

The productive parts of the veins in the Old Dominion and other mines have long been inaccessible for inspection, and no detailed descriptions of the veins are available. Ransome's (1903, p. 125–128) decriptions deal almost entirely with the highly oxidized, near-surface ore bodies. Apparently the veins pinch and swell and range from a single quartz stringer to broad zones of wholly or partly replaced breccia, or lodes comprised of several to many irregular, discontinuous stringers. The character of the vein changes abruptly with changes of wall rocks. Where the vein faults traverse quartzite, the veins are zones of loose, angular breccia in which the vein minerals occur as replacement films or crusts coating the rock fragments and locally, fill the spaces between the fragments. In other places, the vein faults contain only sporadic deposits of quartz, coarse granular pyrite intergrown with some chalcopyrite, and specular hematite. Specular hematite is commonly present in otherwise barren parts of the vein faults, and it may continue far beyond the limits of areas characterized by quartz and sulfides.

Most of the copper veins have been affected by supergene enrichment, much that probably occurred while the veins were exposed during the interval of erosion that preceded the eruption of dacite, because rich chalcocite ore and some leached gossan are present under thick cover of dacite and Gila conglomerate. In the Old Dominion mine, ore in the enriched and oxidized parts of the vein contained from 3 to 5 times as much copper as the primary ore on the lower levels of the mine. Ransome (1903, p. 121) studied the Old Dominion mine at the time the transition zone between the completely oxidized ores and the secondary-sulfide ores was exposed on the 11th and 12th levels. In this zone, all the chalcopyrite and most of the pyrite had been replaced by chalcocite.

The leached zone, which undoubtedly was formed at the time of enrichment, is rarely preserved below the outcrops of the copper veins, and oxidized ore generally extends to within a few feet of the surface. In the western part of the Old Dominion vein and along some of the smaller veins, during the later part of the interval and during recent times, erosion has largely removed the leached zone and, in some places, part of the chalcocite zone. Because most of the acid-forming pyrite had been replaced, there was little movement of copper, and the chalcocite was oxidized in place to carbonates, cuprite, and native copper. In some places, oxidation penetrated to the underlying zone of primary sulfides.

Where limestone forms one or both walls, as in the upper parts of the Old Dominion vein southwest of the Copper Gulch fault, there were large bodies of rich oxidized ore within a few feet of the surface. These were due partly to enrichment and partly to much hypogene mineralization of the limestone. In spite of the reactive carbonate wall rock, considerable enrichment is known to have occurred within the vein because of the abundance of chalcocite below the oxidized ore. There was also considerable enrichment in the limestone as a result of direct deposition of copper carbonates from supergene solutions. Masses of copper carbonates that show no evidence of having formed by oxidation of sulfides in place are common in limestone along the veins.

OLD DOMINION AND UNITED GLOBE MINES

HISTORY

The early chronicle of the Globe-Miami district is largely the history of the discovery and development of the Old Dominion and United Globe mines.

After temporary subjugation of the Apache Indians in 1874, a party of prospectors from Florence came up the valley of Queen Creek to the present site of Superior and up Silver King Wash to the present site of the Silver King mine. From there they followed a trail built by General George Stoneman over the high, dacite-covered mesa to Pinal Ranch and down to the present site of Miami by way of Bloody Tanks Wash. They prospected the Globe area and located the Globe claim on the Old Dominion vein. On their return trip, they discovered and located claims on the Silver King deposit near the foot of the Stoneman trail. A short time later, the silver lodes at McMillanville and Richmond Basin were discovered, and the Globe claim, destined to become one of the richest copper producers of the district, received little or no attention.

Production of silver from the Stonewall Jackson mine began in 1878 and from the McMorris in 1880. Other silver deposits in the Globe-Miami and Richmond Basin areas were discovered and worked during the period from 1878 to 1893, including the Centennial, Ramboz, Rescue, Fame, Democrat, Mexican, Comet, Grand Prize, Silver Era, Turk, LaPlata, Silver Nugget, Hannibal, Washington, Robert E. Lee, Little Mac, Black Prince, Esperanza, and Providence. According to the Globe City Chronicle, there were 20 organized mining companies in the district in 1880, and 12 plants treating gold and silver ores had a total of 82 stamps.

From 1878 to 1893, the production of silver from the Globe and Richmond Basin areas amounted to about $3.650 million. Silver mining practically ceased after 1893, owing to the exhaustion of the rich near-surface ores and the decline in the price of silver.

The copper deposits of the district received little attention until 1881. In that year the Old Dominion Copper Co. was organized to develop a small copper vein in schist on the New York claim in Smelter Canyon near what is now the western edge of Miami. A small copper furnace was erected nearby in Liveoak Gulch. The deposit proved to be only a small pocket, and the mine was soon abandoned. The smelter was moved to Globe, and it operated for a short time on siliceous copper-gold ore from the Original Old Dominion mine on Pinal Creek, 3½ miles northwest of Globe.

In 1882 the Long Island Copper Co. and Buffalo Mining and Smelting Co. were organized to work the present Old Dominion and Buffalo veins. Both companies built small smelters and produced some copper. The following year the Old Dominion Copper Co. purchased the holdings of the Long Island Copper Co., which included the Globe, Globe Ledge, and Alice claims. From this time on the mine became generally known as the Old Dominion.

In 1887 the Buffalo mine and smelter were leased to Alex Trippet, and the mine was operated by him and his associates until November 1891, when it was purchased by Phelps, Dodge & Co. The latter company consolidated several properties, including the Buffalo, Hoosier, Gray, Cuprite, and other claims adjoining the Old Dominion holdings on the north and east, under the name United Globe Mines Co.

In 1886 the Old Dominion property was sold at auction to William Keyser of Baltimore, the reported price being $130,000. The Old Dominion Copper Co. was reorganized in 1888, and the sixth level was opened from the new Interloper shaft. Production continued at an average rate of about 7 million pounds of copper per year until July 1895 when the Old Dominion Copper Co. was sold for $1 million to the Lewisohn-Bigelow interests and reorganized as the Old Dominion Copper Mining and Smelting Co. The mine was closed, and the plant enlarged, in anticipation of the arrival of the railroad to Globe. Until this time the mines had operated under great difficulties. English coke was used for smelting, and all supplies had to be hauled by wagon from Willcox, a distance of 120 miles. Lack of fuel caused frequent shut downs, and only the richest oxidized ore could be mined at a profit.

The Gila Valley, Globe, and Northwestern Railroad was organized in 1894 and began building a line from Bowie toward Globe. The line was completed to Geronimo, 50 miles from Globe, in January 1896, and mining was resumed on a limited scale. The Old Dominion mine had been developed to the 8th level, and the first serious trouble with water began.

United Globe Mines Co. had enlarged its plant in 1895, and it, also resumed operations in 1896, directed chiefly to the development of the Hoosier claim, which had produced some high-grade ore from deposits in limestone near the surface. During the next three years, both companies continued to expand their plants. In the meantime the railroad was completed to Globe on December 1, 1898.

Toward the end of 1901, the shareholders of Old Dominion Copper Co. had ragained control of the property from the Lewisohn-Bigelow interests. The mine had been opened to the 12th level, and further difficulty was experienced with water. New pumps were installed, and the mine was finally drained to the 12th level in 1903.

In December 1903, the Old Dominion Copper Mining and Smelting Co. and United Globe Mines Co. were acquired by the Old Dominion Co., which had been organized as a holding company under control of Phelps, Dodge & Co. The two properties were placed under the management of L. D. Ricketts. A new smelting plant was built, and the "A" shaft was sunk. A concentrator was started and completed early in 1905. For the next 10 years, the mine produced at an average rate of about 27 million pounds of copper a year. A new concentrator designed by H. Kenyon Burch to use the flotation process was begun in 1912 and completed in October 1914. The mine had been opened to the 18th level, and it was necessary to pump about 3.75 million gallons of water per day to keep the workings drained.

After unusually heavy rains during the later part of 1914 and the first months of 1915, the inflow of water increased rapidly (Beckett, 1917). By the middle of January, 6.5 million gallons a day was being pumped and by the middle of February, 10.2 million gallons a day. On February 26, the water pumped from the mine exceeded 12 million gallons and on March 3, amounted to 12.6 million gallons. The next day there was a great inrush of water that threatened to flood the entire mine, and 14 million gallons of water was pumped that day. Every available pump was put in service, and temporary air-lifts were hurriedly installed in an attempt to save the mine. During the month of March, 407 million gallons were pumped. By extraordinary effort the flooding of the mine was prevented, and by the end of July the inflow had decreased to 4 million gallons a day.

Operations continued uninterrupted, except for a period of 6 weeks during the summer of 1917 when the mine was idle because of labor trouble. The smelter was permanently closed in November 1924, and shipments of ore and concentrate were made from that date on to the International smelter at Miami. The concentrator was remodeled and enlarged to a capacity of 1,400 tons of ore per day. Lower grade ore was being produced, but cheaper mining methods had been introduced that permitted profitable operation at the current price of copper. Late in 1930, the Old Dominion Co. purchased the property of Arizona Commercial Copper Co., which had recently ceased operations, owing to exhaustion of ore reserves.

At the beginning of 1931, the price of copper had fallen to less than 10 cents a pound. The 26th level of the Old Dominion mine had been developed with discouraging results. The known ore reserves had been almost depleted; and rather than continue to operate at a loss, the mine was closed October 14, 1931, after 50 years of almost continuous operation.

In 1940 all holdings of the Old Dominion Co. that are within the Globe-Miami district were purchased by Miami Copper Co. The Old Dominion mine has never been reopened, but serves as a valuable source of water for domestic and metallurgical use in the operations of Miami Copper Co.

PRODUCTION

During the period from 1882 to the cessation of operations in 1931, the Old Dominion and the United Globe mines produced approximately 765 million pounds of copper, 89,480 ounces of gold, and 4,536,000 ounces of silver having a total value of about $125 million. The early records from 1882 to 1895 are incomplete, and those available probably are not entirely accurate, but the production for this period accounts for only about 7 percent of the total value, and any inaccuracies should not affect the totals for the various metals to a noteworthy extent. The total dividends paid by the Old Dominion Co. from 1905 to 1931 amounted to $14,405,260.

DESCRIPTION

Ransome examined the Old Dominion and United Globe mines in 1901 and 1902, when he made his first study of the Globe copper district. His excellent descriptions of the mine and ore bodies were published in U.S. Geological Survey Professional Paper 12 in 1903. At the time of his study, the mine had been opened to the 12th level, but little, if any, ore had been mined below the 8th level.

He described the rich oxidized ore bodies that replaced the Paleozoic limestones in the hanging wall of the Old Dominion and Interloper faults, and noted (Ransome, 1903, p. 142) that they occur particularly along contacts between rocks of different kinds: between dacite and limestone, between limestone and quartzite, or between limestones of different lithological character. One of the largest ore bodies of this type occurred at the bedding contact between limestone and quartzite on the 2d level. This mass of ore is said to have been nearly 100 feet wide, 200 feet long, and about 60 feet thick. It dipped generally a little west of south at a low angle.

The lower levels of the mine at that time were in the transition zone between the oxidized ore and the secondary-sulfide ore. According to Ransome (1903, p. 144), chalcocite was first noted on the 5th level, or about 350 feet below the surface, but oxidized ore prevailed down to the 10th level or to a depth of 600 to 700 feet. The change to sulfide ore in the mine, as it was developed at that time, was between the 10th and 11th levels.

Prior to Ransome's study the dacite that overlies the upper Precambrian and Paleozoic rocks in the southwestern part of the mine (pl. 3), was regarded as a "trachyte" dike, mainly because it in turn was overlain by a "granite" (Madera diorite) that, although highly shattered, appeared to be practically in place. Attempts to locate the southwest continuation of the Old Dominion vein by driving through the supposed dike tapped the underground-water channels in the Gila conglomerate of the Globe Valley, thus causing a very serious water problem in the mine workings.

Ransome (1903, p. 146) recognized that the "trachyte" was part of the dacite sheet and also that a fault structure was responsible for its apparent anomalous relationships. He pointed out the futility of further exploration through the dacite and stated that the lower levels of the mine when extended southwestward would probably pass entirely beneath the dacite. He considered the shattered "granite" to be the basal part of the Gila conglomerate. On a later visit (1910, p. 256–257) he realized that the "granite" was a plate of Madera diorite that had been thrust over the dacite.

In 1913, John M. Boutwell was engaged to make a complete examination of the mine. After his examination, a geological department was created as an integral part of the mine organization. Guy N. Bjorge became chief geologist and later served as consulting geologist during the remaining operation of the mine. A. H. Shoemaker was chief geologist from 1926 to 1931. The following discussion is based entirely on a study of maps and records compiled by Mr. Bjorge and his associates. No attempt has been made to compile detailed descriptions of the veins and ore bodies. The purpose of this study has been to record the facts that would influence a decision to reopen the mines and explore for new ore bodies.

Since Ransome's first report was published, the Old Dominion vein has been developed to the 26th level, about 2,200 feet below the collar of the "A" shaft; and the mine workings have been extended 4,500 feet southwestward under the cover of dacite and Gila conglomerate. As will be seen from the longitudinal section along the vein (pl. 3), the stoping was mainly above the 18th level, where the material mined was largely either high-grade oxidized ore or enriched chalcocite ore.

The high-grade oxidized ore and the enriched chalcocite ore continued under the dacite as far as the stopes extend, but both become progressively thinner toward the west. Thus it appears quite obvious that much of the enrichment took place during the period of erosion that preceded the dacite eruption. Oxidation took place, but it is questionable that any appreciable amount of enrichment occurred during the present erosion cycle, except perhaps in the northeastern part of the area.

Undoubtedly, the migration of copper was greatly retarded by the reactive limestone wall rocks along the upper part of the vein, but the presence of chalcocite ore below the oxidized zone shows that there was nevertheless considerable downward movement of copper. During the enrichment period, much of the copper released by oxidation of the sulfides must have been converted to carbonates and remained more or less in place, so that no completely barren leached zone ever existed. However, in the central part of the vein where the limestone was most completely replaced by hypogene sulfides and nonreactive gangue minerals, progressive downward migration of copper continued as long as any pyrite remained in the vein matter. When all the pyrite had been either oxidized or replaced by chalcocite, further oxidation altered the chalcocite to copper carbonates and oxides which are stable in the oxidized zone. Ransome (1903, p. 144) observed that chalcocite appeared at higher levels than pyrite in the zone of transition from oxidized ore to enriched sulfide ore, showing that no pyrite was left in the upper part of the chalcocite zone.

During the later part of the period before the eruption of dacite, enrichment must have progressed very slowly if at all. Erosion removed the leached zone and exposed the underlying enriched chalcocite zone to the work of surface oxidation, which penetrated to depths well below the erosion surface. Southwest of the "A" shaft, erosion cut more deeply and probably more rapidly (p. 49) than in the area to the northeast, so that the work of oxidation reached nearly to the bottom of the enriched chalcocite zone, and from the southwestern limit of the stopes to the end of the mine workings, the enriched zone was largely eroded away. The limestones of Paleozoic age, which contained the largest and richest ore bodies, have been truncated by erosion so that they become progressively thinner toward the southwest and apparently have been completely removed in the area at the southwest end of the mine.

According to G. N. Bjorge (written communication, 1928) every known ore shoot in the mine, except the disseminated body on the 22d and 24th levels, has definitely bottomed in pyritic vein matter of very low copper content. The enriched chalcocite ore in the western part of the mine grades downward into primary ore of good grade, which in some places has persisted as much as 500 feet vertically before changing into low-grade pyritic vein matter (Bjorge and Shoemaker, 1933, p. 710). In the western part of the mine, the enriched chalcocite zone is thinner and invariably grades downward into low-grade pyritic vein matter. This observation would suggest that the top of the low-grade pyritic zone was approximately horizontal; and because of the deeper erosion in the western part of the vein before the eruption of the dacite, enrichment affected only low-grade protore of the pyritic zone. Such a condition would be a discouraging factor in the quest for new ore bodies southwest of the present limits of the mine.

Some primary-sulfide ore has been found in the pyrite zone, but its copper content was relatively low when compared with the average grade of the ore mined. The stopes below the 20th level, 1,800 feet west of the "A" shaft, are in a body of disseminated primary ore that G. N. Bjorge (1928, written communication) described as "clean chalcopyrite mineralization with minor amounts of bornite." The host rock is mainly diabase, which is relatively little altered and only moderately shattered. Chalcopyrite occurs in seams and veinlets or, to a less extent, is disseminated. This ore body is bounded on the south by the southward-dipping Old Dominion fault; on the west, it ends against a westward-dipping fault; and on the north and east, the limits are defined by the prevailing economic cut-off grade. The best ore containing as much as 3.5 percent copper, is along the footwall of the Old Dominion fault. Based on an arbitrary cut-off grade of 2 percent copper, the ore body, as defined on the 24th level, has an average width of 100 feet and a length of about 900 feet. The body has a known vertical extent of about 300 feet from near the 21st level to below the 24th level. On the 25th and 26th levels, the body has not been as systematically explored as on the levels above, apparently because the rock exposed by the trunk workings is too low in copper to be considered ore. The host rock on these lower levels is mainly quartzite that contrary to the general rule, was not as well mineralized as the diabase above. However, there probably are large tonnages of rock on these levels that contain 0.5 to 1.5 percent copper.

The disseminated copper minerals in this area appear to have been localized by the intersection of a system of northeastward-trending faults with the footwall of the Old Dominion fault at a very acute angle. The faults that are units of the system include the Buffalo, Maggie, and Josh Billings vein faults, all of which are mineralized and contained small ore bodies in the footwall block of the Old Dominion vein north of the "A" shaft.

Other places in which primary sulfide ore has been mined within the pyritic zone are east of the Grey shaft between the 14th and 18th levels and in the Maggie vein. In both of these places G. N. Bjorge (written communication, 1928) considers the change in the copper content of the rock as being definitely related to changes from diabase to sedimentary rocks in the walls of the veins.

RELATION OF MINERALIZATION TO WALLROCKS

Most geologist familiar with the vein deposits of the Globe area have stressed the influence of wallrocks on the mineralization of the vein faults; that is, on the volume and character of the vein material. The longitudinal sections, plate 3*A*, *B*, show the main workings and stopes of the Old Dominion and United Globe mines projected on a vertical plane parallel to the general strike of the Old Dominion vein, and also the rock formations in the footwall and hanging wall of the vein. The relative productivity of the various parts of the vein is roughly illustrated by the projections of the stopes. However, there are many stopes in the limestones of Paleozoic age on the upper levels of the mine that cannot be shown because adequate records of the early operations are not available.

The only place in which there has been extensive stoping where both walls of the vein are diabase is between the 10th and 16th levels in the vicinity of the "A" shaft. From the 10th to the 13th level, most of these stopes range from 20 to 30 feet in width; but from the 13th to 16th level, they narrowed to about 5 feet in width.

The presence of limestone or quartzite in one or both walls undoubtedly had an important effect on the amount of vein matter that was deposited in the fault zone above the 20th level, as was discussed on page 97. However, extensive sections of the vein below the 20th level should have been equally favorable, based on wallrock associations, but are not sufficiently rich in copper to warrant stoping. The downward change to the pyrite zone in which very little copper was deposited probably is a far more important cause of the bottoming of the ore shoots than the lack of favorable wallrocks on the lower levels of the mine.

Northeast of the "A" shaft, the position of the base of the sedimentary formations in the footwall of the vein probably ranges from about 50 feet below the 26th level, in the vicinity of the Kingdon shaft, to 350 feet below it at the "A" shaft (pl. 3); in the hanging wall its position is about 800 feet, plus the thickness of any diabase sills that may be present, below the 26th level at the "A" shaft. To these depths, the walls of the veins will be various combinations of Dripping Spring quartzite, Pioneer formation, schist, and diabase.

Southwest of the "A" shaft, the positions of the formation boundaries are known only vaguely. At the southwest end of the mine, the position of the base of the sedimentary formations in the hanging wall is at least 1,200 feet plus the thickness of any diabase sills that may be present below the 26th level. Beyond the southwest limits of the mine and below the 26th level, there are extensive areas of the vein fault in which the wallrocks are various combinations of Mescal limestone, Dripping Spring quartzite, Pioneer formation, schist, and diabase.

Projections made on the basis of known data indicate that the sedimentary formations gradually become thinner toward the southwest as the result of truncation by erosion preceding the eruption of dacite. The limestones and Troy quartzite of Paleozoic age have been completely stripped off at the southwest end of the mine, and there is no reason to suppose that they are present beyond the mine limits. The thrust fault between dacite and the overriding plate of Madera diorite would eventually cut out the dacite to the southwest and also the sedimentary formations. However, exploration by drilling shows that the thrust plate thins toward the southwest and the erosion that preceded deposition of the Gila conglomerate very probably cut through the gently dipping thrust fault and removed much if not all of the underlying dacite and possibly the sedimentary strata also. There is evidence that this erosion was very deep farther southwest (p. 56). The effects of any unknown normal faults in this area in preserving such rocks cannot be predicted.

Wallrocks of Pioneer formation and Dripping Spring quartzite were favorable for ore deposition in the Iron Cap mine along the northeastern part of the vein, but the vein in these rocks has not been productive on the lower levels of the Old Dominion mine. The only explanation for this difference is that the lower levels are entirely within the pyritic zone and are thus below the zone favorable for the deposition of copper minerals. The top of the Pioneer formation is about 2,500 feet lower in elevation at the southwestern end of the Old Dominion mine than in the Iron Cap mine.

The possibility of finding ore in the Pinal schist will be one of the chief considerations in the quest for new ore bodies below the 26th level of the Old Dominion mine. There appears to be no theoretical basis for assuming that the schist is less favorable as a host rock than the arkosic quartzites of the Apache group or the Troy quartzite. Some units of the schist are very arkosic and have a strong tendency to form clayey gouge, but many units are relatively pure quartz sandstone. Development of the vein in schist has been rather limited in scope, but so far as can be determined, there are no places in the mine where schist wallrock shows an adverse effect on the intensity of metallization as compared with that of other rocks.

East of the Iron Cap shaft, between the 11th and 14th levels of that mine, a small body of primary ore has been mined between Pinal schist in the footwall and Pioneer formation in the hanging wall. The indicated width of the stope is only 5 or 6 feet, but the ore body had contracted to this size several hundred feet above the top of the schist, where the wall rocks are of Pioneer formation and Dripping Spring quartzite. The bottom of the stope, at elevation 2,700 feet, is roughly the elevation of the top of the pyrite zone east of the Budget fault.

It appears that favorable wallrock is an important factor within the zone in which copper minerals were deposited. Portions of the vein fault that have sedimentary rocks in one or both walls are more likely to contain ore bodies than parts where both walls are of diabase, probably because of differences in the permeability of the fault in these rocks. Also, some of the sedimentary rocks are more favorable as host rocks because of their physical character and some are more susceptible to replacement by ore minerals than others. The limestones of Paleozoic age, particularly the Escabrosa, are the most favorable rocks; and the shaly beds of the Apache group are the least favorable (Bjorge and Shoemaker, 1933, p. 713). However, below a certain horizon, which is roughly at elevation 2,200 feet near the "A" shaft and about 500 feet higher near the Iron Cap shaft, the vein is generally poor in copper, regardless of the type of wallrock. This horizon probably marks the top of the pyrite zone. The principal exception to this general rule is the body of disseminated pyrite, chalcopyrite, and bornite west of the "A" shaft between the 21st and 24th levels. This relatively low grade copper ore body may be related to a deeper copper-bearing zone in the branch faults whose intersections with the footwall of the Old Dominion fault appear to have prepared the ground for deposition of the disseminated minerals.

BUFFALO MINE

The Buffalo mine is at the southwest end of Buffalo Hill, about a mile north of Globe. It was first worked on a small scale for silver; but later, beginning about 1882, it was developed as a copper mine by the Buffalo Mining and Smelting Co., which in 1891 became part of a consolidated group of properties operated by the United Globe Mines Co., These properties were acquired by the Old Dominion Co. in 1903 and sold to Miami Copper Co. in 1940. The main ore bodies had been largely removed, and the mine was idle at the time Ransome (1903, p. 151–152) examined the property in 1901. The mine has been reopened by leasers at least once since that time, but no records of these later operations remain.

In the mine two steeply dipping mineralized faults that crop out near the crest of Buffalo Hill (pl. 1) were developed. The faults join at the southwest end of the hill and toward the northeast diverge to a maximum separation of 350 feet. A narrow wedge-shaped graben of Martin limestone between the faults has been inset in Troy quartzite, which overlies a thick diabase sill and forms the top of Buffalo Hill (pl. 4*C*).

The main fault probably is the east branch; it was formed before the intrusion of diabase, and the block to the southeast was relatively depressed. This fault apparently intersected the Old Dominion fault a little northeast of "B" shaft. The movement on the west branch that caused the block of Martin limestone to be inset also may have occurred at this time. Later a thick diabase sill was intruded under the conglomerate at the base of the Troy quartzite on both sides of the fault; but on the southeast side of the fault, a sill-like apophysis of the main body was intruded into the Troy, splitting off the lower part of the depressed block. The top of the apophysis was about on the level of the base of the Troy northwest of the fault. The displaced block of Troy under the sill-like apophysis is now bounded on the southeast by the Old Dominion fault and is almost completely surrounded by diabase. The discordant contact between Troy quartzite and diabase, shown on plate 3*A* as just east of the "B" shaft, is regarded as being approximately the trace of the intersection of the Buffalo and Old Dominion faults. Slight displacement on the old fault after the intrusion of diabase opened a thin channel through the diabase sill. The trace of the fault in the diabase at the southwest end of Buffalo Hill is, however, too obscure to be recognized.

The mine had three levels entered by three adits driven from the southwest end of Buffalo Hill. The upper adit, at elevation 4,025 feet, is about 100 feet below the trace of the fault on the southwest crest of the hill and follows the fault for about 2,000 feet northeastward. It was driven in the quartzite a few feet below the base of the limestone in the inset block. The lower adit, 170 feet below the upper adit, is entirely in diabase and follows a narrow fissure that Ransome states is not mineralized. Several crosscuts to the northwest failed to reveal the second fissure. An intermediate level was driven 50 feet below the upper adit at or near the base of the quartzite.

The best ore occurred as replacement bodies in limestone along the two faults. The most extensive stopes follow the faults between the upper level and the surface, from the junction of the faults for about 700 feet to the northeast. The mine records show stopes in the quartzite between the intermediate and upper levels under the northeastern end of the upper stopes. The records also show several small stopes in the diabase between the lower and intermediate levels. Apparently the fracture through the diabase was too tight in most places to provide more than small local feeder channels leading to the ore bodies in the overlying quartzite and limestone through which the faults are zones of loose, open breccia.

Ransome (1903, p. 152) described the ore as malachite, cuprite, and occasional residual masses or kernels of chalcocite that occurred chiefly as fillings of interstices and small fractures in the shattered quartzite. The replacement bodies in limestone had been mined out before the time of his examination.

JOSH BILLINGS VEIN

The Josh Billings vein crops out in the Troy quartzite along the crest of Buffalo Hill northwest of the Buffalo vein. The outcrops of the two veins are roughly parallel. At the southwest end of Buffalo Hill, displacement of the base of the Troy quartzite indicates that the throw on the vein fault is about 50 feet. Unlike the Buffalo vein, the Josh Billings vein is poorly mineralized where it cuts the Troy quartzite but is sufficiently mineralized in the underlying diabase so that it can be traced across the diabase outcrop with some degree of certainty (pl. 1).

The vein was explored during the early days of the district by three adits driven from its outcrop on the southwest flank of Buffalo Hill. No records of these workings are available, but Ransome (1903, p. 153) states that oxidized ore was being mined from the vein at the time of his examination. The vein has also been explored on several of the upper levels of the Old Dominion mine. Northwest of the "B" shaft, near the 6th level, the vein cuts acutely across a diorite porphyry dike (pl. 4*B*) and possibly follows the dike for a short interval. A little ore has been mined from the vein in the vicinity of this dike.

MAGGIE VEIN

The Maggie vein is about 300 feet northwest of the Josh Billings vein. It is along the fault whose trace is the boundary between diabase and dacite north from the "A" shaft (pl. 1). The vein was first explored by means of an adit crosscut driven from a point near the outcrop of the Josh Billings vein in the bottom of the gulch 1,300 feet north-northeast of the "A" shaft. From this crosscut, a drift followed the vein for 650 feet northeastward, whence a crosscut was driven southeast back to the Josh Billings vein. Ransome (1903, p. 153) states that a single body of very good ore had been stoped from the Maggie vein before these workings were abandoned.

The vein has been explored on some of the upper levels of the Old Dominion mine, but apparently little if any ore was found. Near the 16th level, the vein passes from diabase into Dripping Spring quartzite, and northwest of the "A" shaft between the 18th and 20th levels, a large body of good ore was stoped during the final years of operation. Bjorge (1928, written communication) cites this ore body as an example of copper ore occurring below low-grade, pyritic vein matter; but he attributes the change in type of metallization to the change in the wallrock from diabase to sedimentary rocks.

GEM MINE

The Gem shaft is near the top of Buffalo Hill, 1 mile northeast of the Old Dominion "A" shaft (pl. 1). It was begun by the Globe-Boston Copper Mining Co. and probably was completed by Globe Consolidated Copper Co. about 1909. Globe Consolidated Copper Co. merged with Cordova Copper Co. in May 1909, and the latter company continued exploration work from the shaft, at least through 1910.

From the shaft, reported (Stevens, 1908) to be 1,225 feet deep, extensive crosscuts on the 1,100-foot and 1,200-foot levels explore the Gem and Future veins. No record of these workings have been found, and the identity of these veins is uncertain. Possibly the Gem and Future veins are the eastward continuations of the Buffalo and Josh Billings veins respectively. Only small ore bodies were found. Shipments of ore reputed to have been made in 1909 and 1910 from the 1,200-foot level averaged 3.35 percent copper and $1.30 to the ton in gold and silver.

Apparently the shaft passed through the Troy quartzite that caps Buffalo Hill, and the deeper workings are entirely in the underlying diabase sill, for diabase and a little granite porphyry are the only rocks that can be seen on the dump. The mineralized rock on the dump contains quartz, specular hematite, and masses of coarsely granular pyrite intergrown with a little chalcopyrite.

ARIZONA COMMERCIAL MINING CO.

HISTORY

The Arizona Commercial Copper Co. was incorporated in January 1905 to develop two small groups of claims on the northwestward continuation of the Old Dominion vein. The Copper Hill group, comprising the Copper Hill claim and 3 fractional claims, covers the outcrop of the Old Dominion vein from the United Globe property to the Budget fault and was formerly owned by the Arizona Commercial Co. The Eureka group is a quarter of a mile farther northeast on the projected strike of the Old Dominion vein. It includes a segment of the Great Eastern vein on which the Matamora Co. had sunk the Black Hawk shaft and had done some development work.

The Arizona Commercial Copper Co. continued work in the Black Hawk mine and began sinking the Eureka shaft 800 feet west of the Black Hawk shaft. Shipments of high-grade ore from the Great Eastern vein were begun in July 1905; and by the end of the year, 50 tons of ore a day was being shipped to the Old Dominion smelter and a like amount to the Copper Queen smelter at Douglas. The Copper Hill shaft was started near the west boundary of the Copper Hill group, and considerable development work was done on the Old Dominion vein, but no ore was found.

Operations ceased late in 1910, owing to the financial failure of N. L. Armster, president of the company. The company was reorganized under the name of Arizona Commercial Mining Co., and a large block of shares was underwritten to provide working capital. Charles S. Smith, then president of the Old Dominion Co., was chosen president of the new company.

The mine was reopened in February 1912. The first work was limited to the 800-foot level off the Copper Hill shaft. Later the shaft was deepened, and development of lower levels continued. The first ore was found by a drift driven northeast of the shaft on the 1,200-foot level. An arrangement was made with the Old Dominion Co. to treat the ore in its new concentrator, then under construction. Regular shipments began in October 1914.

The mine produced continuously until in 1930, when all known reserves had been exhausted and the mine was closed. The property was sold to the Old Dominion Co. a few months later and was acquired by Miami Copper Co. in 1940, along with other properties of the Old Dominion Co.

PRODUCTION

From 1906 to 1930, the two Arizona Commercial companies produced about 92 million pounds of copper, 17,000 ounces of gold, and 580,000 ounces of silver with a total value of $15,650,000 (Elsing and Heineman, 1936, p. 92). The total dividends paid (1914–28) amounted to $2,346,250.

DESCRIPTION

The Copper Hill mine develops a segment of the Old Dominion vein west of the Budget fault and also a short segment of the Iron Cap vein that is generally considered to be the continuation of the Old Dominion vein east of the Budget fault. Access to the mine is by means of the Copper Hill shaft, about 1,000 feet west of the Budget fault, and the No. 2 shaft, whose collar is a few feet east of the trace of the Budget fault.

The Copper Hill shaft was started in the hanging-wall block of the Old Dominion vein, and the diabase sill intruded at the base of the Troy quartzite was penetrated (pl. 4*E*). Between the 500- and 600-foot levels, it intersects the Copper Hill fault, which offsets the vein to the northwest, so that below the fault the shaft is in the footwall block of the vein. A little above the 800-foot level the shaft entered Mescal limestone and continued in the sedimentary rocks of the Apache group to the 1,800-foot level, whence there was diabase to the bottom, on the 2,100-foot level.

According to the stope records, no ore was found west of the Budget fault down to the 1,200-foot level on which a body of primary-sulfide ore was cut by a drift east of the shaft. This body of ore continued down to the 1,900-foot level. It is the eastward continuation of the body of primary ore that was mined between the 14th and 18th levels, of the Grey shaft, in the Old Dominion mine (pp. 101–102). It coincides with a part of the vein in which both walls are of sedimentary rocks. No information has been found concerning the condition of the vein on the higher levels. One longitudinal section of the mine shows a thin body of oxidized ore along the intersection of the Old Dominion vein with the hanging wall of the Copper Hill fault, but no record of any stopes in this ore body has been found. From the 1,800-foot level down to the 2,100-foot level, the footwall of the vein is Pinal schist and the hanging wall is diabase. These lower levels explore the vein for distances ranging from 200 to 500 feet, mainly east of the shaft. No records of stoping below the 1,800-foot level have been found.

East of the Budget fault, diabase was penetrated in No. 2 shaft to the 500-foot level, below which the shaft passed through a complete section of Mescal limestone and Dripping Spring quartzite and bottomed in Barnes conglomerate a little below the 1,300-foot level.

A body of secondary chalcocite ore was found, in the Iron Cap vein about 350 feet east of No. 2 shaft, on the 600-foot level. It had a vertical height of about 300 feet and plunged about 15° toward the southwest. West of the shaft it ended against the Budget fault, the bottom near the fault being a little below the 1,200-foot level. A few scattered stopes between the bottom of the chalcocite body down to the 1,500-foot level probably are in primary ore. The chalcocite body continues northeastward into the Iron Cap property. The sill of the deepest stope east of the Budget fault is at elevation 2,550 feet.

The Eureka mine of the Arizona Commercial Mining Co. is separated from the Copper Hill mine by the property of the Iron Cap Copper Co., which covers an interval of about 3,300 feet along the Iron Cap, or Old Dominion, vein. The workings of the Eureka mine are mainly on the Great Eastern vein, which has been regarded as the northeast continuation of the Black Hawk vein in the Iron Cap and Copper Hill mines east of the Budget fault. The Great Eastern vein will be discussed in the description of the Superior and Boston mine to follow (p. 110).

The vein developed in the Williams mine of the Iron Cap Copper Co. probably is the Iron Cap vein, or at least a major branch of it, and continues into the Eureka property; but apparently the northeastern limit of mineralized rock of economic grade and volume is near the property line, about 500 feet southwest of the Eureka shaft. On the Williams 767-foot level, which is 18 feet higher than the Eureka 700-foot level, stopes extend to the property line; but on the higher and lower levels, mining stopped short of the line. The vein continues into the Eureka property but intersects the footwall of the Great Eastern vein on the Eureka 580-foot level, about 400 feet southwest of the Eureka shaft. Projected northeastward, the intersection of the two veins plunges downward and has not been exposed on the lower levels of the Eureka mine. The vein was poorly mineralized and not clearly defined on the lower levels of the Williams mine, so that there was little to encourage exploration for the vein on the deeper levels of the Eureka mine. The base of the sedimentary formations on the footwall side of the Great Eastern vein is on the 1,000-foot level of the Eureka mine, so that below the present workings the walls of the Iron Cap vein are entirely of diabase and Pinal schist. The bottom of the stopes at the northeastern end of the Williams mine is about 20 feet below the 966-foot level and about 95 feet lower than the 800-foot level of the Eureka mine.

IRON CAP MINE

HISTORY

The Iron Cap Mining Co. was organized to prospect a group of seven claims, most of them fractional, that lie between the Copper Hill and Eureka properties of Arizona Commercial Mining Co. The extent of the work accomplished by this company is not known; but one shaft, probably the Williams, was sunk to a depth of 130 feet. The company had financial difficulties, and the property was taken over by National Mining Exploration Co. in November 1905.

National Mining Exploration Co. drove the Williams shaft to a depth of 802 feet. A crosscut on the 350-foot level reached the Great Eastern vein in 1908, and by June 1910 the Iron Cap vein had been cut on the 667-foot level. Both veins were oxidized and leached, and no ore was found. The Iron Cap shaft was sunk to a depth of 600 feet.

In order to finance further development, a loan of $100,000 secured by a mortgage on the property was obtained from N. L. Armster, who was then president of Arizona Commercial Copper Co. In September 1910, Armster failed financially; the note was called and the mortgage foreclosed. The company went into receivership and all work ceased. A reorganization was effected by incorporation of the Iron Cap Copper Co. Funds to continue development were obtained by assessing National Mining Exploration Co. stock 20 cents a share when it was exchanged for common stock of Iron Cap Copper Co. Preferred shares were issued for the assessment.

The mine was reopened in July 1912 under the management of F. A. Woodward. Within a month ore was found on the 667-foot level of the Williams shaft, and shipments of ore to the Old Dominion smelter began in September. The following year a contract was made with the El Paso Smelting Works, and shipments began at a rate of a car a week, mainly ore from development work, and were soon increased to 3 or 4 cars a week. Both the Williams and Iron Cap shafts were deepened, and development of the mine progressed at a rapid rate. The Bird group of claims, which adjoins the original group on the north, was acquired in 1915.

During World War I shipments of high-grade ore to the El Paso smelter increased steadily; and beginning in April 1917, lower grade sulfide ore was treated in the Old Dominion concentrator. In 1919 the Iron Cap company started construction of a 300-ton concentrator which was completed in June 1920. During the construction period, the company leased one section of the new concentrator of Inspiration Consolidated Copper Co. The mine was inactive from February 1921 to February 1922, because of the low price of copper.

From 1919 to 1925, operations were handicapped and profits greatly reduced, owing to litigation. In February 1919, Arizona Commercial Mining Co. filed suit in the State of Massachusetts, charging the Iron Cap Copper Co. with wrongful extraction of ore in excess of 250,000 tons valued at $3 million. The suit was based on alleged geologic evidence that the North vein, which cropped out on claims owned by the plaintiff, is the northeastward continuation of the Old Dominion vein and is the upper part of the Iron Cap vein that had been displaced by the Black Hawk fault. The Massachusetts court refused to hear the charges and directed that they be heard by a court in Arizona. The Arizona Commercial Mining Co. then filed suit in Maine asking an injunction to prevent Iron Cap Copper Co. from disposing of any of its assets until settlement was made.

In October 1920, the Iron Cap Copper Co. filed a counter-suit in Arizona to quiet title, and proceedings in Maine were stayed, pending the decision of the Arizona court. The transcript of the hearing, which took place in December 1921, comprises 571 pages of testimony presented by such eminent geologists and mining engineers as Guy N. Bjorge, Richard N. Hunt, Fred Searles, Jr., S. Louis Ware, Robert R. Boyd, and Horace V. Winchell. After prolonged litigation involving injunctions that greatly hampered work in the mine the suit was finally settled in November 1925 in favor of Iron Cap Copper Co.

In the meantime the known ore reserves had been almost exhausted. The concentrator was closed in November 1926 because its operation became unprofitable, but production of silicious smelting ore continued until November 1927. The concentrator and other equipment were dismantled in 1927, an most of it was moved to Christmas, Ariz., where the company had acquired control of the Gila Copper Sulphide Co., which then owned the Christmas copper mine.

PRODUCTION

From 1912 to 1927, The Iron Cap Copper Co. produced about 60 million pounds of copper, 4,475 ounces of gold, and 1,256,500 ounces of silver valued at approximately $11,700,000 (Elsing and Heineman, 1936, p. 92). The 683,000 tons of ore produced during the life of the mine averaged about 5 percent copper. The total dividends were $1,071,397.

DESCRIPTION

Within the bounds of the Iron Cap property, the Old Dominion vein is commonly called the Iron Cap vein, although there can be little doubt as to its identity. It does not crop out east of the Budget fault, and its apex is its intersection with a low-angle, northward-dipping fault known as the Black Hawk fault. This fault is slightly mineralized and is commonly referred to as the Black Hawk vein.

The Iron Cap vein was developed by means of the Iron Cap shaft on the south side of Copper Gulch 1,000 feet east of the Budget fault and by the Williams shaft about 2,500 feet farther northeast. The general structure east of the Budget fault has been described on pages 52–53.

The Iron Cap shaft was started in diabase in the hanging-wall block of the Black Hawk vein, it passes through that vein into the footwall block about 160 feet below the collar (pl. 4*G*). Below the Black Hawk vein it is in the hanging-wall block of the Iron Cap vein; and from the 1,100-foot level to the bottom, at 1,550 feet below the collar, it is within 25 feet of the hanging wall of that vein.

On the 450-foot level, a crosscut driven N. 20° W. intersected the Iron Cap vein 200 feet from the shaft and the Black Hawk vein 600 feet from the shaft. Drifts along these veins northeast and southwest from the crosscut found no vein matter of ore grade, nor did crosscuts and drifts on the 600-foot and 700-foot levels. A body of good chalcocite ore was found in the Iron Cap vein on the 800-foot level. It was followed southwestward to the property line and northeastward 1,200 feet to a point at which the vein fault was interrupted by a zone of cross faults known as No. 1 fault. The chalcocite ore was continuous to the 1,100-foot level, and the vein has been stoped continuously from the 1,100-foot level to within a few feet of the 700-foot level, for an average distance of 1,600 feet along the fault from the west property line. A zone of oxidized ore averaging less than 50 feet in vertical dimension occurred along the top of the ore body.

No information has been found concerning the character of the vein in the interval between the top of the ore body and the intersection of the vein with the footwall of the Black Hawk vein. Apparently the vein in this interval has been oxidized and leached, for considerable downward migration of copper would have been necessary in order to produce the thick zone of chalcocite ore.

East of the shaft a body of primary ore has been mined below the chalcocite zone to the 1,400-foot level. The stoped length of the ore body ranges from 300 feet, on the 1,400-foot level, to 1,100 feet, on the 1,100-foot level. The sill floor of the deepest stope is at elevation 2,680 feet.

Along the most productive part of the vein between the 700-foot and 1,100-foot levels, the wallrocks are of Dripping Spring quartzite and Pioneer formation. Below the 1,100-foot level along the primary ore shoot, the hanging wall is of Pioneer formation and the footwall is mostly of diabase; but near the shaft, the footwall is Pinal schist on the 1,200-, 1,300-, and 1,400-foot levels. A little ore was stoped above the 1,300-foot level, just east of the shaft, where the footwall of the vein is schist.

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To test the possibility of finding ore bodies in the Pinal schist below the base of the Apache group three exploratory holes were drilled from the 1,400-foot level. The holes were started from a crosscut 200 feet northeast of the shaft on the hanging wall side of the vein (fig. 6).

Drill hole 1 was directed approximately at right angles to the strike of the vein, 150 feet southeast of the hanging wall and was inclined at 60° from horizontal. It passed from Pioneer formation into the schist at 155 feet (elevation 2,540 feet) and from the schist to diabase at 265 feet (elevation 2,444 feet). Vein material was reached at 293 feet and continued to the bottom of the hole at 504 feet. The vein matter is not adequately described in the logs, which state that it contained much hematite and some pyrite and chalcopyrite but assayed less than 0.1 percent copper.

Drill hole 2 was drilled at the same site as drill hole 1 but was pointed S. 85° W. to intersect the vein farther to the southwest; it was inclined 46° at the collar but steepened to 66° in its lower part. It went into schist at 137 feet (elevation 2,572 feet) and intersected the hanging wall of the vein at 273 feet. The richest part of the vein, from 303 to 315 feet, averaged 2.90 percent copper. At 326 feet, the hole entered diabase in the footwall and continued in diabase containing a few veinlets of hematite and pyrite to the bottom at 478 feet (elevation 2,265 feet.).

Drill hole 3 was drilled at right angles to the strike of the vein from a site at the end of the crosscut about 300 feet from the hanging wall of the vein on the 1,400-foot level. It was started at an inclination of 72° but had steepened to 80° at a depth of 300 feet. It passed from Pioneer formation into Pinal schist at 90 feet and from the schist into diabase at 317 feet. Schist was intersected from 835 to 955 feet and a fault zone of diabase gouge and breccia from 955 to 1,004 feet. The remainder of the hole to 1,120 feet is in diabase with a little schist near the bottom. The drill logs indicate that the fault zone cut in the hole from 955 to 1,004 feet was considered to be the Iron Cap vein fault, but this interpretation is questionable. It is quite possible that the hole is too steep to reach the vein.

The position of the base of the Pioneer formation in the three drill holes would indicate that the contact between the Pioneer and Pinal schist dips about 30° NE., whereas the general dip of the bedding recorded on the mine maps is 20°–30° S. This great difference in attitude is conclusive evidence that the contact is a fault, but there are no further data by which to clarify the structural details.

These drill holes have been described in as much detail as possible, because stratigraphically they constitute the deepest exploration made anywhere along the Old Dominion vein system. They give some information concerning the schist-diabase relationships that can be expected below the base of the sedimentary formations but do not prove that wall rocks of schist are unfavorable for ore deposition. The 1,400-foot level may well be at or near the top of the pyritic zone. According to the stope records, the vein on the 1,400-foot level opposite the drill holes has not been mined and therefore probably did not contain ore. The results of the drilling undoubtedly would have been of greater value had the holes been placed about 250 feet farther northeast under the portion of the vein that was productive on the 1,400-foot level.

East of No. 1 fault zone, between the Iron Cap and Williams mines, is a gap of at least 300 feet in which no ore has been mined. East of this gap, the fault structure is more complex, and the mine workings are too limited in extent and the geologic records too meager to give a clear picture of the relationships. The fault along which the productive vein occurs in the Williams mine undoubtedly is a part of the Old Dominion Iron Cap vein system, but the displacement on the vein fault is dying out to the northeast. At the Iron Cap shaft (pl. 4*G*), the vertical displacement of the Barnes conglomerate by the Iron Cap vein fault is about 400 feet, whereas at the Williams shaft (pl. 4*H*) it is no more than 100 feet.

The Williams shaft was started in diabase on the hanging-wall side of the Great Eastern vein. It reached the top of the Mescal limestone at a depth of 400 feet below the collar and the Great Eastern vein at about 650 feet. The first level is 667 feet below the collar, and four other levels were driven at approximately 100-foot intervals. The bottom, or 5th, level is at the same elevation (3,080 feet) as the 1,000-foot level of the Iron Cap mine. The 1st level is at the same elevation (3,480 feet) as the 580-foot level of the Eureka mine, which adjoins the Williams mine on the east.

Oxidized ore was found east of the shaft on the 1st level. It extended 50 to 80 feet above the level but secondary chalcocite ore is reached a few feet below the level. On the west side of the shaft there was little if any oxidized ore, and the top of the chalcocite ore was a little below the 2d level. The bottom of the chalcocite ore was about 30 feet below the 4th level on both sides of the shaft. The stopes extend northeastward to the property line on the 2d level, which is a little below the 700-foot level of the Eureka mine, but they become progressively shorter with depth. Ap-

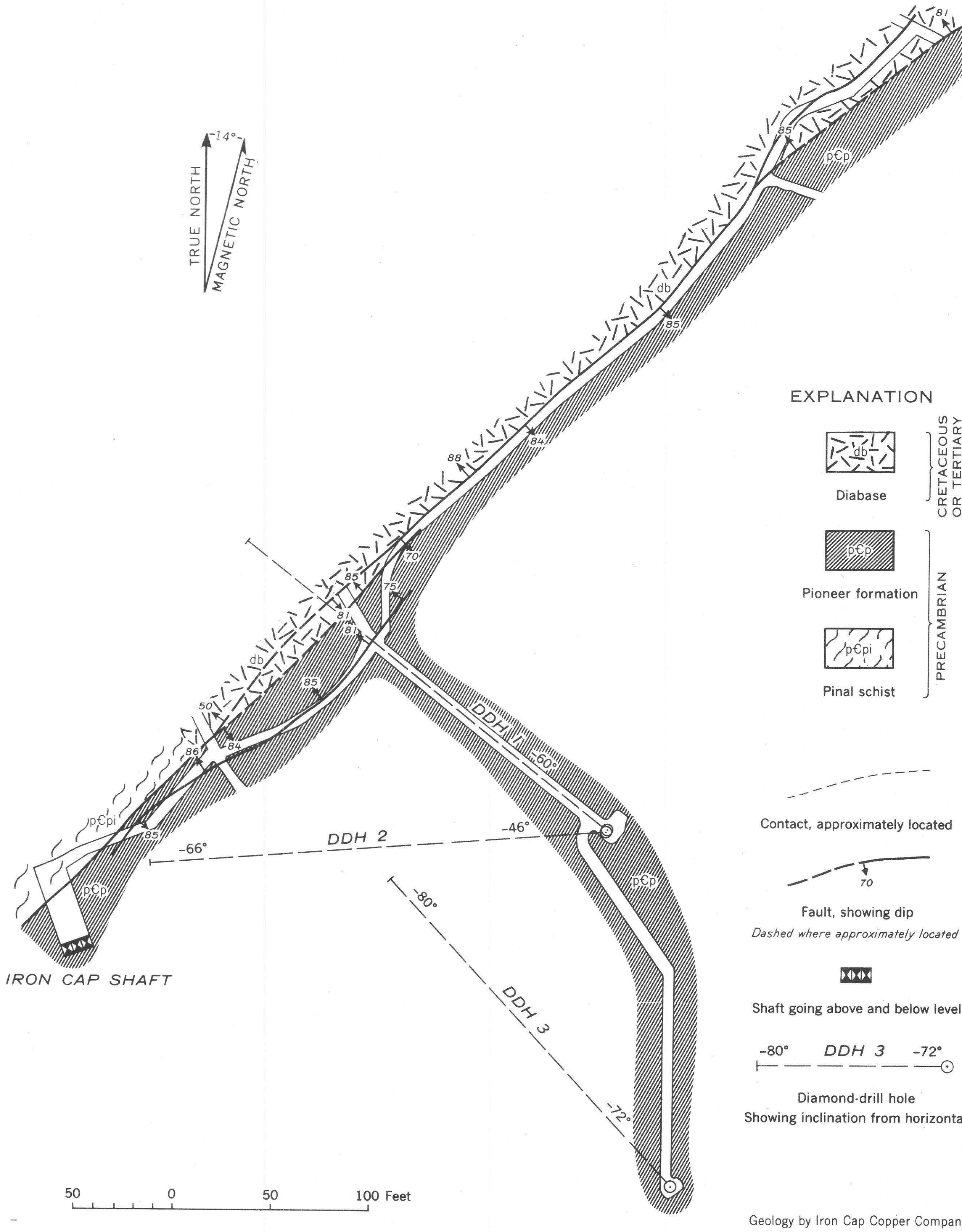

FIGURE 6.—Geologic map of the 1,400-foot level of the Iron Cap mine.

parently no primary vein matter of ore grade (about 4 percent copper in 1927) was found below the chalcocite zone.

After the Bird property had been acquired, the north crosscut from the Iron Cap shaft to the Iron Cap vein on the 800-foot level was extended in an effort to intersect and explore the Bird vein. The crosscut was driven N. 36° W., approximately on the line of section *G*, plate 4, and near the base of the Dripping Spring quartzite. At 920 feet from the shaft, it intersected the Black Hawk fault, and entered diabase. At 2,130 feet from the shaft, the crosscut intersected a strong fault zone striking about N. 5° W. that may possibly be the Budget fault, but, if so, the fault is practically vertical. Near this fault zone, the crosscut was turned to bear about N. 13° E. and continued in this direction for 600 feet. A mineralized fault zone was found about 2,430 feet from the shaft, but detailed descriptions of it are lacking. The company's annual report for 1920 states that at the close of the year the crosscut reached the Bird vein and passed through 5 feet of vein matter, 14 inches of which was highly mineralized. The vein matter was oxidized and was similar to that found in the shallow shafts sunk on the outcrop of the vein. The mine was closed early in 1921 and was not reopened until a year later. There is no record of further exploration of the Bird vein during the remainder of the life of the mine.

SUPERIOR AND BOSTON MINE

HISTORY

The Great Eastern claim, which includes the continuation of the Great Eastern vein east of the Eureka and Black Hawk mines of the Arizona Commercial Mining Co. and is one of a large group of claims originally owned by the Globe and Arizona Development Co. Very little work had been done on the claims before 1906, when the property was taken over by the Superior and Boston Copper Co. Development was begun in 1907, and a little copper ore was produced that year, probably from the Black Oxide claim, which contains the eastern part of the Buckeye vein. The Great Eastern shaft was started in 1907 and the Gardner and McGaw shafts, in 1908. Ore was found in workings off the Great Eastern shaft, and periodic shipments of ore were made to the smelter in El Paso. By the end of 1910 all the known ore in the Great Eastern vein west of the McGaw fault had been extracted, and the mine was closed.

The mine was reopened in March 1913. The continuation of the Great Eastern vein east of the McGaw fault was discovered, and a large ore body was mined from it. An extensive development program was begun in 1915. The Footwall vein was discovered and began to produce ore in 1919, providing the chief support of the development program for several years.

The Rigby vein was discovered in 1920. It was only 1 to 2 feet wide but contained rich copper-silver ore. On the 6th level, bunches of ore were found that are reported to have contained 25 percent copper and 300–400 ounces of silver to the ton. The high silver content of the Rigby vein is reflected in the production records from 1920 to 1926. The company's annual report for 1925 showed production for the year of 14,400 tons of ore that averaged 3.75 percent copper and 10.3 ounces of silver to the ton from four veins: 5,500 tons from the Great Eastern vein, 5,000 tons from the Footwall vein, 3,600 tons from the North vein, and 300 tons from the Rigby vein.

Operation by the Superior and Boston Copper Co. ceased early in 1927, after all the known ore reserves had been mined. The property was later sold for delinquent taxes. The Superior and Boston mine was never reopened, but in recent years a few small lots of ore have been shipped from shallow workings on the Buckeye and Great Eastern veins.

PRODUCTION

From 1907 to 1926, Superior and Boston Copper Co. is credited with a production of 19,556,000 pounds of copper and 1,343,000 ounces of silver having a total value of about $4.3 million (Elsing and Heineman, 1936, p. 92). At least 80 percent of the copper but only about 30 percent of the silver came from the Great Eastern vein. The rest was produced from the Footwall, Rigby, and North veins.

DESCRIPTION

The structure of the Great Eastern vein fault has been described on page 54. Records of the character and extent of the ore bodies along the fault are sketchy and incomplete. The southwestern part of the vein is on the property of the Arizona Commercial Mining Co. and was developed and exploited during the early days of the district by workings from the Black Hawk shaft and later in the Eureka mine.

The main shaft of the Superior and Boston mine, is the McGaw shaft, whose collar is about 650 feet northeast of the outcrop of the McGaw fault. The shaft was started in a diabase sill intruded into a basalt flow that overlies the Mescal limestone. It reached the top of the Mescal limestone at a depth of 454 feet, or 39 feet below the 4th level, and the top of the Dripping Spring quartzite at or near the 8th level. About 60 feet below the 10th level the shaft passed through the McGaw fault and into a diabase sill intruded between the Pioneer formation and the underlying Pinal schist. The sedimentary formations and intruded sills dip 15° to 30° SE.

The main ore body of the Great Eastern vein extended from the northeastern part of the Eureka mine into the Superior and Boston mine to the McGaw fault. An offset segment of the ore body continued northeast of the fault in the depressed hanging-wall block (pl. 6).

The vertical extent of the ore body appears to have been largely controlled by the wallrocks. Most of the ore occurred where the wallrocks are the Mescal limestone, Dripping Spring quartzite, and Pioneer formation; in the most productive parts being where the Mescal limestone forms the hanging wall and Dripping Spring quartzite the footwall. In general the vein was poorly mineralized where diabase forms one or both walls.

West of the McGaw fault, the top of the ore was about 100 feet above the 4th level of the Superior and Boston mine, the bottom was at or near the 10th level. The upper part of the ore body was oxidized, but some chalcocite appeared 50 feet above the 4th level; and from the 8th to the 10th level, the copper occurred mainly in chalcocite. On the 12th level west of the McGaw fault, the workings are entirely in the lower diabase sill; and the vein, though wide, is poorly mineralized. The 14th level, the bottom level of the mine, is entirely west of the McGaw fault. A crosscut driven northwest from the McGaw shaft on this level intersected the lower southeast-dipping contact of the diabase sill 130 feet from the shaft and passed into the underlying Pinal schist. The vein was cut 280 feet northwest of the shaft, but it was so poorly mineralized that the level was abandoned after 350 feet of drifting had been done.

The available records show the top of the stopes east of the McGaw fault as being about 60 feet above the 6th level, but it is possible that mining was continued up to or a little above the 4th level during the later years of the operation. The bottom of the ore ranged from 40 feet above the 8th level, near the McGaw shaft, to about 100 feet above the level, at the east end of the ore body. All the ore east of the McGaw fault is said to have been oxidized and to have changed at depth to pyritic vein matter containing very little copper. Drifts on the 6th, 8th, 10th, and 12th levels explored the vein fault for about 1,000 feet northeast of the ore body, but, according to C. W. Bostford (1919, written communication), the vein was very weakly mineralized.

By 1920 the ore bodies along the Great Eastern vein had been largely mined out, and much exploration work was done in the footwall and hanging wall of the vein. Crosscuts were driven northwest on every level to prospect the North vein. A little copper ore was found on the 8th level, but on all other levels the vein matter was composed chiefly of manganese oxides containing some silver but very little copper. The Footwall vein, which had been discovered earlier, was developed and soon became the chief support of the operation. C. W. Bostford (1919 written communication) decribes the Footwall vein as being 700 feet south of the Great Eastern vein and approximately parallel to it in strike and dip. It probably is the vein that crops out 300 feet northwest of the Limestone shaft (fig. 5).

The Rigby vein, whose location is not recorded, was discovered in 1920. It was only a foot or two wide but contained very rich copper-silver ore, some assaying 300 to 400 ounces of silver to the ton.

The Limestone shaft is 1,800 feet south-southeast of the McGaw shaft. It was sunk to explore the Limestone vein, which strikes N. 80° E. and dips 70° to 80° N. The shaft was started in Mescal limestone at the outcrop of the vein and passed into Dripping Spring quartzite at a depth of about 130 feet. Short crosscuts on the 100-, 200-, and 300-foot levels intersected the vein at short distances north of the shaft. On the 300-foot level, a drift to the east apparently cut the McGaw fault 240 feet from the shaft. A drift to the west followed the vein for 145 feet to a cross fault that displaces the vein 35 feet to the south. The offset segment was followed westward for 210 feet; it carried little copper but considerable manganese oxides and specular hematite. The vein ranged in width from a few inches to 5 feet and, according to C. W. Bostford, contained some small but good ore bodies in the upper shaly beds of the Dripping Spring quartzite.

The Gardner shaft is 2,850 feet south-southeast of the McGaw shaft, and started in diabase but intersected the top of the Mescal limestone at 28 feet below the collar. At 370 feet it passed from limestone into Dripping Spring quartzite and continued in it to the bottom at 435 feet. The lateral workings are all on the 400 level (elevation 3,721 feet) and explore mainly the Black Oxide or Buckeye vein, which will be discussed in a later part of this report (p. 112).

A small vein known as the Iron King crops out about 300 feet south of the Gardner shaft; it strikes N. 80° E. and dips 70° N. At the outcrop, diabase and Precambrian basalt form the footwall and Mescal limestone the hanging wall. The vein has been explored by a shaft 70 feet deep and a few shallow pits, but apparently little if any ore was found. Bostford states that a crosscut driven southeast on the 400 level of the Gardner shaft intersected the vein fault but found no copper.

The McGaw fault is generally regarded as being younger than the copper, but a communication by Frank H. Probert, which was written before the displaced eastern segment of the Great Eastern vein had been found, gives the impression that the McGaw fault was followed southeastward in the belief that it was the weakly mineralized continuation of the Great Eastern or another vein, but because the ore being mined at that time (1910) was almost completely oxidized, the ore minerals found along the fault probably were not very different from those found in the vein. Thus it is uncertain whether the minerals represent hypogene mineralization, or whether they were deposited by supergene solutions that contained copper leached from the main vein. The fault is now too poorly exposed to reveal the true relationships.

TELFAIR MINE

The Telfair shaft is about 1,600 feet north-northeast of the McGaw shaft and is on the Telfair claim, which is one of a large group of claims formerly owned by the Arizona & Michigan Mining Co. (fig. 5).

The shaft was started in a small outcrop of Dripping Spring quartzite that is almost completely surrounded by diabase. The south end of the quartzite abuts a much larger outcrop of Mescal limestone also surrounded by diabase (pl. 1). About 390 feet below the collar, the shaft passed from quartzite into diabase and continued in diabase to the bottom at 520 feet. The only lateral workings are on the 500-foot level. A crosscut 1,270 feet long was driven on a general bearing of S. 52° E. with the obvious purpose of reaching the North vein. It passed from diabase into quartzite, probably Dripping Spring, about 490 feet from the shaft and continued in this rock to the end. The crosscut intersected a fault zone about 1,100 feet from the shaft that may represent the North vein. Apparently the fault zone was not sufficiently mineralized to warrant exploration, for no drifting was done along it. The intersection of the crosscut with the fault zone is 1,600 feet northeast of the McGaw shaft and is about 20 feet higher in elevation than the 6th level of the Superior and Boston mine.

At a point about 140 feet from the shaft, a crosscut 550 feet long, bearing N. 30° W., intersected a fissure that strikes N. 75° E. and dips toward the northwest. Probably this fissure was mineralized, for about 150 feet of drifting was done along it. It may be the weakly mineralized fissure that crops out a few feet southeast of the shaft collar, although the fissure near the collar has a more northerly strike and a steeper dip than the fissure in the crosscut. At about 300 feet from the shaft, the crosscut passed from diabase into Barnes conglomerate and a few feet farther northwest entered quartzite that probably is Pioneer formation.

No record of any metal production from the Telfair mine has been found.

BUCKEYE DEPOSIT

The Buckeye vein, portions of which are also known as the Black Oxide and Carrie veins, crops out along the crest of Buckeye Mountain on the south side of Copper gulch (pl. 1). The general strike of the vein is about N. 65° E., roughly parallel to the Old Dominion vein; but its dip is 60° to 80° NW., whereas the Old Dominion vein dips southeast. The vein fault has a reverse throw of 100 to 150 feet, that is, the hanging-wall block on the northwest side has been elevated with respect to the footwall block.

Along the outcrop both walls of the vein are of Troy quartzite, which overlies a thick diabase sill. The sill was intruded near the base of the Troy quartzite, in some places above and in others below remnants of the Precambrian basalt flows that underlie the old erosion surface on which the Troy was deposited. On the northeast flank of Buckeye Mountain, basalt crops out both above and below the diabase sill.

The most extensive development work on the vein is adjacent to the Buckeye shaft (fig. 5) which was sunk by the United Globe Mines Co. on the outcrop in the gulch west of Buckeye Mountain. On the west side of the gulch, three adits explore the vein for about 1,400 feet southwest of the shaft (fig. 7). The lowest adit is at the level of the collar of the shaft, the other two are at 75 and 155 feet higher elevations respectively. The mine maps show several small stopes above the lower adit. There are three adits that were driven northeastward from the east side of the gulch. No records of these adits are available, but apparently narrow ore bodies were found which have been stoped to the surface.

The geologic maps of the underground working from the Buckeye shaft are far from complete, but they

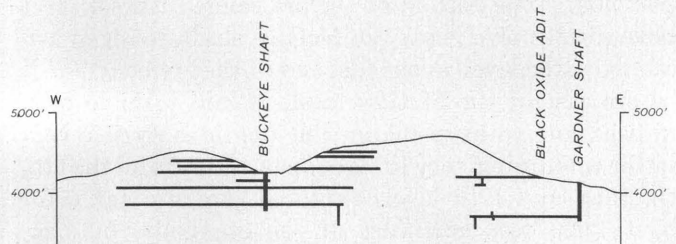

FIGURE 7.—Mine workings on the Buckeye-Black Oxide vein projected on a vertical plane through the Buckeye shaft and the Black Oxide adit, looking north.

show that the vein fault is a conjugate system of fractures rather than a well-defined regular break. They show also that in many places the drifts followed practically barren fractures. It is possible that in some of these intervals, crosscuts to the north or south would have found more strongly mineralized segments along parallel or branching strands of the fault zone.

On the 100-foot level, which extends for only about 350 feet southwest of the shaft, both walls of the vein are of Troy quartzite. Apparently no vein matter of ore grade was found. The 200-foot level extends 1,800 feet southwest of the shaft and about 1,000 feet northeast. In the vicinity of the shaft the level is between the offset upper contacts of the diabase sill and Troy quartzite. The hanging wall of the vein is diabase and the footwall is quartzite. Farther southwest both walls are quartzite, and northeast of the shaft both walls are diabase. For most of its extent, the 400-foot level, the deepest level of the mine, was driven in the diabase sill. The last 600 feet of the level southwest of the shaft does not follow any structure but appears to have been driven entirely in the footwall of the fault zone. At a point 1,300 feet southwest of the shaft, the drift crosses an intrusive contact between diabase and quartzite dipping 23° S. For 350 feet beyond this contact to the end of the workings, the drift is in the conglomeratic basal beds of the Troy quartzite. Since the drift is probably in the footwall of the Buckeye fault, it shows no evidence that the contact between the quartzite and diabase has been displaced.

The northeastern extension of the Buckeye vein into the property of the Superior and Boston Copper Co. is known as the Black Oxide vein. It has been explored by an adit known as the Black Oxide tunnel, which was driven southwestward from the east side of Buckeye Mountain. The adit was begun in the diabase sill on the projected strike of the vein, which appears to be almost vertical where it crops out near the top of the mountain 500 feet west of the portal. Actually the vein dips about 80° SE. in this area, and the adit proved to be a little north of the vein. The adit intersects the vein 660 feet from the portal, whence it continues for nearly 400 feet on the south side of the vein and approximately parallel to it.

At the intersection, the adit passes from diabase, which forms the north wall, into the Precambrian basalt which forms the south wall. Farther southwest, the drift enters the basal conglomeratic beds of the Troy quartzite, which dip 15° to 25° SW. Ore of minable width was found in the interval from 90 to 250 feet west of the intersection of the adit and the vein. A raise 110 feet high and a winze 109 feet deep were driven in the ore above and below the adit level.

At a point approximately under the ore body on the adit level, the vein was cut by a drift on the 400 level (elevation 3,720 feet) of the Gardner shaft, which is 500 feet east of the portal of the Black Oxide adit (fig. 7). At the place of intersection, the vein is 18 inches wide and Mescal limestone forms the north wall and diabase, the south wall. A winze sunk on the vein shows that from 60 feet below the level to the bottom of the winze 140 feet below the level both walls are of Mescal limestone. The top of the limestone in the north wall of the vein should be 40 to 90 feet above the level, as shown approximately on the cross section through the Eureka shaft (pl. 4*I*).

Some ore was mined from these workings, but the extent of the stopes is not known. According to Frank H. Probert (1910, written communication) the ore was oxidized and contained much calcite, specular hematite, and manganese oxides. The workings in the limestone cut many fractures containing manganese oxides and specular hematite but little if any copper.

A long crosscut from the 8th level (elevation 3,220 feet) of the McGaw shaft reached the Black Oxide vein at a point 500 feet below the 400 level of the Gardner shaft. At this level the vein is probably in Dripping Spring quartzite. According to Mines Handbook (Weed, 1925), some chalcocite ore was found but not in sufficient volume to warrant exploitation. The extent of these workings is not known.

The formations of the Apache group undoubtedly form one or both walls of the vein to a depth of 1,000 to 1,200 feet below the 400 level of the Gardner shaft. This condition is generally favorable for deposition of ore in all the developed veins of the Globe Hills area. As shown by the cross section through the Eureka shaft (pl. 4*I*), which cuts the vein near its northeastern limit, the top of the favorable zone is approximately at an elevation of 3,800 feet, or about 600 feet below the outcrop. Where the cross section through shaft No. 2 (pl. 4*F*) cuts the southwestern end of the vein, the position of the top of the Apache group is more uncertain, but it is probably near elevation 3,200 feet, or about 1,100 feet below the outcrop. All the interval of the vein between these limits, a distance of 3,400 feet, can be considered favorable for prospecting. In all the veins of the Globe Hills area the ore bodies formed where the physical character of the vein fractures was most favorable and alternate with intervals that have been more weakly mineralized, and therefore the fact that ore was not found in the workings from the 8th level of the McGaw mine cannot be considered proof that no ore bodies are present along the Buckeye vein within this zone of sedimentary wall rocks.

The vein matter that can be seen in the outcrops of the Buckeye fault and on the dumps of the mine workings consists mainly of quartz, specular hematite, and cuprite. The minerals are in small discontinuous veinlets and form crusts on fragments of fractured quartzite along the fault zone. They appear to have been deposited by hypogene solutions, for the veinlets and crusts have bleached borders in which the quartzite is partly replaced by sericite. There is no evidence that sulfides were ever present. Tovote (1914, p. 489) reports that he saw no pyrite, chalcopyrite, or bornite in the Buckeye vein to a depth of 800 feet except in one locality where he found a few kernels of chalcopyrite in oxidized ore less than 50 feet from the surface.

Malachite and chrysocolla are common and probably account for a large proportion of the copper content of the ores. These minerals seem to have formed partly by alteration of cuprite that is intergrown with specular hematite and partly by direct deposition from copper-bearing supergene solutions.

The copper production of the Buckeye mine must have been relatively small and probably was reported with that of the United Globe mines.

DIME AND STONEWALL DEPOSITS

Several prominent northeastward-striking faults crop out southwest of Buckeye Mountain in the large area that is underlain mainly by Troy quartzite and intruded bodies of diabase (pl. 1 and fig. 5). Most of these faults are mineralized to some extent and have been explored by many open pits, adits, and shallow shafts. The most extensive exploration in this area has been along the Dime and Stonewall faults.

The Dime and Stonewall faults form a continuous outcrop that has a general strike of N. 65° E. from Copper Gulch on the west to McCormick Wash on the east, a distance of 1¼ miles; but despite their apparent continuity, it is doubtful that they are the same fault or that they were formed at the same time. The Dime fault dips vertical to 55° SE., whereas the Stonewall dips vertical to 55° NW. The Stonewall fault may be the eastward continuation of a fissure striking northeast to east, known as the Arizona vein, whose outcrop joins the outcrop of the two faults just west of the Stonewall mine.

For 1,500 feet northeast of Copper Gulch, the Dime vein fault is practically vertical and forms the contact between Troy quartzite and diabase on the north and a depressed block of Martin limestone on the south. The base of the Martin probably is less than 50 feet below the outcrop of the fault. Two shafts, one known as the Dime shaft, have been sunk in this interval. No records of these workings are available, but it appears that little, if any, vein matter of ore grade was found. Along the rest of the Dime fault, as well as along the Stonewall fault and the Arizona vein, the outcrop on both sides are of Troy quartzite and intruded bodies of diabase.

A substantial amount of ore has been extracted from shallow workings on the Stonewall fault near its junction with the Dime and Arizona faults. About at the turn of the century, the Stonewall mine was operated intermittently for several years, principally by lessees. The copper production probably has been credited to that of the United Globe Mines.

About 1,200 feet southeast of the mine at the junction of the faults is a narrow outcrop of Martin limestone that is bounded on the north and south sides by northeastward-striking mineralized faults. The limestone outcrop is 1,200 feet long and has a maximum width of 300 feet. At the east end, the limestone is in normal contact with Troy quartzite, and the bedding dips about 10° SW. The limestone and the quartzite on which it rests form a narrow graben inset between outcrops of quartzite and diabase. The veins along the boundary faults have been explored by many shallow workings.

A vertical shaft was sunk in the limestone about 250 feet from the northeast end by the Globe Dominion Copper Co. About 100 feet below the collar, the shaft passed from limestone into Troy quartzite and from quartzite into diabase at 335 feet, whence it continued in diabase to the bottom at 853 feet. On the 800-foot level, a crosscut bearing N. 15° W. was driven to intersect the boundary fault and other mineralized fissures that crop out north of the limestone. At 700 feet from the shaft, the crosscut was offset about 300 feet to the east to avoid entering the property of the United Globe Mines and continued northward to intersect the Stonewall fault. The crosscut was begun in diabase, but the meager records are vague as to whether it continued in diabase to the end and also as to whether the Stonewall fault was found. Rock on the dump of the shaft indicates that some of the underground workings penetrated the basal conglomeratic beds of the Troy quartzite and also the Mescal limestone. It appears most probable that these rocks were cut by the northern part of the crosscut. Another crosscut on the 800-foot level was driven southeastward from the shaft for 725 feet. It is said to be in diabase to the end.

The vein material that can be seen along the outcrops of the Dime and Stonewall faults, and also along the numerous other faults and fissures that traverse the Troy quartzite in this area, is similar to that of the Buckeye vein, consisting mainly of quartz, specular hematite, cuprite, and copper carbonates and silicates. The stratigraphic sequence in the vicinity of these veins can be assumed to be approximately the same as that in

Buckeye Mountain. The Troy quartzite is somewhat thicker because, in general, the outcrops are those of higher strata in the formation than those along the Buckeye vein. The diabase sill underlying the Troy probably continues southward as it does along the Old Dominion vein to the west, but its thickness is subject to considerable variation. The depth of pre-Troy erosion also differs from place to place, but it is not likely that more than a part of the Mescal limestone has been removed.

The small ore bodies that have been found along these faults generally would not be considered justification for prospecting at greater depth than is reached by the present workings. However, the fact that mineralizing solutions have leaked up through a thick diabase sill, in which the fault fractures probably are tight, and have deposited some vein matter of ore grade in the overlying quartzite offers some encouragement that better deposits may be found in the rocks of the Apache group that are beneath the sill. In the veins of the Globe Hills area, specular hematite is intergrown with sulfides of the ore bodies and occurs along the vein faults in an outer zone beyond the limits of the sulfides. If a similar pattern can be assumed for the vertical zoning, the occurrence of specular hematite in the quartzite breccia along the Dime and Stonewall and other nearby faults may be an indication that sulfides were deposited in the faults at deeper levels. Probably the most promising areas for prospecting would be near the junction of the Dime and Stonewall faults and along the faults that bound the depressed block of Martin limestone south of the Stonewall workings.

BIG JOHNNIE MINE

The Big Johnnie copper deposit is in an irregular block of quartzite that crops out on the western flank of Black Peak along the east side of Big Johnnie Gulch. The block is composed of Pioneer formation, Barnes conglomerate, and Dripping Spring quartzite and is completely surrounded and underlain by diabase. The sedimentary strata dip 10° to 40° SE. A little displacement along the northwest contact between the quartzite and diabase was sufficient to permit the passage of mineralizing solutions, and the contact fissure has been slightly mineralized for more than 6,000 feet along the strike. Northeastward from the Big Johnnie mine, the contact fissure contains less copper but increasing amounts of manganese minerals. In the northeastern part on the Superior and Globe property, considerable manganese ore has been mined from shallow workings.

For about 500 feet near the south end of the quartzite outcrop the west or hanging wall of the contact fissure is formed by a small triangular block of Pioneer formation and Dripping Spring quartzite; and from the north edge of this small block, a branch fault cuts northeastward diagonally across the main quartzite outcrop (pl. 1). The portion of the main quartzite block south of the branch fault has been relatively depressed several hundred feet, probably at the time of the diabase intrusion.

The Big Johnnie vein is along the branch fault and along the segment of the main contact fault that is south of the junction. Both faults dip 80° to 85° NW. The deposit had been developed prior to 1901 and, according to Ransome (1903, p. 153), had produced some very good copper ore from opencuts in quartzite breccia. The average width of the fault breccia is less than 2 feet. It consisted of fragments of quartzite cemented and partly replaced by cuprite, malachite, chrysocolla, and specular hematite. Later, a small block of good ore was mined from a stope that extended from an adit level (elevation 4,070 feet) to the surface and to about 25 feet below the adit level. The Big Johnnie shaft was sunk in the diabase hanging wall near the intersection of the two vein faults. Two crosscuts were driven to intersect the vein at intervals of 100 and 200 feet, respectively, below the adit level and were designated as the 2d and 3d levels. After the vein had been explored for only 130 feet by drifts from the 2d-level crosscut, the mine was closed.

Late in 1915 the Old Dominion Co. unwatered the shaft and began drifting on the vein from both levels. The drift on the 2d level was extended northeastward and exposed the vein for a total distance of 706 feet along the strike. An ore shoot was found that extended from 130 feet to 270 feet northeast of the shaft crosscut; beyond the shoot the vein became narrower and was but slightly mineralized. On the 3d level, drifting on the vein proved to be impractical, owing to heavy ground, and drifts were driven parallel to the vein. Short crosscuts were driven from the drift to intersect the vein at 50-foot intervals along the strike. Thus the vein was explored for 570 feet southwest of the shaft crosscut and for 580 feet to the northeast. According G. N. Bjorge (1917, written communication) the vein fault was well defined but contained only small streaks of specular hematite and occasional stains of copper. Raises driven from the 3d level showed that the ore shoot northeast of the shaft extended only about 30 feet below the 2d level. On both the 2d and 3d levels, the footwall of the vein is quartzite, and the hanging wall is diabase. At a depth of 70 feet or less below the 3d level the diabase will undoubtedly form both walls of the vein fault. The quartzite block northwest of the branch fault is thin and extends only about 25 feet below the 1st, or adit, level.

The ore shoot northeast of the shaft was stoped from 70 feet above the 3d level to the bottom of the underhand stope below the adit level and yielded about 2,600 tons of ore that averaged 5 percent copper. The feeble mineralization of the vein on the 3d level discouraged further development of the vein, and the mine was closed in January 1917.

NEW DOMINION PROPERTY

The New Dominion property is on the northwest side of Big Johnnie Gulch, 2 miles north of Globe and 1 mile north of the Old Dominion "A" shaft. It includes the Mallory, or IXL, mine and several small veins that are reported in Mines Handbook (Weed, 1925) to have yielded manganese-silver ores from shallow workings during the early days of the district. Later work was centered on two copper-bearing veins that contained minerals like those of the Old Dominion vein. There is evidence on the ground that a little copper ore was produced from surface workings.

At the date of the earliest records, the claims of the New Dominion group were owned by the Globe-Boston Copper Mining Co. This company sank the Mallory shaft to a depth of 465 feet and drove crosscuts to the copper-bearing veins on the 200-foot and 450-foot levels. A vein found on the 450-foot level was oxidized and leached but contained a little chalcopyrite and bornite. In 1906, the property was acquired by the Globe Consolidated Copper Co. The Mallory shaft was deepened to 817 feet, and some development work was done on the 800-foot level. The general business depression of 1907 caused the mine to be closed, and the company merged with the Cordova Copper Co. in 1909.

The New Dominion Copper Co. purchased the property in 1916. Development work was done on all three levels, and some copper ore was produced during 1916 and 1917. The Mallory shaft was retimbered in 1923 and deepened to 1,200 feet. New levels were opened at depths of 1,000 and 1,200 feet, but no records of this later work have been found.

In 1942, the 11 claims that constitute the New Dominion group were acquired by T. J. Long of Globe. In February 1955, Long sold the claims to C. W. Via, who for several months produced manganese ore from the deposits in limestone.

One of the veins, whose outcrop passes through the collar of the Mallory shaft, strikes N. 37° E. and dips 70° NW. It forms the boundary between a thin block of Troy quartzite and a thick diabase sill that crops out in Big Johnnie Gulch and underlies the Troy quartzite on Buffalo Hill to the east (pl. 1). The other vein strikes about N. 10° E., and the outcrops of the two veins join 300 feet southwest of the shaft. The second vein follows a fault that brings the Martin and Escabrosa limestones into contact with the thin block of Troy quartzite, and south of the junction of the two veins it forms the boundary between the Escabrosa limestone and the diabase sill. Most of the displacement on these faults probably preceded or was contemporaneous with the intrusion of diabase, and the later displacement appears to have been very small. The relationships of the thin block of Troy quartzite and the small block of Pioneer formation, Barnes conglomerate, and Dripping Spring quartzite that is completely surrounded by diabase 1,000 feet northeast of the shaft are difficult to account for by displacement after the intrusion of diabase. The blocks probably were outlined by faults and then pushed upward by diabase magma intruded under them.

The Mallory shaft is in diabase to a depth of at least 600 feet (fig. 8). The 800-foot level was driven near the base of the Mescal limestone. The Mescal limestone here must be but a thin remnant, for immediately to the north it has been completely removed by erosion; and the Troy quartzite or, in places, the Martin limestone rests directly on Dripping Spring quartzite.

On the 800-foot level, a contact between Mescal limestone and diabase is vertical and strikes N. 70° E. It probably is an old fault that has been reopened after the intrusion of the diabase so as to permit the passage of mineralizing solutions that formed a narrow vein along the contact. The outcrop of this vein, which would be bounded by diabase on both sides, has not been recognized.

The rock on the dump of the Mallory shaft indicates that the vein filling was much like that of the Old Dominion vein, consisting chiefly of quartz, coarse granular pyrite, chalcopyrite, bornite, and specular hematite. Sulfides were present on the 800-foot level, but they had been oxidized and leached on the two upper levels.

The faults described above coincide approximately with a northeastward-trending structural zone along which there was an abrupt change in the horizon at which the main diabase sill was intruded. Southeast of this zone, the sill is between the base of the Troy quartzite and the top of the Apache group; whereas on the northwest side, thin remnants of Troy quartzite rest directly on Dripping Spring quartzite; and the main diabase sill was intruded at or near the base of the Pioneer formation.

The sedimentary strata north of this zone form a large block that is bounded on the north by the Irene

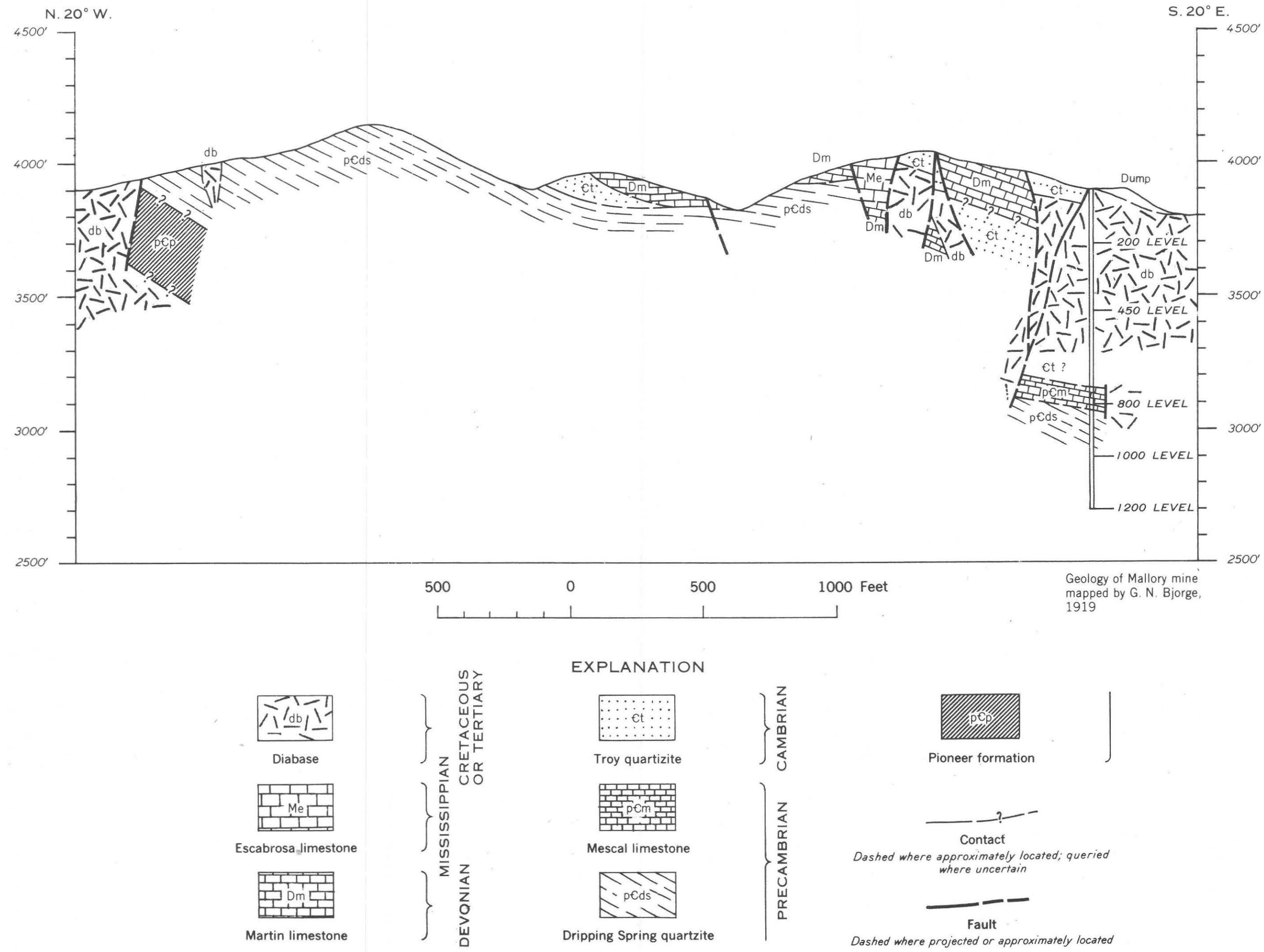

FIGURE 8.—Interpretation of geologic section through the Mallory shaft.

vein fault and on the southeast by a northeast-striking fault that is commonly referred to as the New Dominion vein. Both faults had large displacements before the intrusion of diabase, but probably less than 50 feet of displacement afterwards. The western part of the block is overlapped by dacite.

The fault that forms the southeast boundary of the block splits about 1,700 feet northeast of the Mallory shaft, and a narrow wedge of Martin and Escabrosa limestones between the two branches has been relatively depressed. Both branches of the fault are mineralized, and several small ore shoots have been mined along the outcrops. Other small, generally discontinuous, veins occur along fractures and minor faults that traverse the Martin limestone in the southern part of the block. The Martin in this area is thin and lacks the conglomeratic and arenaceous members that are characteristic of the lower part of the formation in most places. It was deposited on a irregular erosion surface that stood relatively high underlain by Dripping Spring quartzite and thin remnants of Troy quartzite.

The ore minerals in these veins are entirely different from those in the veins developed by the Mallory mine. The richer portions of the veins, which appear to have been small lenticular shoots, have been largely mined out. The veins that can now be seen range from a few inches to a foot in width, but some of the stoped portions of the veins may have been as much as 3 feet wide. They have been highly altered by supergene oxidation and leaching.

Most of the central part of the veins is quartz containing many drusy vugs and cavities formed by solution of the hypogene vein minerals. This part grades outward into partly replaced limestone breccia cemented by calcite and by manganese oxides, mainly pyrolusite and psilomelanelike minerals, a network of veinlets and irregular replacement masses of manganese oxides intergrown with calcite and chalcedony extend outward into the limestone walls for as much as 10 feet. Spongy masses of quartz are crusted by hemimorphite, descloizite, and globules of vanadinite generally intergrown with white calcite. Finely granular cerussite is disseminated throughout the oxidized vein matter, and sandy aggregates of willemite are common. Smithsonite could not be recognized, but crusts of fine-grained calcite contain appreciable amounts of zinc. In general, the zinc minerals are inconspicuous, but most samples of the vein matter contain 2 to 12 percent zinc. Copper minerals, mostly chrysocolla, are extremely rare. No limonite residues characteristic of leached sulfides were found. Although the ore were mined for their silver content, no minerals of silver could be recognized.

The veins are completely oxidized to the depths reached by the mine workings and probably down to the permanent water table, which is likely to be near the level of Pinal Creek west of the property, or about at an elevation of 3,350 feet, which is 650 feet below the outcrops of the veins. This is approximately the elevation of the lower limit of oxidized minerals in the Mallory mine. In the Irene vein, a half a mile to the north, the lower limit is known to extend down to an elevation of 3,100 feet, but the average level probably is a little higher.

The character of the parts of the veins in the quartzites and diabase underlying the Martin limestone is not known. It is uncertain whether any of the stopes extended to the base of the limestone.

The hypogene minerals are not exposed in any of the accessible workings. They probably consist of quartz, rhodochrosite or manganoan ankerite, sphalerite, galena, and a little chalcopyrite. The veins contained little, if any, pyrite. The zinc content of the hypogene ore shoots may well have been as much as 30 percent. The vanadinite and descloizite probably were present in the hypogene vein matter but may have undergone some solution and redeposition by supergene solutions.

ORIGINAL OLD DOMINION OR KEYSTONE VEIN

The Original Old Dominion vein is on the Old Dominion and Keystone claims on the east side of Pinal Creek, about 3½ miles northwest of Globe. It was first worked by the Old Dominion Copper Co., the predecessor of the Old Dominion Co., but in 1883, this company bought the Globe, Globe Ledge, and Alice claims and transferred all its activities to development of the Old Dominion vein.

The vein, which is generally less than a foot wide, occupies a fissure that crops out in Dripping Spring quartzite. It strikes N. 45° E. and dips about vertical. The richer parts of the vein have been stoped from unknown depths to the surface. Only very poorly mineralized parts of the vein, which contain sparse copper carbonates, vuggy quartz, limonite, and specular hematite, can now be seen. According to Ransome (1903, p. 154–155) the ore consisted of an ocherous dark-red mixture of cuprite and iron oxides finely streaked with chrysocolla and malachite. The red oxides commonly showed native gold in the form of short wires and thin leaves.

HIGHLINE DEPOSIT

The Highline claim is about 1,500 feet southeast of the Original Old Dominion or Keystone vein. It contains several breccia zones in Dripping Spring quartzite that are sporadically mineralized with copper carbonates. A few thousand tons of ore has been mined from shallow opencuts. The property is credited with a production of 400,000 pounds of copper mined in 1929 (Elsing and Heineman, 1936, p. 92).

ZINC-LEAD VEINS

Vein deposits in which the principal metals are zinc and lead occur in widely separated localities in the outer fringes of the copper-bearing areas. The simplest type is represented by the Money Metals vein in Myberg Basin and the Black Bess and Eder veins, and several unnamed deposits in Powers Gulch. The Irene vein also is essentially of this type although its upper part shows some characteristics of the veins that also contain vanadium and molybdenum minerals and are described on pages 123–124.

Except for the Irene vein, these deposits have been very superficially explored, and their total production amounts to only a few hundred tons of ore. In the explored parts of these veins, the ore minerals are in too small volume and are too sporadically distributed to permit economic operations under present conditions.

The veins occur along steeply dipping fissures or faults of slight displacement, mainly in diabase. The fissures are not uniformly mineralized, and the deposits range in size from a single stringer a few inches wide to stringer lodes as much as 20 feet wide, formed by replacement of diabase wallrock, gouge, and fault breccia. The vein matter consists mainly of white or greenish, fine-grained but vuggy quartz and diabase in various stages of alteration and replacement. The ore minerals are pyrite, chalcoprite, sphalerite, and galena. Sphalerite is generally the most abundant sulfide, far more abundant that galena. The proportion of pyrite differs greatly in the various deposits and also from place to place within individual deposits; parts of the deposits that contain the most sphalerite and galena contain little or no pyrite. Chalcopyrite is present in very minor amounts, most commonly in fine disseminated grains with sphalerite or pyrite.

Except for the Irene vein, these deposits are not deeply weathered, probably because of the relatively rapid erosion of the diabase country rock and also because the ground-water level is shallow, generally from a few feet to about 40 feet below the outcrops in the veins that have been developed, owing to the basinlike areas formed by erosion of the diabase. Sphalerite is generally leached down to the water table, but galena and pyrite are only partly oxidized.

IRENE VEIN OR LIBERTY DEPOSIT

The Irene vein, also known as the Liberty deposit, is along a zone of fault breccia that crops out for 4,200 feet on the south side of Irene Gulch about 2 miles north of Globe (pl. 1). In some places particularly over the main ore shoot, the cemented breccia has nearly vertical walls and protrudes as much as 25 feet above the surface of the hillside.

Because of its very prominent outcrop, the Irene vein has attracted considerable attention; and since about 1880, there have been many attempts, mostly short lived, to explore and develop the property. At some early date about 1,500 tons of oxidized lead-silver ore was mined from the upper part of the principal ore shoot. The property was held by Anton Trojanovich of Globe for many years. The Comstock Extension Mining Co. was organized, and the various heirs of Anton Trojanovich exchanged their interests in the property for stock in the company. From 1943 to 1945, the property was under option by various mining companies, each of which carried on exploration by diamond drilling. Fifteen holes totaling about 11,000 feet were drilled to prospect the vein at depth. In 1952 the property was purchased by Globe-Miami Copper-Zinc Corp. This corporation extended a winze from the 270-foot level to explore bodies of sphalerite ore that had been cut in two drill holes. The corporation received a contract from the Defense Minerals Exploration Administration in January 1953, and most of the work in and from the winze below a point 525 feet below the No. 1 adit level was financed through this contract. A drift at the level of the drill-hole intersections proved that the ore bodies had but little lateral extent; this poor showing in the drift and the then current low price of zinc discouraged further exploration to determine their vertical extent.

The strike of the Irene vein fault ranges from N. 50° E. at its east end to N. 80° E. at its west end and is roughly parallel to the gulch. The dip, as determined by underground development, ranges from vertical to 75° N.

The underground workings of the Irene mine consist of two adits, known as the Irene tunnels (pl. 1), which give access to drifts, crosscuts, raises, and a winze 800 feet deep. The only known ore shoot is developed by No. 1 adit, which was driven southward to intersect the vein 150 feet below the outcrop. The vein is explored on the adit level for 300 feet along the strike by drifts and a few crosscuts. A winze inclined northward 85° has its collar at the hanging wall and remains entirely within the fault zone to a depth of 270 feet below the adit level, whence it is vertical to a total depth of 800 feet. At 75, 150, 270, and 500 feet below the adit level, short development drifts and crosscuts have been driven (fig. 9). On the 800-foot level, at the bottom of the winze, there is a crosscut 130 feet long from which a drift extends northeastward about 320 feet along the vein fault zone.

No. 2 adit intersects the vein fault about 700 feet east of the intersection of No. 1 adit and at about 33 feet higher elevation. A drift with a few minor tributary workings follows the fault northeastward for 280 feet from the intersection.

Dripping Spring quartzite crops out on the south side of the Irene fault except in one small gulch cutting across the vein, where the underlying Barnes conglomerate and Pioneer formation are exposed. Farther south the Dripping Spring is overlain by small remnants of Troy quartzite and Martin limestone, and by a few caps of Escabrosa limestone on the highest points. Diabase crops out along the north side of the fault, except for a short distance at the west end, where the hanging wall is a block of Pioneer formation. This diabase probably was intruded along an old fault. Movement on the fault after the intrusion of diabase was relatively slight but it produced the breccia zone along the diabase-quartzite contact which later became the channel for mineralizing solutions. Slight displacement occurred after mineralization. Exploration by drilling shows that the diabase forming the north wall of the fault continues to a depth of more than 1,300 feet below the outcrop of the vein.

South of the Irene vein fault, diabase was intruded as a sill at or near the base of the Pioneer formation, as is shown in figure 9. Above the winze, in No. 1 adit, the top of the Pioneer formation on the south, or footwall, side of the fault is about 110 feet above the adit level. The Pioneer formation is exposed in the footwall of the fault zone in a crosscut 150 feet below the adit level. The contact of the Pioneer with the underlying diabase is not exposed in the mine workings, but if it is assumed that the Pioneer is 270 feet thick, the maximum depth of the contact below the adit level is about 190 feet. Below the base of the Pioneer, the

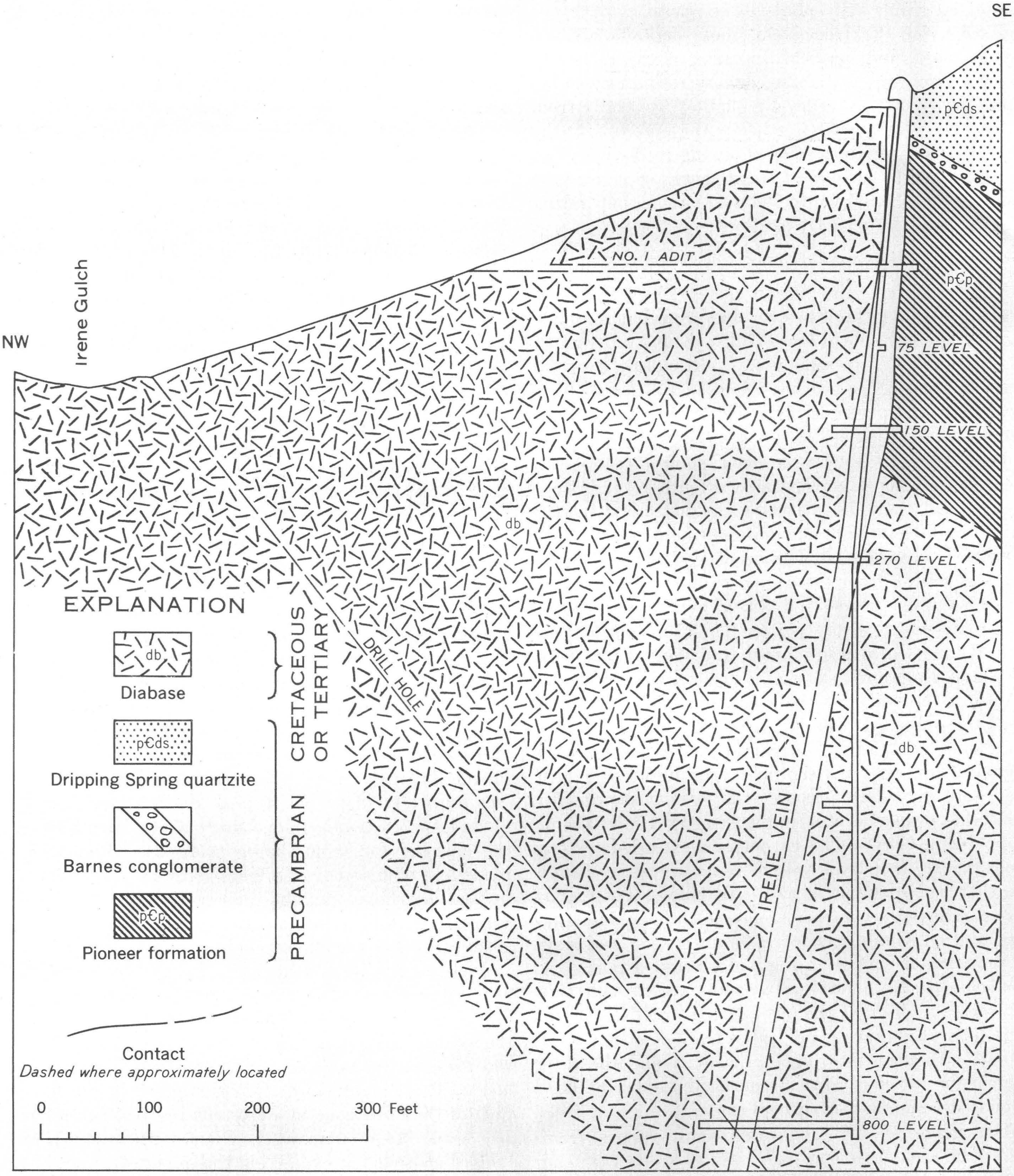

FIGURE 9.—Cross section through winze in No. 1 adit, Irene mine.

fault is in a diabase sill whose thickness is not known, but exploratory drilling indicates that it is at least 600 feet. In this area, the Scanlan conglomerate and Pioneer formation probably rest on Pinal schist, and the sill also probably overlies schist.

At the west end of the vein outcrop, the Pioneer formation forms the north wall for about 900 feet along the strike, indicating that the north wall has been raised in relation to the footwall. The sedimentary formations along the rest of the hanging wall were raised so much higher that they have been completely removed by erosion.

About 1,000 feet east of No. 1 adit, the vein passes into diabase and cannot be traced for more than a few tens of feet beyond the end of the Dripping Spring quartzite; here the vein is weakly mineralized, however, and the exposures are poor. About 1,000 feet farther to the east and approximately on the projected strike of the Irene vein, a fault, which may be its continuation, crops out and can be followed northeastward for about 1 mile. This fault is weakly mineralized throughout its extent, but the chief minerals along the eastern portion are quartz, calcite, and manganese oxides.

The crosscut driven northwestward from the winze at the 800-foot level cut several weakly mineralized fractures approximately at the location of the projected vein. From it, the drift to the northeast passed through a body of sphalerite ore that had been cut by one of the drill holes. This ore body is probably elliptical in plan section, with a strike length of about 80 feet and a maximum width of about 20 feet. The drill-hole intersection indicates a vein 12 feet wide, averaging 19.7 percent zinc. About 160 feet farther northeast, the drift entered another mineralized segment of the vein fault, which also had been intersected by one of the drill holes. This body is not well defined by regular walls but probably ranges from 1 to 5 feet in width where it is exposed in the drift for a strike distance of about 40 feet. The drill-hole intersection, which is about 30 feet below the drift, indicates a vein width of about 12 feet and a zinc content of 7.1 percent, 2.7 percent is in the form of oxidized minerals.

At its west end, the Irene vein is cut off by a cross fault which brings a block of the Martin and Escabrosa limestones into contact with the Pioneer formation and Dripping Spring quartzite that form the walls of the vein.

The Irene vein occupies a zone of fault breccia ranging from 5 to 30 feet in width. The breccia consists of angular fragments of quartzite and diabase. Greenish, stony quartz fills interstices of the breccia and largely replaces the diabase fragments and gouge. Small cavities lined with drusy quartz are common throughout the vein.

Although small amounts of metallic minerals occur in most parts of the fault breccia, only one shoot is known in which the minerals are sufficiently concentrated to constitute ore. This shoot is developed by the workings reached through No. 1 adit. As seen in these workings, the vein is bounded by thin seams of gouge that form well-defined, regular walls. In some places gouge-filled fractures, generally parallel to the walls, occur within the vein.

Above the adit level and west of the winze is a large open stope from which the early production of the mine was obtained. Between the adit level and the drift 75 feet below, there is a small stope from which shipments were made in 1947.

The vein is largely oxidized to the depth reached by the mine workings. The oxidized vein matter is a soft porous mass consisting mainly of quartz, chlorite, quartzite fragments, and altered and partly replaced diabase. The chief ore minerals are cerussite, hemimorphite, and willemite. Crystals and crusts of hemimorphite and willemite are widely disseminated throughout the oxidized vein. Cerussite is less widely distributed and generally occurs as small rounded masses that commonly surround kernels of galena. A little vanadinite and descloizite are present in some places generally near the margins of the vein. Stains of copper carbonates are rarely seen. Specular hematite is generally present and locally forms 10 to 20 percent of the vein matter. Limonite and powdery masses of manganese oxides are abundant in some places and lacking in others.

The base of the oxidized zone appears to be very irregular and in places extends well below the permanent ground-water level, which is approximately at the level of Pinal Creek west of the deposit, or about 200 feet above the 800-foot level of the mine. In one drill hole the zinc minerals are partly oxidized to a depth of 40 feet below the 800-foot level.

The primary vein matter, as seen in drill cores and on the 800-foot level, consists mainly of light-colored sphalerite and specular hematite in a gangue of quartz and partly replaced wallrock. The oxidized ore in the upper part of the shoot contains about 3.5 percent lead, probably in part a residual concentration resulting from supergene leaching; the sulfide ore on the 800-foot level contains only traces of galena. The average silver content of the vein between the adit level and the 270-foot level is about 2.5 ounces to the ton, and the ore shipped from the stopes above the adit level, which undoubtedly was hand sorted, is said to have contained about 14 ounces of silver to the ton.

Adit No. 2 intersected the vein fault 575 feet northeast of the face of the east drift in adit No. 1. From the point of intersection, a drift follows the fault zone along the diabase-quartzite contact for 250 feet northeastward. The fault breccia exposed in this drift is not as completely replaced and cemented by quartz as that exposed in the workings from adit No. 1. The metallization was weak and discontinuous, and the vein matter is not of commercial grade or volume. The northeast end of the drift, which continues a short distance beyond the quartzite footwall block to the southwest, is entirely in diabase, in which the fault zone contracts to a few indistinct and unmineralized fissures. About 150 feet northeast of the end of the drift, a drill hole intersected 16 feet of poorly metallized vein matter 400 feet below the level of the drift.

Southwest of the mine workings, the outcrop of the vein fault become less prominent. The breccia zone is narrower, and in some places, the fault shows as a single gouge-filled fracture along the contact of the diabase and quartzite. It has been explored by a few shallow pits sunk at intervals along the outcrop.

MONEY METALS PROPERTY

The Money Metals property, comprising a group of 21 claims, is situated at the east end of Myberg Basin, 2¾ miles northwest of Inspiration. Interest has been centered mainly on the development of the Money Metals vein. At one time a small mill on the property produced some lead-zinc concentrate and extracted gold and silver by the cyanide process. Luis Winn of Globe operated the property under lease in 1928 and 1929 and again in 1938. During these periods, he shipped five small lots of selected gold-silver-lead ore totaling about 75 tons. Later Winn and Kenneth Hoopes acquired the property at a tax sale, and in 1952 sunk several churn-drill holes to prospect the deposit.

The early workings on the property are all caved and inaccessible. They are said to include an inclined shaft sunk on the vein to a depth of 190 feet, with levels at 65, 100, and 190 feet. Drifts on each level extend from 40 to 100 feet northeastward and southwestward from the shaft. Two vertical shafts and an inclined shaft are reported to be 40, 50, and 100 feet deep respectively. There are also several short adits, all of which are now caved.

The "vein" is actually a system of linked veins deposited along a broad fault zone in a thick diabase sill intruded between beds of the Pioneer formation (pl. 1). East and west of the fault zone, the higher hills are capped by remnants of Pioneer formation that are portions of the hanging wall of the sill. To the north, the diabase is in contact with Ruin granite of the Granite Basin mass. The diabase-granite contact probably represents an old fault along which rocks of the Apache group have been moved down into contact with granite before intrusion of the diabase. South and west of the property, the diabase is overlain by dacite, which conceals all the older formations in an area several square miles in extent.

The mineralized fault zone strikes N. 30° E. and dips about 75° NW. At the north it appears to end near the contact of the diabase and granite, whence the outcrop can be traced for about 1,000 feet southwestward to the north edge of talus deposits from the dacite cliffs that form the south rim of Myberg Basin. What probably is the continuation of the fault zone crops out for about 200 feet in a small inlier of diabase at the north edge of the dacite.

The fault zone exposed in the underground workings is said to be about 20 feet wide and is bounded by clay gouge and slickensides. The ore minerals occur in lenses, in which the gouge and breccia are largely replaced by quartz, pyrite, and a little chalcopyrite. Small bunches of galena and sphalerite are present locally in the replaced breccia, but their relationship to the more extensive quartz-pyrite vein matter could not be observed. The five small lots of selected ore that have been shipped from the property averaged about 0.4 ounce of gold and 10 ounces of silver to the ton. Three of the lots, shipped to a lead smelter, contained from 7.5 to 14.5 percent lead.

Three churn-drill holes sunk near the shafts indicated that a broad zone of altered diabase contained small amounts of very light colored sphalerite. One hole intersected a small body of good lead-zinc ore between 20 and 45 feet from the surface. The holes were drilled in a wash where the bedrock is not well exposed, but they probably were started directly over or very close to the fault zone

The zone of supergene oxidation of the sulfide minerals is shallow and probably does not extend to a depth of more than 20 feet below the outcrop.

Although the metal content of the Money Metals lode is of little economic importance, it probably is greater than that of any of the other zinc-lead deposits in the district. The deposit is of great interest as a possible indication of undiscovered ore bodies under the dacite cover. Projected southwestward 6,000 feet, the vein fault would pass very close to a small area in which copper-bearing supergene solutions leaked through the dacite cover (p. 141). It cannot be assumed that the mineralized fault continues for as much as 6,000 feet southwest, but it is possible that the deposit is an outlier of a more intensely mineralized area. The relatively large gold and silver content of the deposit is characteristic of the deposits on the fringes of the copper-bearing areas of the district. It is comparable with that of the Continental deposit near the Castle Dome ore body (Peterson, Gilbert, and Quick, 1951, p. 129).

POWERS GULCH VEINS

Several small zinc-lead veins crop out in Powers Gulch, near the southwest corner of the Inspiration quadrangle (pl. 1) in a diabase sill intruded between Pinal schist and Pioneer formation. They are along fissures or faults of very slight displacement that strike N. 30°–60° E. and dip nearly vertical. Some of the vein fissures can be traced for a thousand feet or more by the zone of dark chloritic alteration of the diabase, but only short intervals or shoots, generally less than 200 feet long, contain appreciable amounts of ore minerals that range from a few inches to a foot in width. In some places, the shoots comprise several generally discontinuous and lenticular stringers of vein matter that form lodes as much as 4 feet wide.

The veins formed by replacement of diabase wall rock, fault breccia, and gouge. The vein matter consists of quartz, sphalerite, galena, a little chalcopyrite, and altered diabase.

Most of the shoots that crop out have been prospected by shallow workings; a few have been followed down to or below the water table. Any ore found has been largely removed, and the extremities of the workings are in poorly mineralized portions of the veins. One recent working on the east side of the gulch was in a shoot of ore that was oxidized down to the water table, about 20 feet below the outcrop. Most of the zinc had been leached out and the galena altered to cerussite.

The Black Bess vein on the west side of Powers Gulch (pl. 7) and another small vein about 400 feet southeast of the Black Bess shaft have been followed down to the Pinal schist at the base of the diabase sill. Near the veins, the sill is known to be only 60 to 70 feet thick, for several thin remnants of Scanlan conglomerate rest on the diabase a short distance northeast of the Black Bess shaft. The veins are said to be practically barren in the underlying schist. At one time ore from the Black Bess supplied a small concentrating plant, but the amount of concentrate produced is not known and probably did not exceed 200 tons. The rock on the dump indicates that sphalerite was the principal ore mineral and the only one recovered.

Farther down Powers Gulch, in the Haunted Canyon quadrangle, two small zinc-bearing veins have been superficially explored. One is well mineralized where it is crossed by the gulch.

CEDAR TREE DEPOSIT

The Cedar Tree claim is near the south contact of the Lost Gulch quartz monzonite mass, about 4,000 feet southwest of Copper Cities open-pit copper mine (pl. 7). The Cedar Tree deposit was a small ore shoot along a minor fissure between two tongues of quartz monzonite projecting southward from the main mass in the adjacent Pinal schist. The fissure strikes N. 70° E. and dips 80° S. Its trace is apparent only where it crosses the schist and a narrow diabase dike intruded along the east contact. The schist in this area is intricately intruded by fine-grained rocks of the Precambrian dioritic complex.

The deposit was developed by an adit drift driven along the fissure from a gulch at the west end. The ore shoot was cut about 75 feet from the portal. It has been stoped to the surface and for some distance below the adit level; the underhand stope is now partly filled with waste. The width of the stope is 3 to 4 feet, probably approximately the thickness of the ore shoot. The east end of the stope is inaccessible, but the strike length probably is about 100 feet.

At present no ore in place can be seen. Material of the dump, which probably represents rejected vein matter sorted from the ore, shows that the vein matter consisted mainly of quartz containing irregular stringers and small masses of galena and sphalerite and very minor amounts of chalcopyrite and euhedral pyrite. The quartz is generally fine grained and stony but contains numerous drusy cavities and partly replaced fragments of country rock. The vein was clearly a replacement of the schist and dioritic rocks along a narrow breccia zone.

The sulfides were almost completely oxidized and leached for a few feet below the outcrop, but apparently were but slightly oxidized at the adit level. Material stripped from the outcrop over the ore shoot shows the clean siliceous boxwork that is characteristic of leached sphalerite.

The property was operated about 1913 by the Louis d'Or Gold Mining Co. mainly for the silver and gold. No records of the production of metals or grade of ore are available. The total ore mined was less than 2,500 tons.

ZINC-LEAD-VANADIUM-MOLYBDENUM VEINS

Closely related to the zinc-lead veins are veins that contain zinc and lead minerals associated with appreciable amounts of vanadium and molybdenum minerals. Typical examples of this group are the Defiance, or Apache, vein and the Albert Lea vein, each credited with a small production of lead ore. Many other de-

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posits are too small and too weakly mineralized to be of any economic significance but are not fundamentally different from the zinc-lead veins and probably represent deposition at higher horizons farther from the source of the mineralizing solutions. The Irene deposit, which has been described under zinc-lead veins (p. 119), could be included in either group, but the others are distinctive enough to warrant classification in a separate group.

The typical deposits of this group are deeply weathered, and, except for the Irene vein, have not been developed deep enough to expose the primary minerals. The veins were deposited along faults that cut quartzite and intruded diabase. The fault zones are 2 to 20 feet wide, are generally bounded by rather smooth, regular, and commonly slickensided walls, and are composed of sheared or brecciated rock that was wholly or partly replaced by vuggy quartz which, before oxidation, enclosed irregular masses and blebs of sphalerite and galena. The quartz and sulfides partly or completely replaced the rock across the full width of the fault zone in the principal ore shoot in the Irene mine, but, in the smaller deposits replacement was limited to small lenticular shoots or irregular, discontinuous bands that apparently followed the most pervious parts of the fault zone.

The oxidized vein matter is generally a loose porous mass of altered or partly replaced gouge and fragments of quartzite and diabase traversed by irregular ribs of vuggy quartz and silicic boxwork characteristic of leached sphalerite. Clay and chlorite are abundant. Galena was oxidized in place to masses of cerussite, many enclosing cores of galena. Zinc derived from sphalerite was widely dispersed throughout the vein matter where it appears as granular masses of willemite and drusy crusts of hemimorphite. A little zinc carbonate is present but is not easily recognized. The general scarcity of limonitic residues and copper stains indicate that pyrite and chalcopyrite were not abundant in the hypogene ore.

Crystalline crusts of manganite and botryoidal crusts and powdery deposits of pyrolusite and other manganese oxides are sparingly present throughout the oxidized veins, indicating the probable presence of small amounts of manganese-bearing carbonates in the primary vein matter. Calcite veinlets, probably supergene, traverse the vein matter and the adjacent wall rocks. Minute veinlets and small clots and masses of specular hematite occur sporadically in most of the veins.

Vanadinite, descloizite, and mottramite are present throughout the veins, particularly near the edges, and in fractures in the wallrocks in places as far as 20 feet from the main vein fault. They form crystalline crusts which coat breccia fragments and the walls of open fractures. Vanadinite occurs as prisms, some as much as a quarter of an inch long. Crystalline calcite usually is found with the vanadium minerals. Wulfenite is extremely rare in the larger deposits of this type. It is far more abundant in the outcrops of some of the smallest veins explored only by shallow pits a few feet deep. It occurs in its characteristic habit, either as plates attached to the walls of open fractures or partially intergrown with cerussite.

These deposits have been worked chiefly for lead and silver. All ore shipped came from the oxidized zone of the veins and was carefully hand sorted. It contained 5 to 39 percent lead, 2 to 11 percent zinc, and 3 to 10 ounces of silver to the ton. The primary ore undoubtedly contained considerably more zinc than the shipped ore but a much smaller amount of lead and silver.

ALBERT LEA PROPERTY

The Albert Lea property is near the south boundary of sec. 22, T. 1 N., R. 15½ E., 1½ miles northeast of Globe. The property contains several small veins, which were developed and worked intermittently by Ceferino Liano of Globe. From 1944 to 1946, he shipped to the smelter in El Paso 1,200 tons of selected lead ore that averaged about 12 percent lead, 4 percent zinc, 0.10 percent copper, and 0.012 ounce of gold and 6.7 ounces of silver to the ton. The smelter paid for 232,250 pounds of lead and 7,500 ounces of silver, valued at about $25,800.[2]

The mine workings are two adits from which drifts and crosscuts explore several weakly mineralized fissures. The adits are 35 feet apart vertically and connected by a vertical shaft sunk in a prominent fault zone that strikes N. 35° W. A small pocket of ore is said to have been found near this shaft.

The main productive vein was reached by a northward-trending crosscut from the upper adit, apparently by chance, for the outcrop is concealed by quartzite talus. A drift from the crosscut follows the vein fissure for 140 feet to the east (fig. 10). About midway in this drift a winze was sunk on the vein fissure to a depth of 120 feet below the adit level, and three sublevel drifts were driven from the winze at depths of 38, 65, and 95 feet. Most of the production of the property was obtained from small stopes between the sublevels and above the drift on the adit level.

The rocks that crop out in the vicinity of the Albert Lea property are the Troy quartzite and narrow dikes and small irregular bodies of diabase and diorite por-

[2] Published with permission of the owner, Mrs. Leonor C. Liano.

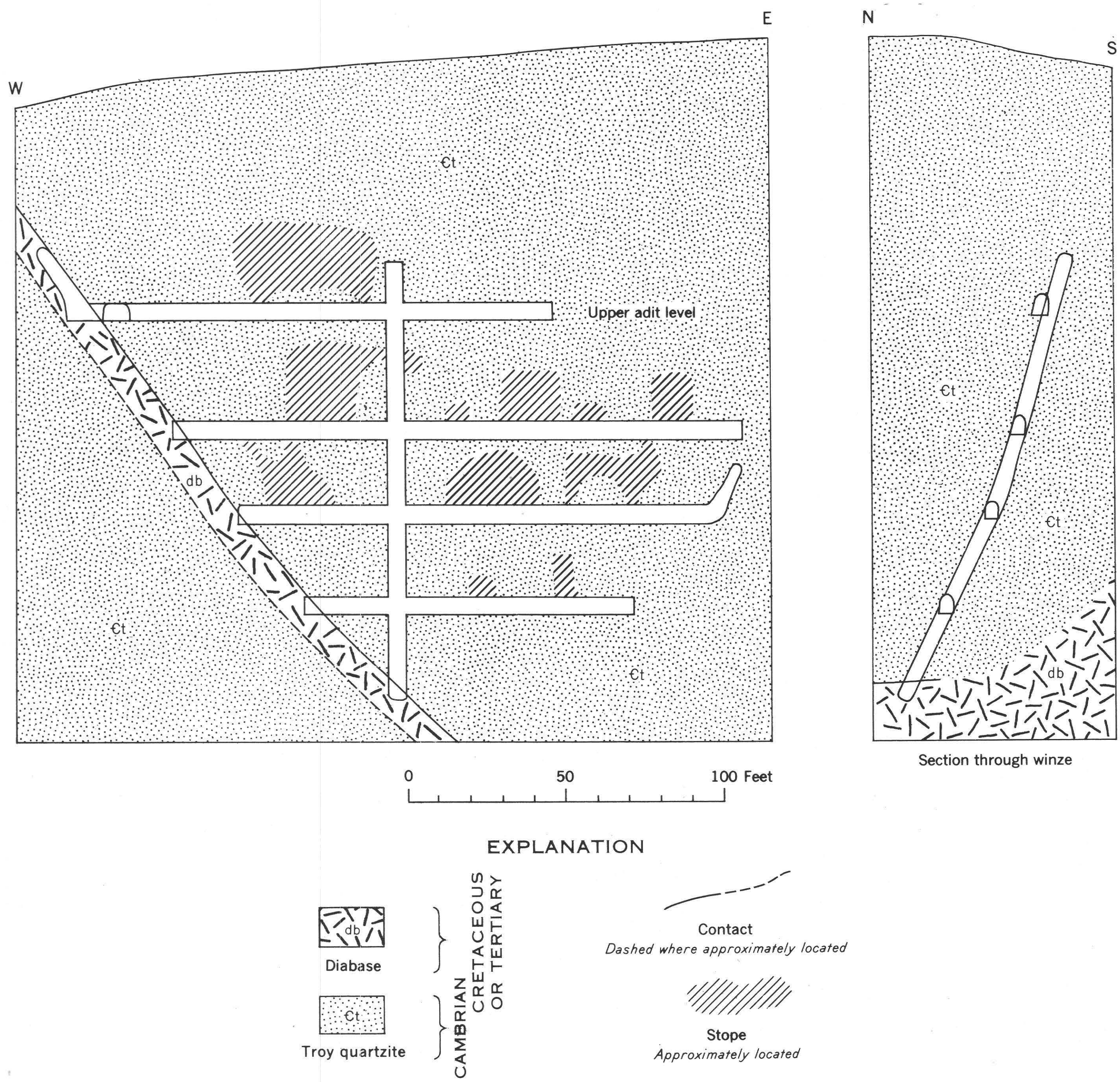

FIGURE 10.—Albert Lea mine, mine workings along vein projected on vertical section.

phyry. The quartzite generally dips about 10° S. to SW. and is cut by many minor faults; along the faults it is broken to a coarse open breccia. Thin discontinuous diabase dikes have been intruded along some of the faults. Later displacement occurred along the walls of the dikes, and along small cross faults, some of which offset the dikes a few feet.

The bedrock at the mine is largely covered by quartzite talus, but some of the faults are marked by cemented breccia that stands above the talus. A few patches of diabase can be seen but are too obscure to map in detail. To the west the mineralized fissures are terminated by a steeply dipping, northeastward-striking fault, along which the block to the southeast has been depressed several hundred feet.

As seen in the mine workings, the productive vein strikes about due east; the dip ranges from about 75° N. on the upper adit level to about 60° N., 65 feet below the level. At the west end, the vein ends against a diabase dike intruded along a fault that strikes north and dips

55° E. The collar of the winze sunk on the vein is 95 feet east of the dike on the adit level; and at 120 feet below the collar, the winze bottoms in the dike. To the east, all the drifts end in nearly barren parts of the vein. The maximum development on the vein is on the first sublevel, where the drift extends 175 feet east from the dike.

The ore occurred as small bunches or shoots along the vein in quartzite breccia. The location of the stopes indicates the bunches of ore had no definite pattern. Between the stopes the quartzite breccia is practically barren of ore minerals. Only a few small patches of ore remain from which the character of the mineralization can be roughly determined.

The vein matter is completely oxidized, except for a few scattered remnants of galena. Lead is present mainly as cerussite, which is commonly accompanied by a sprinkling of bright-yellow massicot. Hemimorphite and descloizite are the only zinc minerals recognized. Mixtures of brown limonite and manganese oxides, mainly hard psilomelanelike minerals, are abundant especially along the hanging-wall side of the vein fault zone. Drusy quartz occurs throughout the mineralized quartzite breccia, and most specimens of the ore contain small amounts of clay. Fragments of vein material containing veinlets of specular hematite were seen on the mine dumps.

Breccia fragments and fractures in the walls of the vein are commonly coated by thin crusts of pale-yellow or orange vanadinite crystals or brown descloizite. Rosettes of thin platelike rhombohedrons of calcite and tufts of fine, almost hairlike, crystals of hemimorphite are attached to the descloizite crusts. Much of the rock on the mine dumps, which probably is low-grade vein material sorted from the ore, is coated on one or more sides by crusts of vanadinite and descloizite. Most of the vanadium minerals seen in the mine were on the upper adit level and on the upper sublevel.

DEFIANCE (APACHE) MINE

The Defiance mine, formerly known as the Apache mine, is 5 miles northwest of Globe and 1¼ miles northeast of Radium, a siding on the railroad connecting Globe and Miami.

Vanadium minerals in the outcrop of the Defiance vein first drew attention to the property. In 1930, Edward C. O'Brien & Co. produced and shipped 20 tons of vanadium concentrate. From 1936 to 1948, the mine was operated intermittently by the owner, D. S. McDonald, and various lessees. During this period, 1,300 tons of selected lead ore was shipped to the smelter in El Paso. According to records furnished by the owner, the smelter paid for 424,637 pounds of lead, 3,755 ounces of silver, and 227 ounces of gold.[3]

The rocks exposed in the vicinity of the Defiance mine are Pioneer formation and diabase. The Pioneer formation, which here is a hard fine-grained feldspathic quartzite, crops out in several small blocks on the south slope of a chain of low hills that trend west-northwest (pl. 2). The general dip of the beds is 30°–40° S., a little steeper than the slope of the hillsides.

The Defiance vein strikes N. 35° E. and dips 80° SE. The outcrop of the vein fissure can be traced for 1,500 feet southwest of the mine; though along most of its course, it is marked only by a darker color of the diabase, caused by slight mineralization and chloritic alteration. Northeast of the mine, the vein ends at the north contact of the Pioneer formation with the diabase. About 300 feet southeast of the end of the Defense vein, a weakly mineralized fissure extends northeastward from the north edge of the Pioneer outcrop. A fissure that may be the continuation of this fissure crops out for nearly a mile northeast of the quartzite. The southwestern part of this fissure contains small amounts of lead and vanadium minerals, but along the northeastern part the vein minerals are mainly manganese oxides. Northwest of the mine several short weakly mineralized fissures in the quartzite and diabase are about parallel to the main vein.

The mine workings on the Defiance vein comprise two shafts and about 1,400 feet of drifts, crosscuts, and raises. Much of the workings have been used for the disposal of waste rock and are now inaccessible.

Shaft No. 1, commonly called the Vanadium shaft, is 150 feet deep, with levels at 50 and 150 feet below the collar (fig. 11). Shaft No. 2 is 160 feet to the southwest, and its collar is 40 feet lower. It is 110 feet deep, with levels at 30, 65, and 110 feet. It is filled with waste rock below the 65-foot level. The 110-foot level is said to connect with the 150-foot level of shaft No. 1. The present water level in the mine is 14 inches above the sill of the 150-foot level of shaft No. 1. Drifts from the two shafts explore the vein for 550 feet along its strike, and except for small pillars left to protect the shafts, the vein has been stoped continuously for at least 450 feet. Large portions of the stopes have been backfilled with waste rock sorted from the ore.

The collar of shaft No. 1 is in the outcrop of the Defiance vein 220 feet south of the outcrop of quartzite of the Pioneer formation. The quartzite has a steep contact on the north side; the south contact is parallel to the bedding and dips under the diabase. The shaft was begun in diabase but enters the underlying quartzite about 35 feet below the collar. Below the 50-foot

[3] Published with permission of the owner, Mrs. Ida McDonald.

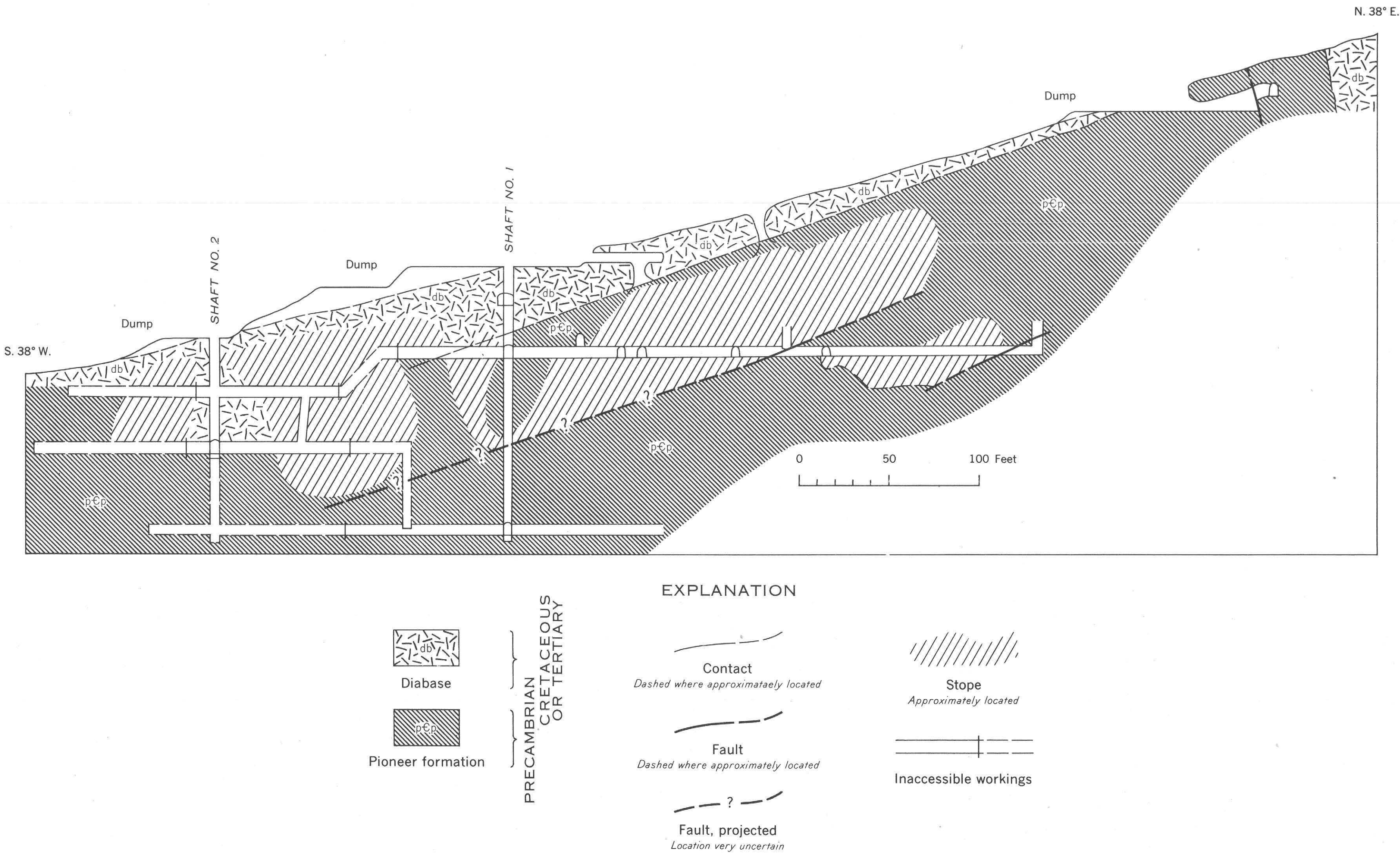

FIGURE 11.—Defiance mine, projection of mine workings on a vertical section N. 38° E.

level the shaft crosses the footwall of the vein fissure and on the 150-foot level is 20 feet northwest of the footwall. Near the shaft on the 50-foot level, the vein fissure is filled with diabase gouge, and no quartzite is visible in the south wall. Both walls probably are diabase a short distance southwest of the shaft. In the workings accessible from shaft No. 2, no quartzite appears in either wall of the vein. Striations on the walls of the vein fissure indicate that at least, the latest displacement was nearly horizontal, but the displacement must have been small, for no offset of the quartzite can be recognized where the vein fissure crosses the outcrop.

The main vein is bounded by regular walls that generally dip 80° to 85° SE. The stopes range in width from 3 to 12 feet and average about 5 feet. The top of the stopes is near the contact of the quartzite with the overlying diabase. The bottom limit of the ore is said to be a bedding-plane fault that crosses the 50-foot level 150 feet northeast of shaft No. 1. The influence of this fault cannot be determined by examination of the accessible workings. At the northeast end of the mine, in the footwall block of the main vein, a short segment of a vein has been stoped for short distances both above and below the 50-foot level. The underhand stope is filled and could not be examined. The vein segment is parallel to and 20 feet southeast of the projected strike of the main vein If the two veins were once continuous, the present relationship could be explained by a reverse displacement of about 30 feet on the bedding-plane fault. The continuity of the fault through the mine workings could not be established.

On the 150-foot level, the drifts driven northeast and southwest from shaft No. 1 follow a well-defined fissure, which is very poorly mineralized in comparison to the vein worked on the level above. Crosscuts into the footwall and hanging wall did not reveal any other mineralized fissures. It is possible that the bedding-plane fault served as a barrier that obstructed, to a large extent, the passage of mineralizing solutions into the rocks below the fault rather than as a means of offsetting the mineralized fissure.

Southwest of shaft No. 2, the vein has been explored by drifts for 100 feet, but stopes extend for only about half this distance. The stopes and drifts are not accessible, and the reason for discontinuing work in that direction cannot be determined underground. However, the fissure beyond the stopes is very weakly mineralized at the surface. Probably, as in many of the other veins in the Globe area, mineralized rock of ore grade does not continue for more than a short distance beyond the point where both walls of the fault are diabase.

The mineralized fault zone consists chiefly of quartzite fragments and of diabase gouge that has been altered to a white porous mass of clay, sericite, and finely disseminated calcite. The ore minerals appear to have been confined largely to a narrow band in the middle part of the zone. The ore that was shipped to the smelter was carefully hand sorted and probably represents no more than 20 percent of the rock broken in the stopes. It averaged approximately 19 percent lead, 3.7 percent zinc, 0.55 percent copper, and 0.17 ounce gold and 3.7 ounces of silver to the ton.

The lead was present mainly as masses of cerussite which commonly surrounded small kernels of galena enclosed in shells of anglesite. Willemite occured as granular aggregates of small hexagonal prisms interspersed with fine-grained vanadinite and descloizite. Limonite is present but is not abundant. There is no general silicification of the mineralized rock, and the only introduced quartz occurs as thin stringers and fine-grained druses.

Vanadinite, descloizite, and mottramite are present throughout the mineralized fault zone but are most abundant in the fractured quartzite wall rock. How far the vanadium minerals penetrated into the wall rocks is not known; but in the vanadium stope on the north side of the vein, crusts of large, orange-red vanadinite crystals coat the walls of fractures 20 feet from the vein. In and near the vein, the vanadinite is finer grained and is generally associated with descloizite, mottramite, and calcite. Calcite was deposited on vanadinite crystals and in the open spaces between them. In some places the two minerals appear to be intergrown, although most of the calcite is clearly the younger. Along the margins of the vein, corroded crystals of vanadinite are commonly engulfed by thin crusts of descloizite and mottramite.

DOUGHBOY SHAFT

The Doughboy shaft is situated on the west flank of a ridge around which Irene Gulch bends sharply to the south about 1 mile east of the confluence of the gulch and Pinal Creek. It is 2,000 feet north of the west end of the Irene vein. The shaft, reported to be 963 feet deep, was sunk about 1901 by Arizona-Colorado Copper Belt Gold Mining and Milling Co. According to oral reports, a crosscut 1,200 feet long driven southeastward on the 800-foot level found a vein from which ore containing 2.5 to 7 percent copper was shipped to the Old Dominion smelter. The ore, however, contained so much zinc that it could not be economically treated, and the mining ceased in 1913. Mineralized rock on the dump of the shaft substantiates a part of these reports.

The shaft and crosscut were driven in diabase that forms the hanging wall block of the Irene vein. Several narrow weakly mineralized fissures crop out in diabase in the vicinity of the shaft. They strike northeastward and dip 50° SE. to vertical (pl. 1). Two exploratory holes have been drilled to crosscut these fissures at depths ranging from 300 to 500 feet below the outcrops. The fissures cut by the drill holes are comparable in size and mineral content to those that crop out. There is no surface indication of a large ore body that could have been located by the crosscut, but it is entirely possible that more intense metallization may have occurred along portions of these minor fissures.

In 1951, Comstock Extension Mining Co. attempted to reopen the Doughboy workings and retimbered the shaft to a depth of 350 feet. The reclaimed portion of the shaft cuts several southward-dipping slightly mineralized fractures, but the minerals that can be seen are mainly wulfenite and vanadinite, which occur as discrete crystals or clusters of crystals on the walls of the fractures.

Several other faults and fractures containing small amounts of wulfenite and vanadium minerals crop out in the quartzite southwest of the Doughboy shaft. A fault at the edge of the dacite half a mile southwest of the Doughboy shaft contains a relatively large amount of vanadium minerals and a little wulfenite. The fault strikes northeast across a small embayment on the north edge of the dacite mass that overlaps Pioneer formation and Dripping Spring quartzite. The fault contains a narrow vein of vuggy and drusy quartz that fills the interstices of the fault breccia and to some extent appears to replace the quartzite fragments. In many of the vugs, the protruding quartz crystals are completely covered by crusts of vanadinite, descloizite, and possibly mottramite, which in turn are coated by thin films of manganese oxides. The dump of a shaft sunk on the vein contains a few fragments stained by copper carbonate and silicate. The deposit probably contained some cerussite and zinc silicates, but none could be found on the dump.

CROWN POINT NO. 6 CLAIM

The Crown Point No. 6 claim is on the west side of Pinto Creek about half a mile north of the Carlota mine in the Inspiration quadrangle (pl. 7). The southern half of the claim covers a small outcrop of diabase. A fault along the east side of the outcrop brings the diabase into contact with the Pinal schist of a thrust plate overlying diabase and Whitetail conglomerate. On the north, west, and south sides, the diabase is overlapped by dacite.

A small fracture, which has been slightly mineralized for about 60 feet along the strike, crops out in the diabase. The mineralized fracture strikes N. 60° E. and dips 50° SE. The meager vein matter, which is a replacement of the diabase wall rock, consists of quartz, cerussite, wulfenite, and vandinite. Some of the cerussite surrounds small kernels of galena.

DAY PEAKS VEINS

Several small molybdenum-bearing veins crop out on the east flank of Day Peaks, 1½ miles southwest of the Copper Cities open-pit mine. They are of no economic significance but are of special interest because the most abundant ore mineral seen in the shallow workings that explore the veins is wulfenite, most of which is a variety that contains more tungsten than molybdenum and more properly should be termed molybdinian stolzite.

These veins were explored for gold during the early days of the district, but apparently their gold content was too small to justify exploitation. They are structurally similar to many other small gold-bearing veins that crop out to the northeast between Day Peaks and Copper Cities. The strongest mineralization was along two narrow eastward-striking fracture zones in diabase near the edge of the dacite that caps the Day Peaks. The outcrops are poorly exposed because of the abundant talus from the dacite outcrops higher on the slope.

As seen in the shallow workings, the vein matter is completely oxidized and consists of honeycombed and drusy quartz, coated with crusts or sprinkled with tiny crystals of yellowish-orange wulfenite. Some cavities contain clusters of large plates of very pale yellowish-gray wulfenite. Generally, the small crystals that form the crusts occur as pointed prisms or as globular intergrowths of crystals. Cerussite also is present as crusts and as small white crystals clinging to the cellular quartz. Powdery brown limonite is abundant throughout the vein matter. J. N. Faick of the Geological Survey examined the workings with an ultraviolet light and reported traces of scheelite in an adit driven on one of the fractures. In contrast to other occurrences of wulfenite in the district, no vanadium minerals were recognized in these deposits.

MANGANESE-ZINC-LEAD-SILVER VEINS

There are many small veins in the Globe Hills area whose outcrops are characterized by abundant oxides of manganese. Most are in a zone about 2 miles wide, extending from Pinal Creek northeastward along the north side of the Old Dominion vein system. This group includes the veins on the Rescue and Ramboz properties southeast of Ramboz Peak. the network of small veins on the Mineral Farms claims in Big Johnnie Wash, several deposits on claims of the Superior and Globe Copper Co., and the California group northeast of Black Peak, also deposits in limestone north of the Mallory shaft on the New Dominion property and on the Darius claim half a mile north of the Old Dominion "A" shaft, and several other smaller deposits. Most of these deposits contain some silver, and some deposits, including the Ramboz, Rescue, and New Dominion veins, contained pockets of rich silver ore that were mined during the early days of the district. Some were mined for manganese during the two World Wars, and in 1953 nearly all were being exploited for low-grade manganese ore.

These deposits were formed by replacement of breccia and gouge along fissures and faults of minor displacement. Some of the stronger veins are along contacts between Pioneer formation and diabase, which probably are old faults that have been reopened by slight displacement after the intrusion of diabase. Along many of the intrusive contacts between diabase and quartzite or limestone that show no evidence of such displacement, the rock is weakly mineralized. The deposits on the New Dominion property are replacement veins along faults cutting Martin and Escabrosa limestones. Only short segments of the vein fissures are sufficiently well mineralized to constitute ore bodies or shoots.

Development of these deposits has been limited almost entirely to the oxidized zones in which the vein minerals are chiefly various oxides of manganese, limonite, quartz, and secondary calcite. Pyrolusite and manganite are conspicuous minerals in all the deposits, but much of the ore is a soft earthy aggregate of indeterminate oxides of manganese and iron and altered host rock. The best ore is at or near the outcrops. Generally, the ore becomes poorer in manganese and more siliceous within 50 feet of the surface. The total amount of quartz in the veins probably is fairly constant within the limits of observation; but the ratio of manganese oxides to quartz decreases rapidly with depth. The ore contains a little lead and as much as 12 percent zinc; little of it contains less than 2 percent zinc.

The development of these deposits has been too shallow to provide more than a cursory glimpse of the primary vein matter. Scattered remnants of sphalerite and galena are present in some of the deeper underground workings. The few specimens of the unoxidized vein matter that have been obtained, which probably are not truly representative, consist mainly of carbonates, quartz, pale-yellow sphalerite, and a little galena. Chalcopyrite and bornite are present in very minor amounts and a little specular hematite is generally intergrown with the quartz. All the hypogene sulfides show a little supergene replacement by chalcocite and covellite. The veins probably contained a little pyrite although none was seen. The carbonates are coarse-grained rhodochrosite and fine-grained manganian ankerite.

The manganese oxides and limonite are residual concentrations formed by oxidation of the manganese-bearing carbonates. The presence of botryoidal crusts and concretionary masses of hard psilomelanelike minerals at or near the surface suggests that there has been further enrichment as a result of solution and redeposition of manganese by descending ground water. Thus, the deposits are richer in manganese at or near the surface and gradually become poorer down to the limits of oxidation.

Some of the veins in limestone are bordered by irregular replacement bodies of manganese oxides extending outward into the wallrock along certain favorable beds or along branching or cross fractures. The shale and marl beds at the top of the Martin limestone were especially susceptible to replacement by the manganese minerals.

The relatively high zinc content of the oxidized vein material considered in conjunction with the general tendency of zinc to be carried away under supergene conditions suggests that, in some places, the unaltered parts of the veins may contain enough sphalerite to furnish zinc ore. Also, it is possible that the zinc content of the veins will increase with depth, as a result of hypogene mineral zoning. The most discouraging factor opposing deep exploration of these veins is their small size. The ore shoots, as seen in the manganese workings, are rarely more than 4 feet wide or more than 200 feet long.

RAMBOZ PROPERTY

The Ramboz vein is 3½ miles north of Globe and 0.7 mile southeast of Ramboz Peak. It strikes about N. 60° E. and dips vertical to 80° SE. The principal ore shoot, which was mined for silver during the early days of the district, is 300 feet southeast of the saddle at the head of Rescue Canyon (pl. 2). A shaft 80 feet deep, sunk on the shoot; an adit about 90 feet long, driven southwestward from its portal in the canyon at a point northeast of the shaft; and several shallow pits form the mine workings.

The ore shoot on which the shaft was sunk is said to have been stoped from the level of the bottom of the shaft to the surface and for about 100 feet along the strike. The stope is now filled with waste rock, but it appears to be from 3 to 4 feet wide.

The vein is a replacement of diabase along a minor fault, and ranges from a mere stringer a fraction of an inch wide to a replaced zone 4 feet wide. The vein is completely oxidized to the depth reached by the shaft. The vein matter, which is mainly quartz and partly replaced diabase containing seams and irregular masses of pyrolusite, manganite, and psilomelanelike minerals. Light-brown, pulverulent limonite is generally present but is not abundant. The middle part of the vein, where sulfides were most abundant, is a cellular boxwork characteristic of leached sphalerite. The thin siliceous septa are coated with manganese oxides. There are occasional small knots of cerussite and scattered masses of lamellar barite. The iron and manganese oxides generally contain a little copper, probably as finely disseminated cuprite or carbonate. A little pale-yellow cerargyrite was recognized, and probably all the silver occurs in this mineral. No zinc minerals were recognized in the oxidized vein matter, but undoubtedly a little zinc carbonate or zinc silicate is present. About 3 tons of ore mined in 1950 from a small pocket near the old shaft contained 55 ounces of silver to the ton and about 2 percent copper. The grade of the ore mined during the early operations is not known, but undoubtedly only the richest material obtainable by careful hand sorting was shipped. About 1,000 tons of rock from the dumps shipped to the smelter in 1947 contained about 6 ounces of silver to the ton.

A small pocket of sulfide ore cut by the adit may be approximately representative of the hypogene vein matter. It consists of light-colored sphalerite, a little galena, and carbonates, predominantly rhodochrosite and ankerite. The ankerite is generally fine grained and is commonly intergrown with quartz. The rhodochrosite is coarsely crystalline and appears to be younger than the ankerite. Most of the sphalerite and galena are intergrown with the rhodochrosite, but a little is disseminated in the ankerite. Apparently replacement of diabase by quartz occurred only in those parts of the vein that are most heavily mineralized.

A nearly parallel branch of the main vein crops out about 150 feet to the southeast. The outcrop of the branch shows about the same intensity of mineralization as that of the weaker part of the main vein.

The vein faults probably continue northeastward and intersect a broad fractured zone lying between two nearly parallel faults whose general strike is N. 20° E. These faults and the rock between them are not well exposed at the surface, but evidence of mineralization can be seen in some places. From a shaft sunk on the west fault, a drift along the fault and a crosscut to the east were driven. These workings are inaccessible, but they are reported to have exposed several mineralized fractures that contain manganese oxides, probably formed by oxidation of manganese-bearing carbonates. The east fault forms the contact between diabase and a small block of Pinal schist.

About 750 feet southwest of the shaft, the faults extend across a saddle and continue into the head of Big Johnnie Gulch, whence they can be traced southwestward to within 1,000 feet of the northeast end of the Irene vein fault, which probably is a part of the same fault system.

Just south of the saddle, a segment of the fault zone is covered by the Vacey-Constance claim, which was worked about 1886 and is credited with a production of $100,000 in silver (Elsing and Heineman, 1936, p. 92). The Vacey-Constance workings consist of several shallow adits and opencuts now caved and almost obscured by detritus from the surrounding diabase.

RESCUE MINE

The Rescue vein crops out in Rescue Canyon south of Ramboz Peak (pl. 1). It is a mineralized fissure, mainly in diabase, which can be traced for about 8,000 feet. In the eastern part, it strikes N. 70° E., but in the western part, the strike changes to about N. 25° E. The fissure is essentially vertical. The diabase is a thick sill intruded into the lower part of the Pioneer formation, which in this area overlies Pinal schist.

The fissure is slightly mineralized along most of its length, and a few shallow pits prospect the most promising looking segments of the vein outcrop. The only productive ore shoot crops out on the top of a ridge about 3,000 feet southeast of Ramboz Peak and 750 feet north of the ore shoot in the Ramboz vein. It was developed by an opencut across the top of the ridge and several adits driven at various levels from both the east and west sides of the ridge.

High-grade silver ore was produced from this shoot during the early days of the district. The character of the vein matter apparently is very similar to that of the Ramboz vein. About 1,000 tons of rock, probably reject sorted from the high-grade ore, was shipped from the mine dumps during 1946 to 1950. It averaged 6.8 ounces of silver to the ton, less than 0.5 percent copper, and a trace of gold. It contained a little lead, but the amount was not reported in the smelter returns.

MINERAL FARMS GROUP

The Mineral Farms group of claims, which is also known as the Eagle Pass group, is near the head of Big Johnnie Gulch, 3 miles north of Globe. The claims include a group of small veins that crop out about half a mile northwest of Black Peak (pl. 1) in a sill-like body of diabase intruded into the lower part of the Pioneer formation. The basement rock in this area is Pinal schist.

The veins are along a network of branching fissures that strike N. 20° E. to east and dip 45° NW. to vertical. They range in size from thin stringers an inch or two wide to zones of partly replaced breccia 6 feet wide. The veins were formed by replacement of gouge and angular breccia fragments along the fissures. As seen in many shallow pits, most less than 5 feet deep, the vein matter is completely oxidized and consists of porous and honeycombed quartz and angular fragments of altered and partly replaced diabase with ribs of hard "psilomelane" minerals and pockets of soft, earthy oxides of manganese and iron. Many vugs are filled with crystals of manganite, and some manganite occurs with the earthy oxides. Along some of the strongest veins, outcrops of silicified breccia protrude several feet above the ground surface. A shaft, said to be 215 feet deep, was sunk near two of the most prominent outcrops. No records of the workings from this shaft are available, but fragments of mineralized rock on the dump offer clues to the character of the primary vein matter.

As judged from these specimens, the most abundant vein minerals are quartz, rhodochrosite, manganian ankerite, sphalerite, galena, and chalcocite. The sulfides are closely associated with and appear to replace the carbonates, which are cut by veinlets of quartz. Plates of specular hematite are intergrown with the quartz and also with all the sulfides, particularly sphalerite. Galena occurs in rounded masses that invariably are surrounded by sphalerite. Chalcocite replaces sphalerite and galena and is altered to covellite along boundaries with gangue minerals and specular hematite. Some polished surfaces of chalcocite show small islands of bornite and shredlike remnants of chalcopyrite, which suggest that bornite and chalcopyrite were the primary copper minerals. However, some of the chalcocite with inclusions of bornite appears to have formed by replacement of sphalerite.

Although these veins are small and of no current economic importance, they may lead toward more concentrated metallization at depth, where the rocks may be more favorable for the formation of permeable channels. If some of the Pioneer formation underlies the diabase, such a condition is highly probable; but whether the schist, which undoubtedly underlies the Pioneer, will prove to be a favorable rock in this respect is uncertain. The pattern of small branching fissures is suggestive of the structure caused by renewed movement on an old fault whose continuity has been interrupted by diabase or whose position was offset by it. Search for such a fault may eventually be justified.

SUPERIOR AND GLOBE GROUP

The early activities of the Superior and Globe Copper Co. were concerned with exploration for copper ore on a group of claims that are about half a mile north of Black Peak in the east-central part of the Globe quadrangle. A vertical shaft 680 feet deep was sunk on the Copper Trust No. 2 claim in 1909, and crosscuts 520 and 233 feet long were driven to the north and south respectively on the 650-foot level. The shaft and crosscuts are in diabase, except for a short interval in Gila conglomerate at the collar of the shaft. No copper ore was found, and the work ceased late in 1910. A few years later, interest in the property shifted to several small manganese-bearing veins from which some manganese ore was produced during the first World War. In 1954, low-grade manganese ore was mined and shipped to a Government stock pile.

The main productive vein, along a contact between Pioneer formation and diabase, extends across the west flank of Black Peak and thence northeastward for a total distance of about 6,000 feet (pl. 1). The contact probably represents an old fault formed before the intrusion of diabase and reopened by slight displacement after the intrusion. The dip of the vein fault ranges form vertical to 50° NW. Near the southwest end, the vein fault intersects the Big Johnnie vein; and for some distance northeast of the intersection, it contains copper-bearing vein matter similar in character to that of the Big Johnnie deposit. It has been explored by a few shallow pits and trenches, but apparently little copper ore was found. Toward the northeast end, the character of the vein filling changes, and manganese oxides are the predominant ore minerals.

The main manganese workings are on the Keno Fraction and Magnet claims, about 4,000 feet north-northeast of Black Peak, where the vein fault splits so as to include a small, lenticular block of Pioneer formation between the two branches. The vein is most strongly mineralized along a short segment of the west branch, in which diabase forms the hanging wall. Along this short segment, the vein has been stoped from the surface to an unknown depth, perhaps to about 50 feet below the outcrop. The stopes range from 2 to 8 feet in width; the average width probably is 3 to 4 feet. Beyond the end of the block of Pioneer formation, the vein continues northeastward in diabase for about 200 feet, becoming narrower and less clearly defined to the bottom of a small wash that cuts eastward across the outcrop. Several small pockets of ore have been mined from this interval of the vein. On the north side of the wash, several narrow discontinuous veins in diabase have been explored by shallow pits and short adits and little ore has been mined from a few small shoots.

These veins were formed by replacement of gouge, breccia, and diabase wallrock. The vein matter is completely oxidized to the depth reached by the mine workings and probably for a considerable distance below. It consists of a soft, earthy mixture of maganese oxides, limonite, clay, calcite, unreplaced diabase, and riblike masses of vuggy quartz. The best ore was formed by residual concentration and downward enrichment of manganese oxides and did not extend below a depth of about 20 feet from the surface. According to Wilson and Butler (1930, p. 61), who examined the property in 1917, when only the richest near-surface ore had been mined, the veins became more siliceous within 20 feet of the surface, and the manganese content was much smaller than at the surface.

CALIFORNIA GROUP

The California claims of the old Globe Commercial Copper Co. adjoin the Superior and Globe claims on the southeast. The principal workings are 1,500 feet southeast of the Superior and Globe mine. Wilson and Bulter (1930, p. 60) reported that 33 cars of ore containing from 16.7 to 35.5 percent manganese were shipped from the property in 1916 and 1917. Recently, mining has been resumed, and several cars of low-grade manganese ore have shipped to the stock pile in Deming, N. Mex.

The California vein follows a contact between Pioneer formation and diabase for about 1,200 feet, it strikes N. 75° E. and dips about 60° NW. The outcrop has been explored along most of its length by open pits, shafts, and short adits which revealed but one mineable ore shoot near the western end of the vein.

The ore shoot was developed by two shafts about 50 feet deep from which it has been stoped to the surface for a strike length of about 200 feet. The stopes are 2 to 3 feet wide, but apparently the ore shoot was even narrower, for much waste rock remains on the mine dumps.

The vein matter that can be observed in the workings is similar to that of the Superior and Globe veins. The best ore was obtained near the surface; manganese content decreased and the silica increased progressively toward the bottom of the shafts. According to Wilson and Butler (1930, p. 61), the ore shipped in 1916 and 1917 was reported to contain about 2 ounces of silver to the ton, and a little ore from this vein was mined for its silver content during the early days of the district.

GOLD-SILVER VEINS

In the same general area that contains the manganese-bearing veins, there are many workings from which ores containing native gold and silver are reputed to have been mined during the early days of the district. Examples are the Centenial, Mexican, Tom Boy, Bull Hill, Bonanza, Badger, Tiger, and many others whose names have long been forgotten.

Undoubtedly some, if not all, of these small deposits should be included in the groups that have been discussed, but practically no information about them is available, and very little can be learned from examination of the surface. Apparently all the ore came from the oxidized zone in which the precious metals of all the various types of deposits are normally concentrated. The adits and shafts, probably none of which reached depths of more than 50 feet, are caved and inaccessible. Even shallow opencuts are so badly caved that detritus from the barren wallrocks conceals all exposures of the mineralized rock, or else the ore occurred in small pockets that have been completely mined out.

The veins, if the term "veins" can be applied to these deposits, must have been short, discontinuous segments not more than a few inches wide. The workings are commonly alined as if along intermittently mineralized fissures; if so, the traces of the fissures are so inconspicuous that they can rarely be followed from one working to another. The alinement is clearly northeast, like that of all other mineralized faults and fractures in the district.

The mineral asemblages probably were most like those of the weakest zinc-lead-vanadium veins, but in their reputedly high content of gold the deposits resembled some of the simple zinc-lead veins. The ore bodies must have been small pockets for even in narrow opencuts from which ore must have been shipped, the wallrocks show no evidence of local hydrothermal alteration or the effects of oxidation or leaching of sulfide minerals. Most of the meager vein matter must have been quartz. The wallrocks are diabase, Pinal schist, or early Precambrian dioritic rocks.

The total production form these deposits could not have been more than a few thousand tons, and it is questionable that the operations were profitable. The small pockets probably served mainly as an incentive for further prospecting.

MOLYBDENITE VEINS

BRONX PROPERTY

The Bronx property is in the northwestern part of the Pinal Ranch quadrangle, 1¾ miles northeast of Pinal Ranch. It contains several mineralized fractures that crop out in the Schultze granite near the western edge of the stock. The mineral assemblage of these veins is unlike that of any of the other deposits of the district, but it has characteristics that suggest a relationship to the quartz-muscovite veinlets that occur throughout the most prominent set of joints of the Schultze granite.

The vein fractures on the Bronx property strike northeast and dip 60° to 80° SE., approximately parallel to the general strike of the muscovite-bearing joints, but they are perhaps a little stronger and more persistent than most joints of the set. The veins are exposed in a deep rugged canyon tributary to Pinto Creek, which is about 4,000 feet to the northeast. The outcrop of one vein can be followed for about 1,000 feet, but the others cannot be traced for more than 100 to 200 feet. The veins range in size from stringers an inch or two wide to irregular, partly replaced zones as much as 3 feet wide. They are widest and most strongly mineralized near the bottom of the canyon, suggesting that the outcrops are near the upper limits at which mineralization occurred.

The granite wallrock of the fractures is replaced mainly by quartz and muscovite. Where mineralization was strongest, the middle part of each vein is mostly quartz intergrown with coarse muscovite and containing small masses and scattered grains of pyrite and chalcopyrite. Outward from the middle part the vein commonly grades into loose, porous aggregates of coarse muscovite containing occasional grains and small masses of purple or colorless fluorite. Clots and thin sheaves of molybdenite flakes are abundant in the transition zone between the middle part of the vein and the muscovite envelope. In some places, muscovite aggregates form lenticular masses 2 or 3 feet thick that commonly contain narrow vuglike masses of quartz intergrown with muscovite and molybdenite and with euhedral quartz filling the central part. The molybdenite is generally associated with quartz; but in some places, coarse flakes of molybdenite are intergrown with flakes of muscovite several inches from the quartz masses.

Pyrite and chalcopyrite are generally present within a foot or two of the surface, but usually they show some replacement by chalcocite. Along some of the more open fractures, they have been completely oxidized and leached, and some of the copper has been redeposited as azurite and malachite. Powdery masses of ferrimolybdite that formed by oxidation of molybdenite can be seen in a few places.

The similarity of the occurrence of muscovite in these deposits and with that in the veinlets associated with the principal set of joints in the Schultze granite suggests a possible genetic relationship. Besides muscovite, the veinlets along the joints commonly contain a little quartz and occasional grains of pyrite. The origin of the quartz-muscovite veinlets in not understood, but their widespread and uniform distribution throughout the granite mass suggests that they were deposited by solutions that emanated from the granite itself during the final stages of solidification. The veins on the Bronx property may represent a more intense phase of this same deuteric process; but if this is the reason it is difficult to understand why there are not other areas containing similar deposits. None have been found.

PYROMETASOMATIC DEPOSITS

Several small deposits, none of economic importance, contain replacement minerals of the pyrometasomatic type, including garnet, magnetite, hematite, sillimanite, and antigorite.

On the south flank of Jewel Hill east of the Castle Dome mine, the Martin limestone along a fault contact with Dripping Spring quartzite is replaced by garnet, magnetite, and hematite. Small amounts of oxidized copper minerals are exposed in a few shallow pits along the fault. Similar minerals occur southwest of the Castle Dome mine along a fault between Martin limestone and Pioneer formation in a small isolated block completely surrounded by diabase and undoubtedly an inclusion. The deposit does not continue into the surrounding diabase; hence it is regarded as older than the diabase and therefore older than the Castle Dome deposite. If so, it may be related to the intrusion of the quartz monzonite.

Magnetite associated with antigorite replaces Mescal limestone along a fault about 1½ miles west-southwest of Webster Mountain. In another place on the east side of Granite Basin, the Mescal limestone is replaced along minor fractures by irregular masses of greenish-yellow garnet, which enclose small masses and stringers of magnetite generally asssociated with a little antigorite. The peripheral parts of the garnet masses are coarsely granular and contain much antigorite that is intergrown with the garnet. Antigorite also appears to form a thin sheath around the garnet masses.

Near the northeast corner of the Pinal Ranch quadrangle, Pinal schist adjacent to an outcrop of Solitude granite has been completely replaced by an intimate intergrowth of magnetite, sillimanite, and a little quartz. The megascopic texture of the schist is faithfully preserved in the replaced rock. This type of replacement is apparently related to the intrusion of the Solitude granite, for it has not been seen associated with any of the other intrusive rocks of the district.

COPPER DEPOSITS FORMED BY METEORIC WATERS

A singular group of copper deposits in the Globe-Miami district contains only oxidized copper minerals, mainly silicates and carbonates and probably a little tenorite. The most productive of these deposits are those in which the copper occurs as silicates replacing tuff and tuffaceous conglomerate that are clearly related to the eruption of dacite, and therefore they are younger than the hypogene copper deposits. Some deposits in diabase, schist, and granite do not have the usual products of hydrothermal alteration in such host rocks. Other deposits, such as the Van Dyke, are along faults or fracture zones in hydrothermally altered and leached schist or granite, but are clearly the result of the direct deposition, filling fractures and the interstices between breccia fragments. The complete absence of sulfide minerals in the fractures or any substantial evidence of their former presence would appear to be adequate proof that the copper silicates and cabonates were deposited by supergene solutions containing ionic copper leached from nearby hypogene deposits or, as in the Van Dyke deposit, from small amounts of disseminated sulfides in the wall rocks. Referring to the deposits in tuff Ransome (1903, p. 131) states:

> The structure of the chrysocolla is closely and minutely related to that of the tuff it has replaced, which would probably not be the case did the ore result from the alteration of former bodies of sulphides. For, even if the sulphides preserved some vestiges of the original texture of the tuff, the further change into chrysocolla could scarcely fail to obliterate them entirely.

The six major deposits of this type have produced about 46.5 million pounds of copper valued at a little more than $7 million.

WARRIOR GROUP

HISTORY

In 1896, the Black Copper group of claims in Webster Gulch near the present site of Inspiration was owned by Havaly, Higdon, and Beard, who had sunk a 100-foot shaft in copper silicate ore. The property was bonded to James A. Fleming and J. M. Ford, who with others incorporated the Black Warrior Copper Co. A quarter of the stock was sold in Eastern United States to obtain working capital. Two more shafts were sunk on the Black Copper property. In May 1898, five claims adjoining the Black Copper group were purchased from Beard and Howie. Ore from development work has hauled to the United Globe smelter at Globe. A leaching plant was completed in 1899, and 100,000 tons of silicate ore was reported blocked out. The venture was unsuccessful and closed after operating for 1 month.

In 1900, the Black Warrior Copper Co. was consolidated with the Donellan Co. and reorganized as Black Warrior Co. Amalgamated. A new treatment plant, consisting of a 100-ton concentrator, a leaching plant, and a reverberatory smelter, was completed in 1901, and a sulfuric-acid plant, in 1902. Many operational difficulties were experienced, and the plant was run only intermittently until August 1903, when all operations ceased. No records of production up to this date are available. The company was reorganized as the Warrior Copper Co. in 1905.

From 1904 to 1909, the property produced about 6.5 million pounds of copper, but the historical details of this period are lacking.

In October 1909, the Warrior Copper Co. was bonded for $1,250,000 to Hoval A. Smith, Henry B. Hovland and associates, who organized the Warrior Development Co. This company mined ore at a rate of 75 to 100 tons a day, most of it going to the El Paso Smelting Works. The option was surrendered in October 1911. In January 1912, the property was leased to Fiske and Snell, of Globe, who operated steadily until January 1920, when the property was sold to Inspiration Consolidated Copper Co.

The Geneva claim, which adjoins the property of the Warrior Copper Co. on the east, was owned by the Old Dominion Copper Mining and Smelting Co. and was worked by lessees about 1900.

PRODUCTION

The production from the properities of the Warrior Copper Co. from 1904 to 1919 is approximately 30.5 million pounds of copper valued at $5,175,000 (Elsing and Heineman, 1936, p. 92). The production from the Geneva claim is relatively small and probably was reported with that of the Old Dominion mine.

DESCRIPTION

The Black Copper, Black Warrior, and Geneva deposits are along a complex system of faults that extends from a point about 1,700 feet west-northwest of the main shafts of the Inspiration Co. eastward to the Miami fault. The system is generally referred to as the Warrior fault zone, although a segment at the western end does not appear to be related to the faults of the main portion of the zone. In this report the name Warrior fault zone is restricted to the segment of the zone that is east of the Black Copper shaft (pl. 7).

The main structure, which trends about due east, is made by two roughly parallel faults bounding a narrow depressed block. Its continuity is interrupted by several branching and cross faults, and its outcrop is obscure wherever both walls of the faults are of dacite or of the tuffaceous conglomerate that underlies the dacite in this area.

The mine workings are now inaccessible, and little if anything can be learned about the former ore bodies by a study of the surface. Only brief descriptions of these deposits, based largely on Ransome's observations, will be presented in this report.

The Black Copper mine is situated about 800 feet northwest of the Inspiration Co's. main shaft. The ore body was along a fault that strikes north and dips 35° E., apparently at its intersection with an eastward-striking fault in the footwall. The latter fault is approximately on the westward projection of the Warrior fault zone, but it dips in the opposite direction, and the depressed block is on the north side, whereas the Warrior fault depresses the block on the south side.

In the mine workings, dacite forms the hanging wall on the east side of the northward-striking fault and schist the footwall. The throw is about 400 feet. A short distance south of the mine, the fault splits; the east branch probably is the Pinto fault, and the west branch may be the northward continuation of the Bulldog fault. Both the Pinto and Bulldog faults displace the Miami-Inspiration ore body and could have served as channels for copper-bearing, supergene solutions.

According to Ransome's (1903, p. 156–158) description, which is based on information furnished by Dr. Irving, the ore body was as much as 12 feet thick and contained from 10 to 22 percent copper. It consisted of fragile, brittle chrysocolla, commonly so darkly colored by manganese oxides as to resemble bituminous coal, that probably replaced dacite breccia and the tuffaceous material dragged from the tuffaceous conglomerate underlying the dacite sheet. Apparently commercial ore did not extend below the second level of the mine, which is about 80 feet below the collar of the shaft.

The Black Warrior deposit is along the Warrior fault zone. The earliest mining was done at the east end of the deposit, about 400 feet north of the Inspiration post office. The ore occurred in tuffaceous conglomerate on the hanging-wall side of a fault that strikes east and dips steeply southward. The fault, which has no more than 50 feet of displacement, drops the tuffaceous beds into contact with schist on the north, or footwall, side.

The tuffaceous conglomerate is about 50 feet thick and rests on an uneven erosion surface of shattered Pinal schist. It is overlain by the black vitrophyre at the base of the massive dacite sheet. Ransome (1903, p. 155–156) described the ore as resulting from metasomatic replacement of dacite tuff by chrysocolla in which all gradations may be traced from solid chrysocolla resulting from almost complete replacement to tuff showing mere traces of copper minerals or none at all. The ore body was a flat blanketlike mass lying at or near the base of the tuffaceous beds.

Later development followed the deposit westward under the dacite almost to the Black Copper mine. The mine maps indicate that the ore occurred in a narrow down-dropped block of tuffaceous conglomerate and dacite breccia between two parallel fractures of the Warrior fault zone. The details of the structure, as depicted by cross sections of the stopes, (fig. 12) are not entirely clear, but it is apparent that the best ore, ranging from 7 to 15 percent copper, occurred in the lower part of this narrow graben, which is of tuffaceous conglomerate 15 to 30 feet wide that has been dropped about 50 feet between walls of schist. The base of the ore body was the irregular surface of the schist on which the conglomerate had been deposited. Upward, the grade of the ore decreases gradually, the stopes become narrower, and the ore pinches out 60 to 130 feet above the base of the conglomerate. In the upper part of

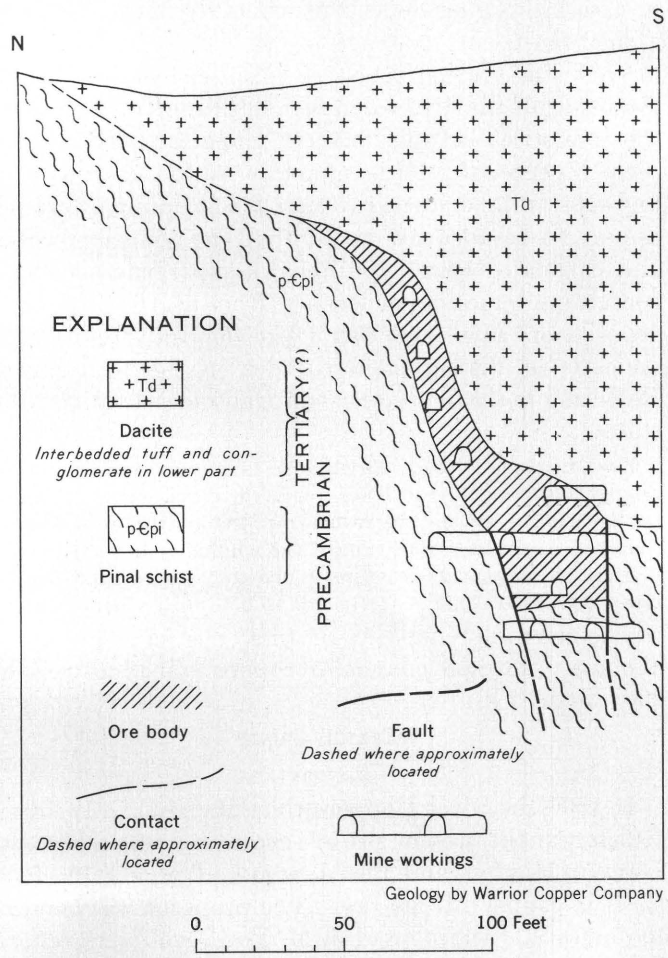

FIGURE 12.—Typical cross section through the Black Warrior ore body.

the ore body, dacite forms the hanging wall on the south side, and schist the footwall. This interval probably represents a normal contact along which the dacite abuts a steep cliff on the old land surface possibly formed by the fault scarp. The cross sections of the ore body, of which figure 12 is typical, indicate an offset in the base of the dacite of 90 to 100 feet. The outcrops over this offset in the base of the dacite are fairly free of detritus, yet, despite careful search, no evidence of a fault through the dacite has been found.

The Geneva mine is about 2,000 feet east of the Black Warrior mine, near the intersection of the Warrior fault zone with the Miami fault. The copper deposit is in a narrow graben of interbedded tuff and conglomerate in the Warrior fault zone. According to Ransome (1903, p. 158–159), the tuffaceous conglomerate is about 50 feet thick. The ore body was nearly horizontal, 4 feet in maximum thickness, and 15 feet wide, lying near the base of the tuff. It rarely possessed definite boundaries but graded into low-grade ore, and this into argillized tuff faintly tinged green by copper. The ore was like that of the Black Copper and Black Warrior deposits; the best ore contained about 20 percent copper.

LIVE OAK AND KEYSTONE VEINS

HISTORY

The earliest mining in the area of the Miami-Inspiration disseminated-copper deposits was done on the Keystone and Live Oak veins, which cropped out in the western part of the mineralized area. All outcrops of these veins have long since been obliterated by caving operations of the Inspiration mine.

Development of the Keystone vein was begun in 1897; and to 1905, about 1,000 tons of hand-sorted silicate ore had been shipped to various reduction works. In 1905, the Keystone Copper Co. was organized to continue exploitation of the deposit. A cholorination leaching plant having a daily capacity of 25 tons was built to treat the ore. This operation never became an economic success but was continued until 1907, when the bottom of the silicate ore had been reached.

The Live Oak Copper Mining and Smelting Co. was organized in 1898 to develop a group of four claims owned by J. J. Marshall, who had sunk a shaft 160 feet deep on a copper-silicate vein resembling the Keystone vein. The company started sinking a new shaft which reached a depth of only 40 feet, when all work was discontinued. The operation was resumed in 1905 and continued until 1907.

Since 1909, the history of the Keystone and Live Oak properties is concerned with the exploration and development of the Miami-Inspiration ore body.

The Keystone and Live Oak deposits are credited with productions of 427,000 pounds and 2,890,000 pounds of copper, respectively, with a total value of about $600,000.

DESCRIPTION

The Keystone and Live Oak veins occupied fissures in the sill-like body of granite porphyry facies of Schultze granite that overlies the schist in the western segment of the Miami-Inspiration disseminated copper deposit (pl. 7). Ransome (1903, p. 160–161) described the ore in the Keystone vein as "bluish-green, brittle chrysocolla adhering finely to the porphyry walls of the fissures and frequently inclosing fragments of the country rock." The ore contained a little quartz and malachite, the latter as streaks in the chrysocolla. It appeared to fill mechanically formed spaces for the most part, but there was also a little replacement of the wall rocks. The richest ore contained about 25 percent copper, and the maximum width was about 18 inches. The ore was followed down to the underlying schist where it ended at the contact (Ransome, 1919, p. 19).

The chrysocolla undoubtedly was deposited by supergene solutions that collected in the fissures and contained copper leached from the surrounding rock which is now being mined as low-grade oxidized copper ore. In the general area in which these veins occurred, there are many small veinlets containing chrysocolla similar to that described by Ransome.

VAN DYKE DEPOSIT

HISTORY AND PRODUCTION

When exploration in the Miami-Inspiration area showed promise of future large scale mining operations, Cleve Van Dyke acquired the property on Miami Flat, which is now the site of Miami, and organized the Miami Townsite Co. This company sold building lots to individuals but retained the mineral rights below a depth of 40 feet from the surface. Van Dyke then organized the Van Dyke Copper Co., and these mineral rights were transferred to it.

In 1916, Van Dyke Copper Co. started a drill hole from the top of a ridge 1,000 feet southwest of the present main (No. 5) shaft of Miami Copper Co. The hole was drilled with a rotary rig similar to those used in drilling for oil. At a depth of 1,182 feet the drill intersected a fault zone heavily mineralized with copper carbonates and copper silicate. A few feet below the footwall of the fault, the bit twisted off, and the hole was abandoned. A second drill hole, 2,600 feet east-southeast of the first hole, intersected a zone of mineralized breccia for 41 feet that, according to assays recorded in the drill log, averaged about 4 percent copper, in the form of carbonates and silicate. A third hole, about 6,700 feet farther southeast, was abandoned at a depth of 1,400 feet, without getting through the Gila conglomerate.

In 1919 the Van Dyke shaft was sunk at a location 200 feet south of the first drill hole to a depth 1,692 feet and intersected the same mineralized fault zone that had been cut by the drill hole. The sharp decline in the price of copper in 1921 discouraged development at that time, and exploration was discontinued.

In 1928 the shaft was unwatered, and development of the copper ore body was resumed. Shipments of ore were made the following year and continued until 1931, when the decline in metal prices made further operation unprofitable.

The mine was reopened in 1943 as a National Defense project, but the ensuing operation was not an economic success, although the average copper content of the ore produced was about 5 percent. The difficulties experienced in getting the ore to the surface from the 1,212-foot level and servicing the underground operations through the single small hoisting compartment of the Van Dyke shaft were largely responsible for the excessive costs that precluded the mining of lower grade ore. The mine was closed in June 1945 and is now inaccessible.

The production of the Van Dyke mine during the two periods of operation is shown in the following table 6.

TABLE 6.—*Copper production of the Van Dyke mine*

	Copper (pounds)	Value
1929–31	[1] 11,000,000	$1,200,000
1943–45	[2] 851,700	113,330
Total	11,851,700	$1,313,330

[1] Elsing and Heineman (1936, p. 92).
[2] Published with permission of Van Dyke Copper Co.

DESCRIPTION

The Van Dyke deposit is in the depressed hanging-wall block of the Miami fault, opposite the east end of the Miami-Inspiration ore body. The Van Dyke shaft was sunk in Gila conglomerate and entered the underlying Pinal schist at a depth of 760 feet (fig. 13). To a depth of 1,440 feet, the schist has the general characteristics of capping formed by supergene oxidation and leaching of a low-grade disseminated-sulfide deposit. It contains residual limonite and small amounts of oxidized copper minerals. According to the mine records, the shaft passed through a low-grade chalcocite zone from 1,440 to 1,600 feet below the collar; and below this passed through schist containing a little pyrite and chalcopyrite. The lower 60 feet of the shaft is in very heavy ground, possibly the Miami fault zone.

The shaft intersected a breccia zone from 1,183 to 1,218 feet below the collar. The zone was sufficiently mineralized with copper carbonates and silicate to constitute an ore body. The footwall of the ore body is clearly defined by a layer of tough red gouge that strikes a little west of north and dips 20° E. The most extensive development in the ore body is north of the shaft. About 200 feet northeast of the shaft, the ore body is

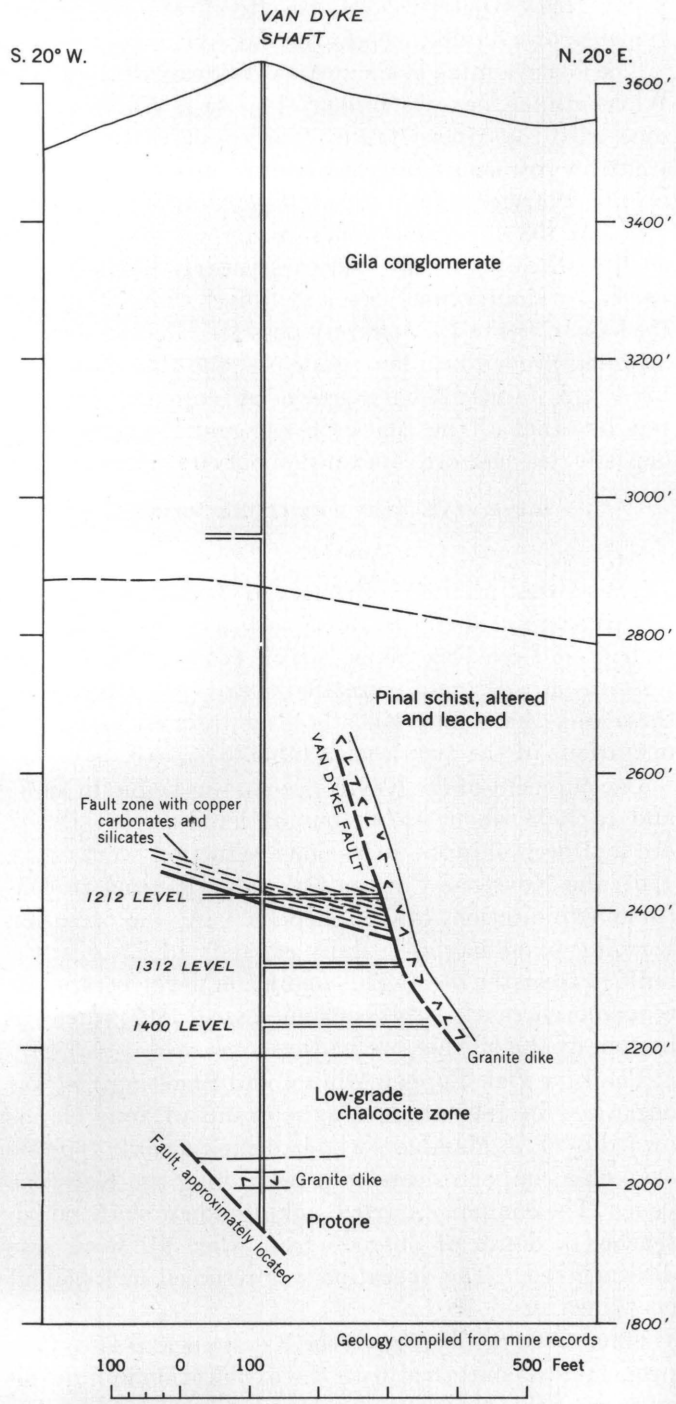

FIGURE 13.—Section along a line striking N. 20° E. through Van Dyke shaft.

terminated by the Van Dyke fault, which is coincident with the footwall of a granite porphyry dike. The fault and dike strike N. 70° W. and dip 70° NE.

The localization of the copper minerals apppears to have been controlled by the intersection of the low-angle fault zone with the Van Dyke fault. The greatest amount of brecciation and the best ore occurred near the intersection, and the amount of brecciation and ore minerals decreases progressively southwestward. The Van Dyke fault clearly served as a barrier to the copper-bearing solutions that seeped into the low-angle fault zone.

The copper minerals in the ore consist entirely of azurite, malachite, chrysocolla, and tenorite. According to I. A. Ettlinger (written communication, 1929):

> These oxidized copper minerals are not the result of oxidation in place of a primary sulphide ore body which contained copper but were first deposited as carbonates and silicates by laterally moving or descending solutions either in a practically barren fault zone or at least a fault zone containing small amounts of pyrite and traces of chalcopyrite. This fact is clearly demonstrated by the oxidized copper minerals which are filling voids and act as a cementing material for irregular angular fragments of practically unaltered schist. The oxidized copper minerals in filling these voids between the schist fragments appear as crustations and in many places assume botryoidal form.

The deposition of the copper carbonates and silicate may have occurred while oxidation and leaching of the surrounding sparsely mineralized schist protore was in progress, probably before the Gila conglomerate was deposited and possibly before the eruption of dacite. The age of the faults has not been determined. The Van Dyke fault, if projected upward, would intersect the shaft near the point where it enters the schist; but whether the fault displaced the Gila is not known. At the time the shaft was sunk, the ground-water level was at 300 feet; that is, about 900 feet above the ore body. Most likely the ore body was formed before displacement occurred on the Miami fault, when the water table in the block now depressed was below the level of the ore body.

The mineralized zone cut by the second drill hole is about 670 feet lower in elevation than the ore body cut by the first hole, but its attitude is not known. The intersection of the faults, as seen in the mine workings, plunges southeastward with a dip and bearing that, if projected, would pass near the ore zone cut by the second hole. It is possible that the two bodies are along the same structure, and they may be connected.

CARLOTA DEPOSIT

Near the southwest corner of the Inspiration quadrangle, deposits of copper carbonates and silicates occur in shattered rock along the Kelly fault zone (pl. 7). At two places the rock has been sufficiently mineralized to constitute ore; one is on the Carlota property, the other is 2,000 feet southeast of the Carlota mine near the old Arizona National shaft.

The Kelly fault zone has an average strike of N. 60° W., and it dips 60° to 70° NE. At the Carlota mine and northwestward to the edge of the quadrangle, a diabase sill intruded between Pinal schist and the base of the Apache group forms the footwall of the fault zone, and dacite forms the hanging wall. In the vicinity of the mine, the dacite is underlain by Whitetail conglomerate and hydrothermally altered Pinal schist; but farther westward, it probably is underlain by Whitetail conglomerate and Paleozoic limestone. The details of structural relationships as they were before the eruption of the dacite cannot be determined. Southeast of the Carlota mine a wedge of shattered but unaltered schist crops out within the fault zone; whereas just northwest of the mine the fault structure becomes complex, and lenticular blocks of Whitetail conglomerate, Paleozoic limestone, diabase, and altered schist crop out in the fault zone.

In the Carlota deposit, the copper minerals occur in brecciated diabase in the footwall of the fault zone. The ore body has no sharp boundaries but grades into low-grade material in which the mineralized fractures are too narrow and too widely spaced to make ore. Its maximum dimensions at the outcrop are about 250 feet long by 100 feet wide. The depth to which rock of ore grade extends is not known. On the deepest level of the mine, about 200 feet below the outcrop, the mineralized zone appears to have contracted to a few major fractures.

A small ore shoot 2,000 feet southeast of the Carlota mine occurs in schist breccia within the Kelly fault zone. At this point altered schist forms the hanging wall of the fault and unaltered, coarse-grained, quartz-sericite schist the footwall. About 1904, a shaft was sunk by the Arizona National Copper Co. to explore the fault zone in the vicinity of the ore body. According to the mine records, which are rather meager, the shaft was sunk about 250 feet in schist breccia, at which depth it entered diabase. A crosscut driven northeastward on the 280-foot level is reported to have intersected a zone of carbonate ore, but the extent of the ore and its location in relation to the shaft are not described. The shaft and a northeast crosscut on the 125-foot level should have intersected the ore zone, but the records do not show that they did. The shaft is now caved.

Some shipping ore was produced in 1943–45 from an opencut on the outcrop of the fault zone. The mineralized fault breccia is mainly of unaltered schist, but in places there is considerable admixture of frag-

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ments of hydrothermally altered schist derived from the hanging-wall block. Except for the difference in host rock, the mineralization was of the same type as the Carlota deposit.

In both deposits the ore minerals are malachite, a little azurite, and various hydrated copper silicates. They occur in veinlets ranging from microscopic to as much as half an inch thick and also as crusts coating the breccia fragments. Where the breccia was especially open, the fragments are commonly covered by several superimposed, botryoidal crusts composed of radially oriented, fibrous silicates that differ in color, texture, and optical properties. Some of the silicates have vitreous luster and are so intimately fractured as to suggest solidification of a colloidal gel. Small botryoidal masses of black tenorite generally embedded in and veined by chrysocolla are present in many places. Silicate layers commonly are separated by thin black films that probably also are tenorite.

The copper minerals have clearly formed by direct deposition either from true or from colloidal solutions that contained copper not derived from minerals originally present in the immediate host rock. There is no evidence whatever that they have formed either by replacement or by alteration in place of older, hypogene, copper-bearing minerals.

The hydrothermally altered schist in the hanging wall of the Kelly fault zone is the host rock of the Cactus ore body. The rock in the outcrops has been thoroughly oxidized and leached, but underground development and exploratory drilling have disclosed a small chalcocite blanket formed by supergene enrichment (p. 95). The altered schist has been thrust over unaltered schist along the Cactus fault, a low-angle fault that dips southwestward and crops out about 900 feet southeast of the Hamilton shaft. This low-angle fault is cut off but the Kelly fault zone along that portion of it in which the deposits of copper carbonate and copper silicate occur. Copper-bearing supergene solutions drained into the Cactus fault zone and deposited large amounts of copper carbonates and silicates in the fault breccia. It is not difficult to imagine how these solutions could have percolated into the Kelly fault zone, whence they could have ascended along especially permeable channels. On the other hand, deposition by descending supergene solutions presents no serious problem of explanation.

In both of the developed deposits on the Kelly fault zone, the ore bodies decrease in size with increasing depth. It is not likely that deposits of this type would be formed below the zone of active ground-water circulation.

PORPHYRY RESERVE

In 1929 and 1930, the Porphyry Reserve Copper Co. produced 350,000 pounds of copper (Elsing and Heineman, 1936, p. 92) from terrace deposits of stream gravels along the sides of Tinhorn Wash east of the Copper Cities open-pit copper mine. The gravels are composed of detritus of local origin, mainly fragments of quartz monzonite, granite, porphyry, diabase, quartzite, and limestone. The fragments are firmly cemented by limonite and copper carbonates deposited by supergene solutions that carried iron and copper, probably as sulfates, leached from the nearby Copper Cities copper deposit. Much of the copper occurs as replacement shells of malachite coating fragments of limestone; the rest is partly in the matrix and partly in the diabase fragments, where it probably replaces carbonates formed by weathering of the diabase.

POWERS GULCH (64 GROUP)

In the southwest corner of the Inspiration quadrangle and for 1½ miles southward in the Pinal Ranch quadrangle, the schist that crops out under the dacite on the west side of Powers Gulch contains small amounts of copper carbonates and silicates. The copper minerals occur as impregnations and veinlets that range in width from microscopic to nearly an inch. They are not evenly distributed, and bulk samples of the rock from various places would probably assay from 0.1 to 0.25 percent copper.

The copper-bearing schist shows no evidence of hydrothermal alteration or the former presence of sulfide minerals, except in a small area just north of the common corner of the quadrangles and also along the contact with a body of the granite porphyry facies of Schultze granite that crops out under the dacite 4,500 feet south in the Pinal Ranch quadrangle. The granite along the contact shows considerable sericitization and slight metallization by pyrite and chalcopyrite

Although the copper content of the rock is too low to be of any economic importance, the total amount of copper in this area undoubtedly amounts to many millions of pounds; and it is significant as a possible indication of extensive hypogene copper metallization in the general vicinity of these outcrops. The copper carbonates and silicate undoubtedly were deposited by ground water; and, since no evidence has been found of any concentration of copper minerals in the tuff that underlies the dacite and which is normally a good precipitant of copper, it is probable that the deposition occurred before the eruption of the tuff and dacite.

The source of the copper is not known, but the wide distribution of the copper minerals suggests a source of considerable lateral extent, most likely a body of disseminated hypogene sulfides under the dacite to the west. The copper may have been derived from a very low-grade deposit too sparsely mineralized to produce an ore body. However, the fact that there is little or no Whitetail conglomerate between the dacite series and the schist in this area suggests that the terrain stood relatively high during the predacite period of exposure and therefore conditions were favorable for the action of supergene processes. Thus, if a disseminated deposit comparable in copper content with that of the protore of other disseminated deposits of the district was present, it is possible that an ore body could have been formed by supergene enrichment before the eruption of dacite.

In 1930 and 1931, five diamond-drill holes were sunk along the rim of the dacite mass. The drill passed through 500 to 1,235 feet of dacite and tuff and penetrated 70 to 410 feet into the underlying schist and granite. Most of the samples recovered were classified in the logs as leached capping and contained less than 0.3 percent copper. Rock of one interval 156 feet long averaged a little more than 0.5 percent copper. All the copper was present as silicate or carbonates, and no sulfides were reported from any of the holes.

The drill holes are only 400 to 1,000 feet from the edge of the dacite along which schist showing no clear evidence of hydrothermal alteration or the former presence of sulfides is exposed. It is difficult to recognize the effects of mild hydrothermal alteration in many local types of schist except by microscopic examination, and the rock described in the drill logs as capping may well be weathered chloritic schist containing a small amount of exotic copper that has been leached and transported by ground water from a more remote source.

OTHER SIMILAR DEPOSITS

Along the southern margin of the Miami-Inspiration mineralized area, just north of Bloody Tanks Wash, the highly shattered granite porphyry is stained by copper salts and contains numerous veinlets of copper silicates and copper carbonate. The minerals of the rock are remarkably fresh and show no evidence of hydrothermal alteration, but the fracture surfaces of the rock are coated by thin films of clay faintly stained by adsorbed copper. The larger fractures contain thin masses of azurite and botryoidal crusts of copper silicates. Thin sections of even the least stained rock show scattered minute areas of fibrous copper silicate that apparently formed by replacement of plagioclase.

To show a probable source of the copper in these deposits presents no great difficulty. The outcrops of schist adjacent to the granite porphyry have been slightly mineralized by hypogene solutions, but the primary sulfides have been almost completely oxidized. In general, the schist in this area contains a little more copper than the granite, and the distribution of copper in the schist suggests slight supergene enrichment. However, as is characteristic of the southern part of the Miami-Inspiration deposit, the mineralized schist contained a very small proportion of pyrite, and consequently there has been but little migration of copper. A little of the copper deposited as carbonates and silicates in the granite porphyry may have been derived from nearby bodies of weakly mineralized schist, but the major part of it probably was leached from the much richer deposits to the north, which were not deficient in pyrite.

An interesting occurrence of exotic copper is on the Empress claim, 2.2 miles east-northeast from Porphyry Mountain, where copper silicates are present in a fracture zone in dacite (pl. 1). The outcrop of the mineralized fracture zone can be traced for only 200 to 300 feet along the west side of a narrow gulch. The zone strikes about N. 40° W. and dips 80° NE. The copper silicates are in thin discontinuous veinlets that fill open fractures and partly replace the dacite wall rock. The veinlets range in width from microscopic to an inch.

A few shallow pits and a shaft about 40 feet deep explore the fracture zone in places where the copper minerals in the outcrop are especially conspicuous. Although the fracture zone in dacite cannot be recognized except where it has been mineralized, it may be a minor fault and continue for some distance along the strike. About 2,000 feet northwest of the copper deposit and on the west side of the same gulch is a small remnant of a basalt flow that overlies a thin bed of Gila conglomerate. It is possible that the west boundary of this basalt outcrop may also be a minor fault, and the continuation of the fracture zone in which the copper silicates were deposited. If so, the block to the northeast has been relatively depressed.

Although this copper deposit is of no economic importance, it is noteworthy as a possible indication of a copper deposit in the rocks that underlie the dacite in this area. Because the dacite is younger than any recognized period of hypogene mineralization, there can be little doubt that the veinlets were deposited by ground water that carried copper leached from older hypogene deposits. It is very difficult to account for an origin by descending solutions considering the present high topographic position of the deposit and the fact that the block in which it occurs was depressed with respect to the adjacent blocks after the eruption of the dacite. The dacitic rocks especially the vitric tuff member generally present at the base, are among the most reactive rocks in the district, and it is inconceivable that the copper could have traveled through these rocks for more than a few hundred feet without being precipitated. The presence of Paleozoic limestones in the downfaulted block east of the Castle Dome ore body practically eliminates the possibility that ground water could have transported the copper from that deposit.

STRUCTURAL CONTROL

In the detailed study of the Globe-Miami district, one is greatly impressed by the prevalence of northeastward structural trends, particularly those related to such deep-seated phenomena as igneous intrusion and mineralization. All the productive mineral deposits of the district, as well as those of the Pioneer (Superior) district a few miles to the southwest, are distributed along a northeastward-trending belt about 6 miles wide (fig. 14). Within this narrow belt, there are 14 mines whose past production and known reserves are valued at more than $1 million for each mine. Of this number, 2 of the mines have already produced more than $300 million each, 4 have or will produce more than $100 million each, and 2 others have produced more than $10 million each. There are many smaller deposits that have yielded from a few thousand to several hundred thousand dollars in metals. The total production of the Globe-Miami district recently passed the billion-dollar mark, and the Pioneer district has produced about $230 million in copper, silver, gold, and zinc.

The northeastward continuation of the belt includes the small but rich silver mines of the Richmond Basin district with a total production of a little more than $1 million. The southwestward extension takes in several small silver, lead, and zinc deposits of the Reymert, Martinez Canyon, and Mineral Hill districts, which probably have a total production of about $1 million.

The outcrop of the mineral belt is interrupted in the Globe Valley area between Globe and Miami by a thick cover of Gila conglomerate that is younger that the period of primary copper mineralization. Tertiary (?) volcanic rocks, which also are postmineralization

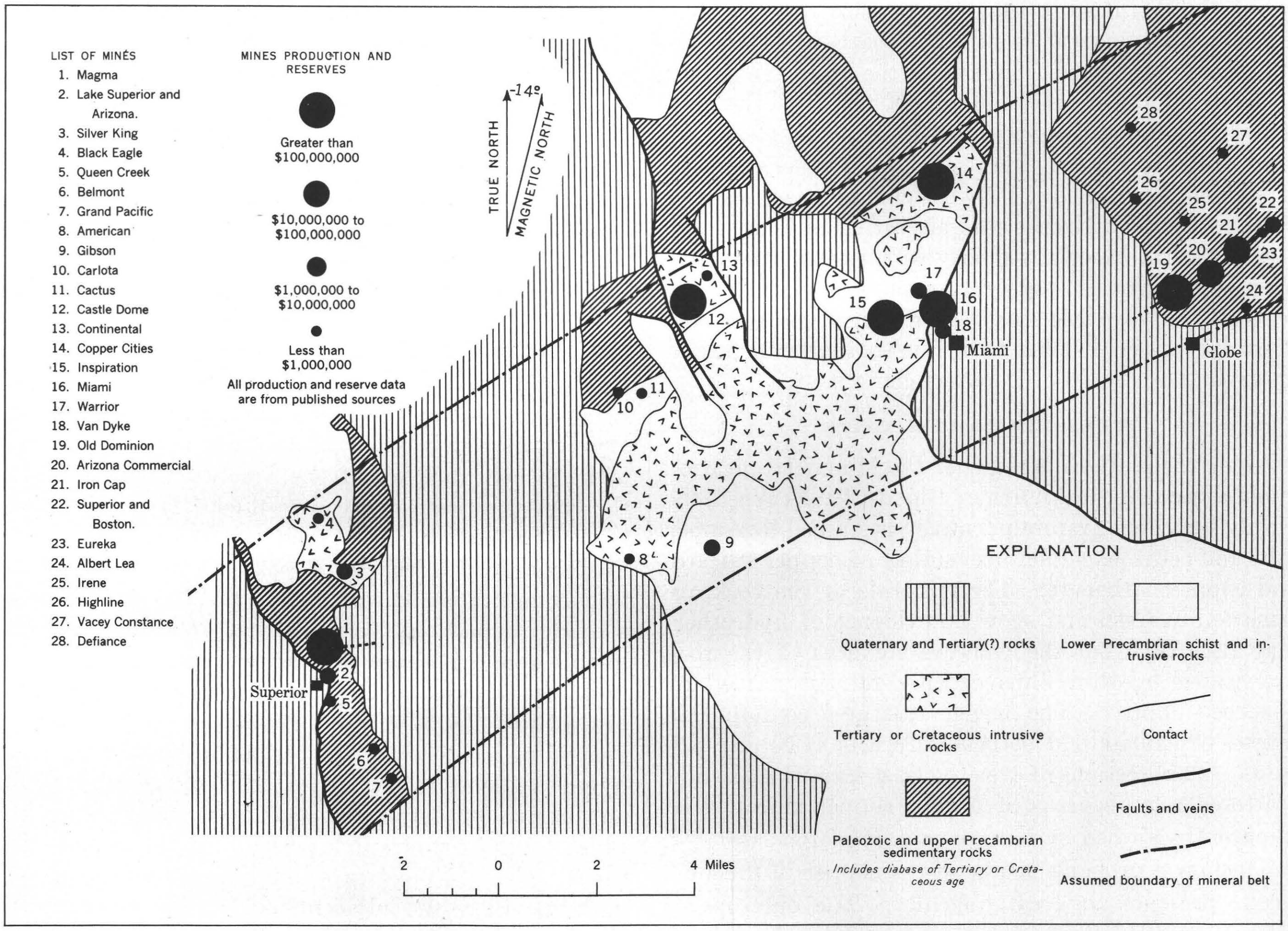

FIGURE 14.—Index map of the Globe-Miami and Pioneer districts showing assumed limits of the mineral belt and the location of the productive deposits.

in age, cover a 6-mile interval between Miami and Superior and the mineral deposits of the Superior area occur in a narrow window of premineralization formations between the volcanic rocks and alluvial deposits to the west. The Magna vein has been followed eastward for some distances under the volcanic cover.

Nearly all the mineral deposits of the Globe-Miami district that are of hypogene origin show the same general trend as the mineral belt. Among the large deposits, the Miami-Inspiration ore body shows the greatest deviation from this general trend (pl. 7). In the western part, the long axis of the ore body strikes about N. 55° E.; but in the eastern part, it changes to a nearly east strike. The strike changes to conform with that of the contact between Schultze granite and schist, which appears to have been the important local control of this particular mineral deposit.

The Castle Dome ore body measures 4,000 feet long and has a maximum width of about 1,000 feet. The strike of the long axis is N. 75° E., which is also the trend of the mineral zones (Peterson, Gilbert, and Quick, 1951, p. 98–101) and the prevailing strike of the mineralized veinlets throughout the deposit.

The mineralized area at Copper Cities (pl. 7) as defined by the boundary of strong to moderate hydrothermal alteration measures 10,000 feet long by about 3,000 feet wide, and its long axis strikes N. 60° E. Northeastward-striking veinlets prevail throughout most of the mineralized area.

An important control of both the Castle Dome and Copper Cities deposits appears to have been a deeply rooted channel along a portion of the contact between Pinal schist on the south and an extensive lower Precambrian mass of Ruin granite to the north. Vertical displacement of as much as 1,200 feet has taken place along this boundary zone, which strikes about N. 60° E. within the limits of the district. The field evidence of the contact of the granite and schist and the possible displacement along the same general zone has been described on page 57.

The Old Dominion vein has been explored for a strike distance of more than 3 miles. Its general strike is about N. 55° E. All the other smaller veins in the Old Dominion area and also the veins of hypogene origin in other parts of the district strike northeast to east-northeast.

The trend of the mineral deposits in the Pioneer district is not as clearly defined as those in the Globe-Miami district but is probably more nearly east. The strike of the Magma vein ranges from N. 65° E. to N. 80° W., but the general strike is a little north of east. The Koerner vein strikes a little north of west. Most of the smaller deposits are replacement deposits along contacts between sedimentary rocks, but at least some of them are related to northeast-trending faults.

The mineral belt also contains many small int sions of granitic rocks that are not represented beyond the limits of the belt. Nearly all are elongated in a northeast direction, and the outcrops of the various bodies of similar rocks are alined in this same direction. This alinement is especially prominent in the outcrops of Willow Spring granodiorite and the granite porphyry that has a close spatial relationship with the mineral deposits. The two main bodies of Lost Gulch quartz monzonite, which contain the Castle Dome and Copper Cities deposits, a body of granodiorite in Gold Gulch, and a chain of small granite porphyry bodies, appear to have been intruded along the above mentioned contact between schist and Ruin granite. The Schultze granite, which is generally regarded as being the source magma of the mineral deposits of the Globe-Miami district, crops out in the central part of the belt.

The distribution of the various types of mineral deposits is markedly symmetrical with respect to the Schultze granite. The large disseminated copper deposits are either grouped within a short distance from the stock or are partly within it. Northeastward from the stock are the vein-copper deposits of the Old Dominion area, and about the same distance to the southwest are the vein deposits of the Pioneer district. Still farther northeast are the silver deposits of the Richmond Basin district, and to the southwest, beyond Superior, are the silver, lead, and zinc deposits of Reymert, Martinez Canyon, and Mineral Hill. It is also noteworthy in this respect that the copper deposits of the Old Dominion area become progressively richer in silver from southwest to northeast.

The faults of the district show two major trends: one is north to northwest, the other is northeast. However, the most outstanding fact is that only the faults that strike northeast have been mineralized by hypogene solutions. This suggests that only faults with a northeast trend are related to the deeply-rooted structures that controlled the mineral belt.

A northeast trend is also an outstanding feature in the structure of the lower Precambrian basement rocks of the region. Although no complete structures have been recognized in these rocks, because of the rather small size of the outcrops that are within the map area, the general attitude of the bedding and foliation of the Pinal schist suggests close folds whose axes strike northeast. The lower Precambrian igneous intrusions within the schist also show this trend; for example, small intrusions of lower Precambrian granite form a northeastward-trending chain of outcrops about 4 miles long in the central part of the belt.

This local Precambrian structural trend is parallel to the early Precambrian mountain ranges of central Arizona, remnants of which are represented by Mazatzal land, the buried granitic Holbrook ridge, and the Defiance and Zuni uplifts. These features as defined by Huddle and Dobrovolny (1952, p. 80) are shown on figure 15. The Globe-Miami mineral belt lies southeast and parallel to the southeast side of Mazatzal land.

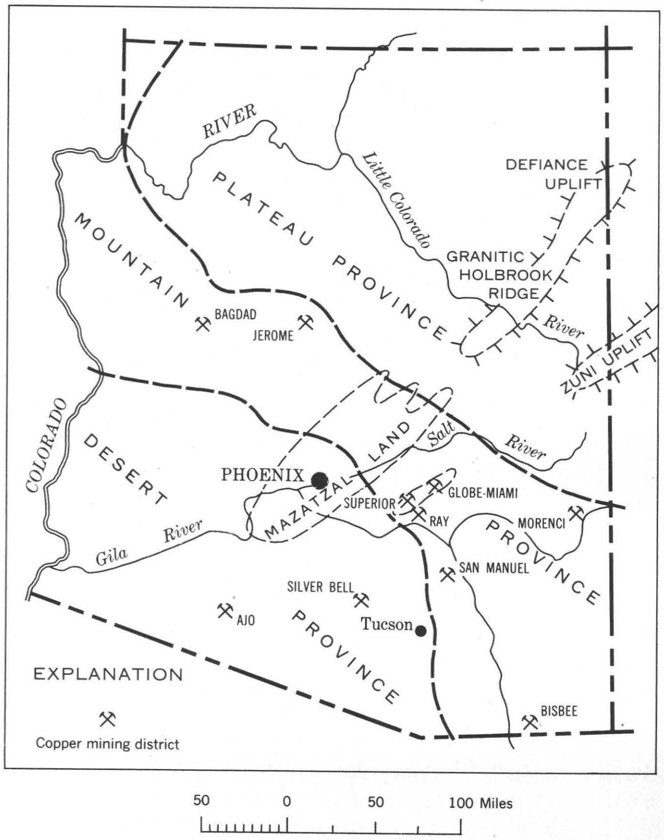

FIGURE 15.—Map of Arizona showing relation of the Globe-Miami mineral belt to the mountain province and Mazatzal land.

When the Globe-Miami district is related to its regional setting, the local northeastward trend is completely overshadowed by the grosser northwestward trend that dominates the geologic map of Arizona. This northwestward trend is most prominent along a mountainous zone that extends diagonally across the State, roughly from the northwest corner to the southeast corner. Physiographically, this zone coincides with Ransome's (1903, p. 14) mountain province that separates the plateau province, on the northeast, from the desert region, on the southwest. Throughout the area of the plateau area, the lower Precambrian rocks are buried beneath a sequence of nearly flat-lying sedimentary formations that range in age from upper Precambrian to Tertiary and which are only mildly affected by folding and faulting.

The bordering mountainous zone is characterized by a chain of short, subparallel echelon northwestward-trending mountain ranges that are separated by structural valleys filled by thick fluvial deposits of Tertiary and Quaternary age. These ranges are composed of highly deformed and faulted blocks of upper Precambrian and Paleozoic sedimentary formations resting on lower Precambrian schists and granites.

Only a few of these ranges have been carefully studied and mapped, and little is known concerning details of their structure or regional relationships. Their representative sedimentary sections are abnormally thin and much interrupted by erosional unconformities and intervals of nondeposition as compared with the vast thicknesses of sections of Paleozoic and Mesozoic sedimentary rocks around the western, northern, and eastern borders of the Colorado Plateau. It is clear, however, that the mountainous zone represents a zone of folding and large-scale crumbling; and as Butler (1929) has pointed out, the lower Precambrian rocks within the zone have been raised considerably above their altitude within the plateau area; or as Suess (1904, p. 590) observed, the mountains present the characters of horsts.

From the great bend in the Colorado River near the northwest corner of the State almost to the Globe-Miami district, the zone forms the southwest rim of the Colorado Plateau. East of Globe, the rim of the plateau is buried by lava flows, but apparently it swings eastward and probably passes 20 to 30 miles north of Morenci. What appears to be the continuation of the main structural zone swings southward near Globe and is joined by a similar belt extending from the southeast rim of the plateau in New Mexico. It continues southward across the international boundary and merges with the intermountain plateau of central Mexico.

The desert province also is characterized by short, northwestward-trending mountain ranges, and the boundary between it and the adjacent mountain province is rather indistinct and arbitrary. The main difference is that the rocks exposed in the ranges of the desert region are deeply eroded and are mostly lower Precambrian schist and granite and Tertiary(?) lava flows that are almost buried by overlapping fluvial and lacustrine deposits.

Butler (1929) has called attention to the concentration of ore deposits in the border zone of the Colorado Plateau. Billingsley and Locke (1935; 1941), Gabelman (1593), Reinhardt (1949), and others have endeavored to demonstrate that important mining districts commonly are situated at intersections of major orogenic belts. The Globe-Miami and Pioneer districts are outstanding examples of extensively mineralized areas situated on the crossing of two structural belts. The northwestward-trending belt is a major structural feature that is clearly related to the Late Cretaceous or early Tertiary orogeny of the Rocky Mountain region. It cannot be clearly defined mainly because the zone has not been studied in detail. The northeastward-trending structures, which show the most direct effects on the localization of mineral deposits, were formed during this same period of deformation and igneous activity, but they probably represent a deeply rooted zone of weakness inherited from the early Precambrian Mazatzal revolution.

The Globe-Miami district is in a depressed block between the Pinal Mountains on the southwest and the Apache Mountains to the northeast. The Pioneer district is in a downfaulted and tilted block on the west side of the Pinal Mountains. The depressed block between the Pinal and Apache Peaks is but a segment of a long, largely structural valley that is continuous with the Tonto Basin to the northwest and the Gila River Basin to the southeast. The mineral belt coincides with a low divide across this valley whence the drainage is northwestward into the Salt River and southeastward into the Gila River. Precambrian and Paleozoic rocks crop out on this divide, whereas to the northwest and southeast the valleys are filled by fluvial deposits of Tertiary and Quaternary age.

ECONOMIC POSSIBILITIES OF THE DISTRICT

Productive mineral deposits have been found only in those parts of the district in which rocks that are older than the premineral deposits crop out. Continuations of some of these deposits, notably the Old Dominion vein and the Miami-Inspiration disseminated deposit and also the Magma vein in the Pioneer district to the west, have been explored for some distances beneath cover of postmineralization formations. From the northeast end of the Old Dominion vein system to the Concentrator fault, which limits the known extent of the Magma vein at Superior to the west (fig. 14), nearly half the area included within the mineral belt is underlain by formations that are younger than the period of mineralization. Erosion has been largely controlled by structural deformation caused mainly by northwestward-trending faults that do not appear to be closely related to the structures that show the most direct influence on the localization of the mineral deposits. Thus there is no apparent reason to assume that mineral deposits occur only in those areas from which erosion has removed the younger formations; and undiscovered ore bodies may be present within those portions of the mineral belt where only the younger formations crop out. Three such areas are worthy of consideration. One is the interval between Superior and Miami, in which a sheet of dacite conceals all the older formations, another is the dacite-covered area between Castle Dome and Copper Cities, and a third is the interval covered by Gila conglomerate between the Miami fault on the west and Pinal Creek to the east.

The largest covered area is that which lies between Miami and Superior; it comprises about 35 square miles in which the outcrops are entirely of dacite. On both the east and west sides the older formations crop out on steep slopes capped by cliffs of dacite. On the west side, the base of the dacite is inclined eastward about 15°, and, where notched by Queen Creek, the dacite is more than 1,200 feet thick (Short and others, 1943, p. 45). Along the east side, the base of the dacite is inclined westward as much as 45°, and in one place a vertical drill hole, 1,000 feet from the edge of the sheet, passed through 1,235 feet of dacite and vitric tuff. The dacite was laid down on a surface of considerable relief, but many of the irregularities and steep dips probably are the results of faults and tilting of the faulted blocks. Geologic mapping now in progress in and around the dacite outcrops is expected to provide some information concerning the major structures of the area.

The dacite was erupted over a surface of considerable relief, but many of the irregularities and steep dips probably are the result of tilting and other displacement of the faulted blocks.

Indication that copper deposits may be present beneath the dacite is given by widespread supergene copper silicates and carbonates in the schist west of Powers Gulch along the east side of the dacite outcrop. (See p. 140.)

Bodies of Schultze granite, particularly of the granite porphyry facies, that intrude the Pinal schist may have an importance influence in the localization of the hypogene ore minerals. One such body of porphyry crops out under the edge of the dacite near the head of Powers Gulch in the Pinal Ranch quadrangle. Locally, the rock in the outcrop is highly sericitized and contains small amounts of pyrite and chalcopyrite. The most abundant oxidized copper minerals in the schist are near the southwest corner of the Inspiration quadrangle, three-quarters of a mile north of the granite porphyry outcrop.

The dacite outcrop between Castle Dome and Copper Cities lies across a prominent structural zone that probably was an important factor in the localization of these two disseminated copper deposits. Possible evidence of a copper deposit in the underlying rocks is furnished by the deposit of copper silicates in the fractured dacite 2 miles east-northeast of Castle Dome and about 3½ miles west-southwest of Copper Cities (pl. 2, section *C–C′*). This deposit of exotic copper, known as the Empress vein, has been described in an earlier chapter of this report (p. 141). The Money Metals vein may also indicate the presence of mineral deposits in this general area (p. 122).[4]

The large outcrop of Gila conglomerate that covers the mineral belt between Globe and Miami constitutes a relatively depressed block bounded by normal faults. Its structure has been described in as much detail as possible on pages 54–57.

The Miami-Inspiration ore body is terminated by the Miami fault, which forms the west boundary of the depressed Globe Valley block. Some prospecting has been done just east of the fault, but the mineralized rock found there is not of sufficient volume or copper content to constitute ore under present conditions. On the east side of the block, the Old Dominion vein has been explored for a strike distance of about 4,500 feet under the cover of Gila conglomerate. The vein continues southwestward for an unknown distance beyond the end of the mine workings. The southwestern part of the vein was truncated by the erosion that preceded the eruption of dacite, and the apex of the vein on the old erosion surface becomes progressively deeper below the present surface toward the southwest, and therefore any exploration of the southwest continuation of the vein must be on or below the bottom level of the mine. The fact that the vein becomes more pyritic and relatively poor in copper on the lower levels of the mine makes such exploration unpromising.

Another factor for consideration is the effect of the low-angle fault on which lower Precambrian rocks were thrust over the dacite at the southwestern end of the Old Dominion mine. Although its location and attitude are unknown beyond the limits of the mine workings, this fault almost certainly truncated the vein; and to the south or southwest of the fault, the bedrock must represent the thrust plate which is composed of lower Precambrian schist and quartz diorite.

[4] In 1955, three exploratory churn-drill holes were sunk in the vicinity of the Empress vein. These holes reached the base of the dacite at depths of 625, 535, and 890 feet, respectively. Below the dacite, the first hole was drilled 785 feet into a rock that is composed largely of fragments of diabase but with subordinate amounts of quartzite, limestone, schist, and granitic fragments and is similar in character to the Whitetail conglomerate that crops out in the Jewel Hill fault zone along the west side of the dacite sheet. The fragmental rock can thus be identified as Whitetail conglomerate. The other two holes passed through 165 and 240 feet of a highly altered, gray, fine-grained rock before entering the Whitetail conglomerate, which one of the holes penetrated for 1,105 feet. The fine-grained gray rock probably is a unit formed in the earlier volcanic eruption. None of the holes reached what could be definitely identified as rocks older than the Whitetail conglomerate.

Prospecting under the Gila conglomerate in this area will probably be limited to the finding of extensions of known deposits. The great thickness of the Gila, which in the southern part of the area within the mineral belt is known to exceed 4,000 feet, will undoubtedly discourage the search for new deposits for which there is no evidence at the present time.

The parts of the district in which formations of premineralization age crop out have been carefully studied and extensively prospected. It is unlikely that they contain undiscovered disseminated ore bodies of commercial volume and grade or vein deposits comparable in size with the deposits that have been mined along the Old Dominion vein system. There are, however, a few undeveloped veins in the Old Dominion area that warrant further prospecting. The best ore bodies in this area have been found along parts of the veins that traverse the formations of the Apache group. Therefore, veins that crop out in either Troy quartzite or in the diabase sill that commonly underlies it may contain commercial ore bodies below at levels of favorable wallrocks even though mineralization was not of ore grade at the outcrops. Fractures in Troy quartzite generally form permeable channels for mineralizing solutions; but if the quartzite is underlain by diabase, the favorable channels may become largely inaccessible to the solutions. Some examples of such veins are the Dime, Stonewall, Buckeye-Black Oxide, Arizona, and Albert Lea.

The possibility of finding small bodies of zinc ore beneath near-surface concentrations of manganese oxides has been discussed (p. 130); but here again, the presence at depth of rocks that had permeable channels for solutions is an important factor.

LITERATURE CITED

Beckett, P. G., 1917, The water problem at the Old Dominion mine: Am. Inst. Min. Eng. Trans. (for 1916), v. 55, p. 35–66.

Billingsley, P. R., and Locke, Augustus, 1935, Tectonic position of ore districts in the Rocky Mountain region: Am. Inst. Min. Metall. Eng. Trans., v. 115, p. 59–68.

——— 1941, Structure of ore districts in the continental framework: Am. Inst. Min. Metall. Eng. Trans., v. 144, p. 9–59.

Bjorge, G. N., and Shoemaker, A. H., 1933, Applied geology at the Old Dominion mine, Globe, Gila County, Ariz. *in* Ore deposits of the western states: Am. Inst. Min. Metall. Eng., Lindgren volume, p. 709–716.

Butler, B. S., 1929, Relation of ore deposits of the southern Rocky Mountain region to the Colorado Plateau. Colorado Sci. Soc. Proc., v. 12, p. 23–36.

Campbell, M. R., 1904, The Deer Creek coal field, Arizona: U.S. Geol. Survey Bull. 225, p. 240–258.

Darton, N. H., 1925, A resumé of Arizona geology: Arizona Bur. Mines Bull. 119, geol. ser. 3, 298 p.

——— 1932, Algonkian strata of Arizona and western Texas [abs.]: Washington Acad. Sci. Jour., v. 22, no. 11, p. 319.

Elsing, M. J., and Heineman, R. E. S., 1936, Arizona metal production: Arizona Bur. Mines Bull. 140,112 p.

Gabelman, J. W., 1953, Definition of a mineral belt in south-central Colorado: Econ. Geology, v. 48, no. 3, p. 177–210.

Gastil, Gordon, 1954, Late Precambrian vulcanism in southeastern Arizona: Am. Jour. Sci., v. 252, p. 436–440.

Gidley, J. W., 1922, Preliminary report on fossil vertebrates of the San Pedro Valley, Ariz., with descriptions of new species of Rodentia and Lagomorpha: U.S. Geol. Survey Prof. Paper 131, p.119–131.

Gilbert, G. K., 1875, Report on geology of portions of New Mexico and Arizona: U.S. Geog. and geol. Survey W. 100th Mer. Rept., v. 3, p. 501–567.

Graton, L. C., and Murdoch, Joseph, 1914, The sulphide ores of copper; some results of microscopic study: Am. Inst. Min. Eng. Trans., v. 45, p. 26–93.

Huddle, J. W., and Dobrovolny, Ernest, 1952, Devonian and Mississippian rocks of central Arizona: U.S. Geol. Survey Prof. Paper 233–D, p. 67–112.

Knechtel, M. M., 1936, Geologic relations of the Gila conglomerate in southeastern Arizona: Am. Jour. Sci., 5th ser., v. 31, no. 182, p. 81–92.

Larsen, E. S., and Berman, Harry, 1934, The microscopic determination of the nonopaque minerals: U.S. Geol. Survey Bull. 848, 266 p., (2d ed.).

Noble, L. F., 1914, The Shinumo quadrangle, Grand Canyon district. Arizona: U.S. Geol. Survey Bull. 549, 100 p.

Palache, Charles, Berman, Harry, and Frondel, Clifford, 1944 and 1951, Dana's system of mineralogy: New York, John Wiley and Sons, Inc., 7th ed., v. 1 and 2.

Peterson, N. P., 1954, Copper Cities copper deposit, Globe-Miami district, Arizona: Econ. Geology, v. 49, no. 4, p. 362–377.

Peterson, N. P., Gilbert, C. M., and Quick, G. L., 1951, Geology and ore deposits of the Castle Dome area, Gila County, Ariz.: U.S. Geol. Survey Bull. 971, 134 p.

Ransome, F. L., 1903, Geology of the Globe copper district, Arizona: U.S. Geol. Survey Prof. Paper 12, 168 p.

——— 1904a, Description of the Globe quadrangle [Arizona]: U.S. Geol. Survey Geol. Atlas, Folio 111, 17 p.

——— 1904b, The geology and ore deposits of the Bisbee quadrangle, Arizona: U.S. Geol. Survey Prof. Paper 21, 168 p.

——— 1910, Geology at Globe, Ariz.; Min. and Sci. Press, v. 100, p. 256–257.

——— 1916, Some Paleozoic sections in Arizona and their correlation: U.S. Geol. Survey Prof. Paper 98–K, p. 133–166.

——— 1919, The copper deposits of Ray and Miami, Ariz.: U.S. Geol. Survey Prof. Paper 115, 192 p.

——— 1923, Description of the Ray quadrangle [Arizona]: U.S. Geol. Survey Geol. Atlas, Folio 217, 24 p.

Reinhardt, E. V., 1949, Can a study of topography locate undiscovered mineralized areas?: Eng. Min. Jour., v. 150, no. 9, p. 90–93.

Ross, C. S., 1955, Provenience of pyroclastic materials: Geol. Soc. America Bull., v. 66, no. 4, p. 427–434.

Ross, C. S., and Kerr, P. F., 1934, Halloysite and allophane: U.S. Geol. Survey Prof. Paper 185–G, p. 135–148.

Schwartz, G. M., 1921, Notes on textures and relationships in the Globe copper ores: Econ. Geology, v. 16, nos. 4–5, p. 322–329

——— 1947, Hydrothermal alteration in the "porphyry copper" deposits: Econ. Geology, v. 42, no. 4, p. 319–352.

Short, M. N., and others, 1943, Geology and ore deposits of the Superior mining area, Arizona: Arizona Bur. Mines Bull. 151, Geol. ser. 16, 159 p.

Stevens, H. J., 1908, The Copper Handbook: Horace J. Stevens, Houghton, Mich., v. 8.

Stoyanow, A. A., 1936, Correlation of Arizona Paleozoic formations: Geol. Soc. America Bull., v. 47, no. 4, p. 459–540.

——— 1942, Paleozoic paleogeography of Arizona: Geol. Soc. America Bull., v. 53, no. 9, p. 1255–1282.

Suess, Edward, 1904, The face of the earth [Das antlitz der erde]: Oxford, Clarendon Press, v. 1, 604 p. (English translation by Hertha B. C. Sollas.)

Tovote, W. L., 1914, The Globe mining district, Arizona: Min. and Sci. Press, v. 108, no. 11, p. 442–449, 487–492.

Trischka, Carl, 1938, Bisbee district, *in* Some Arizona ore deposits: Arizona Bur. Mines Bull. 145, Geol. ser. 12, p. 32–41.

U.S. Bureau of Mines, 1924–53, Minerals Yearbook.

U.S. Geological Survey, 1911–23, Mineral Resources of the United States.

Weed, W. H., 1925, The Mines Handbook: The Mines Handbook Co., Tuckahoe, N.Y., v. 16.

Willis, C. F., 1922, New Dominion Copper Company: Arizona Min. Jour., v. 5, no. 23, p. 38.

Wilson, E. D., 1939, Precambrian Mazatzal revolution in central Arizona: Geol. Soc. America Bull., v. 50, no. 7. p. 113–1163.

Wilson, E. D., and Butler, G. M., 1930, Manganese ore deposits in Arizona: Arizona Bur. Mines Bull. 127, 107 p.

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