151

Charles L. Fair

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ARIZONA BUREAU OF MINES

GEOLOGY AND ORE DEPOSITS OF THE SUPERIOR MINING AREA, ARIZONA

BY

M. N. SHORT, F. W. GALBRAITH, E. N. HARSHMAN,
T. H. KUHN, AND ELDRED D. WILSON

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4. The Bureau provides an ore-testing service for ores originating within the state of Arizona. Full details will be furnished on request.

(Continued on inside back cover)

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INTRODUCTION

LOCATION, CULTURE, AND TRANSPORTATION

The Superior mining area is in northeastern Pinal County, Arizona (Fig. 1). The area was officially organized as the Pioneer mining district but is better known as the Superior mining area.

Superior, the principal settlement within the area, in 1940 had a population of about 5,000, depending principally upon operations of the Magma Copper Company. The old town of Silver King, now largely deserted, was at the Silver King mine, in the northern part of the area shown on Plate I.

The Magma Arizona Railroad, 35 miles long, extends from Superior to Magma, a station on the Winkelman branch of the Southern Pacific, 9 miles west of Florence. It is maintained by the Magma Copper Company. Superior is on U.S. Highway 70, about 64 miles east of Phoenix and 20 miles west of Miami. A graveled state highway extends from Superior to Ray, 15 miles south. A graded county road 7 miles long connects Superior with Silver King. Various secondary roads lead to ranches and mines.

PHYSIOGRAPHY

Superior is on the eastern margin of a basin-shaped valley in the mountainous region between the Superstition and Pinal ranges. The Superior mining area, as here considered, consists of a central northward-trending mountainous belt ¾ to 3 miles wide which rises eastward from this valley to a mesa.

The Central Belt ranges in altitude from about 2,800 feet at Superior to a maximum of 4,500 feet below Apache Leap, the rim of the mesa. It consists largely of faulted eastward-dipping limestone, quartzite, and shale, underlain by schist and including areas of intrusive diabase, diorite, and porphyry (Pl. I). Its topography reflects somewhat the bedrock character and structure. Semiarid, rapid erosion has formed cliffs and steep slopes upon resistant limestone and quartzite; medium slopes or rounded hills upon uniformly textured diorite; and gentle slopes upon shale and diabase. The trend of the mountain front follows rather closely the strike of the beds, as shown on Plate I.

The Valley extends west from Superior, along the drainage of Queen Creek, beyond the limits of Plate I. It is bounded on the

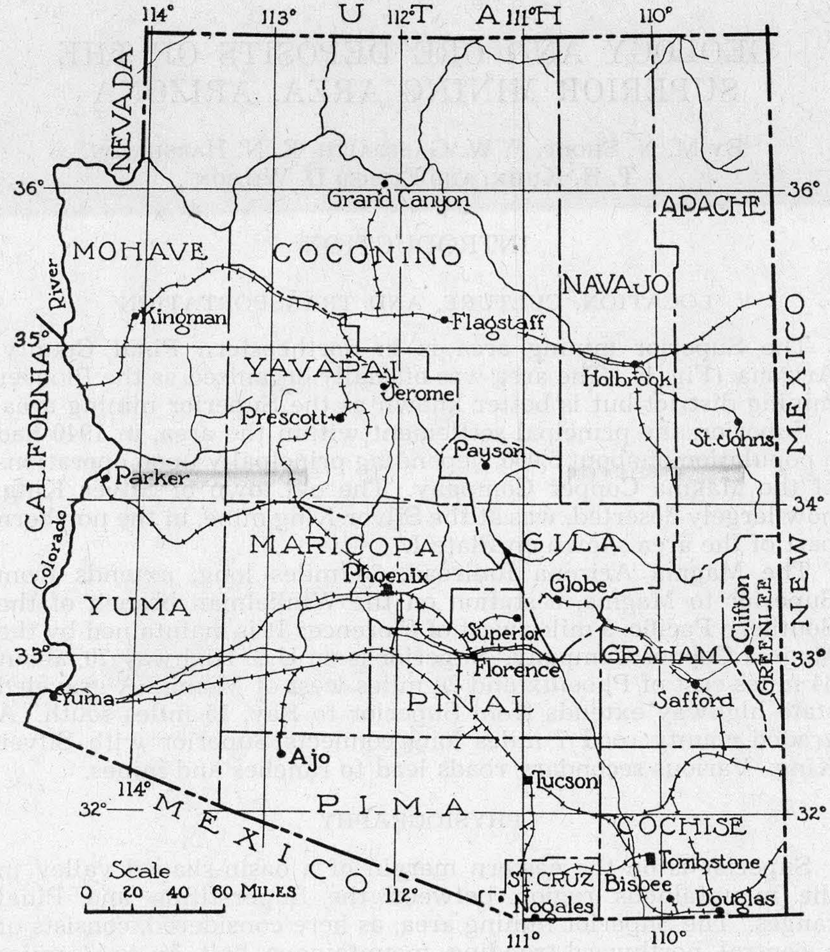

Figure 1.—Index map of Arizona.

east by the Concentrator fault and appears to be of tectonic origin. Its margins are floored by a pediment of dacite conglomerate and older rocks, and its inner area is covered by gravel and silt suggestive of fluviatile and lacustrine deposition. Recent erosion has dissected its surface to a moderate extent.

The mesa extends east from Apache Leap to the Pinal Mountains, beyond the margin of Plate I, and ranges in altitude from approximately 4,500 feet on the southwest to 5,530 feet at King's Crown, on the northwest. This mesa is floored by a thick series of volcanic flows and tuffs overlapping a deeply eroded, beveled surface of the rocks of the Central Belt. In general conformity with its surface structure, the mesa slopes gently eastward for

cost of printing the geologic map (Pl. I). The authors are appreciative of the active interest and co-operation of the engineering staff of the company, especially J. F. Flanagan, Chief Engineer, and B. Van Voorhis and Fred Crosby, engineers.

GENERAL GEOLOGY

SUMMARY

A generalized geologic columnar section of the Superior area is shown in Figure 2.

The oldest rock is Pinal schist, of early pre-Cambrian age. The schist is largely of sedimentary origin, but in places it contains greenstone derived from basic igneous rocks, probably lavas. In the Pinal and Mescal mountains, 30 to 50 miles southeast of Superior, the schist is invaded by extensive granitic intrusions of early pre-Cambrian age. They are not exposed in the Superior area.

Unconformably overlying the schist is the late pre-Cambrian Apache group, consisting, from base to top, of Scanlan conglomerate, Pioneer shale, Barnes conglomerate, Dripping Spring quartzite, and Mescal limestone. In places the Mescal is overlain by a basalt flow which is usually included in the Apache group.

Overlying the Apache group are the Cambrian Troy quartzite, Devonian Martin limestone, Mississippian Escabrosa limestone, and Pennsylvanian Naco limestone. The entire sedimentary series is conformable in dip and strike but is separated by at least four disconformities.

Intrusive into the Pinal schist, Apache group, and Troy quartzite are sills of diabase which in the Superior area total more than 3,000 feet in thickness. In places the diabase breaks across the intruded strata. Its age is considered to be post-Cambrian and pre-Devonian.

The Apache and Paleozoic rocks presumably remained horizontal until Laramide time (the interval including late Cretaceous and early Tertiary). No igneous intrusions other than of diabase took place during the Paleozoic era. There is little evidence for faulting during the late pre-Cambrian and Paleozoic eras. No Mesozoic rocks are found in the area; if any were formed, they were removed by erosion.

Presumably in the Laramide interval the region was subjected to compressional stresses which resulted in thrust faulting and possibly in folding and east-west faulting. This deformation was associated with invasion by stocks and dikes of granitic rocks, probably apophyses of the Central Arizona batholith. In the Silver King subarea a stock of quartz diorite intrudes the Paleozoic and earlier rocks. Associated with the undoubtedly satellitic to this stock are numerous dikes, as well as the Silver King quartz diorite porphyry stock which was the locus of the Silver rized.[3] In 1938 Short and Wilson published a brief report[4] on the geology of the Magma mine area.

The geology of the mine below the 2,000 level has been mapped by engineers of the Magma Copper Company under the direction of J. F. Flanagan, Chief Engineer.

FIELD WORK

For purposes of description the Superior area is divided into three subareas. The Belmont subarea includes all the area shown on Plate I south of Queen Creek. The Magma subarea includes that part from Queen Creek on the south to the Magma Chief tunnel on the north. The Silver King subarea includes that part north of the Magma Chief tunnel.

Galbraith[5] mapped the topography and geology of about 6 square miles in the Silver King subarea on a scale of 600 feet per inch.

Harshman[6] mapped the topography and geology of the Belmont subarea on a scale of 500 feet per inch.

During 1936-40 University of Arizona students mapped the topography of adjacent areas, mainly on the dacite mesa east of, and on the flat west of, Superior. Wardwell[7] made a topographic and geologic map on a scale of 600 feet per inch of about 4 square miles in the Potts Canyon area, which adjoins the Silver King subarea on the west.

Part of Wardwell's map and all the others mentioned have been incorporated into Plate I of this report. The part of Wardwell's map includes the area west of a line north from U.S. Geol. Survey B.M. 3,023.

M. N. Short has been gathering data regarding the area and mines since 1916-17, at which time he was an engineer for the Magma Copper Company; he has made exhaustive microscopic studies of the ores.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the co-operation of officials of the Magma Copper Company, especially A. J. McNab, Vice-President, the late William Koerner, former General Manager, and E. G. Dentzer, General Manager, during this investigation. The company rendered financial assistance to the extent of half the

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[3]Ettlinger, I. A., and Short, M. N., The Magma mine, Superior: 16 Int. Geol. Cong., Copper resources of the world, vol. 1, pp. 207-13, 1935.

[4]Short, M. N., and Wilson, Eldred D., Magma mine area, Superior, Arizona: Bur. Mines Bull. 145, pp. 90-8, 1938.

[5]Galbraith, F. W., Geology of the Silver King area: Univ. Ariz., Doctorate Thesis, 153 pp., maps, 1935.

[6]Harshman, E. N., Geology of the Belmont-Queen Creek area, Superior, Ariz.: Univ. Ariz., Doctorate Thesis, 168 pp., maps, 1939.

[7]Wardwell, H. R., Geology of the Potts Canyon mining area near Superior, Arizona: Univ. Ariz., Master's Thesis, 1940.

about a mile from Apache Leap and flattens along the eastern margin of Plate I. In places the rock exfoliates into rounded forms, but more commonly it erodes along vertical joints into pinnacles and cliffs.

The east-west earlier faults and mineralized veins as a rule have little or no topographic expression. Later faults have guided erosion but left few prominent scarps.

Drainage of the Valley, Central Belt, and part of the mesa is by ephemeral streams tributary to Queen Creek, which carries sufficient water during a few months of the year to provide an auxiliary supply for Superior. The drainage pattern on the mesa is determined partly by dip and partly by joints and fissures in the lava. On the Central Belt the drainage is parallel with, or at right angles to, the strike of bedding except where guided by faults. As shown by Plate I, the streams enter the Valley at right angles to the Concentrator fault.

CLIMATE

The climate of Superior is semiarid. The following data are from records kept by the Magma Copper Company:

Total Inches Rainfall

1921	15.60	1932	21.51
1922	18.64	1933	19.14
1923	19.15	1934	10.56
1924	12.59	1935	21.64
1925	17.10	1936	23.30
1926	20.79	1937	16.82
1927	19.49	1938	14.36
1928	15.46	1939	12.45
1929	11.81	1940	18.62
1930	24.00	1941	31.75
1931	28.65		
		Average	18.74

The monthly average rainfall during 1921-41 was as follows:

January	1.70	August	2.56
February	2.30	September	1.45
March	1.97	October	0.96
April	0.94	November	1.56
May	0.36	December	2.43
June	0.32		
July	2.21	Total	18.76

As seen from these data, most of the rains occur in two periods, July to August and December to February. About one half of the rain falls in summer when cloudbursts, accompanied by heavy runoff, are the rule.

Temperatures have been as follows:

Month	Jan.	Feb.	Mar.	Apr.	May	June
Av. max. degrees F.	64	65	72	75	89	97
Av. min. degrees F.	45	46	51	55	56	73
	July	Aug.	Sept.	Oct.	Nov.	Dec.
Av. max. degrees F.	102	100	93	83	73	67
Av. min. degrees F.	76	77	72	61	54	48

VEGETATION AND ANIMALS

The lack of soil and the dry periods separating heavy rains allow only drought-resisting desert type of flora to exist in that portion of the area lying west of Apache Leap. Here are found mesquite, cat claw, desert broom, creosote bush, palo verde, and hackberry bush, as well as many varieties of cacti, such as cholla, prickly pear, hedgehog, and sahuaro.

In the area east of Apache Leap the soil is sufficiently thick and moist to support a moderate growth of scrub oak, manzanita, mescal, and occasional piñon trees.

Wild life is sparingly present. Cottontails and jack rabbits are frequently seen, as are squirrels, chipmunks, pack rats, and mice. Wild pigs, wild cats, coyotes, and deer are rare. Bats frequent many of the abandoned mine workings. During summer sidewinders, centipedes, scorpions, and vinegarroons are common, especially in old prospect holes.

PREVIOUS WORK

The first geologic map of the Magma mine area, covering approximately 1 square mile on a scale of 100 feet per inch, was made by I. A. Ettlinger in 1912. Part of his map was included by Ransome[1] in the first published description of the Magma mine. At the time of Ransome's visit, mining had reached a depth of only 800 feet.

In 1921 Ettlinger extended the map area to the vicinity of the Magma Chief tunnel on the north and the Magma Apex shaft on the west. His map was included in the next published report[2] on the geology of the mine. At the time of that report, mining had reached a depth of 2,000 feet. In 1935, when the Magma mine was 3,200 feet deep, the further geologic developments were summa-

[1] Ransome, F. L., Copper deposits near Superior, Arizona: U.S. Geol. Survey Bull. 540, pp. 39-58, 1913.

[2] Short, M. N., and Ettlinger, I. A., Ore deposition and enrichment at the Magma mine, Superior, Arizona: Am. Inst. Min. Met. Eng. Trans., vol. 74, pp. 174-222, 1926.

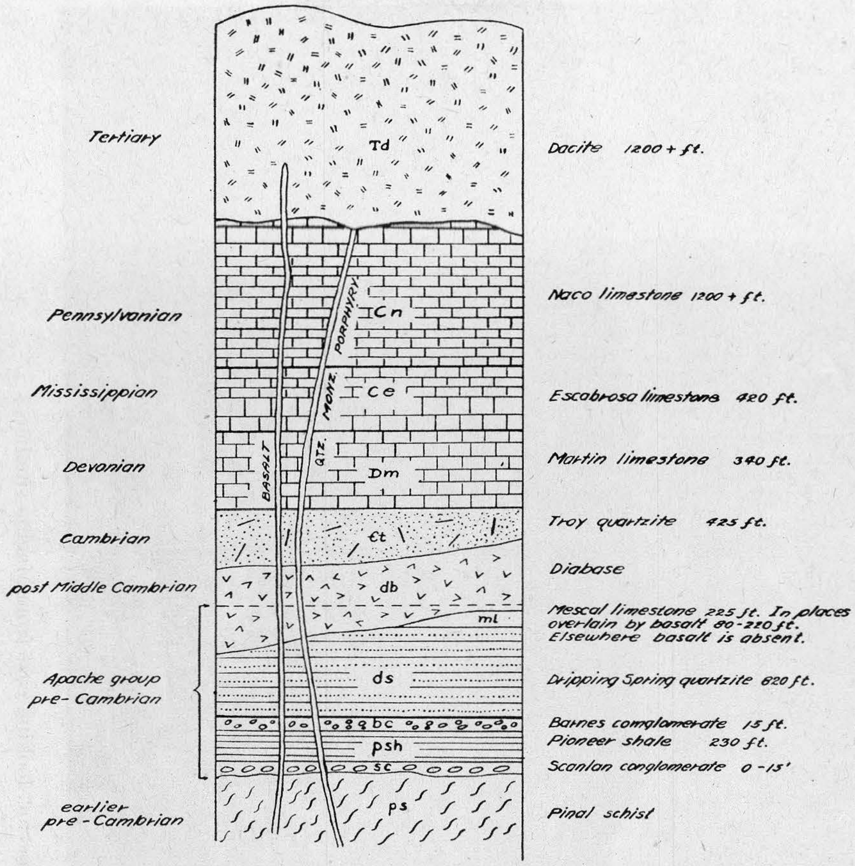

Figure 2.—Generalized geologic column, Superior mining area.

King ore body. In the Magma mine are numerous dikes of quartz monzonite porphyry which cut the Escabrosa and earlier rocks. One of these dikes was the locus for part of the Magma vein.

Ore deposition closely followed the intrusions and may have begun before fault movements entirely ceased. The Magma fault, which strikes east, is the locus of the Magma vein. It has a displacement, measured obliquely along the fault plane, of at least 500 feet. The Koerner vein, about 1,200 feet south of the Magma vein, is in a nearly vertical east-west fracture zone believed to belong in this period of faulting.

The ore bodies of the Magma mine occur as replacements of shattered rocks in fault zones. Above the 800 level the ore bodies are in a porphyry dike and in Paleozoic beds. From the 800 to the 4,000 level the rocks are mostly in diabase, but some are in blocks of Troy quartzite included in diabase and in Apache beds. Below the 4,000 level Pinal schist is the prevailing wall rock. The grade of ore depends somewhat on the wall rock. The most pro-

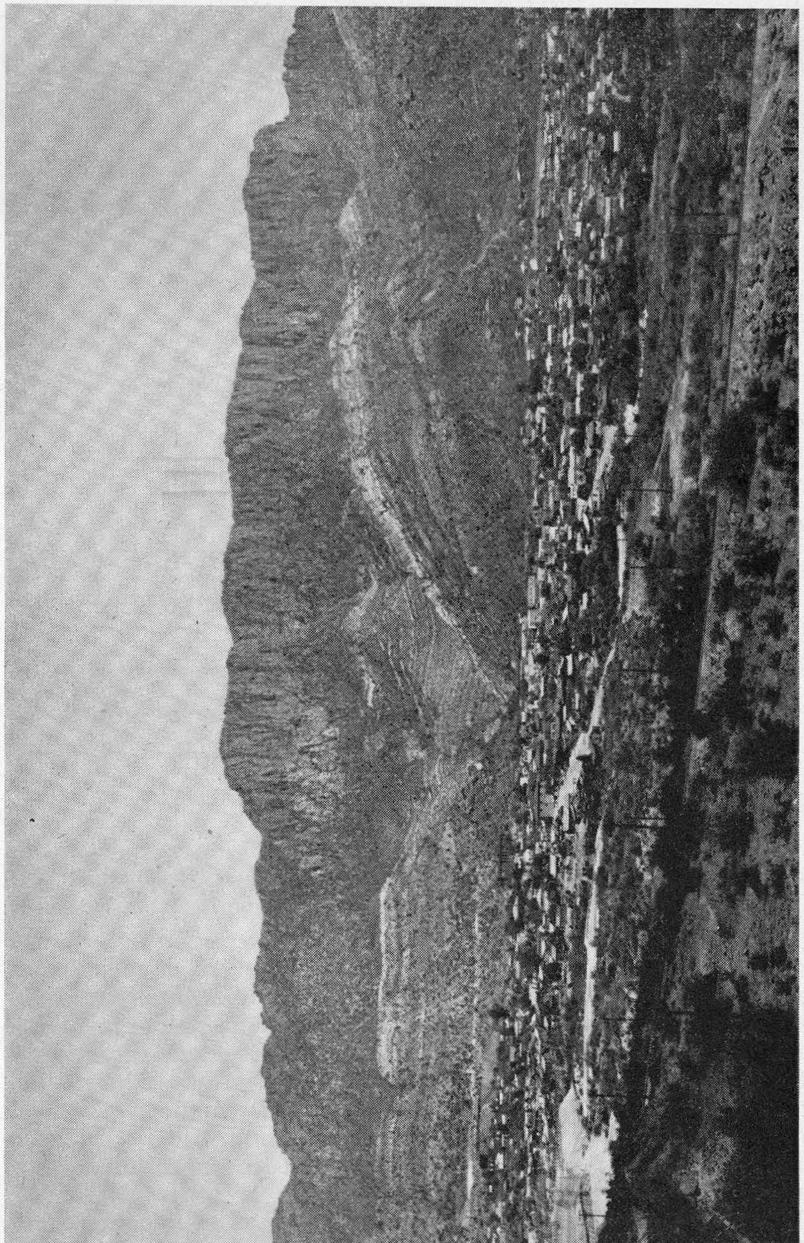

Plate III.—Superior, looking east from Magma smelter.

ductive ore bodies are in diabase because it was most easily replaced by ore solutions.

In the Lake Superior and Arizona mine the ore bodies are where fractures of eastward strike intersect favorable beds at the base of the Martin limestone. In the gold lodes of the Belmont subarea ore bodies are at intersections of east-west fractures with replaceable beds at the top of the Escabrosa limestone.

According to one interpretation, at the time of ore deposition the sedimentary rocks were horizontal and the surface was of low relief. A period of crustal stability followed in which the copper deposits underwent partial oxidation and supergene enrichment to a depth of at least 1,300 feet. Subsequently the formations were tilted eastward approximately 30°. The time of movement is problematical but is believed to have been between early and middle Tertiary. This tilting was followed by erosion which resulted in sedimentation of the Whitetail conglomerate.

According to another interpretation, the eastward-dipping Paleozoic and earlier rocks represent a limb of a Laramide fold which was formed prior to ore deposition. Oxidation and supergene enrichment of the ores took place during the long erosion interval marked by sedimentation of the Whitetail conglomerate.

Short and Kuhn favor the first of these interpretations and Wilson the second.

In middle Tertiary time, shortly after deposition of the Whitetail, the entire region was covered with a series of prevailingly dacitic volcanic rocks totaling 1,200 feet in thickness.

In late Tertiary, extensive gravel deposits, very irregular in area and thickness, were formed under subaerial or fluvatile conditions. These gravels include boulders and pebbles of all the rocks of the district, but they are predominantly dacitic. They were consolidated in a fine-grained dacitic matrix. This formation, termed dacite conglomerate, is believed to be equivalent to the Pliocene Gila conglomerate of the Globe, Miami, and Ray districts. It crops out only west of the Main and Concentrator faults.

After deposition of the dacite conglomerate and probably beginning before the end of the deposition, the region was extensively faulted. The main break of the district, the Concentrator fault, is at the base of the mountain slopes. It strikes approximately northwest and dips about 70° SW. Its vertical displacement is at least 2,000 feet. Many other postdacite or post-ore faults were formed in the same period. They strike in various directions and are not everywhere readily distinguishable from the preore faults.

The postdacite faults were followed in places by small plugs, dikes, and flows of basalt. In places later movement along the Magma fault has displaced basalt dikes. Subsequently the region has been actively eroded. The dacite cliff has been cut back several hundred feet, exposing the present outcrop of the Magma vein and other ore deposits of the district.

METAMORPHIC ROCKS (PINAL SCHIST)

The oldest rock exposed in the district is Pinal schist, of early pre-Cambrian age. In the area mapped on Plate I, it appears only in the northwest portion, north and west of Silver King Wash. On U.S. Highway 70, half a mile beyond the western limit of the map, schist appears in road cuts. In the Magma mine it forms one or both walls of the main vein from the 3,600 level downward. Here the schist is light gray and prevailingly satiny, but in places in the mine it is composed almost entirely of quartz.

Although the pre-Cambrian intrusives of granite and diorite described by Ransome[8] are nowhere exposed within the Superior area, the schist in many places shows their metamorphic effects.

In general, the Pinal schist is a light gray, fine-grained, highly sericitic rock with finely developed schistosity. Most specimens have a lustrous satiny sheen on foliation surfaces. In many places these surfaces are knotty; this is due to crystalloblasts of hornblende, andalusite, and sillimanite.

In thin section the schistosity is recognized most readily by a concentration of small rounded grains of magnetite and some hematite into roughly parallel bands. The iron oxides occupy about 5 per cent of the section. Roughly 85 per cent of the rock is composed of equigranular, crystalline quartz ranging in grain size from 0.01 to 0.08 mm. The remaining 10 per cent is muscovite, the long dimension of the flakes reaching 1 mm. The orientation of these flakes parallel to the schistosity is not readily visible as they bend around the quartz grains. A little serpentine and chlorite have formed apparently from mafic minerals. Associated with the muscovite in and around these areas is considerable leucoxene, which is entirely wanting in other places. This suggests alteration from biotite, which probably formed from a still earlier mineral.

Greenstone occurs at some places in the schist. This rock is dark green, distinctly schistose, and of coarser grain than the gray sericitic variety. Its schistosity is in places contorted into close folds. It contains abundant hornblende needles, but some layers are largely chlorite. Veinlets of quartz which swell and contract, conformable to the schistosity, penetrate the rock.

In thin section the greenstone shows the following composition: chlorite approximately 50 per cent, epidote 15 per cent, hornblende 25 per cent, and magnetite 10 per cent. Chlorite occurs as an aggregate of plates in parallel arrangement. Imbedded in the chlorite is epidote in rounded grains from 0.03 to 0.07 mm. in diameter. Hornblende occurs as prisms reaching a maximum of 2 mm. in length. The pleochroism is unusual, ranging from almost colorless through light yellowish green to distinct greenish blue. It apparently approaches the composition of glaucophane but gives extinction angles of 10° or more with the prismatic cleavage. The hornblende needles do not show parallelism but cut across the schistosity in all directions.

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[8]Ransome, F. L., The copper deposits of Ray and Miami, Arizona: U.S. Geol. Survey Prof. Paper 115, p. 37, 1919.

Chlorite and epidote are earlier than the hornblende. Magnetite is scattered throughout, but it tends to be concentrated in the chlorite rather than in the hornblende.

A gneissoid variety occurs where the quartz diorite intrusion is in contact with the Pinal schist. This rock, light gray and coarsely crystalline, resembles quartzite except for dark streaks composed largely of biotite. Its gneissoid banding in general is moderately crumpled. This facies of the schist grades into the diorite.

The thin section of the rock is nearly 90 per cent quartz, in roughly equigranular, interlocking grains of about 0.15 mm. in size. The remaining 10 per cent is muscovite, filling with random orientation the interstices between the quartz grains. Imbedded in the muscovite are numerous rounded grains of apatite. Hematite as small, round grains is sparsely scattered throughout the rock but tends to be concentrated in the muscovite. Some of the larger muscovite flakes contain remnants of biotite.

At least part of the Pinal schist has been formed from sedimentary rocks. In the saddle south of Fortuna Peak, it is composed of small pebbles of dark gray quartzite in a matrix of light gray sericitic schist. These pebbles are elongated parallel to the schistosity, with the long direction approximately twice that of the shorter, which is rarely over 1½ inches. Its microscopic features are also of sedimentary type. Except for slight schistosity furnished by sparse iron oxides, the rock would be identified as a quartzite. It differs only in this respect and in absence of feldspar from sections of Dripping Spring quartzite.

In the Potts Canyon area, bands of milky white to dark blue quartz several inches thick appear in the schist. These are parallel to the schistosity, which in turn appears to parallel the bedding of the overlying beds. The schist has been invaded by thick sills of diabase and colored dark brown by contact metamorphism.

SEDIMENTARY ROCKS

Scanlan conglomerate: The Scanlan conglomerate, the basal member of the Apache group, is sparsely represented in the area and does not appear in the Magma mine. Where observed in two widely separated places, it differs markedly in character.

On the Reevis Trail, 1,400 feet northwest of Silver King Wash, it is less than 5, and generally only 2 or 3, feet thick. It is composed of small pebbles of white vein quartz and fragments of sericitic Pinal schist in a matrix of purplish shale similar to the overlying Pioneer shale. In places pebbles are entirely absent, and the Scanlan is represented by a few inches of shale containing flakes of gray sericitic schist grading upward within less than a foot into typical Pioneer shale.

In the eastern tributary of Fortuna Wash, at the foot of the southern ridge of Fortuna Peak, the Scanlan is represented by arkosic quartzite 6 feet thick containing 10 conglomerate bands, none of which exceeds 4 inches in thickness. The pebbles, whose

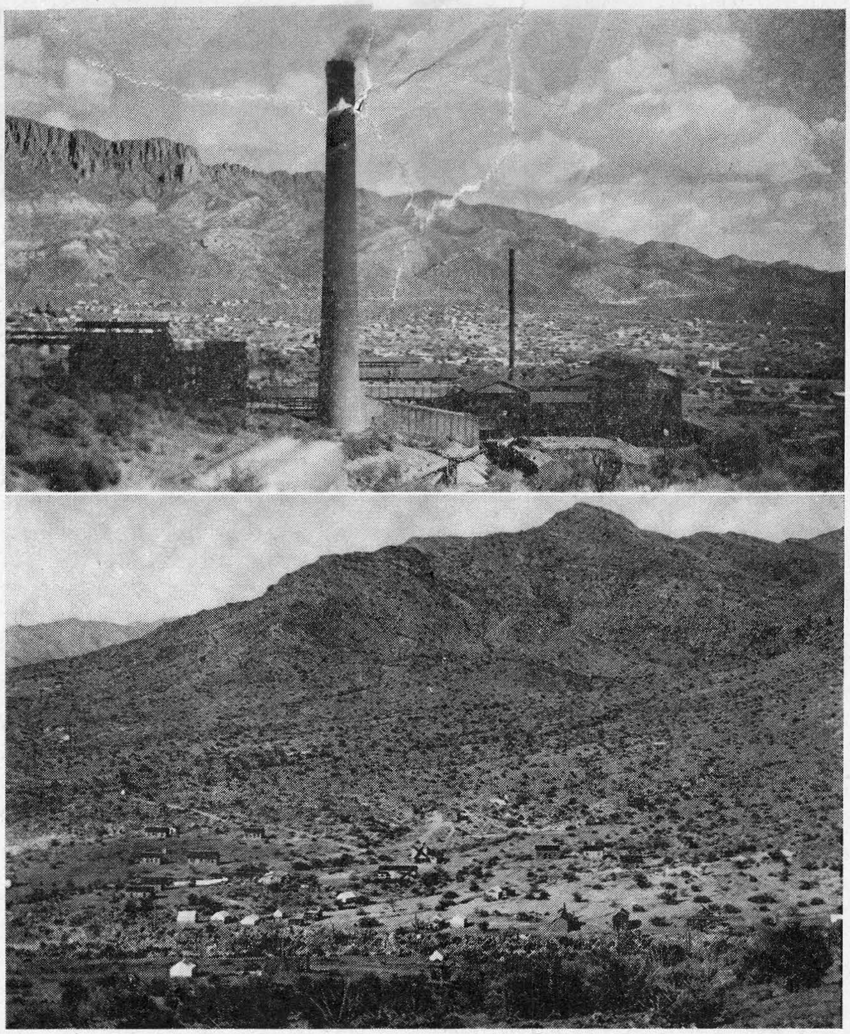

Plate IV.—*A*, Looking southeast toward Magma smelter and Superior. Belmont subarea in background; *B*, Superior in 1908.

maximum diameter is 2 inches, are composed of white vein quartz and light colored quartzite. They are not well rounded and appear to be slightly elongated in the direction of strike N. 8° E. The rock is slightly schistose, probably because of the diorite intrusion a few hundred feet west. The Pinal schist below the Scanlan here is gneissoid.

Because of its thinness, the Scanlan conglomerate was not mapped separately but is included with the overlying Pioneer shale.

Pioneer shale: The most persistent member of the Pioneer formation is a moderately hard, dark purplish brown shale composed largely of arkosic material with considerable pink feldspar. This member is conspicuously marked by round or elliptical light buff spots caused[9] by local reduction and removal of the ferruginous pigment. It is well exposed at the end of Magma Chief Ridge and at the end of the southern spur of Fortuna Peak. In most places this member is at the top of the Pioneer. Near the northwest corner of the map area, however, it is in contact with Pinal schist and makes up the entire thickness, approximately 75 feet, of the formation.

In most places the purplish member grades downward into hard arkosic quartzite of medium texture, varying from light tan to dark brown or black. The light-colored variety is well exposed north of the Concentrator fault in the extreme northwestern portion of the area. The darker facies crops out along Silver King Wash north of the corner between sections 22, 23, 26, and 27. Here it contains interbedded shaly layers 1 to 5 feet thick. As diabase has intruded the lower part of the formation, its full section is not exposed.

Where the Magma Chief road crosses the Conley Spring fault, the purplish Pioneer shale is underlain by a few feet of light brownish gray fissile shale. Along the northwestern boundary of the area the Pioneer formation is a fine-grained, tough, reddish brown to purplish gray quartzite. Its individual beds are thin, and crossbedding is common. Well-preserved symmetrical ripple marks appear in the Pioneer shale in the northwestern and northern portions of the area.

The more quartzitic Pioneer shale is rather fine grained, with laminations averaging about 2 mm. thick. Microscopically, it is made up of about 50 per cent rounded to angular quartz fragments, averaging less than 0.06 mm. in diameter, imbedded in a matrix of kaolin which makes up the remaining 50 per cent of the rock. This kaolin matrix contains a large amount of very minutely divided hematite, which imparts a purplish red color to the rock and makes the stratification visible in thin section.

In the Silver King area, the Pioneer shale averages 200 feet in thickness. In the Magma mine it occurs from the 2,550 level downward (Pl. II). Its maximum thickness is 350 feet, 50 of which rest directly upon Pinal schist, separated from the upper portion by the lower diabase sill. Here the Pioneer is gray to reddish gray, generally fine grained and quartzose. Quartzitic lenses commonly give it a banded appearance.

Barnes conglomerate: The Barnes conglomerate consists of hard vitreous quartzite pebbles, together with subordinate amounts of milky quartz pebbles, in a coarse-grained, sandy, arkosic

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[9]Ransome, F. L., Geology of the Globe copper district, Arizona: U.S. Geol. Survey Prof. Paper 12, p. 31, 1903.

matrix. Many of the pebbles are heavily iron stained, which fact accounts for the characteristically dark reddish brown color of the formation. The pebbles are generally less than 6 inches in diameter, rounded, flat, and ellipsoidal, with the flat sides roughly parallel to bedding. Exceptional pebbles are subangular. In places the formation is composed mostly of pebbles with a minimum of interstitial matrix; elsewhere the matrix alternately predominates over pebbles. Also characteristic of this conglomerate, as first observed by Ransome, are small fragments of vermillion-red chert or jasper in the matrix. Fractures break across pebbles and matrix alike. Weathering tends to free the pebbles unbroken from the friable matrix.

No unconformity is apparent above or below the conglomerate, but the abrupt change from shale to pebble beds indicates a sudden modification of erosion and sedimentation. Ransome[10] considered that the pebbles appear to be derived in part from quartzites (the Mazatzal quartzite) now exposed in the Sierra Ancha and the Mazatzal Range. He concluded that this formation is "a delta deposit, the work of streams rather than of waves."

In the Superior area the Barnes conglomerate is thin but remarkably persistent and nearly uniform. It crops out only in the Silver King subarea. There is almost everywhere more than one conglomerate bed separated by thinner layers of light reddish brown arkosic quartzite. In an outcrop 3,200 feet north of Silver King shaft and 1,000 feet east of Fortuna Wash 10 feet of solid conglomerate are at the base, above which are 3 feet of quartzite and 2 more of conglomerate. The ellipsoidal pebbles are small, ranging from less than ½ inch to 3 inches in diameter. White quartzite pebbles predominate. The rock is fairly uniform, and in much of the conglomerate the pebbles are nearly in contact. Southwestward along Fortuna and Silver King washes the conglomerate becomes progressively thinner and in places is less than 5 feet thick, generally composed of a thicker conglomerate layer at the base and two or more thinner beds above, separated by quartzite. In Silver King Wash south of U.S. Geological Survey B.M. 3,553, the Barnes is composed of numerous lenticular beds of conglomerate, generally only a few inches thick, separated by much thicker layers of quartzite. Near the Silveride fault east of Silver King Wash, the Barnes is locally missing, and Dripping Spring quartzite rests on Pioneer shale.

In the Magma mine, the Barnes is 5 to 15 feet thick and consists of two conglomerate beds 1 to 5 feet thick, separated by quartzite layers. It is easily recognized and forms an excellent horizon marker in exposures from the 3,200 level downward. The best exposure is on the 3,200 level where the formation is followed for several hundred feet by No. 14 West crosscut.

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[10]Ransome, F. L., Description of the Ray quadrangle: U.S. Geol. Survey Folio 217, p. 6, 1923.

Dripping Spring quartzite: Nowhere within the area of Plate I is a complete uninterrupted section of Dripping Spring quartzite exposed at the surface. In the Belmont and Magma subareas, the upper part of the formation appears in isolated fault blocks, but the lower part has been downfaulted by the Concentrator fault and covered by dacite conglomerate. In the Silver King subarea along Magma Chief Ridge, three sills of diabase have invaded the Dripping Spring quartzite parallel to its bedding. The total thickness of diabase and quartzite is 1,995 feet, of which quartzite totals 890. A completely uninterrupted section of Dripping Spring quartzite crops out on the east side of Potts Canyon just west of the Prudential mine, about 2 miles northwest of the area of Plate I. Here the thickness is 820 feet, which is taken as the average total thickness of the formation in the Superior area.

The Dripping Spring quartzite is remarkably uniform. It consists of strongly banded alternating buff, yellow, or brown beds which range from a few inches to 2 feet in thickness. It is strongly arkosic, with 20 to 40 per cent of pink feldspar intermingled with fragmental quartz. The buff to brownish red beds appear to contain more weathered pink feldspar than the buff to cream-colored beds, whereas the latter contain more quartz.

Toward the top of the formation the beds become thinner, averaging only a few inches in thickness, and tend to grade into the Mescal limestone. In places shaly beds alternate with beds of normal quartzite; elsewhere thin layers of limestone are interbedded with the shaly layers.

In thin section the typical rock is approximately 75 per cent quartz, 10 per cent potash feldspar, and nearly 15 per cent sericite, with accessory magnetite and zircon. The quartz occurs in two distinctly different grain sizes. The larger, making up about 40 per cent, are angular with an average diameter of 0.25 mm. The other 35 per cent consists of very fine grains averaging about 0.03 mm., closely compacted between the larger grains. The potash feldspar occurs in grains of approximately the same size as the larger quartz grains. Some of the feldspar exhibit microperthitic structure, and occasional grains of myrmekite are present. The cementing material is sericite between closely packed quartz and feldspar. Tiny grains of magnetite are rather abundant, apatite is fairly common, and zircon is relatively rare.

Throughout the Superior area, diabase has extensively invaded the Dripping Spring quartzite along bedding planes. For widths of several feet along the contacts, the quartzite has been baked and colored dark brownish black. More easily weathered, the diabase generally forms swales or hollows between ridges of quartzite.

In the Magma mine only the lower 280 feet of the Dripping Spring quartzite is exposed. On the 2,550 level it consists of monotonous dark gray quartzite beds from a few inches to 2 feet thick. The striped colors, so pronounced on the surface and probably due to iron oxide, are missing, and the formation probably could not be identified as Dripping Spring except for its stratigraphic position directly above Barnes conglomerate. Banding in much less contrasting colors occurs on the 3,200 and 3,600 levels at zero crosscut and elsewhere on the lower levels. A sill of diabase 2,000 feet thick separates the Dripping Spring from the Troy quartzite, with about 600 feet of Dripping Spring, all the Mescal limestone, and at least 100 feet of the lower part of Troy quartzite missing. What has become of these beds is a great mystery. They could not have been taken into solution in the invading diabasic magma. The other alternative is that they somehow were carried away before or during emplacement of the magma.

Mescal limestone: The Mescal limestone and the basalt overlying it form the upper part of the late pre-Cambrian Apache group.

The Mescal limestone is generally thin bedded and contains many bands of chert parallel to bedding. Its color is light buff, gray, or brown. Individual beds range from a few inches to 1½ feet thick. The siliceous segregations are as a rule in irregular layers which stand out upon weathered surfaces and give the formation a characteristicly gnarled, rough appearance. Although present throughout the formation, the chert bands are most abundant in the middle portion. Some banded relief also results from differences in composition of the limestone beds. The algae, characteristic of the Mescal elsewhere in Arizona, were not found in this area.

In the Magma mine the Mescal limestone is lacking; in its place is a great sill of diabase. In the Belmont mine this is also true, and maps of the flooded workings show only residual blocks of limestone "floating" in diabase.

The diabase produced some contact metamorphism in the intruded limestone. Megascopically this alteration resembles silicification, but under the microscope it is seen to be a development of a very fine-grained greenish aggregate of tremolite.

About 8 feet below the contact of the limestone and the overlying basalt is a 2-foot bed of dense white or light gray chert containing small vugs lined with quartz crystals. This bed is continuous throughout the Belmont subarea and forms an ideal marker between the Mescal and the basalt.

In the Belmont subarea, the Mescal limestone is overlain by four basalt flows which have a maximum total thickness of 200 feet in Donkey Canyon. They are described in the section on igneous geology.

The Mescal limestone varies in thickness. Throughout the Belmont subarea it averages 225 feet. Near the bend in the Magma Apex road, the Mescal is about 100 feet thick. Here the basalt, which overlies the formation south of Queen Creek, is missing, due to pre-Troy erosion. Northward from this point the thickness of the Mescal diminishes progressively and, where cut off by an east-west fault 1,000 feet east of the Magma Apex shaft, it is only 40 feet. North of this point for a distance of 1,200 feet,

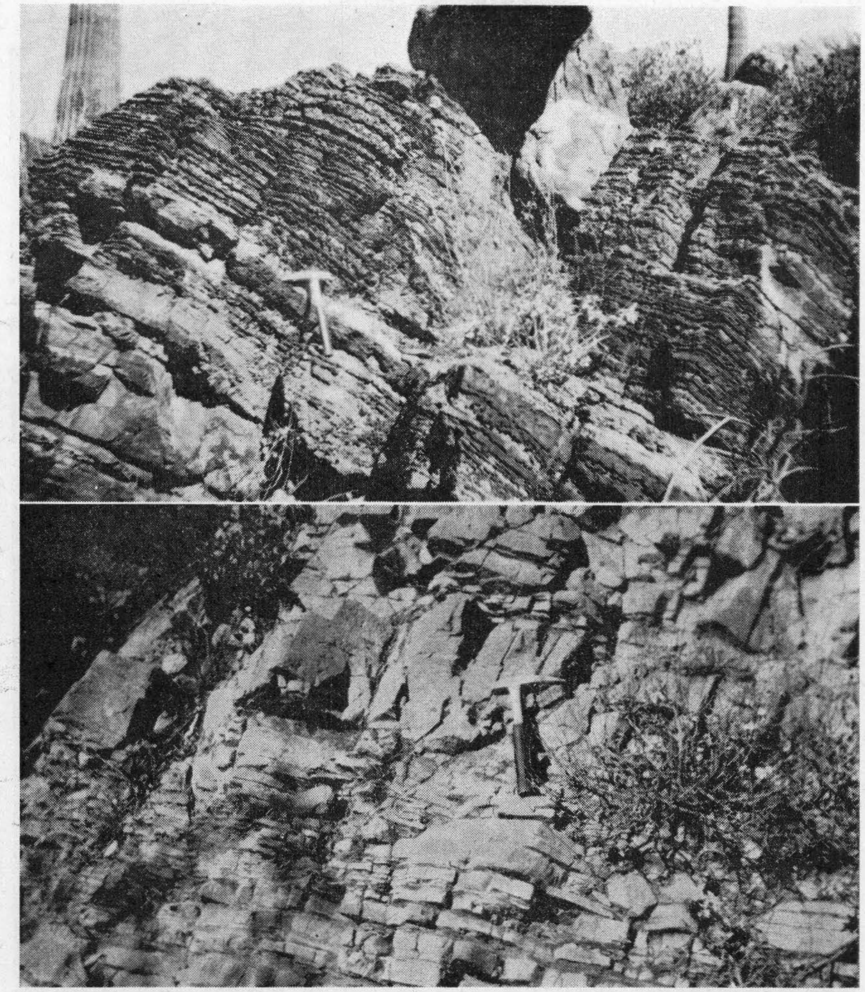

Plate V.—*A*, Cherty Mescal limestone; *B*, Typical Mescal limestone.

it and the overlying basalt are missing, and Troy quartzite rests disconformably on Dripping Spring quartzite. At the Silveride fault the Mescal reappears 100 feet thick, but the overlying basalt is missing. Between the Magma Chief tunnel and the Conley Spring fault the basalt is continuous. On Silverado Ridge the Mescal attains a thickness of 350 feet, its maximum in the Superior area.

The variability in thickness of the Mescal limestone is due to erosion of its upper surface. The unconformity at its top was first noted and described by Darton.[11]

[11]Darton, N. H., Resumé of Arizona geology: Ariz. Bur. of Mines Bull. 119, p. 37, 1925.

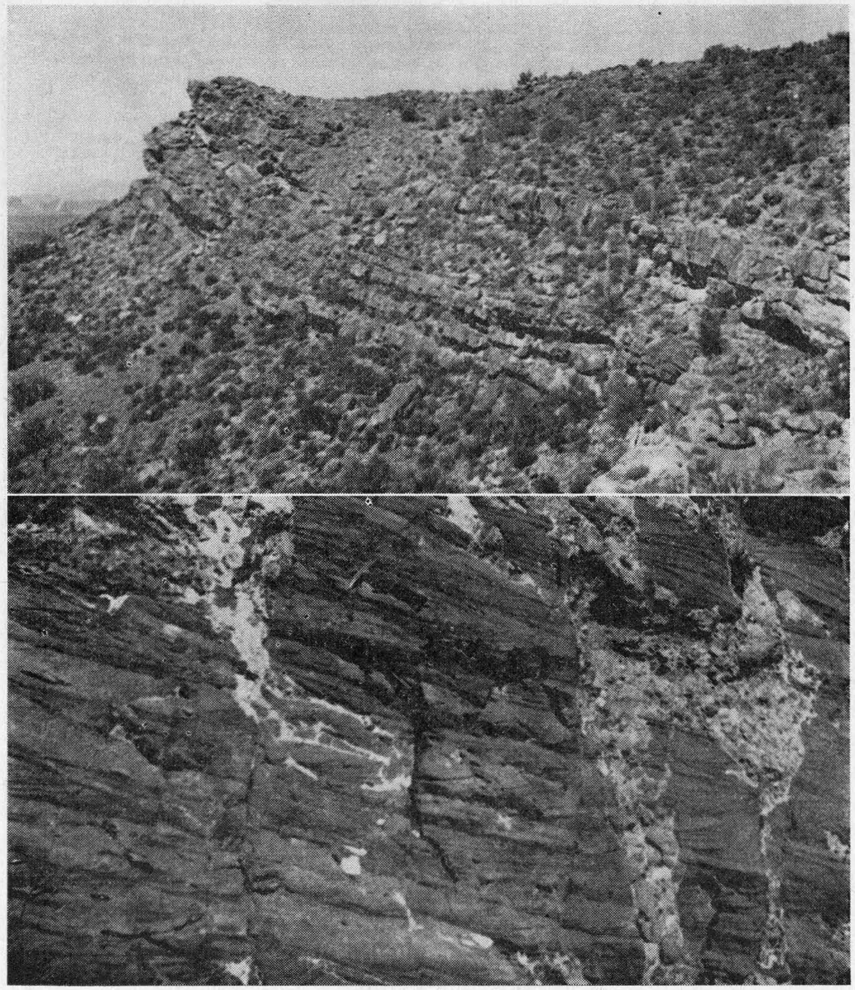

Plate VI.—*A*, Basal cliff-forming member of Troy quartzite looking north from Cross Canyon; *B*, Typical cross-bedded Troy quartzite in Pacific Canyon.

Troy quartzite: Unconformably overlying the Mescal limestone and basalt is the Troy quartzite, of Middle Cambrain[12] age.

In a complete section, as in the Belmont subarea, the Troy is approximately 425 feet thick. Where faulted, it may appear to be half or double that amount. South of Pacific Canyon it seems abnormally thick, but here step faulting has repeated the normal section. In several places, particularly in the area north of the Belmont road and west of the Lead Hill fault, displacement al-

[12]Stoyanow, A. A., Correlation of Arizona Paleozoic formations: Geol. Soc. Am. Bull., vol. 47, p. 475, 1936.

most parallel to bedding has reduced the thickness of the quartzite to about 100 feet. Such displacements are marked by breccia along the planes of movement.

Between Cross Canyon and a point 1,000 feet north of the Magma concentrator, only the upper part of the Troy quartzite is represented; the lower part is occupied by a great sill of diabase which in the Magma mine is 2,000 feet thick. Some 1,000 feet north of the concentrator the upper and lower contacts are exposed, and the thickness is about 200 feet. In the Silver King subarea the normal upper and lower contacts of the formation are exposed only between the Magma Chief and Conley Spring faults; here the thickness averages 150 feet. Northward from the Conley Spring fault, the lower part of the Troy is occupied by andesite porphyry and diabase intrusions. At the northeast border of the map the thickness is 540 feet. There a diabase sill separates Troy and Mescal, and both formations seem to have their full thickness.

In the Magma mine the thickness of Troy varies from 50 to 400 feet. In the upper levels of the mine the intrusive contact between quartzite and diabase is very irregular (Pl. II). Isolated "islands" of quartzite with the same attitude as the Troy beds occur in diabase below the lower contact of the Troy. The islands are believed to be blocks of Troy, but there is no proof that they are not Dripping Spring quartzite, as in the Magma mine the two quartzites are difficult to distinguish lithologically.

On fresh surfaces the Troy is almost white, but where weathered it has been stained by iron oxides to rusty, buff, purple, yellow, or dull white.

Characteristically the Troy consists of cross-bedded pebbly quartzite which forms prominent cliffs. It may be divided into three lithologic units.

The lowest 75-foot unit consists of massive cliff-forming beds, up to 15 feet thick, of coarse-grained, cross-bedded quartzite with many pebbly zones. At the base there are normally about 3 feet of conglomerate, well shown in Donkey Canyon. This conglomerate consists of varicolored quartzite and basalt pebbles in nearly equal proportions, together with sparse limestone and schist pebbles, all in a hard matrix of sandy basaltic detritus. The pebbles make up about 60 per cent of the rock. They are subangular to rounded and range up to 6 inches in diameter. Several feet above the basal conglomerate is a second conglomerate bed whose pebbles are smaller and more rounded and consist largely of quartzite and jasper.

The middle unit of the Troy, 150 feet thick, consists of cross-bedded, somewhat conglomeratic thin beds that form relatively gentle slopes.

The upper unit is lighter colored than the lower portions, fine-grained, and locally cross-bedded. Its beds are generally less than 1 or 2 feet thick, but a massive cliff-forming bed occurs near the top. Shaly members are common.

Microscopically, the Troy quartzite is a typical metamorphosed sandstone. It is composed of at least 90 per cent quartz in uniform grains about 0.6 mm. in diameter, interlocked by secondary quartz developed by recrystallization of the original sand grains. Its accessory minerals include hematite, sphene, calcite, and limonite.

Color, cross-bedding, grain size, and composition help to distinguish the Troy from the Dripping Spring quartzite.

Martin limestone: Overlying the Troy quartzite is Upper Devonian limestone which, on the basis of lithology and fossil content, is correlated with the Martin limestone of the Bisbee, Ray, Globe, and Miami districts.[13]

The Martin tends to form debris-covered slopes separating the cliffs of Troy quartzite below from cliffs of Escabrosa limestone above. Viewed from a distance the Martin presents a distinct yellow or buff color, in marked contrast with the prevailingly iron-stained Troy and the white or gray Escabrosa.

There is no apparent angular unconformity between the Martin limestone and the Troy quartzite. A disconformity between the two formations is evident, especially on a small knob north of Donkey Canyon at an elevation of 3,950 feet. Here Martin limestone rests on an old irregular, boulder-strewn surface of Troy quartzite.

The thickness of the Martin limestone varies greatly. It is 350 feet on Queen Creek, 250 to 350 feet in the Magma mine at No. 2 and No. 3 shafts, and 425 feet on Magma Chief Ridge.

Lithologically the Martin may be divided into three members. The lowest, termed the dolomite member, is unfossiliferous and consists of gray, light yellow, and white thin-bedded, dense dolomitic limestone. Individual beds are generally less than 2 feet thick. Immediately above the Martin-Troy contact, the limestone beds are sandy and are characterized by numerous spherical red spots which are thought to have resulted from diffusion of iron oxide. A specimen collected 15 feet above the quartzite-limestone contact shows that the rock is composed of exceedingly fine dolomitic grains with about 10 per cent of scattered small angular quartz grains up to 0.02 inch in diameter. The sandy beds grade upward into the dolomitic limestone characteristic of the lowest part of the Martin limestone.

The lower portion of the Martin includes 16 feet of sandstone, which was also noted by Ransome[14] in the Ray-Globe region. It is composed of round sand grains up to 0.1 inch in diameter. These grains are frosted, indicative of wind action.

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[13]Ransome, F. L., The copper deposits of Ray and Miami, Arizona: U.S. Geol. Survey Prof. Paper 115, pp. 47-8, 1919.
[14]Ransome, op. cit. p. 45.

The middle portion of the Martin, termed the yellow limestone member, is composed of deep yellow to gray thin-bedded, medium coarse-grained limestone. From a distance the deep yellow of this member contrasts with the light yellow or gray of the lower member. Calcareous shale beds, many of which are fossiliferous, occur throughout the section. Thin sandstone is interbedded with the limestone but makes up only a small part of the total thickness. This middle section contains numerous fossils, in contrast to the unfossiliferous lowest and the slightly fossiliferous uppermost member.

The uppermost portion of the Martin, termed the yellow shale member, is composed of massive cliff-forming dark gray limestone overlain by about 20 feet of thin, papery calcareous shale. On fresh surface the shale is gray, and its yellow color results from oxidation of iron. Its weathered outcrop is everywhere characterized by a yellow to red-yellow color and flaky texture. The line of demarcation between this papery shale and the underlying gray cliff-forming limestone is not sharp; near their top the gray beds become yellower and thinner and grade into the shale. Overlying the shale is thin yellow limestone which attains a maximum observed thickness of about 6 feet in the Belmont subarea, but in many places it is lacking. Where this yellow limestone is missing, the Escabrosa limestone overlies the papery shales with apparent conformity.

Harshman measured the accompanying section of the Devonian series immediately south of the Queen Creek mine shaft (p. 28).

As originally described by Ransome,[15] the Martin limestone in the Bisbee area contained a fauna similar to that of the Hackberry shale of Iowa,[16] and it has been correlated with that formation. Stoyanow[17] noted that in the Superior area a section of Upper Devonian limestone with interbedded clastic sediments was present below the true Martin limestone. These beds contain an invertebrate fauna similar to that of the Cedar Valley limestone, an upper Devonian formation underlying the Hackberry shale of Iowa. Harshman suggests that this lower part of the Martin limestone section be termed the Crook formation, after its locality in the Crook National Forest. The most fossiliferous area is along Queen Creek about 1/4 mile east of Superior. The fossils occur in zone 7 of the section and are limited to several beds of dense gray limestone composed almost entirely of brachiopods. They include such forms as *Spirifer iowensis* Owen. No fossils were found below zone 7, although white spots produced by algae are common throughout the lower part of the formation.

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[15]Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle, Arizona: U.S. Geol. Survey Prof. Paper 21, p. 33, 1904.
[16]Stoyanow, A. A., Correlation of Arizona Paleozoic formations: Geol. Soc. Am. Bull. 47, p. 486, 1936.
[17]Op. cit., p. 489.

Member		Thickness (feet)	
	Lower contact of Mississippian Escabrosa limestone		
Yellow shale member	1. Sandy buff to yellow limestone with individual beds up to 4 inches thick. Somewhat gradational into underlying papery shale	4	
	2. Thin-bedded, fissile, papery calcareous shale. Gray on unweathered surface but yellow when weathered. Gradational into underlying beds	20	24
Yellow limestone member	3. Yellow limestone beds 1 to 9 inches thick, containing some gray crinoidal limestone beds	24	
	4. Gray limestone with beds up to 3 feet thick. Some thin (1 to 6 in.) shaly limestone interbedded with thick gray beds	50	
	5. Sandy gray limestone with many crinoid stems	3	77
Dolomite member	6. Massive dark brownish yellow sandstone containing fish plates	5	
	7. Very thin-bedded yellow limestone with several thin white or gray fossiliferous members in the lower 15 feet of the member, which have a Cedar Valley fauna	31	
	8. Gray crinoidal limestone	2	
	9. Yellow limestone beds 0.1 to 6 inches thick	5	
	10. Thin-bedded gray limestone with abundant crinoid stems	20	
	11. Yellow limestone with some sandy beds	7	
	12. Brownish yellow sandstone made up of frosted, rounded sand grains up to 3.0 mm. in diameter. Individual beds range from 6 inches to 2½ feet thick	16	
	13. Thin-bedded, shaly yellow limestone. No good outcrops	17	
	14. Series of buff, yellow, and light gray beds 1 to 1½ feet thick. Chert nodules and lenses common	95	
	15. Dark gray cliff-forming limestone containing some chert lenses, 1 inch to 3 feet thick. Very pitted, weathered surface. Toward top becomes light gray	30	
	16. Thin-bedded yellow dolomitic limestone, sandy at base but becoming purer toward top. Red spherical spots very characteristic of lower 12 feet	25	253
	Total	354	
	Disconformity		
	Middle Cambrian—Troy quartzite		

The second or yellow limestone member of the Upper Devonian sequence is the Martin limestone in its more restricted sense, as originally dscribed by Ransome. In the Belmont subarea it consists of 77 feet of limestone and includes zones 3, 4, and 5 of the section. At Superior it is characterized by a rich brachiopod fauna, the most common of which are *Spirifer whitneyi* Hall, *Spirifer hungerfordi* Hall, *Atrypa reticularis* (Linné), *Schizophoria striatula* (Schlotheim).

The upper or yellow shale member of the Martin consists of units 1 and 2 of the section. On Pinal Creek, north of Globe, specimens of *Camarotoechia endlichi* (Meek) were found in the impure limestone beds above the papery shale. On the basis of this form, Stoyanow[18] has correlated the papery shale and overlying impure limestone with the lower part of the Ouray limestone of Colorado. No fossils were found in these beds at Superior, but lithologically there is little doubt of the correlation.

From the above evidence, the Martin limestone at Superior includes three distinct Upper Devonian formations: the upper or yellow shale member, equivalent to the Lower Ouray formation of Colorado; the middle or yellow limestone member, equivalent to the Martin limestone at Bisbee and the Hackberry shale of Iowa; and the lower or dolomite member, equivalent to the Cedar Valley limestone of Iowa. Because of local common usage and the scale of mapping, the three proposed subdivisions of the Martin limestone are not shown on Plate I.

Escabrosa limestone: Conformably overlying the Upper Devonian series is the Escabrosa limestone, of Lower Mississippian age. It is the lower portion of the Tornado limestone of the Ray-Globe area and equivalent to the Escabrosa of the Bisbee district.[19]

The Escabrosa limestone, with its prominent white cliffs, is one of the most conspicuous formations in the Superior area. It is a high-calcium limestone, in places made up largely of crinoid stems but containing some chert nodules throughout. Its individual beds are 1 to 8 feet thick, in marked contrast with the thinner beds of the Martin limestone below and the Naco limestone above. Except for crinoid stems, fossils are scarce throughout the formation.

On the basis of color and cliff-forming tendency, the Escabrosa can be divided into four members. The lowest, 100 feet thick, is composed largely of dark gray limestone strata 1 to 3 feet thick, together with several thin white limestone layers. This member includes zones 8 to 12 of the section subsequently described. It forms the basal, less precipitous part of the characteristic Escabrosa bluff.

The second member is a series, nearly 200 feet thick, of white limestone in beds up to 10 feet thick. Throughout the area, it forms nearly vertical white cliffs. This member includes zones 5 to 7 of the section.

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[18]Op. cit., pp. 489-93.

[19]Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle, Arizona: U.S. Geol. Survey Prof. Paper 21, p. 42, 1904.

The third member, zone 4 of the section, consists of about 50 feet of dark gray to brown beds generally less than 2 feet thick. Although thin bedded, this member forms the upper, less precipitous portion of the Escabrosa cliff.

The fourth or top member consists of thin-bedded white limestone, purple shale, and highly siliceous beds (zones 1 to 3 of the section). Throughout the area, this member forms flat surfaces. Some 40 feet below its top is a 30-foot layer of highly siliceous purple shale which forms an excellent marker. It is everywhere stained by iron and manganese and in places contains mineralized pipes.

A section of the Escabrosa limestone south of the Queen Creek shaft has been measured by Harshman as follows:

Lower Pennsylvanian Naco limestone
Disconformity

		Thickness (feet)
1.	White limestone in beds about 1 foot thick. Considerable chert	40
2.	Purplish shale, high in silica. Beds ½ to 1 inch thick	18
3.	Cherty, siliceous, shaly beds. Iron and manganese stains. Ore horizon	13
4.	Gray-brown limestone beds becoming white toward top. Maximum thickness of beds about 2 feet	55
5.	Massive white cliff-forming beds with chert in basal part. Individual beds up to 6 feet thick	42
6.	Thin-bedded yellow to light gray limestone containing black chert in lenticular masses. Beds have maximum thickness of 9 inches	18
7.	White cliff-forming beds 2 to 8 feet thick. Thinner toward the top and somewhat more gray	136
8.	Yellow sandy limestone in beds 6 to 12 inches thick	10
9.	Massive white cliff-forming limestones. Beds 1 to 5 feet thick	18
10.	Dark gray massive limestone, cliff-forming. Beds 3 to 5 feet thick	27
11.	Gray to gray-white limestone in beds 1 to 3 feet thick; fossiliferous	30
12.	Pinkish gray massive limestone in beds 1 to 4 feet thick; no fossils	14
	Total	421

Upper Devonian Martin limestone

In the Belmont subarea the Escabrosa limestone contains a meager invertebrate fauna of Lower Mississippian age. On the basis of the fauna collected by Ransome,[20] the Escabrosa limestone at Bisbee was correlated with the Kinderhook and Osage.

[20]Ransome, op. cit., pp. 42-54.

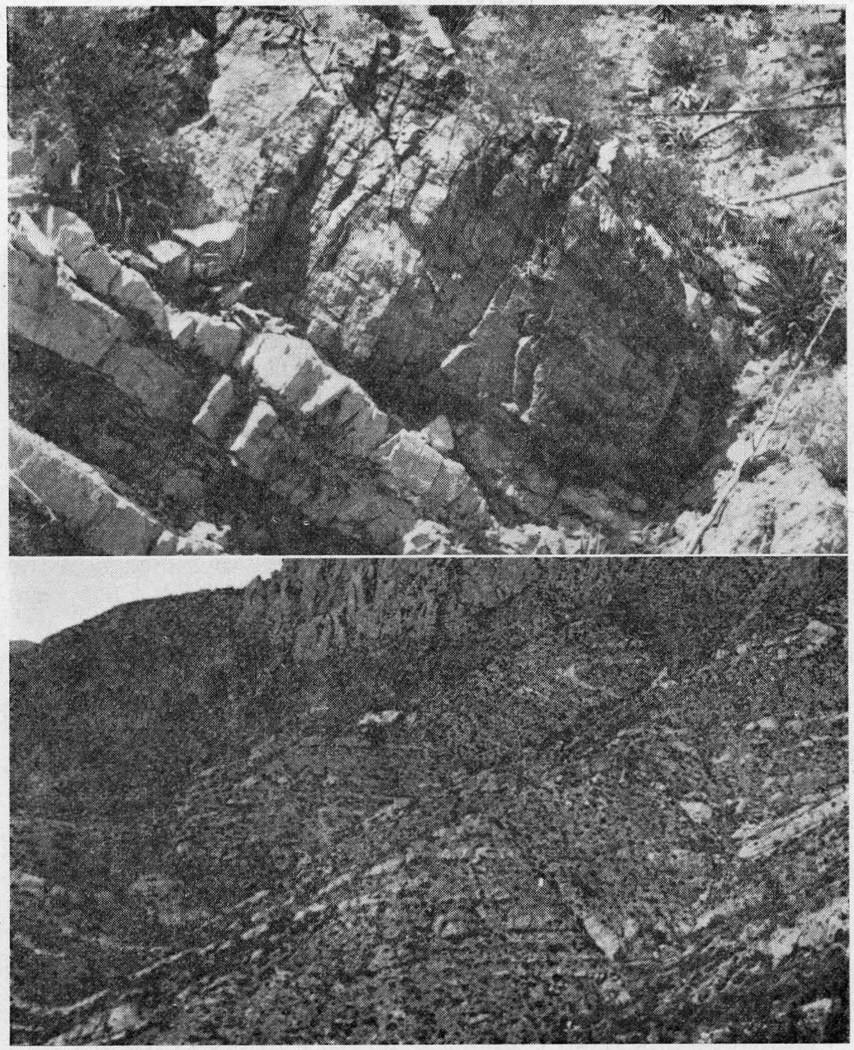

Plate VII.—*A*, Conglomerate bed separating Escabrosa and Naco limestones in Cross Canyon; *B*, Naco limestone showing Elm overthrust.

Naco limestone: The Naco limestone, of Lower Pennsylvanian age, is the upper part of the Tornado limestone[21] of the Ray-Globe area.

The Naco consists of thin-bedded white, light gray, or light pink limestone. Except for several small cliff-forming members, the individual beds are generally not more than 2 feet thick.

[21]Ransome, F. L., The copper deposits of Ray and Miami, Arizona: U.S. Geol. Survey Prof. Paper 115, p. 47, 1919.

Interbedded with it is some thin calcareous shale, small in total thickness. Chert nodules, common throughout the Escabrosa and Naco series, are most abundant in the upper portion of the Naco. Near the top, a prominent yellow chert bed forms a small cliff which is an excellent marker.

As dacite flows cover the uptilted, eroded Naco, its total thickness is not exposed in the Superior area. In the southern part of the area it is only 200 feet, but northward it increases to a maximum of 1,200 at Queen Creek Canyon where the overlying dacite has been removed by erosion. The Naco exposures diminish in thickness northward from Queen Creek, and below King's Crown Peak dacite rests directly on Escabrosa limestone.

The base of the Naco in the Belmont subarea is a conglomerate bed 2 inches to 4 feet thick, with its maximum thickness in Cross Canyon. On the peak a few hundred feet southeast of the Queen Creek shaft, it consists of about 3 feet of firmly cemented rounded pebbles, up to an inch in diameter, of jasper, quartzite, limestone, and schist. Northward the bed thins rapidly and near Queen Creek is only 3 inches thick. Here its pebbles are largely of schist. Southward from Cross Canyon, the bed thins to 2 inches in the area above the Belmont mine. South of there, it has not been recognized.

Since Lower Pennsylvanian fossils occur not more than 50 feet above and Lower Mississippian 50 feet below it, this conglomerate probably represents the hiatus between the Escabrosa and Naco formations. The conglomerate is good evidence that the Mazatzal land mass, from which the schist and quartzite pebbles must have been derived, stood high until early Pennsylvanian time.

The Belmont subarea is unusual in that a definite break in sedimentation between the Escabrosa and Naco limestones is thus clearly shown. In most central Arizona areas, the two limestones cannot be separated on lithologic evidence.

North of Queen Creek, the basal conglomerate is missing, and the top of the maroon shale has been mapped as the Escabrosa-Naco contact.

The Naco limestone contains a large, well-preserved invertebrate fauna of Lower Pennsylvanian age. Among the common forms are *Spirifer rockymontanus* Marcou and *Productus cora*.

Whitetail conglomerate: The coarse debris and silty material which accumulated on the old predacite surface has been termed Whitetail conglomerate.[22] In the Belmont subarea it rests on Naco limestone and is covered by dacite. Its best exposure is along Queen Creek east of the lower hairpin curve on the Superior-Globe road, where it shows a maximum thickness of slightly more than 100 feet. No outcrops of it appear north of Queen Creek.

[22]Ransome, F. L., Geology of the Globe copper district, Arizona: U.S. Geol. Survey Prof. Paper 12, p. 46, 1903.

This formation is composed of subangular to angular fragments (ranging from fine silt to boulders 2 feet in diameter) of all the older rocks in the district. The fragments are essentially unstratified but grade from coarser to finer towards the top. They consist largely of diabase in some places and of limestone, schist, or vein quartz in others. Apparently diabase is most common in the lower part of the conglomerate and vein quartz and quartzite in the upper part.

Near Queen Creek, the Whitetail is made up almost entirely of mudstone, with several thin pebbly layers largely of diabase and limestone. Here its deposition probably took place along a relatively mature stream. Near the North Lease, the upper 25 feet of the Whitetail is compactly cemented with secondary silica, so-called water quartz, and tinted red. This alteration and cementation seems to have been caused by heat and solutions from the overlying dacite flow.

No fossils were found in the Whitetail conglomerate. It probably accumulated during Middle Tertiary while the Laramide or early Tertiary ore deposits of central Arizona were undergoing erosion and oxidation.

Dacite conglomerate: West of the Main and Concentrator faults, thick conglomerate overlies the dacite. It consists of fragments of various older rocks, generally unstratified and weakly consolidated in a sandy dacitic matrix. In the Potts Canyon area, it contains intercalated beds of tuff and a lenticular flow of iddingsite basalt.

The easily eroded dacite conglomerate forms topographic lows, as the Superior townsite, and is exposed only in stream channels, road cuts, and underground workings. As the formation rests on a surface of considerable relief and has been extensively eroded, it ranges greatly in thickness. In the Potts Canyon area, on Happy Camp Wash, approximately a mile west of U.S.G.S. Bench Mark 3,023, some 400 feet of this conglomerate overlies dacite. The Magma No. 7 shaft passes through an unknown thickness of dacite conglomerate concealed by timbers, but is in dacite on the 2,000 level. South of the main adit of the Magma, the conglomerate-dacite contact is obscured by surface wash (Pl. I). South of Queen Creek, a vertical diamond drill hole sunk through dacite conglomerate entered Martin limestone at a depth of 1,050 feet.

As the dacite conglomerate is missing everywhere east of the Concentrator fault, it may represent a fanglomerate that was deposited on the west or downthrown side of this fault while the region on the east side was undergoing uplift and its deposition essentially completed before faulting ceased. This interpretation would explain both the localization of the conglomerate and its fault contact with the older volcanics on the east.

The dacite conglomerate is in general similar to the Gila conglomerate, of Pliocene age, which occurs extensively in southern and southeastern Arizona. The Gila in the Globe district likewise contains flows of iddingsite basalt.[23]

IGNEOUS ROCKS

Apache basalt: Late pre-Cambrian basalt occurs at the top of the Mescal limestone. Previously it was regarded as one flow, generally not more than 100 feet thick but persistent over large areas. At several places in the Superior area, it includes at least four separate flows with a total thickness of approximately 220 feet. The flows are similar in composition and general appearance, but they may be distinguished by their red oxidized and vesicular tops.

Harshman measured the following section in Donkey Canyon, where the flows are best exposed:

Middle-Cambrian—Troy quartzite Unconformity	Thickness (feet)
1. Fine-grained vesicular basalt. Vesicles most common in central portion. May represent two flows, the top of the upper one having been removed by pre-Troy quartzite erosion	90
2. Vesicular fine-grained basalt. Amygdules, up to 3 inches long and oriented vertically, common in top one third of flow. Red oxidized top	50
3. Flow fine grained at base, coarser grained and vesicular at top. Red oxidized top with pipe amygdules	55
4. Fine-grained vesicular basalt with deep red oxidized top	25
Total	220
Unconformity Pre-Cambrian—Mescal limestone	

The basalt flows occur throughout the Belmont subarea except where diabase has intruded their horizon. In the southern part of the area the total thickness of the basalt is only 100 feet, because of either early Cambrian erosion or the absence of one of the flows.

Megascopically the basalt is a tough, fine-grained rock, reddish to dark brown, and in most areas amygdular. The amygdules contain chlorite, calcite, and epidote, elongated horizontally at the top and vertically toward the bottom of the flows.

Microscopically, the rock consists of the following minerals, aside from amygdules.

Essential	*Alteration*
Plagioclase feldspar—60%	Hematite
$Ab_{45}An_{55}$—0.10 mm. max. diam.	Magnetite
Olivine—30%	Serpentine
0.05 mm. max. diam.	
Accessory	Sericite
Quartz—5%	
0.03 mm. max. diam.	Kaolin
Magnetite—5%	

[23]Ransome, op. cit., p. 95.

In surface outcrops the rock is highly altered. The feldspar has altered to masses of sericite and kaolin, the olivine to serpentine, and the probable augite to hematite. The original basaltic texture is apparent, with euhedral laths of plagioclase in a haphazard pattern surrounded by hematite, magnetite, and serpentine. The serpentine and some of the magnetite grains are pseudomorphic after boat-shaped crystals of olivine.

The quartz is arranged in parallel bands or in clusters of small grains. It is not an original constituent of the magma but probably represents reworked inclusions of quartzite.

The vesicles contain the following minerals: quartz, calcite, chlorite, epidote, and a uniaxial, high-index mineral of very weak refringence, probably garnet.

North of Queen Creek, the Apache basalt crops out only between the Magma Chief and Conley Spring faults. There the base of the formation consists of 20 feet of dark red basalt with vesicles flattened and elongated parallel to the surface of the flow. Overlying this flow are 60 feet of purplish shale of basaltic composition, evidently reworked basalt; probably the flow occurred close to sea level. North of the Magma Chief tunnel, where the cliffs of Troy quartzite are most prominent, the flow is represented by abundant pebbles and boulders of red, highly vesicular basalt in the basal conglomerate of the Troy.

Diabase: Intrusive into the Pinal schist, Apache group, and Troy quartzite are many sills of diabase. This widespread formation has been fully described by Ransome in the Globe and Ray-Miami reports.[24]

Diabase of similar character and geologic occurrence crops out at various places in the Santa Catalina, Galiuro, Dripping Spring, Mescal, and Mazatzal ranges and the Sierra Ancha and along the upper Salt River, over a region roughly 130 miles long from north to south by 50 miles wide. In this region, the greatest known thickness of diabase is in the Magma mine where two sills totaling 3,100 feet in thickness have been cut by mine workings.

In the Belmont mine, diabase extends from the 500 level for an unknown distance below the 1,600 or deepest level and is more than 900 feet thick. In the Silver King subarea, along Magma Chief Ridge, are three sills of diabase which total 1,100 feet in thickness. In some localities of the Globe district[25] the diabase is thicker than the sedimentary formations above the Pinal schist. Likewise in the Magma mine, sedimentary formations above the schist total 2,400 feet, and the diabase 3,100 feet, in thickness.

In areas of limestone and quartzite, emplacement of the diabase apparently was accomplished by forcing apart the intruded rocks, although locally assimilation may have been important.

[24]Ransome, F. L., U.S. Geol. Survey Prof. Paper 12 (1903) and Prof. Paper 115 (1919).

[25]Ransome, op. cit.

Ransome[26] concluded that its intrusion took place at shallow depths.

The Dripping Spring quartzite horizon is the most extensively invaded by diabase, although the Mescal limestone is missing in the Magma mine and represented only by isolated blocks in the Belmont mine.

Based on mineral composition, the diabase may be divided into three types: (a) quartz-orthoclase diabase; (b) normal or augite-hornblende diabase; (c) olivine-augite diabase. All three types are believed to be derived by differentiation within the same magma chamber. Descriptions of representative specimens of each type follow:

Petrography of quartz-orthoclase diabase: Megascopically, fairly fresh specimens have the usual ophitic texture characteristic of diabase. Laths of dark gray plagioclase feldspar 5 mm. to 2 cm. long with parallel sides and good cleavage are surrounded by dark-colored ferromagnesian minerals of indeterminate character. Irregularly scattered through this intergrowth are rounded grains of a pink mineral up to 5 mm. in diameter. Under the hand lens these pink grains appear to be orthoclase. Hence the quartz-orthoclase diabase can be distinguished readily from the other two types.

Under the microscope the pink grains are seen to be a microgranitic or myrmekitic intergrowth of quartz and orthoclase in the familiar graphic patterns. The quartz-orthoclase grains make up from 5 to 40 per cent of the total volume and average about 16 per cent. A typical specimen showed labradorite 38 per cent, augite 15 per cent, uralite (fibrous hornblende) 20 per cent, biotite 2 per cent, apatite 1 per cent, and magnetite 7 per cent. Hydrothermal alteration has greatly affected the original constituents. Uralite and some of the magnetite and biotite have been derived from augite. The feldspars are partly sericitized.

Petrography of normal diabase: In hand specimen this type is identical with the quartz-orthoclase variety except for the absence of pink orthoclase-quartz. Under the microscope a fairly fresh specimen showed the following minerals: labradorite 45 per cent, augite 15 per cent, hornblende 10 per cent, uralite 14 per cent, biotite 2 per cent, apatite 3 per cent, magnetite 10 per cent.

Petrography of olivine diabase: In hand specimen this type appears identical with normal diabase. Olivine cannot be distinguished from the other ferromagnesian minerals. Microscopically, the diabase has the following mineral composition:

Essential	*Alteration*
Labradorite—48% $Ab_{35}An_{65}$—grains to 3.0 mm. max.	Uralite—15% masses to—0.4 mm. max.
Augite—15% grains 2.5 mm. max.	Magnetite—8% grains to 1.0 mm. max.
Accessory	
Olivine and olivine pseudomorphs—8% grains 0.7 mm. max.	Biotite—4% grains to 1.0 mm. max.
Apatite—1% grains to 0.1 mm. max.	Antigorite, Actinolite / Talc, Sericite

[26]Ransome, F. L., The copper deposits of Ray and Miami, Arizona: U.S. Geol. Survey Prof. Paper 115, p. 87, 1919.

In most specimens the olivine has been replaced entirely by talc and magnetite. The only evidence of the original olivine is the characteristic boat-shaped crystals standing out in high relief above the augite and plagioclase.

Diabase in Magma mine: In the Magma mine, two sills of diabase with a combined thickness of more than 3,000 feet have intruded the Pinal schist, Apache group, and Troy quartzite. The upper sill, 2,000 feet thick, is between the Dripping Spring and Troy quartzites. Along the north wall of the vein on the east 2,000 level, the diabase has broken almost across the Troy. Here the upper contact of the sill is obscured by a small cross fault, but Martin limestone occurs not more than 50 feet stratigraphically above the diabase. On the East 2,550 level, limestone has been faulted down against the diabase.

Within the upper sill are numerous isolated bodies of quartzite which range from a few feet to 300 in thickness. Their width across the strike is not known, but one of them extends down the dip for a distance of 3,000 feet. They are probably "splinters" of Troy quartzite. A remarkable feature of these xenoliths is that they have the same dip and strike as the main mass of quartzite from which they are separated. This attitude is difficult to understand if the blocks sank down in a molten magma.

The lower sill, 1,100 feet thick, in most places intrudes Pioneer shale, but on the West 4,400 level it is in contact with Pinal schist. On the West 3,200 level, it breaks through the Apache beds and connects with the upper sill (Pl. II). No direct assimilation of the intruded rocks is evident. In the mine the entire Mescal limestone, the upper two thirds of the Dripping Spring quartzite, and much of the lower part of the Troy quartzite are missing.

The diabase of the Magma mine consists of the three mineralogical types already described. Most of it is the normal type. The quartz-orthoclase variety occurs only in the upper sill. The olivine diabase is found mostly in the lower, and to a minor extent in the upper, sill.

In places hydrothermal alteration, probably before the rock had cooled, has been intense; the ferromagnesian minerals have been extensively altered to serpentine and chlorite. On fractured surfaces the rock thus altered shows slickensides with a greasy, shiny, black luster. In some places the alteration has been so intense that the rock resembles a dark organic shale. Because of closely spaced fractures the altered rock is weakly resistant to stress, as on the 1,200 West drift, where the ground is heavy and must be timbered.

Magnetite, both primary and secondary, is a common accessory mineral, principally in the lower levels. A group of six selected specimens of diabase contained sufficient magnetite to affect the needle of a Brunton compass.

The variations of mineral content were probably due to differentiation of the parent melt with the heavier iron and magnesium constituents settling to the bottom and forming olivine. A later stage in the solidification of the diabase produced a melt high in potash, alumina, and silica, and the micropegmatitic intergrowth of orthoclase and quartz.

As seen in the mine, the diabase is peculiarly jointed. Its joint planes are parallel to the upper surface of the sills and have the same dip and strike as the overlying Paleozoic sediments, which gives the appearance of bedding.

Age of the diabase: Much discussion has centered on the age of the diabase.

Ransome,[27] after examination of the Ray-Miami districts, assigned the diabase to the early Mesozoic or late Paleozoic. He found dikes of diabase in the Tortilla Mountains, which cut "all rocks up to and including the Tornado (Escabrosa and Naco) limestone" and in the Dripping Spring Range, as at Steamboat Mountain, where "small bodies or dikes of the diabase cut the Martin and Tornado limestones."

In summarizing Ransome concluded:

> Intrusive relations show very clearly that the diabase is younger than the Troy quartzite. The Mescal (Martin?) and Tornado limestones have been cut only here and there by small bodies of diabase, but these are supposed to represent parts of the same magma that solidified in the larger masses. The diabase is thus younger than the Pennsylvanian epoch of the Carboniferous.

Darton,[28] however, states: "I am sure that these (small bodies and dikes of diabase that cut the Martin and Tornado limestones) are not the same intrusions as the sills and dikes in the Apache group but feeders of some of the Tertiary or Quaternary basalts. In other portions of the region I have found that the diabase invades mainly the strata older than the Troy, but in some instances the lower part of the quartzite is invaded."

Short and Ettlinger found evidence in the Magma mine that the diabase engulfed the lower part of the Troy quartzite but has not intruded the Martin limestone.[29] They regarded the diabase as post-Middle Cambrian and pre-Upper Devonian, an opinion which is retained in this report.

In addition to the evidence in the Magma mine, the intrusive relationship of the diabase to the Troy quartzite is shown in Cross Canyon about 2,500 feet east of the Superior-Ray road. There the upper contact of a small sill intruding the Troy quartzite is exposed as described in the following section from west to east:

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[27]Ransome, F. L., The copper deposits of Ray and Miami, Arizona: U.S. Geol. Survey Prof. Paper 115, pp. 53, 56, 1919.

[28]Darton, N. H., A resumé of Arizona geology: Ariz. Bur. Mines Bull. 119, pp. 254-5, 1925.

[29]Short, M. N., and Ettlinger, I. A., Ore deposition and enrichment at the Magma mine, Superior, Arizona: Am. Inst. Min. Eng. Trans., vol. 74, p. 181, 1926.

1. Coarse-grained diabase similar to diabase in the Ray-Miami area.
2. A 4- to 5-foot transition zone from normal coarse-grained diabase to an extremely fine-grained facies at the Troy contact.
3. A contact facies 3 to 6 inches wide, extremely fine grained, greatly fractured or jointed, but containing few or no fragments of quartzite.
4. The diabase-quartzite contact.
5. A band of baked quartzite 1 to 6 inches thick.
6. Normal Troy quartzite, 2 to 4 feet thick.
7. A narrow band of baked quartzite.
8. A sill of diabase, very fine grained and fractured, 1 to 2 feet wide.
9. A narrow baked contact of Troy quartzite.
10. Normal Troy quartzite continuously exposed eastward, without structural break, to its contact with the overlying Martin limestone.

Replaceability of diabase: Because of its chemical composition, the diabase was a favorable formation for deposition of ore bodies in the Magma mine. The most productive stopes are where diabase forms one or both walls of the vein. An investigation as to the relative replaceability of the three different types of diabase was carried out by Kuhn.[30] He concluded that there was no essential difference between the three types as far as replacement by ore solutions is concerned and that the ores are as rich and abundant in any one type as in the others.

Alteration of diabase by ore solutions is intense within the Magma vein but dies out within a few feet of it. The chief effects are silicification and sericitization. Where this alteration was most intense, the rock is almost white and consists of quartz, sericite, calcite, and titanium residue. Under the microscope, ghosts of the replaced feldspars can usually be discerned. Altered porphyry appears almost identical with altered diabase in the hand specimen, but it is readily distinguishable microscopically.

Intrusive andesite: In the Silver King subarea between the Conley Spring fault and the Black Diamond prospect, the horizon between Mescal limestone and Troy quartzite is occupied by a sill of andesitic composition. In hand specimens, the rock is indistinguishable from diabase.

About 500 feet north of Conley Spring Wash, a zone of intrusion breccia up to 30 feet thick crops out at the base of the Troy quartzite. This breccia is of two types. One type consists of angular quartzite fragments in a matrix of pulverized quartzite. The other variety has a matrix of amygdaloidal andesite and occurs mostly at the base of the brecciated zone. In the andesite matrix, flow banding, accentuated by alignment of tiny amygdules, is apparent. In places andesite layers bend around quartzite inclusions. The base of the sill in this part of the area is also amygdaloidal. Many of the amygdules have weathered out, and others have weathered to a soft, clayey residue.

Near the Black Diamond prospect andesite cuts across Mescal limestone, Troy quartzite, and Martin, Escabrosa, and Naco lime-

[30]Kuhn, T. H., Report to the Magma Copper Co., 1941.

stone. It is therefore of post-Carboniferous age. A few hundred feet south it is clearly cut and altered by the quartz diorite.

The andesite varies throughout its exposed area. Typically it is dark greenish black and coarse grained and consists of plagioclase laths surrounded by unidentifiable mafic minerals. In places the rock is so fine grained that no constituent minerals can be recognized.

Microscopically the rock is composed of 20 per cent plagioclase, 10 per cent magnetite, and 70 per cent hornblende, with accessory apatite. The feldspar, andesine $Ab_{60}An_{40}$, occurs as aggregates of small, roughly equidimensional, interlocking grains and a few elongated laths. Some of the feldspar shows sharp multiple twinning, and all is somewhat sericitized. The magnetite is scattered throughout the section and ranges in size from minute particles to corroded grains 0.25 mm. in diameter. Most of the hornblende occurs as tiny seedlike grains averaging 0.06 mm. in diameter, but some is present in irregular areas which exceed 2 mm. in the long dimension. The hornblende is clearly embayed by feldspar, indicating that the hornblende was earlier. This contrasts with diabase, in which feldspar is the earlier mineral. The amount of apatite is obscured by the abundance of hornblende.

Quartz diorite: The quartz diorite crops out in the Silver King subarea as a stock of roughly rectangular outline 1½ miles long by a mile wide. It intrudes the Naco and earlier formations and on Apache Leap is unconformably overlain by Tertiary dacite.

The quartz diorite weathers readily, occupies few prominences, and generally forms gentle, even slopes, for the most part covered with rock debris. On steeper slopes it has weathered into large rounded blocks. Where disintegration has progressed to a marked degree, the coarse sandy material generally contains rounded remnants of firm rock.

Porphyritic border facies of the quartz diorite probably represent more nearly the original composition of the magma. More rapid chilling at the contact caused crystallization of the principal mafic constituent, hornblende, as well as quartz and feldspar. The central part of the intrusive, enriched in volatile constituents by crystallization of the borders, remained hot and fluid for a longer period, allowing further differentiation and settling of the early-formed hornblende. This depleted the residual melt in calcium, magnesium, and iron, which crystallized as the more acid quartz diorite.

The main body of quartz diorite is in general a light gray holocrystalline rock composed of quartz, feldspar, and large amounts of biotite and hornblende. The feldspar and hornblende are generally euhedral crystals, the former up to a centimeter, the latter 2 to 3 mm. in length, while the quartz is interstitial. The rock weathers readily by kaolinization of the feldspars and chloritization of the mafic minerals.

In thin section this normal or main body of diorite exhibits two varieties distinguished by local development of porphyritic texture which apparently has no significance. A section of nonporphyritic quartz diorite is composed of approximately 60 per cent andesine-labradorite, $Ab_{50}An_{50}$, 30 per cent quartz, and subordinate amounts of augite, biotite, chlorite, leucoxene, and magnetite. Accessory minerals are apatite and zircon. Feldspar occurs as euhedral lath-shaped forms exceeding 1.5 mm. in length and a few equidimensional zoned feldspars. Sericitization has been slight and principally confined to the centers of the feldspars. Quartz is largely interstitial in large interlocking anhedral grains up to 1 mm. in diameter. Little of the original augite remains, the mineral, whose prismatic sections reached 1.7 mm. in length, now being almost completely altered to biotite, shreddy chlorite, and epidote, the three commonly arranged in alternate bands. Leucoxene is associated with the alteration. Some, if not a considerable portion, of the biotite is original and not an alteration product of augite. Magnetite is concentrated in and around the other mafic minerals, and apatite, while exhibiting the same tendency, is also found scattered throughout the field. A little zircon in perfect euhedral prismatic crystals is likewise present. Calcite is rare. Zoisite is present in some quantity, occurring in small formless grains with the habit of epidote but almost colorless or faintly pale yellow.

The age of the quartz diorite is uncertain. It invades Pennsylvanian strata, but not the Tertiary volcanics and is believed to be a part of the Central Arizona batholith[31] of late Cretaceous or early Tertiary age.

Dikes complementary to quartz diorite: The quartz diorite is intruded by many fine-grained, light gray dikes consisting of quartz and feldspar with subordinate biotite. They range in thickness from less than an inch to about 2 feet and, where weathering has been intense, stand out in conspicuous relief. These felsite dikes are conspicuous in a cut on the Silver King road a short distance west of U.S. Geological Survey B. M. 3,553. The presence of the dikes is indicative of quartz diorite where the host rock is too weathered for determination or locally dark and resembling diabase.

Crossing the quartz diorite stock near its north end is the Grandfather Lead, a nearly vertical dike of andesite porphyry 5 to 30 feet wide. It is not confined to the quartz diorite but extends outward in both directions, cutting diabase on the east border, and schist on the west border, of the stock. It maintains its general trend with great persistence throughout a length of about 3 miles.

The hand specimen from the Grandfather Lead is a dense cream-colored porphyry with feldspar phenocrysts as large as 3 mm. in diameter and muscovite flakes 4 mm. in diameter, embedded in a light-colored aphanitic groundmass. Weathered surfaces of the rock are stained brown and show distinctly cubic pits as large as 1.5 mm. along an edge. Along fresh breaks these pits are found to contain earthy limonite after pyrite. Manganese stain along joints and cracks in the rock is common. More weathered specimens clearly show sericitization of the groundmass.

Microscopically, the rock consists approximately of 10 per cent phenocrysts, mostly plagioclase with some muscovite, and 90 per cent groundmass. The feldspar phenocrysts are sericitized and kaolinized but retain original albite twinning planes. The altered plagioclase phenocrysts are andesine, $Ab_{70}An_{30}$. Subhedral muscovite phenocrysts are scattered throughout the slide with abundant shreddy sericite from alteration of andesine in the groundmass. Mafic minerals have been completely altered to limonite and hematite. Traces of magnetite in tiny grains are surrounded

[31]Ettlinger, I. A.: Ore deposits support hypothesis of a central Arizona batholith: A.I.M.E., Tech. Pub. 63, 1928.

by white alteration product, probably leucoxene. The mineral composition of the dike is as follows:

Essential	*Alteration*
Andesine $Ab_{70}An_{30}$—65%	Sericite
0.03 to 1.3 mm.	Kaolin
Quartz—5%	Magnetite } 2%
0.20 mm.	Leucoxene }
Accessory	
Muscovite—25%	Limonite } 3%
0.08 mm.	Hematite }

Silver King quartz monzonite porphyry: The Silver King porphyry, in which was developed the Silver King ore body, crops out as a roughly elliptical mass approximately 2,500 feet long from east to west by 1,200 feet wide. It was intruded into the southeastern part of the quartz diorite stock, and 1,000 feet southeast of U.S. Geological Survey B. M. 3,553 a small tongue of porphyry follows the Pioneer shale-Barnes conglomerate contact.

Topographically the porphyry resembles the quartz diorite. The feldspar phenocrysts weather most rapidly and alter to kaolin. Further decomposition is slow, but where it has obliterated the outlines of the feldspars the rock is difficult to distinguish from well-weathered quartz diorite.

In the vicinity of the mineralized zone the porphyry has weathered into spheroidal forms of variable size, mostly more than a foot in diameter. The outcrop of the mineralized zone is a conical hill, partially caved into the old workings. The relatively greater hardness of the rock in this hill, and possibly also its spheroidal weathering, may have been caused by silicification related to the mineralization.

The least altered area of Silver King porphyry, southwest of the open pit, is a quartz diorite porphyry. It is a medium dark gray granitic rock of distinctly porphyritic texture. Phenocrysts of feldspar with a maximum diameter of 1 cm. clearly show plagioclase twinning striations. The groundmass is composed of approximately equidimensional feldspar, quartz, and biotite.

Microscopically the rock is composed of approximately 30 per cent labradorite, 10 per cent biotite, and 60 per cent groundmass, with subordinate chlorite and calcite and accessory hematite and apatite. The groundmass is made up of roughly equigranular andesine, $Ab_{65}An_{35}$, occupying 40 per cent of the total section, quartz 13 per cent, and orthoclase 5 per cent. The quartz has two sizes of grains; those averaging about 0.6 mm. in diameter make up the smaller part and are probably original, while the finer grains may be attributed to subsequent solutions. The phenocrysts are euhedral to subhedral in form, of composition $Ab_{46}An_{54}$, and have a maximum length of 2 mm. A few of the phenocrysts show poorly defined zoning. The biotite occurs in sections up to 0.6 mm. in length and are somewhat altered to chlorite with which is associated a little calcite.

The rock changes toward the open pit, and in the southeastern part of the intrusive it is a diorite porphyry. Roughly rectangular phenocrysts of feldspar about 2 mm. in largest dimension, some few scattered clumps of chlorite, and a few minute phenocrysts of quartz about 1 mm. in diameter comprise some 20 per cent of the rock. The remainder is groundmass which is so fine grained that the constituent minerals could not be recognized. In thin section the phenocrysts are euhedral crystals of labradorite, $Ab_{46}An_{54}$, whose maximum length is nearly 2 mm. These constitute about 20 per cent of the total area. The groundmass, which makes up 65 per cent of the rock, is extremely fine-grained andesine, $Ab_{60}An_{40}$. Tiny flakes of hematite are abundantly scattered throughout this groundmass, and larger grains are also present. Secondary chlorite constitutes about 5 per cent and later calcite 10 per cent of the total area. Minor amounts of anthophyllite, apatite, and leucoxene are also present.

Some of the phenocrysts are zoned. A section cut parallel to (010) gave the following: an outer zone making up 15 to 20 per cent of the phenocrysts of andesine, $Ab_{62}An_{38}$, and an inner zone of labradorite, $Ab_{48}An_{52}$. The feldspar phenocrysts show considerable alteration to sericite, whereas the groundmass is comparatively unaltered. The phenocrysts also contain considerable calcite, both within and adjacent to their boundaries, and small areas of calcite are found scattered throughout the groundmass. Calcite fills fractures in the phenocrysts, indicating origin from later solutions. Chlorite accompanies the larger part of the calcite. It occurs in euhedral to subhedral sections up to 1 mm. in length and is apparently an alteration product of hornblende through biotite, as the remnants of typical amphibole cross sections are preserved. A little anthophyllite is associated with the chlorite, occurring as small heterogeneous fibers. A little apatite is present, and also considerable leucoxene is associated with the chlorite and scattered in small specks throughout the section.

In the vicinity of the mineralized area, the porphyry is light brown and highly weathered. A specimen from inside a large spheroidal boulder is medium gray with faintly greenish tint. The rock is fine grained and holocrystalline. Quartz as euhedral phenocrysts is the only unaltered mineral present. Ghosts of potash feldspar phenocrysts can be distinguished, as well as altered mafic minerals of undetermined composition.

The alteration is predominantly sericitization. The more basic feldspar phenocrysts are first affected, then the mafic minerals, and finally the fine-grained groundmass.

The Silver King porphyry shows progressive increase in quartz towards the mineralized zone. Two generations of quartz are visible in all but the freshest rock.

Differentiation of the quartz diorite magma: It seems likely that the quartz monzonite porphyry was a differentiate of the main quartz diorite body and followed closely its intrusion, probably while the diorite was still in a partially viscous condition. The roughly elliptical outline of the porphyry, the highly irregular contact with small tongues of porphyry extending out into the diorite, and the absence of fracturing or brecciation suggests that its intrusion took place before complete solidification of the older rock. The more acid nature of the porphyry, with its preponderance of sodic feldspar and additional quartz, seems to represent a third stage in differentiation of the original quartz diorite magma. The first stage is represented by the more basic border phases of the larger stock. The pink quartz monzonite, which cuts both diorite and porphyry as dikes, is believed to be a further differentiate, while the mineralizing liquids, which formed the Silver King ore body and caused silicification of the surrounding rock, as well as depositing large bodies of vein quartz, appear to be the final residual liquids of a completely differentiated magma.

There thus appears to be a complete series of differentiates beginning with the mafic porphyries through quartz diorite to quartz monzonite and ending with deposition of metallic ore minerals and quartz from aqueous solutions.

The Central Arizona batholith: The acid intrusives form a part of what Ettlinger[32] termed the Central Arizona batholith. This great body includes the post-Cambrian (probably Laramide) granitic intrusives of the Globe, Miami, Ray, Pioneer, Troy, and Silver King mining districts and a southern extension in the Banner district. The rocks range in composition from diorite to porphyritic granite.

The principal mines of the Superior, Miami, and Globe districts are within 2 miles of a line joining the Magma and Old Dominion mines, and this line is coincident with the maximum elongation of the Schultze granite, which is the largest Tertiary intrusive in the region. Ettlinger believed that these features are dependent upon a line of weakness or shear zone caused by postdiabase adjustments.

The principal producing vein mines are in roof rocks of this batholith, while the disseminated copper deposits are in Pinal schist bordering the batholith and in adjacent portions of the batholith itself.

Magma quartz monzonite porphyry: In the Magma mine are numerous dikes of light-colored porphyry, termed the Magma quartz monzonite porphyry. The most important of these dikes occupies the Magma fault from the outcrop to the 1,200 level. Below this level the dike leaves the Magma fault but in many places forms either the north or south wall of the vein and has been cut by mine workings and diamond drill holes.

Fresh specimens of porphyry from the upper levels are not to be obtained, as alteration by vein solutions has changed its original character. Where alteration has been extreme the rock is powdery white, commonly indurated by silica, and none of the constituent minerals can be identified. Fresher specimens show the outlines of feldspar phenocrysts, some as long as 4 mm. with square or rectangular cross sections set in a grayish white powdery groundmass. Long, slender greenish needles represent the only ferromagnesian mineral recognized. Alteration has obscured their original cleavage and other characteristics, but their general habit suggests hornblende.

Microscopically the feldspar phenocrysts show extensive alteration to platy sericite, but the outlines are very clear and sufficient remnants of albite twinning lamellae remain to identify some of them as plagioclase,

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[32]Ettlinger, op. cit.

although their exact composition could not be determined. Other phenocrysts show no traces of albite twinning and are regarded as orthoclase.

The groundmass consists of small sericite plates and rounded quartz grains. The quartz is an original rock-forming mineral and was not introduced by the solutions which deposited the sulfides. Magnetite and zircon are accessory minerals. Apatite is relatively abundant in some specimens but rare in others.

Ferromagnesian minerals are abundant as phenocrysts. The outlines of long needles of hornblende and six-sided plates of biotite could be distinguished, but alteration has changed them to chlorite even in the freshest specimens examined. Where alteration has been more intense, even the pale greenish chlorite disappears and sericite takes its place. The fibres of the sericite are oriented parallel to the cleavage of the original hornblende or biotite, in contrast to the shapeless shreds or plates of the sericite formed from the feldspar phenocrysts.

Minute formless grains of epidote, unlike the epidote of contact metamorphic rocks, are found as alteration products in the phenocrysts. Kaolin is abundant in porphyry from the upper levels of the mine. Calcite and quartz are abundant in veinlets.

The replacement of the rock minerals by sulfides is very clear. Pyrite grains invariably occur in the fresher specimens and in places tend to form in phenocrysts rather than in the groundmass.

Other light-colored fine-grained porphyry dikes occur in the 3,600 and lower levels of the mine. They are nearly vertical but apparently do not reach the surface. All are earlier than the Magma ores.

Dacite series: Overlying the Paleozoic and older rocks, the Silver King quartz diorite stock, and the Whitetail conglomerate, is a thick series of predominantly dacitic volcanic rocks. It is termed the dacite series, or dacite.

Dacite flows, tuff, and agglomerate cover much of the region west of Globe to Apache Junction, south of Salt River. This volcanic material is 1,300 feet thick on Picket Post Mountain, 4 miles west of Superior, and 2,500 feet thick in the Superstition Mountains. It was erupted on a deeply eroded surface during Tertiary time but long after the mineralization.

The largest area of dacite shown on Plate I occupies the summit of the range and fills inequalities of the post-Naco erosion surface. Extending far beyond the limits of the map, its width is from 4 to 10 miles and its length more than 30 miles in the general direction of the range. Where notched by Queen Creek, its thickness exceeds 1,200 feet but may be greater within the mass. Its western margin is a precipitous bluff which towers above Superior and, south of Queen Creek, forms Apache Leap. Near the north border of Plate I it forms King's Crown, the highest elevation of the area.

South of Queen Creek the dacite series consists of four members which have been mapped as one unit. The three lower members are of variable, but generally small, thickness. The following is an average section:

Present erosion surface	Thickness (feet)
1. Normal pink dacite showing flow structure and containing many vesicles	1,200+
2. Brown to black vitrophyre containing large vesicles and small phenocrysts	12
3. Light brown porphyritic andesite showing flow structure in aphanitic groundmass	6
4. White tuff of consolidated andesitic material containing ing numerous biotite fragments	8
Total	1,226+
Unconformity	
Whitetail conglomerate	

Member (4), the white to light pink andesite tuff, ranges in thickness from a minimum of 2 feet near the Belmont mine to a maximum of 15 in the central part of the Belmont subarea. It is generally uniform in composition but in a few places contains thin beds of small diabase pebbles. In all outcrops where it overlies the Whitetail conglomerate, the andesite tuff grades upward from conglomerate through sand, mud, and muddy to pure tuffs. Its contact with the dacite vitrophyre is also gradational, and much tuffaceous material occurs in the basal part of the vitrophyre.

The andesite member (3) was found only in the extreme northern part of the Belmont subarea, where its maximum thickness is 6 feet. It is probably the flow equivalent of the underlying tuff.

Member (2), the vitrophyre, occurs in uniform thickness along the entire length of Apache Leap. It is a very brittle, dense, light brown to black glass containing large vesicles throughout and in some outcrops including fragments of earlier rocks. The vitrophyre is everywhere broken by joints of which one set is parallel to its base. This glass forms an excellent marker bed, easily found even when covered by considerable talus. It probably represents a chilled facies of dacite.

Member (1), the series of dacite flows and minor tuffaceous beds, in all more than 1,200 feet thick, overlies the vitrophyre. On fresh exposure the dacite is light pinkish gray and, although apparently porous, is a dense, tough rock. Weathering has not altered even the intricately jointed areas of the flows, and fresh specimens can be secured a fraction of an inch below their surfaces. Abundant glassy constitutents cause the weathered surfaces to be very rough and pitted. Thin sections of samples taken every 50 feet from the base to the central part of the flows showed no variation in mineralogical composition. Individual flows of almost similar composition are undoubtedly present in this thick volcanic pile. The tuffs are well exposed in Oak Flat, where they lie flat and are about 10 feet thick. Inclusions of older rocks, principally lava fragments but also sedimentary rocks and schist, are common throughout the flows.

The dacite has been broken by joints of which one set parallels the flow planes; the other two dip vertically and strike north and east, respectively.

Phenocrysts are plagioclase and biotite, rarely 4 mm. in length, and porphyritic texture is not conspicuous. Occasional quartz, hornblende, and sanidine crystals are seen. Large vesicles, undoubtedly gas bubbles, mostly lined with an unknown white amorphous material, occur throughout the rock.

Essential	*Accessory*
Glass—40%	Biotite—2% grains 0.7 mm. max. dia.
Andesine—38% $Ab_{60}An_{40}$—grains 1.5 mm. max.	Hornblende, Magnetite, Hematite, Rutile, Zircon, Sphene — 2%
Quartz—15% grains 1.7 mm. max.	
Orthoclase—3% grains 1.0 mm. max.	

In thin section the dacite shows grains of quartz, andesine, and biotite surrounded by a ropy vitreous groundmass. All the feldspars, but more particularly the andesine, have been altered by magmatic corrosion. They are, however, fresh and clear. The quartz is in embayed anhedral grains and is subordinate to both the feldspars. Biotite, strongly pleochroic, occurs sparingly. Some has been bleached and altered to magnetite. Hornblende is sparsely scattered throughout the section in very small euhedral crystals. Accessory minerals are magnetite, apatite, and sphene.

Flow texture is well shown in the ropy groundmass. Devitrification has produced spherulites and trichites in the glass, but original crystallization is not apparent. Finely divided hematite and many needles of rutile are scattered through the glass.

Dacite in Silver King subarea: In the Silver King subarea the lower members of the dacite series differ somewhat from those of the Belmont subarea, as is shown by the following section measured by Galbraith:

		Feet
1.	Dacite	500+
2.	Dacite tuff	5 to 10
3.	Gray to reddish glassy vitrophyre, in the cavities of which are numerous glass bubbles or lithophysae. Particles of ash appear in the upper portion	200
4.	Gray-brown glassy vitrophyre	30

Dacite in the Magma mine: In the Magma mine the main body of dacite is cut only by No. 6 shaft, which is in this rock from the collar to a depth of 1,324 feet (Pl. II).

Dacite also occurs west of the Concentrator fault on the 2,000 and 2,550 levels. Here the rock is similar to that on Apache Leap except for a large proportion of limestone inclusions up to 4 inches in diameter; probably it was erupted on a limestone surface. It is cut by veins, up to an inch thick, of postore calcite of unknown origin.

Dacite between Main and Concentrator faults: One large and two small blocks of dacite, similar in character to the main mass

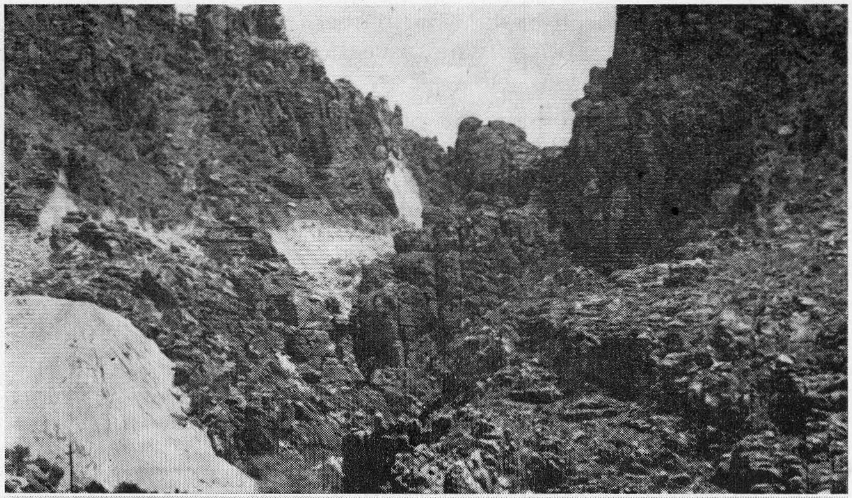


Plate VIII.—*A*, Dacite in gorge of Queen Creek; *B*, Dacite, Oak Flat.

on Apache Leap, crop out on the hill between the Magma concentrator and Magma Wash.

The larger block, mapped as dacite agglomerate by the engineers of the Magma Copper Company, is well exposed in railroad cuts between the main and No. 5 portals of the Magma mine and in the main adit (500 level) between the portal and the Main fault. At the fault it is in contact with Martin limestone. The attitude of this dacite is not shown at these localities, but on the hill immediately north of the high-tension power line and 850 feet S. 20° W. of the portal of the Flindt tunnel the dacite is underlain, with almost vertical contact, by an obsidian vitrophyre flow.

North of the block already described is a small elongated block of normal dacite 50 to 200 feet wide. From a point 650 feet west of the portal of the Flindt tunnel it extends westward for 1,200 feet. It is bound by faults, and the attitude of the flows cannot be determined, but from the shape of the outcrop they are probably nearly vertical.

Tertiary basalt: The youngest igneous rock in the district is olivine basalt. It occurs as minor intrusive bodies and flows later than the post-dacite faults of the region and therefore is late Pliocene or Pleistocene.

In the Magma mine are many essentially vertical dikes of basalt. One of them, later than the Magma fault and the ore bodies, extends from the surface to the lowest levels of the mine.

The most extensive outcrop of basalt in the area of Plate I is a small plug which intrudes diabase along the footwall of the Concentrator fault a short distance west of the new Silver King road. Intruding the Concentrator fault northward from Silver King Wash is a dike of basalt 900 feet long and about 25 feet in maximum width. On the west border of Plate I is a flow of basalt about 75 feet thick, identical in character to that intruded along the Concentrator fault. It crops out for a length of 1,800 feet, resting on an eroded surface of dacite and dacite conglomerate and in turn overlain by a series of waterlain tuffs.

In the Belmont subarea the basalt is limited to a dike in the southwestern portion. A specimen of it is described as follows:

Megascopically the rock is dark purplish gray on fresh surfaces. Some phenocrysts of reddish brown iddingsite as long as 3 mm. and amygdules of calcite 1 mm. in diameter are embedded in an aphanitic groundmass. Tiny plagioclase laths, likewise embedded in this groundmass, reflect light as hairlike crystals.

Exposed surfaces of the basalt are weathered to light brown. Depth of weathering varies from 1 to 2 mm. from the surface of the rock. These weathered surfaces are pitted as a result of removal of iddingsite and calcite.

Microscopically the basalt shows the following composition:

Essential

Labradorite $Ab_{35}An_{65}$—50%
1.75 mm. to 0.02 mm.

Augite—25%
0.75 mm.

Olivine—4%
0.40 mm.

Accessory

Magnetite—2%
0.03 mm.

Alteration

Iddingsite—15%
0.80 mm.

Amygdular

Calcite—4%

Subhedral phenocrysts of labradorite as large as 1.75 mm. in diameter and subhedral phenocrysts of augite as large as 0.75 mm. in diameter are sparingly present in a fine-grained groundmass of labradorite laths and intersertal augite with typical basaltic texture. The feldspar phenocrysts are zoned. Augite phenocrysts show polysynthetic twinning. Labradorite phenocrysts are embayed by augite. In the groundmass are euhedral laths of labradorite, the majority of which are approximately 0.02 mm. in length. Flow structure is clearly shown by parallelism of these laths and elongated euhedral phenocrysts of augite.

Both labradorite and augite phenocrysts are fresh. Only evident alteration in the section is that of olivine to iddingsite. The larger phenocrysts of olivine have not been altered to iddingsite within their peripheries. Smaller olvine phenocrysts have been completely altered to reddish brown iddingsite. Some iddingsite and olivine-iddingsite phenocrysts retain strong euhedral hexagonal outlines of original olivine.

A multitude of magnetite grains occurs scattered throughout the groundmass. Calcite is found only as amygdules filling irregularly shaped vesicles.

It is probable that the rock contains phenocrysts of olivine approximately 1.5 mm. in diameter, but only the iddingsite borders of these large phenocrysts are preserved in the slide.

METAMORPHISM

Processes: Metamorphism results from two distinct processes—regional and contact.

Regional metamorphism: Regional metamorphism results from pressure, and to a less extent temperature, operating for a long time over large areas. Shale is changed to slate by moderately intense regional metamorphism or to schist by more intense action. The same processes convert acid igneous rocks to quartz-sericite schist and basic igneous rocks to greenstone; sandstones are converted to quartzite and limestones to dolomite.

In the Superior area, regional metamorphism is the most pronounced in the Pinal schist. In the Globe district the schist has been invaded by both the pre-Cambrian Madera quartz diorite and the Tertiary Schultze granite. It is probable that the Pinal schist in the Superior area has been intruded by underlying masses of pre-Cambrian granite which superimposed contact metamorphism upon regional metamorphism.

The shales and sandstones of the Apache group have been more or less altered by regional metamorphism. The Pioneer shale ranges from slaty to distinctly quartzitic. The Dripping Spring quartzite has been completely metamorphosed from an arkosic sandstone. The Mescal limestone was less metamorphosed by regional processes, and the effect has been largely obscured by contact action of the diabase.

The Paleozoic Troy quartzite of the Superior area has been recemented in most places but locally is a cross-bedded sandstone. The Paleozoic limestones show little or no regional metamorphism.

Contact metamorphism: Contact metamorphism is the effect of igneous rock magmas which are intruded into pre-existing rocks. It is caused partly by heat of the intruding magma but more largely by chemical change in the intruded rocks brought about by transfer of liquid and gaseous emanations from the magma.

The effect of contact metamorphism upon rocks whose chemical composition differs from that of the invading magma is greater than it is upon rocks of similar chemical composition. Thus the effect of a granitic magma on a limestone is generally great, but the effect of the same magma upon a granite is slight. In the Silver King subarea the effect of the quartz diorite stock on invaded Paleozoic limestones is considerable, but that of the later Silver King quartz monzonite porphyry upon the quartz diorite is almost nil.

The effect of an intrusion is largely a function of its size. The quartz diorite stock and the thick diabase sills have brought about the most contact metamorphism in the Superior area. On the other hand, the narrow Magma quartz monzonite porphyry dikes and the postdacite basalt dikes and plugs have caused negligible metamorphism.

Quick-cooling rocks, such as basalt and dacite flows, cause little metamorphism.

Contact metamorphism by diabase: In the northern part of the Silver King subarea, diabase has invaded Pinal schist without producing any discernible alteration. In the same area Pioneer shale, where intruded by diabase, has been baked and thoroughly bleached from the typical brown or maroon color to bluish gray and milky white bands of much finer-grained, harder shale. This metamorphism extends to a depth of roughly 1 inch from diabase contacts.

Metamorphism of the Dripping Spring quartzite is limited to a baking and darkening of the rock for a few feet from the intrusive, as is shown by exposures along the lower part of Magma Chief Ridge. In the Belmont subarea the quartzite has been baked and colored reddish black in a zone which is nowhere over 18 inches wide and in some places is absent.

The diabase had its greatest contact action on the Mescal limestone, with the development of abundant tremolite. In hand specimen this metamorphosed rock resembles fine-grained silicified limestone, but microscopically it is an aggregate of tiny colorless tremolite needles together with some chlorite and silica. Where metamorphism is less intense, residual calcite or dolomite forms the matrix between alteration products.

In the Potts Canyon area scattered lumps of magnetite up to a few inches in diameter accompany lime and magnesium silicates. In the Prudential mine this alteration extends into the Mescal limestone for several feet from the diabase contact.

The contact action of diabase on Troy quartzite is generally negligible. One exception is on the Belmont mine road, immediately east of the Lone Star fault, where baked and decomposed sandy material forms a 75-foot zone of transition between diabase and normal Troy quartzite. The material grades from normal

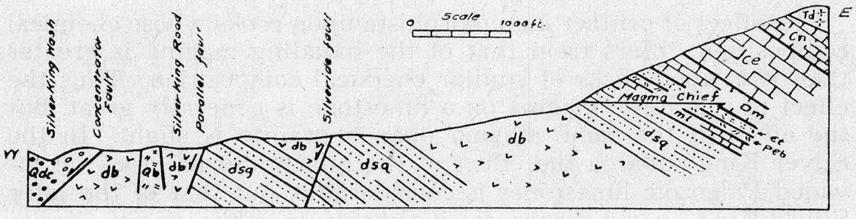


Figure 3.—East-west geologic section through Magma Chief tunnel.

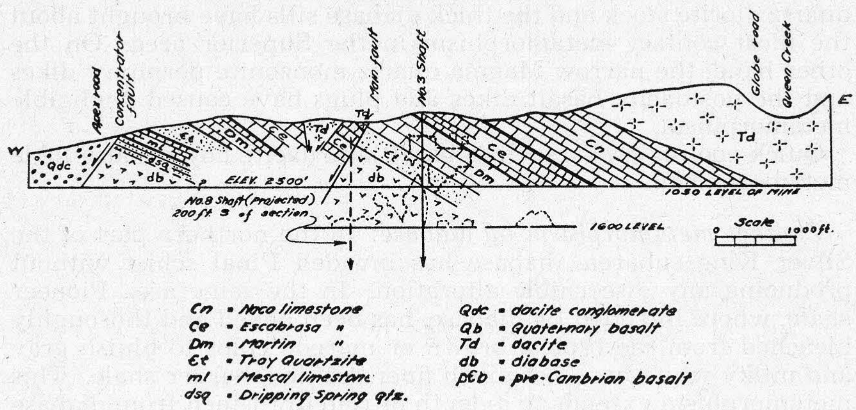


Figure 4.—East-west geologic section through Magma No. 3 shaft.

diabase through a highly altered, decomposed, iron-stained siliceous zone into unaltered cross-bedded Troy quartzite.

Contact metamorphism by quartz diorite: The quartz diorite stock of the Silver King subarea has produced negligible metamorphism in rocks of the Apache group. Its effect on the diabase, however, is considerable. In places a transition zone several feet thick occurs between quartz diorite and diabase, and here the rock is distinguished with difficulty. Microscopically the ophitic texture of the diabase is visible, but the ferromagnesian minerals have been largely recrystallized into hornblende prisms up to 3 cm. long.

The Carboniferous limestone in contact with the quartz diorite at the Black Diamond mine near the base of the dacite cliffs contains a mass of specular hematite and siderite nearly 100 feet wide and several hundred feet long. The mirrorlike crystals of hematite are grouped into foliated rosettes. Copper stain is common, but no sulfides could be distinguished. Above the specularite deposit the limestone was permeated by the diorite solutions. Some beds were recrystallized and grossularite was formed. The shaly layers were epidotized, probably because of their higher alumina content.

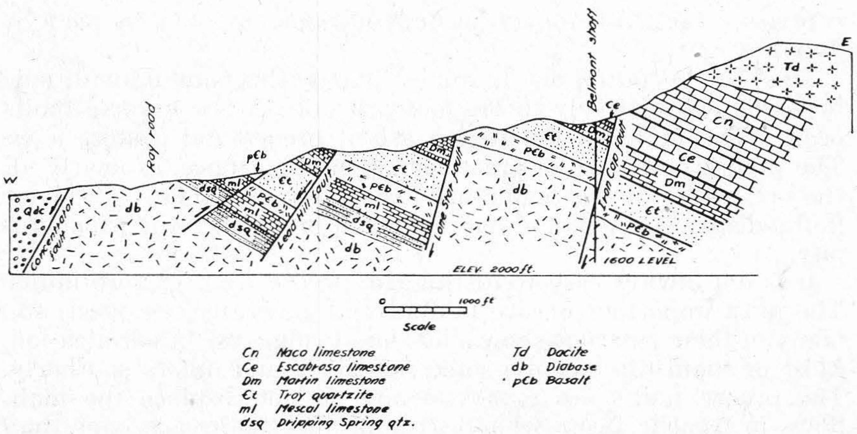


Figure 5.—East-west geologic section through Belmont shaft.

Near the northern edge of the map area, a dikelike offshoot of diorite has produced a metamorphic zone several feet thick in Carboniferous limestone. This zone is composed almost entirely of green grossularite accompanied by notable amounts of tourmaline. The tourmaline is green, coarsely fibrous, and nonpleochroic.

STRUCTURE

FOLDING

East of the Main and Concentrator faults, the Paleozoic and Apache beds dip east, northeast, and southeastward, as shown on Plate I. In the Belmont subarea their strike is northwestward. North of Cross Canyon it changes gradually, and at Queen Creek it is almost north. In the Magma subarea the average strike is N. 10° E. In the Silver King subarea between Magma Chief tunnel and King's Crown Peak it averages N. 30° E. These changes in strike are reflected by the trend of the mountain front. Possibly the structure represents a limb of an arcuate fold formed during late Cretaceous-early Tertiary (Laramide) time, in association with emplacement of the Central Arizona batholith, and extensively broken by later faults. Compressional stresses are indicated by the Elm thrust and by horizontal displacement on the east-west faults.

Some drag folds of limited extent occur, associated with the larger faults.

FAULTING

The mountain ranges of this region have a general northwest trend and are commonly bounded on one or both sides by faults. Many of the ranges are relatively uplifted fault blocks modified by erosion. The intramontane valleys, such as Superior Flat, represent relatively down-faulted portions, covered in part by detritus.

Most of the faults are normal—that is, the hanging-wall side has dropped relatively to the footwall side. A few reverse faults occur. The faults of the region are of preore and postore ages. The preore faults are of great economic importance, as nearly all the ore bodies of the region are associated with them. The later faults displaced them and had profound influence on the topography.

It is not always easy to distinguish preore from postore faults. The most important preore faults trend generally east-west, and many of their outcrops show silica and manganese mineralization. Most of them dip steeply, some northerly and others southerly. The preore faults are predacite and do not displace the main flows in Apache Leap, whereas the postore faults are later than the dacite.

Many if not most of the postore faults trend northerly or northwesterly. Several of the faults are of uncertain age.

The two systems of faulting were related to periods of igneous activity. The preore faults were related to the emplacement of the Central Arizona batholith, and the postore faults followed or were contemporaneous with deposition of dacite conglomerate which immediately succeeded the outpouring of dacite.

PREORE FAULTS IN MAGMA SUBAREA

The Magma fault, identical with the Magma vein, is discussed in detail on pp. 79-82.

The Koerner fault, subparallel to the Magma vein, is discussed on pp. 82-84.

East-west faults mapped in the Lake Superior and Arizona mine are shown on Figure 6.

PREORE FAULTS IN BELMONT SUBAREA

East-west faults are important in the Belmont-Queen Creek area, for along them the ore-bearing solutions ascended. Also along these faults were intruded the narrow dikes of quartz monzonite porphyry common in the northern part of the area.

Many of the east-west faults appear to have displacements of 10 to 30 feet. In the Main Lease, in a small open cut northeast of the Belmont shaft, however, striations on the hanging wall of one of these faults indicate that the last movement, at least, was almost parallel to the dip of the beds and that the movement is probably several times greater than is indicated by the apparent displacement of the beds.

One of the most important of the east-west mineralized fissures is the Sandal fault. It crops out southeast of the Grand Pacific mine (Pl. I), and the ore mined in that area occurred along it.

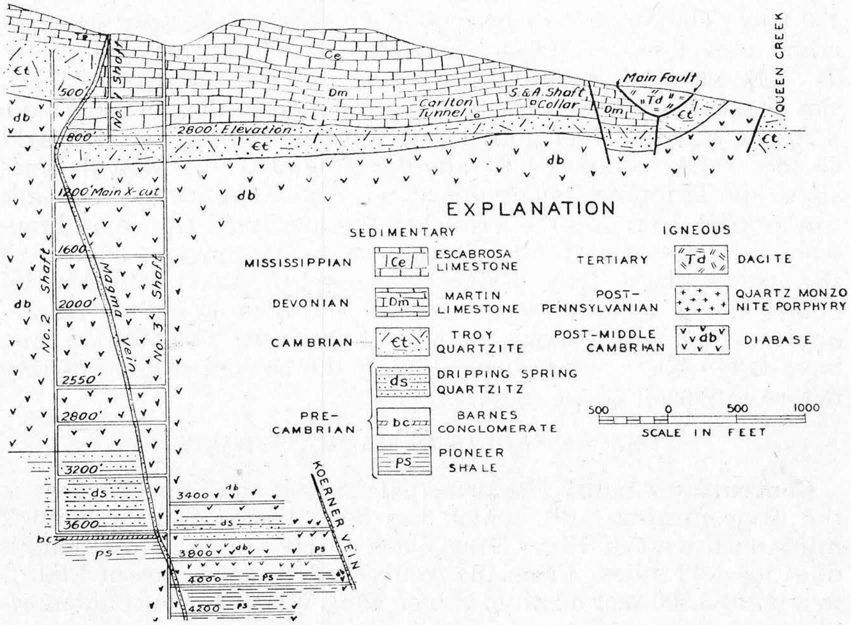


Figure 6.—North-south section through Magma shafts.

Where it was opened on the 1,600 level of the Belmont mine, its displacement was estimated to be over 500 feet.[33]

Most of these east-west faults have no surface expression, and unless prospected, their attitudes are difficult to determine. Most of them dip 60-75° S. and are normal, with major movement almost parallel to the dip of the beds.

An overthrust crops out in Elm Canyon below the dacite (Pl. I). This fault dips northeast at about the same angle as the bedding. The postore Lone Star normal fault has dropped the west portion of the thrust relative to the east. The Elm overthrust, as exposed, is entirely in Naco limestone and has moved younger beds over older ones. It is presumably of about the same age as the mineralized east-west structures.

PREORE FAULTS IN SILVER KING SUBAREA

Magma Chief fault: The Magma Chief fault was the only preore fissure studied in the Silver King subarea. Other preore faults may be present but obscured by the quartz diorite intrusions and by debris.

The Magma Chief fault has been explored by the Magma Chief tunnel for a length of about 1,800 feet. It strikes N. 83° E. and dips 82° S., and it dropped formations on the south relative to those on the north (Pl. I). Its vertical displacement is less than

[33]Ettlinger, I. A., Personal communication to Chester Hoatson.

100 feet. The amount of breccia along the fault suggests considerable movement. Striations indicate that the last movement was 30° S.E., nearly parallel with the bedding, and that the southern side of the fault moved westward in relation to the northern side.

At the Magma Chief tunnel the fault has formed breccia nearly 50 feet thick, composed of angular fragments of Mescal limestone and Dripping Spring quartzite. Above the tunnel the fault can be traced up into the Troy, but the overlying Devonian limestone does not show the break, and no displacement is evident at the contact of the Troy. Below the tunnel the fault is covered by debris down to the diabase which intrudes Dripping Spring quartzite and which shows no trace of the fault. The faulting may have taken place before deposition of the Devonian and possibly before intrusion of the diabase.

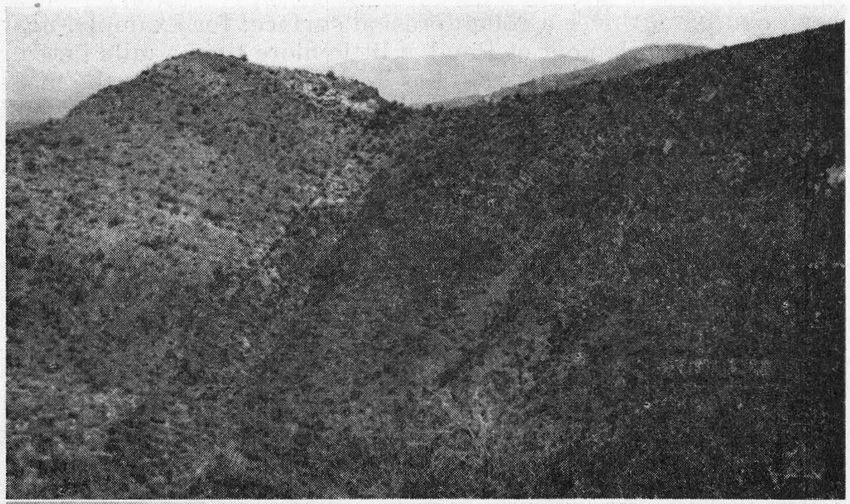
POSTORE FAULTS IN MAGMA SUBAREA

Concentrator fault: The principal fault of the Superior area is the Concentrator fault, which has been traced from a point 2 miles northwest of Silver King Wash nearly to Ray, a total length of at least 12 miles. From the south border of the area of Plate I to a point 3,500 feet north of Silver King Wash, dacite conglomerate crops out as the hanging wall, and Apache beds, diabase, and Troy quartzite occupy the footwall. In the northern part of the area Apache rocks, schist, and diabase appear on one or both walls of the fault.

All outcrops of the Concentrator fault are at the foot of the mountain slopes. Its average strike is nearly north in the Belmont subarea. Between Queen Creek and Silver King Wash it averages about N. 40° W., although it varies considerably. Locally in the Magma mine on the 2,550 level it is N. 80° W. North of Silver King Wash it makes other bends, and from the wash to the north border of the map near the McGinnel claim it averages N. 16° W.

The Concentrator fault dips at an average of 70° SW. and is normal, with its southwestern side dropped relatively to its northeastern. Evidence as to the magnitude of its displacement is furnished by a drill hole, immediately south of Queen Creek and west of Ray Road, which passed through dacite conglomerate into Martin limestone at an altitude of 1,800 feet and into Troy quartzite 50 feet lower. The Troy-Martin contact crops out 1,200 feet east of Ray Road. Projection of this contact westward to a point over the drill hole indicates a vertical displacement of 2,000 feet.

In the Magma mine a much greater displacement is indicated, but exact data are lacking. Dacite was found in the hanging wall of the Concentrator fault where it was cut by the 2,000 and 2,550 levels, by No. 7 shaft a short distance below the 2,000 level, and by a diamond drill hole on the 2,800 level. The total vertical difference between the dacite on Apache Leap east of No. 4 shaft and that on the 2,800 level of the mine is about 2,900 feet; if the



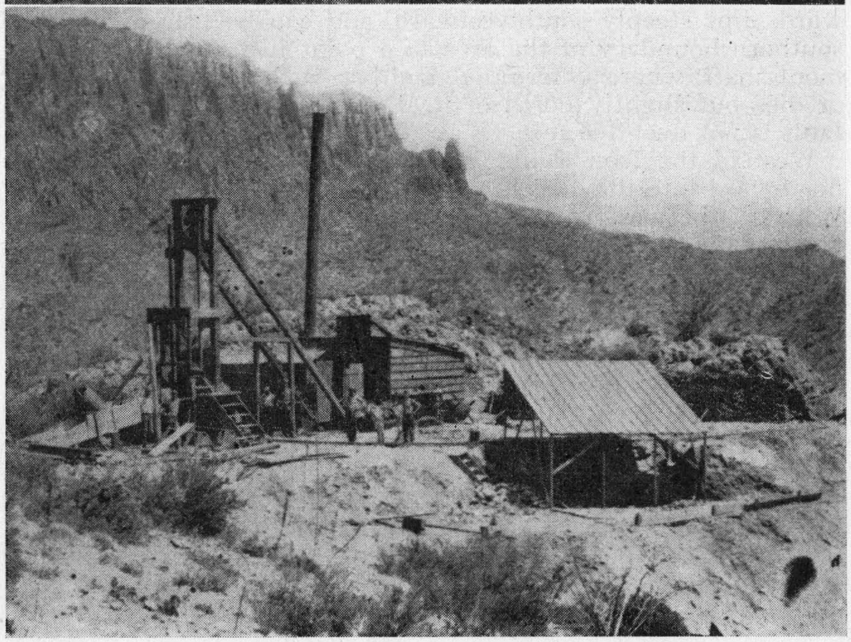


Plate IX.—*A*, Lead Hill fault, looking north from Belmont Canyon; *B*, Silver Queen (Magma No. 1) shaft, 1907.

sloping base of the dacite shown on Plate II is projected westward to the upward projection of the Concentrator fault the total difference is 3,700 feet. Of this, 500 feet might be assumed for the Main fault and the rest for the Concentrator fault, with no indication of the elevation of the bottom of the dacite. However, these measurements mean little, because the dacite is known to have been poured out over a rough erosion surface; for example, near the deserted settlement of Pinal, a little more than a mile farther southwest, dacite directly overlies Pinal schist. Despite the magnitude of the displacement, scarps along the fault are few and small; apparently the mountain slopes have eroded back from it.

Owing to the magnitude of the fault, the Magma Copper Company has not explored for ore west of it.

Main fault: The main fault is discussed in relation to the Magma mine, page 84.

POSTORE FAULTS IN BELMONT SUBAREA

Postore faulting broke the Belmont subarea into long, narrow blocks and influenced topography. The four principal breaks from east to west are the Iron Cap, Lone Star, Lead Hill, and Concentrator faults, shown on Plate I, and Figure 5.

The smallest is the Iron Cap reverse fault. It strikes northwestward, dips steeply southwestward, and can be traced from the southern boundary of the area to a point just north of the Belmont shaft, where it terminates either at the Monte Carlo fault or dies out slightly north of it. Displacement on the Iron Cap fault is not over 100 feet.

West of the Iron Cap is the Lone Star fault which extends northward into the dacite, as shown on Plate I. It dips 60 to 70° W., with the western block relatively downthrown. Its vertical displacement in the southern part of the area is nearly 900 feet, but toward the northeast it decreases to about 100 feet. Such decrease northward seems to be characteristic of most of the major north-south faults in the Belmont and Magma subareas. In Donkey Canyon the Lone Star fault is complicated by a cross fault. The Lone Star fault displaced the Elm thrust.

The Lead Hill normal fault, west of the Lone Star, dips steeply westward. As measured in Belmont Canyon its west side has dropped 600 feet relatively to its east side. This structure can be traced from the southern margin of the area to Cross Canyon, where it splits into two minor faults which join the Concentrator fault.

Some faults later than the dacite trend northeastward, as exemplified by the Grand Pacific fault along Pacific Canyon.

POSTORE FAULTS IN SILVER KING SUBAREA

Most of the faults in the Silver King subarea are of postore age. Except for the Concentrator fault, already described, the most prominent is the Conley Spring fault. It strikes about N. 75° W., almost at right angles to the trend of the range, and dips steeply south. It is traceable from near Silver King Wash to the summit of the dacite mesa, where its identity eastward is lost. On the west its outcrop is concealed by alluvium, but on the cliff it is very prominent, owing to the juxtaposition of Escabrosa and

Naco limestones on the north with dacite on the south. The formations south of the fault have been dropped about 300 feet vertically with respect to those on the north.

The Parallel and Silveride faults, shown on Plate I, converge west of the Silver King road and join the Concentrator fault. On the southeast, the Parallel fault joins the Concentrator fault, and the Silveride joins the Main fault. The Parallel fault is marked in places by a scarp of Dripping Spring quartzite on its east, projecting about 6 feet above the diabase surface on its west side. The southwest walls of both the Parallel and Silveride faults are relatively downthrown, but the amount of displacement is not known.

MAGMA MINE

HISTORY

1875-1906: Little is known of the early history of the Magma mine. Previous to the organization of the Magma Copper Company in 1910 the mine was known as the Silver Queen, a name no doubt suggested by that of the famous Silver King mine 2 miles farther north.

The prominent outcrop of the Silver Queen vein was located soon after the discovery of the Silver King mine. The Hub claim, 720 feet long by 600 feet wide, was located March 29, 1875, by W. Tuttle. In the center of this claim is the Silver Queen shaft, now No. 1 shaft of the Magma Copper Company. Adjoining the Hub on the west is the Irene claim, 1,500 feet long by 600 feet wide, which was located September 1, 1876, by Irene Vail, of Globe.

The Silver Queen Mining Company was organized in New York in 1880 by Philip S. Swain and associates. Mr. Swain was actively interested in the property until 1910, when it was sold to the present owner, the Magma Copper Company.

The Silver Queen Mining Company patented the Irene claim October 31, 1885, and the Hub November 3, 1886. All the productive stopes of the mine before 1920 were within these two claims. No records are known of the operations prior to 1882, but a map of that date shows the Silver Queen shaft as 400 feet deep, with short crosscuts in both directions on the 100, 200, 300, and 400 levels.

Many tales, some undoubtedly fantastic, have been told about the richness of the ore found in those early days. All agree that only silver was mined and the rich copper ore left untouched. The silver was in metallic form, associated with chalcocite. Operations were expensive. Previous to 1879 supplies were shipped by freight wagons from Yuma, which then was the nearest railway town. In that year the Southern Pacific Railroad, under construction eastward from Los Angeles, reached Casa Grande,

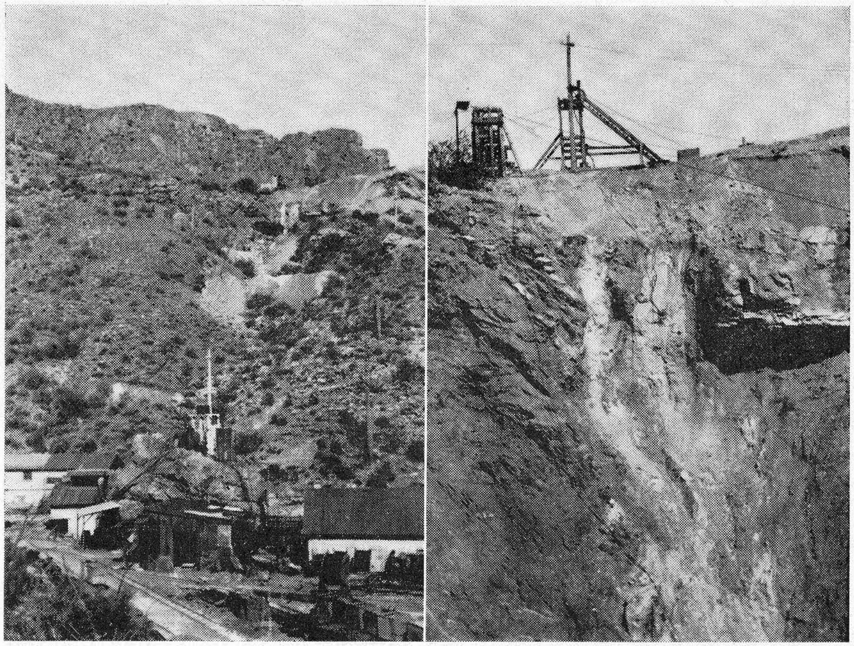


Plate X.—*A*, Outcrop of Magma vein, from Flindt tunnel; *B*, Outcrop of Magma vein, glory hole, and No. 1 shaft.

which became the shipping point for the mines of the Pioneer district. The townsite of Hastings, immediately west of the Gem or Lake Superior and Arizona mine, was projected before 1882. Apparently the townsite was unsurveyed and allowed to lapse; no record other than the original application for it appears in the U.S. Land Office.

The Silver Queen mine was shut down about 1893 because of the low price of silver. George Lobb, from the Silver King, served as repairman and caretaker for several years. In 1901 he sorted out some ore from the Silver Queen dump. Henry Krumb, mining engineer, states in his first report to the Magma Copper Company, March 6, 1910: "Seven cars of silver ore were shipped by Mr. George Lobb in the early days of the property."

1906-7: A report dated November 9, 1906, by George Andrus, a mining engineer of Globe, shows that little exploration was carried on in the Silver Queen between 1882, the date of the map above mentioned, and 1906.

The Andrus report is summarized as follows: On the 100 level a crosscut driven 84 feet north from the shaft passed through porphyry and into quartzite. At or near the contact was an 8-inch streak of malachite. A crosscut driven south through prophyry and 80 feet into limestone showed no ore.

On the 200 level a crosscut north from the shaft passed from limestone into porphyry at 6 feet. At 34 feet a stringer of malachite was cut. A crosscut driven south 25 feet showed no ore.

On the 300 level a crosscut north from the shaft passed from limestone into porphyry at 36 feet. At 50 feet the vein (probably a fracture zone in the porphyry), 4 feet wide and completely oxidized, was encountered. A sample across the full width of the vein ran Au 0.04 oz., Ag 0.70 oz., Cu 2.4%. At 70 feet the crosscut passed into quartzite, and a drift eastward followed decomposed porphyry for 35 feet.

On the 400 level a crosscut north from the shaft passed from limestone into porphyry at 100 feet and near this point encountered a strong 5-foot vein in the porphyry. This vein was followed for 36 feet and was found to contain three streaks of oxidized copper minerals. The north streak, 18 inches wide, averaged 2.6% Cu, the south streak 3.0% Cu, and the center streak, 8 inches wide, assayed 10.2% Cu.

Andrus stated: "Technically there is no ore in sight, and none in quantities can be expected until the leached zone is passed through, unless the 'Superior vein' (the Martin-Troy contact. See p. 152.) develops ore, which is very probable as the Lake Superior and Arizona mine develops ore at a very shallow depth." He recommended that the drift be driven west along the lime-porphyry contact on the 400 level to the intersection of the "Superior vein" on the south side of the (Magma) fault. The shaft should be sunk 200 feet deeper before further crosscutting. "An adit should be driven from Hub creek (now Magma wash). It will follow the (Silver Queen) vein about 500 feet and enough ore will be taken out to pay expenses." (This adit, called the Flindt tunnel, was driven in 1910.) At the time of his visit, hoisting was done by a horse whim and buckets.

In 1906, when the Lake Superior and Arizona mine was being actively developed, attention was called to other properties in the vicinity. Messrs. Fisk and Crawford, of Globe, leased the Silver Queen mine from Mr. Swain and organized the Queen Copper Mining Company. Officers of this company were A. M. Crawford, President; Richard Fleming, Vice-President; E. F. Kellner, Secretary and Treasurer; William D. Fisk and George Gausler, Directors. A steam hoist was installed at the Silver Queen shaft, on the crest of a ridge about 500 feet above the flat. Wood fuel for the boiler was hauled by pack animals. Operations were carried on for about a year following late 1906 but were suspended when the First National Bank of Globe failed during the depression of 1907.

Mr. Kellner states[34] that no work was done by the Queen Copper Mining Company below the 300 level. No operations below

[34]Oral communication, November 28, 1942.

water level, which fluctuated about 50 feet annually, were attempted. In the winter of 1906-7 some chalcocite was found on the 300 level in small stopes left by the early silver miners. Oxidized copper ores were not mined during the period of the lease. In 1907, 212 tons of ore, mostly chalcocite, were shipped to the Humboldt (?) Smelter. Returns were: Cu 23.03%, Ag 65.66 oz., Au 0.21 oz., Fe 7.85%; total value, $27,777.

After 1907, as the bond and option were about to expire, Mr. Fisk purchased control of the stock of the Silver Queen Mining Company.

1910-11: Mr. Fred Flindt, a field mining engineer for George Gunn and William Boyce Thompson, came to Superior to examine the Daggs group of claims south of Queen Creek. While there his attention was attracted to the strong faulting along the Silver Queen vein, and he took an option on the property for his principals.

Messrs. Gunn and Thompson were experienced mine operators. Mr. Gunn, whose headquarters were in Salt Lake City, was interested in coal mines in southern Wyoming. Mr. Thompson was largely instrumental in the development of the Inspiration Copper mine at Miami, Arizona. At their direction a more detailed examination of the Silver Queen was made by Henry Krumb. Mr. Krumb has been consulting mining engineer for the mine since that date and is now (1942) a director of the Magma Copper Company.

His report dated March 6, 1910, is summarized as follows:

> I was very favorably impressed with this property, as it has the strongest cross fissure in the district. The lime-quartzite contact on the north side of the dike has been thrown about 400 feet to the east relative to the contact on the south side of the dike.
>
> On the 300-foot level the work is all north of the shaft, as the footwall of the dike is 40 feet north of the shaft. In a drift to the east a bunch of high-grade chalcocite was exposed, and above the level some stoping had been done. The plan of development should be to locate the intersection of the lime-quartzite with the dike and the fissure at the level of enrichment. As there is some chalcocite exposed on the 300-foot level, this may be the proper horizon, but I would suggest that the 400-foot level be unwatered for inspection, as I believe the 300-foot level is not deep enough. The lime-quartzite contact should be explored on both sides of the dike. If this is done on the 300-foot level, a drift should be driven east on the north side of the dike and another drift should be driven west on the south side of the dike.

About June, 1910, soon after this report was submitted, the Magma Copper Company was organized. The company was incorporated under the laws of Maine, with capitalization of $1,000,000, shares $5 par. First officers were E. M. Leavitt, President and Treasurer, and F. S. Schmidt, Engineer. James Neary, from the Lake Superior and Arizona mine, became Superintendent. The company took a bond and lease dated August 1, 1910, on the Silver Queen property. The Silver Queen Company was to be paid $500,000, of which, at the option of the Magma, $300,000 might be paid in shares of the Magma Copper Company. Work was started at once. The Flindt adit tunnel was driven from the surface and connected with the Silver Queen shaft on the 215 level. The shaft was deepened to 650 feet. This work was completed by the middle of 1911.

1912: The shaft was deepened to the 800 level, and the 500, 600, and 800 levels were actively developed. An operating staff was transferred from the Inspiration mine to the Magma mine. Among these men were W. C. Browning, who became General Manager of the Magma Copper Company; E. H. Lundquist, Mine Superintendent; Henry Robinson, Master Mechanic; and I. A. Ettlinger, Chief Engineer. Operations were carried on thenceforth with vigor and efficiency. Officials of the Magma Copper Company were H. F. J. Knobloch, President; H. E. Dodge, Secretary-Treasurer; W. H. Aldridge, Managing Director.

During 1910-12 the Silver Queen vein was not highly regarded as a prospective ore zone. Work in the adjoining Lake Superior and Arizona mine had focused attention on the Cambrian quartzite-Devonian limestone contact, hereinafter referred to as the L. S. and A. contact (the Superior vein of Andrus' report). Accordingly, when the 650 level was opened a crosscut was driven west to intersect this contact. It was found to be barren. A drift followed the contact, and where it intersected the Silver Queen porphyry dike a rich bonanza of supergene chalcocite was found. The Silver Queen vein, which followed the dike, was immediately recognized as the productive structure, and exploration was centered upon it.

In the summer of 1912, Dr. F. L. Ransome, of the U.S. Geological Survey, spent two days in the district. In a short description of the Queen mine, he noted that large ore bodies recently had been opened on the 800 level which exceeded in size those above that level. Bornite and chalcopyrite were the predominant minerals on the 800 level.[35]

The townsite of Superior was surveyed in 1912 by Ed Stewart, of Globe. Previous to that time the village consisted of a few wooden dwellings and tent houses scattered haphazardly on the plain north of Queen Creek. The post office had been established in 1902, at the beginning of operations in the L. S. and A. mine. It was suggested that the new post office be named Sieboth, after A. C. Sieboth, Superintendent of that mine, but this was not acceptable to the postal authorities, and the name Superior, after the mining company, was selected. George Lobb became the first postmaster and was succeeded in 1907 by E. F. Kellner, Jr. The town, never incorporated, is governed by representatives of the County Supervisors.

[35]Ransome, F. L., Copper deposits near Superior, Arizona: U.S. Geol. Survey Bull. 540, p. 153, 1914.

In 1912, ore from the mine was hauled by wagons to Florence at a cost of $5.00 per ton, and the return rate for supplies was $7.00 per ton. From Florence the ore was shipped by rail to the Hayden smelter. Only high-grade ore was shipped, but lower-grade material was developed. Shipments during 1912 were as follows:

Class	Tons	Cu	Ag	Au	Fe	Value, less treatment and freight
1st	104	48.19	68.0	0.11	11.2	$ 15,495
2nd	3,168	15.92	18.02	0.06	12.4	$141,542

1913: In a report dated April 21, 1913, Mr. Krumb stated:

> The ore is not in continuous shoots, but is irregular in lenses or pockets. To a depth of 400 feet the ore occurred in small bunches, but on the 650- and 800-foot levels, it is more continuous. I consider this a favorable indication and expect that with greater depth the ore occurrence will be still more regular and in larger bodies.
>
> The mine cannot be operated at a profit with expensive steam power as at present.

As a result of favorable showings on the 800 level, the company prepared to expand operations. After experiments on Magma ores by the General Engineering Company, of Salt Lake City, a concentration process, using gravity separation and Callow pneumatic flotation machines, was evolved.

1914: Work on the concentrator, begun early in the year, was completed in August. The initial capacity was about 200 tons per day. An aerial tramway 2,600 feet long was constructed from the portal of the Flindt tunnel to the new mill.

The increased scale of operations necessitated more adequate transportation facilities. Some years previously the L. S. and A. Company had surveyed a broad-gauge branch railroad from Florence. Its estimated cost, about $500,000, was considered by the Magma Copper Company as too high for that time. It was decided to build a narrow-gauge railroad 30.4 miles long, connecting with the Arizona Eastern Railroad near Florence. The minimum estimated cost was $160,000. E. G. Dentzer,[36] who had been a construction engineer for the Inspiration Copper Company, directed the survey and construction of the new railroad. Work upon it commenced November, 1914, and was completed May, 1915. As first built, it amounted to little more than stringers laid on the ground, with maximum grade of about 4 per cent and maximum curvature radius of 120 feet. The estimated cost was closely met, and improvements came later. At this stage a greater investment seemed unjustified, as the future of the mine was uncertain. It was not then known whether the bornite of the bottom level was supergene (secondary) or hypogene (primary); if supergene, the ore in depth might change to a lower grade.

[36] Now General Manager of the Magma Copper Company.

A power line 15 miles long was constructed to Inspiration, where it connected with the government-owned power line from Roosevelt dam, on Salt River. Power was contracted from the U.S. Reclamation Service for about $49 per horsepower year.

Altogether, improvements completed during the year cost nearly a million dollars.

1915: A new three-compartment shaft, No. 2, located 400 feet north of No. 1 shaft, was sunk from the Flindt tunnel from the 215 to the 1,200 level. This became the main working shaft of the mine, and No. 1 continued to be used as an auxiliary for the 800 and higher levels.

The mine earned a net profit of $611,729.02.

1916: No. 2 shaft was sunk to the 1,500 level, on which the Magma vein was found to be mineralized from wall to wall. Where intersected by the main crosscut south from No. 2 shaft, the vein was 34 feet thick, with an average of 10.52% Cu, 5.37 oz. Ag, and 1.26 oz. Au per ton. The copper was mainly in chalcopyrite and bornite. Drifting on the vein showed an average for 235 feet of 5.00% Cu, 4.4 oz. Ag, and 0.52 oz. Au.

In the annual report for 1916, W. H. Aldridge, President of the Magma Copper Company, wrote: "The favorable showing on the 1,500-foot level, which is not yet fully developed, insures the continuation of the main ore shoot below the 1,500-foot level. As to what depth is problematical, but the fact that the bornite and chalcopyrite found in the lower levels is believed to be primary ore, the chances are favorable for the main ore shoot to continue for a considerable depth." A noteworthy feature is his statement regarding the primary (hypogene) origin of the chalcopyrite and bornite. It was based on the results of polished-section study of the ores, made by McLaughlin.[37]

The capacity of the concentrator was increased to 300 tons daily. The additional section was designed for zinc-lead ores but was converted to treat copper ores.

1917: No. 2 shaft was deepened from the 1,500 to the 1,800 level, and intervening levels 100 feet apart were opened. All showed satisfactory copper values. As only No. 2 shaft extended below the 800 level, a new vertical shaft, No. 3, was started late in 1917, with its collar on the surface 400 feet south of No. 1 shaft. The southward dip of the vein was well established by that time, and the new shaft was expected to intersect it at some point below the 3,000 level. A contract was made with the U.S. Reclamation Service to construct a power line of 600 kw. capacity from Goldfield, on the Salt River, to Superior, supplementing the power line from Inspiration. That year the mine made a net profit of $1,067,986.

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[37]McLaughlin, D. H., The origin and occurrence of bornite: Doctor's dissertation, Harvard University, 1917.

1918: No. 3 shaft was completed to the 1,600 level, and the Goldfield power line was constructed. The cost per pound of copper mined was 16.425 cents and the selling price about 25 cents. The high unit cost was due partly to increased prices during the first World War and partly to rapid development of the mine.

1919: Both No. 2 and No. 3 shafts were deepened to the 2,000 level. No. 3 shaft was equipped as the main hoisting shaft for depths below the 2,000 level. The main tunnel, connecting the surface with Nos. 2 and 3 shafts at the 500 level, was driven. Up to that time all hoisting had been to the Flindt tunnel level, nearly 300 feet higher.

In 1919 the net cost of producing copper was 14.92 cents per pound and the average net selling price 18.53 cents per pound. Net earnings, disregarding depletion, were $178,077.

1920: Operations were somewhat curtailed, owing to the low price of copper and the high cost of supplies. Development on the 1,600 and 1,800 levels was continued actively. On the 1,600 level the main ore body was opened for a length of 1,300 feet and an average width of 12.5 feet. On the 1,800 level the corresponding stoping length was 1,400 feet and the average width 21.5 feet.

Electric haulage was installed on the Main tunnel (500) and 2,000 levels. During the year all classes of development work totaled 6,515 feet and showed 55.4 tons of ore per foot. Reserves of ore above the 2,000 level were estimated by Mr. Browning as follows:

	Tons	Cu (%)	Ag (oz.)	Au (oz.)
Copper sulfide ore	827,000	5.00	3.0	0.02
		Zn (%)	Pb (%)	Ag (oz.)
Zinc-lead ore	20,000	13.5	2.0	12.0

Total production for the year was 100,872 tons averaging 4.93% Cu, 3.412 oz. Ag, and 0.438 oz. Au.

1921: The company mined ore only during the first three months of 1921, and the concentrator was shut down at the end of March. The average cost of producing copper was 14.9 cents and the average net selling price 14.7 cents. The depression of 1921 was marked by an accumulation of nearly 8,000,000 pounds of unsold copper.

Development was continued with excellent results. In the annual report for that year, Mr. Browning made the following comments:

Some of the last cross-cuts driven on the 2,000 level have given very interesting mineral results. In addition to the bornite and chalcopyrite which have been the main copper mineralization for some time, these cross-cuts are showing quite an appreciable amount of chalcocite and gray copper (tennantite) which are very likely of primary origin, the same as the chalcopyrite and bornite. It is exceedingly interesting and gratifying to secure these high-grade copper minerals at the depth now attained in the Magma mine, and in my opinion gives very encouraging indications that we may expect high-grade values for quite some greater depth.

These last observations are based in part on the results of a study by M. N. Short of polished sections of specimens collected during the summer of 1921.

Mr. Browning writes further:

It is interesting to compare the size of the ore body on the upper levels of the mine with the size of the main ore body on the lower levels of the mine, as represented by the 1,800 level. It will be recalled that above the 1,000 level the ore shoot was only 300 to 500 feet long, and from 5 to 8 feet in width. On the new lower levels there will be mined for every vertical foot of ore shoot about ten times the amount of ore that was produced per foot on the upper levels.

No. 2 shaft was sunk to a depth of 2,450 feet below the collar of No. 1 shaft. It was concreted between the 600 and 1,200 levels, where swelling ground near the vein endangered its alignment.

1922: As the mine had enough ore reserve to last for several years at an output of 600 tons per day, no new development work was undertaken. No. 2 shaft was deepened 100 feet. Sinking of the new air shaft, No. 4, 1,000 feet northeast from No. 1 shaft, continued.

A standard-gauge railroad was constructed from Magma Junction to Superior under the direction of E. G. Dentzer, Assistant Superintendent. The narrow-gauge line was then dismantled. The standard-gauge railroad parallels the narrow-gauge location across the desert but in the hills departs from it as much as ½ mile, eliminating the heavy grades and sharp curves.

Up to this time concentrates and ore had been hauled to Hayden for smelting. During 1922 plans for a smelter, with an estimated maximum capacity of 3,000,000 pounds of copper per month, were prepared by Messrs. Bradley, Bruff, and Labarthe. To provide bricks for the new construction, a plant capable of making 20,000 bricks per day from local clay was erected at Superior. The capacity of the concentrator was increased from 400 to 600 tons per day without enlarging the building. No ore was stoped or shipped during the year.

To finance these improvements, the company issued and sold $3,600,000 in ten-year 7 per cent convertible gold bonds.

1923: Construction of the smelter, started in December, 1922, continued. No. 4 shaft was completed to the 1,500 level. Development was largely limited to putting the mine in shape for the proposed increased production. Stoping was resumed. The railroad construction, started in 1922, was completed, and the broad-gauge locomotive proved able to haul eight times as much freight as was formerly handled by the narrow-gauge locomotive.

1924: Little new development was carried on. The ore body had been blocked out for several hundred feet below the stopes and sufficient tonnage developed to maintain the estimated production for several years. The ground in places was heavy and difficult to keep open. Mine oxidation was rapid and lowered the percentage of extraction by the concentrator. For these reasons the policy of the company was not to develop ore reserves unnecessarily far in advance of stoping.

Stoping was carried on with an average production of 617 tons per day, as compared with the original estimate of 600 tons. The copper market recovered to an average selling price of 12.865 cents per pound.

On March 29 production from the smelter began, and it proved more efficient than originally estimated.

1925: Mr. Browning, General Manager since 1913, was succeeded by William Koerner. The 2,250 level was developed. In previous years exploratory work in the east part of the mine (east of shafts No. 2 and 3) below the 1,000 level had partly developed some ore bodies of zinc, lead, and copper. During the year this development was continued, especially on the 1,600 level.

The copper market continued to improve and the price averaged 14.007 cents per pound. As the expansion program had markedly increased efficiency of operation, the net cost exclusive of interest and depletion was 7.51 cents per pound.

1926: A new shaft, No. 5, 2,400 feet southwest from No. 3 shaft, was sunk 650 feet. The 2,550 level was actively explored and a crosscut driven south from its western end to connect with the new shaft.

A surface electric tram was constructed from the Main (500 level) tunnel portal to the mill. The aerial tram, which formerly transported ore from the Flindt tunnel portal to the mill, was abandoned.

1927: No. 5 shaft was sunk to the 2,550 level, and the crosscut west of No. 3 shaft was extended to it. At a depth of 2,150 feet the West (No. 5) ore body was encountered.

On November 24 a disastrous fire in No. 2 shaft caused the loss of seven lives. The timbering of the shaft was destroyed from the 2,550 to the 1,200 level, above which the shaft had been concreted.

The average selling price of copper was 12.956 cents, and the cost after deducting gold and silver values was 9.972 cents per pound. The average extraction by the concentrator was 98.06 per cent.

1928: No. 5 shaft was sunk to the 2,960 level. No. 2 shaft was concreted from the 1,800 to the 2,550 level. Below the 2,000 level development was limited to the west part of the mine pending the repair of No. 2 shaft. Some development was done on the East 2,000 level.

The average selling price of copper was 14.79 cents, the average cost of production 9.227 cents per pound.

1929: Because of poor ventilation in the eastern part of the mine below the 1,500 level a new shaft, No. 6, was started early in the year. It is 4,500 feet easterly from No. 3 shaft and about 1,700 feet northeast from the tunnel on the Superior-Miami highway.

In order to provide ventilation for workings west of No. 5 shaft, another new shaft, No. 7, was begun. It is about 500 feet west of the Magma concentrator and 8,350 feet west of No. 6. Sinking on No. 7 totaled 149 feet for the year.

The new West (No. 5) ore body was developed on the 2,550 level. The Main ore body was actively developed on the 2,800 level. Concreting was completed in No. 2 shaft, which was deepened to the 2,915 level.

During 329 days of operation the mine produced an average of 823 tons a day. Selling price for copper averaged 18.2 cents, and cost after deduction for gold and silver values was 9.99 cents a pound.

1930: Following the panic of October, 1929, the selling price of copper steadily dropped and averaged 12.24 cents per pound for 1930. Accordingly, production was reduced. Development was carried on in both the west and east sections of the mine. On the 2,800 level the vein in the new West (No. 5) ore body was found to be as wide as on the 2,550 level but below commercial grade.

No. 7 shaft was sunk to the 2,444 level. No. 6 shaft reached a point corresponding to the 1,576 level. No. 2 shaft was deepened to the 2,178 and No. 3 to the 2,800 level. The mine operated 303 days with 30 per cent fewer shifts than in the previous year. The concentrator worked 330 days and the smelter 319.

1931: The price of copper continued to drop and, as sold by the company, averaged 8.93 cents per pound. The cost per pound after deducting gold and silver values was 8.39 cents; this included state and county taxes but no allowance for depletion or for federal taxes. As a result, the company did little more than break even.

Stoping was discontinued from June 13 to September 16; the concentrator shut down from June 16 to September 16 and the smelter from June 22 to October 1. Development was resumed July 27.

During the year No. 6 shaft was sunk to the 2,316 level and the East 2,000 drift was extended to the shaft; this greatly improved ventilation in the east workings. Some development was carried on in the east workings below the 2,000 level. No. 7 shaft was sunk to the 2,550 level and connected with the workings there. No. 3 shaft was lowered to the 3,000 level. From No. 5 shaft on the 3,200 level a crosscut was driven north toward the Magma vein. As rock temperature was 126° F. at this point, good ventilation became vitally necessary and more than justified the large expenditure for shafts. Development was kept to a minimum. The ores on the 2,800 and 3,000 levels were mostly pyrite and chalcopyrite, with very little bornite and lower in grade than those above.

1932: The company operated at a loss. The average price received for copper was 6.15 cents, and the cost of production was 8.39 cents per pound.

Stoping was discontinued during June 12 to December 5 and development from July 1 to September 16. The concentrator was idle from June 10 to December 15, as was the smelter for the rest of the year after June 30.

No. 3 shaft was sunk to the 3,200 and No. 6 to the 2,550 level. As developed on the 3,200 level, the main ore body averaged higher in copper than on the 3,000 level.

1933: The copper market remained depressed. In general, the company followed its previous year's schedule. Breaking of ore was discontinued from June 19 to December 3. The smelter was idle from June 18 to December 21. The concentrator closed on June 26 and worked part time during October 1 to January 1. On the east side the 2,550 level was connected with No. 6 shaft, greatly improving ventilation. A ten-day layoff was again taken at the end of the year. Development was resumed on September 1.

Copper sold by the company averaged 6.767 cents and the net cost 7.80 cents per pound.

1934: The copper market improved somewhat, and the summer shutdown was materially shortened. Stoping ceased from July 11 to August 13. The concentrator and smelter were shut down for approximately a month.

The average selling price for copper was 7.85 cents, and the average cost after deducting gold and silver values was 5.73 cents per pound. This low cost was made possible by keeping development to a minimum.

The company's annual report gave estimates of reserves in the Main ore bodies on the 3,000 and 3,200 levels.

1935: The copper market remained about the same as in the preceding year, and the company again closed down during July. Development was kept to a minimum, and most of the new workings were preparatory for stoping. Some exploratory work was done on the east side on and below the 1,800 level. A new shaft, No. 8, was begun from the surface between No. 3 and No. 5 shafts. It was designed for ventilation, to provide an upcast draft for the entire western side of the mine.

The average net selling price of copper was 7.68 cents, the cost 5.62 cents per pound.

1936: The copper market improved slightly. The mine and plant were again closed for approximately one month during the summer. The 3,600 level was actively explored by workings from No. 5 shaft. No. 3 shaft was sunk to the 3,400 level and No. 8 shaft to the 2,447 level.

The average net selling price was 9.24 cents and average cost 5.69 cents per pound.

1937: The copper market improved decidedly. Production in the mine was curtailed for about a month during the summer; the mill worked on a one-shift basis, and the smelter shut down a month during that period. The Main ore bodies were actively explored on the 3,600 and 4,000 levels. The 3,600 level showed considerable enargite and more bornite than any higher level below the 2,800. No. 8 shaft was completed to the 4,000 level.

An air-conditioning plant was installed on the 3,600 level at No. 5 shaft. It consisted of two Carrier refrigerating machines, designed to cool the stopes of the Main ore body on the 3,600 and 3,400 levels. The results exceeded estimates.

Active exploration was carried on in the east section of the mine, on and below the 2,250 level. Small amounts of copper ore were mined on the East 3,000, 2,800, and 2,550 levels. Some copper-zinc ore came from the East 2,550, 2,250, and 2,000 levels.

A new unit of 250 tons daily capacity for treatment of complex zinc-copper ore was added to the concentrator.

The average selling price for copper was 12.04 cents and the average cost 7.67 cents per pound.

1938: The average net cost of producing copper, after deducting gold and silver values, was 7.75 cents, and the average price was 9.52 cents per pound. At the end of the year 7,003,179 pounds remained unsold. The 1938 copper market was erratic, with demand concentrated in four months during which 70 per cent of the year's sales occurred. Dividends for the year amounted to $1.50 per share.

The mine produced continuously from January 1 to July. Through July, maintenance and some development were carried on. Normal production was resumed August 1 and carried on until October 24, the effective date of the "Fair Labor Standards Act of 1938." Through the remainder of the year mine production was curtailed to approximately five days per week.

Two new Prescott Horizontal Duplex pumps were installed on the 3,600 level near No. 8 shaft. Each pump had a capacity of 600 gallons per minute pumping to the surface, a lift of over 3,200 feet.

The mill treated 246,690 tons of copper ore assaying 5.12% Cu and 32,974 tons of zinc-copper ore assaying 2.08% Cu and 8.41% Zn. The tailings averaged 0.31% Cu and the copper recovery was 95.87%.

Operations in the zinc section of the mill were carried on intermittently and much experimental work was done. The yield amounted to 1,159 tons of zinc concentrates which assayed 49.1% Zn and 1.83% Cu.

1939: Copper sales averaged 10.655 cents a pound. Dividends were $2.75 per share.

A Carrier centrifugal refrigerating machine was installed on the 4,000 level.

The mill treated 236,991 tons of copper ore assaying 5.22% Cu and 67,074 tons of zinc-copper ore assaying 1.99% Cu and 8.09% Zn. The tailings averaged 0.32% Cu and the copper recovery was 95.22%. Zinc concentrates, 5,155 tons assaying 48.63% Zn, were shipped.

At No. 3 shaft a new motor generator set was installed and the hoist rebuilt. This new equipment was capable of hoisting its load from 5,000 feet at a speed of 1,600 feet per minute. The old hoist had reached the limit of its capacity at 3,600 feet.

1940: Dividends totaled $2.50 per share.

The average net cost of producing copper was 7.80 cents a pound, and the average price was 11.321 cents a pound.

On June 30, 1940, William Koerner, General Manager for sixteen years, died. He was succeeded by Edward G. Dentzer.

During July, mine operations were limited to maintenance, development, and some stoping.

In January, the Koerner vein was discovered by diamond drilling. Although idle during July, the mill during the year treated 237,003 tons of copper ore assaying 5.16% Cu and 79,044 tons of zinc-copper ore assaying 1.74% Cu and 7.31% Zn. The tailings averaged 0.29% Cu and the copper recovery was 95.61%. The 7,098 tons of zinc concentrates produced and shipped assayed 49.64% Zn.

The Mowry and Bilk claims in the Silver King district were acquired for reserve water supply. A two-compartment shaft on the Bilk claim was retimbered to a depth of 125 feet and equipped with a deep-well pump with a capacity of 200 gallons a minute.

1941: Dividends totaled $2.50 per share.

The average net cost of producing copper, after deducting gold, silver, and zinc values, was 7.90 cents a pound. The average price received by the company on all copper produced in 1941 was 11.96 cents a pound.

Because of the urgent need for copper and at the request of a federal government agency production was increased, beginning in September, to the practical maximum of the property.

The mine was shut down during July except for maintenance, repairs, development work, and approximately 20 per cent of normal stoping. On August 4 normal production was resumed and carried on at an increasing rate until October 1, when a maximum hoisting capacity was reached. From October 1 to the

PRODUCTION OF MAGMA MINE

Year	Ore (tons)	Copper (lbs.)	Silver (oz.)	Gold (oz.)	Zinc (lbs.)	Total average grade		
						Cu (%)	Ag (oz.)	Au (oz.)
1911	129*	67,540	....	....	....	....	....	....
1912	11,214	1,104,010	64,160	201	....	....	....	....
1913	14,135	1,400,312	69,281	119	....	....	....	....
1914	18,917	2,203,604	118,310	522	....	....	....	....
1915	59,219	6,046,459	366,027	1,976	....	....	....	....
1916	93,808	8,473,580	506,523	3,173	....	....	....	....
1917	107,529	10,148,632	537,995	5,979	....	5.375	5.752	0.056
1918	90,321	10,968,556	463,503	5,699	....	6.637	5.452	0.059
1919	89,156	9,698,002	416,773	4,577	....	5.943	4.974	0.053
1920	100,872	8,854,917	303,258	4,437	....	....	....	....
1921	21,445	2,028,889	59,794	819	....	5.249	3.149	0.038
1922	....	....	....	....	....	....	....	....
1923	78,889	6,956,576	204,081	2,567	....	5.267	2.867	0.034
1924	222,307	23,301,511	533,204	7,589	....	6.115	2.797	0.033
1925	229,377	27,020,516	719,881	9,085	....	6.50	3.43	0.031
1926	248,787	29,135,132	860,184	9,100	....	6.27	2.78	0.028
1927	221,855	28,502,521	989,652	8,528	....	6.61	3.44	0.031
1928	263,094	35,228,810	917,048	8,665	....	7.19	3.42	0.034
1929	269,579	36,516,511	1,031,535	10,196	....	7.62	3.92	0.036
1930	251,872	31,558,508	830,009	8,519	....	6.90	3.31	0.033
1931	231,862	28,760,628	701,576	7,513	....	6.65	2.98	0.033
1932	149,010	21,675,521	486,036	5,152	....	7.53	3.22	0.035
1933	145,425	19,628,135	473,384	4,597	....	7.92	3.62	0.035
1934	264,094	31,646,576	713,712	9,100	....	6.54	2.93	0.034
1935	259,553	29,730,633	625,839	8,661	....	6.49	2.46	0.032
1936	274,065	30,280,458	552,114	7,944	....	6.30	2.45	0.029
1937	302,360	31,043,725	507,593	9,142	....	5.92	1.83	0.030
1938	334,628	32,151,163	466,660	8,650	966,548	....	....	....
1939	364,281	34,065,869	599,588	11,610	4,261,616	....	....	....
1940	378,024	34,281,249	629,417	11,307	5,992,796	....	....	....
1941	405,540	37,152,224	631,189	11,741	7,715,313	5.23	1.79	0.024
1942	....	40,390,671	547,396	12,818	7,315,034	....	....	....
1943	414,718	37,223,963	408,397	11,177	7,780,306	4.91	1.20	0.024

*High-grade ore shipped to smelter.

end of the year the mine produced approximately 15 per cent, on an annual basis, in excess of the production of the past two years.

Development work in the Magma mine was done on the East 3,400, 3,800, and 4,000 levels, the West 4,200 and 4,400 levels, and in the Koerner vein on the 3,600 and 4,000 levels.

The mill treated 245,885 tons of copper ore, assaying 5.26% Cu and 80,810 tons of copper-zinc ore, assaying 1.77% Cu and 8.16% Zn. The tailings averaged 0.23% Cu and the recovery was 91.12%. There were produced during the year 9,137 tons of zinc concentrates assaying 49.67% Zn.

In order to take care of the additional output of the Magma mine, the amount of gold and silver custom ore treated by the smelter during the last half of the year was reduced to approximately 25 per cent of the amount treated during the first half of the year.

The labor situation took a decided turn for the worse. High wages in defense plants attracted many people. Many of the younger men entered military service. It became necessary to train inexperienced help. Wages were the highest since the first World War, but production per man-shift dropped steadily during the year.

MINERALIZATION

Summary: The ore bodies of the Magma mine occur as replacements of crushed wall rock within two fault zones of the east-west system. Those of the Magma vein, in the Magma fault, constitute by far the greater proportion of the tonnage extracted or developed. The ore is not continuous throughout length and depth but consists of several distinct shoots separated by barren vein material.

The Main ore body is the largest. It is contained laterally between a vertical north-south plane 500 feet east of No. 3 shaft and the Main fault. It is developed vertically from the 400 to the 5,000 level as measured below the collar of No. 1 shaft.

The West or No. 5 ore body is in a faulted segment, possibly of the Magma vein, west of the Main fault.

The East ore bodies, in the Magma vein east of shafts No. 2 and 3, are of limited dimensions. As developed, they extend from the 1,400 to the 3,000 levels.

The only ore body of the mine not in the Magma fault is within the Koerner fault, nearly parallel to and about 1,200 feet south of the Magma fault. The Koerner fault is of small displacement and without surface expression. The ore body has its apex apparently below the 3,200 level and extends vertically downward to the 4,200 level or lower. At present it is only partially explored.

The ores of the Main, West, and Koerner ore bodies are similar mineralogically. Copper is the principal ore metal, but silver and gold are recovered as by-products in smelting. The principal ore minerals are pyrite, bornite, chalcopyrite, and enargite, with

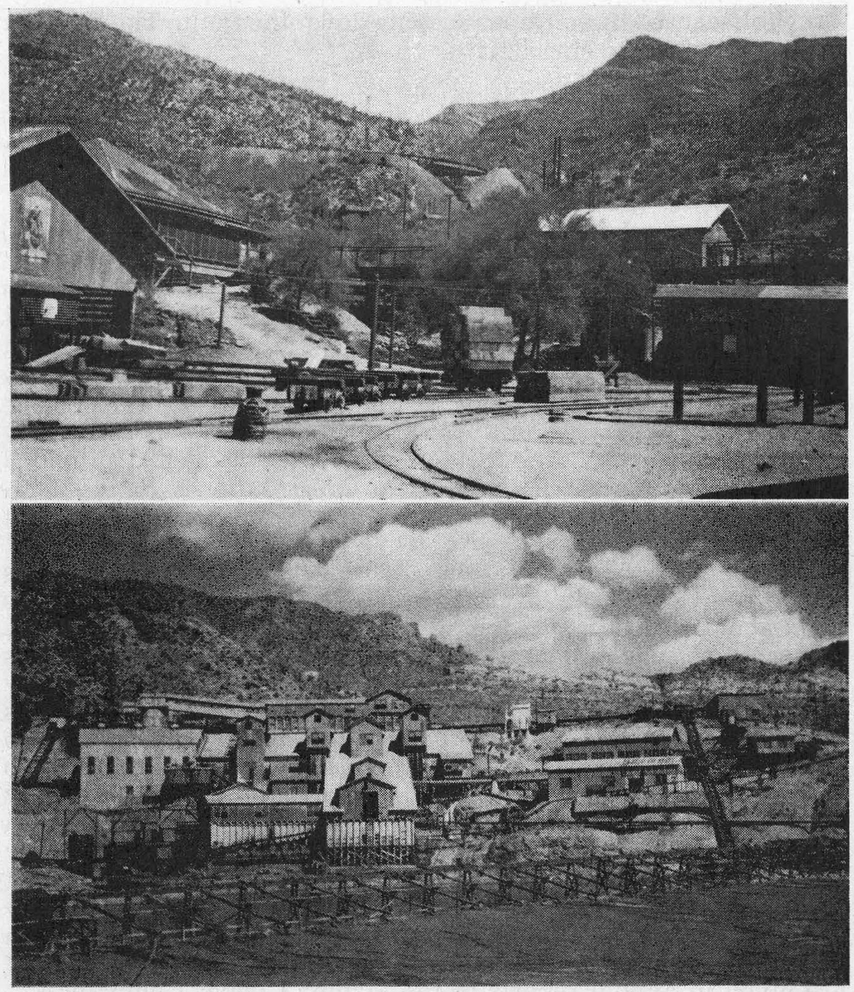

Plate XI.—*A*, Magma mine from main portal; *B*, Magma concentrator.

subordinate tennantite and hypogene chalcocite. Some sphalerite occurs in the upper eastern portion of the Main ore body, especially from the 900 to the 1,200 level. Below this, sphalerite occurs sparsely in small bunches. A little galena accompanies sphalerite but insufficient to be recovered as a by-product in concentration.

Sphalerite is the predominant mineral in the upper and more easterly, and chalcopyrite in the lower and more westerly, of the East ore bodies.

Supergene enrichment is important in the Main ore body above the 800 level. In the West ore body it formed a small tonnage, although locally intense near the Main fault. There the enrichment is not related to the upper surface of the ore body but was probably caused by solutions seeping down the fault. The Koerner ore body shows no enrichment.

Main ore body: Considering the size of the Magma ore bodies, the outcrop of the Magma vein is inconspicuous. Above the Main ore body the bleached, faulted porphyry dike is stained by oxidized copper and iron minerals with locally small masses of residual chalcocite. (Pl. X *B*).

The Main ore body has its apex a short distance above the 400 level and extends to the lowest workings. Most of the production of the mine has come from this Main ore body or shoot, which has been mined almost continuously below the 900 level. Above that level the ore was bunchy. The Main ore shoot pitches west at about right angles to the sedimentary beds. The reasons for its localization are not clear. This portion of the vein was replaceable by the copper-bearing solutions either because of its permeability or because some condition of premineral faulting had provided passage for a greater portion of the ore solutions. Relative replaceability of the wall rocks affected somewhat the lateral extent of this ore body.

The Main ore body above the 1,500 level consists of two shoots which join near that level (Pl. II). The western shoot has its apex about 50 feet above the 1,200 level at 4,600 departure. Here the ore consists of sphalerite and a little galena, with only traces of copper. Between the 1,300 and 1,400 levels it changes abruptly into a bornite-rich ore with little or no zinc and lead. In levels above the schist the width of the Main ore body ranges from 5 to 40 feet. Where the vein is wide, the ore generally occurs in two or more rich stringers separated by poorer vein material, partly below commercial grade. For example, on the 2,000 level a rich stringer occurred near the hanging wall and another one near the footwall. Some selective mining was practicable, but in most places the vein was mined for its full width.

Complete data of stoping length, width, and grade for the Main ore body on various levels are not available, but the following are given in annual reports of the Magma Copper Company.

Level	Length	Av. width	Cu (per cent)	Ag (oz.)	Au (oz.)
1,000	300-500	5-8	......	......	......
1,600	1,300	12.5	(6.00	3.2	0.04)*
1,800	1,550	20.8	5.72	2.64	......
2,250	1,050	27.5	8.3	3.94	0.025
3,000 (west part)	300	10.2	4.25	0.9	0.01
3,000 (east part)	735	13	5.9	1.1	0.01
3,200 (west part)	750	8	5.1	0.67	0.01
3,200 (east part)	500	13.8	4.2	0.71	0.01
3,400	1,498	......	......	......	......
3,600	1,540	......	......	......	......
4,000	2,260	......	......	......	......
4,400	1,800	......	......	......	......

*Figures for 1,000 feet of stoping length.

Below the 4,400 level the ore body is not fully developed, but exploration to date indicates the ore to be less continuous than on the 4,000 and higher levels.

West ore body: The West ore body is in a faulted segment, possibly of the Magma vein, west of the Main fault. It was discovered accidentally. In sinking No. 5 shaft, a small stringer of ore was found at the 2,150 level. Followed westward, this stringer developed into a commercial body. The West ore body is in a vein that continues above, below, and west as far as explored. The vein strikes nearly east and dips steeply north. The apex of the ore body is at the 2,100 and its bottom at the 2,675 level. The maximum stoping length, 750 feet, is on the 2,550 level. Its average stoping length is about 250 feet, its average width about 15 feet, and its average copper content about 7 per cent.

Bornite is the predominant copper mineral, with subordinate chalcopyrite, tennantite, hypogene chalcocite, and sphalerite. Enargite is absent. Oxidation and supergene enrichment have been intense in places, especially on the 2,550 level near the Main fault. Here some specimens consist of massive steely supergene chalcocite with some malachite, cuprite, and native copper.

Prior to faulting, the West ore body was several hundred feet higher than it is at present.

There is no well-defined enrichment zone paralleling the upper surface of the ore body, but nearly all specimens show at least some supergene chalcocite. In comparison with the weight of hypogene copper minerals, the supergene minerals are relatively unimportant. The proximity of oxidation to the Main fault suggests that oxidation and enrichment are due to solutions seeping down the fault.

The West ore body is not a faulted segment of the Main ore body, as the latter is nowhere in contact with the Main fault. On the 2,800 level the Main ore body is within 50 feet of the fault, but with each succeeding deeper level the fault flattens and diverges farther from the Main ore body. The West ore body is now nearly mined out.

East ore bodies: The East ore bodies lie east of zero crosscut and include zinc-copper in the upper levels and copper in the lower. Sphalerite predominates above the 2,550 level and chalcopyrite below. The ore in the eastern portion of the mine is not continuous, and none of the known ore shoots persists for over several hundred feet. No structural reason can be given for the scarcity of ore east of zero crosscut, and no apparent controlling structural features join the various isolated bodies. It can only be assumed that in contrast to the Main ore body the mineral-carriers and the forces impelling these carriers were not sufficiently strong to form continuous ore. Sulfides were deposited only where permeability and conditions for replacement were favorable.

The possibility of ore in the lower levels east of zero crosscut is indicated. On the east 3,400, 3,600, 3,800, and 4,000 levels ore has been found that has no continuation to levels directly above or below.

Koerner vein: The role that chance may play in the discovery of new ore bodies was demonstrated in the case of the Koerner vein. In January, 1940, a diamond drill hole was driven horizontally from the 4,000 level. It was not drilled primarily to seek ore but to develop water for the lower levels. The drillers, directed to drill southerly, lined up the hole in such direction as to give maximum space for removing drilling rods. This direction happened to be S. 10° W. At a distance of approximately 1,225 feet the hole passed into an ore body in the Koerner vein. This vein has proved to be spotty. Had the hole been driven due south it would have encountered the vein in a barren part, and further exploration of it might have been delayed indefinitely.

The Koerner vein is identical with the Koerner fault. The ore body is similar to the Main ore body, but smaller. The company's annual report for 1941 states that on the 4,000 level a total of 1,800 feet of drifting, of which approximately 900 feet were in ore, had been done. The average width was about 9 feet and the average grade somewhat better than 5 per cent copper. On the 3,600 level, drifting on the vein has totaled 1,797 feet, of which approximately 950 feet are in ore 4 to 15 feet wide and averaging about 5 per cent copper. On the 3,200 level, the vein has been cut by diamond drills at three places above favorable areas on the 3,600 level. As none showed ore bodies, the 3,200 level may be above the productive part of the vein. On the 4,400 level at No. 14 crosscut, the vein is below commercial grade. One raise on the vein from the 4,000 to the 3,600 level and another on the vein from the 4,000 to the 3,800 level showed that the ore is not vertically continuous (Fig. 11).

Mineralogically, ore of the Koerner vein is indistinguishable from that of the Main ore body on the same levels. Bornite and enargite are the predominant copper minerals, with subordinate chalcopyrite and tennantite and minor hypogene chalcocite. The difficulty of ventilation at present when refrigeration machines are not available retards exploration and mining of the Koerner vein. This vein is, however, an important reserve for future operation.

A diamond drill hole driven south from zero crosscut on the Koerner vein traversed 2,300 feet of diabase and ended almost directly below Queen Creek. No ore was encountered.

FAULTING

The ore bodies of the Magma mine are associated with east-west fault fissures, as are other ore bodies of the Magma and

Belmont subareas. Postore faults of northwest to northeast strike have displaced the east-west fissures.

PREORE FAULTS

Magma fault: The Magma fault, in which occurs the Magma vein, has the largest displacement of the east-west faults. It can be traced on the surface for about 3,300 feet, limited on the west by the Main fault and on the east by overlying dacite. Underground it has been followed for almost 7,000 feet, with a width of zone ranging from less than 1 foot to more than 50 feet.

Above the 2,250 level of the mine the Magma fault is approximately east-west, but below that level it strikes nearly N. 80° E. Locally, its strike varies from N. 65° E. to N. 80° W. Its average dip from the surface to the 900 level is 65° N., and below that level it is 78° S. (Fig. 6); local changes in dip are common.

Movement on the Magma fault did not take place along a single fracture but along a zone of closely spaced fractures. Shattering near the vein is slight, and the walls commonly are definite, especially in diabase. On the lower levels in Pinal schist the fault forms a wide shear zone whose walls are not easily determined. The apparent horizontal movement of the Magma fault near the Main ore shoot averages about 475 feet, with the north side moved east in relation to the south side. There are indications that movement decreased with depth and increased eastward (Fig. 7). Offsetting by the fault in the upper levels was described by Ransome as follows:[38]

> An observer walking east on a level driven along the vein has on his right hand rocks higher in the stratigraphic column than those on his left. Moreover, in consequence of the general easterly dip of the beds, after he first sees limestone on the right hand he must continue for 400 to 450 feet before he reaches the same stratigraphic horizon on the left.

Formations south of the fault are about 500 feet below those north. This movement was not vertical but oblique (Fig. 9).

A line joining the bends in the vein at the 650 and 900 levels is assumed to be the direction of the fault movement. This axis inclines westward, at an angle of about 55° to the dip of the beds. It is believed that if movement had been vertically downward, the rocks adjacent to the fault would have been more extensively shattered and fractured. In places the fault is clean-cut, sharp, and narrow and in the absence of shattering, difficult to follow.

The indicated direction of movement is only approximate, as the Magma fault is a warped surface and the axis of its bend is not likely a straight line.

The major movement was along the footwalls and hanging walls, and in places they show considerable gouge. Some of the

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[38] Ransome, F. L., Copper deposits near Superior, Arizona: U.S. Geol. Survey Bull. 540, p. 145. 1912.

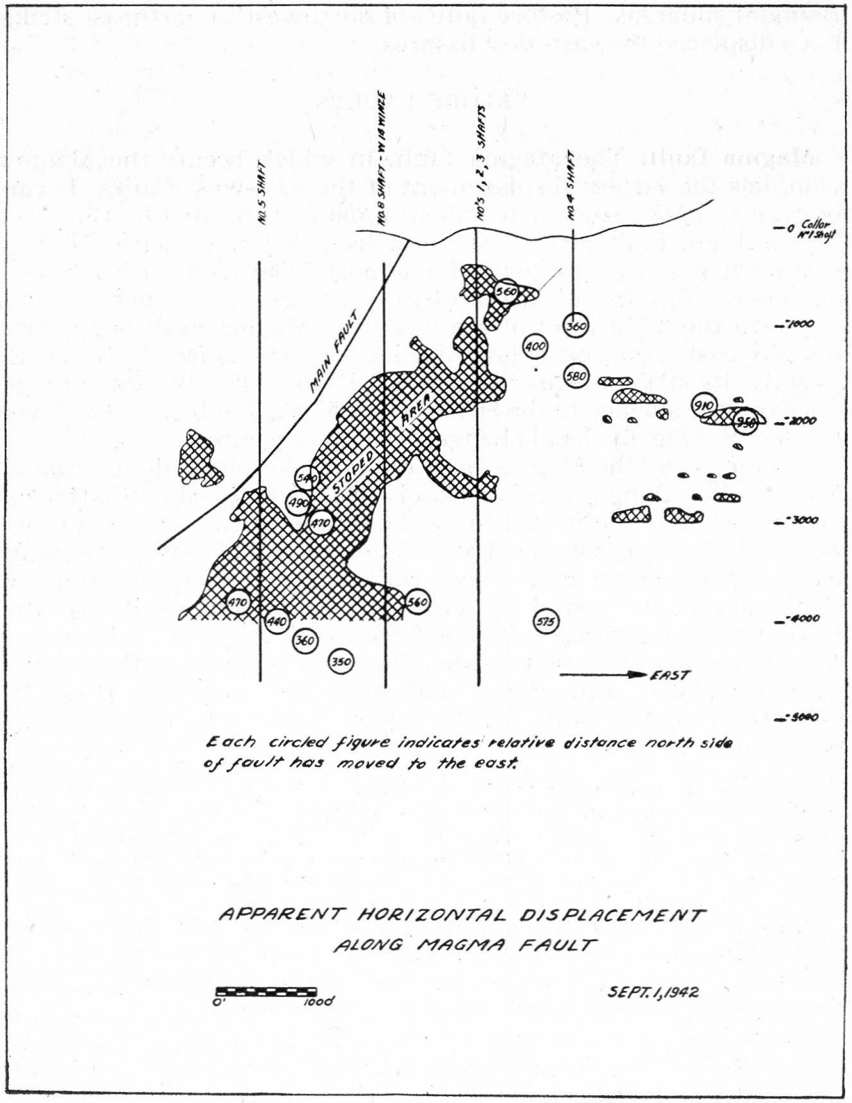

Figure 7.—Apparent horizontal displacement along Magma fault.

movement within the fault zone was postore, but probably most of it was contemporaneous with movement along the walls.

With depth, particularly in Pinal schist, the walls of the fault zone tend to flare. The zone is wider, the walls less defined, and horses of relatively unbroken, unmineralized wall rock are common.

The age of initial movement along the Magma fault is post-Upper Pennsylvanian (post-Naco limestone) and predacite. Prob-

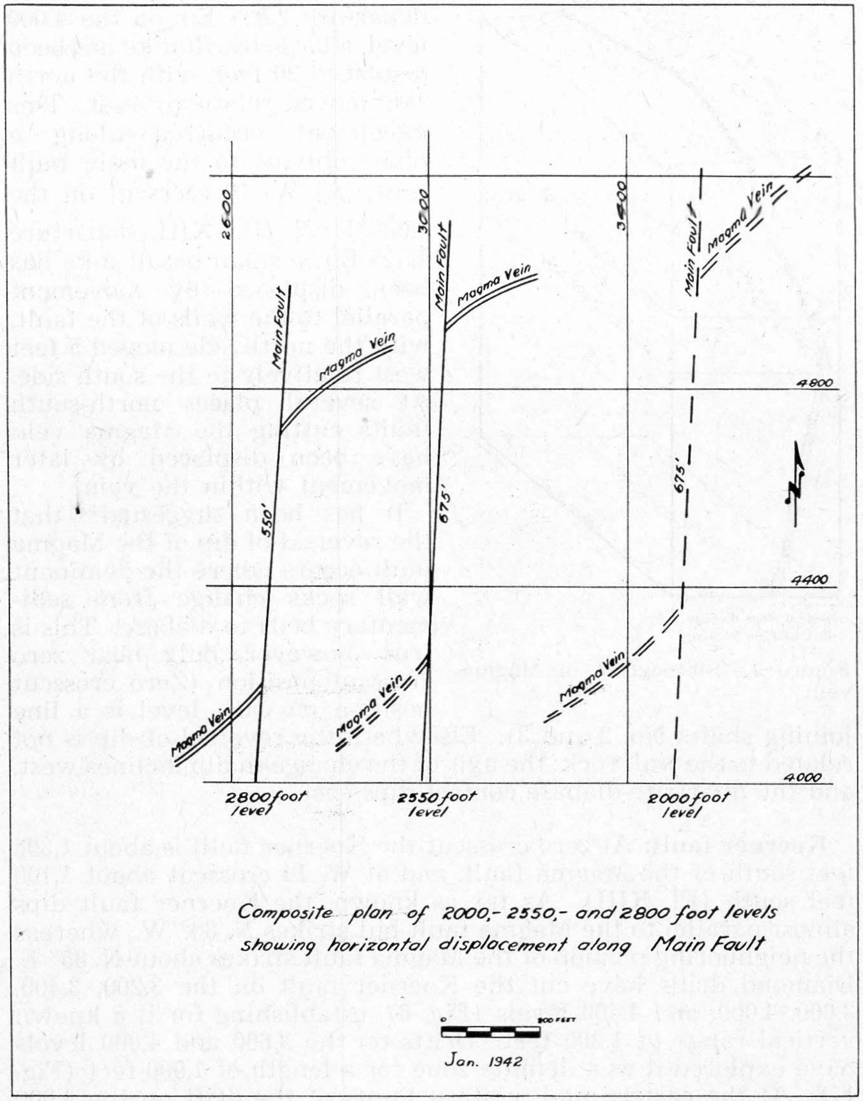

Figure 8.—Composite plan showing horizontal displacement along Main fault.

ably the forces causing it[39] and the other east-west faults of the region were connected with the emplacement and cooling of the Central Arizona batholith in early Tertiary (Laramide) time. Additional local movement within the Magma fault zone occurred at a much later time. Basalt dikes later than the dacite are displaced within the vein on planes of movement generally subparallel to the walls of the fault. Near W. 32 crosscut (Pl. XIII,

[39]Short and Ettlinger, op. cit., p. 185.

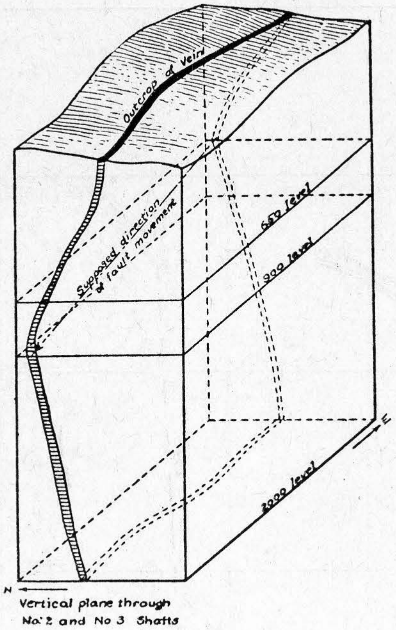

Figure 9.—Stereogram of Magma vein.

departure 2,825 E.) on the 4,000 level, a large basalt dike has been displaced 20 feet, with the north side moved relatively east. This movement occurred along a plane oblique to the main fault zone. At W. 10 crosscut on the 4,000 level (Pl. XIII, departure 4,515 E.), a small basalt dike has been displaced by movement parallel to the walls of the fault, with the north side moved 5 feet west relatively to the south side. At several places north-south faults cutting the Magma vein have been displaced by later movement within the vein.

It has been suggested[40] that the reversal of dip of the Magma fault occurs where the dominant wall rocks change from sedimentary beds to diabase. This is true, however, only near zero crosscut position (Zero crosscut position on each level is a line joining shafts No. 2 and 3). Elsewhere the reversal of dip is not related to the wall rock; the axis of the change in dip inclines west, and the quartzite-diabase contact dips east.

Koerner fault: At zero crosscut the Koerner fault is about 1,300 feet south of the Magma fault, and at W. 14 crosscut about 1,100 feet south (Pl. XIII). As far as known, the Koerner fault dips almost parallel to the Magma fault but strikes N. 80° W., whereas the neighboring portion of the Magma fault strikes about N. 85° E. Diamond drills have cut the Koerner fault on the 3,200, 3,400, 3,600, 4,000, and 4,400 levels (Fig. 6), establishing for it a known vertical range of 1,200 feet. Drifts on the 3,600 and 4,000 levels have explored it as a definite zone for a length of 1,900 feet (Fig. 11). At the eastern and western limits of the drift on the 4,000 level its zone narrowed to 1 to 4 feet.

The outcrop of the Koerner fault has not been definitely determined. Several small faults crop out on the ridge south of No. 3 shaft, and one of them may be the Koerner fault. The displacement along these faults does not exceed 25 feet, and they can be traced for a length of only about 1,000 feet. Below these outcrops a group of faults striking approximately east cut the 500 haulage

[40]Short, M. N. and Wilson, E. D.: Magma mine area, Superior, Arizona (in *Some Arizona Ore Deposits*): Arizona Bureau of Mines Bull. 145, p. 93, 1938.

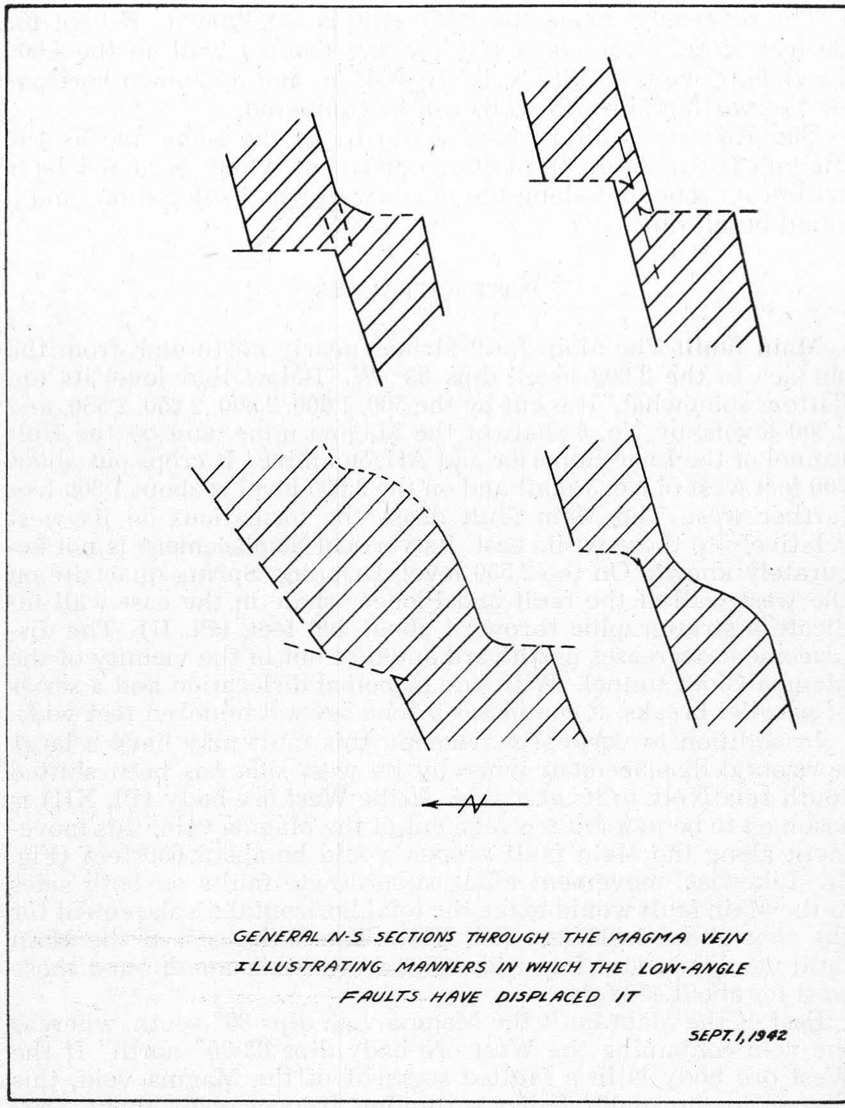

Figure 10.—General north-south sections through Magma vein, showing low-angle faults.

level a short distance south of No. 3 shaft. Two strong faults in E. 19 crosscut on the 1,600 level projected to zero crosscut strike close to the upward projection of the Koerner fault. The known dip of the Koerner fault in the lower levels, the faults projected from E. 19 crosscut on the 1,600 level, and the faults cutting the 500 level all indicate the outcrop to be about 1,000 feet south of the Magma outcrop.

The movement along the fault zone is not known. Except for 80 feet of quartzite along the hanging (south) wall on the 4,000 level, both walls on all levels are diabase, and no known horizons on the north and south walls can be compared.

The Koerner fault is assumed to be of the same age as the Magma fault. As in the latter, movement which occurred later within its zone and along the north wall has displaced ore and a small basalt dike.

POSTORE FAULTS

Main fault: The Main fault strikes nearly north and, from the surface to the 2,000 level, dips 63° W. Below that level its dip flattens somewhat. It is cut by the 500, 1,800, 2,000, 2,250, 2,550, and 2,800 levels, by No. 8 shaft of the Magma mine, and by the Holt tunnel of the Lake Superior and Arizona mine. It crops out about 700 feet west of No. 3 shaft and on the 2,800 level is about 1,800 feet farther west. The Main fault drops the formations on its west relatively to those on its east. Its vertical displacement is not accurately known. On the 2,550 level, Dripping Spring quartzite on the west wall of the fault and Pioneer shale in the east wall indicate a stratigraphic throw of about 500 feet (Pl. II). The displacement decreases northward and dies out in the vicinity of the Magma Chief tunnel. With one principal dislocation and a series of parallel breaks, it comprises a zone several hundred feet wide.

In addition to vertical movement, this fault may have a large horizontal displacement whereby its west side has been shifted south relatively to its east side. If the West ore body (Pl. XII) is assumed to be in a faulted segment of the Magma vein, this movement along the Main fault proper would be about 650 feet (Fig. 8). Likewise, movement along subordinate faults on both sides of the Main fault would make the total horizontal displacement for the zone about 1,400 feet (Pl. XII). The faults east of the Main fault would account for at least 300 feet of this amount and those west for about 450 feet.

East of the Main fault the Magma vein dips 80° south, whereas the vein containing the West ore body dips 68-80° north. If the West ore body is in a faulted segment of the Magma vein, this change in dip might indicate rotation from a point about 2,500 feet north of the Magma vein or approximately where the Main fault dies out. Another possibility is that the West ore body, if part of the Magma vein, may have been above the bend in dip of the vein (p. 79) prior to displacement by the Main fault.

East of the Main fault, the Paleozoic and Apache beds dip approximately 30° east and are relatively undisturbed except by the Magma fault. In contrast, the area between the Main and Concentrator faults, where not covered by dacite, reveals a mosaic of fault blocks. Locally, remnants of downfaulted dacite indicate postdacite faulting, presumably of the same age as the

Main fault. The northward trend of the sedimentary beds is still apparent but very irregular.

Prior to exploration in lower levels, the Concentrator fault was regarded as subordinate to the Main fault, but it is now known to be the principal dislocation of the district. The latter is a branch of the former, and their surface junction, concealed by alluvium, is probably near the Superior High School.

Transverse faults east of Main fault: The Magma vein has been displaced by several faults. Their strikes range from N. 85° W. to N. 70° E. but mostly are between N. 60° W. and N. 45° E. Their dips range from 45° W. to vertical. Their displacements are various, with a maximum of 120 feet. For the majority of these faults, particularly near the Main fault, the west side moved south.

Several of the faults are designated by letter on Plate II. Faults A, B, C, and D, at or near the western limits of the Main ore body, are described as follows:

Fault	Av. strike	Av. dip	Vertical range (levels)	Relative movement
A	N. 30° E.	80° W.	3,800-4,400	West side 35 ft. S.
B	N. 15° E.	75° W.	2,800-4,400	West side 20± ft. S.
C	N. 30° E.	50° W.	1,200-3,200	West side 15± ft. S.
D	N. 20-35° E.	45° W.	Surf.-2,550	West side 40± ft. S.

These four faults in echelon form a continuous zone from the surface to the 4,400 level.

Except for faults C and D, the persistent cross faults west of zero crosscut are limited to the lower levels of the mine. There are numerous faults above the 3,000 level, but none has been traced for more than 100 to 200 feet.

The faults east of zero crosscut appear to be more persistent than those on the west side. Faults H and J can be traced with reasonable certainty from the 4,000 to the 3,200 level and with less certainty to the 1,800 level. Other faults in upper levels of the east side may continue over long ranges, but, as in the case of faults H and J, definite evidence of them is missing on a few levels.

In some places, a fault can be followed through stopes from one level to the next. Generally, however, the faults were projected from level to level entirely on their characteristics of movement, dip, and strike. The dip of a fault plane, as seen in a drift, however, may be entirely different from its general dip over a 1,000-foot range. Its strike also may vary from place to place. The relative direction and amount of movement is the most important criterion used in connecting faults exposed only on the main levels.

A summary of data for faults E, F, G, H, and J is given in the following table:

Fault	Av. strike	Av. dip	Vertical range (levels)	Relative movement
E	N. 15° E.	65° W.	3,200-4,400	West side 15 ft. S.
F	N. 55° W.	75° E.	3,600-4,400	West side 20 ft. N.
G	N. 30-55° W.	85° E.	3,000-4,400	West side 25-100 ft. N., increases with depth
H	N. 45° W.	75° W.	3,000-4,000	West side 120 ft. N.
J	N. 5° W.	70° W.	3,200-4,000	West side 5 ft. N.

Faults E, F, and G are fairly close together, with F apparently cut off by G just above the 4,400 level and cut off by E between the 3,400 and 3,600 levels. Faults E and G may intersect near the 3,000 level.

Between the 1,500 and 1,800 levels east of zero crosscut is a fault striking N. 75° W., nearly parallel to the Magma vein, in which the east side has been displaced for 120 feet.

Very few other faults mapped show movement of over 5 to 10 feet. Many of them are found only on one level, although five or six show vertical ranges of 300 to 500 feet. The faults seen only on one or two levels have an average dip of about 75° W., but their strikes range from N. 60° W. to N. 60° E.; they are markedly similar in dip, and less noticeably similar in strike, to the major transverse faults. These smaller faults are more numerous in the west side of the mine, in or near the Main ore body. Of the faults mapped on the various levels, only about one in five is strong enough to continue to the next level. In many places faults offsetting the vein as much as 15 or 20 feet are not found in drifts only 50 to 100 feet away.

As the Main fault is approached from the east, the smaller as well as the larger transverse faults show definite relationship to the Main fault. It is most striking as to direction of movement. For all of them, as well as for the Main fault, the west side has moved south with reference to the east side. Most of the subordinate faults strike northeast, making an angle of about 45 degrees with the Main fault. The movements along these subordinate faults vary up to about 100 feet, and the total movement along them is about 300 feet. The direction of movement along the fault planes could not be definitely determined, but an oblique movement is indicated. In several places where the vein has been offset, ore is found on one side and low-grade vein on the other of the fault. At these places it is common to find drag ore on only the side of the fault next to the ore. A simple horizontal movement, except under very unusual conditions, could not cause this difference. An oblique movement, on the other hand, would have a horizontal component, and a drift following the vein and fault would encounter drag ore only next to the ore-bearing vein segment. Such conditions have been encountered in the Magma

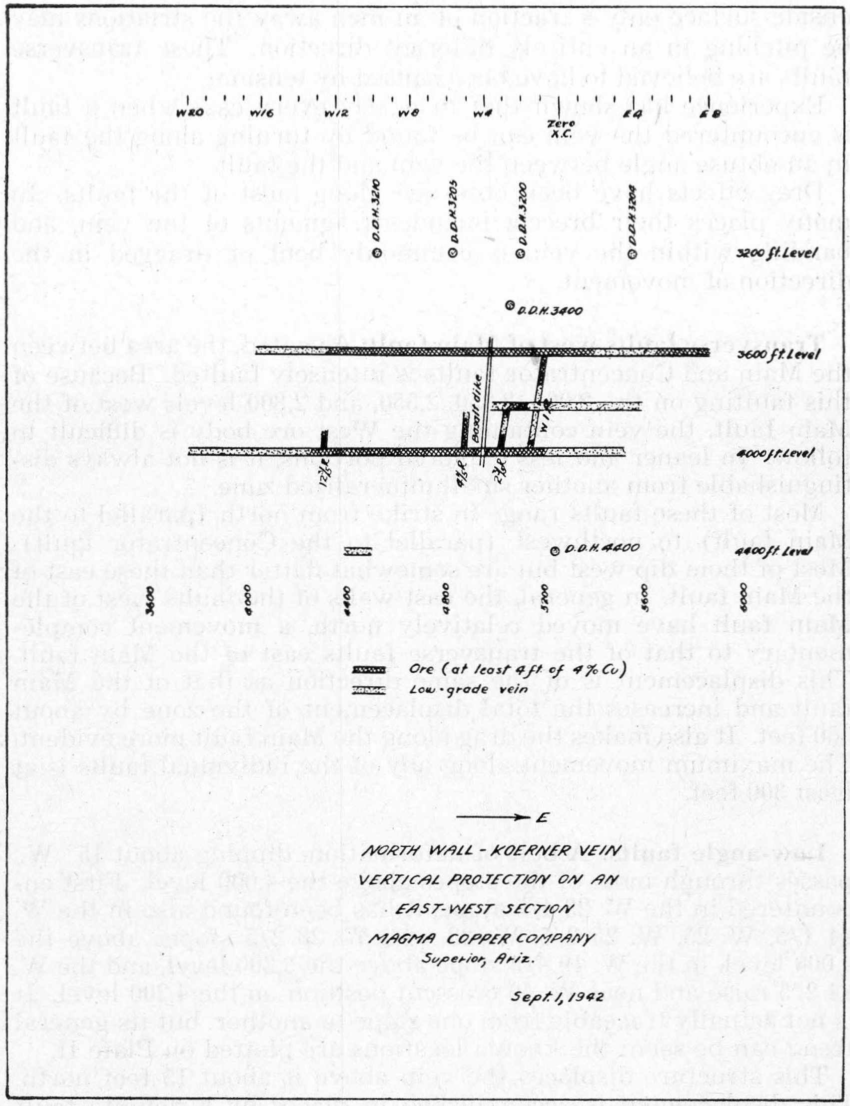

Figure 11.—Longitudinal projection of north wall, Koerner vein.

mine. A vertical movement could give the same effect, but to offset the vein 100 feet would require a vertical movement of about 400 feet, which seems excessive. Many striations on slikensides pitch down the fault plane at a small angle from the horizontal, but they cannot be relied upon as definite evidence of directions of faulting. Movement has taken place on a series of parallel planes rather than on a single plane and, although on one plane the striations may be in one direction, on the next slickenside surface only a fraction of an inch away the striations may be pitching in an entirely different direction. These transverse faults are believed to have been caused by tension.

Experience has shown that in nearly every case when a fault is encountered the vein can be found by turning along the fault in an obtuse angle between the vein and the fault.

Drag effects have been observed along most of the faults. In many places their breccia includes fragments of the vein, and banding within the vein is commonly bent or dragged in the direction of movement.

Transverse faults west of Main fault: As noted, the area between the Main and Concentrator faults is intensely faulted. Because of this faulting on the 2,000, 2,250, 2,550, and 2,800 levels west of the Main fault, the vein containing the West ore body is difficult to follow. In leaner and less explored portions, it is not always distinguishable from another small mineralized zone.

Most of these faults range in strike from north (parallel to the Main fault) to northwest (parallel to the Concentrator fault). Most of them dip west but are somewhat flatter than those east of the Main fault. In general, the east walls of the faults west of the Main fault have moved relatively north, a movement complementary to that of the transverse faults east of the Main fault. This displacement is of the same direction as that of the Main fault and increases the total displacement of the zone by about 500 feet. It also makes the drag along the Main fault more evident. The maximum movement along any of the individual faults is at least 300 feet.

Low-angle faults: A belt of deformation, dipping about 15° W., passes through most of the stopes above the 4,000 level. First encountered in the W. 23 4/5 stope, it has been found also in the W. 24 1/5, W. 25, W. 25 2/5, W. 28, and W. 28 2/5 stopes above the 4,000 level, in the W. 19 4/5 stope above the 3,800 level, and the W. 34 2/5 raise and near W. 40 crosscut position on the 4,200 level. It is not actually traceable from one stope to another, but its general trend can be seen; the known locations are plotted on Plate II.

This structure displaces the vein above it about 15 feet north. This displacement is accomplished in places by a definite fault through either the hanging or footwall and in other places by a sharp fold. In no place have both walls been affected in the same manner. Figure 10 shows several ways in which the offsetting has taken place. In places the flat faults have been offset and dragged by movement parallel to the Magma fault. The later transverse steep angle faults have displaced this belt and in a plane parallel to the Magma fault have the effect of vertical movement.

This flat-dipping structure, for want of a better name, is referred to as "low-angle faults." Consisting partly of faults and partly of a fold or roll, it may represent a sharp fold in the vein which, under stress of deformation, produced faulting in places; or it may be a fault in which the vein took up some of the movement by folding in one wall instead of by faulting in both. Whatever the actual mechanics of the movement, there is a zone in which the vein has been moved horizontally. It has not been possible to mine these portions in a normal manner.

This zone of deformation has not been found east of W. 19 2/5 raise above the 3,800 level.

RELATION OF FAULTING TO ORE

Only two faults in the Magma mine, the Magma and the Koerner, are known to be preore. Movement continued after the initial displacement and offset some of the preore movement, but the period in which it began is not clear. There appears to be relationship between the ore and some of the transverse faults, which fact suggests that these faults influenced ore deposition.

As shown on Plate II, faults A, B, C, and D bound the western extremity of the Main ore body and indicate a continuation of its westerly pitch. In only a few isolated stopes has any mining been done between these and the Main fault. In addition there appear to be more transverse faults cutting the ore bodies than the barren vein. If the faults are postmineral, these relations are purely coincidental and had no bearing on ore deposition. If the faults are premineral and all evidence of premineral movement is destroyed, perhaps by postmineral movement, these relations are then important and can be used as guides in prospecting. At present the age of some of these faults must remain in doubt. The broad relations certainly indicate premineral origin, but actual evidence favors postmineral inception. The possibility of premineral faulting should be kept in mind when prospecting is undertaken near these faults.

The proximity of the Main fault to the Main ore shoot suggests for it a possible premineral origin. This assumption would be logical if faults A, B, C, and D are premineral, as they appear to be related to the Main fault. To suggest that the Main fault might be premineral raises several questions, especially in its relation to the Concentrator fault which has such a large postmineral displacement. With the information now available these questions cannot be answered, and no attempt can be made to prove a premineral origin for the Main fault.

FOLDING AND TILTING

Small-scale folding is represented only by flexures between faults. The rocks tended to deform by breaking rather than by bending.

East of the Main fault the predacite beds have been tilted approximately 30° E. Between the Main and Concentrator faults they also have been tilted, but the tilting has been greatly modified by smaller faults.

The mechanics of tilting cannot be adequately explained until the detailed structure of a larger region surrounding the Superior district has been worked out. As the tilting preceded the dacite eruption, and the Main and Concentrator faults are postdacite, these faults cannot be regarded as the cause unless a predacite initial movement for them is assumed. The eastward-tilted beds may represent a limb of a large broken fold, and the preore east-west faults may be accompanying tear breaks.

ORE DEPOSITION

Processes: Replacement was by far the most important process in deposition of the Magma ore. This process may be defined as the dissolving of a mineral or group of minerals and the simultaneous deposition of another mineral or group in its place. Solution and deposition ordinarily proceed concurrently without intervening development of appreciable open spaces, and the substitution commonly involves no change in volume. A second, but distinctly minor, process of the deposition of Magma ores is deposition in open spaces. Filling of open fractures did not occur, and this second process is indicated only in filling of small vugs. In places the process of ore deposition has occurred in two stages, solution and deposition, leaving small irregular cavities. These were lined with quartz crystals, and the spaces between were later filled with sulfides.

RELATION OF ORE TO WALL ROCKS

Quartz monzonite porphyry: From the surface to the 1,200 level a dike of quartz monzonite porphyry occurs within the Magma fault zone. Below that level the dike in many places forms either the north or south wall of the vein, and on the 4,400 level the vein passes without displacement through a porphyry dike. The dike is later than the Magma fault but earlier than the mineralization. The ore is probably genetically related to the quartz monzonite porphyry, in that the dike represents offshoots of the igneous mass which furnished the ore solutions. From the levels now open for inspection it is evident that the porphyry dike was a poor host to the ore solutions. In several places the dike is rather strongly mineralized but not sufficiently to constitute ore.

Pyrite is the most common sulfide in the dike. It lacks copper mineralization probably because it was intruded after the major movement and accompanying brecciation of the country rock. There has been but slight fracturing of the dike, and the ore solutions had little chance of penetrating and replacing the tight porphyry.

Diabase: As shown on Plate II, there is a definite relation between the diabase and the shape of the Main ore shoot. All pronounced increases in stope length of the Main ore body are where both walls are diabase, and most of the maximum increases are nearly parallel to the contact between diabase and sedimentary beds. This increase in stoping length is most noticeable in the lower diabase sill. Probably because of certain physical characteristics, the diabase is more favorable for ore deposition than the sedimentary rocks, particularly the lower quartzite and shale. Undoubtedly the brecciated diabase was more susceptible to replacement by the ore-bearing solutions than was the highly siliceous quartzite and shale.

In 1941, Kuhn made a detailed study of the relation between ore bodies within the Magma vein and various types of diabase that form a large part of the vein walls.[41]

All specimens were taken from the north or footwall side of the Magma vein. In general, the footwall drifts were best for systematic collecting. Since thin sections of highly altered rocks contain few primary minerals and show little of the original texture, specimens with minimum alteration were selected wherever possible. The specimens were collected below the 1,200 level at about 400-foot intervals, both horizontally and vertically, and any irregularity in distribution or type was taken into consideration. A total of 68 specimens, mostly from the footwall drift about 75 feet north of the Magma vein, were collected.

This study of the diabase proved that the locations of ore shoots within the Magma vein have in no way been influenced by variations in type of diabase.

Although no difference in the replaceability of the various types of diabase could be noted, it is quite evident that the stope length is greater in the lower olivine-diabase sill than in the upper quartz-diabase sill. In view of Kuhn's investigation, however, this difference may more logically be ascribed to some other feature, probably the presence of Apache beds above the lower sill rather than to a difference in the types of diabase.

Basalt: The basalt was intruded much later than deposition of the vein and hence did not influence ore deposition. The effect of the basalt in the mineable portions of the vein is to dilute and spread apart the ore. The wider dikes, which in most places cut the vein at about right angles, have pushed the ore apart and replaced it with barren basalt. The smaller dikes must be mined with the ore, which causes dilution.

Sedimentary rocks: The Pioneer shale, Barnes conglomerate, and Dripping Spring quartzite are highly siliceous, and for this discussion can be grouped as one unit. Plate II shows that on the

[41]Kuhn, Truman H., Private report to the Magma Copper Co., 1941.

lower levels the stoping length of the Main ore body is shortest where the Apache group forms one or both walls of the vein. There also appears to be a difference mineralogically between the sulfides in the vein where the walls are formed by the Apache group and where they are diabase. On the 2,675, 2,800, 3,000, and 3,200 levels where one or both walls are sedimentary, the sulfides are predominantly pyrite and chalcopyrite, much of which ore is low grade. In contrast, much richer bornite-chalcopyrite ores are in the vein above, and richer bornite-chalcopyrite-tennantite-enargite-chalcocite ores are below. No satisfactory explanation can be given for this distribution of the sulfides.

The Main ore shoot does not reach the Troy quartzite, but its upward extension, as represented by smaller discontinuous ore bodies, has quartzite, limestone, or diabase as wall rocks. Practically all the zinc ore bodies have quartzite or limestone for one wall. Except for one or two small stopes in the upper levels, no ore has been mined where both walls are limestone. These relations between copper ore and the Paleozoic beds in the Magma mine are probably more a function of the strength and zoning of the ore solutions and of oxidation than any particular property of the quartzite and limestone. The location of the zinc ore bodies, although mainly a matter of zoning, appears to be somewhat influenced by the Troy quartzite (Pl. II).

Replacement bodies in limestone account for only a small amount of the ore. They are limited to the zinc-copper stopes in the upper levels east of zero crosscut. Particularly in stopes above the 1,800 level, a 20-foot bed at the bottom of the Martin limestone, just above Troy quartzite on the south side of the vein, has been replaced for about 20 feet. This horizon just above the Troy quartzite-Martin limestone contact is particularly important in the Lake Superior and Arizona mine.

In E. 33 south crosscut on the 1,800 level, there has been some replacement of limestone. This area is near the projection of the Martin-Escabrosa contact, and the beds at this contact may be slightly more replaceable than others.

In the Belmont mine area, the top 20 to 25 feet of the Escabrosa limestone is the host rock for most of the ore bodies. This horizon has not been prospected in the Magma mine.

Pinal schist: Mining has not progressed sufficiently to establish any definite relations between ore and schist, but certain important tendencies are strongly suggested.

The Main ore body has a schist wall only in the western portion of the mine below the 3,600 level. There the ore shoot maintains the same westerly pitch as in the lower diabase sill.

Of great importance is the character of the Magma fault and vein in the schist. On the upper levels, particularly in diabase, the vein walls are sharp, with little mineralization and alteration beyond them. Such is not the case in the schist. There the zone of faulting and mineralization is considerably wider than in the upper levels and commonly contains horses of fairly unbroken and unmineralized wall rock. Its walls are less distinct and in many places indefinite. Adjustment of forces within the fault zone did not take place in one definite zone but rather in a series of them perhaps over 100 feet wide. The ore solutions worked their way up through zones of weakness within the broad zone, and ore deposition was not confined between definite walls. As a result of this spreading out, the ore bodies are not continuous for any great distances but tend to be lenticular both horizontally and vertically. These lenses of ore may be close together and constitute a single ore body, they may be separated by low-grade mineralized schist, or they may be separated by unmineralized, fresh schist. In position they may be opposite one another, end to end, in echelon, close together, or far apart. Each lens has definite walls striking and dipping about parallel to the general trend of the vein, and an adjacent lens may have equally definite walls. The boundaries of the vein are arbitrary lines enclosing all these lenses and all the mineralized schist. The full width of the vein in the schist cannot be mined, and much of it will be of very low grade.

In conjunction with the widening of the mineralized zone in the schist, the mineable vein forms two branches, the "Main vein" and the "North branch." This split has been found only where both walls of the vein are in schist. On the 4,000, 4,200, and 4,400 levels, the junction of the North branch and the Main vein is fairly well known, and this junction plunges east approximately parallel to the Pinal schist-Pioneer shale contact (Pl. II). The distance between the two branches west of the contact is fairly constant, ranging between 75 and 125 feet. In a general way these two branches appear to form a hanging-wall and footwall belt for the wide mineralized zone. Both branches are strongly mineralized in places but at others are almost barren. The ore in the branches occurs as lenses such as those already described. Between the Main and North veins the schist in many places is altered, broken, and mineralized. Not enough prospecting has been done to determine whether or not any ore lies between the two branches.

WALL-ROCK ALTERATION

No detailed study was made of the wall-rock alteration. Extensive serpentinization and uralitization (formation of fibrous hornblende), probably during or closely following the emplacement of the diabase, rendered the diabase essentially impervious to ore solutions a short distance from the permeable fault zone. Later alteration by the ore solutions sericitized the feldspar and produced some kaolin. Chlorite was formed from the earlier augite and hornblende. Some carbonates were introduced. Alteration of the siliceous and aluminous sedimentary rocks and schist likewise consists of silicification and sericitization, but it is of less intensity than in the diabase.

AGE OF MINERALIZATION

Ore deposition closely followed the premineral faulting and may have begun before it entirely ceased.

WATER TABLE

In 1910, before extensive mining operations, water stood at about the 400 level (elev. 3,150 feet above sea level) in the No. 1 shaft, but since that time it has been continually lowered by new workings. At present, water is flowing into the 1,100 level (elev. 2,450) of the No. 5 shaft, at the bottom of the dacite (elev. 2,500) in No. 6 shaft, and above the 1,600 level (elev. 2,000) near E. 22 crosscut position. Water was encountered also in the east drift of the 4,000 level, in the 4,400 and 4,600 west drifts, in drill holes on the 4,800 level, and in the Koerner vein on the 3,600 and 4,000 levels. In the Lake Superior and Arizona shaft, the water table is near the tenth level (elev. 2,400). About 400 gallons of water per minute are now being pumped from the Magma mine.

OXIDATION AND SUPERGENE ENRICHMENT

Considering the large proportion of iron in the Magma ores and their concentrated rather than disseminated nature, it is surprising that the outcrop does not show a strong gossan. Oxidizing processes have resulted in a leaching of iron at the surface (Pl. X *B*).

Plate X *A* shows the outcrop of the Magma vein, indicated by the line of prospect pits.

At moderate depth, about 100 feet below the surface, carbonates of copper with only a relatively small proportion of iron oxides appear. Even at the top of this zone oxidation was incomplete, and pockets of chalcocite occur high above the general zone of supergene enrichment. The relatively impermeable character of the ores has been a factor in protecting them from complete oxidation, but the chief influence has been the arid climate of the region.

The absence of gossan is attributable to the extremely low proportion of pyrite in the hypogene ore. Blanchard and Boswell[42] state that hydrolysis of ferric iron to limonite is prevented by free sulfuric acid and promoted by copper. In other words, a high concentration of copper in a ferric sulfate solution counteracts the effect of sulfuric acid in keeping iron in solution and precipitates the iron as limonite. Pseudomorphs of limonite after pyrite are

[42]Blanchard, R. and Boswell, P. F., Notes on the oxidation products derived from chalcopyrite: Econ. Geol., vol. 20, p. 616, 1925.

most commonly formed by neutralization of sulfuric acid by carbonate solutions. It follows that if small or moderate amounts of pyrite had been present in the outcrop before oxidation, a considerable part of the iron would have remained as limonite.

Furthermore, Blanchard and Boswell show that sericitized porphyry acts similarly to carbonates in its tendency to neutralize sulfuric acid and thus permits ferric iron solutions to hydrolyze.[43] Oxidation products from pyrite in general travel only a limited distance is sericitized porphyry before being precipitated. Therefore, had there been a small or moderate amount of pyrite in the present outcrop, some of this iron would have precipitated in the porphyry as limonite.

Following Blanchard and Boswell, limonite is used as a field name for fine-grained yellowish or brownish deposits derived by decomposition of iron-bearing minerals. Presumably it is generally ferric oxide monohydrate (goethite), but it may be ferric oxide (hematite), lepidocrocite, jarosite, or certain basic ferric sulfates.[44]

Deeper exploration after 1910 showed that the zones of oxidation and enrichment have no apparent relation to present water level. Sulfides prevail in the western portion of the mine from the 500 to the 800 levels. In the extreme eastern parts between these levels, carbonates and oxides of copper appear with the sulfides, and the porphyry is iron-stained where it is not mineralized. Above the 500 level the bottom of the oxidation zone is practically horizontal.

Between the 800 and 1,500 levels the zone of oxidation does not reach the productive ores, but successively farther east and downward the porphyry changes in color from grayish white, with little or no iron oxide, to rusty brown or gray with intermittent reddish brown streaks along fracture planes. Similar changes are noted where the vein lies entirely within diabase. This change at the lower limit of intense oxidation is indicated by a line on Plate II. The bottom of the oxidation zone dips in a direction opposite to the present surface.

The line on Plate II indicating the lower limit of oxidation is not sharply defined, and a zone of incomplete oxidation underlies it. In places, such as E. 16 to E. 22 stopes on the east 1,500 level, the ore is preponderantly sulfide, but scattered small pockets or seams of limonite and other oxides occur in the midst of sulfides. Such interfingering of oxides and sulfides is common in arid regions.

Above the oxidation line as drawn on Plate II, in stopes above the East 1,800 and 2,000 levels, sphalerite is rare, and much of the zinc has been removed by oxidizing solutions. Some zinc remains as smithsonite and zinciferous tallow clay, associated with abun-

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[43]Blanchard and Boswell, op. cit., p. 631.
[44]Op. cit., p. 615.

dant limonite and hematite. The lower limit of oxidation below the 2,000 level is unknown.

The local base level of the district is the bed of Queen Creek, and drainage is westward. Moreover, before pumping the water level stood 150 feet above the local base level and was higher eastward. Experience has shown that important oxidation below water level is exceptional without long periods of geologic time or unusual conditions of water circulation. It is likely to be local, as cusps extending down from a more or less regular surface.

If oxidation took place after tilting, the water level must have been at least 1,600 feet deeper than at present, as oxidation appears in the 2,000 east drift and the present water table is the 400 level. However, deep oxidation, entirely unrelated to present water level, is common in the ore deposits of the Southwest.

The parallelism shown by the bottom of the zone of oxidation and the base of the dacite (Pl. II) suggests that the oxidation took place after tilting, during the long erosion period marked by the Whitetail conglomerate. On the other hand, the lower limit of oxidation roughly parallels the sedimentary beds. This relation might mean that ore deposition and oxidation preceded the tilting, but such an interpretation seems difficult to reconcile with the structural history of the region and with the occurrence of sulfides down the dip in the L. S. and A. mine (p. 138).

Intense oxidation is limited to places where the vein is in Paleozoic sedimentary beds; little limonite or other oxidation products have been found where the vein is in diabase. This difference is believed to be a factor of permeability. The diabase away from the fault zone is very impermeable in comparison with the sedimentary rocks. The permeability of the sediments permits general circulation, but in the diabase water circulation it is limited to the fault zone. Within the vein, circulation was apparently too limited for oxidation but sufficient to produce small quantities of supergene copper sulfides.

As shown on Plate II, the lower limit of oxidation above the 500 level is essentially horizontal and only 50 feet below the water level which existed before mining. In relatively recent times the water level may have been 50 feet lower than it is at present, and oxidation could have followed it to this depth. As the dacite has been removed from above this portion of the deposit in relatively recent times, recent oxidation would be effective. Thus, for this portion of the mine, recent oxidation appears to have been superimposed on earlier oxidation.

PARAGENESIS

Introduction: Paragenesis refers to the relative ages or periods of deposition—the origin, association, and sequence—of minerals in an ore body. These data are obtained by microscopic study of thin and polished sections of ore specimens. Although the study of mineral paragenesis may not lead directly to discovery of new ore bodies, it gives information regarding the complex processes of ore deposition and to the character of ore solutions. It usually can determine whether sulfide ores are hypogene or supergene.

It is not practical to give in this bulletin a comprehensive discussion of the microscopic criteria; they have been adequately outlined in the literature.[45]

Specimens studied: The following description of the ore minerals of the Magma mine is based on a study made with the reflecting microscope on 314 polished sections. Ninety of them were from the 1921 collection of Short and Ettlinger, comprising specimens from the 400 to the 2,000 levels, inclusive. Of the remainder, collected more recently, 116 are from the Main ore body below the 2,000 level, 14 from the West (No. 5) ore body, and 94 from the East ore bodies.

HYPOGENE SULFIDE MINERALS

Pyrite (FeS_2): The most abundant sulfide in the Magma mine is pyrite. Especially on the lower levels, large tonnages of pyrite, too low in copper to be mined at a profit, occur in many places. Low-grade pyrite is found along the margins of most of the ore bodies. On the upper levels the percentage of pyrite in comparison with the copper sulfides is low, which fact accounts for the lack of conspicuous gossan along the outcrop of the Magma vein. Pyrite crystals are common in polished sections of ore, but most of the pyrite is massive, without crystal faces. The massive pyrite was probably formed by precipitation around closely spaced nuclei, with allotriomorphic development of the grains. The pyrite grains almost invariably show embayments or veinlets filled by other sulfides, but no evidence of its replacement of other sulfides was observed. Pyrite in the "exploded bomb structure" similar to that depicted by Graton and Murdoch[46] is common in Magma ores (Pls. XX *D;* XXIII *B;* XXV *B, C*). This structure indicates that pyrite is earlier than the minerals in the cracks of the "bomb."

It is clear that pyrite is the earliest mineral of the Magma ores and that deposition of pyrite ceased before that of the other sulfides began. This relation does not imply that other metals were lacking in solutions depositing pyrite. No doubt they were present, but the excess of iron and sulfur was precipitated in advance of copper, lead, and zinc compounds.

In almost every specimen quartz accompanies pyrite. In some specimens small grains of pyrite are attached to proportionately larger veins of quartz (Pl. XVIII *C*); here the quartz evidently is earlier. In some tiny vugs the space between acicular crystals

[45]Bastin, E. S. and others: Criteria of age relations of minerals with especial reference to polished sections of ores: Econ. Geol., vol. 26, pp. 562-610, 1931.
[46]Graton, L. C. and Murdoch, J., The sulphide ores of copper: Am. Inst. Min. Engrs. Trans., vol. 45, p. 37, 1913.

of quartz is filled with quartz and sulfides. This quartz possibly grew by replacement of the sulfides, but more probably it lined the vugs which were later filled with sulfides. More commonly quartz veinlets cut pyrite (Pl. XXVI *A*). Quartz overlapped both the beginning and end of pyrite deposition, but in no specimen is quartz later than other sulfides. The period of maximum quartz deposition immediately followed that of pyrite.

Sphalerite (ZnS): Sparse sphalerite occurs in the main ore bodies of the Magma mine as small grains surrounded by copper sulfides. It is clearly later than pyrite (Pl. XXIII *B*), earlier than the copper minerals, with the possible exception of enargite, and earlier than galena (Pls. XXIV *B*: XXV *A*; XXVI *B*). The relation between sphalerite and enargite is not clear, as contacts between the two were not observed. Enargite is a relatively high-temperature, and sphalerite a relatively low-temperature, mineral. Hence, they tend to be mutually exclusive.

Sphalerite is abundant on the eastern margin of the Main ore body in the upper levels. In the lower levels it is sparse in the Main ore body but abundant in scattered ore shoots east of the main crosscuts (between shafts No. 2 and 3). Here it is almost invariably accompanied by galena. This association suggests that the two minerals may be contemporaneous, but polished sections reveal galena embayments and veinlets, some of which are parallel to cleavage directions of sphalerite, indicating that sphalerite is earlier than galena. The universal association of sphalerite and galena in many ore deposits suggests similar conditions of solution and deposition. Probably the sphalerite was deposited first and was more or less unstable in the presence of the remaining solutions that deposited galena. Sphalerite tends to form crystal faces, and euhedral forms surrounded by other sulfides are common. Most of them show embayments occupied by galena or copper sulfides.

Enargite (Cu_3AsS_4): Enargite is not found in the upper levels but occurs with increasing abundance downward from the 3,200 level, near No. 5 main crosscut. On and below the 4,200 level it is the most important ore of copper. Here it occurs massive, with prominent, coarse cleavage. The cleavage surfaces generally show rounded areas of pyrite.

In polished sections enargite is almost invariably intergrown with tennantite, and the patterns indicate that tennantite replaces enargite. In some places veinlets of tennantite follow the cleavage of enargite, but in other places the tennantite veinlets are curved and branching. Where replacement is nearly complete, the enargite consists of small, irregularly shaped areas rather closely bunched together and completely surrounded by tennantite. In ordinary light the two minerals cannot be distinguished by the unaided eye, but in polarized light tennantite is isotropic and enargite strongly anisotropic with pink, blue, and green interference colors. They may also be distinguished by etching with 20 per cent KCN solution, which stains enargite black and does not affect tennantite.

These enargite-tennantite intergrowths are common in many parts of the world, as, for example, at the Caridad mine.[47]

According to Schneiderhöhn and Ramdohr[48] the process cannot be considered a replacement in the ordinary sense, since little material is transferred, but the process is analogous to an inversion on cooling. Enargite forms at higher temperatures, but as cooling proceeds it is unstable and reacts with copper-bearing solutions to form tennantite.

On the 3,200, 3,600, and 4,000 levels enargite is the dominant mineral of arsenical copper ores in the western parts of the ore body, whereas tennantite prevails in the eastern margins of the ore body on the same level. Reversals of this general association are common in specimens a few feet apart. This association might be regarded as evidence that the ore body has been tilted eastward; if restored to horizontal, the western part of the ore body on a given mine level would be lower and the eastern part higher than at present. Statistically, tennantite is the dominant sulpharsenite on the 3,200 level, and enargite is the dominant sulpharsenite on the 4,000 level.

The same relations obtain at Butte, where enargite is characteristic of the central copper zone in which relatively high temperatures prevailed, and tennantite is the dominant arsenic mineral in the intermediate copper zone where relatively lower temperatures prevailed.

Enargite is later than pyrite and earlier than the other copper minerals. The age relation between enargite and sphalerite has not been determined, but they are probably nearly contemporaneous.

Tennantite ($5Cu_2S.2(Cu,Fe)S.2As_2S_3$): Tennantite was not found in the mine above the 1,000 level. That it was once present but destroyed by enrichment process seems unlikely, as tennantite is replaced with difficulty by chalcocite and covellite. Probably it was never deposited above the 1,000 level.

From the 1,000 to 3,200 levels it is abundant but less so than bornite and chalcopyrite. Where present it is almost invariably intergrown with bornite without evidences of replacement; probably it is essentially contemporaneous with bornite. The absence of any remnants of enargite indicates that the tennantite in this zone is not a replacement of enargite. Isolated specimens of

[47]Wandke, Alfred, The Caridad mine, Sonora, Mexico: Econ. Geol., vol. 20, p. 315, 1925.

[48]Schneiderhöhn, H. and Ramdohr, P., Lehrbuch der Erzmikroskopie: p. 462, Berlin, 1931.

enargite-free tennantite are also found below the 3,200 level, especially in specimens of low arsenic content.

Chalcopyrite ($CuFeS_2$): The most widespread copper sulfide is chalcopyrite. Above the 3,200 level it accounted for almost, if not quite, as much copper as bornite. Below the 3,200 level it is less abundant than bornite. In the richer ore bodies bornite predominates over chalcopyrite, but, on the other hand, in the low-grade pyritic ores, in zinc-lead ores, and in the ore bodies east of zero crosscut, chalcopyrite is present in various amounts, whereas bornite is lacking or sparse. Some chalcopyrite occurs in most specimens of bornite, with which it appears to be essentially contemporaneous.

Bornite (Cu_5FeS_4): The Magma mine has long been noted for its bornite ores. In the early days much of the bornite was believed to have formed as a supergene enrichment of chalcopyrite, and consequently the rich bornite was expected to give way in depth to leaner pyrite-chalcopyrite ores.

The undiminished continuity of bornite to the bottom level of the mine demonstrates conclusively its hypogene origin. Microscopic evidence confirms this conclusion. The intergrowths between bornite and chalcopyrite indicate essential contemporaneity. They differ widely from those of supergene enrichment, in places overlap of bornite is indicated by veinlets of bornite in chalcopyrite, indentations of bornite in chalcopyrite (Lindgren's "caries" pattern), and other textures indicative of local replacement.

Thin sections of bornite ores show bornite containing unreplaced remnants of rock minerals, bornite embayments in calcite cleavage planes, and bornite veinlets cutting across sericite and penetrating between sericite plates. Either bornite has extensively replaced rock minerals or has replaced pre-existing sulfides which have replaced rock minerals. There are no patterns indicating intensive replacement of the earlier sulfides, pyrite and sphalerite. Limited replacement of these sulfides has taken place, and in most places the original outlines of the pyrite grains have been preserved; where bornite is present, it is in cracks in pyrite (exploded bomb texture). Bornite and sphalerite largely appear to be mutually exclusive. In rich sphalerite ores bornite is absent, and the copper is represented by chalcopyrite or, less commonly, tennantite. In rich bornite ores sphalerite, if present, is represented by tiny isolated grains. The conclusion is then justified that the amount of bornite replacing earlier hypogene sulfides was small in comparison with that replacing rock minerals.

Bornite crystals have not been observed in the Magma mine. In general, bornite has a relatively weak tendency to form crystal outlines, even in open spaces.

Bornite intergrowths with chalcopyrite, with tennantite, and with chalcocite are common; those with galena are less so. All these minerals appear to be essentially contemporaneous.

Galena (PbS): In the Magma mine galena is almost universally associated with sphalerite. This association might suggest that the two minerals are contemporaneous, but detailed investigation shows that sphalerite is invariably the earlier mineral, as evidenced by embayments and veinlets of galena (Pl. XXVI *B*). The association indicates similar conditions of solution and deposition. It appears probable that the sphalerite, deposited first, was more or less unstable in the solutions which later deposited galena. It is doubtful that there was a hiatus between the two minerals. Zinc and lead were carried in solution together, but zinc came down first. Sphalerite always predominates in these mixtures. Galena is nowhere found in commercial quantities.

Intergrowths of galena with bornite, and galena with chalcopyrite, have been observed but are nowhere important. The patterns indicate that galena is essentially contemporaneous with the copper minerals.

Stromeyerite ($Cu_2S.Ag_2S$): Stromeyerite is rare in the Magma mine but has been observed in four widely separated localities. In the East ore bodies, 1,600 east drift, 17 4/5 stope, and 1,800 level, E. 21 1/5 stope, it is intergrown with bornite in subgraphic patterns. A similar intergrowth is found in the Main ore body on the 1,400 level; 8 crosscut (Pl. XXII *B*). A specimen from the 1,200 level, No. 8 raise, shows stromeyerite intergrown with galena in the "mutual boundary" pattern (Pl. XXII *A*).

Stromeyerite is probably contemporaneous with bornite and galena. Its location far below the enrichment zone and the patterns already described indicate that it is hypogene.

Deep-level chalcocite (Cu_2S): The term deep-level chalcocite is used to denote hypogene chalcocite which is intimately intergrown with bornite in graphics, irregular boundaries, and some types of gratings.[49]

The graphic texture has been described elsewhere.[50] It is common in chalcocite-bornite specimens from the 1,200 to the 3,600 levels, but below the 3,600 level the chalcocite-bornite specimens are of the "patchy" type (Pl. XIX *C, D*). The areas in part show smooth boundaries, but in places the impression of partial replacement of bornite by chalcocite is marked. Probably chalcocite partially overlaps bornite, or the areas now occupied

[49]This structure is fully discussed by Schneiderhöhn and Ramdohr (op. cit., p. 284) who termed it "lamellar structure" and believed it to be due to unmixing of a bornite-chalcocite solid solution. Bornite-chalcocite gratings are common in the central copper zones at Butte and in other districts but do not occur in the Magma mine.

[50]Bastin, E. S. et al., op. cit., pp. 571-6.

by the intergrowth were once pure bornite which was later partially replaced by deep-level chalcocite.

Graphic textures have been observed in galena-bornite intergrowths (Pl. XXIII *A*) and many other mineral pairs which are invariably hypogene. It is generally agreed that galena is always hypogene, and this graphic is therefore hypogene. The question is whether the graphic texture is ever produced by supergene processes. Graphic bornite-chalcocite is observed in the zone of enrichment, but the texture has been largely destroyed by oxidation of the chalcocite to covellite (Short and Ettlinger, work cited, Figs. 18-21). In most places in the zone of enrichment the bornite has been completely replaced by supergene chalcocite, and the former graphics have been obliterated to form large masses of pure, steely chalcocite.

Hypogene chalcocite never occurs in isolated masses more than 5 mm. in diameter. Microscopic examination shows that it is everywhere intergrown with bornite.

The field relations offer the best evidence for hypogene origin of the deep-level chalcocite. They can be summarized as follows: If the chalcocite is supergene, the amount should diminish with depth; if hypogene, it may either diminish or increase in depth. The deeper the chalcocite occurs, the less is the likelihood that it is supergene.

Deep-level chalcocite persists to the bottom levels of the mine. Its abundance is indicated by the following table:

Year collected	Level	No. of specimens collected	No. of specimens with deep-level chalcocite
1921	2,000	21	7
1938	3,600	20	6
1940	4,000	28	9

In general, deep-level chalcocite is found only with richer bornite ores, but not all rich bornite ores contain chalcocite. The table, as well as that given in the earlier publication,[51] shows that the ratio of specimens containing deep-level chalcocite is approximately constant from the 1,000 level downward. However, the 4,000 level has a longer stoping length than any level above it, and the total amount of deep-level chalcocite is greater on this level than on any above it. On the lower levels chalcocite accounts for about 5 per cent of the copper mined. The field argument is much more weighty than any based on interpretation of microscopic textures or on laboratory experimentation. In the opinion of M. N. Short, the field evidence proves beyond all doubt that deep-level chalcocite is hypogene.

Digenite (Cu_9S_5): Much of the deep-level chalcocite is actually composed of two minerals. One of them is white, is anisotropic

[51]Short and Ettlinger, op. cit., p. 207.

with steel-blue and pink interference colors, and has a strong etch cleavage parallel to the base. It is orthorhombic chalcocite. The other component is bluish and isotropic and gives an irregular and indefinite etch cleavage. This mineral was formerly believed to be isometric chalcocite, and its color was ascribed to a small percentage of dissolved covellite. The X-ray research of Buerger[52] proved this bluish component to be digenite, Cu_9S_5, a mineral formerly discredited. Digenite does not occur above the 3,400 level, but on this level and below, it forms a part of all deep-level chalcocite-bornite intergrowths. The patterns formed by chalcocite and digenite are of the mutual boundary type, and the two minerals are believed to be contemporaneous (Pl. XIX *B*). When etched with nitric acid, the difference between chalcocite and digenite disappears; both minerals turn dark bluish gray and present good etch cleavages.

SUPERGENE MINERALS

Oxidized minerals: Oxidized minerals are not abundant in the Magma mine. Those recognized are:

Azurite	$2CuCO_3.Cu(OH)_2$
Chrysocolla	$CuSiO_3.2H_2O$
Copper	Cu
Coronadite	$MnPbMn_6O_{14}$
Cuprite	Cu_2O
Dioptase	$H_2O.CuO.SiO_2$
Halloysite	$Al_2O_3.2SiO_2$
Hemimorphite	$Zn_4Si_2O_7(OH)_2.H_2O$
Hydrozincite	$2ZnCO_3.3Zn(OH)_2$
Limonite	Mixture of oxidized iron minerals
Malachite	$CuCO_3.Cu(OH)_2$
Manganite	$Mn_2O_3.H_2O$
Olivenite	$4CuO.As_2O_5.H_2O$
Psilomelane	MnO_2

With but few exceptions the oxidized copper minerals are found above the 500 level. Nowhere do they constitute ore. Emerald-green crystals of dioptase, partly coated with small olive-green olivenite crystals, were found near the surface associated with chrysocolla, malachite, azurite, cuprite, and supergene chalcocite. Chrysocolla and malachite are the principal oxidized copper minerals. Chrysocolla occurred as small bunches and seams down to the 500 level. Most of the malachite replaced chalcocite and covellite. Native copper has been found in small amounts at the outcrop, in a diamond drill hole east of No. 6 shaft on the 2,000 level, and in 7½ stope above the 2,250 level west of the Main fault.

White films of hydrozincite coat some of the sphalerite on the 1,600 level.

Limonite occurs in distinct veinlets cutting the sulfides and gangue minerals, as brown stains in the gangue minerals and as

[52]Buerger, N. W., The chalcocite problem: Econ. Geol., vol. 37, pp. 19-44, 1941.

pseudomorphs after pyrite. The first two modes of occurrence are due to transportation and subsequent hydrolysis of iron sulfate solutions. In the case of pseudomorphs after pyrite, the oxidized iron remained within the boundaries of the parent mineral.

Veins and irregular masses of manganese oxides, probably psilomelane and manganite, are common and fairly abundant south of the Magma vein on the East 1,600 level.

Kuhn (private report to Magma Copper Company, Sept. 1, 1942) noted that little ore has been found in the zone of oxidation. Only isolated bodies of chalcocite and chrysocolla ore with minor amount of azurite, malachite, and dioptase were found in the upper levels. Native silver, native copper, cuprite, chalcocite, coronadite, and tallow clay (probably hemimorphite and halloysite) are found near the lower limits of the zone in the stopes above the 1,800 and 2,000 levels. It cannot be certain whether the small amount of ore in the zone of oxidation is due to leaching or to lack of deposition above what is now the lower limit of oxidation. The lack of a strong gossan and the small amount of secondary enrichment indicate however, that the small amount of ore in the oxidized zone is due more to a lack of primary deposition than to thorough leaching. Oxidation influences the zinc. Some of the zinc stopes above the 2,000 level have been discontinued because of oxidation. Those above the 1,500 level have not yet reached the oxidized zone but are fairly close to it. Two recently identified minerals were found in the 35, 35 1/5, 37, and 37 1/5 stopes above the East 2,000 level. They are near the lower limit of the zone of oxidation in what appears to be a bed replacement in limestone. One, a fairly common white, waxy clay, contains from 14 to 30 per cent zinc. Mr. J. J. Fahey, of the United States Geological Survey, examined it and wrote:

> The sample of zinc-bearing material . . . is of a type referred to as tallow clay. It is composed of clay (probably halloysite) throughout which are disseminated very finely divided particles of a zinc mineral that has much higher indices of refraction than the enclosing clay, and probably is hemimorphite (calamine).

Occurring with the tallow clay is a small amount of a hard, black, zinc-bearing mineral identified by Dr. Harry Berman of Harvard University:

> We find . . . that this black mineral is coronadite, a mineral having the composition $MnPbMn_6O_{14}$. Apparently the particular specimen sent . . . from the Magma has in it some zinc in place of the manganese or the lead, but in other respects it is the same substance. This mineral is exceedingly rare. It has been found definitely only once, in the Clifton-Morenci district, and perhaps also in a locality in Morocco.

Chalcocite (Cu_2S): Massive chalcocite ore bodies were mined from the 500 to the 650 levels. The derivation of part of this chalcocite from bornite is proved microscopically by occasional remnants of bornite in areas of chalcocite and by the fact that these rich chalcocite ores change in depth to ores in which bornite predominates. The chalcocite of the upper levels is steely white in the hand specimen. Under the microscope some specimens of it exhibit a peculiar mottled appearance (Pl. XVI *B*). It is generally of fine granular texture, the different grains having different colors varying from white through grays to very light blue. Rounded hazy patches of slightly grayer color in the chalcocite are believed to represent "ghosts" of the replaced bornite grains, the difference in color being due to incomplete removal of iron in the replacement process. These differences in color instantly disappear when the chalcocite is etched with an oxidizing reagent such as nitric acid or ferric chloride; the whole area turns a dark blue.

The completeness with which the hypogene sulfides of the upper levels have been replaced by chalcocite has obliterated all but insignificant traces of these minerals. Only pyrite appears to have survived the process, and even it has been strongly attacked. Some microscopic areas of unreplaced bornite surrounded by gangue are present. They owe their preservation to protection by the gangue. A small proportion of covellite is found in steely chalcocite (Pl. XVII *B*). The covellite originated as a direct oxidation product of the chalcocite. The steely chalcocite zone is irregular in shape and thickness. It grades upward into an oxidized zone containing pockets of residual sulfides. The lower limit of the steely chalcocite zone is more regular and parallels the sedimentary beds and the base of the dacite.

Native silver is found in supergene chalcocite (Pl. XV *C*). It seems to be later than the chalcocite. It has not been observed in polished sections of the hypogene ores, although analyses show silver. The hypogene silver may be present as stromeyerite or tennantite.

The zone of massive chalcocite changes rather abruptly in depth to a zone of rich bornite containing more or less supergene chalcocite. This zone is very limited and does not extend more than 150 feet below the bottom of the massive chalcocite zone. The 900 level marks its lower limit at its eastern end, and it extends diagonally upward toward the west, paralleling in a general way the dip of the formation. The bottom of this zone is irregular. The veinlets and gangue boundary rims of supergene chalcocite decrease in size and number with increasing depth until they practically disappear. Below this zone supergene chalcocite is seen only in microscopic veinlets and accounts for only an insignificant proportion of the total copper. The chalcocite in this zone is not of the mottled type. Most of it is distinctly bluish. This bluish chalcocite does not etch with dilute nitric acid and in some respects behaves as covellite. In places this blue chalcocite is replaced by tiny veinlets of covellite (Pl. XVI *C*). This evidence indicates that the blue chalcocite is supergene. Similar blue chalcocite is found in the Kennecott mine, Alaska. The blue color of the chalcocite has been shown to be due to a small proportion of covellite contained in solid solution.[53] The presence of minute veinlets of covellite in blue chalcocite in Magma ores suggests that the blue color is due to oxidation of the chalcocite.

Covellite (CuS): Covellite occurs in the Magma mine as (1) a product of direct oxidation of chalcocite and (2) a replacement, generally of bornite and more rarely of galena.

The first mode of occurrence appears only well up in the oxidation zone where the covellite is invariably associated with more or less malachite and mottled chalcocite. This type of covellite is the only one observed in hand specimens (Pls. XV *D*; XVII *B*).

In the second mode of occurrence the covellite occurs as veinlets or as rosettes of small plates along seams or gangue boundaries (Pl. XVII *A, C, D*). The total amount of covellite is insignificant in comparison with hypogene sulfides and does not exceed 2 per cent in any polished section examined. On the 900 level it is relatively abundant, and from this level to the bottom of the mine very small amounts of it are seen in many of the specimens examined. The supergene derivation of this covellite is beyond question. Its distribution is spotty but shows a progressive diminution in the proportion of covellite to bornite from the 900 level downward. In sections from the 4,000 level the covellite is discernible only with higher magnification.

DISTRIBUTION OF COVELLITE

Level	Number of specimens collected	Number of specimens containing covellite	Per cent of specimens containing covellite
900	9	7	78
1,000	5	4	80
1,100	8	1	12
1,200	19	6	32
1,300	4	1	25
1,400	6	5	83
1,500	4	1	25
1,600	8	2	25
1,700	8	4	50
1,800	20	10	50
2,000	21	4	19
4,000	28	4	12

An investigation was made to determine whether mine oxidation might be responsible for the covellite. Specimens of bornite were collected on the 1,000 level from immediately beneath a crust nearly a foot thick which was obviously the result of mine oxidation during the eight years the drift had been open. If mine oxidation is competent to produce covellite it should have been

[53] Posnjak, E., Allen, E. T., and Merwin, H. E., The sulphides of copper: Econ. Geol., vol. 10, p. 526, 1915.

produced here, but none was found. A specimen containing microscopic amounts of covellite was collected from the face of one of the crosscuts on the 1,800 level. As this specimen had been exposed to mine oxidation only a few hours before collection, its covellite cannot be due to mine oxidation. This evidence is conclusive that no covellite is formed by mine oxidation and that all the Magma covellite is supergene.

Although sphalerite enriches easily to covellite, no such enrichment was observed in polished sections of Magma ores. Occasional areas of sphalerite are observed in polished sections of ores from the zone of enriched bornite. The solutions evidently contained sufficient copper to develop covellite as a replacement of bornite but not sufficient to attack sphalerite.

Chalcopyrite ($CuFeS_2$): Chalcopyrite occurs as veinlets and plates cutting bornite. Although not important quantitatively, it is widespread and persists to the deepest workings of the mine. Some of these veinlets and plates follow cracks and seams in the bornite. These veinlets and plates are interpreted by M. N. Short as supergene. The replacement commonly took place along parallel directions in the bornite, giving a grating (Pls. XVII *D;* XVIII *A, B*).

VENTILATION AND AIR CONDITIONING[54]

The Magma mine is in a semiarid region, with an average yearly precipitation from 1921 to 1943, inclusive, of 18.47 inches. The elevation of the 500 or main adit level is 3,034 feet above sea level. The average surface dry-bulb temperature is 72.4 degrees, and the average yearly surface wet-bulb temperature is 57.4 degrees. This represents an average yearly relative humidity of 38 per cent.

Rock temperatures: Rock temperatures taken on the lower levels of the mine are as follows:

Level	Degrees F.	Level	Degrees F.
2,000	109	4,000	140
2,250	112.5	4,200	143
2,550	116	4,400	146
2,800	120	4,600	149
3,000	124	4,800	152
3,200	127		

The high surface temperature coupled with the higher-than-average rock temperatures presents a serious ventilation problem.

Underground water: The underground water varies from 350 to 565 gallons per minute, with a yearly average of approximately 400 g.p.m. The limestone and other sedimentary rocks act as a

[54]By C. B. Foraker, Engineer, Magma Copper Company (Apr. 12, 1944); see also A.I.M.E. T.P. 979, Sept., 1938; A.I.M.E. Trans., vol. 141, pp. 253-67, 1941.

PLATE XV

A.—Supergene chalcocite (light) replacing bornite (dark). Larger areas of bornite are traversed by tiny cracks of chalcocite. By progressive widening of these cracks and rounding of sharp edges of bornite areas, unreplaced bornite is left as formless masses surrounded by chalcocite. This type of replacement has been found only in enrichment zone and has not been observed in deep-level chalcocite. 900-foot level, E. 2½ stope, 20 feet below 800-foot level. (x 100)

B.—Chalcocite replacing pyrite. Enrichment process is intense here and no hypogene copper sulfides remain unreplaced. Outline of a large pyrite grain in midst of chalcocite area in upper right quadrant of picture is very clear, but only a few small patches of pyrite along margins of former grain have escaped replacement by chalcocite; interior of grain is now all chalcocite. Strongly indicative of supergene replacement. 500-foot level, W. 1½ stope. (x 100)

C.—Native silver replacing supergene chalcocite. This type of silver mineralization occurs only in the enrichment zone and accounted for the silver production in the early years of the mine. 650-foot level, E. drift at 7 raise. (x 290)

D.—Pyrite oxidizing to limonite in presence of covellite. Pseudomorphs of limonite are sharp and clean-cut. Area between pseudomorphs is practically all covellite which has replaced chalcocite, only a few small triangular patches of chalcocite remaining unaltered. Different shades of covellite are due to its anisotropism. Process is indicative of strongly oxidizing conditions. Pseudomorphs of limonite after pyrite are probably due to the neutralization by calcium carbonate solutions of sulfuric acid generated by oxidation of pyrite. 500-foot level, 1 W. raise, 30 feet below 400-foot level. (x 100)

cc:—chalcocite
bn:—bornite
py:—Pyrite
Q:—quartz
Ag:—native silver
lim:—limonite
cv:—covellite

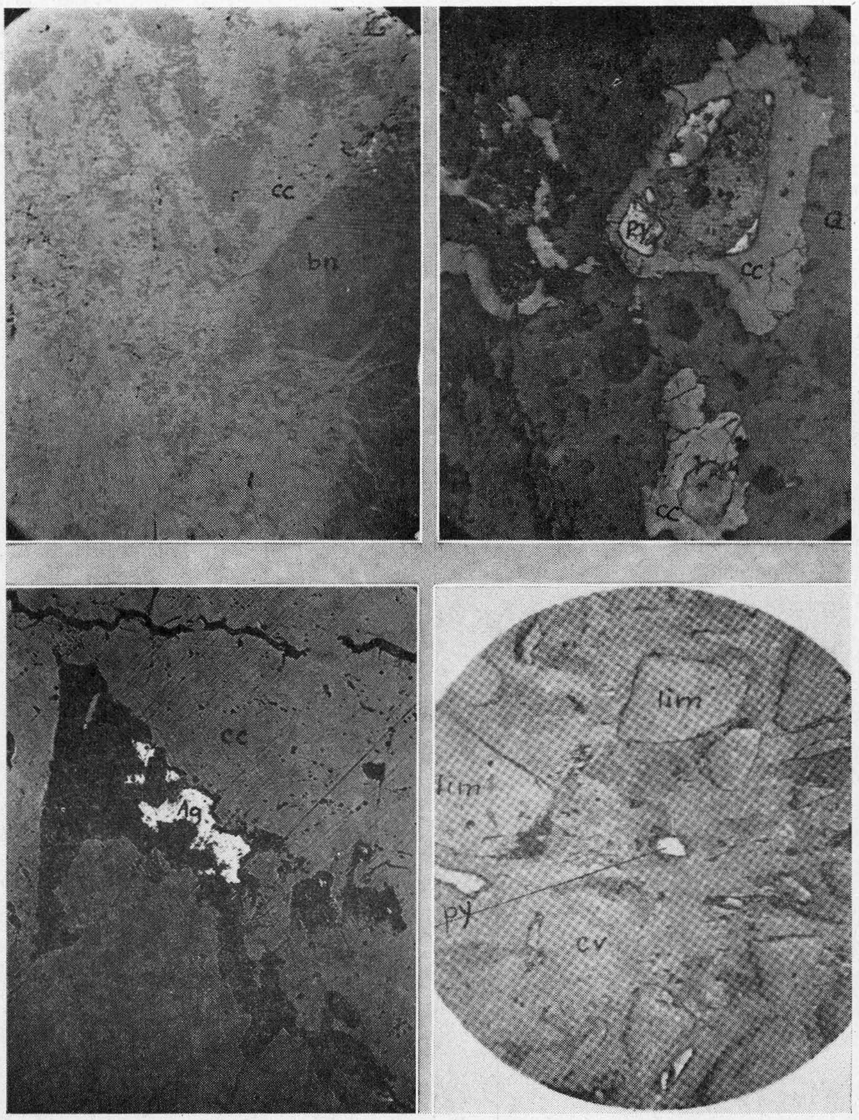

Plate XV.—Photomicrographs of Magma ore.

PLATE XVI

A.—Chalcocite in veinlets cutting chalcocite-bornite intergrowth. Chalcocite in larger areas is of deep-level type. It shows "mutual" and subgraphic patterns with bornite. Chalcocite in veinlets is distinctly later. It follows cracks in bornite. Where veinlets pass into larger chalcocite areas, chalcocite almost loses its identity, but continuity of veinlet is shown by scattered cracks. Cracks are later than deep-level chalcocite, and chalcocite in veinlets is later than cracks which it follows; hence, two generations of chalcocite are represented. It is believed that chalcocite in larger areas is hypogene and that in veinlets is supergene. 2,000-foot level, W. drift. (x 100)

B.—Mottled chalcocite. Small darker patches in midst of lighter chalcocite are believed to represent "ghosts" of unreplaced bornite. When etched with HNO_3 these darker areas give etch tests like lighter chalcocite. This type of chalcocite is invariably supergene. 500-foot level, E. 1½ stope. (x 175)

C.—Blue chalcocite in bornite. This type of chalcocite has been subjected to oxidation. Wide parallel cracks are due to solution and removal of material. Covellite deposited along some of these cracks probably by direct oxidation. Origin of chalcocite in larger areas is obscure; it may be hypogene. Small veinlets of chalcocite near by are probably supergene. 3,600-foot level near main x-cut. (x 175)

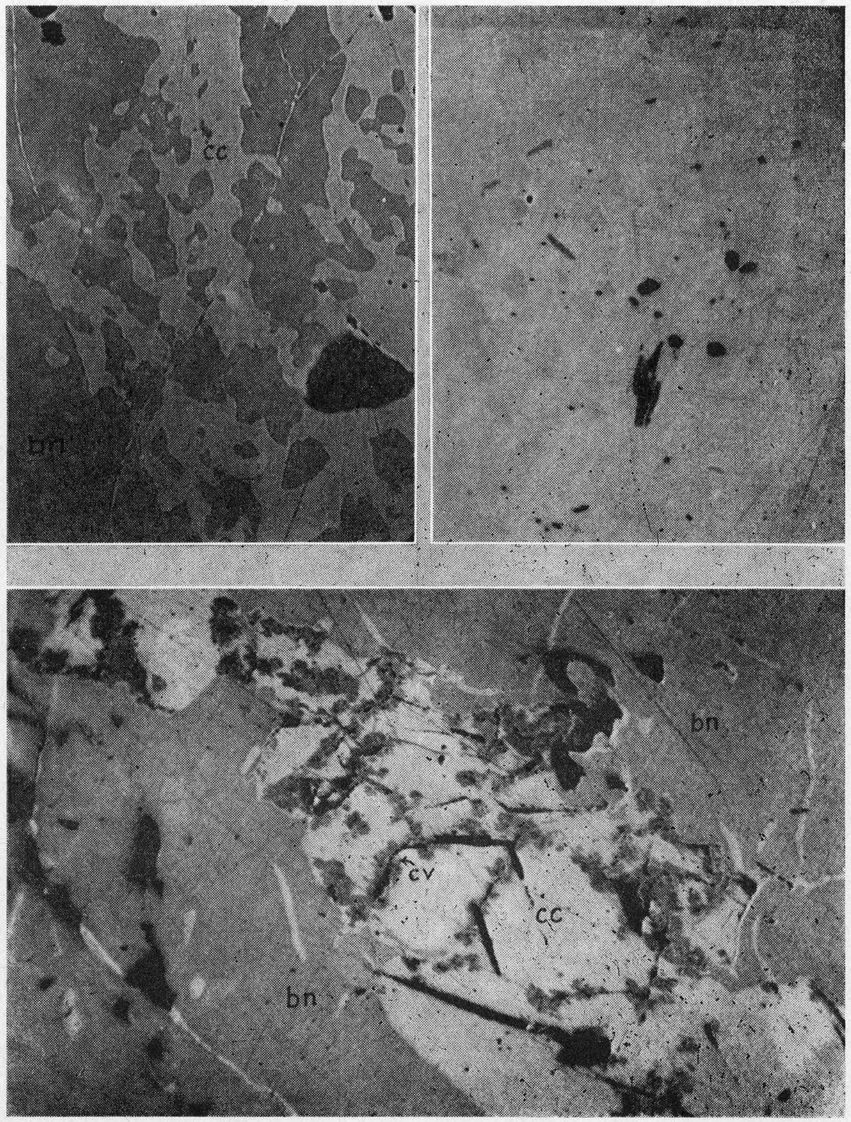

Plate XVI.—Photomicrographs of Magma ore.

PLATE XVII

A.—Supergene covellite replacing bornite. This type of covellite has been found on the 3,600-foot but not on deeper levels. Amount of covellite in specimen is less than 1 per cent of total area. 3,600-foot level, 21 1/5 stope. (x 75)

B.—Covellite replacing chalcocite. Covellite plates show different shades of gray due to anisotropism. This type of covellite is found only high in the enrichment zone where oxidation is superimposed on supergene enrichment. Covellite is due to direct oxidation of chalcocite. Malachite is found in the same specimen. 500-foot level, 1½ raise. (x 100)

C.—Supergene covellite replacing bornite along small cracks. From same specimen as A. (x 100)

D.—Supergene covellite and supergene chalcopyrite replacing bornite. On upper right border of picture covellite follows boundary between quartz and bornite. Elsewhere covellite follows tiny seams in bornite. Chalcopyrite in part follows seam and in part replaces bornite along parallel, probably crystallographic directions. The quantity of covellite in specimen is about 5 per cent. 1,000-foot level, E. drift 30 feet from main x-cut. (x 160)

cp:—chalcopyrite

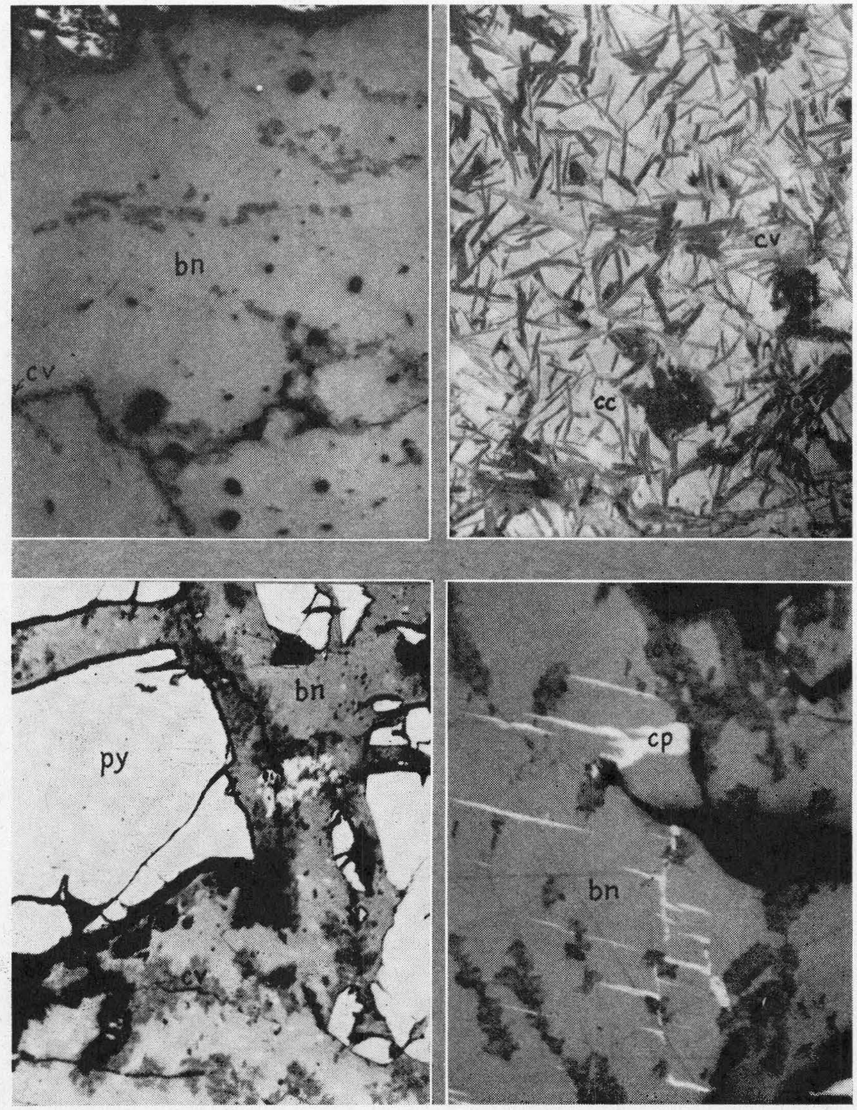

Plate XVII.—Photomicrographs of Magma ore.

PLATE XVIII

A.—Supergene chalcopyrite replacing bornite along fracture. In the main, chalcopyrite follows fractures closely but shows a distinct tendency to go out into bornite as thin plates. Larger areas of chalcopyrite do not follow open spaces, have smooth boundaries with bornite, and are probably hypogene. 2,000-foot level, 15-W. x-cut. (x 75)

B.—Chalcopyrite grating in bornite. Two possible causes for texture. In gratings of replacement origin, enlargements of chalcopyrite areas at intersections of chalcopyrite lamellae would be expected. Here they are lacking. The second and more probable theory for their origin is that the lamellae crystallized from an original solid solution on cooling. Both types cf chalcopyrite-bornite grating have been produced by experiment. 3,600-foot level, 35 3/5 stope. (x 160)

C.—Pyrite aligned along quartz. Pyrite occurs in small rounded grains which owe their position to quartz. Hence quartz is clearly earlier than pyrite. 3,400-foot level, W. 31 3/5 stope. (x 75)

sl:—sphalerite

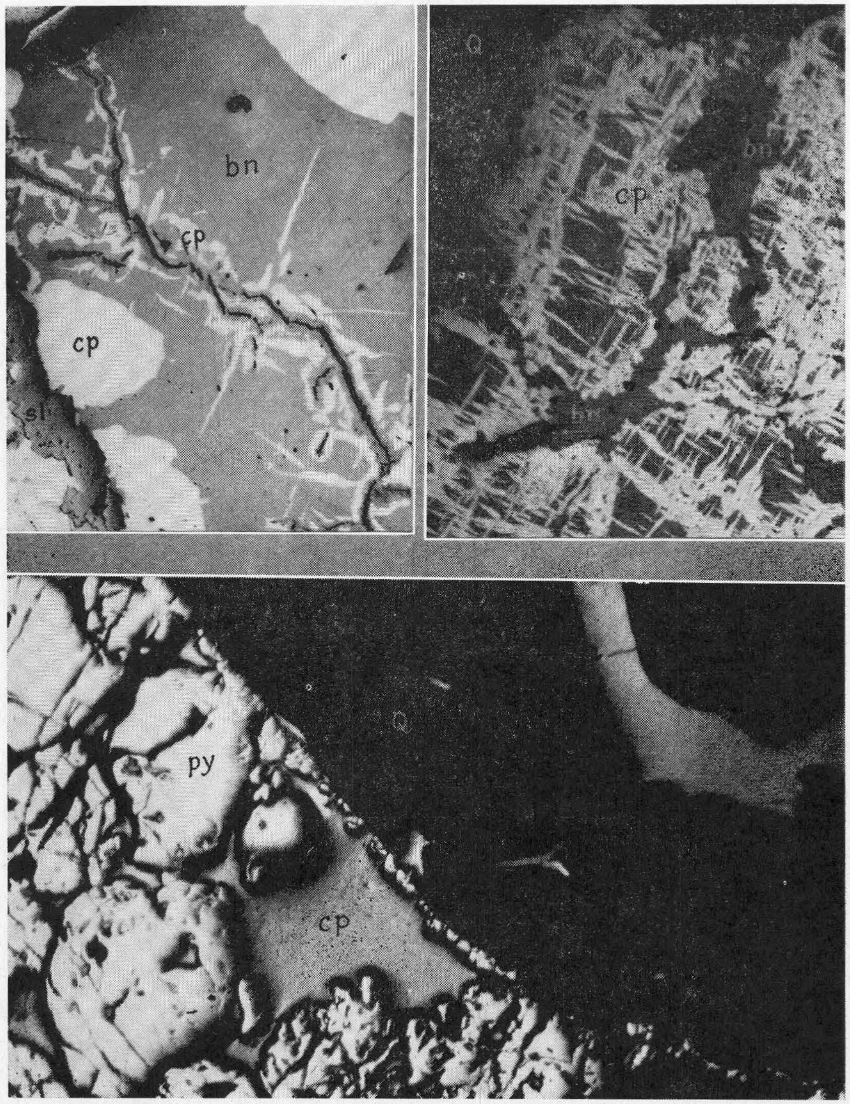

Plate XVIII.—Photomicrographs of Magma ore.

PLATE XIX

A.—Subgraphic bornite-chalcocite intergrowth. In upper left corner parallelism of bornite lobes is sufficient to designate texture as "true graphic." Both minerals hypogene. 4,000-foot level, W. 34 1/5 stope. (x 75)

B.—Digenite and chalcocite intergrown with each other and with bornite. Textures indicating replacement of one mineral by another are lacking. All minerals believed to be hypogene. 4,000-foot level, W. 34 1/5 stope. (x 75)

C.—Patchy chalcocite-bornite intermixture. This is typical of lower levels of mine (below 3,400-foot level). Replacement textures not obvious. Some embayments in bornite areas may represent replacement. 4,000-foot level, 20 feet W. of 17 x-cut. (x 75)

D.—Patchy chalcocite-bornite intermixture. Chalcocite is clearly replacing bornite. Larger chalcocite areas are joined by small veinlets of chalcocite. All chalcocite may be due to replacement of bornite, but it is more probable that most of chalcocite is contemporaneous with bornite, but chalcocite persised after all bornite had been deposited. All chalcocite is hypogene. 3,600-foot level, W. 36 1/5 stope. (x 75)

wcc:—white chalcocite
bcc:—blue chalcocite (digenite)

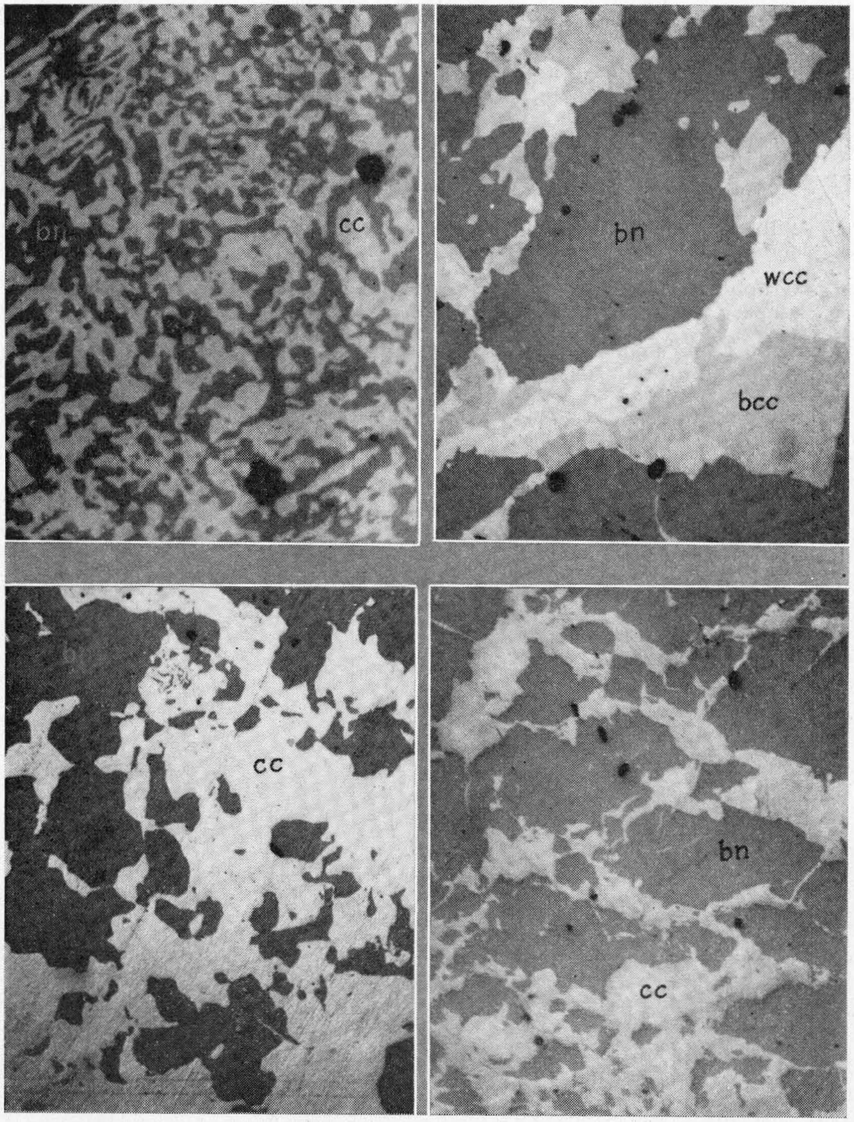

Plate XIX.—Photomicrographs of Magma ore.

PLATE XX

A.—Blue chalcocite areas in bornite. Similar to Plate XVI, C. Parallel cracks in chalcocite show solution and removal of material. At least part and possibly all of chalcocite is hypogene replacement of bornite. Blue color of chalcocite is due to presence of covellite in solid solution. This may be due to direct oxidation of chalcocite. 3,600-foot level, W. 21 1/5 stope. (x 40)

B.—Subgraphic chalcocite-bornite intermixture. Both are hypogene. 2,000-foot level, 8 x-cut. (x 100)

C.—Graphic chalcocite-bornite intermixture. 3,400-foot level. W. 21 1/5 stope. (x 400)

D.—Subgraphic chalcocite-bornite intermixture replacing pyrite in exploded bomb texture. 3,400-foot level, W. 24 stope. (x 100)

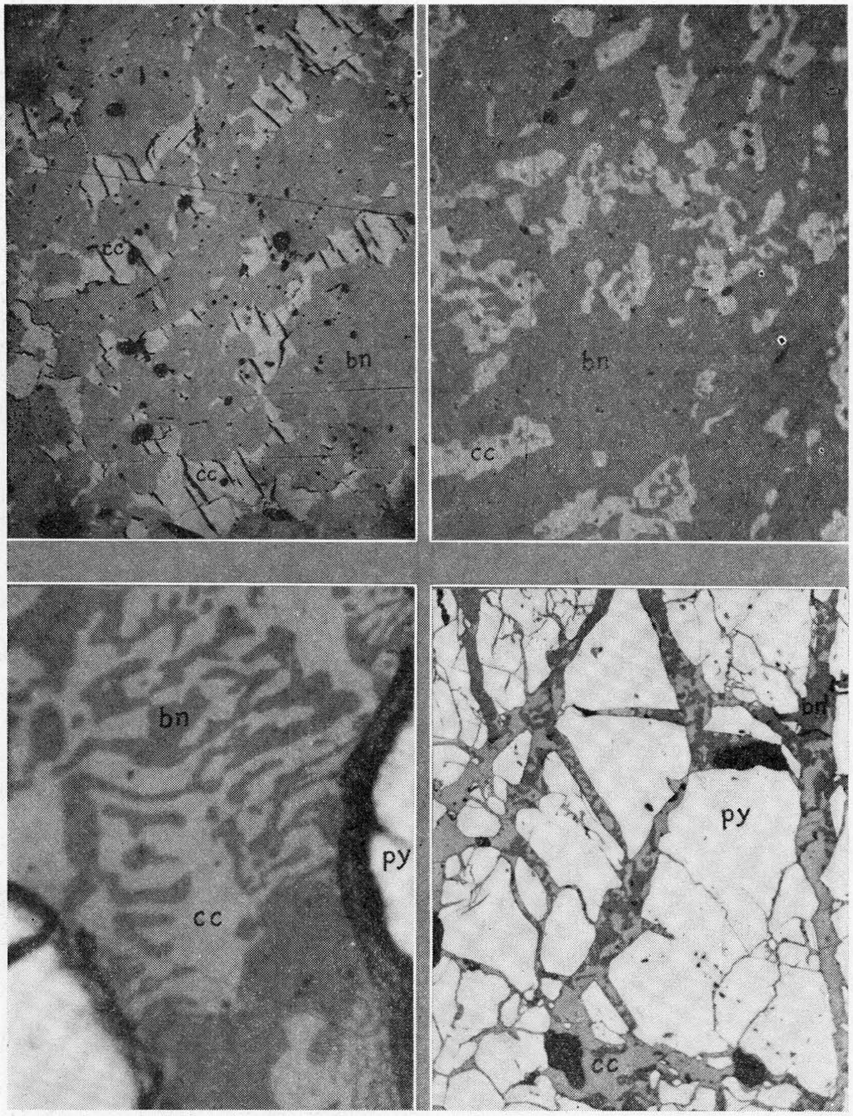

Plate XX.—Photomicrographs of Magma ore.

PLATE XXI

A.—Deep-level chalcocite (light) and bornite (dark). Cigar-shaped bornite areas show pronounced parallelism. Between bornite "cigars" is a subgraphic intergrowth of chalcocite and bornite. It is believed cigars are skeletal crystals of bornite which were first to form. With a decrease in iron content, remaining materials in solution separated out as simultaneous deposition of chalcocite and bornite. 2,000-foot level, 15 x-cut. (x 160)

B.—From same section as A. Some of larger bornite areas are crossed by irregular veinlets of chalcocite. With further decrease in iron content, conditions were such that only chalcocite deposited. Solutions depositing chalcocite had some replacing action on bornite which took form of veinlets. These veinlets lack continuity and regularity of supergene chalcocite veinlets and do not follow cracks and gangue boundaries. All the chalcocite is believed to be hypogene. (x 330)

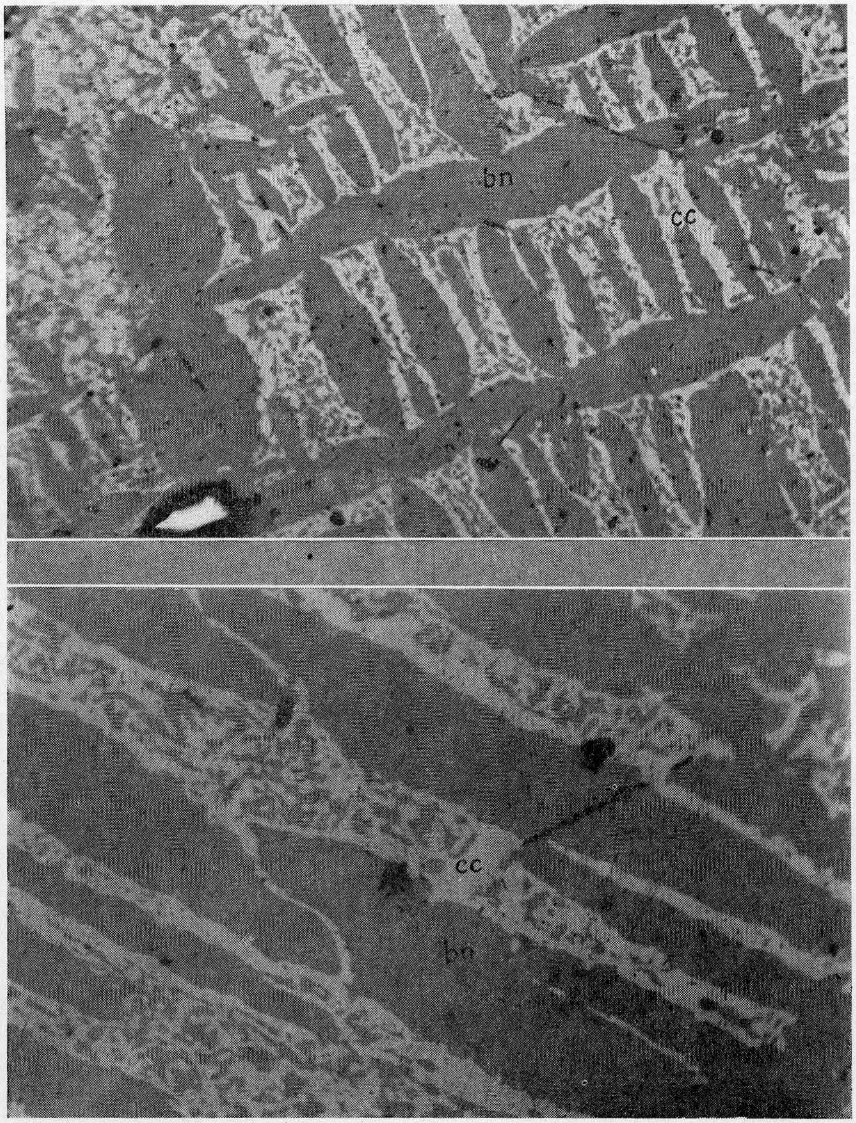

Plate XXI.—Photomicrographs of Magma ore.

PLATE XXII

A.—Stromeyerite-galena intergrowth in quartz vug. Metallic minerals show typical "mutual boundary" pattern. They are believed to be contemporaneous and hypogene. 1,200-foot level, W. drift near 8 raise. (x 100)

B.—Stromeyerite inclusions in bornite. These textures afford no proof of relative age of the minerals. Galena inclusions in upper right corner have same shape as those of stromeyerite. All minerals are hypogene. 1,400-foot level, W. drift, 8 x-cut. (x 160)

gn:—galena
str:—stromeyerite

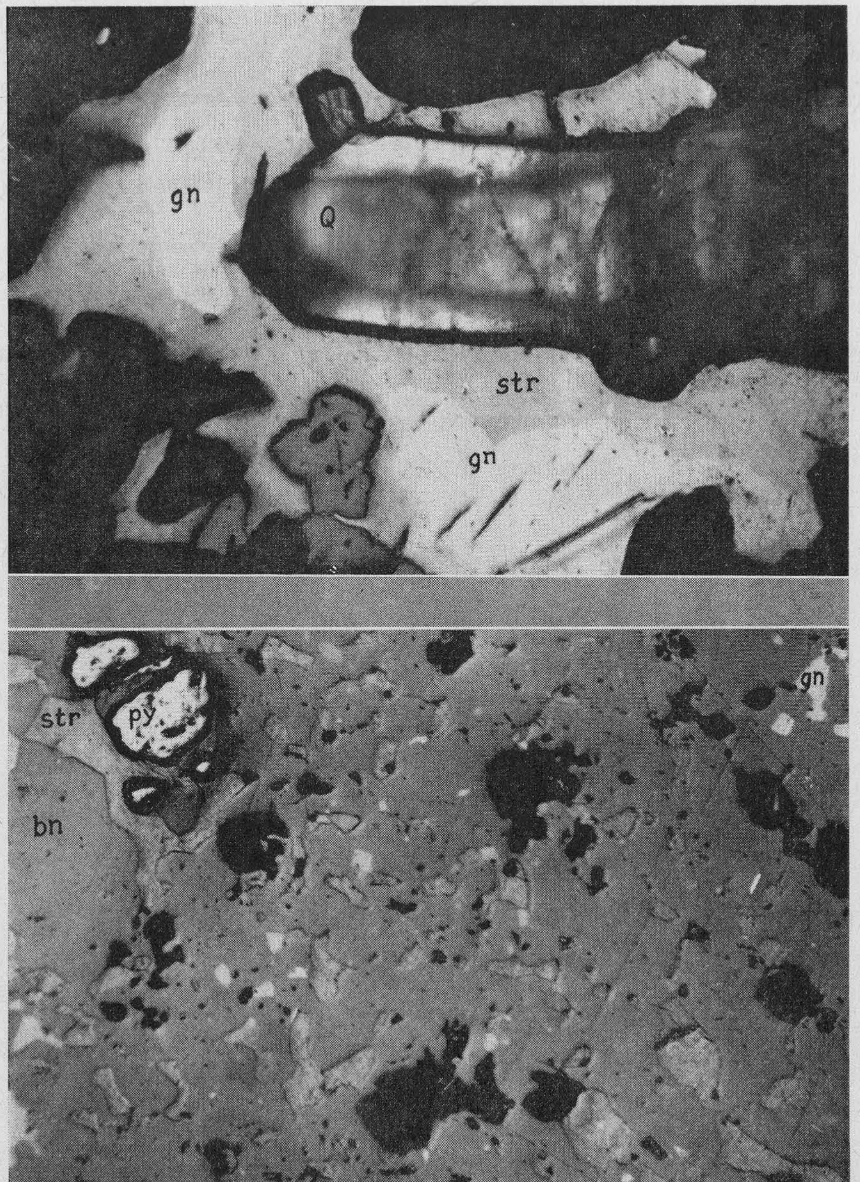

Plate XXII.—Photomicrographs of Magma ore.

PLATE XXIII

A.—Graphic pattern of galena in bornite. Galena is invariably hypogene. Graphic texture is, in this case, a proved hypogene texture. Conclusion is that chalcocite in similar textural relation to bornite is likewise hypogene. 1,000-foot level, E. drift, E. ore body. (x 330)

B.—Sphalerite replacing pyrite in exploded bomb texture. 1,800-foot level, E. drift at 20 raise. (x 75)

C.—Bornite replacing enargite. Parallelism between bornite areas and enargite cleavage (short vertical cracks) indicates that enargite exerted a crystallographic control on bornite deposition. 4,000-foot level, 35 3/5 x-cut. (x 75)

D.—Bornite and chalcocite in veinlets replacing enargite. Bornite and chalcocite have been etched with 1:1 HNO_3 to bring out contrast with enargite. Chalcocite in upper part of picture shows distinct etch cleavage. All minerals are hypogene. 4,000-foot level, W. 37 stope, 2nd floor. (x 80)

en:—enargite

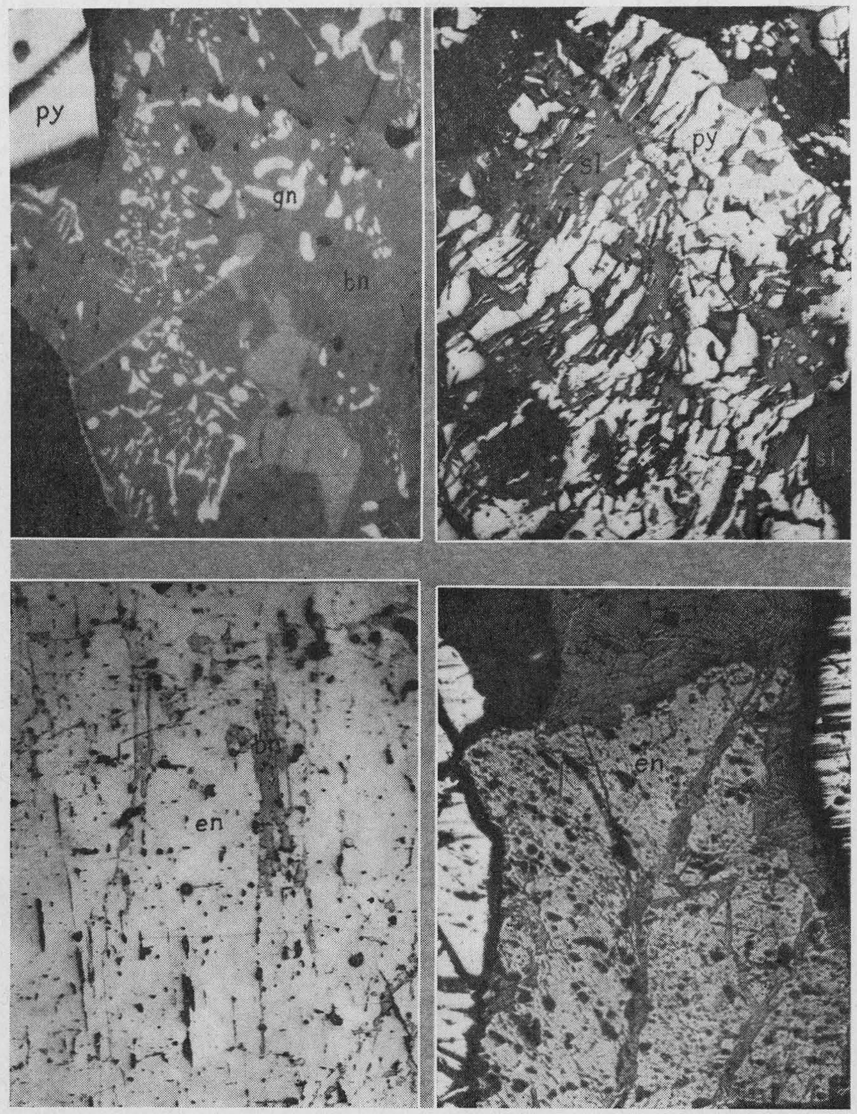

Plate XXIII.—Photomicrographs of Magma ore.

PLATE XXIV

A.—Bornite-tennantite intermixtures. No texture indicative of replacement is seen and both minerals are probably nearly contemporaneous with bornite deposition overlapping that of tennantite slightly. Quartz is euhedral and is probably earlier than all sulfides. Either quartz crystals formed a vug which was filled by sulfides—the more probable explanation—or sulfides have replaced some gangue formerly surrounding quartz. 1,800-foot level, W. drift at 13 x-cut. (x 100)

B.—Tennantite in veinlets cutting sphalerite. In part these veinlets fill cracks in sphalerite and in part tennantite occupies boundaries between quartz and sphalerite. Most geologists regard tennantite as always hypogene, but these textures point rather strongly to supergene origin. 1,800-foot level, W. drift at 18 x-cut. (x 75)

tn:—tennantite

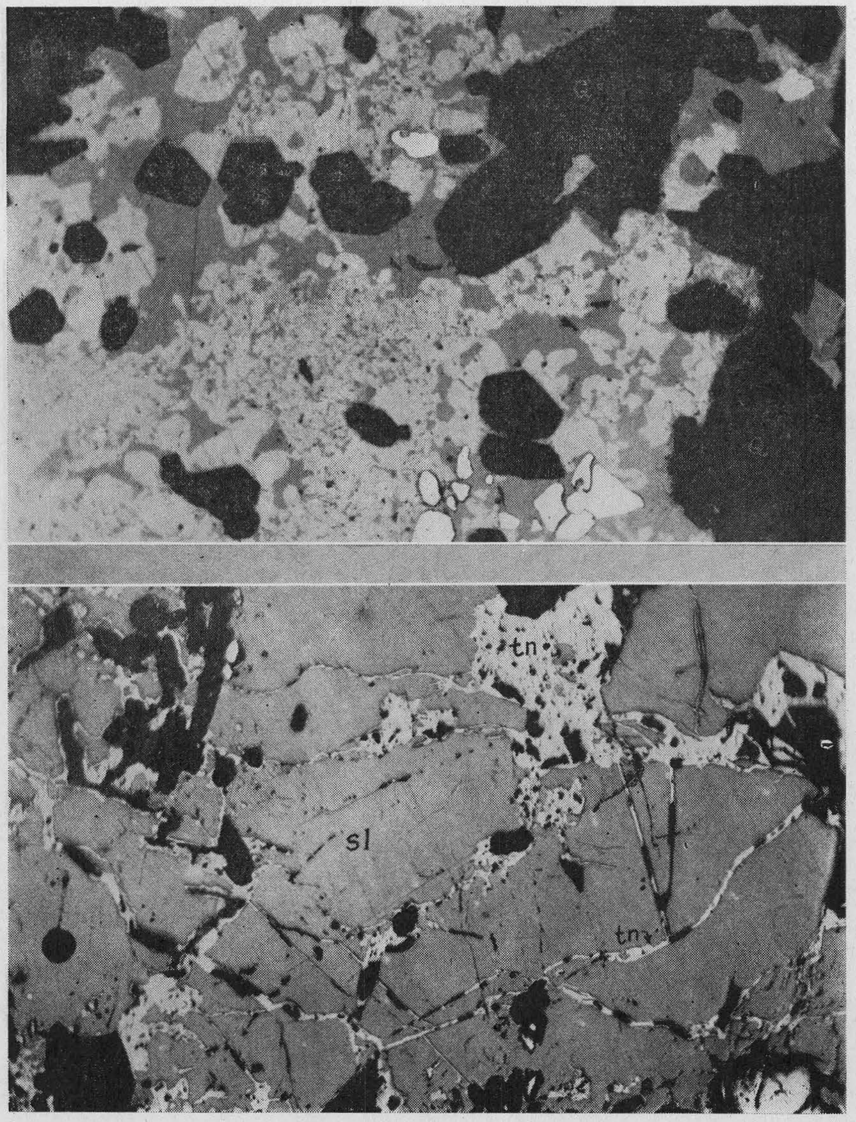

Plate XXIV.—Photomicrographs of Magma ore.

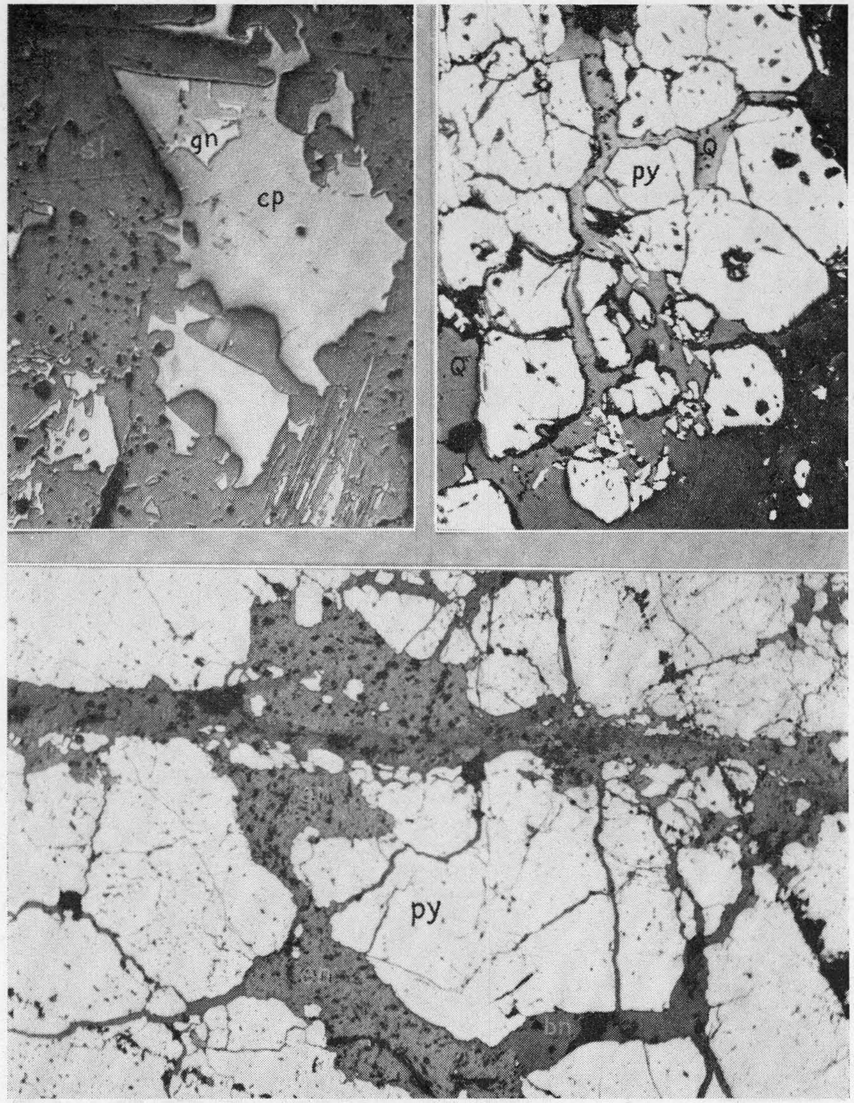

Plate XXV.—Photomicrographs of Magma ore.

A.—Chalcopyrite and galena replacing sphalerite. Straight borders of sphalerite indicate that replacement was controlled by crystallographic directions in sphalerite. 1,500-foot level, 50 feet west of main x-cut. (x 55)

B.—Quartz replacing pyrite. 1,800-foot level, main x-cut. (x 36)

C.—Enargite and bornite replacing pyrite. 4,000-foot level, W. drift at 23 4/5 raise. (x 75)

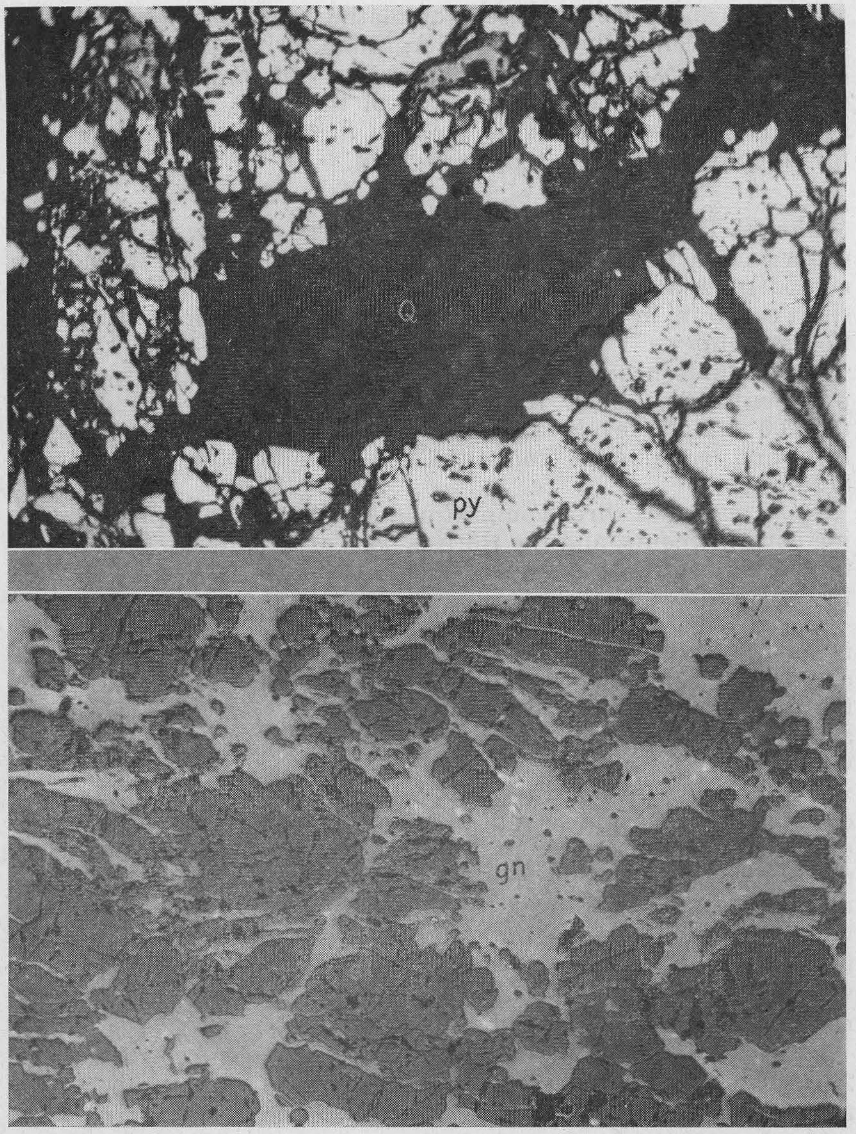

Plate XXVI.—Photomicrographs of Magma ore.

A.—Quartz replacing pyrite. 3,600-foot level, 29 3/5 stope. (x 75)

B.—Galena replacing sphalerite. 1,100-foot level near main x-cut. (x 35) reservoir, and the rain water percolating through them from the surface is eventually found underground, principally on contacts between diabase and sedimentaries. For this reason most of the water is found in the eastern part of the mine, where the sedimentaries have been cut by the east drifts. The vein, however, for the most part, is damp throughout.

Shafts: The eight shafts on the property are numbered in the order in which they were sunk. No. 1, the original shaft, had two compartments 4 by 4 feet and was sunk to the 800 level. This shaft caved in, in 1927, and does not enter into the present ventilation system.

No. 2 shaft has one compartment 3 by 4 feet and two compartments 4 by 4 feet. It is connected to the surface by adits on the 200 and 500 levels. It is concreted from the 200 to the 3,200 level and is timbered from the 3,200 to the 3,600 level, where it bottoms.

No. 3 shaft has three compartments 4 by 5 feet. Two are hoisting compartments, and the third is used as a manway; it also contains pipe columns and power cable. It extends from the surface to the 4,800 level.

No. 4 is the exhaust shaft for the east section of the mine and is concreted throughout. It has two compartments 5 by 5½ feet, one 5 by 6 feet down to the 1,000 level, and two compartments 5 by 5½ feet from the 1,000 to the 1,500 level. On the 1,000, 1,200, and 1,500 levels it is connected by a system of raises to the lower workings.

No. 5 shaft was sunk to prospect the faulted part of the vein on the west end and is southwest of the main stoping area. It extends from the surface to the 4,800 level and has four compartments 4 by 5 feet, of which two are for hoisting, one is for a manway, cable, and pipe, and the fourth is open for ventilation.

No. 6 shaft was sunk from the surface to the 2,550 level approximately 4,550 feet east of shafts No. 2 and 3 for the purpose of ventilating the eastern part of the mine. It has three compartments 4 by 5 feet and is timbered throughout.

No. 7 shaft is west of No. 5 and was sunk from the surface to the 2,550 level to ventilate the stoping area southwest of No. 5. It has three compartments 4 by 5 feet and is timbered throughout.

No. 8 shaft has been sunk from the surface to the 4,800 level, and it is the exhaust shaft for the west section of the mine. It has four compartments 5 by 5 feet square. The sets are of steel, and the shaft is smooth-lined with 2- by 2-inch lagging.

Nos. 2, 3, 5, 6, and 7 shafts are air intakes in the ventilation system, and Nos. 4 and 8 are exhausts. Nos. 2, 3, and 5 are operating shafts, and the others are for ventilation only.

Nos. 4 and 8 shafts are equipped with 8- by 4-foot Jeffery fans which exhaust 330,000 cubic feet of air per minute from the mine.

Drifts and crosscuts: Down to the 2,000 level all drifts and crosscuts were small, generally 5 by 7 feet. As depth and higher rock temperatures necessitated better ventilation, all drifts from the 2,000 level down have been driven 8 by 8 feet in the clear. This construction permits a greater volume of air to pass through and reduces the mine resistance. In general, the ventilation system consists of taking the fresh, or intake, air to the lowest possible level by using booster fans, then letting it ascend through the working places through the stopes and stope raises to the exhaust shafts.

The efficiency of air distribution is maintained by preventing recirculation by the use of air locks. Standard doors are built of a double thickness of 1-inch boards, one layer vertical and the other at 45 degrees to the vertical, with a thickness of roofing paper between the layers. Leakage around the doors is kept at a minimum by skirts, or flaps, made of discarded belting.

The Magma Copper Company has standardized on the No. 8 American high-speed fan for booster service. This fan has been found to be adequate, is easily handled in small shafts, and requires very little rock excavation to install. It is of the double-width, double-inlet type, with backward-curving blades which give a nonoverloading characteristic. Power is supplied by a 40-h.p., 2,200-volt, 25-cycle, 3-phase induction motor directly connected to the fan and operating at 720 r.p.m.

Auxiliary ventilation: In all drifts, raises, and other dead-end working places, auxiliary ventilation is necessary. For this ventilation two types of fan are used: No. 3 Troy Sirocco with forward-curved blades and 10-h.p. motors, and No. 4½ American H.S. with backward-tipped blades and 7.5-h.p. motors. Rubber-covered canvas ventilation tubing 24, 16, and 12 inches in diameter is used to deliver the air to working places. It has been the experience at Magma that efficiency of the workmen falls off rapidly when the wet-bulb temperature is above 85 degrees and the relative humidity is above 85 per cent. Wet drilling and sprinkling of muck piles to allay the dust is of course necessary, even though it tends to raise the relative humidity. Every effort is made to keep drifts and tunnels as dry as possible by confining water to ditches and keeping it from contact with the air.

In the past, occasional, but not serious, cases of heat cramps were caused by the loss of body salt through excessive perspiration. In 1936, 15-grain salt tablets were made available to all the workmen. Swallowed, usually with a drink of water, they maintain the proper saline balance in the body. Since this practice was instituted, no workman who has used the salt tablets has had an attack of heat cramps.

None of the fans have reversing facilities, as it is thought best to maintain all air currents as nearly normal as possible in case of fire. For giving underground fire alarms, ethyl mercaptan is used. This chemical is injected into the compressed-air lines, from which it passes into the ventilation currents and reaches all working places. Ethyl mercaptan is extremely volatile and vaporizes immediately when liberated. It has a very unpleasant odor, and by its use a fire warning can be given to everyone in the mine in twenty minutes.

Air conditioning: After the 3,200 level had been developed, it became evident that artificial cooling and air conditioning would be necessary to assist ventilation. Early in 1936 it was decided to install a refrigeration plant on the 3,600 level to air-condition the 3,600 and 3,400 levels.

For this plant, two Carrier centrifugal compressor units, each of 140 tons refrigeration capacity, were selected. The refrigerant used is Carrene No. 2, monofluorotrichloromethane ($CMCl_3$), which is a colorless, odorless liquid at ordinary temperatures. It is nontoxic, noncombustible, noninflammable, and has a boiling point of 74 degrees. Each unit is powered with a 200-h.p., 2,200-volt, 3-phase, 25-cycle induction motor operating at 1,440 r.p.m., which is stepped up by speed-increasing gears to drive the compressor at 6,750 r.p.m.

When each unit is furnished with 200 g.p.m. of 90 degree condenser water, it will cool 350 g.p.m. of chilled water to 60 degrees. This chilled water is circulated in closed circuit to Aerofin cooling coils. Fans of 30,000 c.f.m. capacity draw air through the cooling coils, and the coils are designed to cool this volume of air 12 degrees on the wet-bulb temperature.

A third unit was installed on the 4,000 level in 1939, and three more were installed in 1941. The six units are almost identical, the only difference being in the condensing temperature. For the purpose of making this difference clear, we shall refer to three machines as Type A, in which the condenser water enters the unit at 93 degrees and leaves at 117 degrees, and the other three as Type B, in which the condenser water enters at 117 degrees and leaves at 135 degrees.

Each machine requires 200 g.p.m. of condenser water. Many unsuccessful attempts have been made to develop water both underground and from the surface. The only water available is that made by the mine, an average of about 400 g.p.m.

Most of the underground water comes from the east section of the mine where its temperature coming from the rock is from 109 to 130 degrees. This water is sprayed into No. 6 shaft where it is cooled to about 90 degrees; it then flows by gravity through ditches and pipe lines to a gathering sump on 3,600 level. It picks up some heat enroute and arrives at the sump at 92 or 93 degrees.

By using machines having different condensing temperatures, it is possible to pass the same water through two machines. The water enters an "A" type machine at 93 degrees and leaves at 117 degrees, and enters a "B" type machine at 117 degrees and leaves at 135 degrees. With six machines this still leaves the problem of furnishing 600 g.p.m. from 400 g.p.m.

To solve this problem a five-stage spray pond was built on the 3,600 level near No. 8 shaft in the exhaust air. This cooling pond cools 200 g.p.m. from 135 to 92 degrees. The spray pond consists of separate ponds, each 8 by 20 feet, and 936 spray nozzles (3/16-in.), divided among the five stages. Condensing water from one condenser enters the first stage at 135 degrees and is sprayed. It is then picked up from this stage and sprayed into the next by a 10-h.p. Byron Jackson "Bilton" pump. This is repeated in the other stages, and the water flows from the last stage back to the original condenser water-gathering sump.

The present arrangement of the machines is two units, one Type A and one Type B on the 3,600 level, with cooling coils and fans placed to serve the 3,600 and 3,800 levels; two units, one of each type on the 4,000 level, to serve two locations on this level; and two, one of each type on the 4,400 level, to serve two different locations on this level.

The circulation of the condenser water is as follows: From the storage sump, 600 g.p.m. is pumped through the three Type A machines on the three different levels and then on through the three Type B machines, on the same levels. The condenser water from the units on 3,600 and 4,400 is returned to the 3,600 level where it is pumped out of the mine by the main mine pumps. The water from the 4,000 level units returns to the 3,600 level and goes through the spray pond for recooling.

The main mine pumps are two horizontal duplex Prescott pumps, 600 g.p.m. capacity against a 3,300-foot head, which are powered with 600-h.p. motors. One is used for pumping, while the other is a stand-by.

MINING METHODS USED AT THE MAGMA MINE[55]

The mining methods used at the Magma mine prior to about 1929 have been described in several articles. Only the methods now being used are outlined in the following brief description.

Recent changes in the mining methods have related chiefly to stoping. The modifications resulted from a change in the type of wall rock, more variation in the vein width on the lower levels, and the desire for more selective mining.

Most of the Magma ore bodies occur as shoots in a strong east-west fault zone which has an average dip of about 75 degrees south. A few ore bodies occur on branches of this fault and on adjacent parallel breaks. The ore shoots range from a few feet

[55]By B. Van Voorhis, Engineer, Magma Copper Company (May 2, 1944). See also E. D. Gardner and C. H. Johnson, Copper Mining in North America: U.S. Bureau of Mines Bull. 405, pp. 234-7, 1938.

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The present arrangement of the machines is two units, one Type A and one Type B on the 3,600 level, with cooling coils and fans placed to serve the 3,600 and 3,800 levels; two units, one of each type on the 4,000 level, to serve two locations on this level; and two, one of each type on the 4,400 level, to serve two different locations on this level.

The circulation of the condenser water is as follows: From the storage sump, 600 g.p.m. is pumped through the three Type A machines on the three different levels and then on through the three Type B machines, on the same levels. The condenser water from the units on 3,600 and 4,400 is returned to the 3,600 level where it is pumped out of the mine by the main mine pumps. The water from the 4,000 level units returns to the 3,600 level and goes through the spray pond for recooling.

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to more than 2,000 in length and have a maximum width of about 30 feet.

A change to the present development and stoping method was made after the 2,800 level was reached. A level interval of 200 feet has been used from the 2,800 level to the present bottom of the mine, the 4,800 level.

The main copper ore body is developed by sinking the No. 3, 5, and 8 shafts and the West No. 14 winze. These shafts are sunk at least 100 feet below the level to be developed to make the necessary shaft length for the shaft pockets, spill pockets, and sump. At a point 60 feet below the proposed level, loading-pocket stations are cut on both sides of the shaft opposite the hoisting compartments. At the top, and back from these loading stations, raises of 55 degrees incline, pointed away from the shaft, are driven to the elevation and position of the proposed level tail drift. The shaft crew then cuts the shaft stations and drives the tail drift from 50 to 100 feet both ways from the shaft. The pocket raises are widened to about 10 by 10 feet and become the shaft pockets. The tops of these pockets are covered with grizzlies made of 70-pound rails spaced 9 inches apart. If the ground will permit the pockets are not timbered, but if the ground is soft or heavy they are cribbed and lined. The loading baskets and air-operated pocket doors are then installed in the shaft-loading pocket stations, completing the shaft-sinking program.

A five-man drift crew drives an 8- by 8-foot crosscut from the shaft tail drift to intersect the vein. A drift of this same size is then started on the vein by working toward each other from opposite shafts. Channel samples of the faces of these extraction drifts are taken at 10-foot intervals for assay records. In addition to the extraction drift, a parallel drift, also 8 by 8 feet, is driven in the footwall on every second level. These two drifts are from 75 to 125 feet apart and are connected by crosscuts at intervals of about 300 feet.

Upon completion of drift work on the level, double-compartment cribbed raises from the extraction drift are driven into the footwall of the vein. These raises are spaced at 105-foot centers along the vein. Drilling is done by self-rotating stopers, using detachable bits, and the rounds are fired by electricity.

At the completion of a stope raise two stopes may be started, because each raise is used as a waste passage, timber passage, manway, and ventilation opening for two stopes. Each stope is laid off nine sets, or 45 feet, measured from the center of the raise along the vein. This arrangement permits a length of 90 feet along the vein to be mined by the two stopes served by the one raise.

The ore is stoped by the standard square-set cut-and-fill method. The stope timber is sawed 10- by 10-inch Oregon pine. The sets measure 6 feet 8 inches high and are spaced 5 feet from center to center. As stoping progresses above the sill floor, an arch or incline of about 35 degrees, with the high end at the stope raise, is maintained throughout the mining life of the stope. This arch conforms to the angle of repose of the waste fill. In the two lines of sets at the low end of the arch (the two lines farthest away from the stope raise) the manway and chute are carried upward as the mining progresses. At the completion of a cut in the stope all broken ore is cleaned out, the flooring is removed, and waste fill is dropped from the level above through the stope raise. When the stope is filled the flooring is again laid over the fill, and the stope is ready for another cut.

The waste fill is mined from a surface glory hole connected to the levels of the mine by raises. All waste produced by development work can be dumped into this raise on each of the levels.

A pillar of ore 15 feet wide is left between each of the stope raises. When adjoining stopes have been mined out and completely filled, the pillar is mined either by a modified Mitchell System and timbered with stringers or by the square-set method of the cut-and-fill upward from the bottom. The manway and chute left open by the two adjoining stopes are used when mining these pillars.

LAKE SUPERIOR AND ARIZONA MINE

HISTORY

The Lake Superior and Arizona mine, locally known as the L. S. and A., is on the east edge of Superior (see Pl. I). It extends from Queen Creek northward for 2,300 feet. The property, now owned by the Magma Copper Company and operated intermittently by lessees, comprises the Golden Eagle and five adjacent claims. In the early days of the camp it was known as the Golden Eagle mine and was worked for gold by the Gem Mining Company. This company, after driving short tunnels and shallow pits and paying some dividends, ceased operations in 1885. The existence of copper in the mine was recognized but not considered economic at that time.

In 1902 the Lake Superior and Arizona Mining Company was organized at Calumet, Michigan, to acquire the property and work it for copper. First officers of the company were John D. Cuddihy, of Calumet, President; Dr. W. A. Holt, of Globe, Arizona, Vice-President; A. E. Petermann, of Calumet, Secretary; Wm. B. Anderson, of Calumet, Treasurer; Alfred C. Sieboth, Superintendent; and Henry Richardson, Engineer. Final payment of $31,000 on lands was made November 30, 1903. During 1904 the vertical Vivian shaft, 279 feet deep, was sunk, and three tunnels, the Anderson, Carlton, and Holt, 200, 250, and 500 feet long, were driven. During 1904 several hundred tons of oxidized copper ore were hauled to Florence and shipped to the Val Verde smelter, near Humboldt. At that time the company had thirty employees.

In 1904 the title was changed to Lake Superior and Arizona Mining and Smelting Company. Total mine openings at the beginning of 1905 were approximately 5,000 feet, of which 4,000 feet were of the earlier, random type and the rest systematic development of the L. S. and A. Company. Three ore bodies were developed in Martin limestone at intersections of east-west fractures with the Troy-Martin contact. The principal ore body was 6 feet wide by about 20 thick and followed the eastward dip of the limestone downward at an angle of 26°. The ores were siliceous carbonates and oxides associated with iron and manganese oxides, quartz, and a little free gold.

By the end of 1905 the L. S. and A. Company had driven a total of 9,497 feet of workings. The Holt inclined shaft, 460 feet deep, was sunk on a slope of 26° from the end of the Holt tunnel, 500 feet east of the portal.

Shipments in 1905 were 13 carloads, which assayed 31.6 per cent copper, 2.2 oz. silver, and $2.67 gold, with a net yield of $24,650.

In 1906 no ore was produced, but about $100,000 was spent on development. Assessments totaling $1.00 per share on about 120,000 shares were levied in 1906, 1907, and 1908. By the end of 1908 the Holt shaft had been deepened to 630 feet below the collar, or 850 feet below the surface. A crosscut from the bottom of the shaft was reported to show high values in both copper and gold. The Carlton tunnel, 100 feet vertically below the Holt tunnel, was connected with it by a winze 165 feet long driven on the dip of the ore body. The Carlton tunnel was extended to its portal on Queen Creek, a total length of about 2,000 feet from the Holt shaft. Power was derived from a steam plant on Queen Creek. Supplies were hauled from Florence by wagon at rather high cost, and the company considered building a branch railroad from Florence to the mine. Operations were suspended about November, 1907, and resumed July, 1908, with a force of about sixty men. Production in 1907 was 92,120 lbs. copper, 1,040 oz. silver, and 188 oz. gold. By the end of 1908 the Holt shaft was deepened to 1,800 feet on the incline from the Holt tunnel. Operations were suspended in 1909. Capital paid in by the end of that year totaled $1,680,000.

On August 1, 1910, an option on the property was taken by the Magma Copper Company. The price was set at $500,000, of which, at the option of the L. S. and A. Co., $300,000 was to be paid in Magma Copper Company stock at par value of $1.00 per share. Some development of the property was carried on by the Magma Copper Company in 1910, but work again ceased in 1911. The option was not exercised, and the property remained idle until 1916.

In 1916 the company was reorganized as the Superior Arizona Copper Company with a capital stock of $250,000, par value $1.00 per share, of which $180,000 was issued. Some dump ore was shipped in 1916, and some development was carried on in 1917. Officers of the company were: H. F. J. Knobloch, President; D. E.

PRODUCTION OF LAKE SUPERIOR AND ARIZONA MINE, 1905-1941

Year	Tons	Lbs. copper	Value	Oz. silver	Value	Oz. gold	Value	Tons manganese ore	Value	Total value
Early years..	?	....	....	....	....	?	?	....	....	?
1904	Several hundred	?	?	?	?	?	?	....	....	?
1905	13 cars	?	?	?	?	?	?	....	....	$ 24,650
1907	?	92,120	$ 18,424	1,040	$ 686	188	$ 3,886	....	....	22,996
1917 1918	4,130	768,673	199,855	?	?	?	?	90	$2,601	202,456
1925	214	28,400	4,033	321	223	21	434	....	....	4,690
1926	134	22,130	3,098	35	22	....	....	....	....	3,120
1927	215	38,200	5,004	215	122	3	62	....	....	5,188
1928-31	0	0	0	0	0	0	0	....	....	0
1932	452	3,980	251	452	127	347	7,172	....	....	7,550
1933	7,441	53,700	3,437	9,320	3,262	5,040	128,822	....	....	135,521
1934	19,136	113,040	9,043	16,466	10,637	12,491	437,185	....	....	456,865
1935	13,438	78,695	6,295	11,591	8,331	6,661	233,135	....	....	247,761
1936	5,479	41,806	3,846	4,258	3,298	2,567	89,845	....	....	96,989
1937	10,703	81,326	9,840	11,090	8,578	4,496	157,360	....	....	175,778
1938	9,068	94,484	9,259	6,833	4,414	3,017	105,595	....	....	119,268
1939	6,113	93,600	9,734	4,760	3,227	1,686	59,010	....	....	71,971
1940	6,357	71,298	8,057	4,870	3,462	1,759	61,565	....	....	73,084
1941	4,765	59,679	7,042	2,591	1,842	1,140	39,900	....	....	48,784
Total	87,645+	1,641,131	$297,218	73,842	$48,231	39,416	$1,323,971	90	$2,601	$1,696,671

Thomas, Vice-President; F. V. Munster, Secretary-Treasurer; and D. E. Thomas, F. V. Munster, F. W. Holmes, and A. E. Petermann, Directors.

During 1917-18, 4,130 tons of ore averaging 10.08 per cent copper and yielding 768,673 pounds of copper were shipped, mainly by lessees. Ninety tons containing 43.78 per cent manganese were produced.

In October, 1920, the property and assets of the Superior Arizona Copper Company were acquired by the Magma Copper Company. Shareholders of the Superior Company were entitled to receive $2.00 per share in cash, or within 90 days they could exchange on the basis of 20 shares of Superior for one of Magma. The mine was idle between 1918 and 1925.

During 1925-27 lessees mined and shipped to the Magma smelter a small tonnage of oxidized ores.

In 1932, after discovering gold-quartz ore in the old workings, Sam Herron and Con Laster leased the L. S. and A. mine from the Magma Copper Company and subsequently opened important bodies of gold ore.[56]

GEOLOGY AND ORE

The Lake Superior and Arizona mine is in Cambrian Troy quartzite and Devonian Martin limestone, which strike northward and dip about 30° eastward. According to Ransome,[57] the quartzite-limestone beds above the contact were brecciated by strike faulting. A later examination by Kuhn failed to recognize extensive brecciation at this horizon.

The ore bodies occur as small lenticular replacements along seven east-west faults. The most productive gold horizon along the faults is within Martin limestone, 10-20 feet stratigraphically above the Troy quartzite.

The principal values are in gold, with lesser amounts of silver and copper. The gold ore consists mainly of oxides of iron and manganese, together with fine-grained yellow to gray quartz. Malachite and chrysocolla are found generally below the gold at the quartzite-limestone contact. Silver is associated with both the gold and copper.

All the ore mined has been oxidized. Pyrite and some chalcocite have been found in the lowest working of the mine, 800 feet vertically below the Holt tunnel level. Considerable limonite is associated with the pyrite. These sulfides may have escaped oxidation because of an irregularity in the water table. On the

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[56]Wilson, Eldred D., Arizona lode gold mines, Univ. of Ariz., Ariz. Bur. of Mines Bull. 137, pp. 168-70, 1934.
Gardner, E. D., Mining methods and costs at Herron and Laster Lease, Superior, Arizona, U.S. Bureau of Mines Inf. Circ. 6799, 1934.

[57]Ransome, F. L., Copper deposits near Superior, Arizona: U.S. Geol. Survey Bull. 540, p. 155, 1913.

other hand, their presence may indicate that oxidation took place before the beds were tilted.

Six shoots of gold ore within a horizontal distance of 1,600 feet have been found on the Carlton tunnel level. All bodies of ore on this level are associated with one or more east-west faults, and very few such faults were found between the ore bodies. Evidently east-west faults acted as channelways for the ore solutions.

In the lower levels only one ore shoot has been found. It is a continuation of the general zone, 100-300 feet broad, mined near the collar of the inclined shaft and cropping out northeast of the Holt tunnel portal. East-west faults were found near this shoot on most levels, but at many places within it mineralization has obscured the faulting.

SILVER KING MINE

EARLY HISTORY

The three published accounts[58] of the discovery of the Silver King mine essentially agree. The following is based upon material published by Wm. P. Blake who, as Territorial Geologist, examined the property at various times.

In the middle of the nineteenth century, while settlements along the Gila River were slowly growing and spreading, the mountainous areas in Pinal and Gila counties were still in possession of the Apaches. These marauding savages dominated the whole region and made it almost inaccessible to prospectors who began to press outward from frontier settlements into the mountains. The country is rugged. One of the trails most frequented by the Apaches led over the steep limestone cliffs about 2 miles north of the site of Superior.

In 1873, General George Stoneman, later Governor of California, was commander of the military department of Arizona Territory. In a campaign to stop Apache raids, he established a camp at the base of the mountains close to the Apache trail and constructed a road, the Stoneman Grade, over the cliffs. It became the main route of travel between the Globe mining districts and the valleys of the Salt and Gila rivers.

A soldier named Sullivan, engaged in construction of the grade, was attracted by some heavy, black lumps of metallic material which flattened when hammered. He gathered a few specimens but said nothing of his find. When his term of service expired soon afterward he went to the Charles G. Mason ranch, near the site

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[58]Raymond, R. W., Eighth ann. rept. of the mineral resources west of the Rocky Mts., 1876.
Blake, W. P., The Silver King mine of Arizona. Tuttle, Morehouse, and Taylor, Printers, New Haven, 1883.
Clark, Chas. M., The discovery of the Silver King mine: Ariz. Min. Jour., vol. 8, no. 9, pp. 11, 26, 1924.

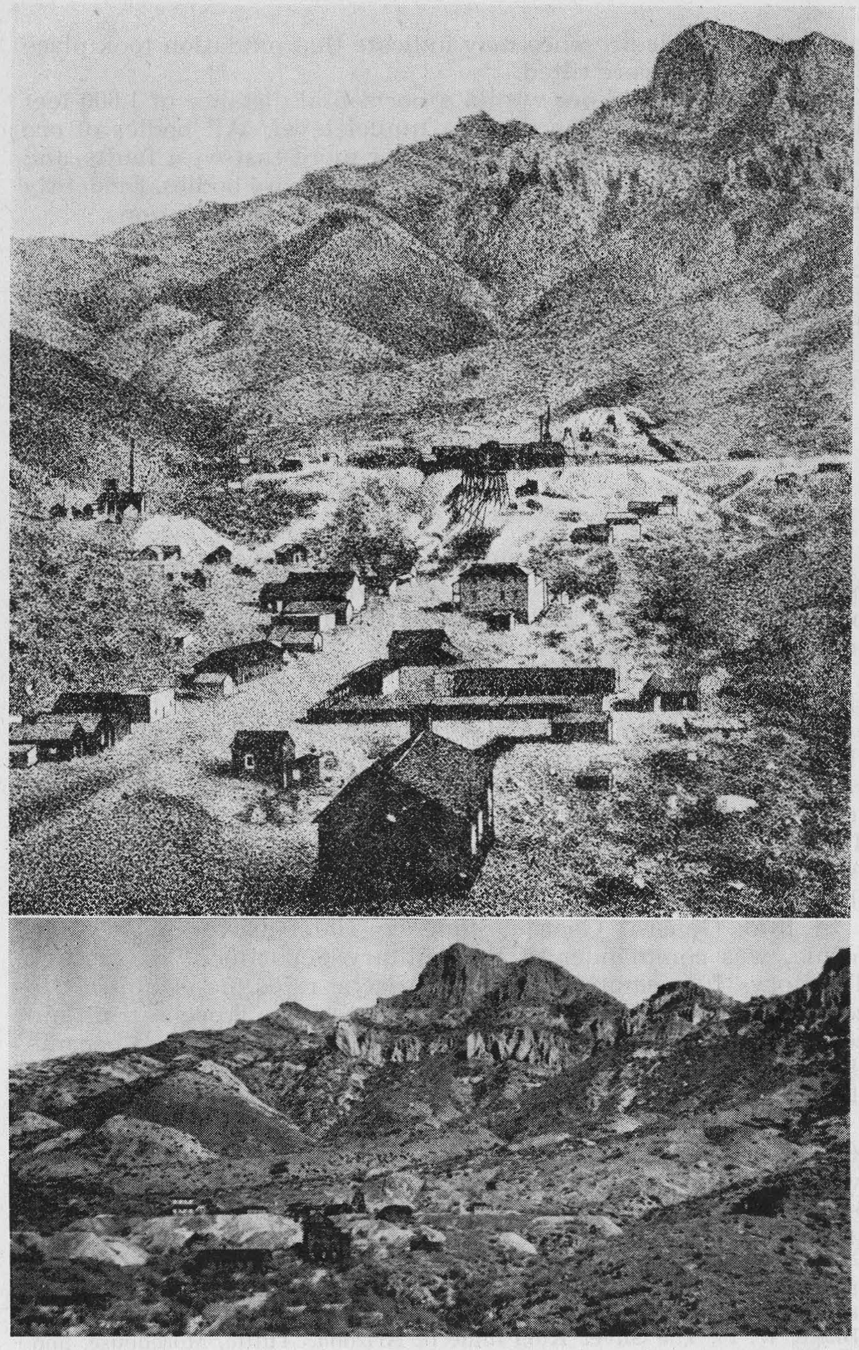

Plate XXIX.—*A*, Silver King in 1880's; *B*, Silver King and King's Crown, 1935.

of Florence, where he frequently showed the black ore. This ore has since been known as nugget silver. Sullivan suddenly disappeared, supposedly killed by Apaches while returning to his discovery.

In 1874 Mason and some fellow ranchers organized prospecting trips to locate Sullivan's find. Their first discovery of importance was the Silver Queen, now known as the Magma mine. Soon afterward the Globe mine, from which the Globe mining district derived its name, was located.

In 1875 Mason, Benjamin W. Reagan, William H. Long, and Isaac Copeland, returning from the Globe district with a pack train of samples, camped near the base of the Stoneman Grade and found more of the black nuggets. This float was followed up a small conical hill near by to the outcrop of ore at its top. On March 22, 1875, the initial location was made, and the Pioneer mining district laid out. Assays by Tom Price, of San Francisco, established the value of the ore, and active mining began.

DEVELOPMENT AND PRODUCTION[59]

In a report on the mineral resources of the Rocky Mountains, Raymond states that by the end of 1875 the shaft was down 42 feet and a 12-foot drift had been driven at the bottom. The shaft started in ore and was sunk along a network of stringers ranging from 3 to 18 inches wide in "granite." The gangue material in the stringers was quartz, and the ore minerals were cerargyrite, argentite, and native silver. This ore, when sorted, ran $2,000 a ton. To treat the ore a small furnace of cupel type was erected at Florence by Cury and Hughes. Pig lead for collecting the silver was obtained from the Mowry mine in the Patagonia Mountains 150 miles south. Five hundred pounds of selected ore from the first 14 feet of the shaft yielded over $5 a pound. The total production from the shaft and drift was estimated at $50,000.

When the news of the discovery reached San Francisco, mining experts representing the Comstock interests were sent to negotiate purchase of the property, and in 1876 the mine was sold to the Silver King Mining Company. Further development was begun, and a small stamp mill and amalgamation plant were erected at Pinal, on Queen Creek, to treat the lower-grade ore. Most of the ore was shipped without milling.

In 1879 Arthur Macy was appointed Superintendent. Exhaustion of the free milling ore necessitated a change in method of treatment in 1882. The ore was crushed at the mine in a Blake crusher and sent to Pinal where it was further crushed by a battery of 20 stamps and concentrated over 12 Frue vanners. The concentrates were sent to the Dome Mining and Smelting Company, Melrose, California, the Selby Works at San Francisco, and the

[59]Abstracted from unpublished manuscript by J. B. Tenney.

Omaha Smelting Works. In 1883 the mill treated 50 to 57 tons a day, with a concentration ratio of about 2 to 1. The average grade of the heads was $61.08 in silver, and the reported extraction was 92.31 per cent. In addition to silver, the concentrates assayed 21.5 per cent lead and 18 per cent zinc.

Active prospecting of adjacent ground closely followed the success of the Silver King mine. In 1883 fourteen groups were worked and three mills, of which the largest was the amalgamation plant of the Windsor Consolidated Company, had been erected. In 1884 this mill was leased by the Silver King Company to treat ore not amenable to concentration. In the same year the mine was developed to a depth of more than 800 feet, and most of the ore was obtained from the 700 and 800 levels. The grade had fallen to $43.00 for concentrating ore and $46.40 for amalgamation ore.

The last year of profitable operation was 1887. The grade had fallen to 21.08 ounces per ton for concentrating ore and 32.47 ounces for amalgamation ore. Lixiviation was tried on some ore high in copper from the 800 level, and some old tailings were reconcentrated. Costs reported by the Superintendent for 1887 were as follows:

Mining, per ton	$10.97
Milling and roasting, per ton	9.69
Total	$20.66

During the first half of 1888 the company operated at a loss, and the President, H. H. Noble, reported a debt of $75,000. An assessment was levied, and operating costs were lowered from $40,000 to $5,000 a month. By December the indebtedness had been paid, the company had a balance of $74,000, and sufficient ore was in sight to run until January 1, 1889.

As prospecting in 1889-90 failed to find commercial ore, the mine was closed in January, 1891. It was reopened in September of that year after 44,000 delinquent shares had been called in. In October a strike was made in a new shaft east of the old workings. This ore was developed in 1892, but the company was again in debt. Ten stamps were moved from Pinal to the mine, and a small production of concentrates was made during the remainder of the year. With the decline of the price of silver early in 1893, the mine was again closed.

In the fall of 1895 the Superintendent, W. S. Champion, resumed work in the new shaft. He reported finding a pocket of ore at a depth of 75 feet worth $40,000. The mine was again closed in 1896.

From 1876 to 1896 the company declared $1,950,000 in dividends, of which the last was paid in 1887. A total of $300,000 in assessments was levied from 1888 to 1895, making the net profit $1,650,-000. The dividends were paid on 100,000 issued shares, and assessments were collected on 56,000 shares.

In 1916, after successful exploitation of the neighboring Silver Queen mine by the Magma Copper Company, the property was acquired by the Silver King of Arizona Mining Company, a Delaware corporation, with A. W. Hildebrand, of New York, as President, and John Fowle as Manager. In 1917 the old main shaft, 987 feet deep, was unwatered and repaired. Small high-grade ore bodies, overlooked by the former operators, were mined on the 120 level. A small flotation mill was completed in 1918 to treat this ore and low-grade dump material. About 35 tons a day were treated, with a reported extraction of 90 per cent. A small vein on the 400 level yielded some rich ore that was shipped to the smelter, and shipments of concentrates continued intermittently to July, 1919. At that time the management claimed to have developed 10,000 tons of ore averaging over $20 per ton.

In July, 1919, a new shaft, financed by a $500,000 bond issue, was started 150 feet northwest of the ore chimney. The old shaft was kept unwatered, and ore from the 120 and 400 levels was treated at the mill. In October a crosscut from the old shaft on the 400 level connected with the 415 level of the new shaft.

In January, 1920, the capitalization was reduced to allow further financing. Shaft sinking continued until June, 1920, when a depth of 635 feet was reached. A crosscut on the 615 level extended to the old workings. The company went into bankruptcy shortly afterward, and a reorganization as the Silver King Mine, Incorporated, was effected, but no further work was done. The total ore treated from 1916 to 1920 amounted to 12,546 tons, averaging approximately $20 a ton in silver. The concentrates contained 1,000 to 1,980 ounces of silver, 20 per cent lead, and 7 to 8 per cent copper.

The Bilk shaft (Pl. XXIX *A*, left) is 450 feet northwest of the new Silver King shaft. It is reported to be over 1,000 feet deep and connects with the lower levels of the Silver King mine. The shaft was sunk during the early days by interests outside of the Silver King Mining Company. Observing the westward pitch of the Silver King ore body, owners of the Bilk assertedly hoped to intersect the Silver King pipe in depth where it passed beyond the side line of the Silver King claim.[60] No mention was made of the apex law.

In 1940 a pipe line was laid from the Bilk shaft to provide an auxiliary water supply for the Magma mine.

In 1941 the Silver King property was owned by Mr. Bat Gays, of Superior, Arizona.

Pinal, on Queen Creek at the base of Picket Post Mountain, was first settled in 1877 during construction of the Silver King mill. As Silver King Wash had insufficient water for milling, the site chosen for the mill was on the north bank of Queen Creek, near

[60]Hamilton, Patrick, The resources of Arizona, 1884.

its junction with Silver King Wash, about 5 miles west of Silver King. The settlement first was called Picket Post but was named Pinal upon establishment of its post office.

Pinal grew rapidly and by 1884 had a population of about 600,[61] with several stores, a bank, two hotels. several saloons, a church, and a school. The newspaper *Pinal Drill* was established by J. DeNoon Reymert, a lawyer, and was maintained for several years prior to 1884. In 1887 the population was about 400.[62]

A telephone, one of the earliest in the territory, connected Pinal with Silver King, and a telegraph connected Pinal with Florence, the county seat.

The settlement of Silver King, around the mine, had during the late eighties a population of about 500,[63] with three stores, two hotels, a post office, a school, and several saloons. Present local tradition gives for both camps a much greater population.

PRODUCTION OF SILVER KING MINE
(Compiled by J. B. Tenney)

Year	Price of silver	Silver (oz.)	Gross value
1875	$1.24	40,323	$ 50,000
1877-79	1.16	706,157	819,142
1880	1.15	439,689	505,642
1881	1.13	574,049	648,675
1882	1.14	714,912	815,000
1883	1.11	533,787	592,503
1884	1.11	429,559	476,811
1885	1.07	764,832	818,370
1886	.99	656,566	650,000
1887	.98	709,134	694,951
1888	.94	319,149	300,000
1889	1.00	55,000	55,000
Total (1875-89)		5,943,157	$6,526,094
1918	1.00	37,000	37,000
1919	1.12	126,892	142,119
1920	1.09	65,872	71,800
1928	.58	3,000	1,755
Total (1918-28)		232,764	$ 252,674
Grand total		6,175,921	$6,778,768

SILVER KING ORE BODY

The Silver King mine is filled with water and therefore is inaccessible for examination. Blake's article[64] contains the only original description of the ore body, although Ransome[65] has given

[61]Hamilton, Patrick, op. cit.
[62]Bancroft, H. H., History of Arizona and New Mexico, 1889.
[63]Bancroft, op. cit.
[64]Blake, Wm. P., op. cit.
[65]Ransome, F. L., Copper deposits near Superior, Arizona: U.S. Geol. Survey Bull. 540, pp. 156-58, 1914.

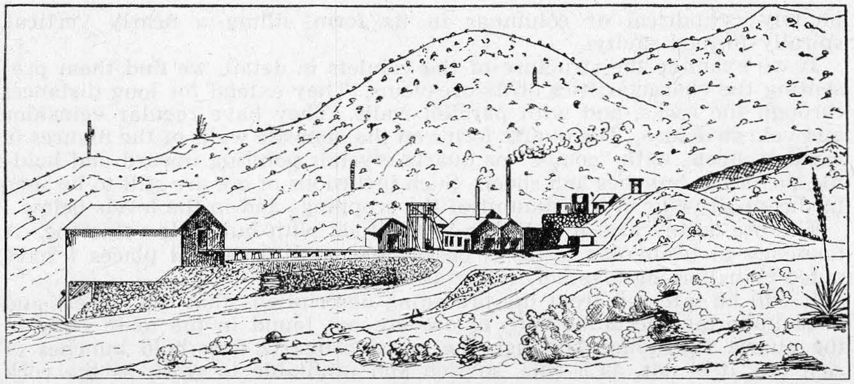

Plate XXX.—Silver King mine and crusher (after Blake).

a concise summary of Blake's description in addition to data collected by himself. Quoting from Ransome:

The ore body formerly cropped out at the top of a little hill about 75 feet high, composed of much-altered yellowish brown to greenish gray porphyry. Stoping was carried to the surface and a crater-like pit from 100 to 125 feet in diameter marks the site of the former outcrop. Here and there in the porphyry walls of the pit may be found small veinlets of rich, partly oxidized silver ore, but, so far as can be seen from the surface, the ore body was determined by the intersection of two or more persistent fissures. It apparently was a compact plexus of veinlets inclosed in comparatively unfissured porphyry. Blake's description and the maps of underground workings show that the ore body was a stockwork about 130 feet in maximum diameter, with a general dip of 70° W. The stockwork was disposed about an irregular core or axis of milk-white quartz, containing some bunches of rich ore but as a whole comparatively barren. This material is abundant and conspicuous in the mine dump and evidently constituted at times the bulk of the waste.

The following description is from Blake:

The portion removed from the open pit consisted largely of rock, the porphyry, so-called, penetrated and seamed with interlacing veinlets of quartz, reticulating and crossing in every direction. These veinlets varied from the thickness of a sheet of paper to ¼ inch or an inch in thickness, and were generally accompanied with ore in a medial position, having quartz on each side of it next to the rock. The same conditions may be seen in the lower levels at the present time. In addition to these veinlets, there are masses and bunches of ore, and apparently (at least in the upper levels) a central mass of quartz, a large and compact body, toward which the system of veinlets converged, or from which they may be said to radiate. This mass of quartz, of irregular dimensions, still exists in the region opened by the lowest levels of the mine, but it has not yet been thoroughly explored. This quartz appears to hold some direct relation to the deposition of the ore: The heavier bodies of ore, so far, having been cut below, or on the foot-wall side of the quartz body. It may be regarded as holding the relation of the chief veinstone to the ore, and as presenting within itself, and together with the branching veinlets, the characters of a true fissure-filling, although it has not the usual sheet-like or tabular form. It is, instead, a columnar or chimney-like mass, some 80 feet in diameter in places, but irregular and without longitudinal extension. In other words, this quartz-vein, instead of having a width much greater than its breadth, is approximately cylindrical or columnar in its form, filling a nearly vertical, spirally-formed cavity.

If we examine the structure of the veinlets in detail, we find them presenting the characteristics of fissure-veins. They extend for long distances through the rocks, and with parallel walls. They have regular veinstone and vein structure. The quartz forms on the opposite walls of the fissures in regular sheets, with "combs" or quartz crystals pointing inward and holding the ore in bunches and sheets. Such inclusions of ore are still to be seen in the small veins at the summit of the croppings and in the levels below.

The ore occurs also in bunches in the rock with but little veinstone. A tendency to triangular forms is observable, and in several places I have noted veins joining together nearly at right angles.

It will be inferred from the preceding descriptions that the richest and most important accumulations of ore are not found in the main body of the quartz veinstone. Although the massive quartz does hold bunches of rich ore, it is not, as a rule, so rich and profitable to work as the rock adjoining it. The ore is more abundant in connection with the small branching veins in the outside rock than in the mass of the quartz itself. It must, however, be stated that the quartz body has not yet been fully explored, being merely cross-cut in the upper levels. It is my opinion, however, based upon what has already been shown that, contrary to the usual conditions in the mines, the chief body of quartz veinstone does not carry the best part of the ore. It appears rather to have been the main channel of the mineralization: the main artery or feeder to the thousands of veinlets branching from it into the wall-rock following the clefts and penetrating the substances of the rock, depositing and diffusing native silver and the sulfides throughout the whole mass of rock for an indeterminate distance on each side.

Through the courtesy of Mr. Bat Gays, owner of the Silver King mine, level maps made by Mr. Starbird, resident engineer for the Silver King of Arizona Mining Company, were examined by the writers. These maps show the stoped area of the ore body to have the following dimensions:

Level	North-South (ft.)	East-West (ft.)
250	100	100
400	80	50
500	60	50
600	80	70
800	180	100

MINERALOGY

General statement: Although the Silver King mine was worked exclusively for silver, the most abundant minerals are those of lead, copper, and zinc. The most important of the base metal minerals are sphalerite, chalcopyrite, tetrahedrite, galena, and bornite. Much of the tetrahedrite contains a small amount of silver, but with this exception stromeyerite and native silver were the valuable constituents of the ore. Chalcocite, covellite, cuprite, azurite, and malachite are present in smaller amounts.

Hypogene minerals: *Pyrite:* Pyrite occurs in only a few of the specimens studied, generally as small, rounded remnants in chalcopyrite, by which it has been replaced most extensively. In sections where pyrite is in contact with sphalerite, the two minerals exhibit smooth boundaries with no marginal relations which

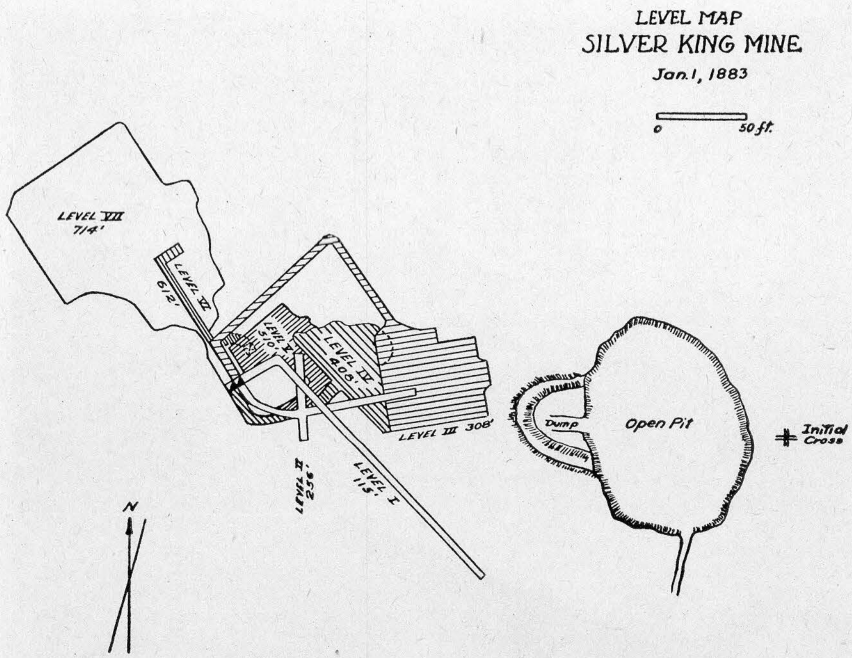

Figure 12.—Map of Silver King mine levels (after Blake).

can be interpreted. In the Magma mine pyrite is the earliest sulfide and is followed by sphalerite. By analogy, the same condition is believed to exist in the Silver King area.

Sphalerite: Sphalerite is the most abundant sulfide mineral. In hand specimen much of it is light colored and translucent; in polished section it is medium gray and gives a weak reaction for iron. Sphalerite, like the other hypogene minerals of the ores, is present largely as open-space filling. However, it replaces quartz to a much greater degree than any of the other sulfides. It is in turn replaced by the other sulfides, particularly galena, with which it is almost invariably associated.

Galena: Next to sphalerite, galena is the most abundant sulfide. It is intimately associated with sphalerite, which it replaces along cleavage cracks. The galena in many places shows mutual boundaries with chalcopyrite and tetrahedrite, but it is later than these minerals. It selectively replaces tetrahedrite, as shown by its numerous tiny tonguelike projections into tetrahedrite and a multitude of small residual masses surrounding the larger areas of that mineral. Microchemical tests of the galena showed no silver.

Chalcopyrite and tetrahedrite: Chalcopyrite and tetrahedrite, the most abundant copper minerals, are present in about equal

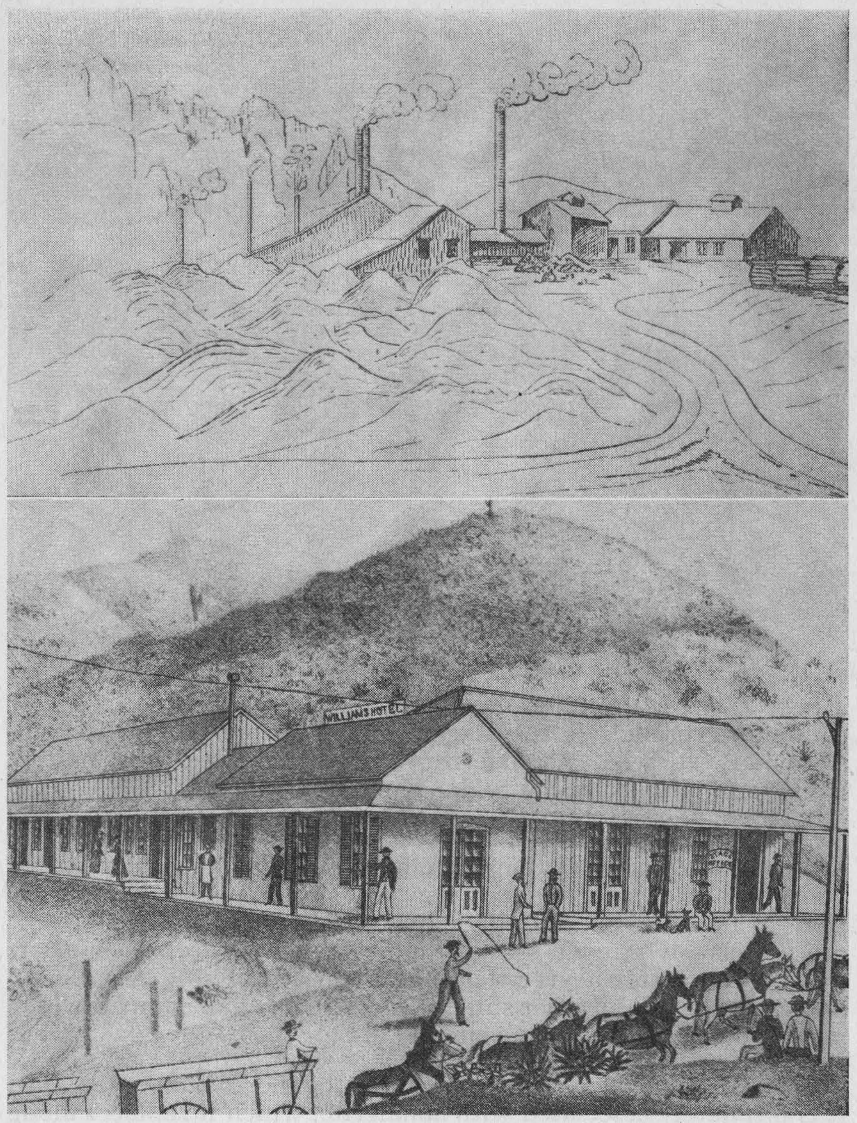

Plate XXXI.—*A*, Silver King mill, Pinal (after Blake); *B*, Williams Hotel, Silver King, 1883.

quantity and intimately associated. Their marginal relations are of mutual boundary type, and no definite evidence of replacement of one by the other was seen. They are believed to be essentially contemporaneous. They generally occur as open-space filling in quartz gangue but also replace sphalerite, and the tetrahedrite is extensively replaced by galena. Microchemical tests indicate that the tetrahedrite contains 1 per cent or more of silver.

Bornite: Although less abundant than chalcopyrite, bornite was observed in nearly all the specimens which contained chalcopyrite. It occurs chiefly as a replacement of chalcopyrite but has also replaed tetrahedrite. The most striking occurrence of bornite is the formation of halos around residual grains of chalcopyrite. These halos occur most commonly between chalcopyrite and stromeyerite but also between chalcopyrite and tetrahedrite. Bornite also forms advance islands and minute veinlets in areas of chalcopyrite. These veinlets probably follow grain boundaries but apparently not open fractures. In several sections the bornite consistently occupies gangue boundaries surrounding areas of stromeyerite, which suggest supergene origin and indicate it to be later than the stromeyerite. Other evidence described later leaves no doubt that the stromeyerite is later than the bornite. It seems probable that the bornite is hypogene, that it replaced chalcopyrite and possibly some tetrahedrite along grain and gangue boundaries, leaving only residual remnants of the chalcopyrite. When supergene solutions attacked these minerals, the tetrahedrite was broken down to form stromeyerite, bornite was slightly replaced, and chalcopyrite was unaffected—a process which should produce the present texture.

Argentite: This mineral was found in only one specimen and in small quantity. It forms graphic structure with tetrahedrite (Pl. XXXIII *B*), which it replaced. The argentite in turn is replaced by galena.

Supergene minerals: *Stromeyerite:* By far the larger part of the stromeyerite in the Silver King ore is believed to be supergene. The stromeyerite has formed by replacement, particularly of tetrahedrite and also of bornite. A supergene origin for the stromeyerite is suggested by reticulated veinlets of it along fractures in tetrahedrite and by residual islands of tetrahedrite in stromeyerite. Microtextures indicate that tetrahedrite was more susceptible than bornite to the replacement process.

A bladed structure in the stromeyerite has been described and explained by Guild.[66] This structure is caused by mixture of stromeyerite and chalcocite, the stromeyerite forming the blades and the chalcocite forming the matrix. Well-formed blades are exceptional, and in most specimens the stromeyerite and chalcocite formed a mixture of small, irregular grains. The structure is rarely visible in plain light on a freshly polished surface but is revealed by etching with nitric acid.

The formation of this mixture was explained by Guild[67] as follows:

[66]Guild, F. N., A microscopic study of the silver ores and their associated minerals: Econ. Geol., vol. 12, pp. 310-13, 1917; Laboratory investigation of ores, pp. 225-8, McGraw-Hill, New York, 1828.

[67]Guild, op. cit.

In the breakdown of the tetrahedrite molecule the sulphide of antimony has been removed leaving the sulphides of copper and silver, some of which appear as the double salt $Cu_2S.Ag_2S$ (stromeyerite).

Guild recognized that this structure might also be formed by replacement of chalcocite by solutions rich in silver or replacement of stromeyerite by solutions rich in copper.

Textural evidence of supergene origin for the stromeyerite has already been mentioned. In addition, blue chalcocite, believed to be supergene, occurs abundantly in the stromeyerite-chalcocite mixture, and veinlets of this mineral are associated with the replacement of bornite by stromeyerite. Many specimens of fine-grained stromeyerite contain supergene covellite, and only in these specimens were malachite and azurite observed.

Massive chalcocite: Although supergene massive chalcocite was observed in only three of the polished sections studied, its mode of occurrence indicates that it was an important constituent of the sulfide ores in upper levels of the mine. Where seen, it constitutes a large portion or all of the sulfides in the specimen. Microscopically, it is distinctly lighter blue than the supergene massive chalcocite from the Magma mine previously described by Short.[68] The mottled character of the Magma ore is present to a slight degree only, but the rounded gray patches described by Short and believed to represent "ghosts" of replaced bornite are readily seen; the difference in color is probably due to incomplete removal of iron. The chalcocite is fine grained, and nitric acid does not bring out the cleavage structure of individual grains as it does on coarse-grained hypogene chalcocite from other localities. This chalcocite has been derived, in large part at least, from hypogene copper sulfides. It replaces chalcopyrite and tetrahedrite, both of which appear as remnants throughout the chalcocite, and tetrahedrite has been replaced by the chalcocite along fractures. Bornite has been almost entirely replaced by chalcocite. It is present as halos surrounding remnants of chalcopyrite (Pl. XXXIII *A*), but rarely tiny areas of bornite alone may be seen. The bornite might be considered an evanescent transitional phase in the replacement of chalcopyrite, but a similar relationship between bornite and stromeyerite, already described, suggests that the bornite is hypogene and a remnant rather than a product of replacement. Furthermore, in many specimens chalcocite replaces chalcopyrite without bornite halos, and the bornite presents an exceedingly hazy or fuzzy boundary toward the chalcocite but a clear, sharp boundary toward the chalcopyrite. Inclusions of bornite in the chalcopyrite contain no chalcocite.

Blue chalcocite: This mineral, determined by Posnjak, Allen, and Merwin[69] to be chalcocite containing a small proportion of

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[68]Short and Ettlinger, op. cit., pp. 202-3.

[69]Posnjak, E., Allen, E. T., and Merwin, H. E., The sulphides of copper: Econ. Geol., vol. 10, p. 526, 1915.

covellite in solution, is observed sparingly in several specimens. It is derived from both chalcopyrite and bornite, which it frequently replaces along minute fractures (Pl. XXVIII *C*). By analogy with covellite, it is believed to be later than the massive chalcocite.

Covellite: Covellite is less common than blue chalcocite. The mode of occurrence of the covellite is identical with that of blue chalcocite, replacing chalcopyrite and bornite along minute fractures. Nowhere in the specimens studied was covellite observed as a product of oxidation of massive chalcocite, and therefore the sequence of formation of massive chalcocite, blue chalcocite, and covellite is not illustrated. In the Magma mine, however, covellite is later than massive supergene chalcocite,[70] and as blue chalcocite is believed to be incipient covellite, the minerals are believed to have been formed in the order described. Supergene covellite also replaces hypogene stromeyerite.

Chalcopyrite: A second generation of chalcopyrite is supergene, but it is not abundant. It is intimately associated with supergene covellite and appears as tiny veinlets in bornite, which it has replaced along open fractures and in tongues branching outward from such fractures.

Native silver: Native silver is intimately associated with massive chalcocite and in places makes up about 30 per cent of the specimen (Pl. XXXIII *A*). Guild[71] has described the relationship as follows:

> The silver is arranged in beautiful filiform structure, the branches of which envelope individual chalcocite grains, some of the finer filaments even extending into fracture and cleavage cracks of the chalcocite. In places the whole design is roughly oriented with reference to cleavage directions of chalcocite. All of these features are well brought out by etching with potassium cyanide solution. The areas showing the structure described grade into stromeyerite, where the native silver disappears altogether, or is confined to borders, veinlets or clumps of more or less rounded outline. The causes responsible for the filiform structure now become clear. Stromeyerite has been broken down into chalcocite and native silver. The chalcocite has crystallized into definite grains of varying size. The silver in recrystallizing has formed around these grains, extending everywhere into the minutest cracks. The silver is also recrystallizing in cracks and along borders of other minerals, both gangue and ore.

Cuprite: Cuprite was observed in only one specimen, but there is no doubt that its supergene origin is later than that of chalcocite and native silver. It replaces these minerals as tongues extending into the residual areas, and at one place it has filled an open fracture extending through chalcocite and native silver.

Azurite and malachite: Azurite and malachite occur as pockets of small, well-formed crystals in the walls of the open pit. In

[70]Short and Ettlinger, op. cit., pp. 203-4.

[71]Guild, F. N., A microscopic study of the silver ores and their associated minerals: Econ. Geol., vol. 12, pp. 323-4, 1917.

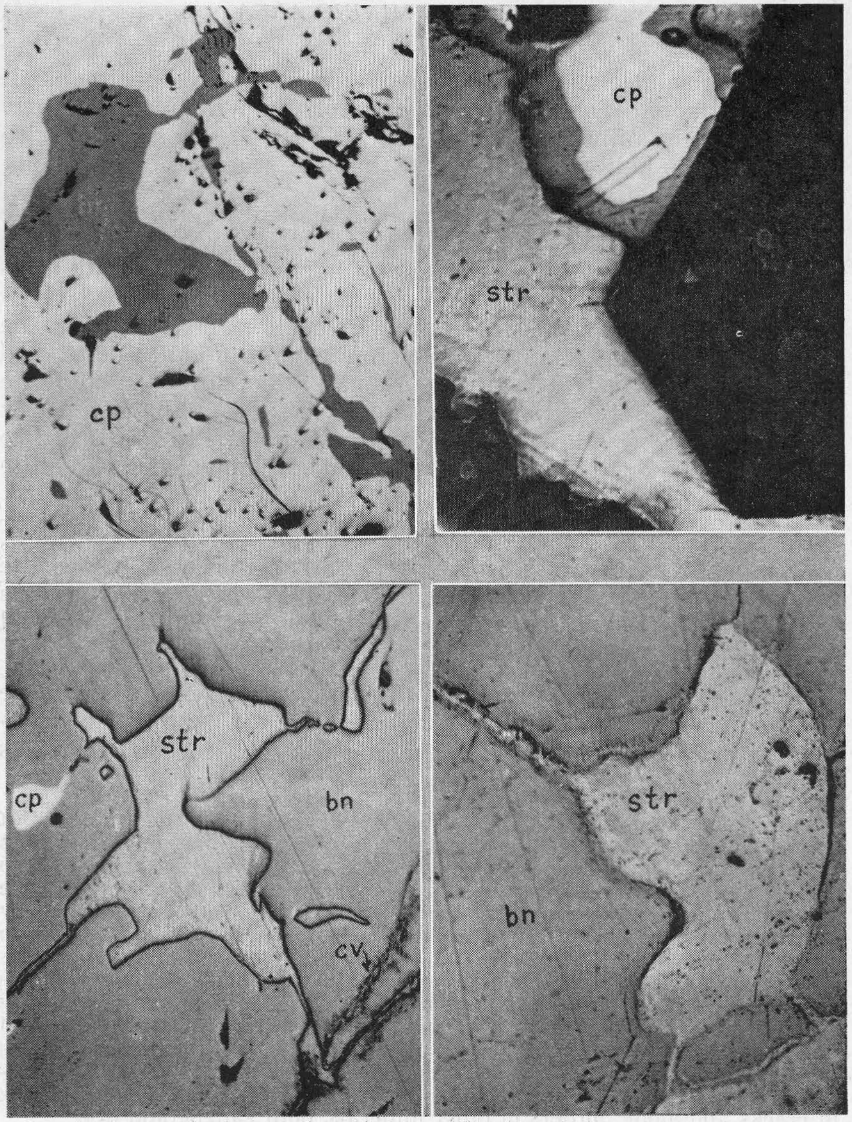

Plate XXXII.—Photomicrographs of Silver King ore.

A.—Minute veinlets and advanced islands of bornite (dark) replacing chalcopyrite (light). These minerals exhibit smooth mutual boundary relations in other parts of the same section. (x 30)

B.—Open space filling beside euhedral quartz crystal by chalcopyrite (white) which is replaced by hypogene bornite (dark gray), in turn replaced by supergene stromeyerite (light gray). (x 106)

C.—Hypogene stromeyerite (light gray) replacing bornite (dark gray). The stromeyerite does not cut through the chalcopyrite (white). Supergene covellite is younger than the stromeyerite. (x 184)

D.—Supergene mottled stromeyerite (light) replacing bornite along fractures. The bornite is also replaced by supergene blue chalcocite. (x 425)

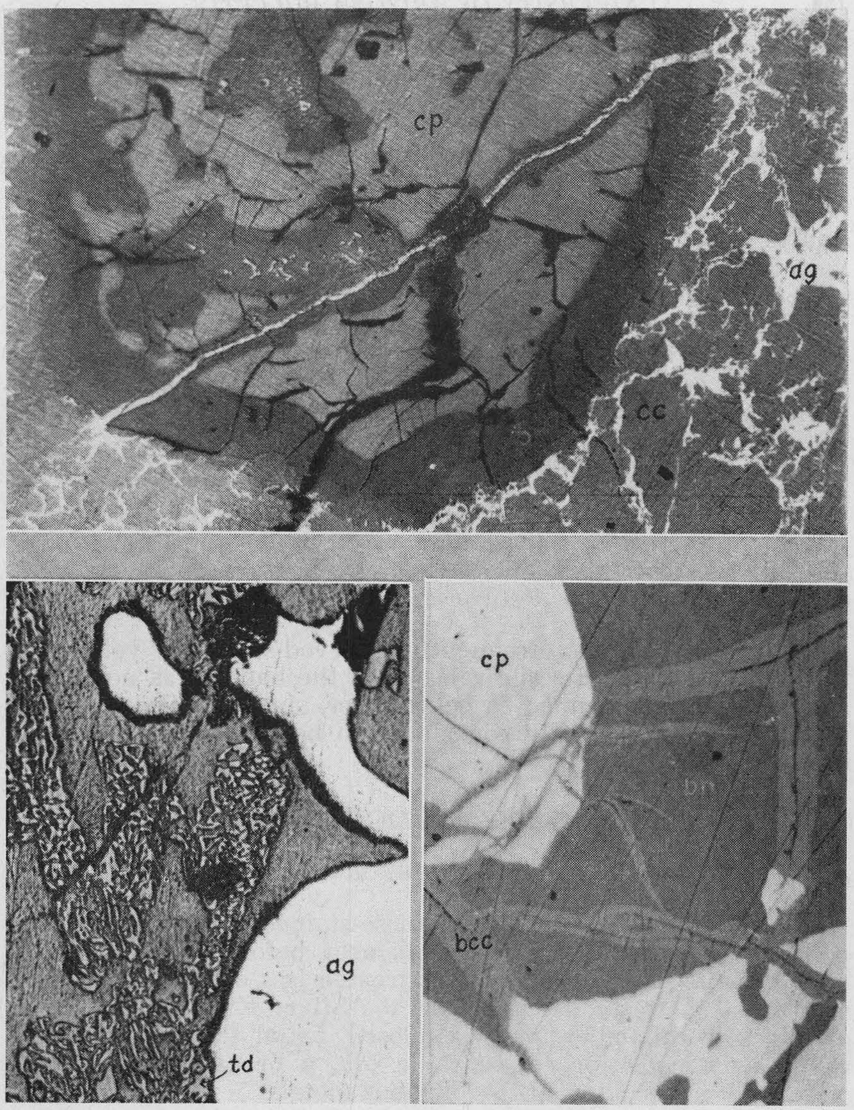

Plate XXXIII.—Photomicrographs of Silver King ore.

A.—Hypogene chalcopyrite (medium gray) replaced by hypogene bornite (dark gray). The bornite has been replaced by supergene massive chalcocite (light gray). Supergene native silver (white) has extensively replaced the chalcocite and to a lesser extent the bornite. (x 84)

B.—Hypogene argentite (light gray) replacing tetrahedrite (dark gray) in a graphic texture. Both tetrahedrite and argentite have been replaced by supergene native silver (white). (x 156)

C.—Hypogene chalcopyrite (white) and bornite (dark gray) replaced by supergene blue chalcocite (light gray) along fractures. (x 190)

td:—tetrahedrite

bcc:—blue chalcocite

polished sections, the minerals occur as stains along minute fractures in quartz gangue.

Anglesite: In one specimen anglesite replaces galena, forming a network of tiny veinlets in open fractures.

Gangue minerals: *Quartz:* At least 95 per cent of the gangue is quartz. It occurs in two forms, one a rather fine-grained crystalline variety and the other as euhedral crystals extending from walls of the fine-grained gangue (Pl. XXXII *B*). Hand specimens as well as thin sections show both varieties of quartz to be later than the Silver King porphyry in which the ore body was formed. Open spaces left after deposition of the quartz were the most favorable locations for deposition of ore minerals.

Barite: In the specimens studied, small amounts of barite occur in two generations—

1. Earlier than the ores, as open-space filling in the quartz.
2. Later than ores, numerous narrow veinlets cutting through the sulfides. The later generation is much less common than the earlier.

Calcite: Calcite was infrequently observed as narrow veinlets in the quartz gangue. Its age relative to the barite was not determined, but it is assumed to be younger, since in other districts most calcite is generally considered to be later than the latest barite.

MINES IN THE BELMONT SUBAREA

EARLY HISTORY

Some mining, largely of manganese-stained vein outcrops, was done in the Belmont-Queen Creek area before 1900. This ore, mined for its silver and gold, was treated in a custom stamp mill near Pinal. After construction of the Silver King Mining Company's mill, this older mill was closed, for at the new one provision was made for roasting the ore, a process which aided materially in recovery of the precious metals.

Most of the present claims were located shortly after 1900 by Henry Thomson, C. H. Smith, A. C. Norris, A. J. Daggs, John Sandal, and many others. Organized prospecting, begun in 1912, has been carried on intermittently.

MINERALIZATION

Two favorable horizons for ore deposition, the Troy-Martin contact and the upper portion of the Escabrosa, have been recognized.

Troy-Martin contact: The Troy-Martin contact is known as the L. S. and A. contact, from the Lake Superior and Arizona mine which developed it north of Queen Creek. Considerable breccia occurs throughout along the contact but particularly in the northern part of the Belmont subarea. This breccia is particularly well developed in the quartzite, and in some places it is 15 to 20 feet thick. It indicates a strong bedding fault. The movement on this fault was not determined, but it must have been considerable.

The brecciated quartzite of this zone formed a porous channel along which solutions could ascend, and the limestone was a reactive rock by which solutions might be neutralized.

The Queen Creek mine has prospected this contact to a depth of 800 feet on the dip of the vein.

In the central and southern parts of the area, mineralization, if present, is weak at the surface.

Escabrosa ore horizon: The second and most important ore horizon in the area is the top 20 to 25 feet of the Escabrosa limestone. As no structural evidence was found to explain why this horizon should be favorable to ore deposition, the limestone was host to mineralization presumably because of its chemical composition. This favorable zone, locally known as the "Big Ledge," is continuous from the northern to the southern part of the area.

The ore occurs as shoots along intersections of the stronger east-west faults with the chemically favorable beds. The ore bodies are irregular, in places pinching to mere seams and elsewhere widening to 20 or 25 feet. Their outcrops are characterized by iron and manganese oxides. The Black, West, North, and Main leases are in this horizon.

Apparently the mineralizing solutions rose along the east-west faults through the underlying, chemically unfavorable quartzite and limestone. Upon reaching the favorable beds at the top of the Escabrosa limestone they spread laterally, forming the ore deposits. Because of the eastward regional dip of the beds, these ore bodies dip eastward, which makes mining difficult. Postore faulting of small magnitude has displaced them and made systematic mining almost impossible.

Oxidation and enrichment: The ore in these near-surface mines is completely oxidized. Ore minerals are cerargyrite, silver, gold, malachite, and azurite. Wulfenite and sparse vanadinite are present in most of the ore. Cerussite and calcite are common. Fine-grained sandy quartz and massive vein quartz occur as gangue.

Microscopic examination of ore from the mine dumps showed supergene argentite in galena and sphalerite. The amount of enrichment which has occurred is speculative, as an unknown amount of erosion has taken place since the hypogene mineralization.

Chemically, sufficient pyrite was present to yield sulfuric acid and ferric sulfate upon oxidation. This acid in the presence of ferric sulfate attacked argentite, producing silver sulfate. It also attacked galena and sphalerite, producing lead and zinc sulfate. In a reactive gangue such as limestone, the acid solutions were soon neutralized and the metals precipitated as carbonate. Chlorine, which is present in most arid regions, would precipitate the silver as the chloride, cerargyrite.

The wulfenite and vanadinite are thought to have been derived by oxidation of minute amounts of molybdenum and vanadium contained in the primary ore.

BELMONT MINE

History: In 1913 the Calumet and Arizona Mining Company obtained an option on many of the claims in the Belmont area. With John C. Greenway in charge, the Belmont shaft was sunk to the 700 level and about 6,000 feet of work was done on the 140, 500, and 700 levels. In 1914 the option was released.

Early in 1923 F. S. Stephen obtained an option on the various claims, which he then turned over to the North Butte Mining Company. This company began exploration in May, 1923. New equipment was installed, the shaft was retimbered to the 700 level, and several thousand feet of drifts and crosscuts were driven on the 140 and 700 levels. Because of disagreement on company policies, the option reverted to Mr. Stephen.

In November, 1924, Stephen organized the South Syndicate, supported by A. Mackay, Captain Thomas Hoatson, and others. This company did some work on the 500 and 700 levels but found only highly oxidized ore of low grade.

In February, 1925, the Belmont Copper Mining Company was formed and obtained the option held by the South Syndicate. The Belmont company first worked on the 700 level, then deepened the shaft to the 1,600 level. Work was done on the 1,000, 1,150, 1,450, and 1,600 levels. Development by this company totaled 16,000 feet of drifts and crosscuts, 1,000 feet of raises and winzes, 922 feet of shaft, and about 50,000 feet of diamond drilling. The three companies did about 30,000 feet of development in addition to the diamond drilling.

In 1928 a small flotation mill was constructed on the Belmont property. It treated about 4,000 tons of galena and gold-silver ore. As the known ore bodies were small, it was soon closed.

The present holdings of the Belmont Copper Mining Company include one hundred twenty claims, of which twelve are patented. No development is being done at the Belmont mine below the 140 level. The shaft is flooded to the 700 level, and the 500 level station is caved. Present production is by lessees, principally from the Main, North, and West leases. Intermittently, some work is done on the 140 level by the Belmont Copper Mining Company.

Production: During 1926 and 1927, 200 tons of ore, averaging 50 oz. Ag, 0.35 oz. Au, 2% Pb, and 3% Zn, were mined on the 1,150 level. In 1928 the small mill near the Belmont shaft treated

3,327 tons of ore which averaged 4 oz. Ag and 0.04 oz. Au. In 1931 C. H. Smith, lessee, shipped 270 tons of ore, averaging 6% Cu and 1 oz. Ag from the 165 sublevel. In the same year he also mined and shipped from the 140 level 30 tons which assayed 38% Pb, 2% Cu, 11 oz. of Ag, and 0.06 oz. of Au.

Lessees have been actively mining on the property only since 1934. Total production from 1934 to 1938, inclusive, was recorded by the Belmont Copper Mining Company as follows:

Lease	Tons	Gross value
Main	9,637	$101,048
North	3,388	43,639
West	3,033	22,890
Others (6)	2,000	17,147
Total	18,058	$184,714

Production by metals for the period was 211,909 pounds of copper, 217,255 ounces of silver, and 3,422 ounces of gold.

Ore deposit: As the deeper workings of the Belmont mine are flooded, the following description is taken from private reports by I. A. Ettlinger.[72]

Most of the development in the Belmont mine has been along a strong fissure vein, the Eureka. Its outcrop, highly stained with iron and manganese oxides, is just north of the Belmont shaft. Some near-surface gold-silver ore was mined from it, mostly during the early 1900's.

The ores were formed chiefly by replacement of the shattered walls of the Eureka fault zone. Open space filling was not common. On the 1,150 and 1,450 levels the wall rock is shattered diabase, but on the 1,000 and 1,600 levels Mescal limestone blocks occur in the diabase. On the 1,000 and 1,150 levels the vein is developed for several hundred feet along its strike. It ranges from 2 to 5 feet in width and is mineralized by pyrite, chalcopyrite, galena, sphalerite, and argentite. It was from this area that the lead-silver ore previously mentioned was mined. On the 1,450 level the vein was developed for 730 feet along its strike. Here the silver content is lower, but the copper content is higher than on the upper levels. From the 1,450 level of the Belmont mine, the Sandal vein of the Grand Pacific mine is developed for 1,300 feet along its strike. It is a fissure vein from 1 to 5 feet wide. Weak mineralization by base metal sulfides and strong silicification of the diabase walls characterize this structure. On the 1,600 level the Eureka vein is developed for over 2,000 feet along its strike. Mineralization on this level is weaker than on those above. The wall rocks are highly silicified, and the vein contains minor

[72]Ettlinger, I. A., Private reports to the Belmont Copper Mining Company, 1927 and 1929.

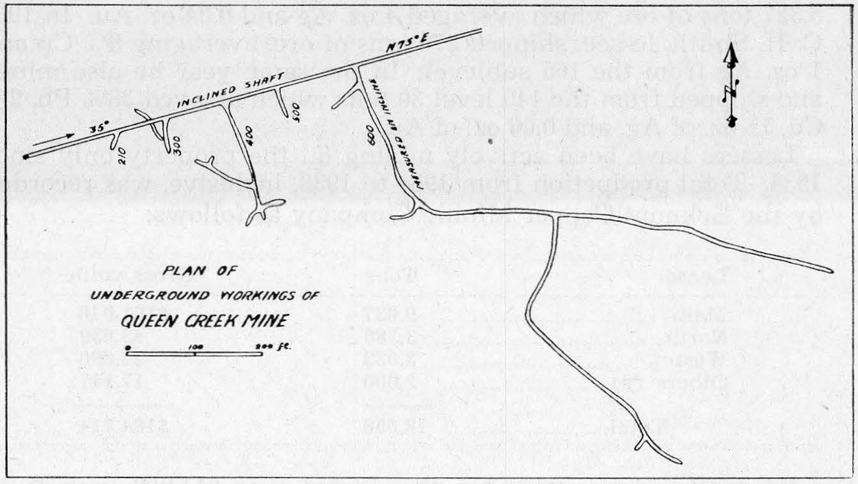

Figure 13.—Map of Queen Creek mine workings.

amounts of pyrite, chalcopyrite, and sphalerite. Mineralization is strongest where both walls are diabase. Westward the vein feathers out and becomes very indefinite; at a point 900 feet west of the shaft it could not be definitely located.

From the above description it is apparent that the Eureka vein shows remarkable zoning, passing from a barren pyrite-quartz vein on the 1,600 level to a galena-silver vein on the 1,150 level within a distance of only 350 feet.

GRAND PACIFIC MINE

History: The Grand Pacific claims were located in the early 1900's, and major prospecting began about 1910. Work continued intermittently until shortly after the first World War. Since 1920 little work has been done on the property.

The Grand Pacific Mining Company holds thirty-five claims of which seven are patented. The only available record of production of the Grand Pacific shows that 1,000 tons of ore with a gross value of $50,000 were shipped in 1918. It is believed to have been essentially the total production of the property.

QUEEN CREEK MINE

History and production: The claims of the Queen Creek property were located in the early 1900's. Prospecting began in 1916 when the Queen Creek Copper Company was organized by A. Mackay and F. Stephen. The first work, diamond drilling of fissures in diabase, showed mineralization in these fissures to be weak. The main shaft, on the L. S. and A. contact, was started in the summer of 1917 and a year later reached water level at an inclined depth of 800 feet. During 1918-20 drifting was done on the 600 level. Since 1920 the mine has been worked by lessees.

The Queen Creek Copper Company now holds forty-six claims and fractions, five of which are patented. Recent work has been limited to prospecting on the lower levels of the Queen Creek mine and at the Black lease.

Records in the office of the Queen Creek Copper Company give the following production for 1934-38:

Location	Tons	Value
Main workings	1,815	$17,340
Various leases	986	5,074
Total	2,801	$22,414

Production by metals for the period was 746 ounces of gold, 11,819 ounces of silver, and 7,140 pounds of copper.

Ore deposit: The ore consists of limonite, hematite, quartz, and free gold and silver. The vein outcrop carries considerable iron and manganese oxide. In general the ore occurs in shoots along fissures which cut the Troy-Martin contact transversely. Some ore has been found in the footwall part of the vein, but the best and largest ore shoots are in the hanging wall. This vein has been prospected for a distance of ¼ mile south of Queen Creek, but commercial ore was taken only from the Queen Creek mine and the Baer tunnel.

OTHER PROPERTIES

Three other groups of claims, The Arizona Hancock (four patented claims), the Lobb group (four claims), and the Consolidated Holding Trust (twenty-six claims), lie within the boundaries of the area described in this report. No data were available on their past history, and no work was being done on them at the time of the visit to them.

SERVICES OFFERED BY THE ARIZONA BUREAU OF MINES

(Continued from inside front cover)

5. Semitechnical meetings with miners and prospectors are held throughout the state.

6. The collection and dissemination of statistics relating to the mineral industries of the state.

7. The collecting and filing of all items relating to Arizona mines and minerals that appear in Arizona newspapers and in many technical periodicals.

MAPS OF ARIZONA

The Arizona Bureau of Mines now has available for distribution the following maps of the state:

1. Base map of Arizona in two sheets on a scale of about 8 miles to the inch. This map is strictly geographic, with the positions of towns, railroads, rivers, surveyed lands, national forests, national parks and monuments, etc., indicated in black, and the location of mountains and other topographic features shown in brown. It was issued in 1919 and is sold unmounted for 25 cents.

2. Topographic and highway map of Arizona in one sheet, on the same scale as the base map. It conveys all the information given by the base map and, in addition, shows the highways and carries 100-meter contours. There is a meter-foot conversion table on the map. It was issued in 1933 and is the most complete and up-to-date map of Arizona in print. It is sold, unmounted, for $1.00, or mounted on cloth with rollers at top and bottom for $3.25.

3. Geologic map of Arizona on the same scale as the base map, printed in many colors. It does not show the positions of mines or mineral deposits. It was issued in 1924 and is sold unmounted for $2.50, or mounted on cloth with rollers at top and bottom for $4.75.

4. Base map of Arizona similar to No. 1 but printed entirely in black on one sheet 21 by 26 inches. It was issued in 1940 and sells for 20 cents unmounted.

5. Mineral map of Arizona, 25 by 26 inches. This map consists of a red overprint made on map No. 4 and shows the chief mineral deposits by means of representative symbols. The production figures of the major metals in each district are given, and the total production of each metal for the state is also shown. Roads are also indicated. The map was issued in June, 1941, and sells for 35 cents.

The following unmounted Arizona map may be obtained from the U.S. Geological Survey, Washington, D.C., for $1.00:

Relief map of Arizona on the same scale as the base map, printed in various shades of brown, black, and blue. It was issued in 1925 and looks exactly like a photograph of a relief model of the state.

The Arizona Bureau of Mines is also an agent for the sale of available U.S. Geological Survey Arizona quadrangle sheets. Most of these sell for 10 cents.

Postage prepaid on all maps.

All communications should be addressed and remittances made payable to the Arizona Bureau of Mines, University Station, Tucson, Arizona.

BULLETINS AVAILABLE

The Arizona Bureau of Mines still has the following bulletins available for *free distribution to residents of Arizona.* Bulletins not listed herein are out of stock and cannot be procured from the Bureau.

Because of the very heavy demand for bulletins from nonresidents of Arizona, which quickly exhausted stocks, it has become necessary to discontinue sending free bulletins out of the state. *Nonresidents may purchase bulletins* at the prices quoted, which include mailing charges.

123. Geology and Ore Deposits of the Courtland-Gleeson Region, Arizona, by Eldred D. Wilson. 1927 .... .15

125. The Mineral Industries of Arizona, by J. B. Tenney. 1928 .... .25

126. Asbestos Deposits of Arizona, by Eldred D. Wilson. 1928 .... .25

129. Second Report on the Mineral Industries of Arizona, by J. B. Tenney. 1930 .... .25

130. Petroleum, by G. M. Butler and J. B. Tenney. 1931 .... .15

131. Geology and Ore Deposits of the Oatman and Katherine Districts, Arizona, by Carl Lausen. 1931 .... .25

134. Geology and Mineral Deposits of Southern Yuma County, by Eldred D. Wilson. 1933 .... .50

137. Arizona Lode Gold Mines and Mining, by E. D. Wilson, J. B. Cunningham, and G. M. Butler. 1934 .... .50

138. Treating Gold Ores (Second Edition), by T. G. Chapman. 1935 .... .15

139. Some Facts About Ore Deposits, by G. M. Butler. 1935 .... .15

140. Arizona Metal Production, by Morris J. Elsing and Robert E. S. Heineman. 1936 .... .25

141. Geology and Ore Deposits of the Ajo Quadrangle, Arizona, by James Gilluly. 1937 .... .25

142. Arizona Gold Placers and Placering (Fourth Edition), by E. D. Wilson, G. R. Fansett, and others. Reprinted in 1937 .... .35

143. Geology and Ore Deposits of the Tombstone District, Arizona, by B. S. Butler, E. D. Wilson, and C. A. Rasor. 1938 .... .50

144. Geology and Ore Deposits of the Mammoth Mining Camp Area, Pinal County, Arizona, by Nels Paul Peterson. 1938 .... .25

145. Some Arizona Ore Deposits, by numerous authors. 1938 .... .35

146. Bibliography of the Geology and Mineral Resources of Arizona, by Eldred D. Wilson .... .35

148. Tungsten Deposits of Arizona, by Eldred D. Wilson .... .25

150. Field Tests for the Common Metals (Eighth Edition), by G. R. Fansett .... .20

ARIZONA BUREAU OF MINES BULLETIN 151
GEOLOGICAL SERIES No. 16

UNIVERSITY OF ARIZONA BULLETIN
Vol. XIII, No. 1
January 1, 1942

PLATE 1.

Geology by M. N. Short, I. A. Ettlinger, F. W. Galbraith and E. N. Harshman with corrections and additions by H. R. Wardwell and T. H. Kuhn.

GEOLOGIC MAP OF SUPERIOR MINING AREA ARIZONA

Scale 1in. = 1000 ft.

1000 0 1000 5000 Feet

Contour Interval 100 Feet

Datum is mean sea level

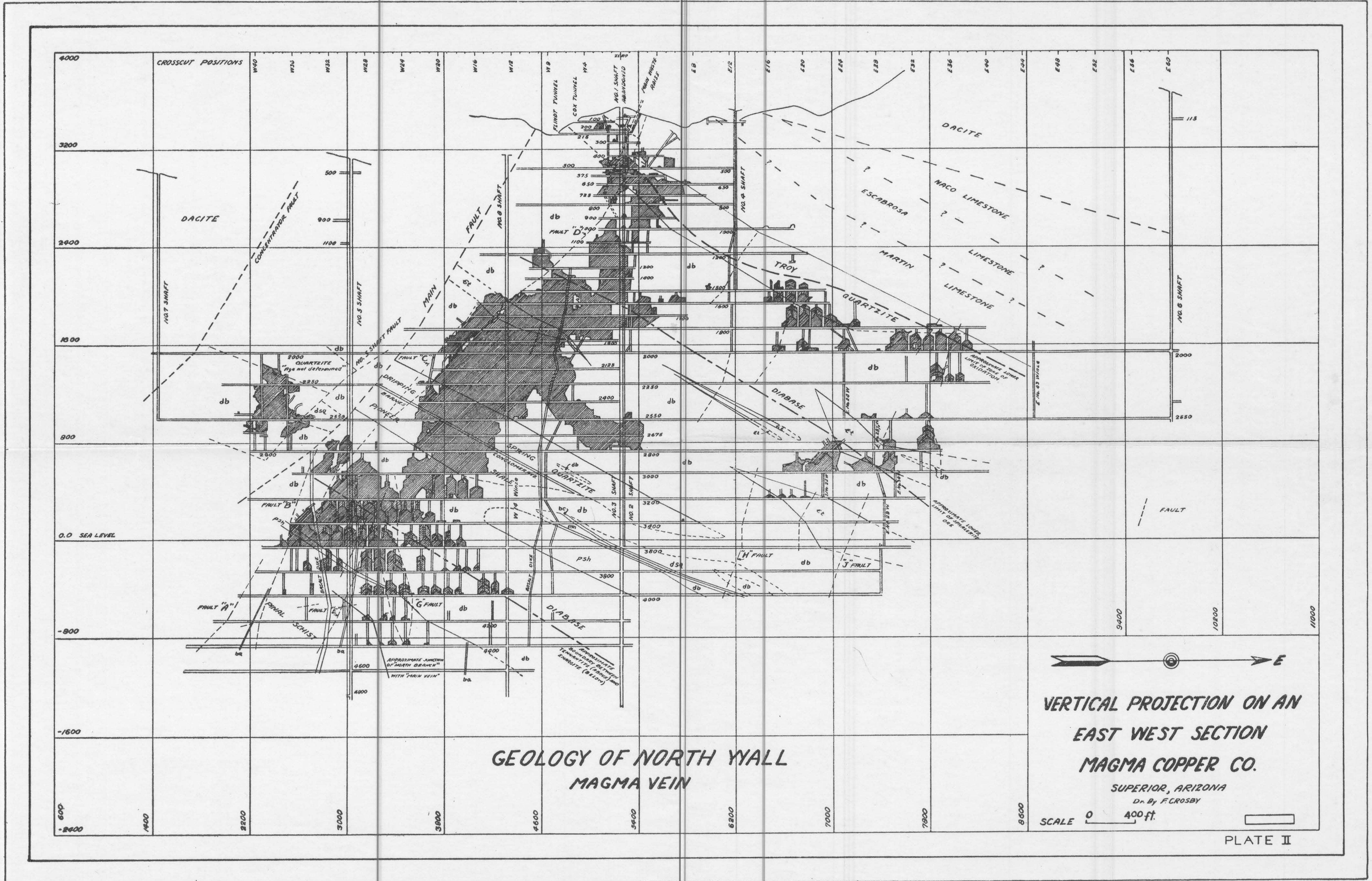

Plate II.—East-west projection showing geology of north wall, Magma vein.

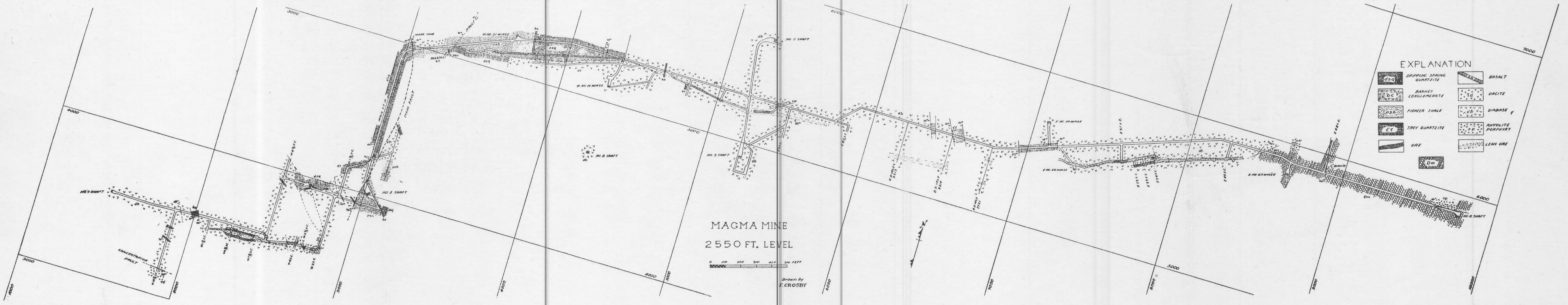

Plate XII.—Map of 2,550 level, Magma mine.

Plate XIII.—Map of 4,000 level, Magma mine.

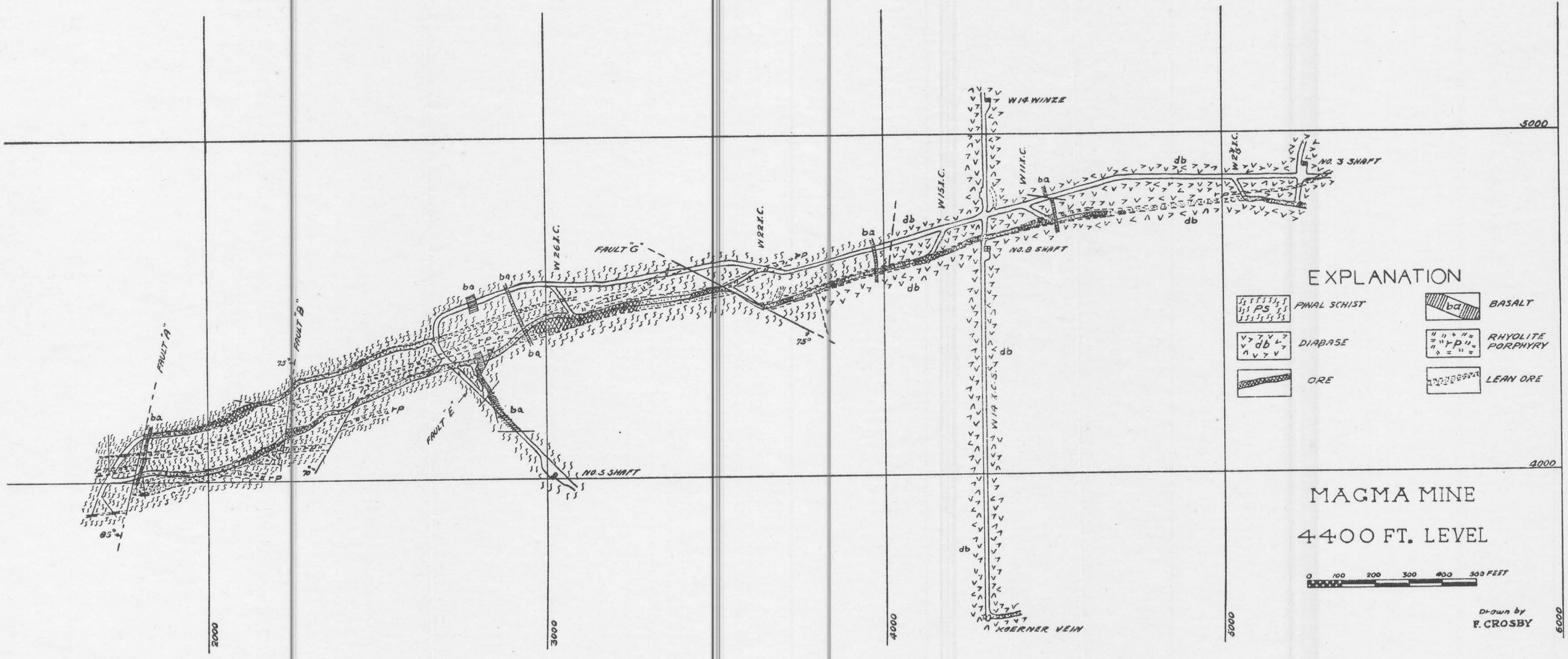

Plate XIV.—Map of 4,400 level, Magma mine.

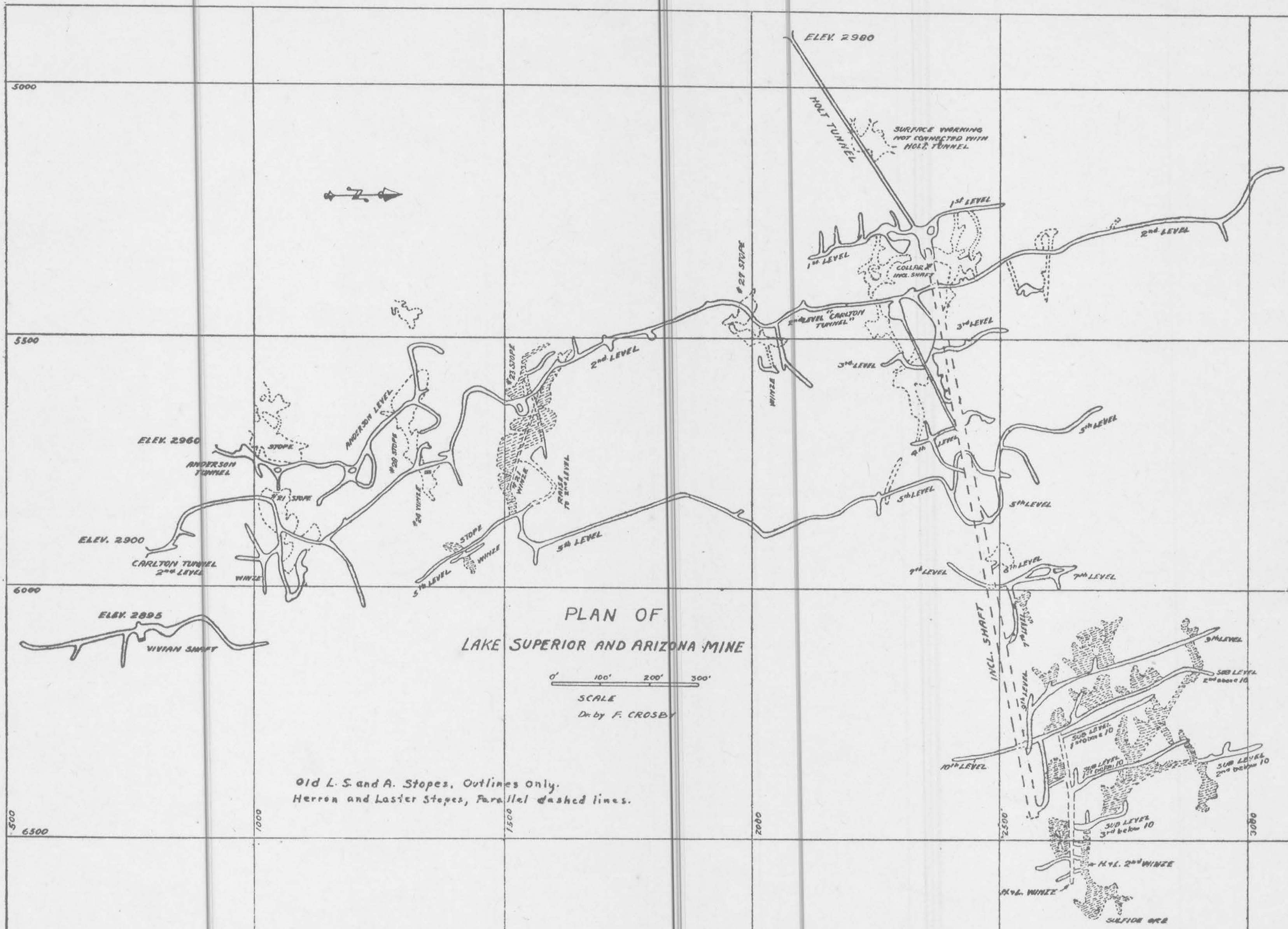

Plate XXVII.—Composite level map, L. S. and A. mine.

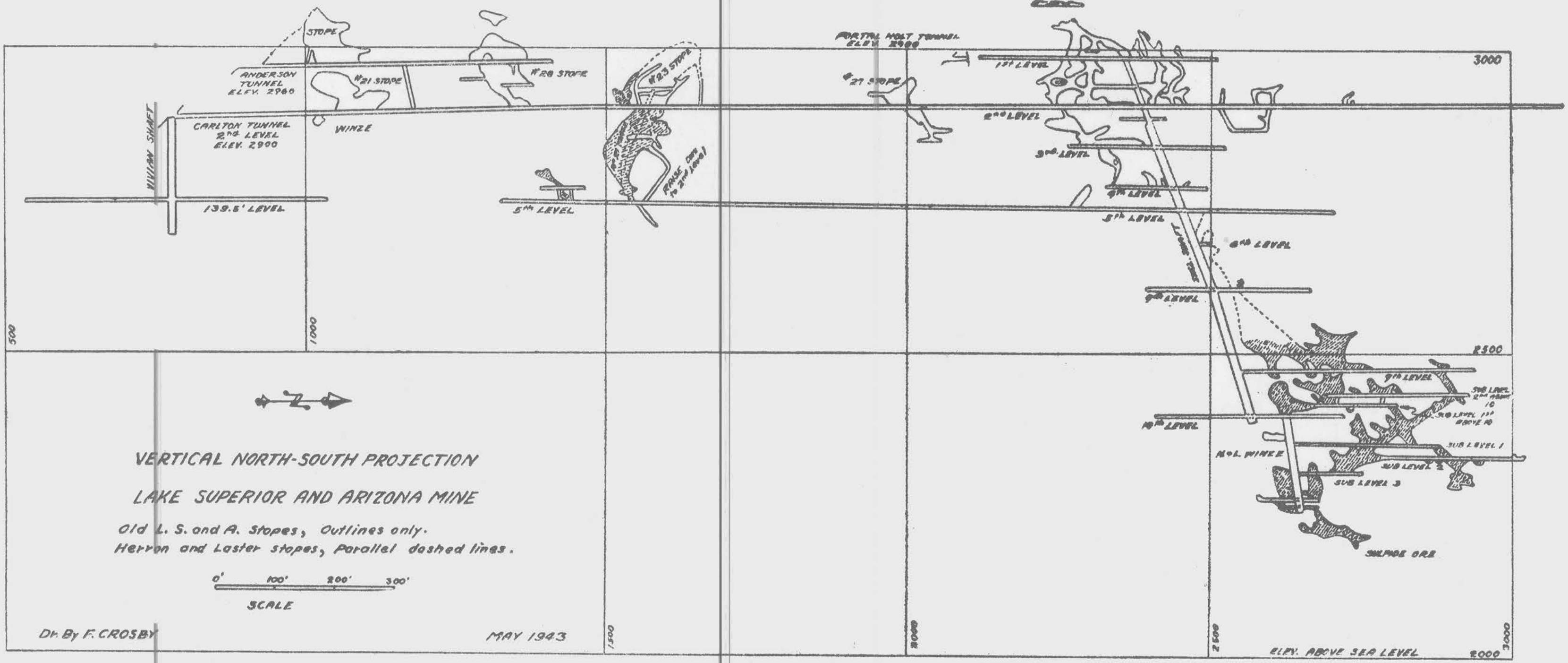

Plate XXVIII.—North-south vertical projection, L. S. and A. mine.

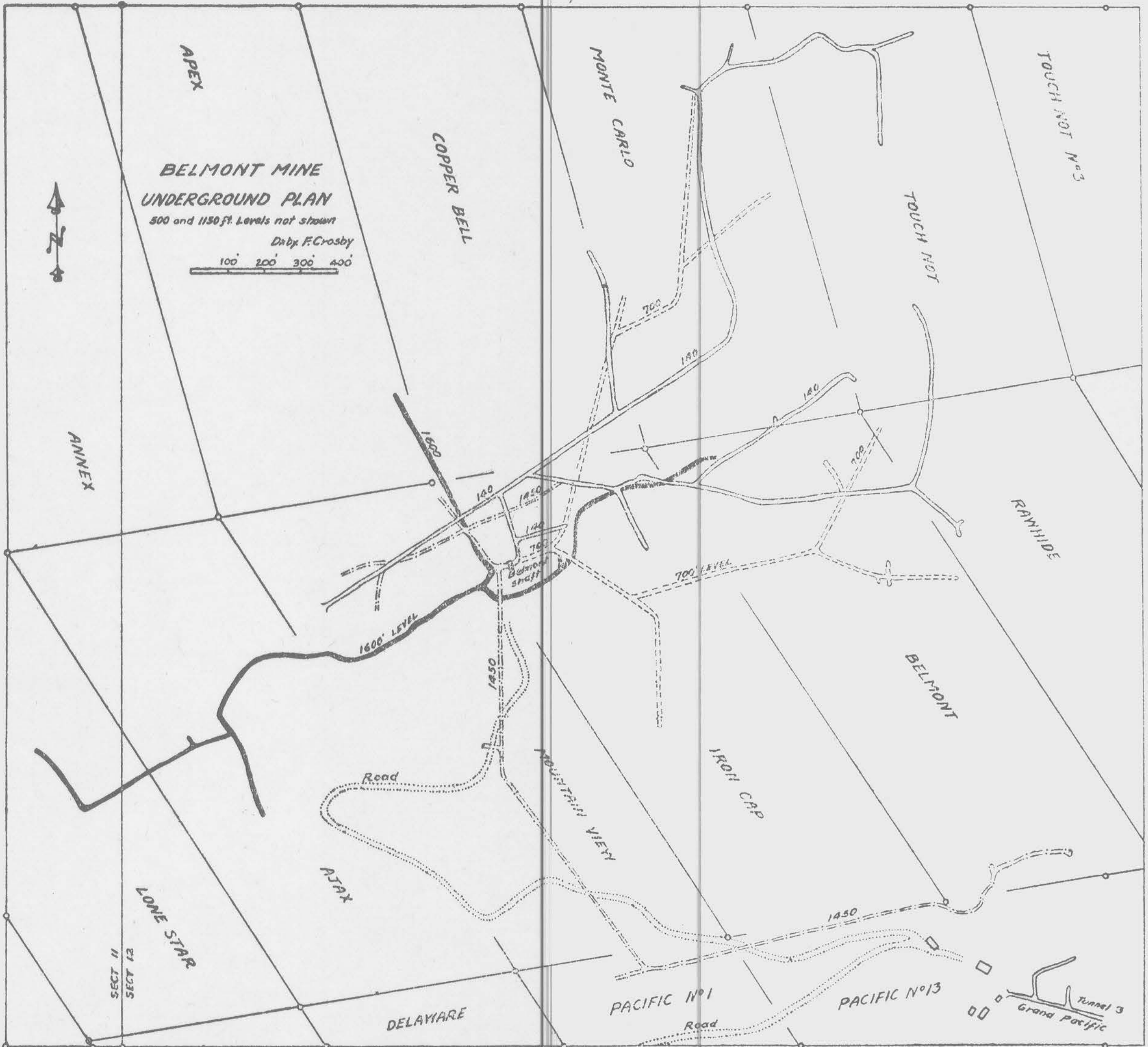

Plate XXXIV.—Composite level map, Belmont mine.

RESOLUTION
COPPER

402 W. Main Street
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April 18, 2018

US Forest Service
Supervisor's Office
2324 East McDowell Road
Phoenix, AZ 85006-2496

Subject: Resolution Copper Mining, LLC – Mine Plan of Operations and Land Exchange – Groundwater Working Group Action Items – April 2018

Dear Ms. Rasmussen,

Enclosed on the attached CD and uploaded into the GW Group Actions_ April 2018 folder on SWCA's SharePoint for your review and consideration, please find the following references for the DRAFT WSP model construction and calibration report:

Reference Name	**File Name**
Barnett B., Townley L.R., Post V., Evans R.E., Hunt R.J., Peeters L., Richardson S., Werner AD., Knapton A. and Boronkay A. 2012. **Australian groundwater modelling guidelines**. Waterlines report No. 82, National Water Commission, Canberra	Australian Groundwater Modelling Guidelines.pdf
HydroGeoLogic, Inc., 1996. **MODFLOW-SURFACT: A Comprehensive MODFLOW-Based Hydrologic Modeling System.** Software Documentation, 1307 p	MODFLOW SURFACT Manual.pdf
Konikow L.F., 1978. **Calibration of Ground-Water-Models, in Verification of Mathematical and Physical Models inv Hydraulic Engineering**. American Society of Civil Engineers, New York, 87-93 p	Calibration.GW.Models.ASCE.1978.pdf
Montgomery & Associates, 2002. **Results of short-term hydraulic testing at Exploration Borehole RES-3D, Pinal County, Arizona.** Memorandum report prepared for Resolution Copper Company, Superior, Arizona, December 2, 2002, 4 p.	FINAL RES3dtest.pdf
Montgomery & Associates, 2015. **Well DHRES-15 – Results of 70-day aquifer test, Resolution Copper Mining LLC, Pinal County, Arizona.** Report prepared for Resolution Copper Mining LLC, August 19, 2015, 21 p.	FINAL_DHRES15_70dTest2015_rev3.pdf
Nevada BLM. 2008. **Groundwater Modeling Guidance for Mining Activities**. Bureau of Land Management, Nevada State Office, Reno, NV. Instruction Memorandum No. NV-2008-035.	Nevada Bureau of Land Management - Groundwater Modeling Guidance For Mining Activities.pdf
Short, M.N., Galbraith, F.W., Harshman, E.N., Kuhn, T.H., and Wilson, E.D, 1943. **Geology and ore deposits of the Superior mining area, Arizona.** Arizona Bureau of Mines Bulletin No. 151, 159 p., 8 sheets.	bulletin 151.zip

402 W. Main Street
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Reference Name	File Name
Spencer, J.E., and Richard, S.M, 1995. **Geologic map of the Picketpost Mountain and the southern part of the IronMountain 7.5' quadrangles, Pinal County, Arizona**. Arizona Geological Survey Open-file Report, 95-15, scale 1:24,000, 1 sheet.	0000768 [16 page report, not a map] ofr-95-15_picketpostmtnsreduced.jpg
Watermark Numerical Computing, 2016. **PEST: Model-Independent Parameter Estimation User Manual.** Software Documentation, 6th Edition published in 2016, 390 p.	PEST Manual.pdf
Woodhouse E. G., 1997, **Perched water in fractured, welded tuff: mechanism of formation and characteristics of recharge.** Dissertation for doctoral degree at University of Arizona, 1997, 258 p.	Woodhouse_EG.pdf

In addition to the above references, the below listed action items are included on the attached CD and uploaded into the GW Group Actions_ April 2018 folder on SWCA's SharePoint for your consideration.

Date	Number	Who?	Action Item	Notes	Status
9/19/17	GW-1	RCM	Provide 2015 Wickham tech memo and other references from WSP report	Reference list attached	WSP references included and listed above
11/19/17	GW-6	RCM	Double check that all hydrologic units go back to a reference	HGU_geologic unit correlation table 6Apr18.pdf	Attached
12/12/17	GW-12	All	Standing – Bring forward any GDE information for consideration	ltr_GDE Table_16Apr2018_v0.1.pdf Seeps & Springs Report.pdf	Attached RC/M&A provided recommendations of GDEs to be assessed with regional model. Westland report regarding surface water vegetation attached.
1/16/18	GW-22	FS/SWCA	If available, bring forward any pertinent adjacent hydro/geo information from Pinto Valley or Carlota	K Distribution_MiamiArea_CMMC APP.pdf	Attached
1/16/18	GW-23	RCM	Provide suggestion of reports that reference pumping tests or other useful information to support interpretation	See Project Record # (PR#) 0000875, 0000880, 0000883, 0000886, 0000888	

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Date	Number	Who?	Action Item	Notes	Status
			of ALT/WTC hydraulic properties, and specifically anisotropy		
2/13/18	GW-35	RCM	Expected report: Re-creation of aquifer tests using model, with comparison to real-world head measurements		Attached
2/13/18	GW-44	RCM	Clarification: Provide justification of selection of hydraulic conductivity for different geologic units, including incorporation of anisotropy	Appendix A - Hydraulic Testing Summary rev6Apr18.pdf	Summarized in Appx A (attached) and stand-alone M&A reports HRES 9 (PR#0000883) and HRES 20 (PR#0000886)
2/13/18	GW-45	RCM	Clarification: Clarification of how recharge was assigned	Revised Areal Recharge Text Section 6.1.3 6Apr18_.pdf	Attached
3/13/18	GW-58	RCM	Expected report: Tech memo addressing available data for GDEs, to supplement SWCA process memo	ltr_GDE Table_16Apr2018_v0.pdf	Attached RC/M&A provided recommendations of GDEs to be assessed with regional model

Should you have any questions or require further information please do not hesitate to contact me.

Sincerely,

Vicky Peacey

Vicky Peacey,
Senior Manager, Permitting and Approvals; Resolution Copper Company, as Manager of Resolution Copper Mining, LLC

Cc: Ms. Mary Morissette; Senior Environmental Specialist; Resolution Copper Company

Enclosure(s): Resolution Copper Mining, LLC – Mine Plan of Operations and Land Exchange – Groundwater Working Group Action Items – April 2018