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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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(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

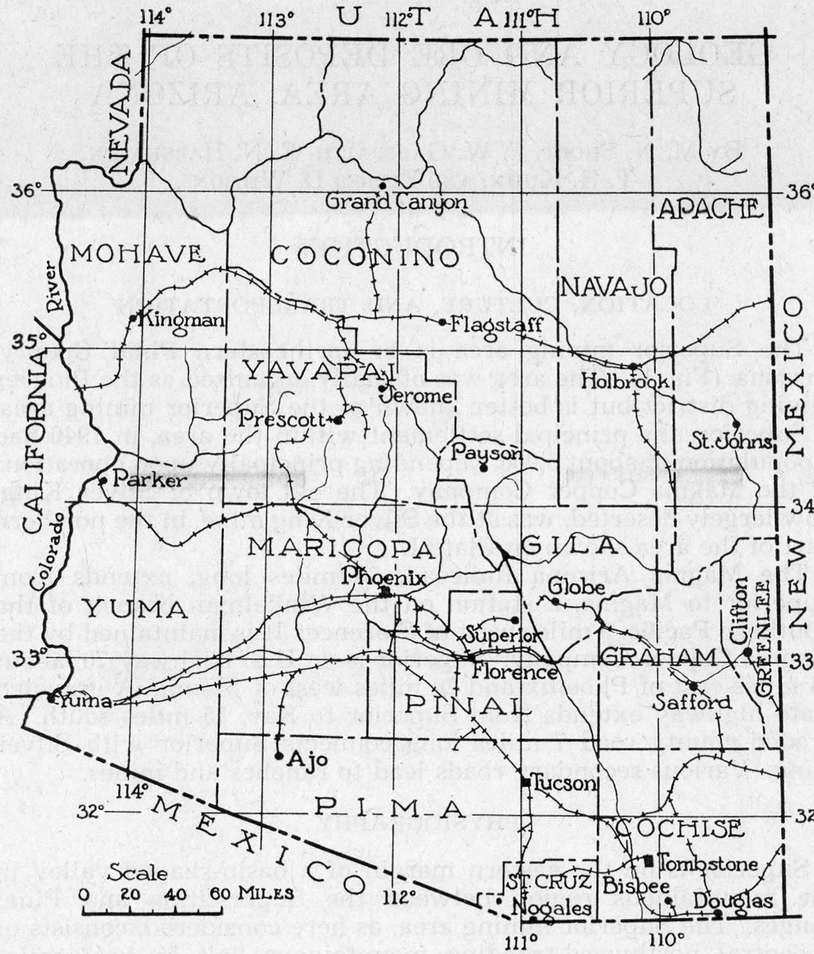

Figure 1.—Index map of Arizona.

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

[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

Year	Inches	Year	Inches
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:

Month	Inches	Month	Inches
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 side-winders, 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.

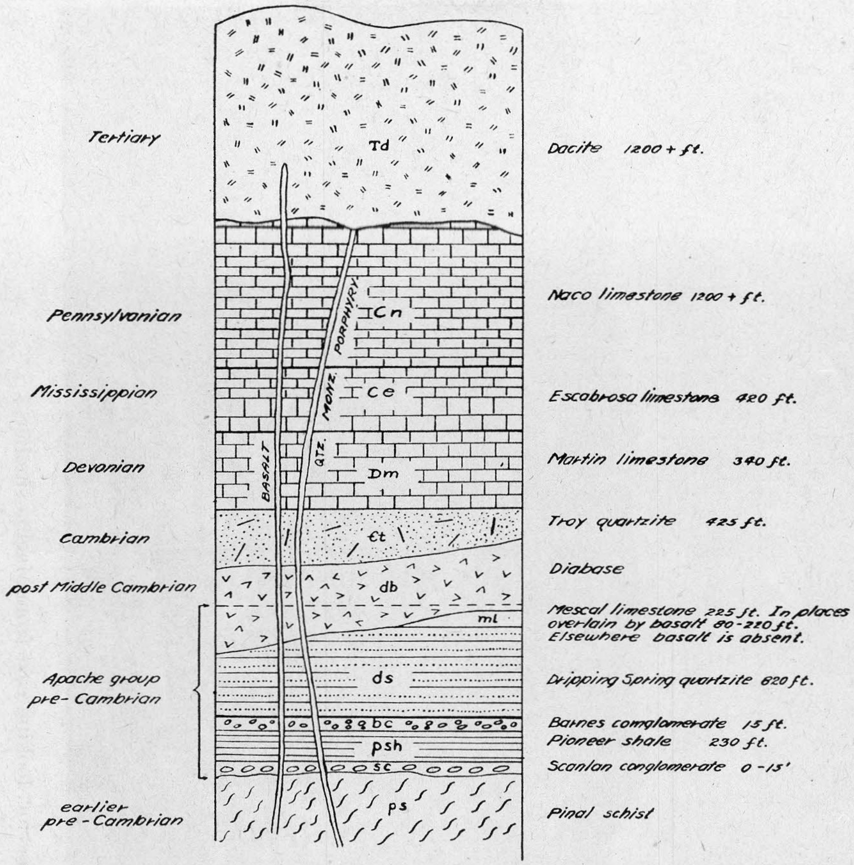

Figure 2.—Generalized geologic column, Superior mining area.

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-

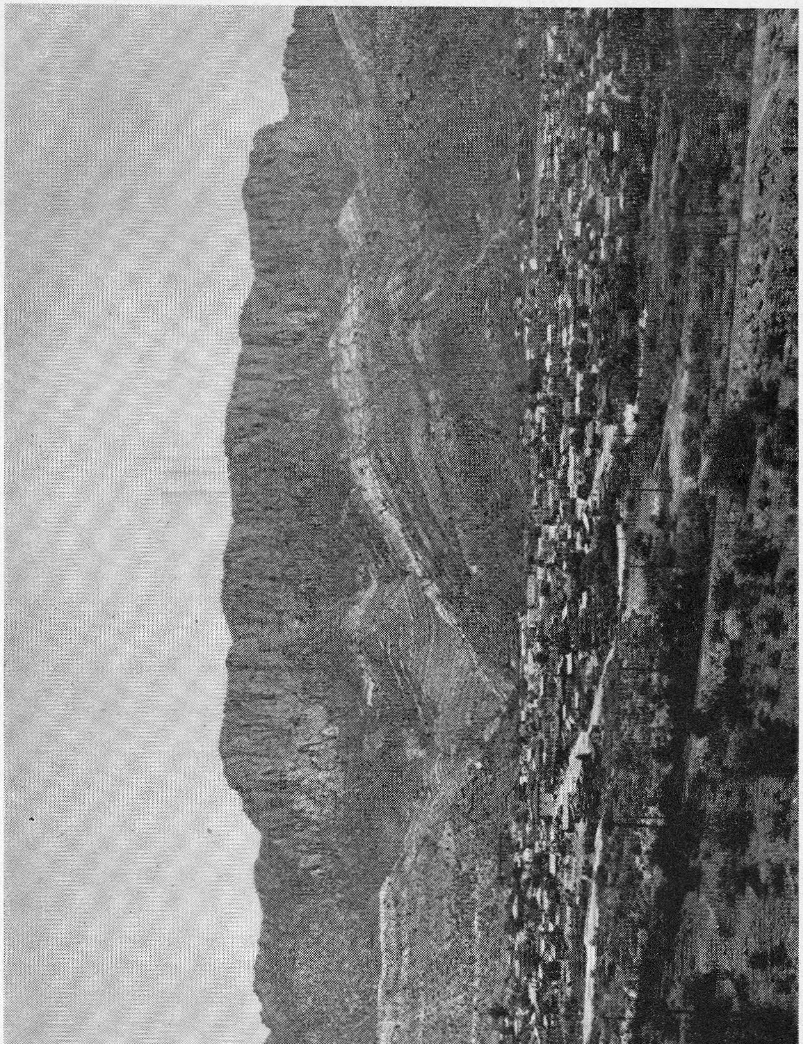

Plate III.—Superior, looking east from Magma smelter.

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 postore 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.

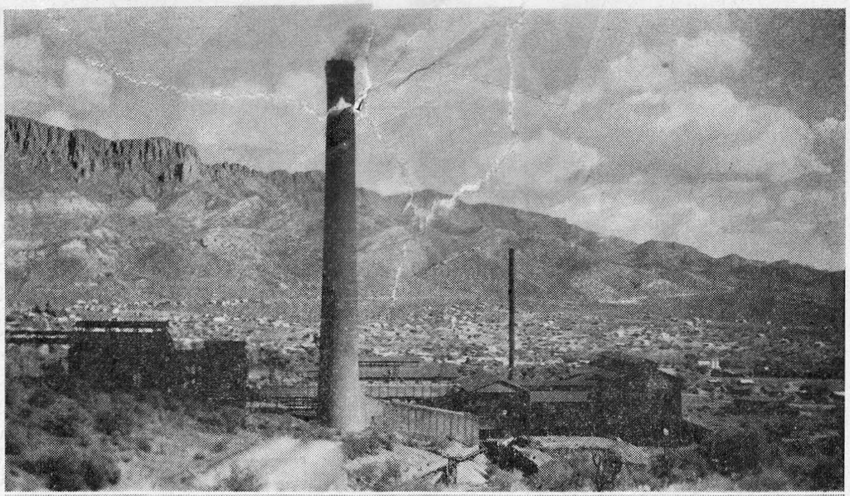
In the Potts Canyon area, bands of milky white to dark blue quartz several inches thick appear in the schist. These are parallel to the schistosity, which in turn appears to parallel the bedding of the overlying beds. The schist has been invaded by thick sills of diabase and colored dark brown by contact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



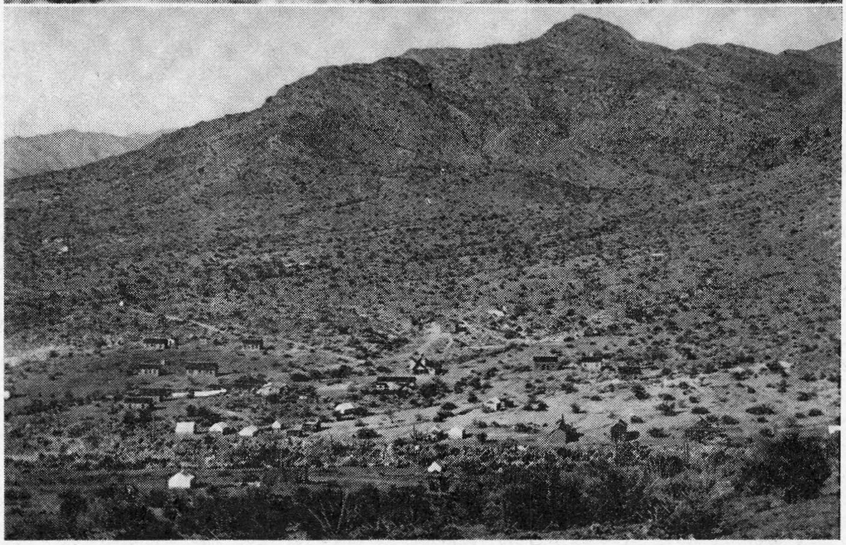


Plate IV.—*A*, Looking southeast toward Magma smelter and Superior. Belmont subarea in background; *B*, Superior in 1908.

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,

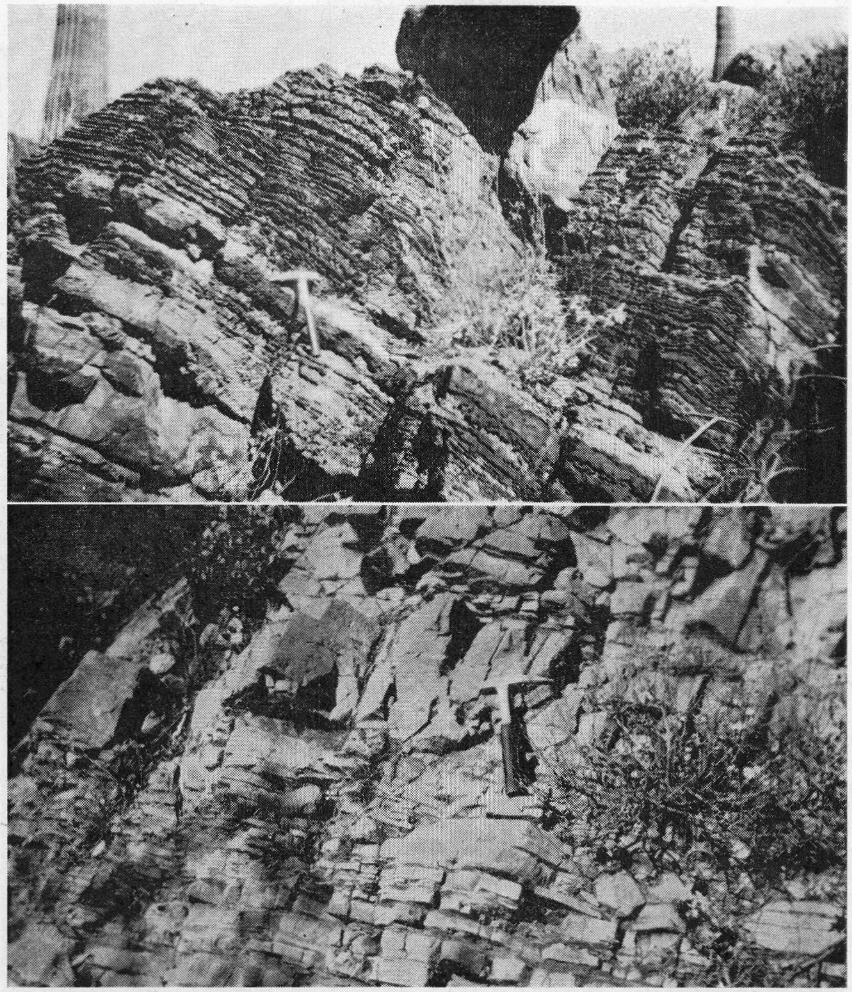

Plate V.—*A*, Cherty Mescal limestone; *B*, Typical Mescal limestone.

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.

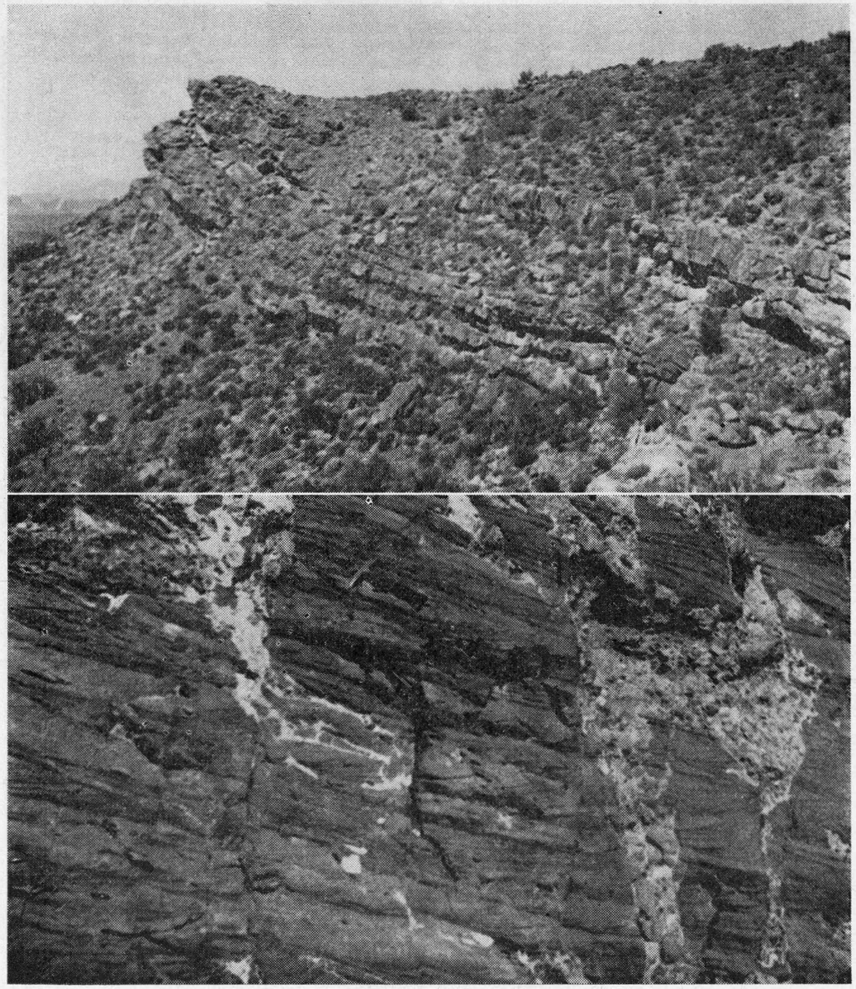

Plate VI.—*A*, Basal cliff-forming member of Troy quartzite looking north from Cross Canyon; *B*, Typical cross-bedded Troy quartzite in Pacific Canyon.

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 ¼ 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.

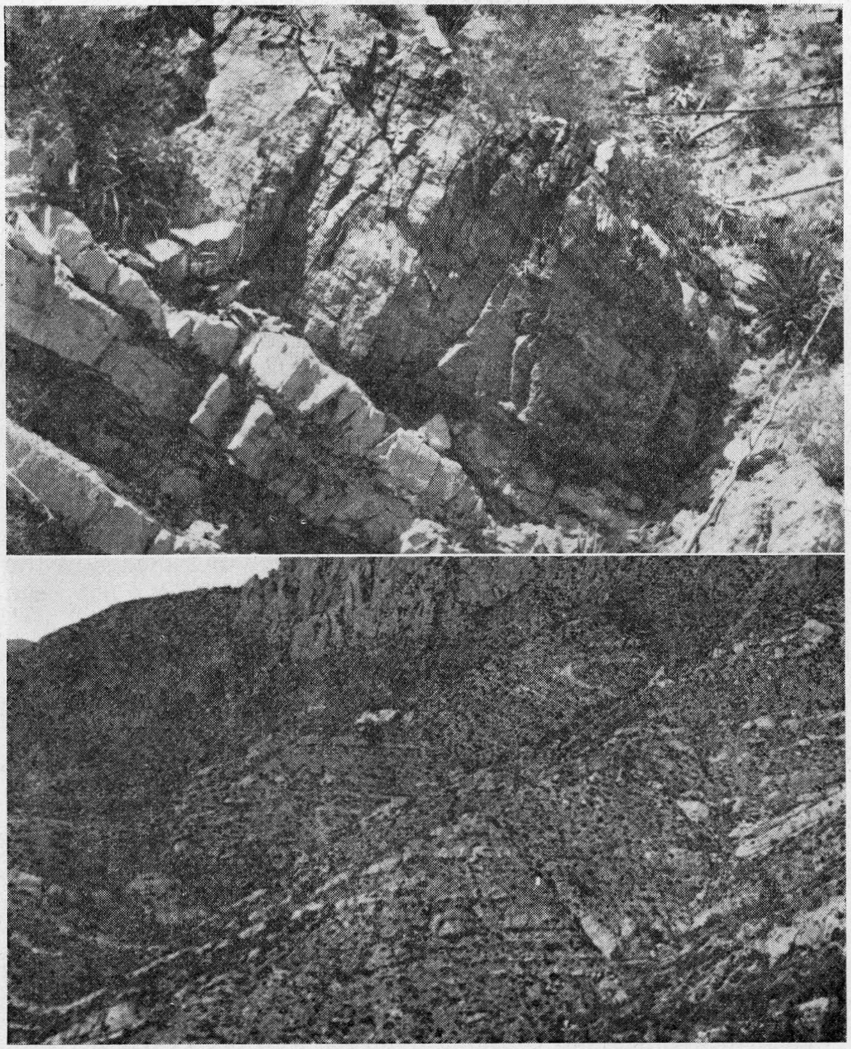

Plate VII.—*A*, Conglomerate bed separating Escabrosa and Naco limestones in Cross Canyon; *B*, Naco limestone showing Elm overthrust.

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.

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[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:

	Thickness (feet)
Middle-Cambrian—Troy quartzite	
Unconformity	
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.

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[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 micrographic 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% 0.03 to 1.3 mm.	Sericite, Kaolin
Quartz—5% 0.20 mm.	Magnetite, Leucoxene } 2%
Accessory	
Muscovite—25% 0.08 mm.	Limonite, Hematite } 3%

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

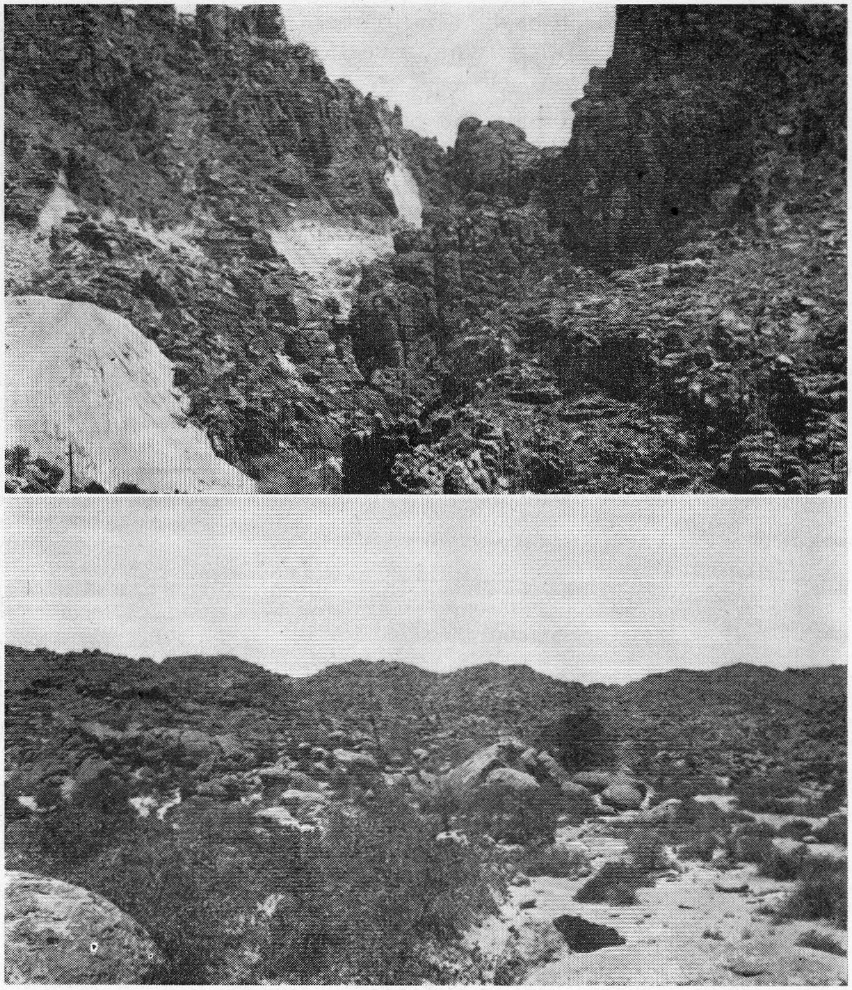


Plate VIII.—*A*, Dacite in gorge of Queen Creek; *B*, Dacite, Oak Flat.

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	*Alteration*
Labradorite $Ab_{35}An_{65}$—50%	Iddingsite—15%
1.75 mm. to 0.02 mm.	0.80 mm.
Augite—25%	*Amygdular*
0.75 mm.	
Olivine—4%	Calcite—4%
0.40 mm.	
Accessory	
Magnetite—2%	
0.03 mm.	

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

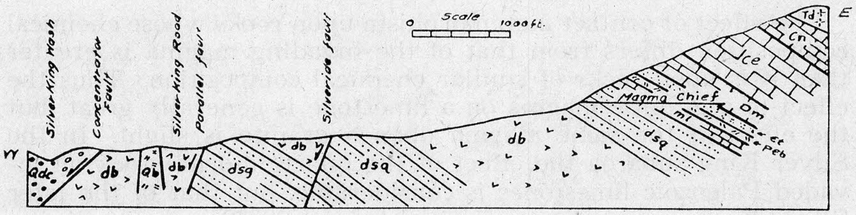


Figure 3.—East-west geologic section through Magma Chief tunnel.

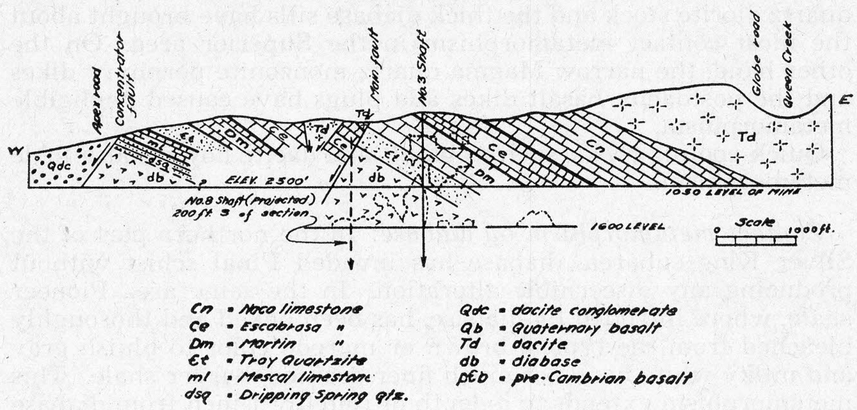


Figure 4.—East-west geologic section through Magma No. 3 shaft.

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.

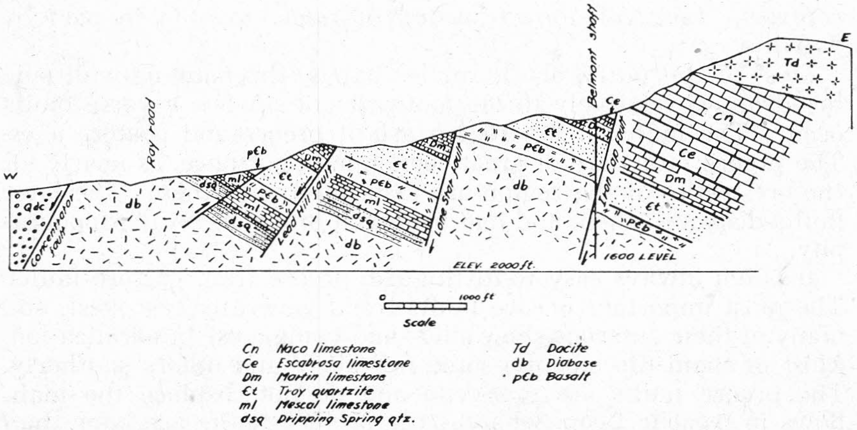


Figure 5.—East-west geologic section through Belmont shaft.

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.

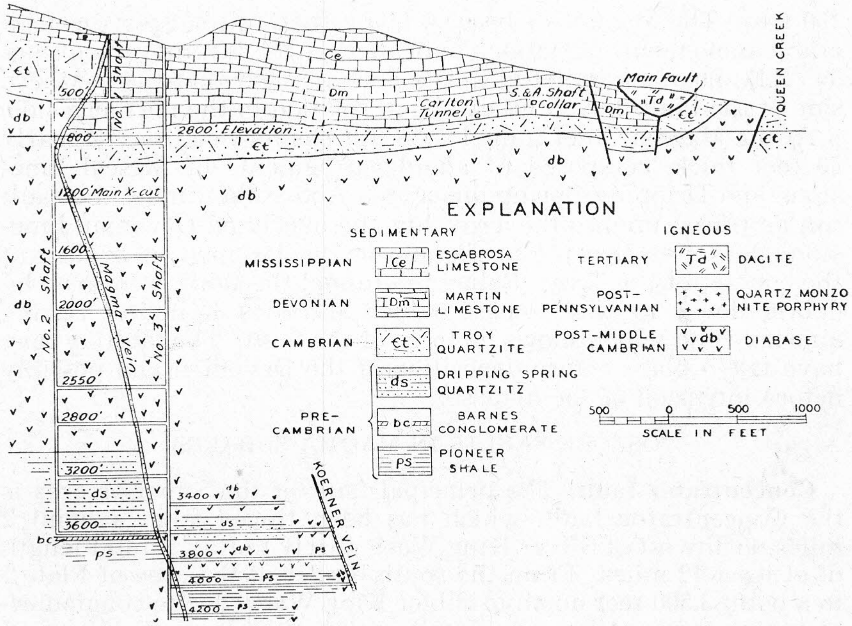


Figure 6.—North-south section through Magma shafts.

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.

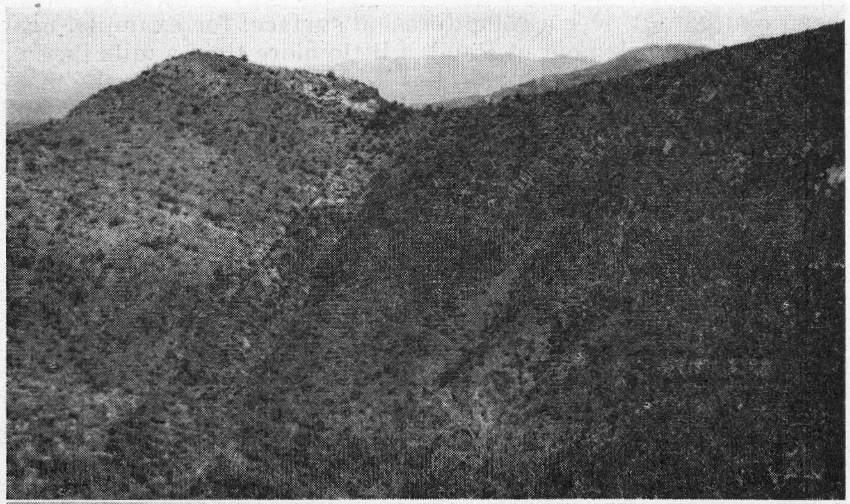
POSTORE FAULTS IN MAGMA SUBAREA

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



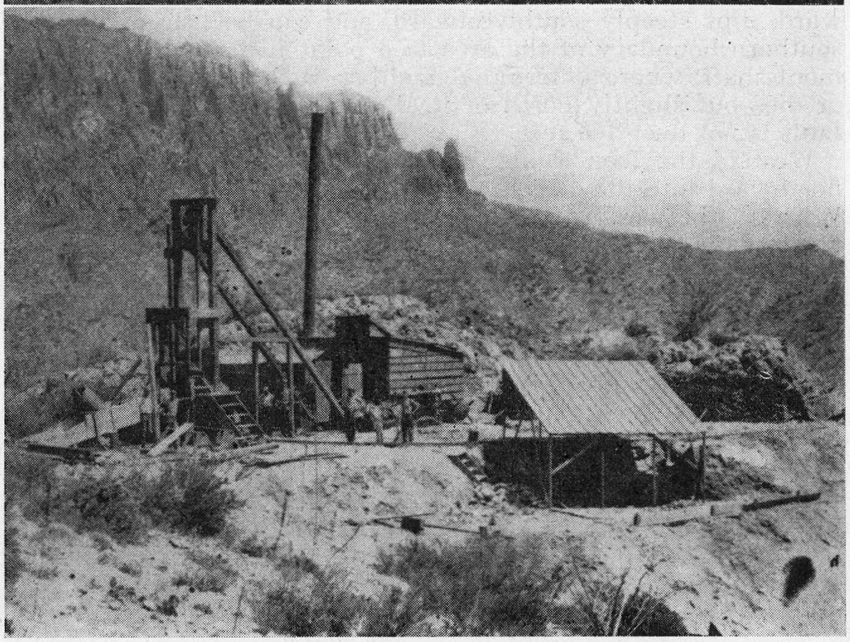


Plate IX.—*A*, Lead Hill fault, looking north from Belmont Canyon; *B*, Silver Queen (Magma No. 1) shaft, 1907.

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,