Geology of

THE OLD DOMINION MINE

Globe, Arizona.

by

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INTRODUCTION

A most thorough investigation was made of the Globe district in 1901 by F.L. Ransome, and the results of this examination published as a Professional Paper [1] in 1903 by the United States Geological Survey. The Old Dominion Mine had then reached the 12th level. Since Ransome's study of this mine an additional 1000 feet of depth has been reached; and although numerous short articles have appeared in the technical literature, no thorough examination was made of the mine until 1913 when Mr. J.M.Boutwell was engaged to make a private report for the company. During the course of this work the surface and all underground openings were mapped in great detail by Boutwell, assisted by Mr. G.N.Bjorge. These detailed maps, started by Boutwell, were kept up as underground development progressed, by Bjorge, by the writer, and later by Mr. W. Porri. As would naturally be expected, the collection of such a large amount of data has thrown new light on the general structure and the occurrence of the ore. The intelligent application of the information collected has been a great aid in the development of this mine.

The writer is very grateful to Mr. W. G. McBride, General

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1. Ransome,F.L.,Geology of the Globe copper district,Arizona: U.S.Geol.Survey Prof. Paper 12,1903.

Manager of the Old Dominion Company, for permission to use the information collected, while in the employ of this company, in writing this thesis; and to Mr.I.H.Barkdoll, superintendent, for many helpful suggestions during the writer's employ as geologist for this company; and to Mr.W.Porri, the writer's successor, for information on the latest developments. Mr.H.S.Duncan, chief engineer, has kindly furnished the writer with data on the water problem.

Much credit is due the pioneer work of F.L.Ransome, and where information is taken from his published data, credit is given in the foot-notes. Some information was obtained in conversations with Prof.F.H.Probert, of the University of California, and the writer has benefitted very materially by discussions of problems relating to the secondary enrichment and the oxidation of the ore.

LOCATION

The State of Arizona has been divided by most geologists into three distinct topographic subdivisions: the Plateau region, the Mountain belt, and the Desert or Bolson. The Globe mining district is located approximately 50 miles southeast of the center of the state, in the heart of the mountain belt. The individual ranges vary from a few miles to over fifty miles in length, and generally have a northwest-southeast trend.

The Old Dominion Mine is located in the intermontane valley between the Apache and the Pinal Mountains. This mine is on the main mineralized fracture of the district, and extends from Pinal Creek northeastward for over a mile. On the continuation of the Old Dominion vein and adjoining the Old Dominion Company on the northeast, is the Arizona Commercial Mine. Beyond the Arizona Commercial Mine is the Iron Cap and the Superior and Boston mines. The Iron Cap is very likely on the continuation of the Old Dominion vein, while a large part of the ore in the Superior and Boston occurs along the Great Eastern fault. To the north of the Old Dominion are numerous small prospects which have produced some lead and a considerable amount of silver from surface workings, while to the northwest are located the large disseminated deposits of the Miami and Inspiration Copper Companies. To the south and southwest no mines of importance within a radius of ten miles have been opened, although a small amount of gold was panned in Pinal Creek, and many small prospects on quartz veins in the Pinal schist show values of this metal.

GENERAL GEOLOGY

Physiography

Within a radius of twelve miles of Globe the physiographic features are quite varied, and the deeply incised canyons of the Pinal Mountains stand out in strong contrast to the more mature relief of the Globe Hills. The relief of the area varies from an elevation of 3000 feet on Pinal Creek near Wheatfields to one of 7850 feet above sea level on the summit of Pinal Peak, a difference in elevation of nearly 5000 feet. The railway station at Globe is slightly over 3500 feet above sea level. The high elevation of the Pinal Mountains is largely responsible for the diversion of currents of cold air which moderates the summer climate in the valley below. A discussion of the age and origin of these mountains will be taken up under the heading of Structure.

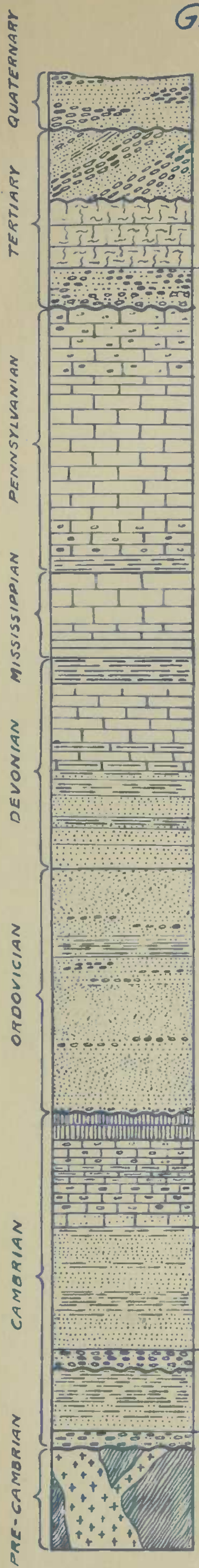
As viewed from the slopes of the Pinal Mountains, the low, mature relief of the Globe Hills presents a mosaic of colored blocks of gray limestone and brown to reddish quartzite set in a frame of olive-colored diabase. While in large part this patchwork of color is due to block-faulting, in a measure it is due to erosion; and the southwesterly trending ridges are capped by the more resistant formations of limestone and quartzite, while in the wider valleys the streams have cut down into the underlying intrusive diabase. Although these low spurs attain an elevation of only a few hundred feet above the bed of Pinal Creek, Buffalo Ridge, the most prominent landmark in the immediate vicinity of the Old Dominion Mine, reaches an elevation of 4350 feet above sea level. Two other Peaks in the Globe Hills are worthy of mention. One of these is Black Peak and is situated somewhat less than a mile north of the Iron Cap Mine. It is an erosional remnant of a faulted block of diabase, and reaches an elevation of 4780 feet. The other is Ramboz Peak, and is located about six miles north of Globe. It attains an elevation of slightly over 5050 feet.

The wide valley between the Globe Hills and the Pinal Mountains is filled with gravels in which streams have entrenched themselves and cut their beds, in some cases, to a depth of over 350 feet. These streams have cut the gravels into a series of long spurs, some of which reach a length of five miles. Generally, they have a parallel trend to the northeast. The tops of these spurs have approximately the same elevation, with a gentle rise to the foot of the mountains, and are the remnants of the old surface formed by the aggradational processes that filled the valley.

To the northeast of Globe the Apache Mountains present a bold face to the southwest, consisting of a series of cliffs and slopes. These cliffs are due to resistant quartzites, undermined by sapping of the soft shales and an altered diabase sill. This gives the mountain a step-like appearance. It is flat-topped and reaches an elevation of over 6000 feet.

Pinal Creek, the main drainage line of the region under consideration, heads in the Pinal Mountains and flows northward, and discharged into the Salt River. Before the close of the Tertiary this stream flowed southeastward with a low gradient, probably not over 25 feet to the mile, and discharged into the San Carlos River, a tributary of the Gila River. The last major uplift of the Pinal Mountains occurred at the close of the Tertiary, and the rejuvenated streams loaded to capacity by the torrential floods built large fans in front of the mountains. These fans not only encroached upon and choked the drainage, but built a barrier across the old stream flowing southward, and formed a temporary lake. Beds of fine silts were deposited during this period, and are intercalated in the Globe gravels. With the raising of the level of the lake an outlet was found and cut down at the northern end of the basin. The supply of detritus from the Pinal Mountains was so much greater than the quantity derived from the Globe Hills that the newly formed stream was crowded to the east against the hard-rock formations of the Globe Hills. For a length of over six miles the west bank of Pinal Creek is in the Globe gravels, while the east bank is in the older formations. This stream usually carries water throughout the year, and the supply is derived largely from melting snows on the high summits of the Pinal Mountains.

GLOBE COLUMNAR SECTION



Contact	Formation	Thickness in feet
	GLOBE GRAVELS Unconsolidated Sands and Gravels.	400 +
Unconformity		
	GILA CONGLOMERATE Consolidated Sandstone, Shale, and Conglomerate.	2000 +
Unconformity		
	DACITE Massive Flows glassy at the base Some Tuffs.	600 +
	WHITETAIL CONGLOMERATE Chiefly pebbles of granite, quartzite, diabase, limestone	0 - 75
Unconformity		
	NACO LIMESTONE White, pink, and gray limestone. Fossiliferous. Black flint and red chert in upper beds. Some sandy beds Shale at the base	325 +
Disconformity		
	ESCABROSA LIMESTONE Massive black limestone overlying white limestone. Buff paper shales at the base.	75
Disconformity		
	MARTIN LIMESTONE Buff paper shales at top White and gray limestone Shaly limestones and shales. Fossiliferous. Massive buff sandstones and shales at base.	400
Disconformity		
	TROY QUARTZITE Cross bedded with worm trails in upper part. Intraformational conglomerates. Shales in upper part.	700
Unconformity		
	BASALT FLOWS	80 to 250
	MESCAL LIMESTONE Cherty, dolomitic limestone. Arenaceous at base.	210
	DRIPPING SPRING QUARTZITE Fine grained bedded quartzites, some ripple-marks. Shale with sun-cracks.	425
	BARNES CONGLOMERATE	15
Unconformity		
	PIONEER SHALE Indurated shales with sun-cracks Quartzites at base with ripple-marks.	275
Unconformity	SCANLAN CONGLOMERATE	10
	PINAL SCHIST Intruded by granite	

The tributaries to Pinal Creek are usually small and carry water only during the torrential storms. Of the larger creeks flowing into Pinal Creek, Bloody Tanks Wash, with its branch up Russel Gulch, drains the largest area. It heads in the northern end of the Pinal Mountains, and also drains the rugged hills just northwest of the town of Miami. The stream flowing through Copper Gulch drains the area as far east as the Superior and Boston Mine.

Sedimentary Rocks

Scanlan Conglomerate: Resting on the old granitic complex of the pre-Cambrian, this formation, at the base of the Paleozoic series, is the most variable in composition and thickness. Where it has been cut in the underground workings of the Iron Cap Mine it has a thickness of ten feet and rests on schist; while near the Roosevelt dam it has a thickness of 30 feet. Locally, as where the Gila River cuts through the Mescal Mountains about 25 miles south of Globe, the formation is absent.

The conglomerate consists of pebbles, usually well rounded and quite variable in size, of milk quartz, chert, quartzite, and schist fragments. Only the more resistant schist fragments were able to withstand the action of the waves. The finer material between the pebbles consists of a coarse sand, usually arkosic, and contains flakes of mica derived from the schist. Although 30 feet of conglomerate occurs at the Roosevelt dam, a locality three miles south of the dam shows the granite overlain by about 70 feet of a coarse sandstone at the base of the Pioneer shale, and the Scanlan conglomerate is absent. This sandstone is the equivalent of the conglomerate and was deposited at the same time that the conglomerate was forming in other areas.

The conglomerate was formed by the waves of an advancing sea over a land area of low relief. The surface was littered with fragments of milk quartz derived from veins in the schist. Where the schist was indurated by contact metamorphism, fragments not destroyed by weathering were incorporated in the conglomerate. Some low monadnocks of granite were encountered and planed down, conglomerate being deposited on remarkably fresh granite. The granitic areas also supplied the detritus for the formation of the arkosic sands.

Pioneer Shale: Following the deposition of the Scanlan conglomerate the Pioneer shale was laid down in quieter water, Towards the base this formation is a sandstone, somewhat arkosic, but changing gradually to arenaceous shale and thin laminated shales. The beds are well indurated, and are colored brown, reddish, and purple. This, however, while the predominant color at the surface, does not hold a depth where the formation is away from oxidizing influences. Where cut in the mine workings of the Arizona Commercial and the Iron Cap Mines, the color is greenish or various shades of gray with a greenish tinge. This suggests ferrous iron, and the clays and silts from which this formation was derived, were evidently deposited under reducing conditions. No determinable fossils have been found, but worm trails and borings are abundant in some beds. These forms of life may have furnished the organic material necessary for the reduction of the iron, if it were oxidized while being transported. A mottled appearance is very characteristic of these shales, and is a valuable criterion in separating them from similar shales in the Dripping Spring formation. On the cleavage planes are numerous sparkling flakes of mica. These partings often show well preserved mud-cracks and worm-trails, and a specimen in the collection of the Old Dominion Mine shows what may be fossil rain-prints.

Following the deposition of the arenaceous beds over the Scanlan conglomerate, a barrier beach was built up by the waves at some distance from the shore. The embayment or lagoon thus formed was the basin in which the finer silts were laid down. This basin, at times, was a shallow tidal flat, and the surface was exposed to the sun and air for several days at a time. Barrell [2] estimates that the tidal flat must be exposed, between tides, for 36 hours as a minimum to sufficiently harden and preserve the mud-cracks against obliteration by the waves. Barrell [3] made experiments on pure clay and also on silty clay containing a small amount of grit, and as a result of these experiments concluded that only pure clay would form and retain mud-cracks. As currents with a velocity of a third of a mile an hour will move fine sand,

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2. Barrell, Joseph, Relative Geological Importance of Continental, Littoral, and Marine Sedimentation: Journal of Geology, vol. 14, p. 545, 1906.

3. Op. cit. p. 528

Barrell's conclusions would suggest that the Pioneer shale was deposited in very quiet water in which the tidal range was not very large. To expose so large an area as is now occupied by the Pioneer shale would require a rather shallow basin with a small tidal range and with no long-shore currents.

Barnes Conglomerate: Apparently conformably overlying the Pioneer shale is the Barnes conglomerate. It consists of very well rounded pebbles, worn extremely smooth by attrition and usually elongated. They lie with their long direction parallel to each other and parallel to the bedding of the underlying shales. The pebbles are usually in contact with each other, although in some instances they are set in an arkosic matrix of sand. They are uniform in size, varying from two to four inches, but occasionally pebbles six inches or more in diameter are found. In other sections pebbles as much as nine inches in diameter are found, but then all the pebbles are large, indicating that there has been some sorting.

Only the most durable rocks compose this conglomerate; and they consist mostly of milk quartz, but pebbles of black and vermillion chert and an older quartzite are also common. The black chert was observed by the writer in the pre-Cambrian schists in the Mazatzal Mountains north of Mount Ord. According to E.D.Wilson, vermillion chert occurs at the north end of the Mazatzal Mountains and in the schist near Jerome. Although some members of the schist series are quartzitic, a close inspection of the fresh fractured surface invariably shows the presence of mica developed by the metamorphism to which this old series has been subjected. Some pebbles of quartzite containing mica were found by the writer, but by far, the larger number of quartzite pebbles contained no mica and were of a purplish cast, coarse-grained, and highly indurated. They were undoubtedly derived from the Mazatzal quartzite described by Wilson [4] as occurring under the Mogollon Rim. The Barnes conglomerate has been observed to rest on schist and granite but no pebbles of either of these two rocks have been seen within it by the writer.

The matrix between the pebbles, while generally arkosic, often consists of a rather pure quartz sand, and is so highly indurated that it is difficult to hammer out pebbles or to break the matrix away from the pebble. A thick, massive bed of this arkosic sand was observed at the base of the Barnes conglomerate resting on granite. In other sections a massive, sandy member divides the Barnes into two beds of conglomerate, and usually shows cross-bedding and wedges out in a short distance. The grains of the matrix are not of a uniform size and are often quite angular. The salmon-colored grains of feldspar are commonly larger than those of quartz, and although highly altered, show cleavage and the characteristic Carlsbad twinning of orthoclase.

Although the formation varies in thickness, it is rather uniform for short distances. It is apparently absent in the

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4. Wilson, Eldred D., Protozoic Mazatzal Quartzite of Arizona: The Pan-American Geologist, vol. 38, 1922, p. 299.

northern end of the Sierra Ancha, but at the southern end of this mountain range Ransome [5] noted a thickness of from 5-20 feet. At Globe the conglomerate has a thickness of 12 feet in the Arizona Commercial Mine, while at Kelvin Ransome measured 55 feet. The greatest thickness observed by the writer was in the Mescal Mountains near the Gila River, where it attains a thickness of 80 feet. It will be noted from the localities and thicknesses given above that the formation becomes progressively thicker towards the south.

The formation may have originated by any one of the following processes: (1) Fluviatile; (2) Marine; or (3) combined fluviatile and marine. Strong arguments can be made for a fluviatile origin, and yet there is some evidence suggesting a marine origin. Many of the facts observed, however, cannot be explained by marine action as we now understand it.

One of the strongest arguments in favor of a fluviatile origin is the long distance the pebbles of red chert were carried before reaching their final resting place. While mapping the geology of the state, no rocks older than the Barnes conglomerate were seen containing red chert south of the Mazatzal Mountains, although a number of localities were carefully examined. To have reached the localities on the Gila River, where they now occur, would require these pebbles to have been transported between 50

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5. Ransome, F.L., Some Paleozoic Sections in Arizona and their Correlation: U.S.Geol.Survey Prof. Paper 98-k, Plate XXV., page 136, 1916.

and 100 miles. No currents along the shore, as we now understand them, are capable of transporting pebbles six to nine inches in diameter for long distances. Large boulders are often moved by storm waves, but this is more of a rolling back and forth with but little transverse movement. Lenses of sandstone with stray pebbles and high angle cross-bedding occur at some localities and divide the conglomerate into two members. According to Gregory [6] these stray pebbles are indicative of fluviatile action. The lenses of sandstone in which these pebbles occur often pinch out rather suddenly, and such structures cannot be explained by marine action.

The best argument that can be advanced to support a marine origin for this conglomerate is the uniform thickness of the formation. This is believed to be characteristic of marine conglomerates formed by the waves of an advancing sea. The thicknesses given above show the formation to vary from a few feet to 80 feet; and while this is quite a difference in thickness, the change is gradual with a thickening to the south, and within a mile or two the variation is small. Of minor importance, but of some value in supporting a theory of marine origin is the constant occurrence of this conglomerate on clean surfaces of such rocks as granite. If this granite were exposed to the air just before the deposition of the conglomerate it would be expected to show considerable disintegration due to a dilatation and

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6. Gregory,Herbert E., The Formation and Distribution of Fluviatile and Marine Gravels: Am.Jour.Sci., 4th ser., vol. 39,p.487, 1915.

contraction of the component minerals by temperature changes. This residual material could be readily removed by the waves and would be less likely to be removed by a depositing stream. This would suggest that some erosion had taken place, and yet this erosion could not have been very intensive, as a small monadnock of coarsely crystalline granite was observed in a cliff section with a length of 15 feet and a height of 3 feet above the general contact of conglomerate and granite. If the thorough rounding of the pebbles was due to wave action, this residual mass of granite should have been planed off.

Dripping Spring Quartzite: Overlying the Barnes conglomerate with apparent conformity is a series of quartzite beds having a thickness of 425 feet in the Old Dominion Mine. The formation consists of thin beds of rather pure quartz sand cemented by silica; the beds average from two to three inches, but are often as much as 12 or 18 inches thick. The beds are often separated by thin shale partings, and in some parts of the section the shaly beds predominate. Where exposed to the action of the weather, the beds are usually of a light to a dark brown with some beds a decided maroon. The shales are often reddish and where they become thicker are of a green or gray color. In the deeper levels of the mine, away from oxidizing influences, the formation is gray with a greenish tinge.

An examination of thin sections shows the quartzite to be composed of small, nearly uniform grains of quartz, usually rounded, but angular grains are not uncommon. Some plagioclase feldspar was seen, and is usually turbid due to alteration. Magnetite occurs in thin, well-defined, parallel bands, and the gray color of the rock is due to the presence of this mineral. The cement between the grains is secondary silica, and the original grains often show secondary enlargement.

The ferrous iron in magnetite, on exposure to the air, oxidizes to ferric and hence the red color on surface exposures of this formation. The writer desires to call attention to an error often made by geologists in suggesting arid conditions during deposition for formations of a red or deep brown color. The Dripping Springs quartzite was not deposited under arid conditions, and the red color now seen in surface exposures is due to a recent change.

The formation was deposited on a delta where the water was quiet enough to permit the settling of fine sand and silts. The well-marked lamination and thin banding may be due to a re-working of the sand by the waves. Some ripple marks are found, and mud-cracks are common in the shaly beds, a suggestion of shallow water during deposition. No fossils other than worm trails and borings have been found, and these are confined to the shaly members. Enough of these forms of life may have lived in the sea at the time of deposition to have kept the iron in a state of reduction.

Mescal Limestone: This limestone has a thickness of slightly over 200 feet, but locally erosion has reduced this thickness to somewhat less than 60 feet. It lies conformably on the Dripping Springs quartzite, and the contact between the two formations is a gradational one. Three massive beds having a combined thickness of 15 feet represent this transition. These transitional beds are an arenaceous limestone with thin shale partings between them. Above these beds are those of the typical thin-bedded Mescal limestone, the beds of which have an average thickness of 18 inches, although many are massive.

On a fresh fracture, the limestone shows a remarkable banding due to variations in composition. These bands are of a pale green and pink, and the intermediate bands are white or cream colored. The more massive beds do not show this banding as well as the more thin-bedded varieties. Where the formation has been exposed to weathering, the surface is rough and contains considerable chert. A fresh fracture, however, does not show this siliceous material, but on treating the freshly broken rock with acid the more soluble carbonates are dissolved away leaving the silica standing out in relief.

The texture is uniformly fine grained, but some of the purer white beds are often granular. Where the more siliceous beds have been replaced by sulphides, the original texture is retained, and the ore has a banded texture, due to the carbonates being more readily replaced by the ore bearing solutions.

The composition of this limestone is quite variable, and this variation often occurs within a few feet stratigraphically higher or lower. A partial analysis quoted by Ransome in his paper on the Correlation of Some Paleozoic Sections in Arizona is as follows:

SiO_2	29.93
Al_2O_3	.42
CaO	21.90
MgO	14.90

This analysis is not typical of the formation as a whole, but represents more nearly the impure phases of this sediment. Some analyses made for the writer in the assay office of the Old Dominion Company show the purer white beds to contain nearly 90% $CaCO_3$. Other analyses show a high percentage of magnesia, and the rock is decidedly dolomitic. This variation probably had an important bearing on the deposition of the ore, and the Mescal limestone is the most important pre-Carboniferous formation from an economic standpoint.

The formation in the vicinity of Globe is unfossiliferous, but on the northeast side of the Santa Catalina Range, E.D. Wilson [7] found fossils indicating an Upper Cambrian age. Here the whole Apache Group is exposed in outcrops, and there is little likelihood that Wilson was mistaken in his horizon. The formation can be correlated with the Abrigo of the Bisbee section, a horizon definitely established as of Upper Cambrian age. It is difficult to explain the absence of fossils in exposures near Globe. The shore was certainly to the south and southwest, and the forms that lived in the sea at the time of deposition of the Mescal limestone may have been

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7. Oral communication.

shallow-water forms. It has been suggested to the writer that the irregular silica banding in this formation may represent a replacement of marine algae.

Before the close of the deposition of the Dripping Spring quartzite the water gradually became deeper, but showed some fluctuation of level before becoming permanently deep. The deposition of limestone began at that time. Although some shaly material occurs as partings between the limestone beds, nowhere in the section are sandy members to be found.

Troy Quartzite: This formation is separated from the Mescal limestone by an erosional unconformity. Locally the Mescal limestone was covered by a series of basalt flows, and this basalt at a locality six miles northeast of Globe has been entirely removed by erosion as well as about 200 feet of limestone before the deposition of the Troy quartzite. The base of the quartzite here contains rounded pebbles of the more siliceous members of the underlying limestone. In the Sierra Ancha the base of the quartzite contains pebbles and grains of the basalt flows.

This formation in the Old Dominion Mine has a thickness of about 700 feet; while to the north, in the Sierra Ancha, it attains a thickness of 900 feet. There is, however, some doubt regarding the age of the upper 200 feet on Aztec Peak. These upper beds do not resemble the underlying beds, nor do they show the induration so typical of the Troy quartzite. On the Gila River, near Christmas, the thickness of this formation is over 1000 feet. Here again, the upper 200 feet do not resemble typical Troy, but are more nearly like the beds occurring in the Sierra Ancha. In these upper beds, N.H.Darton found fossils which may be Upper Cambrian or Ordovician.

The formation consists of clean quartz sand, well rounded, and cemented by silica. The material has been well sorted, and while beds of finer material are often present, coarse grains are the more common. Angular cross-bedding is well developed and at steep angles, and is very characteristic of the formation throughout its entire thickness. Near the upper part of the formation are several prominent shale horizons, and they often inclose lenticular beds of sandstone. Intraformational conglomerates are especially common in the lower part of the formation and to some extent in the upper parts. They consist of well rounded pebbles of milk quartz, chert, and quartzite. At some localities the conglomerate members are very ferruginous and it is believed the iron was deposited with the pebbles as magnetite.

The formation is of continental origin; the lenses of conglomerate and cross-bedded sandstone suggest fluviatile action. Ripple marks are found only in the thicker shale member and they were probably formed on the delta of a large river which also deposited the coarse sandstone and conglomerate.

The fossils found by Darton resemble the genus Obolus, and may be either Cambrian or Ordovician. As the Mescal has been correlated with the Abrigo and assigned to the Upper Cambrian, and as there is a pronounced unconformity at the base of the Troy, it is placed in the Ordovician. But these fossils were found only in the upper beds of the Troy, and as noted above, they are not lithologically similar to the lower beds. It is the writer's belief that the unconformity at the base of the formation has more weight in assigning the whole formation to the Ordovician than the difference in lithology between the upper and lower beds.

Apache Group

The formations described above, from the Scanlan conglomerate to the Troy quartzite inclusive, constitute the Apache Group as redefined by Ransome [8]. When the Globe district was first studied by Ransome in 1901, the Mescal limestone, which separates the two quartzite horizons of the Apache Group, was overlooked due to the intense block faulting existing in this area. A block of the Mescal limestone surrounded by intrusive diabase was seen in the Old Dominion Mine, and near the Superior and Boston Mine a similar block of limestone was seen, but the intrusion of the magma had produced some metamorphism with the introduction of iron and silica, and the rock was mapped as metamorphosed "Globe Limestone" of Devonian-Carboniferous age. A later study of sections south of Globe revealed the true relations of the limestone and the two quartzite horizons.

<u>Martin Limestone:</u> Although lying conformably on the Troy quartzite, these formations are separated by a hiatus, as is indicated by fossil evidence. The Martin limestone consists of buff sandstones,

8. Ransome, F.L., Geology at Globe, Arizona: Mining and Scientific Press, vol. 102, pp. 747-748, 1911.

shales, and shaly limestones, and has a thickness of about 400 feet. The lower beds are massive, buff sandstones, unfossiliferous, without cross-bedding, and with a small amount of shaly material. Above this massive-bedded member are thin-bedded buff sandstones alternating with shale. The formation then becomes progressively more limy and fossils begin to appear, especially in the argillaceous limestone. The uppermost beds consist of rather pure, white limestones and are unfossiliferous. About 15 feet of buff, paper shales overlie these limestones.

As noted above, the massive member at the base of this formation is unfossiliferous, but as the beds become more argillaceous fossils make their appearance in great abundance, but are confined to a few forms. These are generally silicified and weather out readily. In the limy beds fossils are not only abundant, but a great variety of forms are present. The following were collected by the writer assisted by E. D. Wilson:

Atrypa reticularis
" hystrix
" rugosa
Ambocoelia sp.
Spirifer whitneyi
" cf. S. orestes (?)
Leptaena rhomboidalis
Stropheodonta cf. S. varistriata
Schuchertella sp.
Schizophoria striatula
Chonetes sp.
Cladopora prolifica
Fenestella sp.
Zaphrentis sp.
Sponges, 2 sp.
Crinoid stems

In addition to the above forms, Ransome has found the following species:

Productella hallana
Stropheodonta calvini
Cyrtia cyrtiniformis
Reticularia fimbriata
Cyrtina hamiltonensis
Martinia subumbona
Pugnax pugnus

According to Dr. Kindle who examined the material collected by Ransome, these forms indicate Upper Devonian, but may include some Middle Devonian. On the basis of fossil evidence this formation is correlated with the type locality of the Martin in the Bisbee section.

The formation is of marine origin as is shown by the fossils occurring in it. At first the waters were shallow and the sediments rather pure beach sands, but, with the strand line fluctuating somewhat and becoming deeper, shaly beds were deposited. The waters then became progressively deeper and limestones were deposited. The limestones contain some magnesia and are dolomitic, but before the close of the period they became purer. The buff, paper shales were deposited by a rapidly regressing sea.

Escabrosa Limestone: Overlying the paper shales of the Devonian are a few thin-bedded, shaly limestones; and above these are more massive, white limestones; then one massive, black limestone 60 feet thick. Although this massive member appears as a single bed, it really is made up of several beds, with very thin shaly partings poorly developed. It is an important ore bearing horizon.

Boutwell found a few fossils, although these are fragmental, and on the basis of these, the formation was assigned to the Mississippian. To the south of Globe this massive member loses its dark color, is more thin-bedded, and contains abundant fossils. The following forms were collected by Ransome:

Syringopora aculeata
Menophyllum sp.
Amplexus (?) sp.
Rhipidomella aff. R. oweni
" dubia
Leptaena analoga
Schuchertella inflata
Chonetes sp.
Avonia arcuata
Camarotoechia metallica
Dielasma burlingtonense
Spirifer centronatus
Brachythyris pecularis
Spiriferina solidirostris
Syringothyris sp.
Composita humilis
Cliothyridina sp.

These fossils, according to Edwin Kirk who examined this material, definitely indicate a Mississippian age for the beds. The formation forms a cliff and is locally known as the "Cliff Limestone", but as the age is the same as that of the similar Bisbee section it is correlated with that horizon.

<u>Naco Limestone:</u> The white Pennsylvanian limestones are separated from the black Mississippian limestones in the Globe district by a shale member about three feet thick. About 20 feet above this shale the limestone contains Productus semireticularis, Seminula subtilita, and Spirifer cameratus; and there is no doubt as to the

Pennsylvanian age of the beds. The formation consists of white, gray, and pink beds with thin shale partings. The beds vary in thickness from six inches to eight feet and average about three feet; the texture varies from a coarse grained mixture of fragments of fossil remains to an extremely dense one in which no bedding or partings can be distinguished. Many of the beds contain abundant chert inclusions, especially towards the top of the formation as exposed in the vicinity of the Old Dominion Mine, and certain beds contain fossils replaced by red chert. At some horizons a thin bed of an arenaceous limestone may be seen, but as a whole the formation is unusually pure.

The formation is quite fossiliferous and the following forms have been collected by the writer:

Productus semireticularis
Spirifer cameratus
Seminula subtilita
Derbya crassa
Chonetes mesolobus
Fusulina sp.
Phillipsia sp.
Pentacrinus sp.
Fenestella sp.

These forms are typical of the lower part of the Naco of the Bisbee section. At Globe this limestone is known as the "Quarry", as it is quarried as flux for the smelters of the district, but since it is the equivalent of the Naco of Bisbee it is here correlated with that formation.

Originally Ransome [9] included the Devonian and Carboniferous beds in one horizon and named it the "Globe Limestone", but in a later publication [10] he separated the Devonian beds from the Carboniferous, and in this publication states that there is no break in sedimentation between the Mississippian and Pennsylvanian. A separation is made in this paper because of the importance of the black limestones in relation to replacement deposits, and, as no Pennsylvanian fossils are found beneath the shale mentioned above, it was thought best to place the division plane at this place.

The formation has been extensively eroded and only slightly over 300 feet remain in the Globe district, but to the south, in the Ray quadrangle, the formation is nearly 1000 feet thick, and at Bisbee its thickness is about 3000 feet.

With the close of the Devonian this region became deep water and off-shore limestones began to form. During Mississippian time the water remained deep and limestones continued to form, but during Pennsylvanian time there were minor fluctuations of the sea level and shales and shaly limestones were deposited.

Whitetail Conglomerate: This conglomerate consists chiefly of subangular pebbles of diabase, quartzite, and limestone, but does not contain pebbles of dacite; and in this respect it differs

9. Ransome, F. L., U.S. Geol. Survey Prof. Paper 12, 1903.

10. Ransome, F. L., U.S. Geol. Survey, Prof. Paper 98-k, 1916.

from the later Gila conglomerate. The absence of dacite pebbles, however, is not conclusive evidence that the formation examined is Whitetail, as much of the Gila conglomerate does not contain dacite pebbles, and often it is impossible to separate the White-tail from the Gila conglomerate.

The Whitetail conglomerate fills old pre-dacite depressions in an old mature topography. During its formation there were extensive outpouring of lava, and the underlying gravels were protected from erosion until the dacite was cut through by later streams.

The dacite flows are probably middle Miocene, and as these flows are earlier than the Whitetail conglomerate the formation is assigned to the early Miocene.

Gila Conglomerate: G.K.Gilbert, while making a reconnaissance survey of New Mexico and Arizona, noted the occurrence of great thicknesses of gravel filling the valleys of the Gila River and its tributaries, and gave the name Gila conglomerate to these deposits. These gravels he described in the report of the Wheeler Survey as follows:

> The boulders of the conglomerate are of local origin, and their derivation from particular mountain flanks is often indicated by the slopes of these beds. Its cement is calcareous. Interbedded with it are layers of slightly coherent sand, and of trass and sheets of basalt; the latter, in some cliffs, predominating over the conglomerate. One thousand feet of the beds are frequently exposed, and a maximum exposure on the Prieto is probably 1500 feet....... Where the Gila (River) intersects the troughs of the Basin Range system, as it does north of Ralston, the conglomerate is continuous with the gravels which occupy the troughs and floor the desert plains....

> It is, indeed, one of the "Quaternary gravels" of the desert interior, and is distinguished from its family only by the fact that the water-courses which cross it are sinking themselves into it and destroying it, instead of adding to its depth.[11]

Although Gilbert included all the valley fill in the Gila conglomerate, in this report, the name Gila will be applied only to those beds which have been planed off before the deposition of the later Globe gravels. An excellent exposure of this unconformity occurs just south of the town of Globe in a railway cut.

As exposed in the Globe district, the gravels are quite variable in composition. Pebbles of quartzite are most abundant, but locally, dacite may predominate. Schist, limestone, and diabase pebbles are also common. Between the pebbles are arkosic sands, and the whole is cemented by carbonate of lime. There is a great variation in the size of the material making up this formation; many of the pebbles vary from less than an inch to boulders several feet in diameter. Although some of the pebbles are quite angular, many of the harder ones show rounding to a remarkable degree, suggesting transportation for long distances.

Even in the coarse conglomerate beds, the bedding is quite distinct on weathered surfaces. In the lenses of sandstone the bedding is less distinct, and this is partly due to the abundance of cross-bedding. Shales are not common in the exposures studied, and occur chiefly as partings between sandstone members.

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11. Gilbert,G.K.: U.S.Geog. and Geol.Surveys, W. 100th Mer. Report, vol. 3, Geology, Washington 1875.

In the San Pedro Valley, just south of Benson, Kirk Bryan discovered mammalian remains in the shaly beds of the Gila formation. At a locality three miles south of Benson, E. D. Wilson found a part of the upper jaw of a new species of Mastodon. Near by, the writer collected an upper molar tooth of a new species of Hipparion. This tooth was shown to Dr. J. C. Merriam who expressed himself as follows:

> The species is intermediate between my Mohave Desert fauna and the Hipparion of the Mexican Plateau, and is probably middle or upper Pliocene.[12]

Dr. Gidley, of the U.S.National Museum, also collected fossil vertebrate material in this vicinity, and his list of forms contained the following: Mastodon; 2 or 3 species of horse; 2 genera of camel; a large deer; a small antelope (Asiastic type); a large and a small wolf; an otter; a glyptodon; a land turtle; pocket gophers; and a meadow mouse. Although no vertebrate fossils were found at Globe, the beds are undoubtedly equivalent to those of the San Pedro Valley.

Globe Gravels: As noted above, the Globe gravels lie unconformably on the Gila conglomerate; they are not so well consolidated, and differ somewhat in composition. A close inspection shows the gravels to contain a larger percentage of schist fragments and altered diorite boulders. The material is also much more angular

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12. Merriam, J. C., Oral communication.

than the Gila, and as is shown by its composition, was derived largely from the Final Mountains.

The bedding planes in the gravels are hardly noticeable, while the sandstone members with much angular cross-bedding, show bedding planes only where shaly material occurs. Opposite the Old Dominion smelter, an exposure of this sandstone in a road cut shows numerous short, stubby, lenses of conglomerate. These lenses were undoubtedly the old courses of aggrading streams cutting across the sands of a rapidly filling basin. About three miles northwest of Globe, the shaly members of this formation become much more abundant, and of greater thickness. They often contain intercalated lenses of sandstone, and suggest deposition in lake waters.

These gravels have been assigned to the Pleistocene on the basis of their relations to the underlying Gila conglomerates. The gravels are now being dissected rapidly; some exposures show the present streams entrenched to a depth of over 400 feet.

Igneous Rocks

The igneous rocks of this district show great diversity in composition, ranging from very acid granites to olivine diabase. The mode of intrusion or extrusion is also quite variable, and at least three major intrusions of batholithic proportions are present; and a sill of diabase over 1000 feet thick; numerous dikes; and several flows. In age, they range from pre-Cambrian granitic intrusions to basaltic flows intercalated in the Pleistocene gravels.

<u>Ruin Granite:</u> The old batholithic mass is well exposed in the northwest corner of the Globe Quadrangle, and is part of the old pre-Cambrian complex. A small isolated exposure occurs about six miles north of the Old Dominion Mine, and the base of the Apache Mountains consists of this granite. It does not occur in the Pinal Mountains in contact with the schist, but contains xenolithic masses of the schist, and thereby shows the relative ages of the two rocks.

The surface exposures of this granite are highly altered and it is almost impossible to obtain fresh specimens. As seen at the surface, the rock consists of salmon-colored feldspar and quartz, with a small amount of chlorite and magnetite. Fresh specimens collected in some old mine workings in Porphyry Mountain show large porphyritic crystals of potash feldspar, many of them nearly two inches in length. Quartz and gray feldspar, with some chlorite, make up the remainder of the rock. The shape of the laths suggests its derivation from biotite. The rock is of a gray color, while the larger feldspar crystals are of a pinkish tint.

Ransome gives the following petrographic description of this rock in the Globe Folio:

> Under the microscope .... the large feldspar phenocrysts are found to be a finely microperthitic microcline........ They are micropoikilitic also with reference to the other constituents, particularly in their peripheral portions. The groundmass is a hypidiomorphic granular aggregate of quartz, microcline,oligoclase, and biotite, named in order of apparent abundance, with accessory titanite, apatite, magnetite, and zircon. The microcline is generally fresh, but the oligoclase is more or less altered to turbid aggregates of kaolin and perhaps sericite, while the biotite is partially chloritized.

This rock is probably the older of the two pre-Cambrian batholithic intrusions. As it is not at the surface in contact with the main body of the schist, nothing is known of the amount of contact metamorphism produced. This granite is unconformably overlain by the Scanlan conglomerate, the base of the Paleozoic series.

Madera Diorite: This quartz-biotite diorite is a light-gray rock, of an even granular texture and somewhat coarse grained. It resembles granite in the hand specimen as well as in its mode of weathering. Close inspection reveals the presence of abundant striated feldspars, and the rock for this reason is a diorite rather than a granite which it resembles so much. Near the contacts with areas of schist, especially in the northern end of the Pinal Mountains, the rock has a gneissoid texture. This is probably an orthogneiss, and was formed during the period of injection.

The diorite makes up the main mass of the mountain, and, while areas of it are separated by bodies of schist, they undoubtedly connect with the main mass in depth. The contact with the schist is a most intimate one, and although there is a tendency to follow the planes of schistosity, the general strike of the surface exposures is across the schistosity. The rock contains many inclusions varying in size from small fragments to large masses that are probably remnants of roof pendants.

In the hand specimen the rock does not show any evidence of a porphyritic texture. The minerals recognizable with the aid of a hand lens are plagioclase feldspar, orthoclase (or microcline), quartz, biotite, apatite, and magnetite. Locally the rock contains some hornblende, but this is not abundant.

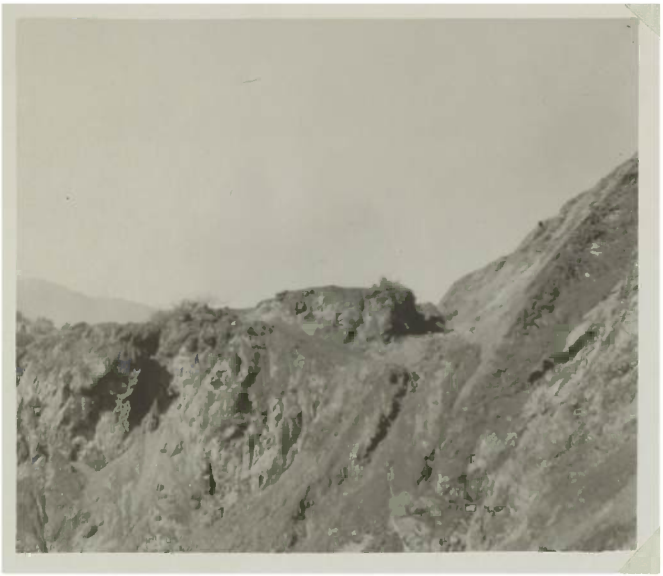
Under the microscope, in a thin section, the rock is seen to consist of a hypidiomorphic, granular texture; and the minerals in the order of abundance are: labradorite, quartz, biotite, microcline, orthoclase, and some muscovite. The accessory minerals are magnetite, apatite, titanite, zircon, and rutile (?). Epidote and chlorite often occur along fracture planes in the rock, or at the contact with schist, and are later alteration products. On the Pioneer road the rock is coarser-grained, contains a larger proportion of orthoclase, and approaches a granodiorite in composition.

After the injection and cooling of this mass, numerous pegmatitic veins were injected into the diorite as well as into the intruded schist. These always consist of an abundance of milk quartz with muscovite and black tourmaline, and occasionally a little orthoclase. The tourmaline occurs as small bunches of radiating needles, but often single crystals over 8 inches in length are found. The larger crystals are often bent and fractured.

This intrusion has produced an intense metamorphism in the schist. The effects have been chiefly physical, such as the production of denser minerals by recrystallization, and a dehydration; and they can be seen for long distances from the contact. A more detailed statement will be made in discussing the metamorphic rocks.

Cambrian (?) Basalt: Following the deposition of the Mescal limestone, basalts were extruded over a wide area. From the Sierra Ancha in the north to the Mescal Mountains in the south, this basalt occurs between the Mescal limestone and the Troy quartzite. The base of the flow is parallel to the bedding of the limestone, but locally the limestone is so very much thinner as to suggest some erosion before the outpouring of the lava. The flow, or rather the series of flows, has a total thickness of 200 feet in the Old Dominion Mine, and to the south of the Superior and Boston Mine over 250 feet.

At the surface the rock weathers to a dark reddish-brown, whereas fresh specimens from underground workings vary from a greenish-brown to a very dark greenish-black. The rock is of a dense, aphanitic texture, and at the base of the separate flows is vesicular. These vesicules are commonly filled with calcite, but



View showing fault plane of the Old Dominion Vein. Foot wall diabase. Hanging wall gossan in limestone.

Weathering of diabase showing development of small knobs due to segregation of feldspar. Photo taken in the Sierra Ancha.

sometimes they contain epidote, specularite, chlorite, and quartz. These latter minerals were probably formed at the time of the intrusion of the diabase.

The age of the flow is not definitely known, and depends on the age of the Troy Quartzite. If this quartzite is Ordovician, the flow is probably upper Cambrian, as the upper surface of the basalt has been planed off and represents an erosional unconformity.

Diabase: No igneous activity occurred in this region after the outpouring of the basalt described above until the widespread intrusion of the diabase in the early Mesozoic. This diabase is very widespread, covering many thousands of square miles in area. It was intruded as dikes and sills, chiefly the latter, along parting planes of the Apache group of sediments. The sills vary in thickness from a few feet to over 1000 feet in the Old Dominion Mine; and a lower sill has a thickness of over 400 feet. Where the diabase has intruded the schists it is generally parallel to the schistosity, but often it shows cross-cutting relations.

The intrusion is most common in the sediments of the Apache group; but in the Old Dominion Mine it cuts the Martin limestone, and in the Mescal Mountains the Tornado limestone. It is, therefore, later than the Pennsylvanian and is probably early Mesozoic.

Fresh specimens of the rock are of a dark gray color, holocrystalline, and of a medium to coarse texture. With the unaided eye the following minerals can be identified: augite, olivine, plagioclase feldspar, magnetite, and occasionally biotite. The texture varies considerably from specimens exhibiting a fine-grained groundmass with large porphyritic crystals of plagioclase to a rock with a typical gabbroidal texture. The diabasic texture, however, is most common.

In a thin section under crossed nicols the plagioclase is seen to be the most abundant constituent. The extinction angle shows it to be basic labradorite near bytownite in composition. The augite is of a pale brown color showing no pleochorism, but sometimes has a purplish tint indicating the presence of titanium. It occurs in broad laths intergrown with plagioclase and showing the ophitic texture. The olivine, which was the earliest of the essential minerals to crystallize out, is usually in rounded grains that sometimes show the outline of the crystal. The mineral is unusually fresh, and shows little or no trace of alteration to serpentine or chlorite, except in specimens near the vein. The biotite is not very common, but where it occurs is of the deep-brown variety with strong absorption. Among the accessory minerals are ilmenite, often showing peculiar arrow-head shapes. Apatite occurs in long needles, and titanite in crystals with rhombic outline. Zircon is rarely seen.

In the thicker sills the diabase often shows magmatic differentiation to a more acid variety. Four miles north of Globe the diabase shows a gradational change to syenite. This syenite consists of pink orthoclase and uralitic hornblende with a few needles of apatite. All gradations can be found between the two rocks. Segregations are also common in the diabase and consist of the same minerals as the diabase, but with a very much coarser texture, some of the augite crystals measuring over six inches in length. Other segregations consist chiefly of plagioclase and some magnetite or ilmenite. These masses are not pegmatite dikes of a basic composition, and their irregular form and gradation in texture to the normal diabase suggest a segregation.

The rock weathers to an olive-colored soil (saprolite), and usually contains rounded boulders and pebbles of unaltered diabase. These boulders have a very rough surface with many small warty protuberances which eventually weather out and form rounded pebbles. Regarding these pebbles, Ransome says:

> Close examination of these little bodies (pebbles) shows that their form and resistance to disintegration are dependent on the presence of rounded crystals of augite.[13]

Thin sections studied by the writer do not support these conclusions. In all sections showing alteration the olivine and augite were the first to undergo change, the feldspar remaining fresh. A close examination of these lumps shows a segregation of the plagioclase with very little augite between the laths. The occurrence of close spaced interlacing feldspar laths is the explanation advanced by the writer for this peculiar mode of weathering.

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13. Ransome, F.L., The Copper Deposits of Ray and Miami, Arizona: U.S.Geol.Survey Prof. Paper 115, p. 54, 1919.

The diabase has produced very little metamorphism other than a baking and hardening in the Pioneer shales. In the Dripping Spring quartzite, as exposed in Mallory Gulch, the rock shows a mottled appearance due to the segregation of magnetite, and this was probably caused by the intrusion of the diabase. In the Mescal limestone specularite has been introduced, and tremolite and epidote developed.

<u>Schultz Granite:</u> This granite occurs on the north slope of the Pinal Mountains and extends from Miami southward for about ten miles. It is a batholithic intrusion and probably extends beneath the later lavas to the Ray district where a lithologically similar intrusion occurs. Relatively little vegetation covers its surface, and the bare slopes of granite are visible for long distances. Two sets of joints intersect the granite, and weathering along these fractures has carved the rock into many tall slabs resembling tombstones. This weathering is well illustrated in the Bloody Tanks Wash west of the town of Miami.

The weathered surface is of a cream color, and the fresh fracture is nearly white. The rock is porphyritic, with large phenocrysts of orthoclase, some of which are nearly two inches long. The remainder of the rock consists of an equigranular, holocrystalline aggregate of quartz and white feldspar with some biotite and magnetite. A close inspection with a hand lens of this white feldspar shows the mineral to be a plagioclase feldspar with albite twinning. The biotite occurs in flakes of an unusually dark color.

A thin section under the microscope shows the granular part to consist chiefly of oligoclase and quartz with some orthoclase. The biotite is strongly pleochroic, and is less abundant than the grains of magnetite. The accessory minerals are muscovite, magnetite, and zircon. Some of the biotite has been changed to chlorite, and occasionally epidote is seen. The oligoclase is rather basic and near andesine in composition.

Ransome gives the following chemical and mineralogical analysis of this rock:

Chemical Analysis of Schultz Granite

SiO_2		70.95%
Al_2O_3		16.30
Fe_2O_3		1.01
FeO		.36
MgO		.23
CaO		1.85
Na_2O		5.16
K_2O		3.34
H_2O	(total)	.63
TiO_2		.23
		100.06

Mineral Composition of Schultz Granite

Oligoclase (Ab_8An_3)	52.24%
Orthoclase	16.82
Quartz	24.09
Biotite	4.50
Muscovite	1.28
Titanite	.43
Iron Ores	.64
	100.00

The high silica and alkalies with a low percentage of iron, lime, and magnesia, shows the rock to belong, chemically, with the granites; and the higher ratio of soda to potash would make the rock a soda-rich granite. The mineral composition shows the rock to be about half plagioclase, and Ransome [14] discusses this peculiarity as follows:

> Upon consideration of the chemical and mineral composition together it appears that the rock does not fit into existing mineralogic schemes of classification. Chemically it is a sodium-rich granite, but mineralogically it is about half plagioclase. It is conceivable that under slightly different conditions the calcium might have gone into mineralogic combination to form pyroxene or amphibole instead of oligoclase and the rock would then have been made up chiefly of alkalic feldspar, and could be placed without hesitation among the sodium-rich granites.

14. Ransome,F.L.,The Copper Deposits of Ray and Miami,Arizona: U.S.Geol.Survey Prof. Paper 115, p. 60. 1919.

Just such a change as is suggested by Ransome in the last sentence of this quotation has occurred at some places near the border of this intrusion. As would be expected, the border is slightly more basic than the main mass, and a specimen collected by the writer consists of a microperthitic intergrowth of orthoclase and albite with some quartz, and abundant radiating needles of aegerite. Mineralogically, this phase is more nearly an aegerite-granite, but with a much lower quartz content it is closely related to the syenites.

The rock shows a fine-grained (chilled) contact with diabase and is, therefore, later than this rock. The intrusion is earlier than the middle Tertiary dacite, and may be late Cretaceous or early Tertiary. It is placed in the early Tertiary by Ransome.

Near the Pinal Ranch, the rock contains a xenolithic mass of Devonian limestone highly altered. It is interesting, in this connection, to attempt to determine the probable thickness of the batholithic cover when the intrusion cooled. The thickness of the Paleozoic sedimentary strata above the base of the Devonian, as exposed today, is less than one thousand feet. If the Pennsylvanian limestone, at the time of the intrusion, had a thickness equivalent to that of the Bisbee section, the cover would then have been 3500 feet thick. With a cover as thin as this, it would seem possible for the intrusion to break through and give rise to extensive flows of rhyolite. If such flows were formed, no record of them remains, and it is necessary to postulate a thicker sedimentary cover over this intrusion. The post-Paleozoic rocks which may have been deposited in this region are the sandstones and shales of upper Cretaceous age. Remnants of these rocks are exposed to the northeast, south, and southeast. It is possible that these sediments at one time covered the region and were stripped off in the early Tertiary; if so, several thousand feet should be added to the figure above to obtain a more reasonable estimate of the thickness of the cover.

Granite Porphyry: Associated with the Schultz granite are numerous dikes of variable width, and with a length of six miles as a maximum. Those of a granitic composition occur chiefly in the schist and Madera diorite of the Pinal Mountains. Near the Old Dominion Mine one of these dikes occurs in an area of schist as part of the material pushed up by the thrust. A specimen collected here by the writer consists of large porphyritic crystals of cream-colored orthoclase and quartz in a finer-grained groundmass. The rock is somewhat altered and no trace of the ferromagnesian minerals remains.

On the south slope of Buffalo Ridge is a narrow dike of quartz-monzonite porphyry intruded in diabase and Devonian limestone. It is probably genetically related to the Schultz granite, but is much more basic in composition. An examination with a hand lens shows the presence of both twinned and untwinned orthoclase, plagioclase, doubly terminated quartz crystals, and chlorite. The groundmass is rather fine-grained and highly altered.

Dacite: From the Superstition Mountains on the west, and extending eastward at least as far as the Apache Mountains, are extensive sheets of dacite. These flows, locally, have been subjected to intense faulting, and exist today only as more or less disconnected fault blocks. Near the Old Dominion Mine, the dacite has been greatly reduced by erosion until only a maximum of a few hundred feet in thickness remains. On the south side of the Pinal Mountains the dacite has been cut down into very deeply by Mineral Creek, and the thickness of the flows is nearly 1000 feet. The flows were poured out over a rough surface, the ravines of which were partially filled by the Whitetail conglomerate, or by extensive beds of tuffs.

The rock weathers to large, rounded boulders of a light brown color. Exfoliation is very common, and slabs a quarter of an inch thick and six or more inches in diameter can readily be peeled off. The weathering is controlled by a preexisting series of joint planes, and along these is most active.

The dacite is a light-colored, pinkish-gray rock, with small but visible crystals of quartz, feldspar, and biotite in a stony groundmass. The quartz occurs in small rounded grains; while many of the feldspar crystals show Albite twinning. Biotite occurs in hexagonal flakes of a golden-brown to black color. The rock is remarkably fresh, even near the surface, and although disintegration has taken place, there is but little decomposition of the mineral constituents. Its lightness suggests considerable porosity, but this is more apparent than real, and a thin section, under the microscope, is quite compact. There are, however, vesicules or gas cavities present, and they are usually long drawn out by the viscuous flow at the time of extrusion.

Under the microscope the rock is seen to consist of clear, rounded, and embayed grains of quartz; plagioclase feldspar slightly more basic than andesine; clear orthoclase (sanidine); and deep brown biotite. Ransome mentions the occurrence of hornblende in this flow, but none was seen by the writer. The groundmass is vitrophyric, showing beautiful flow lines, and is remarkably free from a second generation of crystals. The black glass, at the base of the flow, shows numerous curved cooling cracks.

Metamorphic Rocks

Pinal Schist: The main mass of the Pinal Mountains is made up of a recrystallized sediment, intensely metamorphosed, and intruded by dikes and satellitic masses of the Madera diorite. Many of the smaller xenolithic masses were broken away from the parent rock by magmatic stoping, and engulfed by the invading magma; other and larger areas are roof pendants, a part of the cover of the batholith when the magma froze. Such is the nature of the large area on the southwest slope of the Pinal Mountains, and there the metamorphism is less intense.

The general trend of the schistosity is northeast-southwest, but locally it may change to nearly east-west or north-south. This direction of schistosity is general throughout Arizona, and indicates that the direction of pressure producing schistosity was from the northwest or southeast.

Lithologically, the schists vary depending, in a measure, upon the original nature of the sedimentary or igneous rock from which they were derived. A sericitic schist, with a satiny luster along the cleavage faces, and of a blue or greenish-gray color is by far the most common variety. This was undoubtedly derived from a shale by dynamic metamorphism. Not uncommon, but relatively rare, are metamorphosed beds of quartzite intercalated in the phyllites. At one locality a conglomerate was noted. Basic dikes, or sills, or flows associated with these sediments were altered to chloritic schists. In all the varieties noted above, the schistosity is well developed, but where contact metamorphism has affected these schists, the rock is denser, more coarsely crystalline, and the schistosity is less pronounced. These are the andalusite schists of the contact zone. Intermediate, between the contact zone and the unaltered schists, are the spotted schists, or Fruchtschiefer of the Germans.

In the normal schist, not affected by contact action, a thin section shows the rock to be made up, almost entirely, of quartz and white mica, with a segregation of magnetite here and there. A few small flakes of deep red hematite were observed. The quartz occurs in more or less parallel bands with sericite partly enveloping the individual quartz grains. These grains, although showing some strain effects, are probably a recrystallization rather than a granulation of previously existing larger grains of quartz. Magnetite occurs in scattered grains, but often occurs segregated and drawn out parallel to the schistosity. These schists are rather fine-grained.

The first effects of contact action are shown in the spotted schists of the intermediate zone. These spots are of a dark green color, and consist of a segregation of chlorite. In addition to chlorite, these schists contain quartz, mica, and magnetite; and the grain is as fine as in the normal schist.

On approaching the contact with the Madera diorite, the schist shows a marked change in crystallinity and in schistosity; the rock becomes harder and denser, and new minerals are developed. The mica plates approach a quarter of an inch in diameter, and andalusite is developed in long needles. Nearly all the evidence of original schistosity has been destroyed. In a thin section the rock is seen to be made up of recrystallized quartz, microcline with pericline twinning, andalusite, and a little mica. Tourmaline and sillimanite are occasionally seen. The microcline and andalusite were formed from muscovite and quartz by the driving off of the constitutional water of the molecule of mica. The following empirical equation expresses this change:

$$\underset{\text{Muscovite}}{KH_2Al_3Si_3O_{12}} + \underset{\text{Quartz}}{SiO_2} = \underset{\text{Microcline}}{KAlSi_3O_8} + \underset{\text{Andalusite}}{Al_2SiO_5} + \underset{\text{Water}}{H_2O}$$

The tourmaline is not an original constituent of the rock, but is a later introduction from magmatic gases emanating from the Madera diorite at the time of the intrusion.

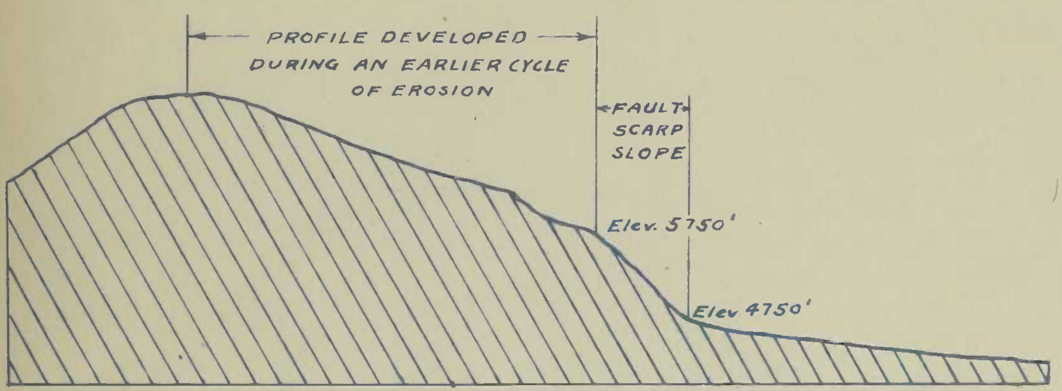
An unusual variety of schist was derived from the metamorphism of a basic igneous rock. In the hand specimen, it is a dark greenish rock consisting chiefly of chlorite, but with some granulated and elongated grains of microcline or orthoclase, and with some secondary silica. Under the microscope the section shows chlorite in a foliated mass, and making up about 75% of the rock; a small amount of sericite, orthoclase, quartz and magnetite.

This schist has been altered by dynamic action rather than by the more intense contact action, as is shown by the abundant occurrence of such hydrous minerals like chlorite and sericite. Contact action would probably have developed minerals of the amphibole or pyroxene group.

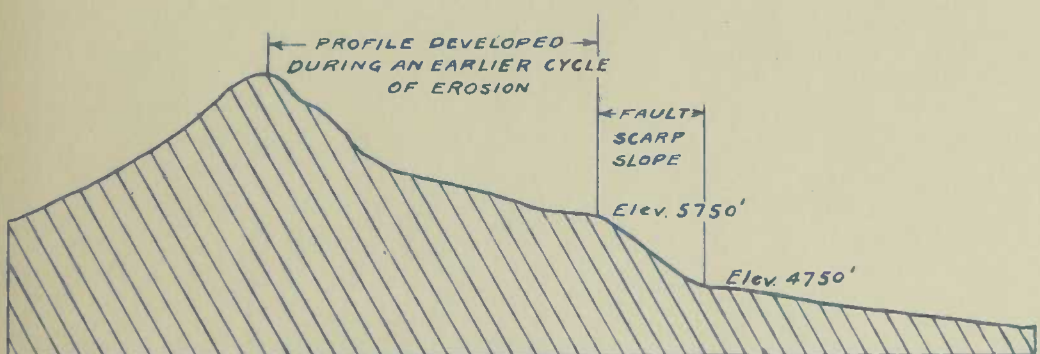
The Pinal schist is the rock mined by the Miami and Inspiration Copper Companies, and contains disseminated grains of pyrite and chalcopyrite as the economic minerals.

PLATE III

DIAGRAMMATIC SECTION SHOWING GRABEN STRUCTURE OF PINAL VALLEY



SECTION UP RIDGE EAST OF ICEHOUSE CANYON
VERTICAL SCALE TWICE HORIZONTAL



SECTION UP ICEHOUSE CANYON SHOWING LOW GRADIENT OF STREAM BED ABOVE FAULT SCARP
VERTICAL SCALE TWICE HORIZONTAL

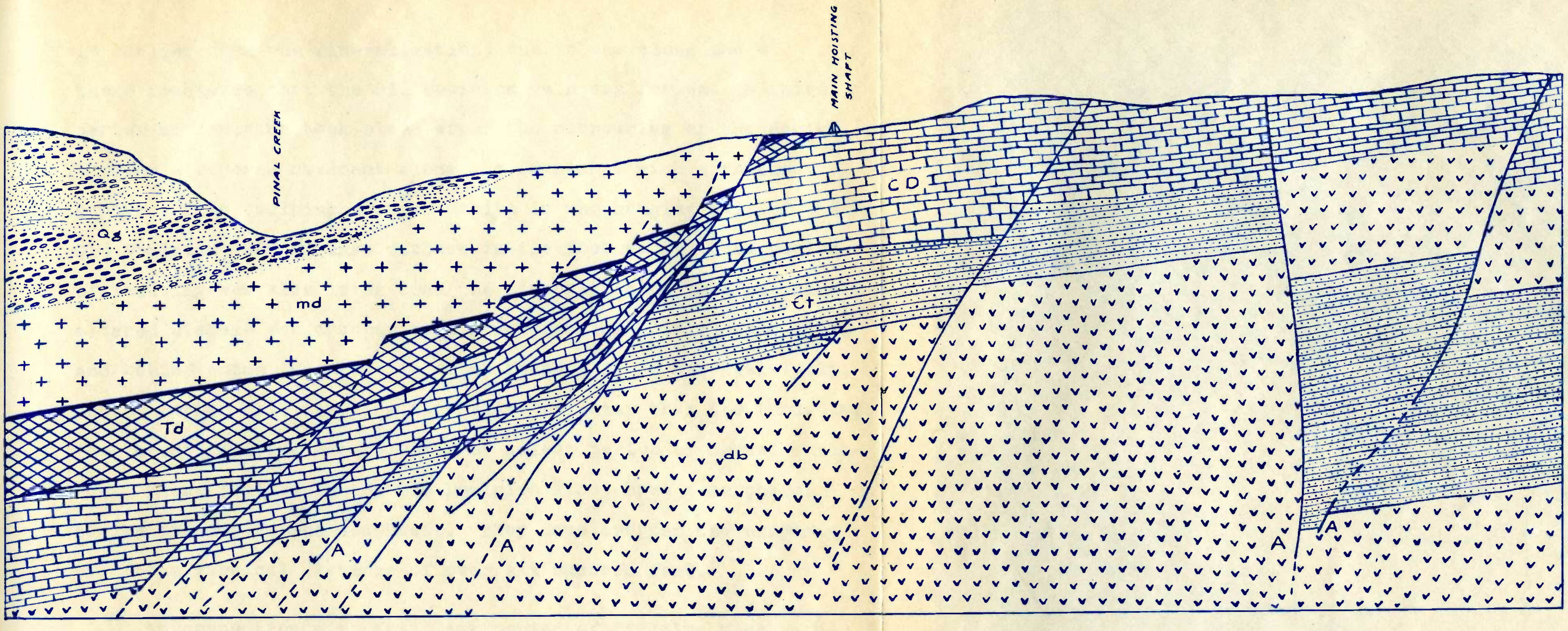
Structure

In the vicinity of Globe, at least two distinct types of mountain structure can readily be recognized; those like the Apache Mountains and the Sierra Ancha, which are remnants of a plateau detached by erosion, and those like the Pinal and Mescal Mountains which are uplifted and tilted fault blocks. Both types have been modified by erosion, and if it were not for the presence of the sedimentary rocks, their origin might be difficult, if not impossible, to determine. The Apache Mountains are not separated from the Natantes Plateau by faulting, and the separation of the two areas is the result of erosion. The Sierra Ancha has a similar origin, and the erosion along Cherry Creek detached this mass from its original eastern continuation. The southwest slope of the Pinal Mountains consists, in part, of sedimentary rocks resting on the pre-Cambrian complex of granite and schist, and the Mescal Mountains consist of sedimentary rocks intruded by sills of diabase. In both cases, the sediments dip to the southwest at angles greater than 20°.

Folding is rather rare in the Globe district, and the few folds that do occur are of minor importance as a structural feature. They are confined entirely to the limestones. Such minor folds can be seen at several places in limestones at the surface, but soon die out in depth. A few minor folds, however, may be seen underground, especially in the vicinity of faults, and are often of some value in determining the downthrow side of these faults where both walls are in the same formation. Folding is very pronounced in the schist series of the Pinal Mountains, and many of these flexures are extremely sharp and have been truncated by erosion.

The faulting in the Globe Hills is mainly along two directions dividing the area into rhomb-shaped blocks. These blocks of sediments dip in various directions and usually at low angles. The faults may be roughly divided into a set having a northeast trend, and one with a northwest strike. Numerous smaller faults occur, however, which do not readily fall into either of these two groups. Many of the faults are marked by a silicified breccia, especially if one or both walls are of quartzite, although the silicified walls of a mineralized limestone may also form a breccia. These breccias are more resistant to erosion and stand out in relief, often several feet above the surrounding rock.

Five distinct periods of faulting may be readily recognized in this district, four of which are of the normal type of faulting, and one is a thrust. The earliest recognizable faulting has a strike varying from N-S to N 25° W. It was along these fractures that the intrusion of the diabase took place. The diabase, coming up along these fractures, spread out as a great sill in the bedded Dripping Spring quartzite, and at the contact of the Troy quartzite with the Cambrian basalt, or was intruded at the base of the Devonian limestone. These pre-diabase faults have been marked "A" on Plate IV. The second period of faulting had a trend approximating N 65° E, and has faulted the diabase sills. This faulting



DIAGRAMMATIC PROJECTION

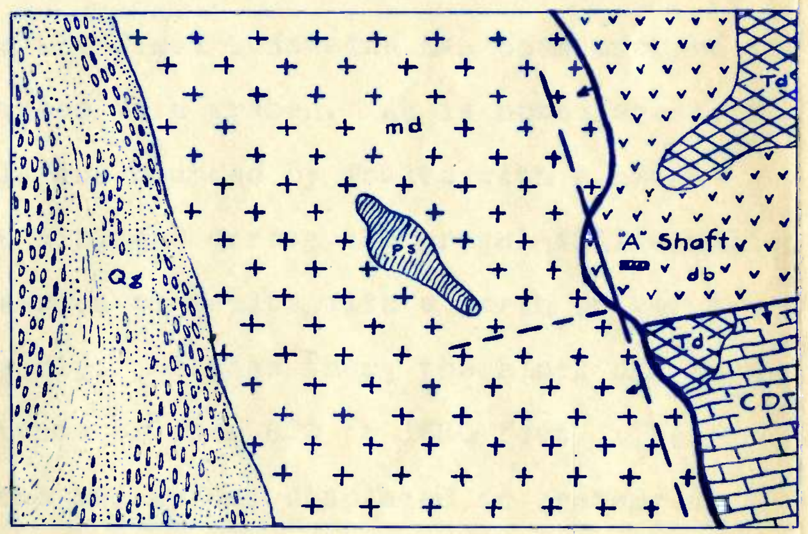
of the Hanging Wall

OLD DOMINION VEIN

GLOBE, ARIZONA

THRUST PLANE SHOWN BY HEAVY LINE

PRE-DIABASE FAULTS MARKED "A".



MODIFIED PLAN SHOWING
POSITION OF THRUST

is earlier than the mineralization, and it was along one of these fractures that the Old Dominion vein was formed. A third period of faulting took place after the outpouring of the dacite, and was a renewed movement along the fractures with a northeast strike. This faulting dropped dacite in the hanging wall of the Old Dominion vein against diabase in the foot wall. This period of faulting was also later than the mineralization, and the highly altered diabase was crushed to a gouge forming a false foot wall, and behind which good ore is often found. It is not positively known whether this faulting is earlier or later than the thrusting. The thrust faulting was followed by a last period of normal faulting. These faults, in the Old Dominion Mine, have a northwest strike and dip to the southwest. They have dropped the oxidized ore for a vertical distance of over six hundred feet.

In connection with this last period of faulting some rather interesting structures have been developed; the gravel-filled valley between the Globe Hills and the Pinal Mountains has been dropped as a block, and should be classed as a graben. As is noted above, the west side of the Globe Hills are bounded by faults with a northwest strike and a southwest dip, and across the gravel-filled valley is a fault, or perhaps a series of faults, with a north or northeast strike and an easterly dip. Between them, the block has been dropped for a vertical distance of from 600 to 1680 feet. The fault on the west side of the valley has displaced an orebody in the Miami Copper Company's ground, and churn drilling in the hanging wall of this fault, for a distance of 1680 feet, has failed to reach the bottom of the gravels.

An interesting thrust fault occurs in the Globe district and can be traced northwestward to Miami, but to the south of Globe soon disappears beneath the later gravels. By this reverse faulting, pre-Cambrian diorite and schist have been pushed over Tertiary dacite in the Globe Hills. An area, isolated by erosion, occurs near the Lime Quarry in Copper Gulch. This thrust plane has been located by churn drilling to the southwest of the mine, and where reliable figures can be obtained, the dip of the thrust plane is about 8°, but to the extreme west may be as low as 5°. The thrust was from the southwest, and the minimum movement was approximately 35,000 feet, or nearly seven miles. The time of this great movement is well delimited by the underlying and overlying rocks. It is later than the dacite flows, to which a middle Miocene age has been assigned, and earlier than the Gila conglomerate of middle or late Pliocene age. The thrust can probably be correlated with the early Pliocene uplift in other parts of the western states.

Reverse faulting is not uncommon in Arizona, and has been observed by Ransome in the Ray district and at Bisbee. Schrader reports a thrust in the Santa Rita Mountains, and C.J.Sarle believes a thrust to exist in the Chiricahua Mountains. The writer has seen thrusts in the Huachuca Mountains, in the Mescal Mountains, and in the Rincon Mountains.

The cause of these great displacements in the earth's crust is not well understood. In the central portion of Arizona, vast quantities of lava were poured out shortly before these thrusts occurred. These volcanic fields cover many thousands of square miles in area and have thicknesses up to several thousands of feet. This would be equivalent to many cubic miles of material transferred from below to the surface. Such outpourings undoubtedly produced unbalanced stresses in the earth's substratum, and may have given rise to these movements.

In attempting to prove a tectonic origin for the valleys of the Ray-Miami region, Ransome [15] discusses the origin of the Pinal Mountains and shows that either a great fold, or a fault with an enormous throw of over 10,000 feet is required, or a series of faults with downthrow on the northeast side to make up this great displacement. This great throw is not impossible, but is rather improbable. It is the writer's belief that, in part, the uplift of this mountain mass is due to thrusting. With a minimum displacement of 35,000 feet along a fault plane dipping 5°, the vertical component would be about 3000 feet; if the dip were 8°, the vertical component would be nearly 5000 feet. With greater displacements than the minimum assumed here, the elevation of the Pinal Mountains could easily be accounted for without the necessity of assuming great normal faulting. The uplift of the mountain is not entirely due to the vertical component of thrusting, but is in part, due to normal faulting. On climbing the Pinal Mountains, on the northeast side, one can hardly fail to notice a remarkable break in topography near the foot of the mountain. This is illustrated in Plate III, and the profile was made from the Globe topographic sheet of the U.S.Geol.Survey.

15. Ransome, F.L., U.S.Geol.Survey Prof. Paper 115, p. 82, 1919.

The first abrupt change in slope, of either the ridge or stream bed, occurs at an elevation of 4750 feet; the second break occurs at 5750 feet. From here the floor of Icehouse Canyon is of a much lower gradient for about a mile. This cannot be accounted for by a difference in the texture of the rock, as it is the same, namely pre-Cambrian diorite. This flat-floored valley, at a high elevation in the mountain, was cut during a previous cycle of erosion, and since then the mountain mass has again been uplifted approximately 1000 feet.

The most important structural feature of the mine is the fault now occupied by the Old Dominion vein. The strike varies along the vein from N 45° E to N 65° E, but the latter figure is more nearly the average throughout its entire length as it is now known. At the surface, the dip in the old glory hole is about 50°, and becomes steeper with depth. The dip also varies along the strike, becoming flatter to the west. The throw on this fault is, at the west end, over 1000 feet.

Plate IV is a projection of the hanging wall to a plane. On this projection are shown a number of faults, some of which are earlier than the diabase intrusion, and others are later than the oxidation of the ore. The occurrence of so many of these faults in a limited area has produced an extremely complicated geologic structure. The Limestone fault and the West fault occur here, together with numerous smaller ones. The total throw on this series of faults is over 600 feet, and for this reason oxidized ores occur at a lower elevation than in the main portion of the mine. Some complex faulting occurs in the extreme eastern end of the mine, and here several faults intersect the Old Dominion vein at a low angle. These have probably been displaced by the later movement on the main fracture. The complexity, however, does not compare with that of the "West side", as it is locally known.

As is shown on Plate IV, the structure of the mine in general is rather simple, and consists of a series of sediments dipping to the southwest at a low angle. These sediments have been displaced to some extent by faulting, but the greatest rupture is due to the intrusion of the diabase. The main sill has a thickness of about 1000 feet, and was intruded between the basalt overlying the Mescal limestone and the Troy quartzite. It is not confined to this horizon, however, and to the west occurs at the base of the Devonian sediments. A second sill occurring in the mine lies at a much lower horizon stratigraphically, and was intruded into the well-bedded Dripping Spring quartzite. So far as is now known it has a thickness greater than 400 feet, and further development in the foot wall may show it to be fully as thick as the main sill.

Near the main shaft, the intrusion of diabase detached a block of Mescal limestone and Dripping Spring quartzite, This occurs between the 6th and the 10th levels. As it is surrounded by diabase, it was probably detached during the intrusion and retained its position until the magma solidified.

Geologic History

The earliest record, as is shown by the composition of the Pinal schist, indicates that this part of Arizona was a part of the sea in which sediments were accumulating. This sea was not deep, as sediments characteristic of the shore were deposited. The bottom subsided as accumulation continued, until several thousands of feet of conglomerate, sandstone, and shale were deposited, with here and there thin lenses of limestone. Just what the nature of the basement rock was on which these sediments were laid down, or where the source of the material was from which these sediments have been formed, is not known. Sedimentation, however, was not continuous, as the surface was exposed to erosion and covered at times by flows of both acid and basic rocks. The occurrence of conglomerates suggests unconformities, and the early history of the Pinal schist in Arizona has been only partly unraveled. The sediments must have been buried very deeply, perhaps to the zone of flowage, as a complete recrystallization by dynamic stresses has taken place. It is possible there was more than one period of dynamic metamorphism, accompanied or followed by the intrusion of batholithic masses of granite and diorite. The region was then uplifted and profound erosion, over a long period of time, reduced the area to a land of low relief.

The beginning of Paleozoic time, perhaps middle Cambrian, saw the waves of the sea advancing over a land of low relief, reworking the loose debris lying on the surface, rounding the harder material to pebbles and boulders, and depositing the whole as the Scanlan conglomerate. A small subsidence of the land would cause the sea to encroach over a wide area, and the water behind the advancing shore-line was, therefore, shallow. In this shallow water, the waves built up barrier beaches and formed lagoons and estuaries. Here the finer silts and muds that made up the Pioneer shale were deposited. The water in these lagoons was so shallow that for days at a time the muds were exposed to the sun and air, and great sun-cracks were formed. These have been preserved in the geologic record.

The deposition of the Pioneer shale was brought to a close by mountain-making movements that threw up great ridges at some distance to the north and west of Globe. On the flanks of these mountains were the massive beds of the well-indurated Mazatzal quartzite, and beneath them were exposures of schist and granite containing red and black chert and veins of milk quartz. Great rivers cutting into this youthful topography found an abundant supply of coarse and fine detritus. This material was transferred, in some cases, for over a hundred miles and deposited as the Barnes conglomerate. During this long journey the boulders were thoroughly rounded, and the fragments of granite were ground to an arkosic sand. The soft Pioneer shale, on which this conglomerate was deposited, has not been eroded, and this may be because it was then a very hard, sticky mud, and yet plastic enough so that the first coarse detritus embedded itself in this mud and formed a protective covering for the softer sediments beneath.

Following the deposition of the Barnes conglomerate, the sands which made up the Dripping Spring quartzite were deposited on the delta of this large river. The sea often advanced across this delta, and waves and currents shifted the sands to and fro. Ripple-marks and sun-cracks were thus formed, and indicate shallow water. Subsidence of the sea about equaled the rate of deposition, and this condition continued until the uppermost beds of the Dripping Spring quartzite were laid down; then a more rapid subsidence took place and the calcareous muds, which later formed the Mescal limestone, began to be deposited.

During the deposition of the Mescal limestone, the depth of the water showed only slight variations, and a small amount of shaly material was laid down between the more massive beds of limestone. The region was then again uplifted, the strand line retreated, and only a small amount of erosion occurred before this part of Arizona was covered by sheets of basalt from fissure eruptions.

Erosion was only temporarily interrupted by the quiet out-wellings of basalt, and continued until all the lava and most of the Mescal limestone were removed in some localities. On this eroded surface great rivers deposited their load of sand and silt. Occasional thin lenses of conglomerate suggest a fluviatile origin for the Troy quartzite formed from these sands.

Between the deposition of the Troy quartzite and the Martin limestone, a time interval or hiatus exists, and the length of this time depends on the age assigned to the Troy quartzite. If this quartzite is Ordovician, then the time interval would include the whole of Silurian time and perhaps also lower Devonian, as the fossils of the marine limestone, although occurring over 100 feet above the base of this formation, indicate middle or upper Devonian. Just what occurred in Arizona during Silurian time is not known, as the beds of the Martin limestone lie conformably on the Troy quartzite without any apparent erosion.

In middle Devonian time the sea again advanced over the land, and along this beach buff-colored sands were deposited, occasionally containing much argillaceous material. This was followed by small variations in the depth of the water in which the fine silts were formed, and was followed by the deposition of calcareous muds. These muds and silts contain a fine record of the forms of life that inhabited the sea at that time. With a deepening of the sea, in which purer limestones were formed, the fauna migrated to shallower water. The sea then very suddenly became shallow, and about 15 feet of paper shales were laid down. There is no evidence that these shales were eroded before the water again became deep and the pure limestones of the Mississippian began to form. Ransome states that deposition was continuous throughout Carboniferous time, but in this paper a separation is made between the Mississippian and the Pennsylvanian, and the plane of division placed at a shale horizon immediately above the black limestone of the Mississippian.

Little is known of the geologic history of the early Mesozoic in this part of Arizona, and it was undoubtedly a land area subject to erosion, but in the northern part of the state, sediments were being deposited. Early in Mesozoic time, faulting took place; and along these fractures large quantities of diabasic magma was forced up between the strata of the Apache Group, forming extensive thick sills and numerous dikes. If any of this magma reached the surface, it would have given rise to extensive flows of basalt. No such flows have been found, and if formed, were entirely removed by later erosion. The later Mesozoic history is better known, and in the southern part of the state fluviatile and marine beds of the Comanche Series were deposited. It is not known whether or not this region of deposition extended as far north as Globe, as no sediments of the lower Cretaceous have been found. The upper Cretaceous is also absent at Globe, but occurs about 20 miles to the south in the Deer Creek region, at Morenci to the southeast, and on the Mogollon Rim. These marine beds may have existed at Globe, and if so, were removed by erosion during the early part of the Tertiary.

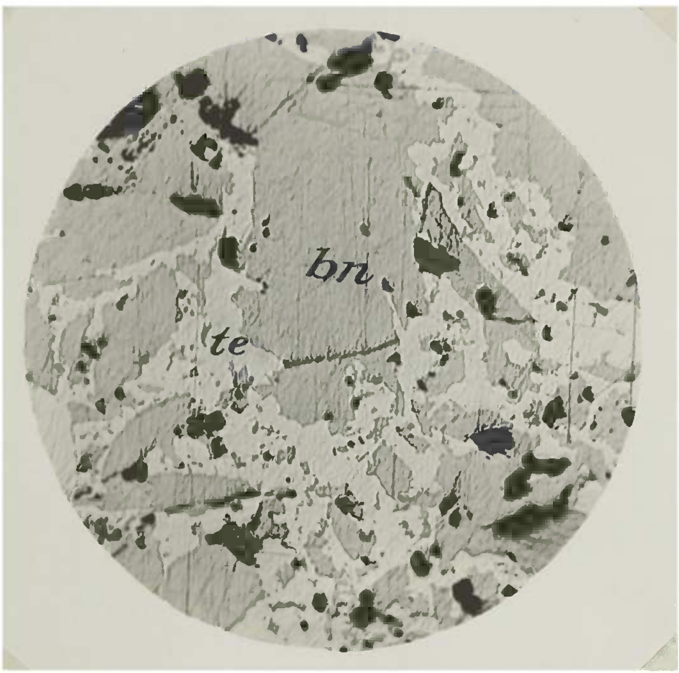
The post-Cretaceous uplift brought about a retreat of the sea from Arizona, and was accompanied by the formation of numerous mountain ranges. The core of many of these ranges were intruded by batholithic masses of granite, monzonite, and diorite. These younger granitic rocks are fairly common in southern Arizona, and one of these is the Schultz granite of the Pinal Mountains. Whether the general northeast faulting in the Globe district preceded or followed the intrusion of this granite, is not known, but the fractures were in existence when the mineralizing solutions from this granite deposited their load of copper.

The newly uplifted mountains were vigorously attacked by streams, and the detritus deposited in the valleys between the mountain ranges. These valley deposits, however, were short-lived, and were rapidly removed by slight changes in local conditions that may have produced a greater rainfall. The Whitetail conglomerate is an example of these early Tertiary, valley deposits. During the middle of the Tertiary volcanoes became active throughout Arizona, and many of the eruptions were of explosive violence, giving rise to extensive beds of tuff. These tuffs filled the depressions before the great sheets of dacite were poured out. The topography was probably somewhat subdued, with here and there a high peak, and all but the higher points were covered by the sheets of lava. These flows reached a thickness of several thousands of feet in some localities, and covered many thousands of square miles in area.

The transfer of such a large quantity of material from the earth's subcrust to the surface produced unstable conditions, and the strains set up were released, in part, by great thrust faults. This thrusting produced renewed uplift of the mountains, and as aridity was becoming more pronounced in Arizona, rock disintegration by dilatation and contraction became an important factor in the reduction of the higher summits. This aridity was accompanied by torrential rains, and the material detached by disintegration was rapidly removed to the valley below by the flood waters. These gravels and sands formed the Gila conglomerate.

The removal of large quantities of rock from the mountains, and the deposition of this material in the valley below, again produced unstable conditions, and renewed normal faulting resulted. This faulting produced an uplift of approximately 1000 feet in the Pinal Mountains. The topography is still in a youthful stage. The material recently derived from the mountain has been deposited over the eroded surface of the Gila conglomerate, and formed the Globe gravels. Even these gravels have been dissected, and streams have cut down into them for a depth of 400 feet.

Pyrite (py) fractured and filled by veins of chalcopyrite (cp), and these in turn replaced by bornite (bn).



Tetrahedrite (te) and bornite (bn) intergrown and suggesting contemporaneous deposition.

ORE DEPOSITS

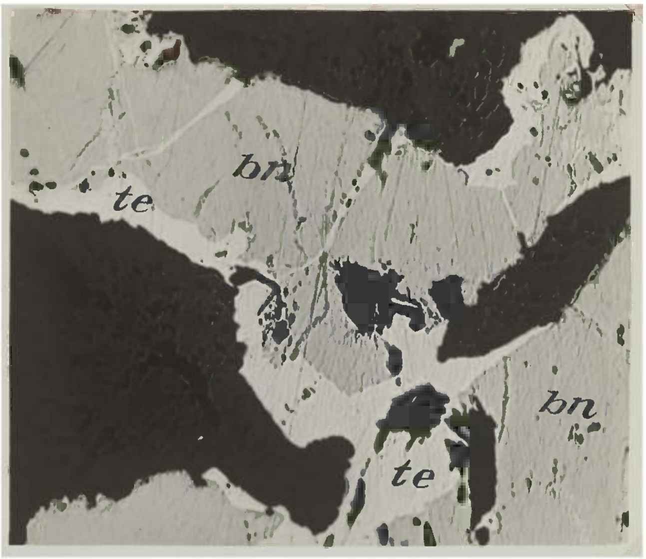
Mineralogy

SULPHIDES

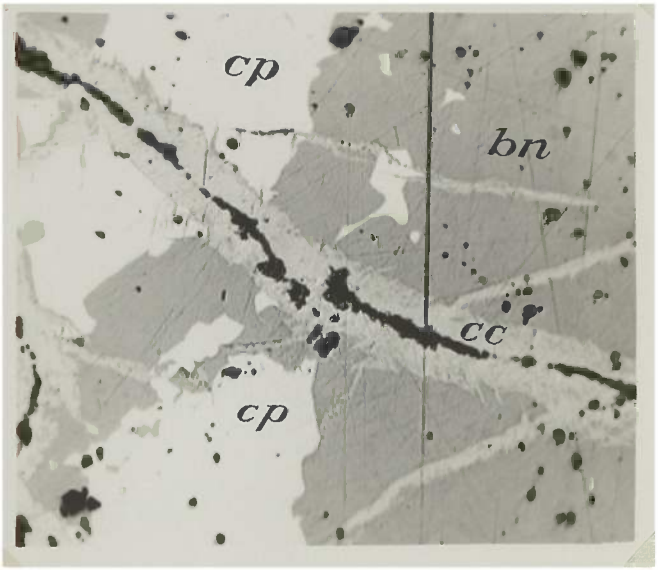
Pyrite. FeS_2 The mineral occurs as a granular aggregate in all the primary ore, and locally is very abundant. Crystals are rare and are usually found in the wall rock at some distance from the vein. The pyritohedron is the only habit. In polished surfaces the mineral is seen to be thoroughly shattered and the fractures are filled with chalcopyrite and bornite. The latter minerals have replaced the pyrite only to a very slight extent. Where enriched, however, the pyrite is entirely replaced by chalcocite.

Chalcopyrite. $CuFeS_2$. No crystals, only the massive variety, of chalcopyrite occursin this mine. In the richer replacement orebodies in the Mescal limestone the mineral occurs in large masses, always associated with bornite. It was the first copper sulphide to be deposited. Polished surfaces often show minute veinlets of secondary chalcopyrite cutting bornite of undoubted secondary origin. They do not cut the chalcocite, and may represent a breaking down of the bornite molecule.

Bornite. Cu_5FeS_4. Bornite is a very common constituent of the primary ore throughout the mine, and is especially abundant in the richer replacement orebodies in the Mescal limestone. In the



Bornite (bn) veined and replaced by tetrahedrite (te). Black is calcite gangue with pits.



Chalcopyrite (cp) replaced by secondary bornite (bn). Chalcocite (cc) veins replacing chalcopyrite and rimmed with bornite. Replaces bornite direct. Black gangue.

majority of specimens studied it is later than and replaces, chalcopyrite. Bornite and chalcopyrite sometimes occur in the primary ore in such an intimate intergrowth as to suggest contemporaneous deposition.

Bornite is also an important secondary mineral. It forms a distinct blanket beneath the chalcocite zone suggestive of downward enrichment. In Plate VI a veinlet of chalcocite is shown cutting bornite and chalcopyrite. Where the veinlet cuts the chalcopyrite it is fringed by secondary bornite. Some intimate intergrowths of bornite and chalcocite suggesting contemporaneous deposition were also seen.

Tetrahedrite. $Cu_8Sb_2S_7$. This mineral was first found as crystals in cavities on a specimen of ore from the 17th level. Here it replaces chalcopyrite. It also occurs in the ore on the 19th level of the Josh Billings vein. The mineral has a deep reddish streak and probably carries some silver. Polished surfaces (Plates V and VI) show the mineral to be definitely later than, but in part, contemporaneous with the bornite. In all its occurrences it is primary.

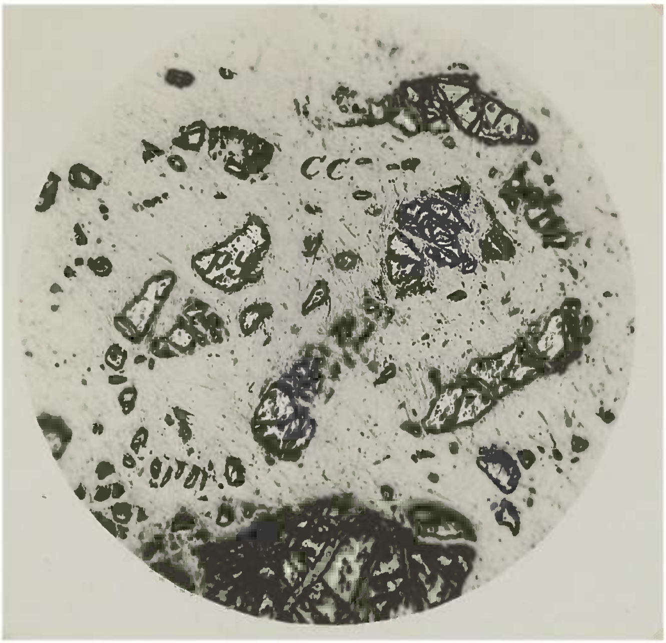
Galena. PbS. Galena was found in a small gash vein in Mescal limestone on the 16th level, and about 100 feet from the main Old Dominion vein. The mineral is also found as small specks and veins in bornite and chalcopyrite. It is primary in all its occurrences.

Sphalerite.. ZnS. This sulphide occurs in small veins, up to 4 inches wide, in diabase. The mineral is of a dark brown color. No other sulphides were found associated with it, nor was it found in any of the polished surfaces studied. Broad flakes of specularite are often associated with the sphalerite.

Covellite. CuS. The cupric sulphide cannot be seen except in a polished surface under the reflecting microscope. It can be found in nearly all specimens of secondary bornite as blades or irregular masses. In one specimen covellite comprises the entire central portion of veins of secondary bornite cutting chalcopyrite.

Stromeyerite. $(Ag, Cu)_2S$. This mineral was seen by the writer in specimens from small prospects north of Globe, but was not seen in the ore of the Old Dominion Mine until polished surfaces were examined. It occurs replacing bornite and covellite, and was probably formed by the breaking down of argentiferous tetrahedrite.

Chalcocite. Cu_2S. This important ore mineral has a wide distribution and a deep vertical range. Chalcocite replaces all the other sulphides in the ore, but pyrite is the last to be entirely replaced. It replaces bornite directly; but chalcopyrite seems, certainly in the majority of cases, to go first to bornite and then to chalcocite. Both the blue and the white chalcocite occur and in a veinlet containing both, the white is in the center. Pyrite, apparently, is not attacked until the other sulphides have been replaced. Some of the masses of chalcocite in this mine were very pure, but in most of the occurrences it is associated with other sulphides, or is being altered to the oxidized ores. At the top of the sulphide



Pyrite (py) almost entirely replaced by chalcocite (cc). Note bomb structure.

Chalcocite (cc) replaced by native copper (n) without going through cuprite stage. Black gangue.

zone, it commonly alters directly to cuprite or malachite, but in one case, as is shown in Plate VII, it alters directly to native copper without going through the cuprite stage.

Pink unknown(?) JM

Coffee Brown Sulphide. Cu-Fe-S(?). This peculiar mineral was seen in a number of polished surfaces, and is invariably associated with secondary bornite. It occurs in grains less than 1/50 inch in diameter replacing chalcopyrite, bornite, or covellite, but is earlier than chalcocite. The color is a coffee-brown, and the hardness is slightly greater than that of chalcocite, but less than that of bornite. It is probably a sulphide of iron and copper.

Native Elements.

Copper. This metal very commonly forms thin sheets in diabase or fragmented quartzite. In the limestone it is less abundant, occurring as a dendritic growth of crystals. In kaolin containing limonite where copper was deposited, the iron had been leached out. It is formed from cuprite with which it is often most intimately intergrown. Plate VII shows native copper replacing chalcocite.

Silver. Native silver occurs as thin flakes, and sometimes as stout wires in the chalcocite from the 6th level. A specimen shown the writer by Mr. Barkdoll contained thin flakes of silver on the fracture planes of chrysocolla and limonite. It was probably formed by the breaking down of stromeyerite. All the ores carry values in silver, but the oxidized ores carry the greater.

Gold. This occurs as very thin flakes on the fracture planes of chrysocolla where it is certainly secondary, although all the ores carry values in this metal. Manganese and chlorine are essential for the solution of gold. Manganese may occur in small quantities in the ore, and the apatite in the diabase may have furnished the chlorine.

OXIDES

Cuprite. Cu_2O. The cuprous oxide is a very common constituent of the oxidized ores. It is more abundant in the diabase and quartzite than in the limestones, though it is common in the shaly beds of the Martin limestone. Cuprite occurs as deep red, translucent grains in calcite, or as acicular crystals of chalcotrichite, or massive and of a deep crimson color. Thin films of the massive variety are of a deep orange color. Cuprite replaces chalcocite, and in one specimen was pseudomorph after a sheaf of malachite. It usually changes to copper pitch, but sometimes alters directly to chrysocolla. It is commonly replaced by native copper and by malachite.

Tenorite. CuO. Some small black crystal tested with the blowpipe yielded only copper, and were probably the cupric oxide. This rare mineral may occur disseminated in limonite and in copper pitch, but is not abundant as large grains or crystals. It is unimportant as an economic mineral.

Specularite. Fe_2O_3. The black, scaly variety of hematite is very common in basic rocks such as diabase or limestone. It is rarely found in quartzite. This mineral was deposited later than the pyrite which it replaces to a slight extent. In the replacement deposits in Mescal limestone the mineral has been deposited at a greater distance from the vein than the copper-bearing sulphides. In the oxidized ore on the 14th level, a drift passed through over 15 feet of massive specularite and quartz. A fine greasy rouge, micaceous hematite, occurs as thin veins penetrating the black variety, or sometimes entirely surrounding the coarser black specularite. This is secondary, but may not have been formed by descending cold solutions. The occurrence in primary ore suggests that the change took place when the chalcopyrite and bornite were deposited.

Magnetite. Fe_3O_4. Specimens in the rock collection show that magnetite occurred on the 6th level. Here the hanging wall is quartzite and the footwall is diabase. The mineral is relatively rare in the deposit.

Quartz. SiO_2. Quartz occurs both as crystal and massive in primary ore as well as in the oxidized ore. This mineral was deposited with pyrite and specularite before any of the copper-bearing sulphides. A second generation of primary quartz occurred after the deposition of calcite and barite. This quartz in one specimen was pseudomorph after barite. Some of the primary quartz is of a brilliant red color, and contains finely divided hematite.

In the oxidized ore, quartz crystals usually line cavities, having been deposited by descending cold solutions. Much free silica was liberated by the breaking down of silicates by cold acid solutions;and considerable of this silica was transported and concentrated by these solutions.

Chalcedony. SiO_2. The cryptocrystalline variety of silica occurs in small quantities in the primary ore, and probably represents the dying stages of mineralization. It is much more abundant in the oxidized ores, and occurs as a lining of cavities or as intergrowths with malachite and chrysocolla. It is usually of a milky color.

HYDROUS OXIDES.

Limonite. $2Fe_2O_3.3H_2O$. Limonite is an abundant and constant constituent of the oxidized ores. In the old glory hole, and in the Hoosier Quarry, the mineral occurs in a gossan at the surface. Most of it is earthy or pulverent, and the color varies from an ocher yellow to a deep red or brown. Some goethite may occur associated with it in these surface deposits, but this mineral has not been positively identified. Underground, the limonite is more massive, with a vitreous luster, and of a deep brown color. Masses showing only a slight green stain often carry good values in copper. The copper probably occurs here as chrysocolla, the true color of which is masked by the deeper color of the limonite. In other occurrences, the copper is most likely present as cuprite.

Manganite. $Mn_2O_3. H_2O$. A small amount of this mineral was seen in surface prospects on gash veins in limestone carrying silver. The mineral, however, is rather rare, and was found at only one locality, although manganese veins are numerous in the limestone.

Psilomelane. This hydrous manganese mineral is abundant in gash veins in limestone, and carries good values in silver. It is massive, of a dark steel-gray color with an almost metallic luster, and shows a fine grain. It has not been seen underground.

Wad. The hydrous, amorphous oxide of manganese occurs associated with psilomelane at the surface, and underground with oxidized copper minerals. It is always earthy, of a dull brownish black color, and feels very light to the hand.

CARBONATES.

Malachite. $CuCO_3 . Cu(OH)_2$. This is one of the important minerals in the oxidized ore, and, as would be expected, is most abundant in the oxidized replacement deposits in limestone. The mineral occurs as masses of fine interlacing fibers; sometimes as small spherical bodies surrounded by chalcedony, chrysocolla, and an oxide of manganese. Small tufts or sheafs of radiating fibers occur on calcite. Malachite has been found as a pseudomorph after crystals of azurite, but the occurrence is rare.

Azurite. $2CuCo_3 . Cu(OH)_2$. Azurite is a rare and an unimportant constituent of the ore. It was found in small quantities on fracture planes in limonite at the Hoosier quarry, and a small amount was found in the upper levels. It has probably been largely replaced by malachite.

Calcite. $CaCO_3$. Calcite occurs in small amounts in the primary ore. It was deposited later than barite and earlier than the second period of quartz deposition. Calcite is more abundant in the oxidized ore, and in quartzite is associated with cuprite and native copper. It also occurs to some extent with malachite; but is absent or very rare in ores containing chrysocolla.

The mineral occurs as "dog-tooth spar" in cavities in the later Paleozoic limestone. In the Mescal limestone the crystals consist of a short, stubby prism topped by a flat rhombohedron. This habit is so characteristic that it can safely be used as a criterion in separating the earlier from the later Paleozoic limestones. The Mescal limestone is dolomitic and this habit of the mineral may be due to the presence of some magnesia in the calcite molecule.

SILICATES.

Garnet. $Ca_3Fe_2(SiO_4)_3$. This lime-iron garnet is usually massive, but occasionally small crystals are found. It is of a rich brown color. It occurs on the 14th level as a narrow vein in basalt, associated with specularite, quartz, and calcite. On the 18th level it occurs replacing certain beds of the Mescal limestone, and is associated with epidote, quartz, and calcite. It is not very abundant.

The occurrence of garnet and epidote in this mine does not necessarily indicate contact metamorphism, and the minerals were probably deposited by high temperature, hydrothermal solutions.

Epidote. $HCa_2(Al\ Fe)_3Si_3O_{13}$. This mineral occurs in small crystalline masses with garnet, as noted above, and on fracture planes in diabase. It was found, at the surface, in a monzonite porphyry dike, in feldspar crystals. It is always of a green color so typical of epidote. The mineral is common in the diabase and basalt.

Tremolite. $CaMg_3(SiO_3)_4$. Tremolite occurs as white interlacing fibers in the Mescal limestone on the 18th level. On some of the bedding planes of this limestone, where some movement has taken place, the variety known as mountain leather is often found. The mineral was formed from the constituents of the impure limestone, in which it occurs, by heated water, and is not indicative of contact metamorphism. Some serpentine and chlorite are associated with it.

Chlorite. (Complex silicate of Mg, Fe, and Al). Chlorite occurs chiefly as an alteration product of hydrothermal solutions in the diabase and basalt. The micaceous flakes are of various shades of green, from pale to dark green. The lighter colored flakes are probably richer in magnesium and low in ferrous iron. It is associated with pyrite, quartz, specularite, and calcite. In the Mescal limestone it is sometimes found with tremolite and serpentine, or with epidote and garnet.

Sericite. $H_2KAl_3(SiO_4)_3$. This mineral is a constant associate of the primary ore. It is very abundant in the diabase and quartzite, and less so in the limestone. It is a product of the hydrothermal solutions that gave rise to the economic minerals, and was deposited when the chalcopyrite and bornite were formed.

Kaolinite. $H_4Al_2Si_2O_9$. Kaolin is a product of acid sulphate waters acting on sericite. It is very abundant in the chalcocite zone and in the oxidized ores. Large masses, often several feet thick occur in oxidized ores in limestone. The mineral is often stained brown by limonite. It sometimes contains thin dendritic films of copper or an oxide of manganese. The copper-bearing variety will be described under chrysocolla.

Serpentine. $H_4Mg_3Si_2O_9$. The most common and abundant occurrence of this mineral is in diabase at and above the water table. This variety of serpentine is of a dark green color, probably due to the presence of ferrous iron. It was derived from the olivine and augite in the diabase. The serpentine in the Mescal limestone is of a pale green, or cream yellow color, and was formed from the constituents in the rock. On the 8th level it occurs in a vein with asbestos in Mescal limestone.

Chrysocolla. $CuSiO_3 \cdot 2H_2O$. This is the most important and most abundant economic mineral of the oxidized ores. It is very widespread in its occurrence, but is most common in limestone and quartzite ores. It forms at the expense of all the other oxidized minerals except the native element. It varies in color from a dirty green to a bright sky-blue. Where the mineral occurs staining kaolin, it is often very deceiving in the amount of copper contained. Some of this material is often of good blue color, but when assayed, is found to carry but a few percent of copper.

SULPHATES.

Barite. $BaSO_4$. Barite is a relatively rare mineral in this mine, and occurs only in the primary ore. A specimen from the 16th level consisted of broad cleavage plates partially replaced by quartz. On the 19th level of the Josh Billings vein the mineral is associated with calcite, chalcopyrite, and bornite, but is later than these minerals.

Alunite. $K(AlO)_3(SO_4)_2+3H_2O$. Alunite occurs in veins up to 6 inches in width, in somewhat altered diabase. The mineral is of a white color, with an earthy texture, and breaks with a splintery fracture. It is the last stage in the primary mineralization.

Chalcanthite. $CuSO_4+5H_2O$. This mineral occurs in old workings as stalactites hanging from timbers or covering the floor.

Pisanite. $(Fe,Cu)SO_4+7H_2O$. This mineral was found on the 15th level in old abandoned workings. It was formed on the floor of a drift by solutions coming up out of the rock.

Goslarite. $ZnSO_4+7H_2O$. The mineral occurs as fine long hairs on the walls of drifts. It is most common in diabase, and was formed by solutions slowly coming out of the rock.

OTHER MINERALS.

Wulfenite. $PbMoO_4$. Orange-colored, tabular crystals of this mineral were found by the writer on the 14th level associated with chrysocolla and limonite. Specimens were also found by Porri on the 19th level associated with oxidized copper minerals. Tabular crystals occur in the Darius tunnel and are coated by silica. The primary sulphide, molybdenite, has not been found in the ores, but probably occur in small quantities.

Vanadinite. $(PbCl)Pb_4(VO_3)_3$. Small red crystals, of unusual dark color, and with a hexagonal outline, were found at the surface in a small gash vein. This cluster of crystals was associated with quartz, calcite, and psilomelane. This is the only occurrence of the mineral on the property of the Old Dominion Company, but two miles north of the mine, vanadinite is common in quartzite, and is associated with chrysocolla, cerrusite, and descloizite.

Cerargyrite. AgCl. Hornsilver of a greenish gray color occurs in manganese ore at the surface in limestone. The mineral is rather common around Globe. To the northeast, in the Richmond Basin, embolite and bromyrite were found.

Copper Pitch. Several black substances with conchoidal fracture are often included under this term. Some of this material is undoubtedly chrysocolla stained by the oxides of manganese, and this may be the reason why analyses show such wide variations. Chrysocolla that shows gradational color from blue to black have been found in this mine, but copper pitch, as the term is used here, occurs only surrounding and veining cuprite. It commonly alters to chrysocolla. When ground to a fine powder and examined with the high powers of the microscope the mineral is found to be opaque, and in this respect, differs from chrysocolla stained by the oxides of manganese. The mineral has a hardness of 4; black streak; conchoidal fracture; and is very brittle.

Lindgren [16] gives the following analysis of this mineral:

	%
CuO - - - - - - - -	28.6
ZnO - - - - - - - -	8.4
MnO_2 - - - - - - - -	21.2
Fe_2O_3 Al_2O_3 P_2O_5 - -	4.0
Insoluble in HCl - -	22.8
Ignition loss 16.3 less oxygen due to conversion of MnO_2 to Mn_3O_4	13.7
	98.7

If the zinc is combined with the silica to form a zinc silicate, and the iron, alumina, and phosphorus figured as impurities, then the remaining substances could probably be considered as a hydrous oxide of copper and manganese.

The material from Globe has not been analyzed, but it is the writer's belief that it is a mineral and not a mixture.

Anthraxolite. This rare mineral was found by the writer on the 14th level as small veins in the Cambrian basalt. The mineral is associated with calcite, quartz, and chlorite, chiefly, but the fracture planes contain thin films of chalcopyrite. Garnet, quartz, and specularite also occur as veins in this rock, but anthraxolite has not been found with them.

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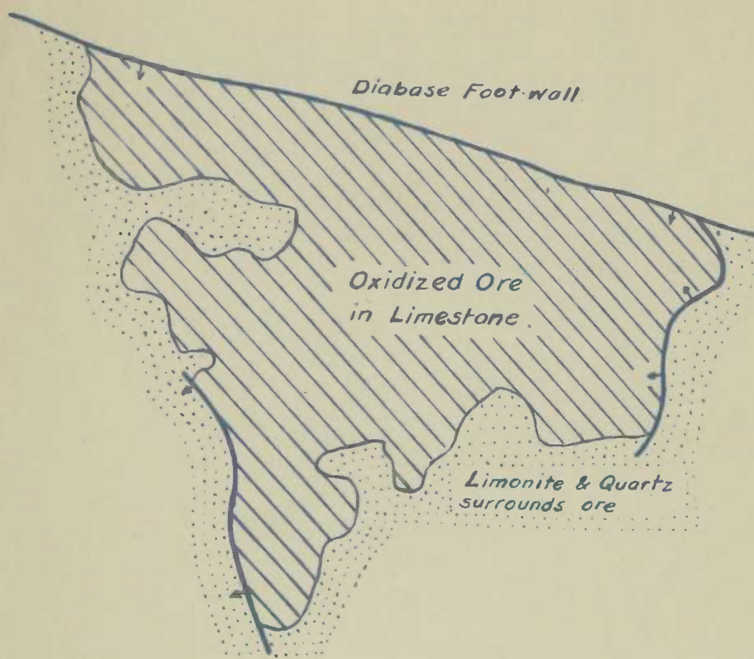
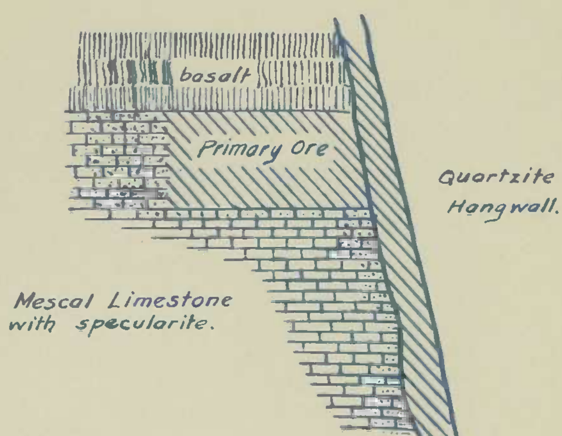
16. Lindgren, W., The Copper Deposits of the Clifton-Morenci District, Arizona. U.S.Geol.Survey Prof. Paper 43. p. 114, 1905.

PLATE VIII

REPLACEMENT OREBODIES IN LIMESTONE



PLAN OF OXIDIZED OREBODY



DIAGRAMMATIC SECTION OF PRIMARY ORE

Specularite shown by dots.

The mineral occurs as more or less spherical grains embedded in calcite. It is of a black color; conchoidal fracture; hardness about 2.5; and extremely brittle. Chemical tests show it to consist chiefly of carbon. A Russian, publication not accessible to the writer now, gave a series of analyses in which the carbon content varied from 88 to 93%. The remainder consisted of hydrogen, oxygen, and nitrogen.

Types of Ore Deposits.

The ore deposits in the mine may be subdivided into orebodies occurring as replacement of limestone and quartzite; vein deposits; mineralized lodes; and gash veins in limestone.

Replacement Deposits. Replacement of the wall-rock by sulphide ores has taken place extensively in limestone and to a lesser extent extent in quartzite, and to only a slight extent in diabase. The replacement that has taken place where the wall-rock is diabase, has been of the alteration products produced by the first wave of heated water rather than a direct replacement of the primary silicates of the wall-rock. This replacement was generally accompanied by the deposition of considerable silica in addition to the sulphides.

Descending solutions which have oxidized the ore, also carried copper, and a further replacement of the wall-rock took place. This is very noticeable in both the limestones and quartzite. Silica was again transferred in considerable quantities.

Irving[17] gives the following criteria as characteristic of replacement deposits.

1. Presence of complete or partly faceted crystals in foreign rock masses.
2. Preservation of rock structures.
3. Intersection of rock structures.
4. Absence of concave structures.
5. Absence of crustification.
6. Unsupported structures.
7. Form.
8. Decrease in volume due to change in composition.
9. Excess of volume of introduced minerals over original pore-space of rock.

It is seldom that most of the criteria listed above can be found in a single orebody, and all are seldom found in one deposit. The last criterion listed is rather difficult of proof, even with an intensive microscopic study, chiefly because of the uncertainty, in a much faulted region, of having the same bed of sediment.

Of the replacement deposits of primary sulphides in limestone, only one, the Mescal limestone, remains today for observation; all deposits in the Devonian and Carboniferous limestone have long ago been modified by oxidation. The Mescal limestone will, therefore, be taken as the type of sulphide replacement in limestone.

The remarkable banding shown on a fresh fracture, or the knotted bands of silica shown on a weathered surface, are often preserved in the ore. Bands of chalcopyrite, or an intergrowth of chalcopyrite and bornite, often form bands parallel to the

17. Irving, J.D., Replacement Ore-bodies and the Criteria for their Recognition: Economic Geology, vol. 6, p.619, 1911.

bedding planes, and are separated by silica. This banding, however, is often absent, especially where the rock has been replaced by specularite, or by solid sulphides. Pyrite is not so abundant, except locally, and then only in minor amounts. Specularite, however, is more abundant and has penetrated and replaced the rock for a greater distance from the main fracture, than the copper sulphides. But the specularite represents an earlier, and probably a more intense hydrothermal action.

The replacement has been selective, certain beds are mineralized for greater distances horizontally than others, and is due in part to the composition of the rock. The degree of fracturing was also responsible for the greater amount of replacement at some places along the Old Dominion vein. Although mineral occurs along the entire length of the vein, the more intense fracturing, especially where a change in strike of the vein has taken place, has developed ore shoots. Partly for this reason, the Mescal limestone, for hundreds of feet, does not contain large economic bodies of ore.

The Troy quartzite forms the hanging wall of the vein for long distances, and splendid orebodies have been formed in this rock. The replacement of the rock by primary sulphides has not been so complete as in the limestones. The brecciation produced during faulting has not been entirely obliterated by replacement; many of the rock fragments are still quite angular, but some replacement has taken place in this quartzite as well as in the Dripping Spring quartzite. On the 19th level, in the Josh Billings vein, the ore occurs as a replacement of the Dripping Spring quartzite. The limits of commercial ore can be determined only by assay, and sulphides have been deposited for many feet from the vein. According to McBride,[18] the lower beds of the Dripping Spring quartzite is a very favorable horizon for the deposition of ore. In this vein crustification is entirely absent, and very rich sulphide ore has been deposited.

The replacement deposits in the Devonian and Carboniferous limestones have been modified by the oxidizing solutions passing through the ore and their original nature masked by this alteration. The Martin limestone contains, at some horizons, considerable shaly material, and this horizon does not contain large or rich orebodies. Much of the limestone is heavily impregnated with limonite, and is more common on fracture plane than in the interior of the rock. The limonite is probably an oxidation product of pyrite, and the occurrence on fracture planes shows that even the hot, primary solutions did not penetrate this limestone for great distances.

While certain beds of the Pennsylvanian limestone contain good bodies of oxidized ore, as a rule, this horizon was unfavorable for the deposition of ore. On the 11th and 12th levels, good oxidized ore was mined from what the writer considers to have been the lower beds of the Naco limestone. Another locality where ore mined was probably in Naco limestone, was on the 16th level in blocks 5 and 6 west. Here, although the ore was rich, the replacement bodies were narrow and were separated from the wall-rock by fractures on which

18. McBride, W.G., Oral Communication.

movement, later than the oxidation of the ore, had taken place. At the surface numerous stringers, often only a few inches thick and containing limonite and quartz, show that the limestone was not mineralized to any great extent. This horizon, at Bisbee, carries good bodies of ore, and the reason for the lack of mineralization at Globe is not known. The limestone shows great variation in texture, from coarse granular to extremely dense. On examining the wall-rock of some of these narrow stringers it is found to be very compact, and shows silica with some copper stain, penetrating the rock for an inch or two. Texture may, therefore, be responsible, in part, for the lack of mineralization.

The best horizon for replacement bodies of oxidized ore is in the massive black limestone member of the Mississippian. Wherever this limestone forms one wall of the vein, it has been almost entirely replaced by copper minerals. The original mineralization probably consisted of an abundance of chalcopyrite and bornite with some pyrite, specularite, and quartz. Because of its position near the surface, all the ore in this limestone has been oxidized. In form, the orebodies are generally tabular, and with a greater horizontal than vertical extent. The outline is very irregular and grades into limonite and quartz containing very little copper. One of these orebodies is illustrated in Plate VIII. The ore consists chiefly of chrysocolla, limonite, and quartz, but occasionally malachite is more abundant than chrysocolla, and often contains nodules and veinlets of deep red, transluscent cuprite.

Vein Deposits. The largest amount of ore in this mine occurs in the Old Dominion vein. It forms a great tabular sheet of ore between well defined walls, with local swelling or contraction in the width of the ore. These swellings occur where there are abrupt changes in strike, and are centers around which a greater amount of shattering and rock brecciation took place during faulting. Above the 16th level the foot-wall is basalt and diabase, and the hanging wall is Troy quartzite. Here the ore occurs in a true fissure with well defined walls. Splits off of the main vein occur, and are in the softer diabase rather than in the quartzite. Such splits always rejoin the main vein further along the strike. The alteration produced in the diabase of the foot wall has been crushed to a gouge by movements along the vein later than the enrichment of the ore.

The minerals of the ore consist of pyrite and chalcopyrite with some bornite. The gangue minerals are mainly quartz and sericite, but calcite and barite are sometimes seen. The sulphides in the vein often occur as a segregation in lenses, roughly parallel to the walls, and is especially noticeable where there is an abundance of sericite. Where the whole width of the vein consists of massive, white quartz and sulphides, the linear arrangement of the sulphides is absent, and the ore consists of sulphide grains disseminated throughout the quartz. The grade of the ore, where it has not been enriched, is generally lower than in the replacement deposits. This is due partly to the mineral composition, the ore consisting chiefly of pyrite and chalcopyrite, and partly to the smaller amount of sulphides per unit of volume. Where both walls of the vein are diabase, the vein is apt to be narrow and low grade. This is especially so below the zone of enrichment.

The Josh Billings vein roughly parallels the Old Dominion vein, but the dip is nearly vertical. It lies to the north of the main hoisting shaft, whereas the main vein is to the south. Like the Old Dominion vein, it occupies a fault fissure, but the throw on this fault is small. At the surface both walls are in diabase. Here good oxidized and enriched ore was found. The high-grade ore soon passed into lean sulphides, and no further development work was done until sufficient depth was reached where one or both walls would be quartzite. The quartzite walls are smooth, and are separated from the ore by about an inch of gouge. On the 19th level the ore extends beyond the gouge and replaces the wall-rock. The ore in the wall-rock, according to Porri,[19] is of a lower grade than that in the vein proper. The ore consists of pyrite, chalcopyrite, and bornite, and with quartz and sericite as gangue minerals. A specimen from the 19th level, sent to the writer by Porri, consisted of chalcopyrite and bornite intergrown, and veined and replaced by tetrahedrite. The gangue consisted of barite. As far as the writer is aware, no tetrahedrite was found on the 18th level.

Mineralized Lodes. On the 18th level, and about 2000 feet east of the main shaft, the upper beds of the Dripping Spring quartzite have been thoroughly shattered. There fractures are nearly parallel

19. Porri, W., Oral Communication.

to the main vein, and with a nearly vertical dip. The fractures are spaced from a few inches to several feet apart. Pyrite and chalcopyrite have been deposited on the fracture planes, and the ore should probably be classified as a mineralized lode. No visible replacement has taken place. The grade of this body of ore is lower than the general run of ore from the mine, partly because of the distance between fractures.

Gash Veins. These veins occur at the surface in Pennsylvanian limestones, and are worked only by lessees. The veins often have a length of a hundred feet or more, and a width up to three feet. The ore is frozen to the wall-rock, but is rather sharply defined. It consists of psilomelane and quartz with some calcite and manganite. The value of the ore lies in its silver content. An interesting feature of this ore is the approximately proportional ratio between the silver content and the amount of manganese present. Some of the ore will run as high as 40% manganese, and will then carry about 100 ounces of silver. In the richer ore, hornsilver is present, but the entire silver content is not present as chloride, and may exist as finely divided metallic silver. A ratio between manganese and silver for one vein will not hold for a second, but with a number of assays available, a new ratio will be found. The ore sometimes consists of massive psilomelane, and as no primary manganese minerals were found in the Old Dominion vein, the origin of this material is very puzzling.

Origin of the Ore.

In his first examination and report on the Globe district, Ransome attributed the source of the copper to the diabase. Development work has now proceeded to below the main diabase intrusion without any change in the ore. It is possible, of course, that another and larger sill exists below, but the diabase is very widespread in the vicinity of Globe and yet the copper mineralization is limited to a rather small area. The close association of the diabase with the ore in the Old Dominion Mine is rather an accidental than a genetic relationship. In a later publication on the Miami-Ray district, Ransome [20] showed that the ore was derived from the Schultz granite with which it is intimately associated. It is possible that offshoots of the Schultz granite may occur at Globe, at greater depth. They have not, however, been found by the deepest development work. The Schultz granite consist of 52% oligoclase feldspar,and is, therefore, a monzonitic phase of granite. This type of intrusive rock is very commonly associated with the larger copper deposits of the western states. Monzonitic rocks are associated with the copper deposits at Miami, Ray, Bisbee, Morenci, and Ajo, in Arizona; at Tyrone, New Mexico; at Ely, Nevada; Bingham Canyon, Utah; and Butte,Montana. As Miami is only four miles in a direct line from Globe, it is probably most reasonable to assign the origin of the metalliferous solutions to the Schultz granite.

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20. Ransome,F.L.,U.S.Geol.Survey,Prof.Paper,115,1919.

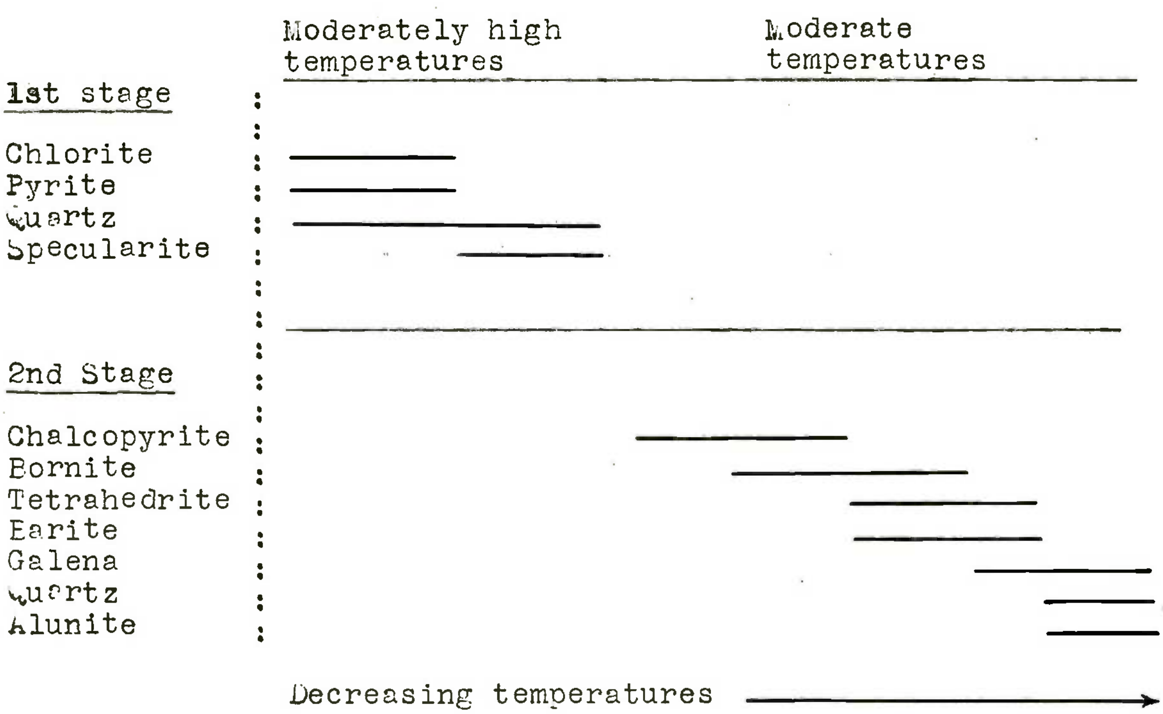
The hot, alkaline solutions from the Schultz granite, probably under considerable pressure, penetrated preexisting fractures in the Globe Hills, and deposited their load of mineral matter. These solutions carried iron, sulphur, copper, and silica in addition to other substances. They produced a propylitic alteration in the diabase with the formation of chlorite and the deposition of pyrite and quartz. There was probably an excess of iron, which was deposited as specularite. This mineral seemed to prefer basic rocks like diabase or limestone. Some of the specularite is certainly later than the pyrite as the latter mineral has been corroded and penetrated by blades of specularite.

The pyrite was then fractured, and in these fractures chalcopyrite deposited. An examination of the upper photograph of Plate V shows these veinlets of chalcopyrite to have nearly parallel walls. This suggests that there has been but little replacement of the pyrite, and the veinlet increased in width by crystal growth forcing out the walls. Bornite followed up and partially replaced the chalcopyrite in these veinlets. In other polished surfaces bornite and chalcopyrite are intimately intergrown and were deposited at the same time. After the deposition of chalcopyrite had ceased, but while bornite was still forming, tetrahedrite began to crystallize out. Tetrahedrite and bornite are intergrown and were deposited together. Later bornite ceased to form, and the tetrahedrite which continued to crystallize out, cut and replaced the bornite. This is shown in Plate VI.

Sphalerite was found associated with specularite as veins in diabase, but the mineral is not associated with other sulphides, and the relations of the two are not known. It probably formed when the galena was deposited. Galena occurs as veinlets in bornite and is probably later than tetrahedrite. Bornite is intergrown with tetrahedrite and was probably formed before galena. The last stage in the primary mineralization deposited a second generation of quartz, which in part replaced barite, and produced veins of alunite in the diabase.

The order of formation of the various minerals is shown in the diagram below.

PRIMARY MINERALIZATION



Enrichment of the Ore.

The mineralization probably began shortly after the intrusion of the Schultze granite, and this was about the beginning of Tertiary time. During the early Tertiary a moist climate existed in Arizona, and a considerable quantity of surface water was available for the oxidation and enrichment of the ore. In northern Arizona the Eocene is represented by extensive beds of sands and fine silts which Gilbert, Powell, and Dutton described as of lacustrine origin. The humid climate of the Eocene may have continued throughout Oligocene time, but early in the Miocene aridity was becoming more pronounced. During almost the entire time from Eocene to middle Miocene, the conditions were favorable for the enrichment of the ore. Thick flows of dacite then covered the region, and little or no enrichment took place until recently, when erosion cut through the lava and again attacked the mineralized sediments.

The water table stood at about the 8th level when the Old Dominion Mine was opened, but during past geological time fluctuated somewhat, and at one time was nearly as low as the 12th level. A short distance above the 12th level cuprite was found associated with chalcocite; indicating that the influence of the oxidizing solutions was felt at this level. The bottom,as well as the top of the chalcocite zone is not flat, but varies somewhat with the topography. The most influential factor was permeability of the wall-rock. In the diabase, serpentine was readily formed, producing an increase in volume and forming a tight vein, and thereby stopping the descending solutions. The quartzite and limestone beds were thoroughly shattered by faulting, and down these fractures enrichment extended for greater distances. The vein deposits in the quartzite show some crustification, and the pores in these were also passageways for the enriching solutions.

Beneath the chalcocite is a zone of secondary bornite fairly well defined, and formed by descending solutions. The upper surfaces of this zone merge into the chalcocite zone, and the lower surface, which is difficult to determine, rests on primary ore. Even with a hand lens, secondary bornite can rarely be distinguished from that of a primary origin. In polished surfaces the two can usually be separated.

In a study of polished surfaces of the secondary ores the changes that have taken place could readily be determined. Considerable bornite was found that is undoubtedly of a secondary origin. One specimen showed chalcopyrite cut by veinlets of bornite, the center of which contained blades of covellite. This bornite is certainly secondary. Again, in another specimen bornite and chalcocite showed a eutectic intergrowth, suggesting contemporaneous formation. As is shown in the lower figure of Plate VI, a veinlet of chalcocite is fringed by secondary bornite. Here the chalcopyrite changes to bornite before going over to chalcocite. Many occurrences of this kind were found. This, however, is not always the case, and chalcocite has been observed directly replacing chalcopyrite. Where a veinlet of chalcocite passes through bornite into chalcopyrite there is a noticeable constriction in the width of the veinlet in the chalcopyrite. It would seem from this that the chalcopyrite is not as readily replaced by chalcocite as is the bornite.

Bornite is also replaced by other sulphides in addition to chalcocite. Covellite was mentioned above as occurring in secondary veinlets of bornite. The mineral also occurs as small blades or irregular masses of a deep blue color replacing bornite. It is often associated with secondary veinlets of chalcopyrite, and the two minerals may have formed by the breaking down of the bornite molecule. In a later stage the covellite is replaced by chalcocite. In addition to covellite, an interesting sulphide of a coffee-brown color is sometimes seen. It occurs only in bornite, always as irregular rounded masses, and never as veinlets. The greatest diameter is usually less than 1/50 inch, and on such a small area it is impossible to make microchemical tests without the surrounding sulphides interfering in the reaction. Where a veinlet of chalcocite cuts this mineral a notable constriction in width occurs.

A number of assays made by the Company of ore rich in bornite, showed a higher silver content than the ore consisting of bornite and chalcopyrite. The writer then expressed the belief that the bornite carried the silver. Polished surface work confirmed this view, and stromeyerite, the copper-silver sulphide, was found in bornite of secondary origin. On a recent visit to this mine, the writer was informed by Mr. Barkdoll, the superintendent, that the ore in the Josh Billings vein, which contains tetrahedrite, also carried good silver values. Stromeyerite was never found in contact with tetrahedrite, but was probably derived from that mineral.

Only a brief mention of chalcocite was made above, and its relations shown to the earlier formed sulphides. A study of some veinlets of chalcocite in bornite, especially the one shown in Plate VI, show a ragged boundary in bornite. An examination of this edge with an oil-immersion lens proves that it is not an intergrowth with bornite. The edge is a blue chalcocite, probably replacing bornite on cleavage, while the center of the veinlet is white chalcocite. Pyrite is not readily replaced by chalcocite as long as bornite and chalcopyrite remain in the immediate vicinity. After the replacement of the latter two minerals, pyrite is readily replaced by chalcocite. This last stage in the replacement is shown in Plate VII. Chalcocite which has entirely replaced pyrite, often has a granular texture, and this it may have inherited from the pyrite. Kaolin was formed from sericite by the solution that deposited the chalcocite, and the two minerals are always associated.

Oxidized Ores.

Many interesting relations were found in the oxidized ores, and some are worthy of more detailed description. Chemical changes that these minerals have undergone, a reversal of these changes; and the conditions which have brought them about, are only partially understood.

Chalcocite, in the presence of oxygenated solutions, alters readily to cuprite. This seems to be the first step, but chalcocite also alters to malachite, and never directly to chrysocolla. Very rarely, chalcocite is seen replaced by native copper without going through the cuprite stage. This is shown in the lower illustration of Plate VII.

Deep red transluscent cuprite is often associated with calcite, and wires of native copper cut through the mass. This peculiar association is rather difficult to explain unless the calcite is later than the copper minerals. Grains of cuprite are embedded in calcite and unattached to other grains. This is an unsupported structure, a criterion characteristic of replacement. If replacement of the cuprite has taken place, it would be logical to expect the basic carbonate to form. But as both malachite and azurite are absent here, the conditions under which cuprite and calcite may exist together are not well understood. Cuprite is also veined and replaced by malachite. Often malachite will grow in cuprite as stubby, radiating crystals from canters, but is not common as veins. Cuprite often alters directly to chrysocolla, but usually first goes to copper-pitch, a black mineral of uncertain composition.

Tabular crystals of malachite were found as a pseudomorph after azurite. In these crystals the fibers of malachite were arranged perpendicular to the flat side of the pseudomorph. Malachite was found in one specimen altering to cuprite, and the sheaf-like structure of the malachite was preserved in the cuprite. Malachite commonly alters to chrysocolla.

Chrysocolla is the end product of the copper minerals formed by oxidation processes. When the chrysocolla is leached by the descending solutions, an aluminous substance, probably kaolin, and limonite and quartz, remain.

The various changes that have taken place in the oxidized ore are illustrated diagrammatically in the figure below: