cut across the foliation planes, which are bent or broken adjacent to many of them. These sulfide veinlets in places are in contact with the original fine-grained chlorite. In other places, the chlorite is in random orientation and is much coarser grained adjacent to the sulfide veinlets. Some veinlets contain quartz and sulfide minerals; others contain dolomite and sulfides; whereas others contain both quartz and dolomite gangue.

In general, the mineralogy is simple: pyrite, chalcopyrite, and sphalerite are the important sulfide minerals, and are essentially contemporaneous, as a single veinlet will contain all three in mutual relationship. Some veinlets consist of nearly pure pyrite; others contain only chalcopyrite and sphalerite. Some fracturing of pyrite occurred before introduction of chalcopyrite and sphalerite, but in several places pyrite veinlets cut chalcopyrite. Arsenopyrite is rare and its age relative to the other sulfide minerals is in doubt. Under high magnification, galena and tennantite are observed in minute grains associated with the chalcopyrite and sphalerite.

The pyrite crystals range from 0.2 to 1 millimeter across, and generally are coarser grained than the pyrite in the massive sulfide. The smaller pyrite grains in the black schist are partly parallel to the foliation planes, indicating that the deposition of some of the pyrite has been controlled by foliation planes.

In most specimens containing coarse flakes of chlorite adjacent to the sulfide minerals, individual chlorite crystals project into chalcopyrite and have straight and sharp boundaries. This relationship is difficult to interpret, for it may mean that the chlorite has crystallized contemporaneously with the chalcopyrite, or the chalcopyrite has been deposited about the chlorite, or the chlorite has replaced the chalcopyrite.

Locally, quartz-carbonate veins are commercially important in the black schist ore, because they contain the same sulfide minerals as the black schist ore. Perhaps tennantite is more important quantitatively where the quartz-carbonate veins are abundant.

QUARTZ PORPHYRY ORE

Quartz porphyry ore consists of intersecting and ramifying chalcopyrite veins ranging from microscopic size to one-half inch in width, cutting through the quartz porphyry (pl. 8*D*). Chlorite is common along the margins of many of the chalcopyrite veins. Blebs of chlorite and chalcopyrite, in a linear arrangement, plunging very steeply to the north, are present locally in one quartz porphyry stope. This is the only recognized structural control possibly related to steeply plunging lineation in the foliated quartz porphyry. Elsewhere in the quartz porphyry ore, chalcopyrite veins cut across foliation.

428436—58——9

Microscopic studies of the quartz porphyry ore show that some veinlets of chalcopyrite are associated with abundant chlorite, and others contain very little (pl. 8*D*). Where chlorite is abundant, the groundmass of the porphyry contains chlorite interstitial to the groundmass quartz, and sericite is absent. In quartz porphyry ore in which chlorite is sparse, sericite is interstitial to the quartz in the groundmass, indicating that the chlorite selectively replaces sericite in the early stages of chloritization. The sericite flakes that form the foliation in the quartz porphyry lie parallel and chalcopyrite veinlets clearly cut across the sericitic layers proving that the sericite is older than the chalcopyrite.

Chalcopyrite is the chief mineral in the sulfide veins, but pyrite and sphalerite are present. Deposition of all three minerals apparently occurred about simultaneously. Nests of randomly oriented chlorite occur along the sulfide veinlets, and individual crystals of chlorite project into chalcopyrite, similar to the relationship of these minerals in the black schist ore. The general association of chloritic margins along the chalcopyrite veins in the quartz porphyry ore indicates that part of the chlorite was formed at about the same time as the chalcopyrite, but fractured veins healed by chalcopyrite indicate that copper is later than the chloritization.

QUARTZ-CARBONATE VEINS

The last period of mineralization is represented by abundant quartz-carbonate veins and nodules that locally contain several sulfide minerals. These veins are not all the same age, for some are cut by the andesitic dikes and others cut the dikes. Some vein intersections show no displacement, whereas in others, older veins are offset as much as 6 inches. The quartz-carbonate veins cut through the black schist, dating the quartz-carbonate vein formation as younger than the bulk of the chloritization. Some chlorite, however, is contemporaneous with vein formation, as shown by chlorite selvages along the vein margin in quartz porphyry; the chlorite forms pale-green plates ranging from 1 to 2 millimeters in diameter, arranged normal to the vein wall, so that the chlorite on many surfaces appears fibrous. Some of the quartz-carbonate veins in the black schist have the same platy chlorite selvages, but this chlorite may be reworked chlorite from the black schist. In a few places, chlorite veinlets cut the quartz-carbonate veins.

The veins range from a fraction of an inch to 2 feet in width, but average between 1 and 2 inches. Where exposures permit observing the veins along strike, they commonly vary in width, and many gradually narrow and disappear within 20-foot distances. Quartz-carbonate nodules ranging from 6 to 8 inches in length and from 1 to 2 inches in width occur in some veins; these nodules are more common in the black schist where they are parallel to the foliation.

Quartz-carbonate veins also occur in the fault-zones along the footwall of the massive sulfide; in places, the vein material is brecciated, but many veins are nonbrecciated, showing that no movement occurred after mineral deposition.

The veins are in all the rock types in the United Verde mine, including the gabbro on the hanging wall. They are rare in the quartz next to the gabbro, and in the massive sulfide, but most common in the black schist. Local concentrations of veins, however, are present in the quartz porphyry several hundred feet away from the massive sulfide. The tuffaceous rocks are cut by a few veins, particularly east and northeast of the massive sulfide pipe.

In some of the black schist, closely spaced veins a quarter of an inch wide have a wrinkled appearance, and contorted veins an inch wide occur locally in the quartz porphyry. The cause of the irregularity in the veins is unknown.

The mineralogy of the veins is simple: white granular quartz and dolomite are the two chief minerals. White calcite takes the place of dolomite in some veins, particularly those in the gabbro. Most of the veins are barren of sulfide minerals, but some contain sulfide, chiefly pyrite, chalcopyrite, pale sphalerite, galena, and tennantite. The veins away from the massive sulfide generally contain only pyrite. Rarely are all the sulfide minerals present in a single vein. The tennantite-bearing veins appear to have a consistent affinity for hosts of black schist or copper-bearing quartz porphyry. Some tennantite contains as much as 40 ounces of silver to the ton. In stopes where tennantite occurs in quartz-carbonate veins, the silver content of the ore was doubled and locally trebled over the average of the ore.

RELATIONSHIP OF ANDESITIC DIKES TO COPPER MINERALIZATION

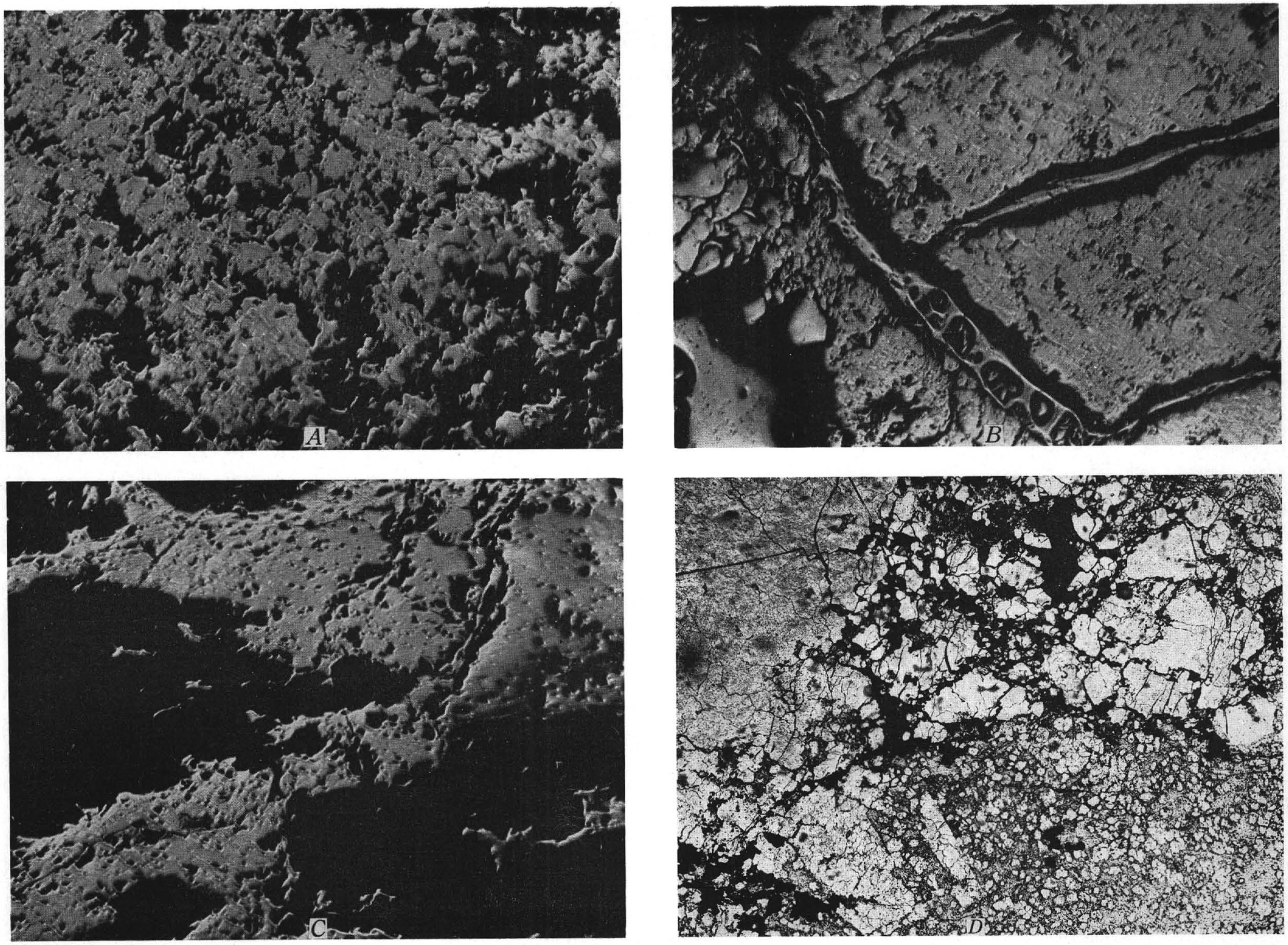
Early exploration entailed driving west or east along the andesitic dikes to intersect the north or northwestward-trending ore shoots, and the operators then believed that the dikes might have had important control in the location of ore shoots. For that reason, the geological staff of the United Verde mine paid special attention to the relationship of the dikes and copper mineralization (Reber, personal communication). Their final conclusions were that the dikes were later than the copper ore shoots. Our studies are in agreement with their conclusions.

It is true that the andesitic dikes in places contain scattered pyrite cubes and in a few places, chalcopyrite veinlets, 2 to 3 inches wide, which cut into the margin of the dikes. They are also cut by many quartz-carbonate veins, and pyrite and chalcopyrite are present in a very few of these veins within the dikes. Clearly, then, some sulfide mineralization occurred after intrusion of the dikes, but a much higher percentage of quartz-carbonate veins carry sulfide minerals outside of the dikes than within, indicating that most sulfide-bearing quartz-carbonate veins are older than the dikes. In one exposure, a quartz-carbonate vein containing pyrite is cut off by an andesitic dike that is cut by barren quartz-carbonate veins.

Where the dikes cut through the massive sulfide, their margins are straight and sharp, regardless of whether the dike cuts a chalcopyrite ore shoot or pyritic massive sulfide. Because fractures in the massive pyrite controlled the copper-bearing solutions to form ore shoots, the absence in the ore shoots of chalcopyrite veinlets in the andesitic dikes indicates that the dikes were intruded after the main chalcopyrite period of mineralization. The fact that the dikes carry many barren quartz-carbonate veins proves that the dikes were fractured.

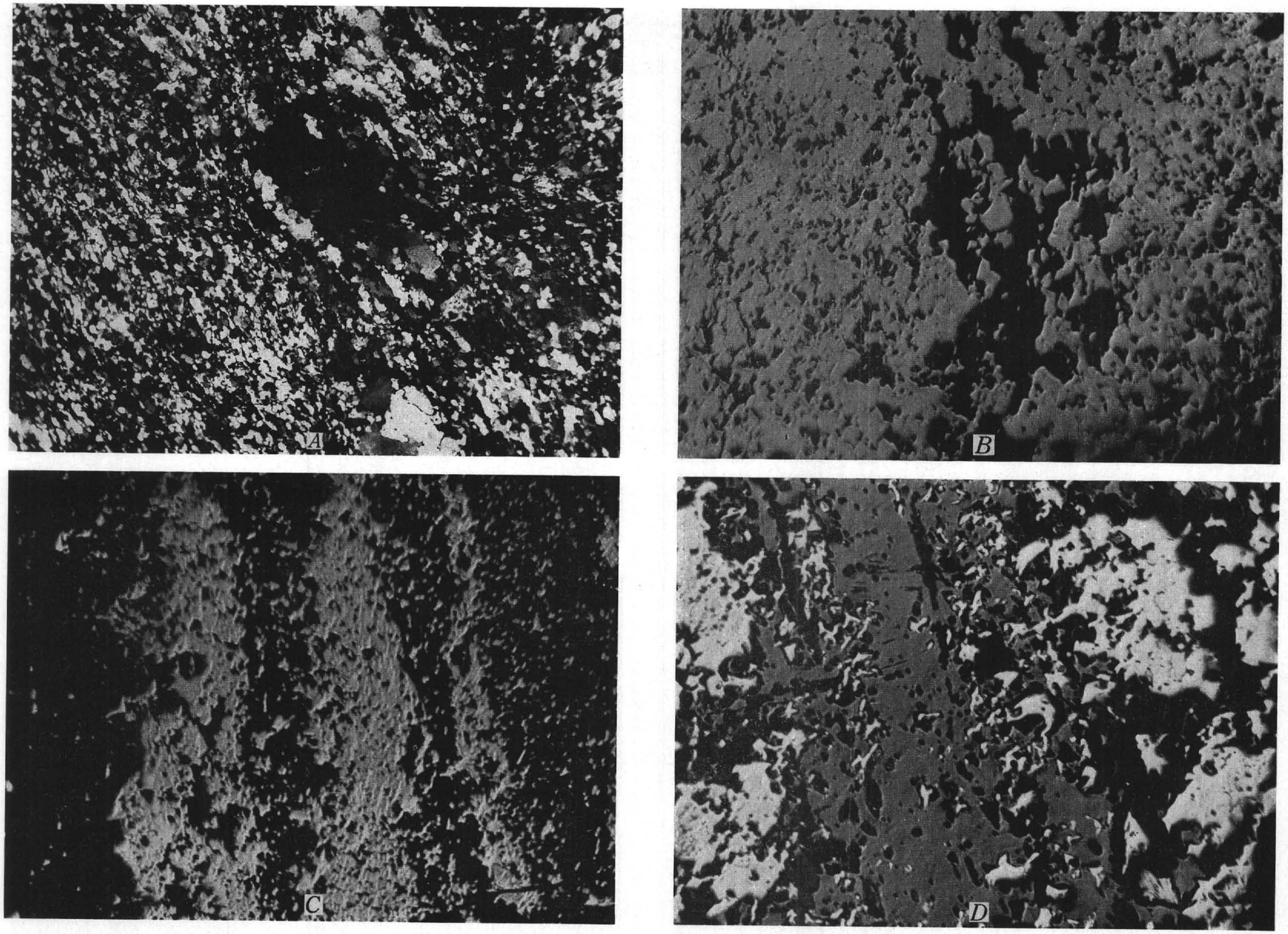
Evidence that the dikes are younger than the main copper deposition seems clearest in the black schist ore shoots where the barren andesitic dikes cut through the chalcopyrite-veined black schist. Here again, the absence of fracture-controlled chalcopyrite in the dikes shows that chalcopyrite mineralization occurred before intrusion of the dikes. Lastly, in one of the quartz porphyry ore shoots, where chalcopyrite with a little chlorite veins the fractured quartz porphyry, an andesitic dike, 1 inch wide, clearly cuts across chalcopyrite veinlets, and a larger dike, 2 to 3 feet wide, contains an inclusion 8 inches long of chalcopyrite-bearing quartz porphyry. The chalcopyrite veinlets in the inclusion are cut off sharply by the surrounding andesite.

The age of the andesitic dikes in relation to the main sulfide mineralization is of some importance as the intrusion of the dikes interrupted the hydrothermal period of activity. Also the relation is of interest because of the debate concerning the relative age of the diabase dikes to the sulfide mineralization at Noranda, Quebec (Price, 1934, p. 138; Wilson, 1941, p. 76–80). At Noranda, northward-trending diabase dikes apparently cut through the massive sulfide bodies and in most exposures, chilled zones of the diabase are in sharp contact with the sulfide mass. In other places, however, the diabase contains stringers of sulfide minerals, and the chilled margins of the dikes are fretted. It can be argued that the chilled selvage of the diabase resisted



PHOTOMICROGRAPHS OF UNITED VERDE SULFIDES

A. Lean pyritic massive sulfide (white) separated by quartz and carbonate minerals (black), × 52. *B*. Massive sulfide ore, showing veinlets of chalcopyrite (low relief) cutting pyrite, × 52. *C*. Black schist ore showing ramifying veinlets of chalcopyrite cutting chlorite (black), × 52. *D*. Quartz porphyry ore (thin section) showing veinlets of chalcopyrite (black) cutting fractured quartz porphyry. Gray material interstitial to quartz (white) in lower right hand corner is chlorite, × 43.



PHOTOMICROGRAPHS OF IRON KING MATERIAL

A. North-end quartz (thin section, crossed nicols) showing cataclastic-granoblastic texture resulting from intense shearing, × 43. *B*. Lean pyritic massive sulfide (white) separated by ankerite and quartz (black), × 52. *C*. Alternating bands of granular pyrite (white) separated by quartz and ankerite (black); probably relict after foliation, × 52. *D*. Massive sulfide ore; sphalerite (gray) replacing pyrite (white) along microscopic shear planes, × 52.

the sulfide replacement, or that the sulfide in the diabase resulted from redistribution of older sulfide, mobilized by the dike. The only purpose of referring to the problem at Noranda is to indicate that essentially unmineralized dikes cutting massive sulfide bodies are pertinent subjects of debate as to age relationship. Straight, sharp dike contacts in massive sulfide bodies may not prove a later age for the dikes. However, the relationship at Jerome leaves no other interpretation but that the dikes are younger than the chalcopyrite.

MINOR STRUCTURAL FEATURES

CHLORITE- AND SULFIDE-BEARING FRACTURES

The "plumbing system" dominated by fractures controlled deposition of chlorite and chalcopyrite, and the foliation planes served merely as distributing channels outward from the fractures. The mineralized fractures have a definite preferred orientation, as illustrated on figure 20, which shows the attitudes of 190 measured mineralized fractures, plotted on the lower hemisphere of an equal-area net. A description of this method of plotting the poles of strike and dip measurements is given by Billings (1942, p. 118–122). The usual method of contouring concentrations could not be used. The dip vector of many of the fractures, plotted as vertical on the net, was not determined because the fractures were observed only on the backs of drifts and stopes. Nevertheless, figure 20 illustrates clearly that all but a very small percentage of the mineralized fractures strike within the range from N. 30° E. to N. 30° W. and that the dips are 60° or steeper toward the east and west. The attitude of the greatest concentration of mineralized fractures essentially parallels the regional foliation, N. 20° W., 80° E. Because foliation preceded fracturing, this coincidence is expectable.

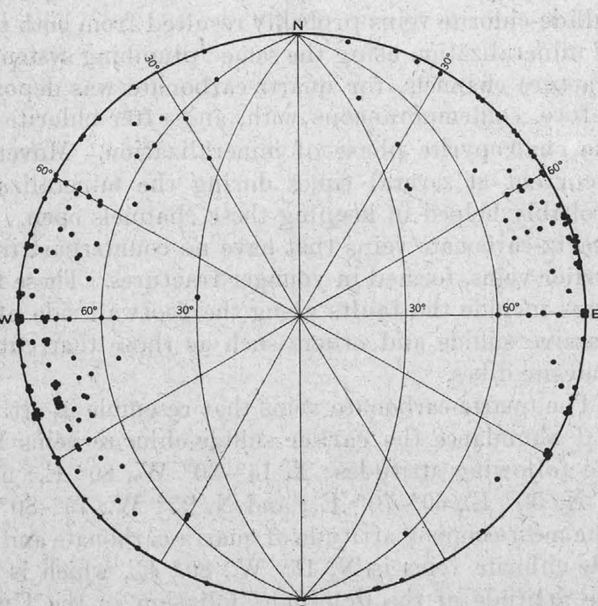


FIGURE 20.—Poles of mineralized fractures in United Verde mine, plotted on lower hemisphere of equal-area net.

Wherever observed, the direction of relative movement on the fractures is reverse. Apparently no consistent age relationship exists, for northeastward-trending fractures do not consistently offset northwestward-trending fractures, or conversely. Presumably this fracture set represents conjugate shears and the reverse movement indicates compression and shortening in a general easterly direction.

Several veins trend N. 30° W. for a short distance and deviate to N. 30° E. indicating that the mineralizing solutions followed first fractures in one direction and then the other. If this deviation took place on a small scale, the resulting vein would strike north. Presumably deviation from N. 30° W. to N. 30° E. on different scales is a partial explanation for the spread in strikes of the mineralized fractures from N. 30° W. to N. 30° E.

The veins produced by the fracture filling are black schist veins, sulfide veins, black schist-sulfide veins, and quartz-carbonate veins. Discussion of the structure of the quart-carbonate veins is reserved for a later section. For all veins measured in the United Verde mine, the proportion of black schist veins to sulfide veins to black schist-sulfide veins is about 1:2:2.

Black schist veins in the quartz porphyry are well displayed on the south wall of the open pit where zones of black schist veins pass northward into tongues of solid black schist that, in turn, form a nearly continuous envelope of black schist along the footwall of the massive sulfide. Similar black schist veins in quartz porphyry are common along the margins of the solid black schist in the underground workings. In the upper levels east of the massive sulfide, black schist veins are present in the tuffaceous rocks of the Grapevine Gulch formation, adjacent to the masses of black schist.

The black schist veins were commonly reopened and pyrite and chalcopyrite introduced into the new fractures, and in some places sufficient copper was added to form ore.

Sulfide-bearing fractures are abundant in quartz porphyry, black schist, and in the massive sulfide in the ore shoots. In a few places, a random network of sulfide veinlets forms a zone parallel to one or the other dominant trend of fractures. Where these zones are observed in the black schist, patches as much as 2 feet across are completely converted to sulfide, chiefly chalcopyrite.

The spatial position and outline of ore shoots reveal clearly that the fracture system was an important control. All or nearly all ore shoots plunge more steeply than the sulfide pipe. This plunge is probably controlled by the dip of the mineralized fractures and the plunge of their intersection. As the average dip of the mineralized fracture is about 80°, and very few dips are as low as 60°, ore shoots controlled by these fractures plunge steeply, somewhat steeper than 60°. The map of an ore shoot commonly reflects the fracture control by elongation parallel to the dominant fracture direction. In several ore shoots, the maximum elongation from one level to another corresponded to either the northeast or the northwest strike of the fractures.

Premineral fractures partly bound some stopes; locally these fractures are veined and ribboned with sulfide and quartz-carbonate. Sulfide minerals are not limited to one or the other side of these controlling fractures, but the grade in copper may be much higher on one side than the other; and in places, the lower grade may be below the cutoff grade used in mining.

Foliation has acted largely as a distributing element for the mineralizing solutions fed into the rocks by the fractures. Along the south wall of the open pit, this function of foliation is shown clearly by the orientation and growth of the chlorite in the fractures in the quartz porphyry. The chlorite grew outward from the fracture with the basal pinacoid of the chlorite parallel to the foliation in the quartz porphyry (mimetic crystallization). At the intersection of fractures, irregular knots or masses of chlorite formed, and the foliation in the black schist (chlorite) is pronounced and continues with that in the surrounding porphyry.

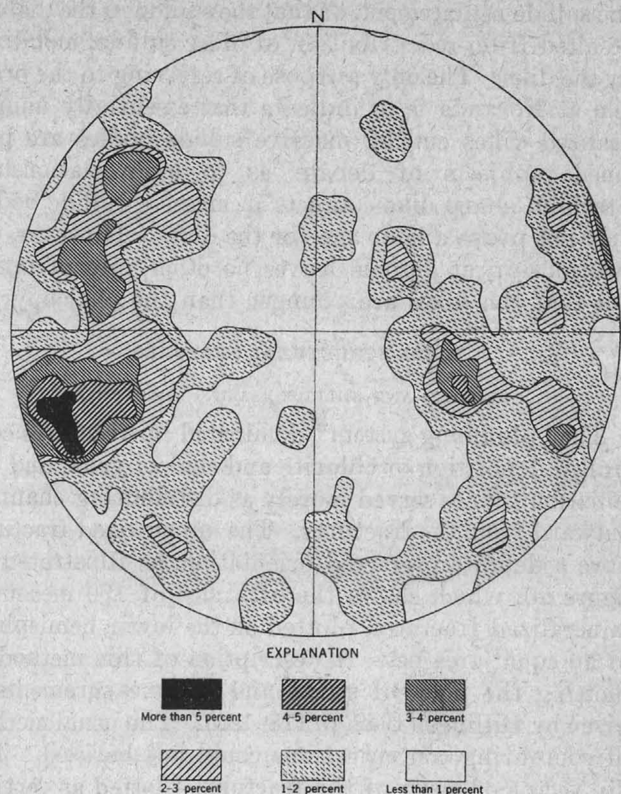


FIGURE 21.—Contour of concentrations of attitudes of quartz-carbonate veins, United Verde mine, plotted on lower hemisphere of equal-area net.

STRUCTURE OF THE QUARTZ-CARBONATE VEINS

Quartz-carbonate was deposited throughout a long period during the formation of the United Verde deposit. Early quartz-carbonate and pyrite together formed the bulk of the massive sulfide pipe before the introduction of the ore minerals. Quartz-carbonate continued to be deposited as veins during the ore-forming mineralization and some quartz-carbonate veins represent the latest hypogene mineralization. The long history of quartz-carbonate deposition accounts for the wide range in attitudes of the quartz-carbonate veins as compared to the sulfide-chlorite veins.

In order to gain a more precise understanding of the fracture pattern that controlled the quartz-carbonate veins, the attitudes of 177 quartz-carbonate veins were measured in the vicinity of the ore deposit. The poles to the planes of the veins were plotted on an equal-area net, and the resulting concentrations contoured; figure 21, which shows two significant features: (1) the quartz-carbonate veins have the same range in attitude and relative intensity of concentration as the earlier sulfide-chlorite veins, and (2) they are also concentrated in a zone that ranges in strike from north to N. 30° E. and ranges in dip from 30° to 80° W. There are also a higher percentage of dips less than 60°. The similarity in attitude between some quartz-carbonate veins and the sulfide-chlorite veins probably resulted from both types of mineralization using the same "plumbing system" of fracture channels, for quartz-carbonate was deposited before, contemporaneous with, and after chlorite and the chalcopyrite phase of mineralization. Movement recurrent at several times during the mineralization probably helped in keeping these channels open. The quartz-carbonate veins that have no counterpart in the earlier veins, formed in younger fractures. These fractures include the faults along the footwall side of the massive sulfide and others such as those that cut the andesite dikes.

The quartz-carbonate veins that resemble in attitude and abundance the earlier sulfide-chlorite veins have the following attitudes: N. 15°–30° W., 80° E.; north to N. 30° E., 60°–70° E.; and N. 25° W., 75°–80° W. The most common attitude of quartz-carbonate and sulfide-chlorite veins is N. 15° W., 80° E., which is also the attitude of the dominant foliation in the United Verde mine. The faults along the footwall of the massive sulfide pipe probably controlled the quartz-carbonate veins that strike N. 23° E. and dip 78° NW. The quartz-carbonate veins that strike N. 25°–45° E. and dip 35°–50° NW. also have no counterpart in the earlier veins. The fractures localizing these veins may have resulted from the same deformation that produced the faults along the footwall of the sulfide pipe.

FOOTWALL FAULTS

The footwall faults occur along the footwall zone of the massive sulfide pipe in the intermediate and lower levels of the United Verde mine (see 3,300 level, pl. 7). These faults first appear as definite structural features on about the 1,500-foot level and gradually become more conspicuous and continuous with depth. From the 2,250 to the 3,450 levels, the faults are pronounced, and extend throughout the length of the massive sulfide body from the 2,850 to the 3,150 levels. Below the 3,450 level, the faults diminish in number, but are present on the 4,500 level.

Two distinct trends characterize the faults. The dominant ones strike northeast and dip west at an angle somewhat less steeply than the footwall of the massive sulfide. These faults appear to strike slightly more easterly than the trend of the massive sulfide body, so that the massive sulfide body and faults diverge northward. These northeastward-trending faults occur only where the footwall of the massive sulfide trends northeastward. The subordinate faults strike northwest and dip northeast; they occur only where the footwall of the massive sulfide trends northwestward. The faults do not exist apparently near the upper part of the deposit where the horizontal section of the massive sulfide pipe is about equidimensional, but they appear where the pipe becomes crescent shaped. The northwestward-trending limb of the massive sulfide pipe is not well defined above the 2,100 level, and on this level the northwestward-trending footwall faults are first perceptible. The northwestward-trending limb of the massive sulfide pipe is not as long nor as wide as the northeastward-trending limb; this is reflected in the number, continuity, and apparent strength of the faults. Where the massive sulfide pipe is divided on the lower levels, the faults follow the outlines of individual segments, and as the massive sulfide pipe dies out, the faults disappear.

The spacing of the footwall faults next to the massive sulfide pipe is not fortuitous, and it is possible that the faults came into existence because of lithologic difference between the massive sulfide and the adjacent black schist and quartz porphyry. Stress would more likely be relieved along such contacts.

The age of these faults is debatable. Pyrite in the fault zones indicates deposition of sulfide minerals before faulting. This evidence is manifested in only two places, on the 3,750 and 3,450 levels. The footwall faults displace andesitic dikes in many places, but in one locality, an andesitic dike apparently intrudes fault gouge. Quartz-carbonate forms veins along the faults and in places part of the fault breccia and gouge. If the faults had been in existence during the major period of intrusion of the andesitic dikes, probably at least a few of the dikes would have used them as channels. In summary, these footwall faults probably originated after the andesitic dikes were intruded but during or just before the late quartz-carbonate mineralization.

RECURRENT MOVEMENT

The indications of recurrent movement consist chiefly of earlier veins cut by later ones.

The northwestward-trending foliation is the oldest planar structure recognized, and recurrent movement occurred along it no less than three times. The period of fracturing produced reopenings along the foliation direction, these fractures were chloritized, and later recurrent movement permitted introduction of sulfide and quartz-carbonate. The third period of movement, perhaps more penetrative than the others, produced a weak to nearly imperceptible foliation in the andesite dikes that coincides with the northwestward-trending foliation in the host rock, generally quartz porphyry. The foliation in the andesite dikes was not utilized by mineralizing solutions, not even those depositing the final quartz-carbonate. In one place on the 3,000 level, an andesite dike is offset by a northwestward-trending zone of fracture and foliation that contains appreciable amounts of chlorite. Here, at least then, faulting occurred during this later period of deformation.

In summary, in chronological sequence movement occurred, (1) at the time of folding (northwestward-trending foliation), (2) probably after formation of the massive sulfide pipe but before deposition of chlorite (the period of fracturing), (3) after deposition of chlorite but before deposition by chalcopyrite (ore-forming period), and (4) after intrusion of andesitic dikes and deposition of some quartz-carbonate veins.

ORE SHOOTS

The massive sulfide pipe and black schist fringe on the footwall were completely formed by the time chalcopyrite was introduced to form the copper ore shoots. Fracturing of the massive sulfide, black schist, and quartz porphyry made these rocks permeable for the copper-bearing solutions which spread throughout an irregular zone extending from the southwestern tip of sulfide and along the footwall of the massive sulfide and along the east margin of the sulfide pipe. Shattered zones within the massive sulfide pipe allowed the copper-bearing solutions to rise upward almost to the hanging wall. The chalcopyrite mineralization formed, in its broadest aspect, a stockwork in which the richer zones of ore are connected by leaner zones, and the ore shoots have assay walls.

The ore shoots generally plunge northward more steeply than the massive sulfide pipe, so that many ore shoots bottom in quartz porphyry or black schist in the footwall of the massive sulfide pipe, and the tops of the ore shoots are well within the massive sulfide (pl. 9). In the upper levels, massive sulfide ore is more common (fig. 14) and in the lower levels black schist ore and quartz porphyry ore are more common.

The outline of ore shoots is controlled in many places by the fracture pattern. North-northwesterly elongation is more common than north-northeasterly; and in a few places, elongation in both directions occurs within a single ore shoot (see stopes 9*R* and 9*Q*, 2,400 level, fig. 22). Elongation along one direction is probably the result of relative abundance, size, and continuity of the fracture. A few ore shoots, particularly in the massive sulfide, are so irregular in outline as to suggest lack of predominant fractures.

The contacts between massive sulfide, black schist, and quartz porphyry exerted some control on the shape of the ore shoots, and below the 1,200 level, most of the ore shoots are located along the contact of massive sulfide and black schist. Stopes on the 1,800, 1,950 and 2,100 levels occupy almost the entire arc of the footwall contact of the pipe. On the 2,250 and 2,400 levels, stopes are common along the footwall of the pipe and along the black schist-quartz porphyry contact (fig. 22); in several places, the stopes reach from one contact to the other. Stopes on the 2,550 level are along both contacts, but those along the contact of black schist with the sulfide pipe are chiefly in the black schist.

Ore shoots along the east margin of the massive sulfide are related to the contact of the massive sulfide pipe; and where this forms a prong extending south-southeastward, ore shoots are located along the east and west contacts (fig. 16).

Black schist was a more favorable host rock than quartz porphyry (fig. 22) and less favorable than massive sulfide. Most of the ore shoots bottom in quartz porphyry, along quartz porphyry-black schist contacts, or in black schist beneath the footwall of the sulfide pipe. The ore shoots in quartz porphyry are generally spatially related to tongues of black chist; and as the ore shoot passes into black schist at higher levels, it widens, and the quartz porphyry on the same level is weakly mineralized. On higher levels, above the black schist ore, the massive sulfide is the favorable host rock, and ore shoots are distributed along the contacts and within the sulfide pipe.

10–O ORE SHOOT

Three ore shoots merit individual description either because of their exceptional size and grade or because

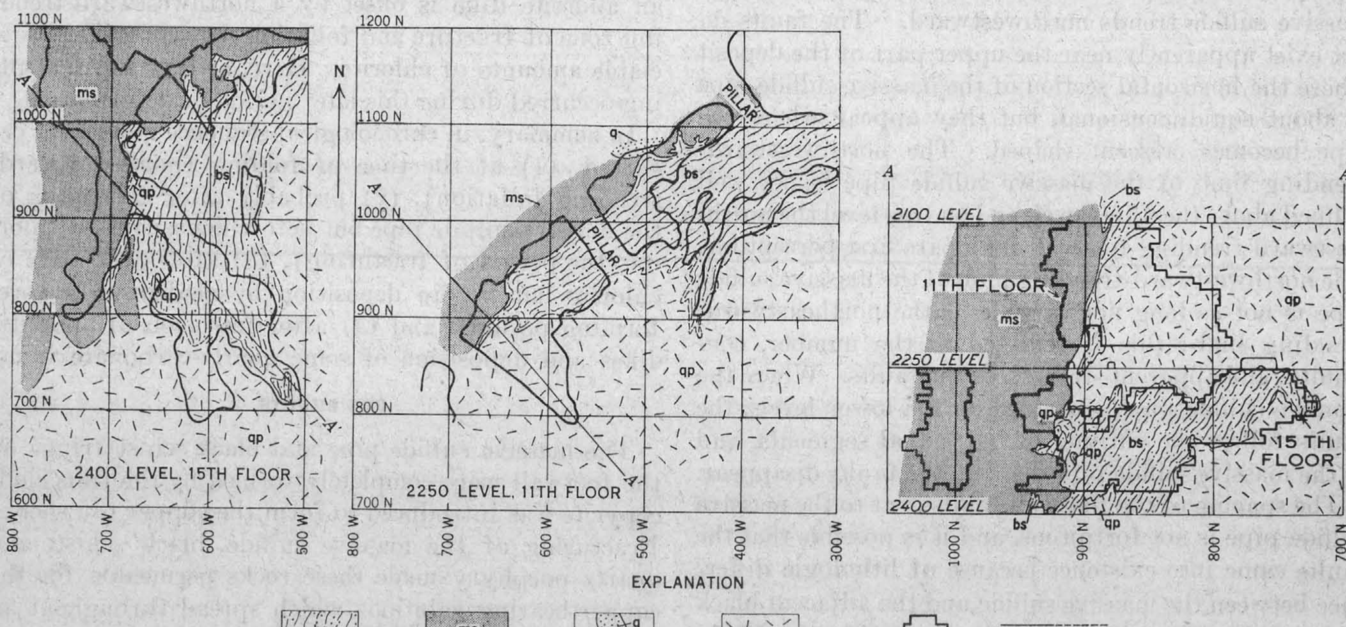


FIGURE 22.—Maps and sections of stopes. Stopes 9*R* and 9*Q*, 2,400 level, 15th floor, show northwest and north-northeast trends in same ore shoot. Stopes on the 2,250 level, 11th floor, show ore shoot including massive sulfide, black schist, and quartz porphyry. Section shows that black schist is more favorable host rock than quartz porphyry for copper mineralization. United Verde mine.

they exemplify a particular kind of structural control. Foremost among these is the 10–O shoot, which was unparalleled in the United Verde mine for size and grade (pl. 9).

The bottom of the 10–O ore shoot was about 40 feet below the 2,250 level, and the top was about 20 feet above the 1,200 level—a vertical range of about 1,100 feet. On the 2,250 level the ore shoot was only 230 feet long and 55 feet in maximum width, but the size increased abruptly upward so that on the 2,100 level it was 800 feet long and ranged in width from 20 to 100 feet. On succeeding levels upward, the size of the ore shoot increased to a maximum on the 1,650 level where the ore shoot was more than 700 feet long and 100 to 250 feet wide. Above the 1,650 level, the ore shoot divided into several parts, most of which were well within the bounds of the massive sulfide pipe. These segments diminish in size with height, and cease at altitudes above the 1,500 level, the largest segment reaching a few feet above the 1,200 level.

A study of the distribution of copper in the 10–O ore shoot revealed that a direct relationship existed between the local dimensions of the ore shoot and copper content. Where the ore shoot had the largest horizontal area, the copper content was highest. The richest ore generally was in a zone in the central part of the ore shoot, and copper content diminished outward from this central core to an assay wall that determined the limits.

WADE HAMPTON ORE SHOOT

The Wade Hampton is the second largest ore shoot in the deposit, reaching its maximum size in the 1,000 and 1,200 levels (pl. 7). It starts in quartz porphyry between the 1,500 and 1,350 levels as three separate ore shoots that integrate upward into the Wade Hampton. The Wade Hampton stope tops on the 8th floor above the 800 level, but the 15–L stope lies directly above the Wade Hampton between the 600 and 500 levels and is probably part of the same mineralized zone. On the 1,200 level, the ore shoot extends along the contact of the massive sulfide and is arcuate. The length along the center is about 260 feet and the maximum width about 80 feet. On the 1,000 level (pl. 7) the ore shoot is within the massive sulfide pipe and is more equidimensional in shape. The maximum dimensions are about 200 by 150 feet. Some of the richest ore in the mine was found in the Wade Hampton. The pattern of distribution of copper in the Wade Hampton ore shoot is similar to that in the 10–O ore shoot.

16–C ORE SHOOT

The 16–C is a long narrow ore shoot in quartz porphyry south of the massive sulfide pipe and the body of black schist (pl. 7, 500–800 S.; 300 E.). It extends from the surface to the 600 level where it has a length of 180 feet and a maximum width of 30 feet. On the 500 level the length is 570 feet and the maximum width 60 feet, but the average width is about 30 feet. The trend of the ore shoot ranges from north-northwest for the southern part to north for the northern part; the dip is nearly vertical (fig. 23).

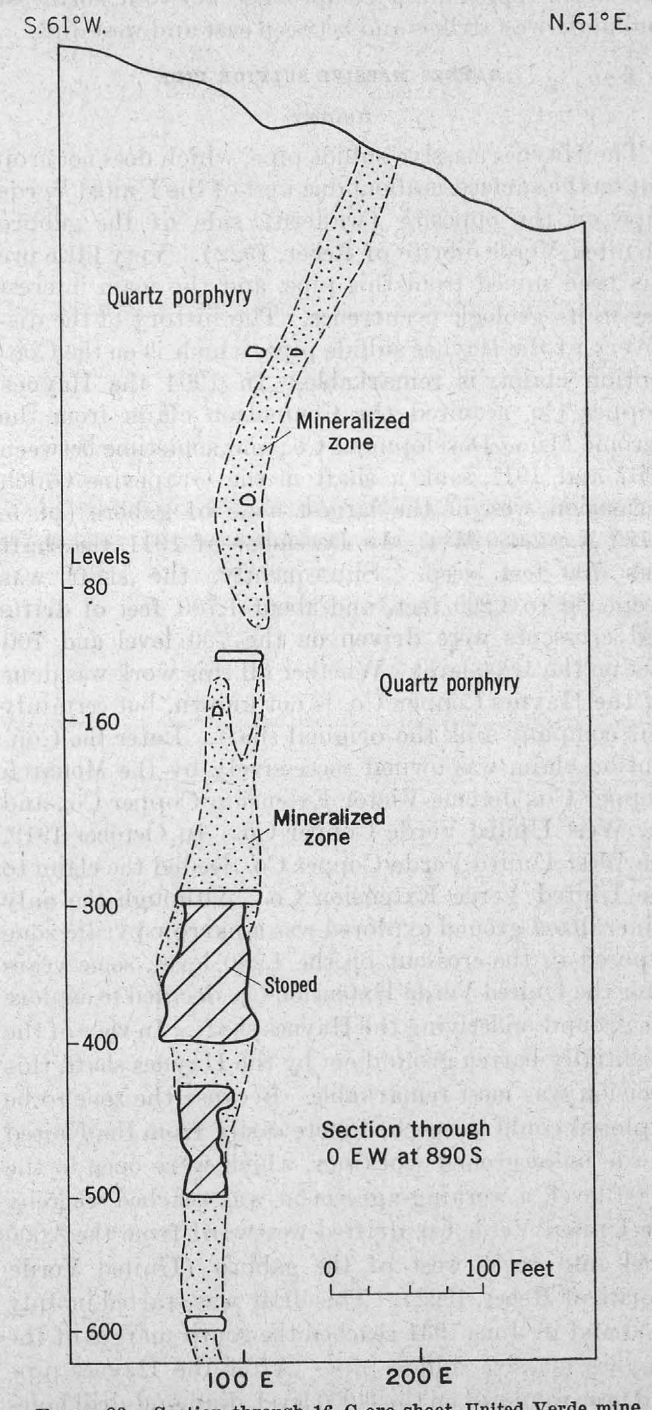


FIGURE 23.—Section through 16–C ore shoot, United Verde mine.

The relationship of the attitude of the ore shoot to mineralized fractures warrants consideration. The ore shoot is made up of many small veins and veinlets of chalcopyrite. These veins strike north-northeast and north-northwest, and dips are east or west, some as low as 60° (fig. 20). But the northern part of the ore shoot strikes north, and the dip is essentially vertical, except for the upper levels. Apparently, the attitude of the ore shoot represents a compromise between northeast and northwest strikes and between east and west dips.

HAYNES MASSIVE SULFIDE PIPE

HISTORY

The Haynes massive sulfide pipe, which does not crop out on the surface, is about due west of the United Verde pipe on the opposite (western) side of the gabbro (United Verde diorite of Reber, 1922). Very little ore has been mined from this pipe, and the main interest lies in its geologic occurrence. The history of the discovery of the Haynes sulfide pipe, which is on the Contention claim, is remarkable. In 1904 the Haynes Copper Co. acquired the Contention claim from the Jerome Mines Development Co., and sometime between 1907 and 1911, sank a shaft in the Grapevine Gulch formation west of the largest mass of gabbro (pl. 5, 1,780 N.; 2,080 W.). In December of 1911, the shaft was 700 feet deep. Subsequently, the shaft was deepened to 1,200 feet, and about 1,700 feet of drifts and crosscuts were driven on the 700 level and 700 feet on the 1,200 level. Whether all this work was done by the Haynes Copper Co. is not known, but certainly this company sank the original shaft. Later the Contention claim was owned successively by the Monarch Copper Co., Jerome Victor Extension Copper Co., and the West United Verde Copper Co. In October 1919, the West United Verde Copper Co. deeded the claim to the United Verde Extension Co. Although the only mineralized ground explored was a narrow pyritic zone exposed in the crosscut on the 1,200 level, some years later the United Verde Extension Co. decided to explore the ground underlying the Haynes shaft. In view of the essentially barren ground cut by the Haynes shaft, this decision was most remarkable. Because the zone to be explored could be reached more easily from the United Verde underground workings, which were open to the 3,000 level, a working-agreement was reached whereby the United Verde Co. drifted westward from the 3,000 level into rocks west of the gabbro (United Verde diorite of Reber, 1922). This drift was started in July 1930 and in June 1931 reached the south margin of the Haynes massive sulfide pipe. After the Haynes pipe had been explored on the 3,000 level, diamond-drill holes from the 3,000 and 3,750 levels of the United Verde mine, and a drift on the 1,500 level further delimited the size and shape and determined the content of base metals.

GENERAL FEATURES

The Haynes pipe is a steeply plunging body of massive sulfide and quartz that is relatively small in cross section compared with the length along the axis (fig. 24). It extends from a short distance above the 2,700 level downward to an undetermined point between the 3,450 and 3,700 levels (United Verde mine levels). On the 3,000 level, the sulfide pipe is triangular, each leg of the triangle being about 120 feet long; the cross-sectional area of the pipe appears to diminish both upward and downward from there. On the 2,700 level, the two maximum dimensions of the irregular-shaped pipe are 70 feet to the north and 60 feet to the east-northeast. With depth the sulfide pipe elongates parallel to the gabbro contact. On the 3,450 level the pipe extends for about 100 feet along the contact and is 40 feet wide.

The bearing of the axis and the plunge of the sulfide pipe are variable. Between the 2,700 and 3,000 levels the axis bears N. 76° E. and the plunge about 67° NE. Between the 3,000 and 3,450 levels, however, the axis bears about N. 60° E. and the plunge about 75° NE.

Gabbro (United Verde diorite of Reber, 1922), quartz porphyry, and Grapevine Gulch formation are the rocks in the vicinity of the Haynes massive sulfide pipe (fig. 24). The gabbro forms the hanging wall (east wall) and quartz porphyry, the footwall (west wall). Actually, gabbro bounds the pipe on the northeast, east, and southeast sides throughout most of the vertical extent, forming an inverted trough in which the massive sulfide pipe lies. Where this inverted trough dies out above the 2,700 level, the gabbro extends over the top of the pipe. Similarly, where the inverted trough dies out in depth, the gabbro underlies the pipe (fig. 24).

The quartz porphyry along the footwall of the pipe is an unusual type—possibly it is actually a quartz-bearing tuff. It consists of numerous quartz phenocrysts in a schistose groundmass containing abundant sericite and chlorite. In places in the quartz porphyry, fragments and the indistinct bands resemble relict bedding. The fragments, bands, and chlorite indicate a sedimentary origin, but the character, distribution, and abundance of quartz phenocrysts(?) indicate quartz porphyry.

The Grapevine Gulch formation is west of the quartz porphyry. It appears typical of the fine- to medium-grained facies found in the United Verde area.

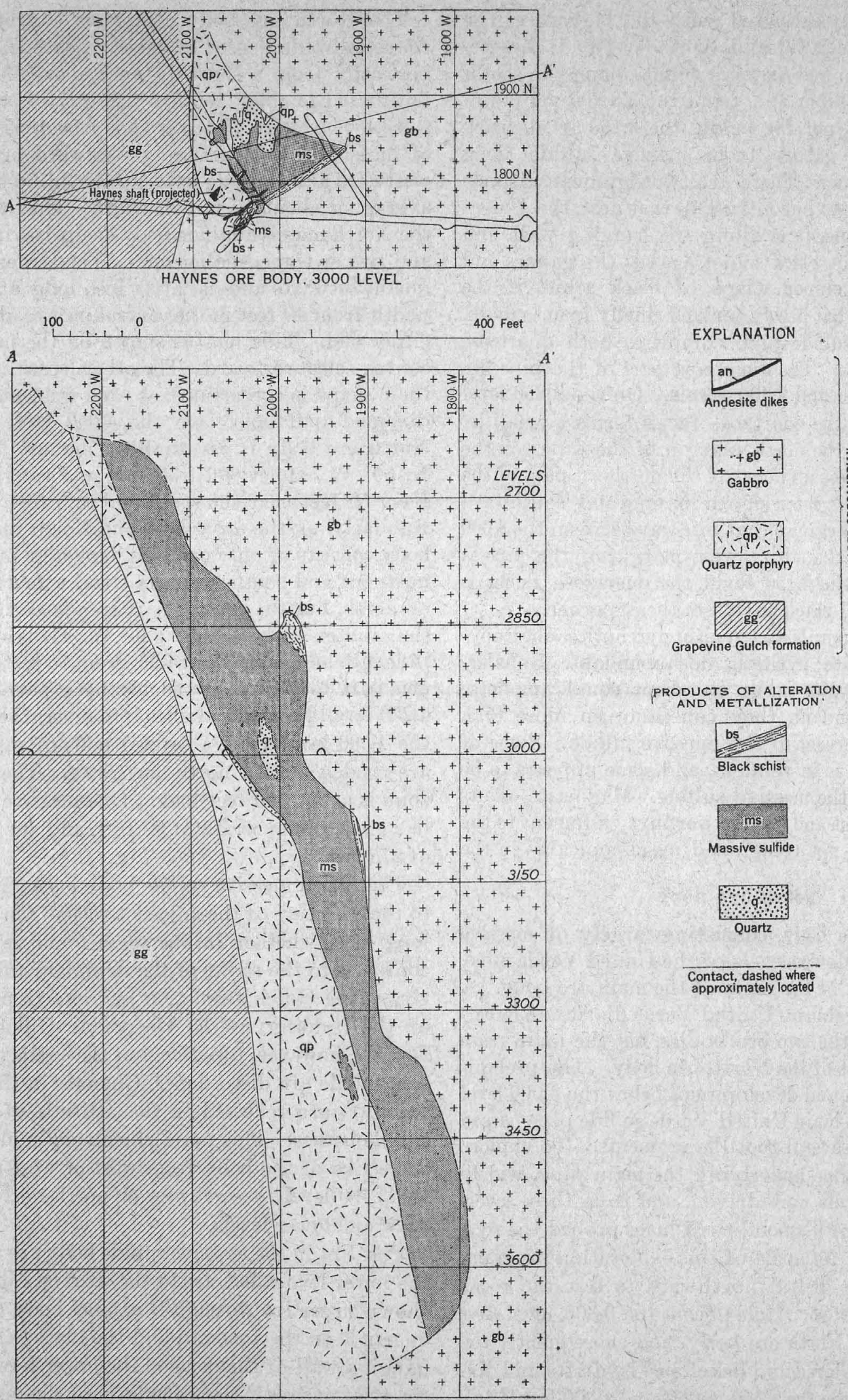


FIGURE 24.—Map and section of Haynes ore body. Furnished by Phelps Dodge Corp.

Black schist is associated with the Haynes sulfide pipe between the 2,850 and 3,000 levels. It lies between the gabbro and massive sulfide along the southeast side of the pipe; and from the 3,000 level downward to a point not far below the 3,150 level, black schist separates gabbro from massive sulfide along most of the contact. There are two significant aspects to the black schist: in contrast to that near the United Verde sulfide pipe, it is along the hanging wall, and the position of the black schist against the gabbro and the small stringers or wisps of black schist in the gabbro indicate that it was derived chiefly from gabbro.

The massive sulfide pipe comprises both quartzose and sulfide facies. The quartzose part of the pipe lies between the 2,850 and 3,300 levels. On the 2,850 level or just below it, the quartzose facies forms a small irregular mass on the north margin of the pipe; on the 3,000 level it makes up most of the northern part of the pipe; and with greater depth it migrates southward along the west margin so that midway between the 3,000 and 3,150 levels the entire west margin of the pipe is quartzose. On the 3,150 level the quartzose facies is limited to a small patch at the southeast corner.

The sulfide minerals are pyrite, pyrrhotite, chalcopyrite, and sphalerite; pyrite is most abundant. Sphalerite and chalcopyrite occur in about equal amounts; where most abundant, they constitute no more than from 10 to 15 percent of the massive sulfide. Some of the chalcopyrite is in veinlets, and some appears to be disseminated in the massive sulfide. Magnetite occurs in the black schist and quartz porphyry adjacent to the pipe, but it was not recognized megascopically in the massive sulfide.

NORTH ORE BODY

The North ore body, consisting largely of massive sulfide, is on the lower levels of the United Verde mine, and to the north of the roots of the main ore body. A small prong of gabbro (United Verde diorite of Reber, 1922) separates the two ore bodies, but the main mass of gabbro is west of the North ore body. The preliminary exploration and development below the 3,000 level revealed that the main United Verde sulfide pipe passed downward into several rootlike segments. To explore adequately the zone underlying the main pipe, widely spaced lower levels were driven, and from these levels nearly 17 miles of diamond-drill holes probed the rock in search of ore. As a part of this exploration program, some holes were drilled northward to test the rocks north of the gabbro. Holes from the 3,300 level first cut through the North ore body, and subsequently the ore body was explored and developed by drifts and diamond-drill holes on the 3,750, 4,050, and 4,500 levels (pl. 7) and by diamond-drill holes on the 3,450 level.

The North ore body comprises a group of interconnected thin lenses of massive sulfide. It extends vertically from a short distance above the 3,450 level downward to about 150 feet below the 4,500 level. On the 3,450 level (pl. 7) the ore body comprises four lenses of massive sulfide, trending westward or west-northwestward and ranging in length from 130 to 35 feet and averaging about 10 feet in width. On the 3,750 level, the North massive sulfide body comprises one large lens and two or three smaller ones. The largest lens trends northwestward and is 2,700 feet long and ranges in width from 40 feet in the central part to about 5 feet at either end. This lens as shown on the map is gently convex southwestward. The other lenses are small, and their shape is conjectural, as each was cut by only one diamond-drill hole. On the 4,050 level (pl. 7) the North ore body is essentially a narrow lens trending N. 30° W., about 600 feet long and ranging in width from 50 feet near the south end to 5 feet at the north. Similarly, on the 4,200 level the North massive sulfide body consists of only one lens, irregular in shape. The northern and southern parts trend a few degrees west of north, but the central part trends about N. 45° W., the average strike being N. 20° W. It is about 650 feet in length and ranges in width from 70 feet in the southern part to 7 feet in the northern part. Below the 4,200 level, the body divides into several segments. On the 4,500 level (pl. 7) several pods of massive sulfide are crudely alined north-northwest. The mineralized zone is about 500 feet long. One massive sulfide body has a maximum width of 90 feet, and another a length of 275 feet.

The North massive sulfide body is nearly concordant to the structure of the adjacent rocks. On the map, the long axis, whether in one segment or several, nearly conforms to the strike of the dominant foliation in the Grapevine Gulch formation and quartz porphyry and of the bedding in the Grapevine Gulch formation. Locally, however, foliation and the contacts of the massive sulfide are discordant. Changes in the attitude of foliation are reflected in the attitude of the massive sulfide bodies. This parallelism results in variation in the strike of the body from west or west-northwest on the 3,450 level to northwest or north-northwest on the 3,750 and lower levels.

The dips in the massive sulfide body are to the east on the lower levels, but are to the west on higher levels as shown on section through North ore body (pl. 7). The quartz is on the footwall and the black schist is on the hanging wall of the zone on the lower levels, similar to the relation below the 3,450 level of the main pipe (fig. 13). On higher levels in both ore bodies, the reverse relationship exists. The two massive sulfide bodies have a similar relationship to gabbro in that the gabbro overhangs both.

RELATIONSHIP TO ADJACENT ROCKS

The North massive sulfide body is largely in the Grapevine Gulch formation, at or near the contact with the quartz porphyry. Normal gray quartz porphyry lies to the east of the lenses of massive sulfide, and in part has been chloritized adjacent to them. West of the massive sulfide body are one or two bands of "purple porphyry" that may or may not be intrusive quartz porphyry; the doubtful origin of this rock has been discussed on page 104. This rock is indicated as quartz porphyry on the 3,450, 4,050, and 4,500 levels as shown on plate 7. West of the mineralized zone, excellent bedding is recognizable in diamond-drill cores and to the east, undisputed quartz porphyry is present. In the mineralized zone, the rocks are highly foliated, and the differentiation of quartz-bearing crystal tuff from the quartz porphyry is difficult; the contacts are, in part, conjectural.

The gabbro contact, viewed in a longitudinal section (north-south) overhangs the North massive sulfide body and the massive sulfide disappears in higher levels beneath the gabbro. In transverse sections (east-west), through the North massive sulfide ore body, the gabbro is 500–600 feet west of the massive sulfide body. A cross section bearing N. 65° E. as shown on plate 7 illustrates the overhanging relationship of the gabbro.

The distribution of the Grapevine Gulch formation north and south of the massive sulfide lenses indicates that the massive sulfide has largely replaced the tuffaceous sediments of the Grapevine Gulch formation, a conclusion confirmed in some stopes where unreplaced sedimentary rocks remain within the massive sulfide, and small drag folds are partly replaced and give a banded structure to the sulfide. Some of the contorted banding within the sulfide bodies may reflect folded tuffaceous sedimentary rock.

The highly foliated zone encloses the body of massive sulfide which dips steeply east parallel to the massive sulfide. This zone appears to be the northern extension of the strong zone of foliation that intersects the main sulfide pipe to the south (fig. 25), and caused the southern extension of massive sulfide and black schist in the lower part of the main pipe. The gabbro is younger than the zone of strong foliation and nonfoliated gabbro separates these two mineralized zones. The North ore body of massive sulfide is overlain by the gabbro that possibly served as a barrier, and the rising mineralizing solutions replaced the highly foliated rocks.

The lenses of massive sulfide strike more westerly along their south margin near the gabbro intrusive mass, indicating a drag pattern against the gabbro. In part the northern boundary of the gabbro is a fault (pl. 7), and the bending of the structure may be a drag structure. The possibility, however, cannot be denied that the gabbro body intruded across the strongly northwestward-trending foliated zone, and pushed the foliated zone eastward to produce the drag pattern.

MINERALOGY

The mineralogy of the North massive sulfide body is similar to that of the main sulfide pipe. In the North ore body along the west margin fine-grained quartz forms scattered lenses as much as 20 feet in width, concordant with the structure. Pyritic massive sulfide and zinc-bearing massive sulfide occur east of the quartz, and veins of pyrite in the quartz indicate that the quartz is older. The massive sulfide is in part nonbanded, particularly in the pyritic facies, but is banded where sphalerite is abundant. Quartz-carbonate in veins and nodules, with or without sulfide minerals, are common, particularly on the east side of the mineralized zone.

The nonbanded massive sulfide is similar to the pyritic facies of the main pipe in that small aggregates of pyrite are separated by a gangue of quartz and carbonate minerals. Arsenopyrite is a minor constituent; it occurs in diamond-shaped crystals, partly embedded in the gangue. Sphalerite is interstitial to the pyrite, and their age relationship is uncertain. Carbonate veins cut the sulfide minerals.

The banded ore is rich in clear sphalerite (light-brown) in thin section that veins the quartz or is interstitial to the quartz grains. Much of the sphalerite averages about 0.2 millimeter across. The pyrite forms cubes ranging from 0.05 to 0.04 millimeter across and averages about 0.02 millimeter. Aggregates of pyrite cubes form crude veinlets in the ore. Galena and chalcopyrite are common in isolated crystals in the quartz gangue. Some of the quartz is very fine grained, and is cut by coarser grained quartz veinlets; other quartz forms columns at right angles to pyrite crystal faces, indicating pressure shadows and a growth later than the pyrite.

Chlorite in some of the massive sulfide ore, forms clusters or subparallel bands parallel to the banded pyrite and sphalerite. The chlorite in part is bright green in thin section; it has a very low birefringence, an index of refraction of about 1.635, and negative optic angle. Inclusions of tuffaceous sedimentary rock in the massive sulfide are heavily chloritized, and the chlorite (ripidolite) has the same optical properties as the chlorite in the ore except for a positive optic angle. Chlorite to

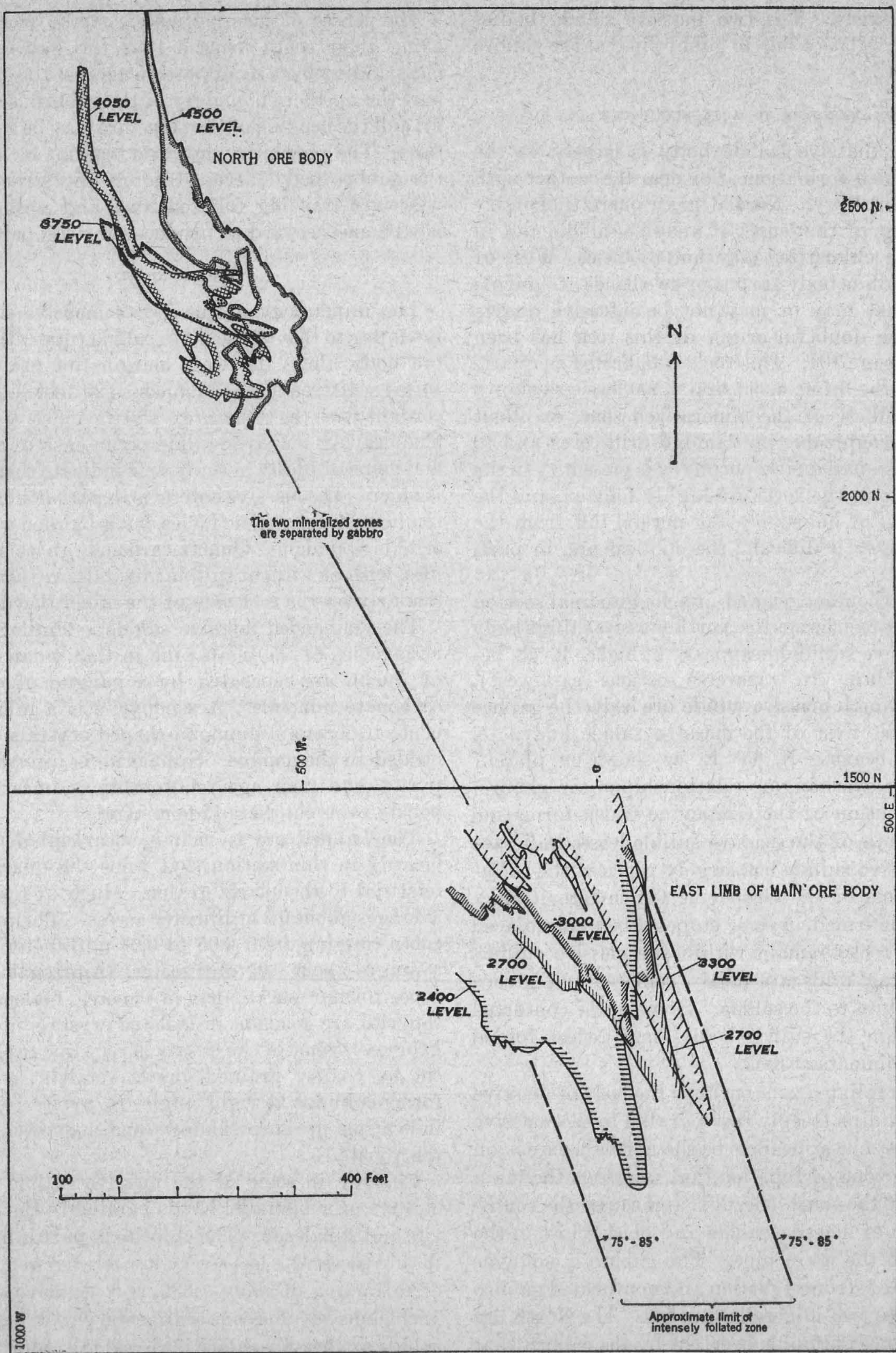


FIGURE 25.—Map showing relationship of zone of intense foliation in main ore body to North ore body, United Verde mine.

the east of the massive sulfide body is like most of the chlorite (prochlorite) south of the main pipe, in that the birefringence is moderate, index of refraction is about 1.610, and the optic angle is positive.

Chalcopyrite and pyrite veins in the black schist in places form minable ore on the east side of the massive sulfide body. This black schist ore is similar to that from the main ore body and does not warrant separate description.

ORE SHOOT

Where the massive sulfide lenses widen appreciably, they are richer in copper and zinc, and one ore shoot was estimated at 85,000 tons of ore containing 4 percent copper and 9 percent zinc (Little, 1950). The minable ore was 180 feet long and ranged from 10 to 60 feet in width. The zinc content was high enough to warrant flotation separation in the concentrator at Clarkdale.

SUPERGENE CHANGES

The oxidized and secondary enrichment zones of the United Verde deposit were removed in the open-pit operations, but Reber (1938) has recorded the pertinent data and the following information has been abstracted in part from his paper.

OXIDIZED ZONE

The gossan of the ore zone formed a blanket about 100 feet in average thickness, penetrating slightly below the 160 level of the mine. The gossan consisted largely of highly colored, soft limonitic material containing lenses and boulders of hard iron oxide. At the southern margin of the gossan, copper carbonate minerals were conspicuous where the mineralized black schist interfingers with the quartz porphyry. Along the northern margin, the primary quartz cropped out against the gabbro. South of the massive quartz and to some extent along the east side of the gossan, brecciated, honeycombed quartz was exposed.

High-grade gold-silver ore was mined from parts of the soft gossan, and high concentrations of native silver were found at several places immediately overlying the sulfide minerals. Almost all of the soft gossan was of commercial grade in the open-pit operation, and portions of the low-grade gold-silver ore were high enough in silica for converter flux.

The following analysis is of oxide ore shipped during 1918 (Reber, 1938, p. 50):

	Percent
Cu	1.42
Fe	31.5
Zn	.2
SiO_2	34.1
Al_2O_3	5.7
S	4.2

SECONDARY ENRICHMENT

In places, unenriched massive pyrite was just below the oxidized ore, but Reber believed that chalcocite enrichment affected the chalcopyrite ore as deep as the 500 level, and possibly much of the highest grade ore on the 300 level was chalcocite. Detailed records of the early mining are lacking, and during the open-pit operations most of the highest grade pillar ore was found as crushed and broken fragments in places mixed with old stope fill. Much chalcocite and considerable bornite were present in the most crushed material from the pillars under the 300 and less extensively under the 400 levels.

Bornite and steely chalcocite were found as lumps and boulders in loose material that showed evidence of intense fire action. Thirty years elapsed from the time of the first mine fire to the opening of the pit; and during much of this time, the material was extremely hot. Boyd[7] concluded that all or nearly all the bornite and probably much of the chalcocite were formed by fire action. Boyd produced bornite by maintaining chalcopyrite at a temperature of 500°C in a reducing atmosphere for 4 to 5 hours. By additional heating, some bornite changed to chalcocite. There is a possibility therefore that much of the chalcocite in the upper levels of the mine was not due to secondary enrichment.

A disseminated ore body in the quartz porphyry, south of the main ore zone and about 500 feet in vertical dimension, contained about 1,000,000 tons of 1.5 percent copper. This ore body was formed by secondary enrichment of very lean disseminated pyrite. The scant leached capping, and minor oxidation throughout the ore body indicate that this chalcocite enrichment was not related to the present erosion cycle.

The distribution and amount of gold and silver in the open pit compared to that in primary ore, led to the conclusion that gold and silver were enriched. Possibly the precious-metal enrichment had some relationship to the fire-zone conditions.

UNITED VERDE EXTENSION MINE

No detailed studies were made by the Geological Survey of the United Verde Extension mine. During the fall of 1947, this mine was opened by lessees to the 1,300 level, which is drained by the Josephine haulage tunnel. The levels below the 1,300 level were not unwatered in 1947. G. W. H. Norman of the Mingus Mountain Mining Corp. prepared geologic maps of the accessible underground workings, and compiled geologic maps of the inaccessible workings, using older reports, hand specimens, and diamond-drill cores on file for guid-

[7] L. M. Boyd, 1935, Microscopic examination of certain ores from the United Verde fire stopes: Unpublished thesis, Colo. School of Mines.

ance. Anderson of the Geological Survey and Dr. Norman spent several days observing critical exposures of the underground workings. Through the kindness of Arthur Notman, president of the Mingus Mountain Mining Corp., the maps prepared by Dr. Norman were made available for study, and some of these are included in this report. Notman also permitted Dr. Norman to help prepare the section on the geology of the United Verde Extension mine and the relationship of the United Verde and United Verde Extension ore bodies.

Much of the information on the ore bodies within the United Verde Extension mine has been obtained from the reports by Lindgren (1926) and Reber (1938). The data on production and dividends were taken from annual reports to stockholders.

PRODUCTION AND DIVIDENDS

The United Verde Extension mine produced 3,878,825 dry tons of ore which yielded 793,331,100 pounds of copper, 6,449,156 ounces of silver, and 152,756 ounces of gold. Production started in 1915 with 9,275 tons of ore, which yielded 5,138,989 pounds of copper, 19,393 ounces of silver, and 183 ounces of gold. The following year, 1916, production increased to 77,461 tons of ore, producing 36,402,972 pounds of copper, 128,467 ounces of silver, and 2,570 ounces of gold.

Peak annual production of the United Verde Extension mine in terms of copper, was reached in 1917 when 63,879,506 pounds of copper were obtained from 115,064 tons of ore. The ore averaged about 27.5 percent copper in contrast to the average grade of 23.5 percent copper in 1916. The grade of the copper ore decreased after 1917, dropping to 15.5 percent in 1919, and 12.8 percent in 1920. Subsequent lowering in grade was more gradual, and in 1929, when the peak annual tonnage from the mine was reached, 358,654 tons, the average grade was 8.6 percent copper. From 1933 to 1938 when the mine was closed, the average grade of the ore ranged from 6 to 7 percent copper. During this period, smelting ore was selected, averaging better than 7 percent copper, but the ore sent to the concentrator ranged in copper content from 4.02 percent in 1934 to 1.48 percent in 1937.

The gold content of the United Verde Extension ore averages about 0.040 ounce to the ton, although the first 5 years of production was under the average, dropping to 0.0144 ounce to the ton in 1917. In 1933, the gold content averaged 0.055 ounce to the ton from a mine production of 241,555 tons. In 1938, the last year of operation, only 18,196 tons were mined and the gold content averaged 1.08 ounces to the ton. This high gold content resulted from mining ore from the "gold stope," a small oxidized ore body between the 950 and 1,100 levels (pl. 10).

During most of the production from the mine, the silver averaged less than 2 ounces to the ton. The highest yearly average was attained in 1918 with an average grade of 4.18 ounces to the ton. In 1934, the average grade was 1.33 ounces to the ton, the lowest yearly average in the history of the mine.

The United Verde Extension Mining Co. authorized 1,500,000 shares of stock, of which 450,000 shares were not issued, leaving 1,050,000 shares of issued stock with a par value of 50 cents per share. The company started paying dividends in 1916 and their record is given in table 23.

TABLE 23.—*Dividend record, United Verde Extension Mining Co.*

Year	Value	Year	Value
1916	$1, 050, 000	1928	$2, 100, 000
1917	2, 992, 500	1929	3, 939, 500
1918	4, 725, 000	1930	3, 150, 000
1919	2, 362, 500	1931	1, 575, 000
1920	2, 100, 000	1932	603, 750
1921	1, 050, 000	1933	420, 000
1922	1, 312, 500	1934	1, 155, 000
1923	3, 675, 000	1935	2, 467, 500
1924	2, 625, 000	1936	787, 500
1925	2, 362, 500	1937	1, 050, 000
1926	3, 150, 000	1938	2, 730, 000
1927	3, 150, 000		
		Total	50, 531, 250

The mine was closed in May 1938, and the dividends paid in that year represented the final liquidation of the property. The total sum paid out to stockholders, $50,531,250, represented $48.125 per share of issued stock.

DEVELOPMENT

Two vertical concrete three-compartment shafts, the Edith and Audrey, are 200 feet apart and 1,000 feet north of the main ore zone. These shafts were used to transport men and supplies, and in the early stages of mining, to hoist ore. Later, a haulage adit, the Josephine tunnel, 2¼ miles long, was driven and connected with the Edith and Audrey shafts on the 1,300-foot level. Ore was hoisted in the Audrey shaft from lower levels to the 1,300-foot level. The Josephine tunnel is 10 by 10 feet in cross section and contained a standard-gage railroad track that connected with the smelter at Clemenceau, 5 miles from the portal of the adit.

Levels were run on the 550-, 800-, 950-, and 1,100-foot elevations, and on 100-foot spacings from the 1,100 to the 1,900 levels inclusive. The elevations refer to the collar of the Daisy shaft, the first exploratory shaft on the property. The elevations below the Edith and Audrey shafts are about 200 feet less.

Production from the main ore body of chalcocite ore came from the 1,300, 1,400, 1,500, and 1,600 levels. Mixed chalcocite-cuprite-malachite ore south of the main ore body was mined from the 800, 950, 1,100, and 1,200 levels. North of the main ore body mixed chalcocite-cuprite-native copper ore was mined from the 700, 800, 950, 1,100, 1,200, 1,300, 1,400, 1,500, and 1,600 levels. The northern ore body of fluxing primary sulfide ore was mined from the 1,500, 1,600, 1,700, 1,800, and 1,900 levels. Secondary ore containing malachite and chrysocolla in the gravel of the Hickey formation was mined from the 300 to above the 700 levels. A small production of malachite and chrysocolla ore in limestone came from above the 550 level.

The main sulfide ore body was mined by square sets, tightly filled with waste, and almost complete extraction with little dilution was achieved (D'Arcy, 1930).

GEOLOGY

By G. W. H. Norman, C. A. Anderson, and S. C. Creasey

OLDER PRECAMBRIAN ROCKS

Paleozoic sedimentary rocks and Tertiary gravel and lava flows cover Precambrian rocks east of the Verde fault in the underground workings of the United Verde Extension mine.

The Deception rhyolite is the main unit of the Ash Creek group exposed in the mine, although a narrow screen of fissile schist separating the Deception rhyolite and gabbro may represent metamorphosed sedimentary tuff of the Grapevine Gulch formation. Quartz porphyry including a spherulitic facies and gabbro are associated intrusive rocks.

Deception rhyolite

The Deception rhyolite exposed in the United Verde Extension mine consists of two facies. The western one is a light-gray to white massive rhyolite like much of the Deception rhyolite exposed in the Deception Gulch except that intense hydrothermal alteration is lacking. Some interbedded tuffaceous sedimentary rocks were noted on some levels. The eastern facies consists of a rhyolitic fragmental rock containing alternating beds of coarse breccia, fine breccia, and coarse tuff. The fragments are dominantly pink rhyolite containing sparse quartz and feldspar phenocrysts in a microcrystalline groundmass.

These two facies of rhyolite are separated by andesitic flows and intercalcated tuffaceous sediments. Locally the andesite is amygdaloidal and has faint fragmental structures. Much of the andesite is massive, and it may possibly be an intrusive mass. No chilled selvages, however, were observed and the andesitic rocks appear generally similar to some of the flows and fragmental rocks interbedded with the Deception rhyolite in the Mescal Gulch area.

The total thickness of the Deception rhyolite and andesitic member on the 1,400 level northwest of the Audrey and Edith shafts (pl. 5) is probably about 750 feet, of which approximately 450 feet is the eastern rhyolitic breccia. On other levels the thickness of the rhyolite breccia also varies: on the 1,100 level near the Audrey shaft, it is only 90 feet, and on the 1,200 level, it is 140 feet. The andesitic member is about 200 feet thick on the 1,200 level, but elsewhere in the mine is thinner. The western exposures of massive rhyolite are about 100 feet thick.

Foliation is intense along the west margin of the Deception rhyolite, but decreases in intensity to the east, where relict textures and structures are easily recognized. The andesitic flows show little orientation of secondary minerals in thin section, and a pilotaxitic arrangement of albitic plagioclase is separated by bright green chlorite and magnetite (or ilmenite). Some thin sections of the andesite show considerable epidote and calcite, masking the original igneous textures.

Grapevine Gulch formation

A band of fissile greenish-gray and grayish-white schist is along the east margin of the gabbro mass, west of the Deception rhyolite. The rock is so intensely foliated that all distinct bedding structures have been destroyed. The interpretation that the original rock was a fine-grained clastic rock is based on fine color-banding similar to that in bedded rocks, and on the fissility of the schist and general similarity to highly schistose units of the Grapevine Gulch formation at outcrops and in the United Verde mine. Evidence of deformation after the formation of the cleavage is shown by contorted foliation associated with quartz veins and silicified zones.

The band of fissile schist may be a thick unit of tuffaceous sedimentary rock interbedded in the Deception rhyolite, or it may be a part of the Grapevine Gulch formation. In the United Verde mine the Grapevine Gulch formation is in contact with the southeast margin of the gabbro (pl. 5), and presumably this formation would continue around the eastern lobe of the gabbro that is downfaulted in the United Verde Extension mine. The geologic maps of the lower levels, such as the 1,700 level (pl. 10) show that the fissile schist extends to the Verde fault, where it could be the faulted extension of the Grapevine Gulch formation from the footwall side. For this reason, the fissile schist is designated Grapevine Gulch formation.

Quartz porphyry

Two large masses of quartz porphyry are in the United Verde Extension mine. One is south of the gabbro and east of the Verde fault; this mass is host rock for much of the massive sulfide ore in the mine. The other large mass is exposed east of the deposit in the Josephine tunnel and on the surface. The surface exposure (pl. 1, 1,368,000 N.; 444,500 E.), has a north-south length of 500 feet or more.

Smaller masses of quartz porphyry are in the gabbro mass east of the Audrey shaft; presumably these masses represent pendants and inclusions of quartz porphyry in the younger gabbro. Dikes, in part parallel to the structure of the Deception rhyolite, intrude the rhyolitic and andesitic members. Many of these dikes have a spherulitic structure; the spherulites now consist of radiating quartz fibers. Some dikes of the spherulitic facies do not contain the conspicuous quartz phenocrysts so characteristic of most of the quartz porphyry.

Gabbro (United Verde diorite of Reber, 1922)

The mass of gabbro north of the ore body and west of the Audrey shaft is cut off by the Verde fault, and presumably this mass is the downfaulted segment of the gabbro exposed at the United Verde mine (United Verde diorite of Reber, 1922). The gabbro in the United Verde Extension mine is more foliated than in the United Verde mine, and on some levels, the foliation is limited to the margin for a width of only 5–10 feet. On other levels, the foliation is much more extensive.

A large mass of gabbro is present east of the Audrey shaft (pl. 5), and a small tongue is exposed in the Josephine tunnel. To the north, its extent is further defined by diamond-drill holes and the A & A workings (pl. 1, 1,370,000 N.; 437,900 E.). This eastern gabbro has a north-south length of 6,000–7,000 feet and a minimum width of 1,600 feet. West of the Verde fault (pl. 5, 3,000 E.; 0 NS) a small body of gabbro, found by underground exploration, was termed the footwall gabbro. Presumably this mass is a faulted segment of the gabbro exposed in the eastern part of the United Verde Extension mine.

Petrographically, the footwall gabbro is similar to the eastern gabbro and both have been altered to the same degree as the gabbro in the United Verde mine. The plagioclase is intensely altered to albite, sericite, epidote, and clinozoisite, and the pyroxene is largely altered to greenish hornblende and chlorite. Relict pyroxene showing an ophitic relationship to plagioclase was noted in one thin section. Bright green chlorite, polarizing to bronzy colors, may be pseudomorphic after biotite. Interstitial quartz is common, and in part, it may represent primary quartz as well as quartz formed by alteration. Leucoxene has replaced primary ilmenite(?) and apatite prisms are common. In some thin sections, carbonate minerals (calcite, dolomite, or ankerite) are present. Possibly these mafic rocks in the United Verde Extension mine were originally dioritic, as indicated by possible original quartz and biotite. The degree of alteration prohibits certainty on this point.

PALEOZOIC AND TERTIARY ROCKS

The Tapeats sandstone(?) is exposed in the 700 and 800 levels of the United Verde Extension mine, where it ranges from 20 to 40 feet in thickness. The dip is about 5° E. and on the 800 level (pl. 10), Tapeats sandstone(?) is exposed at the station of the Edith shaft. The Tapeats sandstone(?) does not extend westward to the Verde fault for it is cut out by late Tertiary gravel of the Hickey formation (section, pl. 10).

The Devonian Martin formation is exposed on the 800-foot level at the station of the Audrey shaft, and an exploratory drift to the south cuts through it. The Martin is cut out by the gravel of the Hickey formation to the west.

The Mississippian Redwall limestone is exposed at the surface of the United Verde Extension property, but not underground, except in the Josephine tunnel east of the Bessie fault.

The late Tertiary Hickey formation overlies the Precambrian and Paleozoic rocks at the United Verde Extension mine. Basaltic flows crop out at the surface overlying a channel containing about 350 feet of gravel (fig. 26). The gravel unit of the Hickey formation rests on Redwall limestone, Martin limestone, Tapeats sandstone(?), and the Precambrian rocks near the Verde fault. To the west, the gravel and basalt are in fault contact with the Precambrian rocks on the footwall side of the Verde fault.

STRUCTURE

Folds

The regional evidence indicates that the United Verde Extension mine is located in the northward-plunging Mingus anticline (discussed earlier on p. 65). The evidence is less certain as to the location of the mine in relation to the axial plane of the Mingus anticline. Two possibilities should be considered. First, the Deception rhyolite and andesitic unit in the mine are on the eastern limb of the Mingus anticline and in fault contact to the west with westward-facing Deception rhyolite and Grapevine Gulch formation. Second, the Deception rhyolite-Grapevine Gulch formation contact is the downfaulted normal contact observed in the pit at the United Verde mine (discussed on p. 106), and the Deception rhyolite in the United Verde Extension mine is on the western limb of the Mingus anticline.

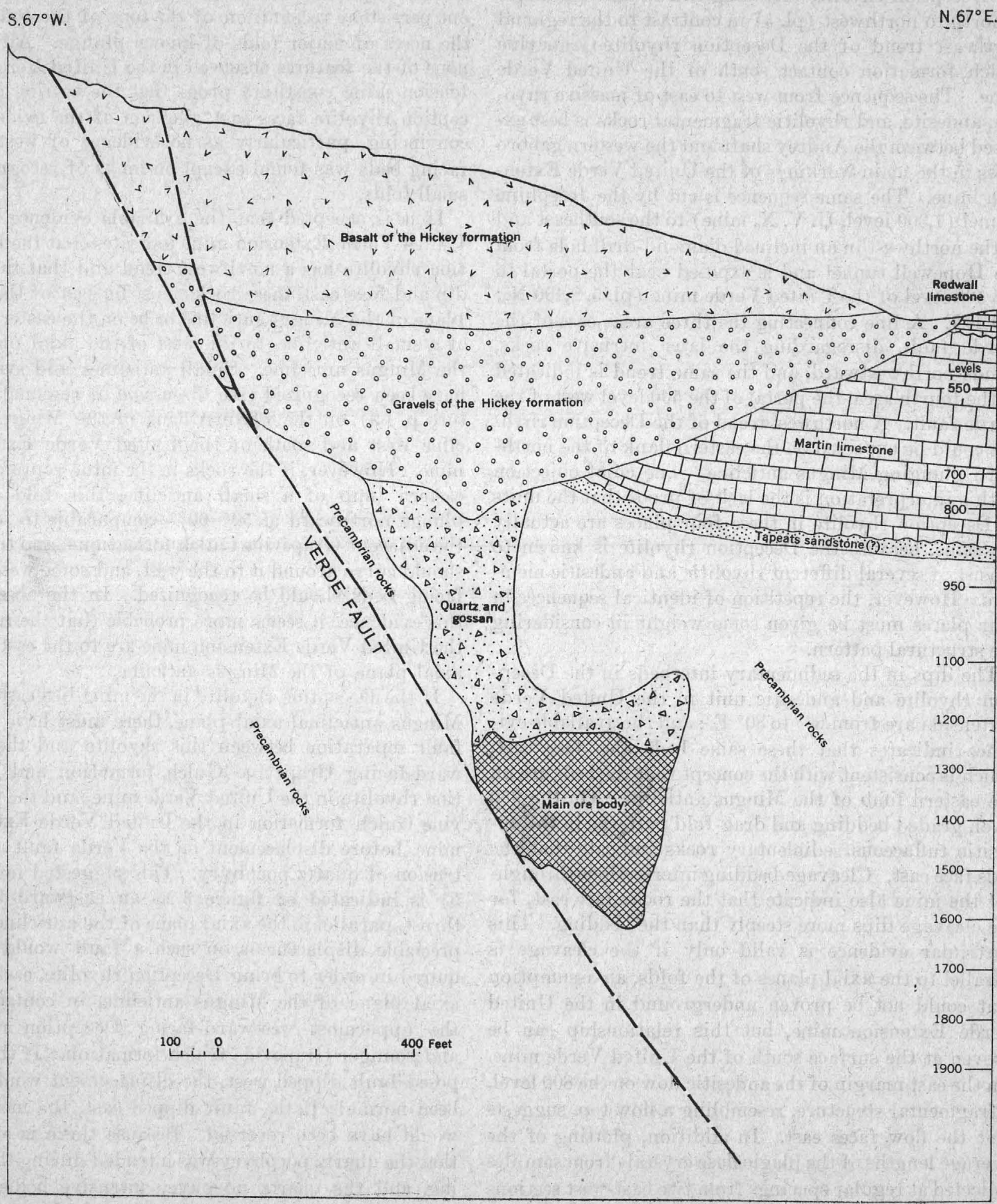


FIGURE 26.—Generalized section through United Verde Extension mine. From Reber (1938).

428436—58——10

The possibility that the Deception rhyolite is on the eastern limb of the Mingus anticline will be considered first. In the United Verde Extension mine, the trend of the Deception rhyolite including the andesitic member is north to northwest (pl. 5) in contrast to the regional northeast trend of the Deception rhyolite-Grapevine Gulch formation contact south of the United Verde mine. The sequence from west to east of massive rhyolite, andesite, and rhyolitic fragmental rocks is best exposed between the Audrey shaft and the western gabbro mass in the main workings of the United Verde Extension mine. The same sequence is cut by the Josephine tunnel (1,300 level, U. V. X. mine) to the southeast and to the northwest in an inclined diamond-drill hole from the Hopewell tunnel and is exposed near the portal to the 500 level of the United Verde mine (pl. 5, 2,400 N.; 150 E.). A line connecting the three areas east of the Verde fault, disregarding the later intrusive rocks, trends northwestward, and the same trend is indicated in the fourth area, the portal of the 500 level west of the Verde fault. A northwest trend of the Deception rhyolite could be expected on the eastern flank of the northward plunging Mingus anticline. The chief objection to this interpretation is the lack of proof that the units of Deception rhyolite in these four places are actually the same, because the Deception rhyolite is known to consist of several different rhyolitic and andesitic members. However, the repetition of identical sequences in four places must be given some weight in considering the structural pattern.

The dips in the sedimentary interbeds in the Deception rhyolite and andesitic unit in the United Verde Extension are from 60° to 80° E.; and the available evidence indicates that these same beds also face east, which is consistent with the concept that the beds are on the eastern limb of the Mingus anticline. On the 950 level, graded bedding and drag-fold patterns in the andesitic tuffaceous sedimentary rocks indicate that the beds face east. Cleavage-bedding intersections throughout the mine also indicate that the rocks face east, for the cleavage dips more steeply than the bedding. This particular evidence is valid only if the cleavage is parallel to the axial planes of the folds, an assumption that could not be proven underground in the United Verde Extension mine, but this relationship can be proven at the surface south of the United Verde mine. On the east margin of the andesitic flow on the 800 level, a fragmental structure, resembling a flow top, suggests that the flow faces east. In addition, plotting of the average lengths of the plagioclase crystals from samples collected at regular spacings from two east-west sections through the flow on the 800 level reveals an asymmetric curve and the steep part of the curve is to the west. This distribution of coarser feldspar to the west indicates that the base of the flow is in that direction.

The absolute proof of the direction that rocks face in a metamorphosed terrane is difficult to determine without persistent recognition of the tops of the beds, and the noses of major folds of known plunge. Although none of the features observed in the United Verde Extension mine constitute proof that the section of Deception rhyolite faces east, the sum of the evidence is convincing, particularly as no evidence of westward-facing beds was found except on limbs of recognizable small folds.

If it is accepted that the available evidence in the United Verde Extension mine indicates that the Deception rhyolite has a northwest trend and that the beds dip and face east, these rocks must lie east of the axial plane of the Mingus anticline or be on the eastern limb of a small anticline, to the west of the axial plane of the Mingus anticline. Small anticlines and synclines have been recognized (see discussion of regional structure p. 69) on the western flank of the Mingus anticline west and south of the United Verde Extension mine. However, if the rocks in the mine represent the eastern limb of a small anticline, this fold should plunge northward at 50°–60°—comparable to folds in the adjacent Grapevine Gulch formation—and the beds should curve around it to the west, and some westward-facing beds should be recognized. In the absence of this evidence, it seems more probable that the rocks in the United Verde Extension mine are to the east of the axial plane of the Mingus anticline.

If the Deception rhyolite in the mine lies east of the Mingus anticlinal axial plane, there must have been a fault separation between this rhyolite and the westward-facing Grapevine Gulch formation and Deception rhyolite in the United Verde mine, and the Grapevine Gulch formation in the United Verde Extension mine, before displacement on the Verde fault and intrusion of quartz porphyry. This suggested fault (pl. 5) is indicated on figure 3 as an eastward-dipping thrust, parallel to the axial plane of the anticline. Appreciable displacement on such a fault would be required in order to bring Deception rhyolite, east of the axial plane of the Mingus anticline, in contact with the uppermost westward-facing Deception rhyolite and younger Grapevine Gulch formation. If this proposed fault dipped west, the displacement would have been normal; if the fault dipped east, the movement would have been reversed. Because there is evidence that the quartz porphyry was intruded during the folding, and the quartz porphyry intrusive bodies show no sign of large-scale faulting, displacement along this proposed fault must have occurred before or during the folding. There is no evidence of a folded fault. Because the eastward-dipping foliation in this immediate area is essentially parallel to the axial planes of the minor folds, it seems logical to suggest that a fault formed during the compression would be essentially parallel to the axial plane of the folds—that is, dip to the east, and be a thrust fault (fig. 3).

The concept of a faulted anticline requires that some attention be paid (1) to the outcrops of Deception rhyolite west of the Verde fault and north of the Haynes fault, and (2) to the exposures of the Grapevine Gulch formation in the United Verde Extension mine. At the first locality, the rhyolite and andesite trend northwest, similar to that in the United Verde Extension, and the sequence is similar—from west to east, massive rhyolite, andesite, and rhyolitic fragmental rocks; the two outcrops possibly were connected before the displacement along the Verde fault. At the second locality, Grapevine Gulch formation west of Deception rhyolite in an eastward-facing section is stratigraphically out of place. The proposed thrust will explain the relationship at both localities by separating westward-facing Grapevine Gulch formation on the west from eastward-facing Deception rhyolite on the east (pl. 5).

Although a comparable thrust fault parallel to the axial planes of the major folds has not been found elsewhere in the Ash Creek group, it must be admitted that deformation is more intense in the vicinity of the United Verde and United Verde Extension mines as shown by the intense foliation in the quartz porphyry, Deception rhyolite, and Grapevine Gulch formation.

The second possibility, which is perhaps a simpler explanation, is that the Deception rhyolite in the United Verde Extension mine is on the western limb of the Mingus anticline. To visualize this structure, it must be assumed that the rocks moved to their approximate relative position before displacement on the Verde fault. This interpretation is most easily understood by matching the faulted lobe-shaped mass of gabbro exposed on the 1,400 level of the United Verde Extension mine to the parent mass of gabbro at the surface of the United Verde mine. (Pl. 5, visually place contact at 100 N.; 3,420 E. to 1,100 N.; 900 E.) Then the Deception rhyolite-Grapevine Gulch formation contact exposed east of the United Verde mine would sweep around the east margin of the gabbro, and connect with the contact west of the Deception rhyolite buried beneath the mine dump north of the Haynes and west of the Verde fault (pl. 5, 2,400 N.; 200 W.). Information obtained in the United Verde mine indicates that the Deception rhyolite-Grapevine Gulch formation contact is overturned and dips to the east, south of the gabbro mass. The east dips of the Deception rhyolite in the United Verde Extension mine may then represent local overturning of the westward-facing limb of the Mingus anticline, as reflected by the eastward bulge of the Deception rhyolite-Grapevine Gulch formation contact along the east margin of the gabbro. This second explanation demands that the evidence be ignored that indicates that the Deception rhyolite faces east in the United Verde Extension mine.

The choice of interpretation depends therefore upon the reliance to be placed upon the evidence of eastward-facing beds in the United Verde Extension mine. The faulted anticlinal interpretation could only be proved satisfactorily if the cover of younger rocks was removed and detailed mapping of Precambrian rocks revealed truncation of members in the Deception rhyolite by the contact of Grapevine Gulch formation to the west or vice versa. We believe that the evidence is sufficiently good to favor the eastward-facing Deception rhyolite in the United Verde Extension mine, so that the faulted Mingus anticlinal interpretation is our preference; but the skeptic is justified on the evidence available to prefer the second interpretation, namely, that the Deception rhyolite-Grapevine Gulch formation contact is the normal depositional contact. In either interpretation, the contact has been destroyed locally by intrusive quartz porphyry and locally bulged eastward by the intrusive gabbro.

Faults

Near the United Verde and United Verde Extension mines, the Verde fault is complex; the fault zone being about 100 feet wide. The main footwall break contains heavy gouge, and much of the movement may have been along this break (Reber, 1938, p. 51). Some movement is distributed over a braided system of small hanging-wall breaks that are difficult to map accurately. The fault dips east at 60° and the eastern block has been dropped. The only accurate measurement of the vertical separation is obtained by displaced Paleozoic rocks; it is about 1,500 feet. Against the footwall side of the fault, between the footwall and hanging-wall strands (pl. 5, 1,300 N.; 850 E.), displaced Tapeats sandstone(?) crops out and indicates only 690 feet of vertical separation (fig. 27) of this block of sandstone caught in the fault zone. The late Tertiary basaltic flows and gravels of the Hickey formation are displaced by the Verde fault (fig. 26), proving that much of the displacement took place after their accumulation, dating the fault as probably late Tertiary.

Precambrian movement along the Verde fault, following the period of metallization and some chalcocite enrichment, has been suggested by Ransome (1932) and Reber (1938, p. 51), but this phase of the history of

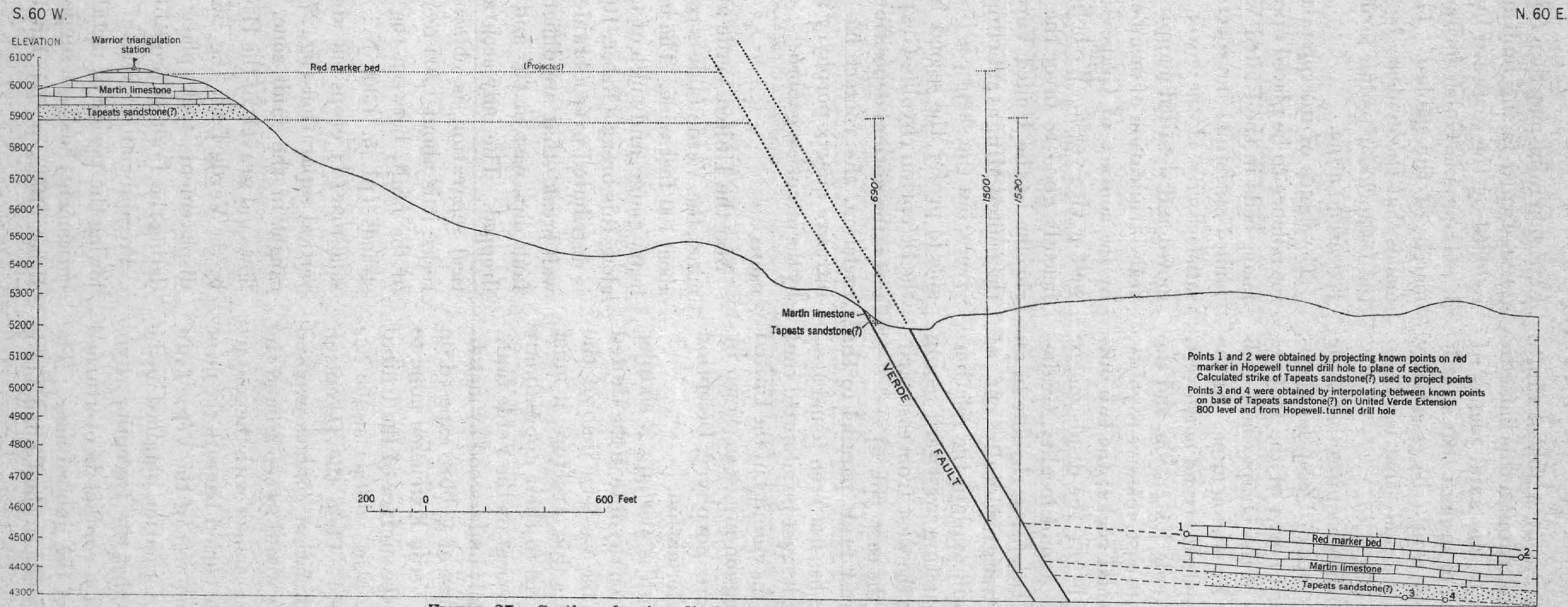


FIGURE 27.—Section showing displacement of Tapeats sandstone(?) by Verde fault.

the Verde fault will be discussed in the next section of this report.

The Florencia fault trends east-northeast and dips 70°–75° S. To the west, it is cut off by the Verde fault (pl. 5). On the 800 level (pl. 10) the Florencia intersects the Verde south of the gabbro, and cuts through the ore zone. On this level, the distribution of the Tapeats sandstone(?) shows that the south side dropped about 40–50 feet, proving that the fault is normal. On lower levels of the mine, the Florencia lies along the south side of the main ore body (see 1,300 level, pl. 10), as if the fault were older than the period of mineralization (which is in the Precambrian) and localized the ore body. The small displacement of the Tapeats sandstone(?) on the 800 level (pl. 10) may represent later adjustments along the fault in Tertiary time. No trace of the Florencia has been found on the footwall side (west) of the Verde. It is tempting to correlate the Florencia with the Hull because of similar attitudes. The probable bearing and plunge of the net slip on the Verde, however, is not permissive.

HYDROTHERMAL ALTERATION

The quartz-sericitic alteration common in the quartz porphyry and Deception rhyolite, in and south of the United Verde mine, is present only between the Verde fault and the ore body in the United Verde Extension mine. The volcanic rocks east of the ore body contain fresh feldspar, and relict textures and structures are recognized easily.

Black schist formed by chloritic alteration is predominant in quartz porphyry and Deception rhyolite south of the ore body in the United Verde Extension mine. According to Reber (1938, p. 52) minor quantities of schistose gabbro as well as quartz porphyry are replaced by black schist north of the ore body.

Jasper is common in the United Verde mine, and some of the hard massive quartz containing small chalcocite ore bodies in the northern part of the upper levels of the United Verde Extension ore body may be a product of similar silicification. The rocks of these upper levels have been appreciably oxidized and leached. How much of the silica remaining is primary silicification, and how much is residual from massive sulfide is unknown.

ORE BODIES

Form and distribution

The main chalcocite ore body is located about 900 feet south of the Edith and Audrey shafts (pl. 5). The top of the sulfide zone was located at the 1,240 level. Oxidized ore for 1 floor above, contained about 10 ounces of silver to the ton, whereas the oxidized zone above this floor was essentially barren. The shape of the main ore body in the upper levels is somewhat rounded to elliptical, with the long dimension east-west. On the 1,300 level (pl. 10), the main ore body was about 500 feet long and about 200 feet wide. On the 1,400 level, the length is 440 feet and the width is 270 feet (pl. 5). On this level, the southwest corner of the ore body is cut off by the footwall strand of the Verde fault, and a hanging-wall strand of the fault cuts through the ore body. Below the 1,400 level, the main ore body tapered; and on the 1,500 level, the southwest margin for 160 feet was bounded by the footwall strand of the Verde. On the 1,600 level, the ore body is oriented northwest; the length is 250 feet and the width ranges from 40 to 70 feet. The Verde is to the west of the ore body on this level, indicating the irregular bottoming of a sulfide lens. The main ore body bottomed above the 1,700 level and was mined to the 8th floor above this level.

On the 1,200 level an ore zone, from 5 to 20 feet wide and rich in native copper, extended for 450 feet north of the main ore body along the east margin of the gabbro. An ore body 120 feet long in this ore zone yielded the first significant tonnage of ore mined in 1915. This eastern ore zone was barren northward to the northeast margin of the gabbro, where a second ore body 350 feet long was found (pl. 10, 2,350 E.; 11,900 N.). This northern ore body was stoped from a few floors above the 1,400 level to 7 floors above the 1,100 level.

Above the 1,100 level, an upward lobe of gabbro is separated from the main mass of gabbro by older rock, and some oxidized ore is in the trough between gabbro (pl. 10, gold stope). On the 800 level (pl. 10), a northwestward-trending gossan zone is west of the gabbro and east of the Verde fault, and some oxide copper ore was stoped from above this level (section, pl. 10).

Small veinlike tongues of mineralized rock with northwesterly plunge extend south and east of the main ore body along shear zones in the quartz porphyry. About 400,000 tons of ore was produced from these tongues above and below the 1,100 level.

Northwest of the main ore body and adjacent to the Verde fault, massive unoxidized low-grade sulfide ore was found on the 1,200 level. This body is about 450 feet long and from 60 to 90 feet wide; the west margin is the footwall strand of the Verde and the east margin is one of the hanging-wall strands. This low-grade sulfide zone extended from the 1,300 to the 950 levels. On the east side, a chalcocite ore body 50 by 100 feet on the 1,200 level and extending from below the 1,300 (pl. 10) to above the 1,200 levels was found; it undoubtedly was "dragged ore" along the Verde fault.

On the 1,300 level (pl. 10) a tongue of chalcocite ore cuts the gabbro from the northwest corner of the main ore body. The connection between this tongue and the main ore body is severed by one of the hanging-wall strands of the Verde fault between the 1,300 and 1,400 levels. This tongue of ore extended below the 1,500 level.

The northern ore bodies on the lower levels appear on the 1,400 level northwest of the main ore body, and are along the Verde fault. These bodies are mainly in contact with the footwall strand of the Verde (pl. 10), and may have been connected originally with the main ore body, but were severed from it by complex faulting. On the 1,900 level, only a mass 40 by 50 feet was found, 70 feet southeast of the footwall strand of the Verde (fig. 29). Thus neither the lowermost part of the main ore body nor the footwall-strand ore bodies bottomed on the footwall strand of the Verde, indicating an irregular bottoming of lenses of ore. These lower level ore bodies were mined for fluxing ore, and probably about half of these were stoped out. The lowest stope was just above the 1,900 level.

The form and trend of the ore bodies were controlled in part by the contact of quartz porphyry with Grapevine Gulch formation and Deception rhyolite, and in part by the margin of the gabbro (Reber, 1938, p. 50). The local schistosity near and in the gabbro trends east in contrast to the northwest trend in the rocks east of the gabbro. The main ore body was elongated in an easterly direction where it had its maximum size, possibly controlled in part by the Florencia fault; but at depth, the trend was northwest, parallel to the regional foliation.

In the lower levels of the mine, the southern contact of the gabbro dips north, and the deeper sulfide lenses generally are closer to the gabbro than in the upper levels. Some of the marginal schistose gabbro was mineralized like the Haynes ore body, in contrast to the nonmineralized marginal gabbro in the main United Verde mine. Reber (1938, p. 51) noted, however, that some of the apparent penetration of the gabbro by sulfide is partly due to faults.

Sulfide zone

The massive sulfide on the lower levels is similar to that in the United Verde mine. Pyritic massive sulfide contained minor quantities of sphalerite and chalcopyrite, represented by 2 to 7 percent zinc and from ½ to 1½ percent copper (Reber, 1938, p. 52). In places the pyritic massive sulfide is banded. Quartz-carbonate minerals separate the sulfide minerals on a microscopic scale, and veinlets of quartz-carbonate cut the massive sulfide.

Some of the smaller ore bodies on the lower levels contained chalcopyrite in similar proportions to the copper-bearing massive sulfide ore in the United Verde mine (Reber, 1938, p. 52).

The rich chalcocite ore that made the United Verde Extension mine famous consisted in part of massive fine-grained orthorhombic chalcocite containing a well-formed pisolitic structure formed by the replacement of pyrite by chalcocite (Schwartz, 1938, p. 26). In places, the chalcocite was sooty and soft (Lindgren, 1926, p. 86). Some unreplaced pyrite was present in the ore, but it was largely concealed by the chalcocite. Native copper and cuprite were abundant in some stopes on the east side of the gabbro, north of the main ore body, and in the southeastern tongues.

Chalcopyrite and sphalerite were absent in the chalcocite ore and must have been replaced by chalcocite. Lindgren (in a private report, quoted by Reber, 1938, p. 53) suggested that chalcopyrite was sparse in the primary ore, but Reber (1938, p. 53) believes that chalcopyrite replacement was most important in parts of the high-grade chalcocite.

The interpretation that the bonanza of chalcocite ore was formed by secondary enrichment has been widely accepted, and Reber (1938, p. 53) has succinctly reviewed the evidence:

> The decrease of chalcocite with depth, the general scarcity of chalcopyrite or sphalerite where chalcocite was most abundant, and the intense kaolinic alteration of the wall rocks, varying with the abundance of chalcocite, conclusively indicate formation by the process of secondary enrichment, which is also confirmed by microscopic evidence.

Enrichment occurred before deposition of the Tapeats sandstone(?) of Cambrian or possibly of Devonian age (see p. 48), for the Tapeats(?) and younger rocks covered the leached capping and gossan. Thus the enrichment is Precambrian or early Paleozoic, or both.

Oxide zone

The bottom of the oxide zone in the United Verde Extension mine is variable, due partly to faulting. It is deepest away from the Verde fault, reaching greater depths over the main ore body than over some of the smaller ones. It is possible that some oxidation occurred when the top of the ore zone was exposed in Tertiary time before the deposition of the gravel of the Hickey beds (section, pl. 10; fig. 26).

Above the 1,200 level, dense fine-grained primary quartz containing a little sulfide was more abundant than at depth. Within this quartz were several irregular lenses of high-grade quartz-chalcocite ore, some with small vertical extent. In the higher ore bodies, malachite with some cuprite was conspicuous (Reber, 1938, p. 53).

Silver enrichment was evident above the top of the massive sulfide; in the average chalcocite ore, the silver content was less than 2 ounces to the ton. The oxidized ore for about 7 feet above the chalcocite ore contained from 10 to 12 ounces of silver per ton, and locally, high-grade masses contained as much as 100 ounces per ton (Lindgren, 1926, p. 86).

The gossan or capping above the main ore body contains much silica, chiefly massive quartz that locally shows repeated brecciation and recementation. Cavernous hard quartz breccia containing appreciable limonite is more abundant than clean quartz. Soft limonitic material, similar to much of the United Verde gossan, occurs only locally, but predominantly close to the top of the sulfide zone. Native copper is abundant in places in the soft gossan. Some of the smaller siliceous ore bodies were capped with 40 to 50 feet of iron-rich gossan, but in a few places the chalcocite merged into massive quartz with no obvious leaching or slumping (Reber, 1938, p. 53–54). Chalcocite, showing only a small percent of malachite, occurred on and above the 800 level within 70 feet of the Tapeats sandstone (?).

The veinlike tongues of ore extending south and east from the main ore body were overlain by 50 to 100 feet of thoroughly leached, kaolinized rock containing some limonitic material. These ore bodies range vertically from near the 1,300 level to a few floors above the 800 level. Oxidized copper minerals were prevalent throughout and, in some of the higher parts of these ore bodies, accounted for more than half of the copper content and entirely masked the finely divided chalcocite. The most abundant oxidized copper minerals were malachite, chrysocolla, and azurite (Reber, 1938, p. 54).

Partly oxidized copper ore yielded nearly one-eighth of the production of the mine. Some ore mined from the gravel of the Tertiary Hickey formation was entirely in the form of oxidized copper minerals, and this ore amounted to only 2 percent of the production. The gravel ore may have formed by ground water carrying copper from the adjacent United Verde ore zone (Reber, 1938, p. 54) or be dragged ore along the Verde fault.

The "gold stope" ore body was a tabular veinlike body along the eastern gabbro contact in the upper levels of the mine that bottomed in a trough in the gabbro (section, pl. 10). The typical ore was fine-grained friable quartz containing almost no residual iron oxide. The maximum length was about 350 feet and the width ranged from 5 to 20 feet. This ore body extended about 200 feet vertically above and below the 950 level. The gold content was variable, and according to Reber (1938, p. 54), may have averaged $10 per ton, with some higher grade sections. Apparently, local conditions were exceptionally favorable to concentrate gold.

RELATIONSHIP OF THE UNITED VERDE AND UNITED VERDE EXTENSION ORE BODIES

By G. W. H. Norman, C. A. Anderson, and S. C. Creasey

Is the United Verde Extension ore body the downfaulted upper part of the United Verde ore body? Debate on this question has been active since the discovery of the United Verde Extension ore body. The simplest structural explanation is that movement on the Verde fault was dip slip, and the Paleozoic rocks on opposite sides of the fault provide the best measure of displacement. This vertical separation (throw) has been measured as about 1,500 feet (fig. 27), and the 1,400 level of the United Verde Extension mine is about 1,500 feet below the surface elevations of the United Verde mine. Reversing the Tertiary displacement of 1,500 feet at right angles to the trace of the Verde fault places the United Verde Extension ore body, as outlined on the 1,400 level, 2,700 feet east-southeast of the United Verde ore body as exposed at the surface (fig. 28, position I). This simple geometry was accepted by Provot (1916) and Rickard (1918, p. 51) as proof that the United Verde Extension ore body was not the faulted top of the United Verde ore body. This explanation overlooks the important fact that although the reversal of the dip-slip movement will result in matching the Paleozoic rocks, the Precambrian rocks on opposite sides of the Verde fault will not match (pl. 5).

The gabbro mass (United Verde diorite of Reber, 1922) north of the United Verde ore body is cut off by the Verde fault and similar gabbro is also cut off north of the United Verde Extension ore body. Matching these two gabbro masses on opposite sides of the fault can be done by reversing the known Tertiary vertical separation of 1,500 feet and moving the hanging-wall block horizontally 2,200 feet to the northwest. Matching the gabbro places the United Verde Extension ore body 1,000 feet northeast of the United Verde ore body (fig. 28, position II). Fearing (1926, p. 770) made this suggestion of pronounced lateral as well as vertical movement to match the gabbro and he concluded that this was proof that the two ore bodies were originally separate before displacement along the Verde fault.

This suggestion of pronounced lateral displacement has the virtue of matching the gabbro and Paleozoic rocks on opposite sides of the Verde fault, but it neglects the fact that the mass of Deception rhyolite on the surface east of shaft 7 (pl. 5; 200 N.; 1,500 E.) on the footwall side (west) is not represented on the 1,400-foot level of the United Verde Extension mine (1,500 feet vertically below the United Verde surface). In addition, at the surface, the quartz porphyry along the west

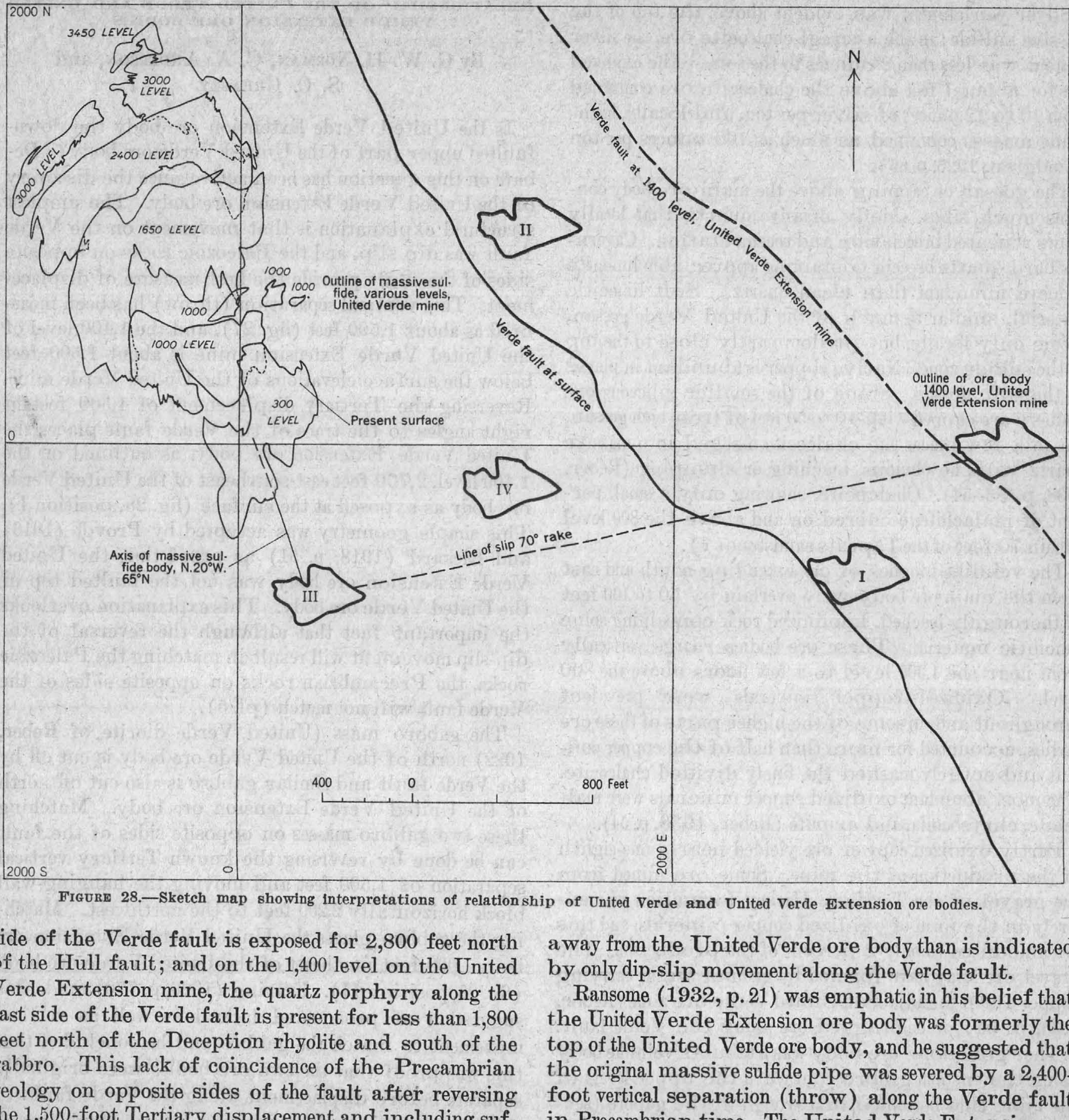


FIGURE 28.—Sketch map showing interpretations of relationship of United Verde and United Verde Extension ore bodies.

side of the Verde fault is exposed for 2,800 feet north of the Hull fault; and on the 1,400 level on the United Verde Extension mine, the quartz porphyry along the east side of the Verde fault is present for less than 1,800 feet north of the Deception rhyolite and south of the gabbro. This lack of coincidence of the Precambrian geology on opposite sides of the fault after reversing the 1,500-foot Tertiary displacement and including sufficient lateral movement to match the gabbro is reason enough to rule out this explanation.

Lindgren (1926, p. 87) was cautious in expressing any positive opinion as to the relationship of the two ore bodies. He did suggest that lateral as well as vertical movement had taken place along the Verde fault and that the lateral movement had not been determined. His conclusions were that the United Verde Extension ore body originally might have been closer to or farther away from the United Verde ore body than is indicated by only dip-slip movement along the Verde fault.

Ransome (1932, p. 21) was emphatic in his belief that the United Verde Extension ore body was formerly the top of the United Verde ore body, and he suggested that the original massive sulfide pipe was severed by a 2,400-foot vertical separation (throw) along the Verde fault in Precambrian time. The United Verde Extension ore body reached its present position by the additional 1,500-foot vertical separation after the deposition of the Paleozoic and Tertiary rocks. Apparently Ransome assumed that the two ore bodies were formerly connected because of the similarity in form and geologic relationship. The amount of Precambrian displacement necessary to connect the two ore bodies was determined by projecting upward the axis of the United Verde ore body (fig. 28) and projecting upward the United Verde Extension ore body along the plane of the Verde fault—using as a line of slip, a rake of 70° to 75° E. This rake corresponds with the rake of rolls and grooves in the Verde fault plane (Reber, 1938, p. 51). Placing the projected 1,400 level United Verde Extension ore body on the projected axis of the United Verde ore body would give the position of the ore body before faulting (fig. 28, position III). Using this method of determining the total vertical separation (throw), our determination is essentially in agreement with the 4,000-foot total throw as suggested by Ransome, of which 2,500-foot displacement must have occurred before deposition of the Paleozoic rocks. (Reber (1938, p. 51) agrees with Ransome's interpretation.

The evidence seems clear that some Precambrian movement along the Verde fault is necessary to match the Precambrian rocks on opposite sides of the fault, but this cannot be accepted as proof that the United Verde Extension ore body is the severed top of the United Verde ore body. It is true that in general the form of the two ore bodies is similar, and both are south of the gabbro (United Verde diorite of Reber, 1922). However, the United Verde ore body is confined entirely to the Grapevine Gulch formation and intrusive quartz porphyry. The United Verde Extension ore body has replaced Deception rhyolite and quartz porphyry (pl. 5). The fissile schist in the United Verde Extension mine may not be Grapevine Gulch formation, but sedimentary interbeds in the Deception rhyolite. The Deception rhyolite-Grapevine Gulch formation contact at the surface is 700 to 800 feet northeast of the center of the United Verde ore body. The geologic setting, therefore, of the two ore bodies is different in spite of the close spatial relationship to the gabbro, and this fact alone casts serious doubt on the probability that the two ore bodies were connected before displacement along the Verde fault. This doubt appears valid whether the Deception rhyolite in the United Verde Extension mine is or is not facing east, and whether it is or is not separated from the Grapevine Gulch to the west by an earlier thrust fault.

The mass of Deception rhyolite at the surface east of shaft 7 is cut off by the Verde fault, and the trace of the north and south contacts in the plane of the Verde fault is shown on plate 5. The western contact of the rhyolite dips 70° to 80° E., whereas the Verde fault dips 60° E. The contact and fault by upward projection should intersect at about 1,000 feet vertically above the present surface. This same contact in the United Verde Extension mine by downward projection should intersect the Verde fault at about 300 feet below the 1,400 level (1,700 level, pl. 10, U.V.X. 11,225 N.; 7,750 E.). Matching these points of intersection of the western rhyolite contact in the footwall and hanging-wall sides of the Verde should give the vertical separation along the Verde, that is, about 2,800 feet. Subtracting the known Tertiary vertical separation of 1,500 feet, indicates that 1,300 feet of Precambrian vertical separation is required. Because the western contacts of rhyolite used in projection are igneous contacts and intersect the Verde fault at an acute angle, no precision is justified; and perhaps it is best to state that the Precambrian vertical separation measured on the displaced rhyolite contact is about 1,000 feet.

Some features of the gabbro north of the ore bodies can be used to obtain additional data on the amount of required Precambrian movement on the Verde fault in order to match the geology on opposite sides of the fault. The downward projection of the eastern contact of the gabbro in the United Verde Extension mine indicates that it would intersect the Verde at an elevation of about 2,500 feet, corresponding to the 2,600 level of the mine. In the United Verde mine, data are inadequate to state positively at what elevation the lower (underneath) eastern contact of the gabbro is cut by the Verde. The gabbro is clearly in fault contact on the 1,200 level in the United Verde mine at an elevation of 4,300 feet, which is 1,800 feet higher than the point where the gabbro cuts out against the Verde fault in the United Verde Extension mine. Both Tertiary and Precambrian vertical separation are included in this 1,800 feet, 1,500 feet for the Tertiary and 300 feet for the Precambrian. The elevation of the intersection of lower contact of gabbro with the Verde in the United Verde mine may be at lower elevations, corresponding to the 1,500 or 1,650 levels, which would decrease the total vertical separation by from 300 to 450 feet. In other words, the gabbro-Verde fault intersection on opposite sides of the Verde, from the data available, does not indicate as great a total vertical separation, 2,500 feet, as indicated by the Deception rhyolite east of shaft 7.

The eastern gabbro-Verde fault intersection again represents planes meeting at acute angles; no precision is justified, but an approximate displacement is indicated. If a Precambrian displacement of 2,500 feet took place, as suggested by Ransome, the east margin of the gabbro necessarily would have essentially followed the future course of the Verde fault for about 1,000 feet—that is, the eastern contact would have dipped to the east at about 60° in contrast to the dominant westerly dip. Igneous contacts cannot be used with assurance in projections; but nevertheless, using known trends for projection gives some measure of possible displacement.

The quartz porphyry near the United Verde mine appears largely as tongues parallel to the Grapevine Gulch formation and Deception rhyolite (pl. 5). These tongues plunge northward and northwestward, essentially parallel to the plunge of the minor folds in the Grapevine Gulch formation. Possibly the tongue of quartz porphyry in which shaft 7 was sunk (pl. 5) had a comparable plunge to the north, steeper than the southeastern gabbro contact. Furthermore, this tongue probably would narrow at higher elevations. It does seem reasonable to presume that the gabbro mass, projected upward and to the south, would partly cut out the narrow tongue of quartz porphyry at an elevation of about 1,000 feet above the present surface. Then the quartz porphyry on the west side of the Verde fault would have a northwest length north of the Deception rhyolite comparable to that exposed on the east side of the fault on the 1,400 level of the United Verde Extension mine. It would then be possible to match the quartz porphyry-gabbro contacts and both the northern and southern quartz porphyry contacts with Deception rhyolite.

The evidence, although weak because we are dealing chiefly with intrusive igneous contacts, indicates that a Precambrian 2,500-foot vertical separation along the Verde fault is more than is needed to match the Precambrian rocks on opposite sides of the Verde fault. A minimum vertical displacement of about 1,000 feet before deposition of Paleozoic rocks seems necessary. The greater the proposed Precambrian displacement in excess of 1,000 feet, the greater the difficulty in matching the eastern gabbro contact on opposite sides of the Verde fault.

Assuming a vertical separation of 1,000 feet in Precambrian time, and projecting upward the southeastern gabbro contact southeastward at 45°, would place the United Verde Extension ore body (fig. 28, position IV) before any faulting, about 1,300 feet to the east-southeast of the surface outcrop of the United Verde ore body (300 level). Projecting the United Verde ore body upward along the axis of the N. 20° W., 65° N. plunge, until its position was 1,000 feet vertically above the present surface, would bring the United Verde ore body approximately west of the suggested position (fig. 28), of the United Verde Extension ore body before faulting. The greater the Precambrian displacement, the closer the proximity of the two ore bodies would be before faulting.

The question has been raised that if the United Verde Extension ore body is not the faulted top of the United Verde ore body, roots of the separate United Verde Extension ore body should be found on the footwall side of the Verde fault. It should be noted, however, that the United Verde Extension ore body tapered with depth, and on the lowest levels the massive sulfide mass was small and not cut off by the Verde fault (fig. 29). Adding at least 1,000 feet of Precambrian displacement to the known 1,500-foot Tertiary displacement, means that at least 1,000 feet of rocks has been eroded from below the former position of the United Verde Extension ore body. East of the United Verde ore body on the footwall side of the Verde, low-grade copper-bearing quartz porphyry is present that might represent the roots of the United Verde Extension ore body.

Another possibility must be considered; in the discussion so far, it has been presumed that the United Verde ore body continued above the present surface along the projected axis of N. 20° W., 65° N. plunge. This upward projection is an assumption. Beginning at the 1,200 level of the United Verde mine, and appearing at higher levels, small bodies of massive sulfide are east of the main body. On several levels, these eastern bodies are separated from the main ore body by quartz porphyry, Grapevine Gulch formation, and black schist. During mining, however, it was discovered that these eastern massive sulfide bodies connected at higher levels to the main mass, and thus represent downward lobes or rolls of massive sulfide. Possibly in the higher levels of the United Verde ore body, now removed by erosion, the east margin of the United Verde ore body replaced rocks progressively to the east at higher elevations, and eventually replaced Deception rhyolite. Thus the United Verde Extension ore body may indeed represent the higher and easternmost part of the upward projected United Verde ore body. With this interpretation, the United Verde Extension ore body could represent the downfaulted top of the United Verde ore body. No compelling evidence is available to prove or disprove this possibility.

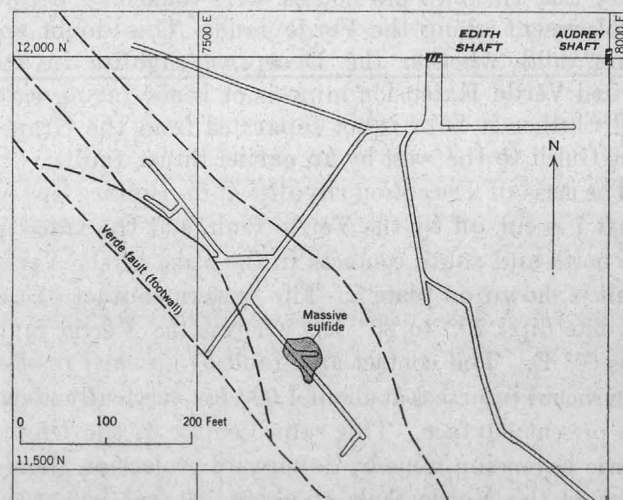


FIGURE 29.—Sketch map showing outline of massive sulfide on the 1,900 level, United Verde Extension mine. Furnished by Mingus Mountain Mining Corp.

The greater quantity of chalcocite ore in the United Verde Extension mine as compared with the United Verde mine has been used as an argument that the United Verde Extension ore body represents the severed enriched top of the United Verde ore body. The history has been so complex that doubt can be raised for this explanation. The evidence is strong that the United Verde Extension ore body was dropped about 1,000 feet in Precambrian time along the Verde fault. By the time the Tapeats sandstone(?) was deposited, the surface above both ore bodies was that of low relief, implying that the United Verde ore body was eroded at least 1,000 feet by Tapeats(?) time. If the two ore bodies were separate before faulting, any appreciable chalcocite in the United Verde ore body would undoubtedly have been removed by the active erosion that would have followed the uplift of the block containing the United Verde mine. Sometime before deposition of the Tertiary Hickey formation, a northward-trending canyon was cut deep into the Paleozoic rocks, and exposed some of the leached gossan in the United Verde Extension mine (fig. 26). The United Verde ore body may have been uncovered during this same period of erosion. After accumulation of the Hickey formation, and Tertiary displacement along the Verde fault, the Paleozoic and Tertiary rocks covering the United Verde ore body were removed by erosion and at least 350 feet of the top of the ore body was eroded judging from the present stream gradients west of the Verde fault. The chalcocite ore in the United Verde mine may have formed during that period of erosion or be relict from the pre-Hickey and (or) Precambrian period of weathering and erosion. Two or three periods of active erosion occurred, therefore, at the site of the United Verde ore body; whereas after displacement along the Verde fault the United Verde Extension ore body was probably only weakly eroded during Precambrian time. Subsequent burial by Paleozoic and younger rocks has protected the United Verde Extension ore body from erosion, except for the fleeting period of time in which the pre-Hickey canyon removed a small amount of quartz and gossan from the leached zone (fig. 26). These facts preclude the explanation that because the chalcocite enrichment in the United Verde ore body is much less than in the United Verde Extension ore body, the latter is the faulted segment of the former.

In summary, the evidence at hand is sufficient to demand movement along the Verde fault before deposition of the Paleozoic and Tertiary rocks. We believe that this Precambrian vertical separation was about 1,000 feet, and that the total vertical separation (throw) was nearly 2,500 feet. Following this interpretation, the United Verde Extension ore body could not be the severed top of the United Verde ore body unless the United Verde ore body shifted eastward at higher elevations above the present erosion surface and did not follow the upward projection along its known axis of N. 20° W., 65° N. plunge.

JEROME VERDE MINE

The Jerome Verde Development Co. owns 28 patented claims north and east of the United Verde Extension mine. The present company was incorporated in 1921 to take over the holdings of the Jerome Verde Copper Co.

The only production came from the Main Top claim and this ore body, known as the Main Top, is a faulted segment of chalcocite ore along the Verde fault and a part of the United Verde Extension ore zone. The ore was discovered in 1917 and mined out by 1920 by the United Verde Extension Mining Co. Lindgren (1926, p. 88) reported that about 10,000 tons of ore mined contained from 8 to 12 percent of copper. Elsing and Heineman (1936, p. 101) state that the production totaled 1,500,000 pounds of copper, $10,000 of gold, and $14,000 of silver, the total value of production amounting to $345,000. If 10,000 tons of ore were mined, the average grade must have been about 7½ percent of copper to match the production of 1,500,000 pounds of copper.

The location of the Main Top ore body is shown on 1,300 level, plate 10 at 11,950 N.; 7,350 E. The ore body was mined from the underground workings of the United Verde Extension mine and stoped from the 1,300 level to the 10th floor above the 1,100 level. The ore body was about 200 feet long and from 10 to 30 feet wide.

Much exploration was done in the Precambrian rocks north of the United Verde Extension mine on Jerome Verde ground during the early exploratory work by the United Verde Extension Mining Co., and in cooperation with this company, but the results were fruitless. Early work on Jerome Verde property was done from the Columbia shaft, 1,000 feet southeast of the Edith shaft in the United Verde Extension mine (Lindgren, 1926, p. 88). The Columbia shaft is 1,061 feet deep and connects with 12,000 feet of workings, mainly on the 1,100 level, which corresponds to the 1,400 level of the United Verde Extension mine. Precambrian rocks were reported at a depth of 426 feet in the Columbia shaft. In 1922, additional work was done north of the United Verde Extension mine without significant discovery.

COPPER CHIEF ORE BODY

DEVELOPMENT AND PRODUCTION

The Copper Chief ore body is 3½ miles south-southeast from Jerome and is accessible by road from Cotton-

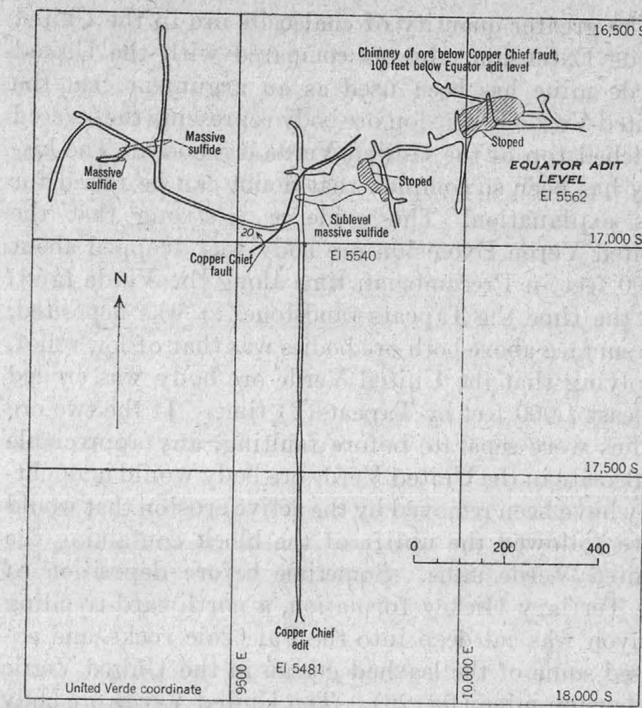


FIGURE 30.—Map showing underground workings, Copper Chief deposit. Compiled by G. W. H. Norman from data furnished by Phelps Dodge Corp.

wood. A property line divided the ore body; the Copper Chief Mining Co. owned the western part and the Equator Mining and Smelting Co., the eastern part. Phelps Dodge Corp. now owns both properties.

The Equator Mining and Smelting Co. was owned originally by Senator Clark who also controlled the United Verde mine. In 1904–5, about 30,000 tons of sulfide ore were mined and smelted in a plant east of the mine. Production during that period totaled 1,300,000 pounds of copper, having a value of $185,000 (Elsing and Heineman, 1936, p. 101). The Iron King claim was the site of this production, and the mine is known either as the Iron King or Equator. In order to avoid confusion with the Iron King lead-zinc mine near Humboldt, the combined Copper Chief-Equator (Iron King) ore body will be referred to as the "Copper Chief ore body."

The western part of the ore body owned by the Copper Chief Mining Co. consists largely of oxidized ore, mined chiefly for the gold and silver content. Most of the production came during 1916–18 by the Hayden Leasing Co. which had a cyanide mill with a capacity of 125 tons daily. The total output during 1916–18 was 71,849 tons of ore that returned $875,800 or about $12 to the ton (Lindgren, 1926, p. 91). Production from 1916 to 1923 included $530,000 in gold and $372,000 in silver. The combined Copper Chief-Equator production totaled $1,087,000 (Elsing and Heineman, 1936, p. 101). A few hundred tons of sulfide ore was mined and shipped to the Humboldt smelter when the price of copper was high (Lindgren, 1926, p. 92; Reber, 1938, p. 56).

During World War II, R. L. d'Arcy and A. B. Peach had a lease on the Copper Chief ore body and produced oxide ore from both ends of the ore body; the east end yielded some oxide copper ore.

The Copper Chief end of the ore body was developed by a shaft 350 feet deep that connected to an adit whose portal was south of the ore body at an altitude of 5,481 feet. Stopes of oxide ore extended from the 240 level to the surface. Withdrawal of ore and waste has formed a large pit at the surface corresponding to the original extent of the gossan.

The Equator end of the ore body was developed by an adit about 80 feet higher than the Copper Chief adit. The Equator adit, with the portal on the east end of the ore body, is about 500 feet long from the portal to the property line. Stoping extended from 15 feet below the adit level to about 70 feet above. A lower adit, 680 feet long at an altitude of 5,344 feet is to the east; no ore was found in it.

GEOLOGY

The Copper Chief ore body is massive sulfide that has replaced highly foliated and sheared Shea basalt and tuffaceous sedimentary interbeds. The Shea basalt has been intruded by quartz porphyry, which at the surface forms the north margin of the ore zone where the contact is essentially vertical and some fault movement is indicated. On lower levels, the quartz porphyry contact dips gently north and the ore zone is wholly within foliated Shea basalt, except for small dikes of quartz porphyry south of the ore zone. Granodiorite porphyry dikes trending north-northeastward cut the Shea basalt, quartz porphyry, and ore zone.

The foliation in the Shea basalt strikes N. 65°–80° E. and dips 50°–75° N. Steeper dips were observed at the surface and lower dips within the mine. The quartz porphyry mass north of the ore zone is poorly foliated.

The Copper Chief fault, named by Reber (1938, p. 55), dips west and northwest at a very low angle, and is exposed at the portal of the upper Equator adit and in the Copper Chief adit (fig. 30). The Copper Chief fault is largely a sheeted zone containing some introduced quartz parallel to the sheeting. The northeastward-trending granodiorite porphyry dikes are displaced to the east in the hanging-wall block, and Reber (1938, p. 56) after a careful study of the displaced dikes reported a horizontal displacement of about 300 feet.

ORE ZONE

The primary ore in the Copper Chief ore body is massive pyritic sulfide shaped as an elongate lens trending N. 80° E. in the highly foliated and sheared Shea basalt, but secondary (oxide) ore extended beyond the limits of the massive sulfide. The surface trace of the ore zone is about 800 feet long; the massive sulfide lens is much shorter and plunges to the east. The massive sulfide replaced the foliated Shea basalt essentially parallel to the foliation so that the southern irregular contact (footwall) dips north. The north margin of the sulfide lens at and near the surface is regular and vertical, controlled by the quartz porphyry contact. On lower levels where quartz porphyry is absent, the north (hanging-wall) margin of the lens dips north parallel to the foliation in the Shea basalt, but is narrower than at the surface.

The western part of the ore body contained a gossan about 60 feet wide and 250 feet long, but the top of the massive sulfide, at a depth of 240 feet, was smaller (Reber, 1938, p. 55). At a depth of 290 feet the sulfide lens was 160 feet long and had a maximum width of 30 feet (fig. 30), and at the 320 level, the massive sulfide bottomed on foliated Shea basalt (Reber, 1938, p. 55).

The top of the gossan plunges eastward and on the surface only a narrow streak of gossan is exposed that follows the quartz porphyry contact to the portal of the upper Equator adit, where a mass of gossan and oxidized copper ore is exposed above and in the Copper Chief fault zone. Massive sulfide is exposed within the adit (fig. 30), within and above the Copper Chief fault; it is strongly brecciated and granulated, proving that the last movement on the Copper Chief fault is younger than the massive sulfide. Near the base of the Copper Chief fault, exploratory workings below the adit level revealed massive sulfide stringers parallel to the foliation in the Shea basalt (N. 65° E., and 60° N.), but the main mass of sulfide was not present below the fault.

According to Reber (1938, p. 55–56) an extensive diamond-drilling program was undertaken on the assumption that the Copper Chief fault cut the ore body; but negative results of this exploration make it fairly certain that there was no downward faulted segment of the Copper Chief ore body, and that the Copper Chief fault merely cuts the bottom of the east end of the massive sulfide lens. Exploration work below the Copper Chief fault did reveal (fig. 30) a small chimney of massive sulfide of about 600 square feet in cross section that trends vertically downward in Shea basalt. Some copper and zinc are reported in the massive sulfide chimney.

In the western workings of the Copper Chief adit, two small thin lenses of massive sulfide were discovered parallel to the foliation in the Shea basalt above the Copper Chief fault (fig. 30). These lenses appear too far north to represent extensions of the Copper Chief ore body and may be downward extensions of gossan exposed on the Wonderful claim west of the Copper Chief ore body, where a little mineralized rock occurs.

The massive sulfide is like the pyritic facies in the United Verde mine and locally contains streaks of chalcopyrite and sphalerite. Galena must be present because of the lead carbonate in the gossan. Chlorite forming black schist is rare and is best observed on the surface at the southwest corner of the pit. The quartz porphyry north of the ore body contains local streaks of chlorite.

A thin zone of secondary enrichment between the massive sulfide and oxide zones contains sooty chalcocite. At the west end of the ore body, the chalcocite zone is from 2 to 5 feet thick, thinning to the east end of the ore body. The chalcocite ore graded downward into sandy pyrite and upward into gossan containing some concentration of copper and lead carbonate minerals. The chalcocite ore is reported to have contained 40 ounces of silver and 0.75 ounce of gold to the ton; the copper content was between 1 and 2 percent.

The oxide zone consists of soft limonitic gossan like that at the United Verde mine, except that the lead content was higher (Reber, 1938, p. 56). The grade of the minable gossan was 0.3 ounce of gold and about 6 ounces of silver to the ton (Lindgren, 1926, p. 91).

RELATIONSHIP OF MASSIVE SULFIDE TO GRANODIORITE PORPHYRY DIKES

The age relationship of the massive sulfide minerals to the granodiorite porphyry dikes cannot be determined with certainty from the accessible underground workings. Some sulfide minerals are clearly younger than the dikes as shown by a quartz vein, 1 inch wide, exposed in the Copper Chief adit, cutting Shea basalt and dike rock. Pyrite is present where the vein cuts the dike, and pyrite and chalcopyrite where it cuts Shea basalt. At the surface, over the eastern part of the ore zone, the granodiorite porphyry dikes contain small stockworks of low-dipping narrow quartz veins containing limonite pseudomorphs after pyrite. When the Copper Chief and Equator mines were more accessible for detailed studies, Reber mapped the underground workings; and from the manner that the dikes cut through the massive sulfide lens, Reber (personal communication) believed that the evidence indicated that the dikes are younger than the massive sulfide lens.

VERDE CENTRAL MINE

The Verde Central mine is on the south wall of Hull Canyon near the Jerome-Prescott highway and about 4,000 feet south of the United Verde mine. The mine was inaccessible in 1952. The mine is owned by Phelps Dodge Corp. The collar of the main shaft is at an altitude of about 5,500 feet, and the bottom is the 1,900 level at an altitude of 3,584 feet. Besides the development work in the productive area, extensive exploratory work was done to the south on both the 100 and 1,000 levels, and a long crosscut was driven to the west on the 1,450 level.

The Verde Central ore zone is along the east margin of the quartz porphyry in contact with the Deception rhyolite. The contact is irregular and interfingering, and dike-offshoots of porphyry cut the rhyolite. The Verde Central was a blind prospect, and the only outcrop of oxidized copper is at the top of the hill, southeast of the main workings.

Two ore bodies were found in the Verde Central mine. One, at the Deception rhyolite quartz porphyry contact, extended south from the shaft, where black schist contained spotty copper showings. This ore body extended from above the 800 to below the 1,000 levels and was about 200 feet long and 9 feet in average width (Reber, 1938, p. 57).

The other, a much larger ore body is a tabular veinlike body of quartz, pyrite, and chalcopyrite in Deception rhyolite east of the main body of quartz porphyry. The vein strikes northwest and dips east, and although irregular in detail, ranges in width from 5 to 30 feet. On the 1,000 level, the vein ore body is essentially continuous for more than 1,000 feet. According to Reber (1938, p. 57), this ore body extends nearly to the top of the mine, and "is fairly strong at the bottom." Chalcopyrite is subordinate to quartz and pyrite, but ore shoots averaging nearly 3 percent copper could be mined. Below the 600 level, such ore made up a part of the vein.

High copper prices were needed to allow the Verde Central to produce copper profitably, and the net profit on the past production plus the potential profit from developed ore remaining in the mine would fall short of returning the cost of exploratory work (Reber, 1938, p. 57).

The appearance of quartz, pyrite, chalcopyrite, and chlorite (black schist) indicates the presence of mineralized rock like that in the United Verde mine. The restriction of chalcopyrite to vertical shoots in the vein indicates a break between pyrite and chalcopyrite, as in the United Verde mine. But there is not much indication that the black schist followed the main pyrite deposition, as in the United Verde mine; for the most part, the black schist appears to be localized along the quartz porphyry contacts. The low content of precious metals may be related to the scarcity or absence of tetrahedrite, galena, and sphalerite, common as minor constituents in the United Verde deposit (Reber, 1938, p. 57).

SHEA MINE

The Shea mine was owned and operated originally by the Shea Copper Co. The holdings consisted of 16 patented claims and 3 unpatented claims. The property is now owned by Phelps Dodge Corp. The mine is located south of the Copper Chief mine on the north side of an east-striking vein that dips south at an average of 42°; at the surface the dip is steeper. The vein was developed by an incline on the vein, 1,220 feet on the incline or 825 feet vertically. The lower tunnel level reached the surface at about 1,300 feet east of the shaft. About 3,000 feet of drifts are on this level. Work on all levels totals about 7,000 feet (Reber, 1938, p. 58).

Production amounted to $65,000 worth of silver, copper, and gold, obtained from 1,200 to 1,300 tons of sorted shipping ore. Silver accounted for 80 percent of the value (Reber, 1938, p. 59).

The Shea basalt is greatly altered near the Shea vein, and chlorite, sericite, epidote, quartz, and carbonate minerals (ankerite? and calcite?) are common. Northward-trending dikes of granodiorite porphyry cut the Shea basalt and are in turn cut by the Shea vein. The dike rocks are strongly sericitized near the vein.

The vein minerals were deposited in a normal fault that has a probable throw of about 100 feet. The vein crops for about 1,200 feet east of the portal of the main adit; its total length is more than 3,400 feet. The surface exposure ends less than 200 feet west of the main shaft where the low-dipping Copper Chief fault cuts off the Shea vein. Both the most western and the eastern parts of the vein contain lenticular and discontinuous vein quartz. Throughout the mine the vein quartz does not average more than a foot in width, although in the ore shoot, the vein exceeds 5 feet.

A large part of the vein consists of coarsely crystalline quartz containing scattered pyrite and a few bunches of coarse ankerite or siderite and pyrite with some chalcopyrite. Locally, some arsenopyrite and tetrahedrite are present. The tetrahedrite, carrying only a little arsenic, contains 600 ounces or more of silver to the ton. Where sulfide minerals including tetrahedrite are most abundant, the vein has a banded structure. Near the ore shoot, sparse galena is present in quartz veinlets cutting the older quartz.

Mining was limited to one locality, on the 300 level from 300 to 400 feet west of the shaft to where the Shea vein is cut off by the low-dipping Copper Chief fault. Near the top of the ore shoot, native silver was associated with tetrahedrite.

The Copper Chief fault is partly mineralized, and above the Shea ore shoot several tons of barite were exposed in the low-dipping fault. The barite is not definitely associated with any other vein material and may be younger than the sulfide.

DUNDEE-ARIZONA COPPER CO.

The Dundee-Arizona Copper Co. owns two patented claims covering the ridge east of the town of Jerome and north of the Jerome-Clarkdale highway. The deposit is of interest because chrysocolla-bearing Verde gravel deposits have yielded the only production. From February 1942 to July 1947, at which time premiums on copper were discontinued, Mark Gemmill, in a leasing operation, mined about 100 tons per week of hand-sorted ore that averaged about 4½ percent copper. The ore was shipped to the smelter at Clarkdale.

In 1920, a shaft was sunk 950 feet. The collar is in Verde gravel deposits, and the shaft cut through the Martin limestone, Tapeats sandstone(?) at the 500-foot level and into Precambrian rocks for an additional 450 feet. Lateral exploration on the 950 level amounted to 2,750 feet. Precambrian rock fragments on the dump include quartz porphyry, Deception rhyolite, and gabbro. Apparently no copper was found in the Precambrian rocks.

The base of the Verde gravel has been explored by 3 levels for a length of 700 feet and width of 80 feet. The portal of the lower level, an adit, is 200 feet southeast of the shaft at an altitude of 4,625 feet. To the west, the two higher levels at altitudes of 4,644 and 4,675 feet, connect by raises to the adit level.

The gravel commonly consists of pebbles, cobbles, and boulders of basalt and limestone, resting on the Martin limestone. The ore consists of chrysocolla-bearing gravel, locally forming ore zones from 4 to 5 feet thick. The blue-green chrysocolla coats and replaces the pebbles and cobbles and fills fractures in the underlying Martin limestone. The chrysocolla forms a mammillary coating on the pebbles, associated with some chalcedony. According to Lindgren (1926, p. 90) the copper-bearing solutions, undoubtedly derived from the oxidation of the United Verde deposit, must have carried cupric sulfate with a great abundance of silica; for otherwise, the copper carbonate minerals would have formed by reaction with the limestone.

PROSPECTING OPERATIONS IN THE VERDE MINING DISTRICT

Much exploratory work was done south and north of Jerome in hopes of finding ore bodies like the United Verde and United Verde Extension. Many millions of dollars was spent without encouraging results, and Reber (1938, p. 42) stated "Away from the quartz-porphyry belts, two to three of the prospecting companies developed enough ore to supply the stockholders with specimens." Most of the properties are closed and inaccessible and practically all the information given below is taken from Lindgren (1926, p. 93–97).

Grand Island Mining Co.—This company owned property south of the Shea mine (1,346,400 N.; 447,400 E.) and sank a shaft 520 feet deep with a southwest crosscut on the 200 level. The shaft was sunk where one of the northward-trending granodiorite dikes intersects the low-dipping Copper Chief fault. The fault is locally silicified and mineralized, and a short thick lens produced more than 100 tons of high-grade copper-gold ore. There was little tetrahedrite, and pyrite carried the gold (Reber, 1938, p. 59). The property is now owned by Phelps Dodge Corp.

Green Monster Mining Co.—A large block of claims north and northeast of the Copper Chief is owned by this company. The main shaft is east of the Verde fault and north of the road leading to the Copper Chief mine (1,351,000 N.; 453,000 E.). Precambrian rocks are exposed in the canyon below the Tapeats sandstone(?), and the collar of the shaft is in quartz porphyry. Fragments of quartz porphyry, Shea basalt, and tuffaceous sedimentary rocks are on the dump. Specular hematite veinlets appear in many fragments, but no sulfide minerals were observed. According to Lindgren (1926, p. 94), the shaft is 930 feet deep and on the 500 level, a northwest crosscut contacted the quartz porphyry containing chalcocite and chalcopyrite in a highly leached zone. West of the Green Monster shaft and of the Verde fault, an adit level containing about 800 feet of workings, explored a northeastward-trending gossan. It is reported that some gold was found.

The Cliff claim is near the western boundary of the Green Monster property and north of the Copper Chief mine (1,350,700 N.; 448,200 E.). Two extensive adit levels prospected a small zone of mineralized quartz porphyry at the southern contact with the Shea basalt. The lower adit, inaccessible in 1947, contains about 1,400 feet of workings, whereas the upper adit contains about 800 feet. Two short adits, each 90 feet long, cut the upper eastern part of the mineralized zone, and a short shaft connects to one of these adits. The copper minerals appear to be controlled by an eastward-trending shear zone, dipping 70° N. and from 6 to 8 feet wide. The quartz porphyry locally contains appreciable chlorite in streaks parallel to the shear zone. Copper carbonate is common at the surface and coarse pyrite and some chalcopyrite are on the dumps. Work was discontinued on the property in 1919 (Lindgren, 1926, p. 94).

Jerome Del Monte Copper Co.—This company owns a large group of claims most of which are east of the Verde fault and north of the Green Monster property. The Jerome Del Monte property extends from north of Mescal Gulch to south of Del Monte Gulch. In 1917, a three-compartment shaft (1,358,300 N.; 451,400 E.) was sunk in limestone to 500 feet, at which depth water was found.

Gadsden Copper Co.—West of the Jerome Del Monte property and about 1½ miles southeast of Jerome, 39 claims are owned by the Gadsden Copper Co. Most of the claims are east of the Verde fault and extend from north of Mescal Gulch to south of Del Monte Gulch. A four-compartment shaft (1,362,000 N.; 445,200 E.) was sunk 1,200 feet deep, which connects 5,619 feet of drifts and crosscuts. The shaft was sunk through limestone and reached the Precambrian rocks at a depth of 400 feet. On the 1,200 level, the rocks are predominantly Deception rhyolite cut by one or two dikes of quartz porphyry. The Verde fault was cut 1,450 feet to the west of the shaft on the 1,200 level. It was reported that ore was found southwest of the shaft that contained from 8 to 10 percent copper, 3 ounces of silver to the ton, and 0.15 ounce of gold to the ton. No information is available as to the size of this ore body; operations discontinued in 1920 (Lindgren, 1926, p. 94).

Verde Combination Copper Co.—Property owned by this company includes a large group of claims south of Mescal Gulch and west of the Verde fault. A shaft, 1,300 feet deep, was sunk west of the Verde fault and a short distance south of Mescal Gulch (1,359,500 N.; 444,500 E.). The shaft was started in Deception rhyolite; and on the dump, fragments of chloritized Deception rhyolite contain seams of pyrite. No copper minerals were observed. Lindgren (1926, p. 94) reports that the underground workings showed a 2-foot fissure vein of 5 percent copper ore.

Pittsburgh-Jerome Mining Co. — This company owned 21 patented claims in the upper part of Mescal Gulch and did prospecting for 16 years, ending in 1921. Phelps Dodge Corp. now owns the property. The exploration work consisted of driving an adit (1,354,500 N.; 439,700 E.) 1,279 feet long, and sinking a connecting shaft, 900 feet deep, 1,000 feet west of the portal. The rocks exposed are the Deception rhyolite, including flow and fragmental rocks and andesitic pyroclastic interbeds. Small clots of intensely chloritized rhyolite are common, particularly in the area that was prospected between the two forks of Mescal Gulch. Malachite in bleached rocks and stringers of chalcocite in rock fragments have been found on the dump.

Cleopatra Copper Co.—This company owned claims in Hull Canyon, south of the United Verde mine; the property is now owned by Phelps Dodge Corp. The principal adit is the Dillon tunnel, 3,200 feet long, which connects to the north with the United Verde 500 level. The rocks on this property are Deception rhyolite and quartz porphyry. North of the Hull fault in quartz porphyry, some copper sulfide is present in irregular quartz stringers and small blebs of massive sulfide. Some ore was shipped and a small smelter was built in the lower part of Deception Gulch west of the Verde fault. A small slag pile is all that remains.

Calumet-Jerome Copper Co.—A small group of claims south of Deception Gulch and to the west of the Verde fault was formerly owned by this company. The property is now owned by Phelps Dodge Corp. A shaft 600 feet deep was sunk just to the west of the Verde (1,361,000 N.; 441,800 E.). It is reported that a crosscut extended west from the shaft on the 600-foot level for 1,800 feet. The underground workings total 7,000 feet. The fragments on the dump are of Deception rhyolite in part chloritized and containing quartz veinlets with pyrite. Lindgren (1926, p. 95) states that chlorite schist rich in chalcopyrite was reported in 1922.

Jerome-Grande Copper Co.—The Verde Grande Copper Co., later reorganized as the Jerome-Grande Copper Co., owned a small group of claims north of Hull Canyon and east of the Warrior fault. The property is now owned by Phelps Dodge Corp. A shaft, 838 feet deep, was sunk east of the Warrior fault (1,361,500 N.; 435,000 E.) and connects with about 2,000 feet of underground workings. The collar of the shaft is in Grapevine Gulch formation. It is reported that the sump is in gabbro and that on the 800 level, a contact of gabbro and quartz porphyry showed some pyrite and chalcopyrite. Lindgren (1926, p. 96) states "The mine was opened with the object of finding the southward extension of the United Verde ore bodies, but this object was not attained."

Arkansas & Arizona Copper Co.—A large group of claims north of the United Verde mine and east of the Verde fault is owned by this company. A shaft (pl. 1, 1,370,000 N.; 438,000 E.), 1,600 feet deep, was sunk through Tertiary basalt and Paleozoic limestone, entering Precambrian rocks at 800 feet. The Verde fault was intersected by a drift, 400 feet west of the shaft. On the 1,600 level, gabbro was found 500 feet southeast of the shaft. Deception rhyolite and quartz porphyry are present elsewhere on this level as well as Tertiary basalt dikes. Reports are conflicting as to whether or not ore was found on the 1,600 level, near the Verde fault.

Jerome Superior Copper Co.—This company owns a very large area of claims north of the Verde Tunnel and Smelter Railroad tract in the Clarkdale quadrangle, and some distance east of the Verde fault. About 3 miles west of Clarkdale (1,374,000 N.; 444,200 E.) a shaft, collared in Verde gravel, was sunk 900 feet. On the dump abundant fragments of quartz porphyry and

Grapevine Gulch formation indicate that the shaft bottomed in Precambrian rocks. It is reported that encouraging showings of chalcocite and chalcopyrite were found, but only pyrite was observed on the dump.

BIG BUG MINING DISTRICT

By S. C. Creasey

The Big Bug mining district, one of the oldest in the region, is bounded on the east by the Agua Fria River and on the north by Lonesome Valley. The district extends south to include the Blue Bell mine (fig. 9), but only the northern part of the district has been studied for this report. The most productive mine and only mine operating in 1952 in the district is the Iron King lead-zinc mine. The McCabe-Gladstone mine was an important early producer of gold and silver, and the Arizona National and Silver Belt mines have produced lead-silver from the same vein. These mines are inactive. The northern part of the Big Bug district has been included in this report because of the increasing importance of the Iron King mine.

The available records (to 1952) indicate that the above-named mines in the Big Bug mining district have produced 321,500 ounces of gold, about 8,500,000 ounces of silver, 3,773 tons of copper, 37,537 tons of lead, and 104,599 tons of zinc.

IRON KING MINE

PRODUCTION

From 1906 to January 1, 1952, the Iron King mine produced about 211,486 ounces of gold, 6,624,101 ounces of silver, 72,573,620 pounds of lead, 209,199,140 pounds of zinc, and 6,345,740 pounds of copper from about 1,640,060 tons of ore (table 24). The average grade of all ore mined on the 400 level and lower levels through 1951 was $7 per ton in gold and silver, 2.21 percent lead, and 6.378 percent zinc. Dollar value of gold generally was about twice that of silver. Samples of the concentrates and tailings were analyzed for selenium by the Geological Survey with the following results: lead concentrate 0.07 percent; zinc concentrate 0.03 percent; pyrite concentrate 0.02 percent; and tailings 0.005 percent.

Table 24.—*Production of recoverable metals, Iron King mine, Humboldt, Ariz.*

[Production data supplied by and published with the permission of Shattuck Denn Mining Corp.]

Year	Tons	Gold (ounces)	Silver (ounces)	Lead (pounds)	Zinc (pounds)	Copper (pounds)
1906–38 [1]	78, 452	15, 690	313, 808	3, 138, 080	6, 276, 160	470, 700
1938 [2]	13, 477	2, 317	45, 938	404, 300	1, 078, 160	67, 400
1939	70, 227	9, 911	272, 604	1, 872, 680	5, 854, 020	351, 120
1940	65, 812	9, 239	266, 497	1, 891, 060	7, 220, 440	329, 060
1941	69, 159	9, 720	331, 746	2, 320, 040	7, 617, 100	345, 800
1942	88, 200	11, 659	392, 458	3, 540, 100	10, 585, 560	441, 000
1943	73, 721	9, 167	307, 465	3, 164, 380	10, 095, 300	220, 720
1944	99, 164	9, 460	308, 567	3, 611, 660	13, 623, 860	423, 820
1945	117, 287	13, 068	436, 506	5, 259, 640	16, 156, 180	455, 280
1946	115, 615	13, 065	467, 387	5, 734, 280	16, 875, 320	485, 780
1947	122, 368	15, 298	533, 642	6, 194, 880	16, 925, 320	411, 820
1948	145, 823	17, 036	540, 548	6, 854, 120	19, 048, 100	453, 020
1949	175, 111	21, 432	737, 925	8, 414, 680	23, 547, 440	546, 660
1950	203, 063	27, 289	904, 284	10, 645, 040	28, 220, 800	686, 460
1951	202, 581	27, 135	764, 731	9, 528, 680	26, 075, 380	657, 100
Total	1, 640, 060	211, 486	6, 624, 101	72, 573, 620	209, 199, 140	6, 345, 740

[1] Production before milling.
[2] Last 3 months of milling.

DEVELOPMENT AND MINING [8]

Shaft 1, the oldest on the property, is located between shafts 2 and 5; only the dump is shown on plate 11, as the collar is caved. Shaft 1, 100 feet deep, serves only for ventilation. Shaft 2 (pl. 11, 3,000 N.; 4,050 E.), 650 feet deep has 2 compartments, and although the head frame is still standing, it serves only as an emergency exit. Shafts 3 and 4 are caved, and records do not indicate their location. Shaft 5 (pl. 11, 2,360 N.; 3,830 E.), 200 feet deep, has 2 compartments; it is used only for ventilation. Shaft 6 (pl. 11, 3,390 N.; 4,070 E.) has 3 compartments with steel head frame, and is the main working shaft of the mine for hoisting ore, men, and supplies. A new working shaft, No. 7, was being sunk in 1952; it is north of shaft 6, beyond the limit shown on plate 11.

Levels are established at 100-foot intervals, and in 1952, ore was being extracted from the 1,300 level, development work was in progress on the 1,400, 1,500, and 1,600 levels and a station was being cut on the 1,700 level of shaft 6.

Drifts are along the veins, and raises extend above them to explore and prepare ore for stoping. The first ore was mined in the oxidized zone about the 200 level. Apparently, ore was mined through shaft 2 from the 200 to the 600 level until shaft 6 was ready for hoisting ore. The exploitation of the mine to the 600 level was not difficult. Walls stood well and the ore was mined and drawn by shrinkage stoping without noticeable dilution, and it was not necessary to fill the stopes with waste. As the mine was further explored to the north at lower levels, the hanging-wall (west) side of the veins became weaker, and in 1946, cut and fill methods were adopted for stoping. Waste for stope fill was obtained by blocking caving barren schist over the north end of the 600 level.

For some years, the development drifts also served as haulage drifts, but the cost of maintenance became excessive, and these haulage drifts are now driven in the firm footwall (east) side of the mineralized zone, and crosscuts are driven at 100-foot intervals across the

[8] Most of the information in this section was taken from Kumke and Mills (1950).

mineralized zone which serves to explore the zone as well as give access to draw points under the stopes.

Mills (1941, 1947) has described the history, ore occurrence, and mining methods; and Hendricks (1947) has reported on the milling practice.

GENERAL FEATURES

The Iron King deposit is a system of 12 westward-dipping massive sulfide veins that are oriented en echelon in a mylonitic sheared zone characterized by a pronounced foliation. The andesitic tuffaceous unit of the breccia facies of the Spud Mountain volcanics forms the wall rock, but on the west or hanging-wall side of the veins, hydrothermal alteration—chiefly silicification, sericitization, and pyritization—modified the rocks, so that in many places the original rock cannot be determined. Reverse strike faults cut the veins; the vertical separation of the faulted veins is generally less than 120 feet.

OLDER PRECAMBRIAN ROCKS

SPUD MOUNTAIN VOLCANICS

The Iron King deposit is in the upper unit of the Spur Mountain volcanics. West of the Iron King deposit, this upper unit comprises interbedded coarse- and medium-grained andesitic tuff, a minor amount of fine-grained tuff, and at least one bed of breccia. The coarser grained tuff abounds in large saussuritized plagioclase crystals or their sheared equivalent, so characteristic of the Spud Mountain volcanics. Undoubtedly, many of these coarse-grained beds originally were crystal tuffs. The interbedded medium-grained tuffs are like the matrix of the crystal tuffs.

East of the Iron King deposit, crystal tuff and conglomeratic beds are absent, and the andesitic tuffaceous unit consists chiefly of alternating beds of medium- and fine-grained andesitic sedimentary tuff. In addition, a rhyolitic tuff and conglomerate bed about 200 feet thick crops out about 500 feet east of the Iron King deposit (pl. 11). The fine-grained andesitic tuff is much more abundant east of the deposit than west. Judging from relicts, the rocks in the zone now occupied by the Iron King deposit (including the hydrothermally altered rocks) did not include any beds of crystal tuff.

IRON KING VOLCANICS

Basalt of the Iron King volcanics crops out about 800 feet east of the Iron King deposit (pl. 11). It consists of grayish-green lava and minor amounts of intercalated sedimentary andesitic-basaltic tuffaceous rock. The lava is well foliated, but relict amygdules of quartz, carbonate, and epidote minerals are abundant. Chlorite and saussuritized plagioclase are the most abundant megascopic minerals.

TERTIARY ROCKS, HICKEY FORMATION

The Tertiary Hickey formation comprises the alluvial fill in the south end of Lonesome Valley. Near the Iron King deposit, it consists of boulders and cobbles crudely sorted in thick beds and intercalated with minor amounts of finer sediments. The Hickey formation, in large part, covers the alteration zone and veins of the Iron King deposit with as much as 500 feet of gravel. Underground openings have exposed the veins for more than 2,000 feet north of the point where they plunge beneath the gravel.

RHYOLITIC DIKE

A light-colored rhyolitic dike crops out about 700 feet east of the Iron King deposit. It is about 15 feet wide and extends from beneath the alluvial fill of Lonesome Valley south-southwestward for about 1,950 feet. A smaller rhyolitic dike of similar composition crops out about 300 feet south of the end of the larger one, and extends southward beyond the limit of the area shown on plate 11.

The dike rock is spherulitic. Thin sections reveal that the rhyolite consists of irregular-shaped, microscopic grains of quartz embedded in a cryptocrystalline base.

The rhyolitic dike is younger than the youngest dynamic metamorphism, which is Precambrian, but there is no way of dating it precisely. In the Bradshaw Mountains, rhyolitic porphyry dikes have been mineralized, and Lindgren (1926, p. 24) has tentatively dated them as Cretaceous or Tertiary. It appears likely that the dike in the Jerome area is one of these rhyolite porphyry dikes.

STRUCTURE

The Precambrian rocks near the Iron King deposit have been folded, faulted, and foliated, and transformed into mineral assemblages stable under low-grade metamorphism. At least two periods of deformation took place, resulting in complex structures.

An early period of deformation resulted in foliation trending northward in the breccia facies of Spud Mountain volcanics lying west of the Iron King deposit (pl. 6). The northeastward-trending folds and foliation, however, nearby and to the east may or may not have formed at the same time as those trending northward. The later deformation resulted in faults and foliation trending northeast and in lineation plunging steeply north. Foliation resulting from the later period or periods of deformation cuts the earlier northward-trending foliation in the breccia unit of the Spud Mountain volcanics (pl. 6, 1,270,500 N.; 390,000 W.), but parallels or accentuates the earlier foliation near the deposit. The shearing that localized the Iron King deposit was probably part of the later deformation. The early phase of mineralization occurred before the end of this deformation, for the minerals introduced by this phase were subsequently granulated and foliated.

The intense deformation of the rocks near the Iron King mine was regional in extent. The rocks are isoclinally folded, nearly all dips are steep, and many of the beds are overturned. Foliation formed concomitant with folds, resulting in approximate parallelism of axial planes of folds and foliation with the possible exception of the northward-trending foliation west of the Iron King mine (pl. 6). On the limbs of folds, bedding and foliation are parallel; but on crests and troughs, they are discordant. Within this disturbed terrane, the Iron King deposit lies in the middle limb of a fold between a syncline to the east and an anticline to the west (pl. 6). Here bedding and foliation are essentially parallel.

Faults undoubtedly are far more abundant near the deposit than is indicated (pls. 1 and 11). Faults are difficult to recognize partly because of lack of marker beds in the Iron King and Spud Mountain volcanics, and partly because of coincidence with foliation. Considerable movement along a relatively narrow zone in the foliated rocks might not be recognized, as deformation was so penetrative and intense that all units and structural elements tend to be parallel.

THE IRON KING DEPOSIT IN RELATION TO REGIONAL STRUCTURES

The Iron King deposit was localized in a sheared and deformed zone essentially parallel to the regional foliation. In this zone, cataclasis rendered much of the rock a fine- to very fine-grained fissile phyllite, but locally relicts of coarser grained andesitic tuff testify to the former similarity to the andesitic tuff adjacent to the deposit. Sporadically, the more fissile facies have been contorted, buckled, or gently flexed into wavelike structures during cataclasis, or by later deformation, or by both. After this deformation, early vein minerals were introduced, and the rocks hydrothermally altered; then renewed deformation once again granulated the early vein minerals. For example, vein quartz so mylonitized is now granoblastic except for a few relicts of bladed quartz with ragged or sutured boundaries (pl. 13*A*), and some quartz recrystallized in the pressure shadows of deformed or recrystallized grains of pyrite. A still later and apparently independent deformation superimposed a fracture cleavage on this intensely deformed zone.

This intense and recurrent deformation possibly was related to the same forces that produced the regional metamorphism, even though the later shearing took place after the rocks were foliated. Lineation is the common feature. Lineation (mineral streaking) in the walls of the veins and lineation that marks the northward plunge of the north ends of the veins both parallel lineation in the nearby rocks. This parallelism attests to the similarity of the stress fields during regional metamorphism and during the localized shearing that permitted access to the mineralizing solutions or fluids. It thus seems most probable that both are integral parts of one long and complex period of deformation. Postmineral structural features are discussed on page 168.

DEPOSITIONAL HISTORY

Before deposition of early hydrothermal minerals and possibly toward the close of the foliation-producing deformation, shearing disrupted the continuity of the regionally foliated terrane and produced a local sheared zone of pronounced foliation. Tuffaceous beds of differing competence may have localized the shearing. In this sheared zone, pyrite, ankerite, quartz, and sericite were deposited. Along the east or footwall side of the sheared zone, quartz, pyrite, and ankerite were concentrated in echelon shears forming well-defined veins. West of the veins, these minerals and sericite were deposited as disseminations and as narrow veinlets alternating with schistose rock. These early veins probably were similar in form to the present ones; the quartzose north ends of the veins are relics of the early mineralized zone.

Later the early veins and the sporadically mineralized zone to the west were intensely sheared. There is no reason to suspect a time gap between deposition of early minerals and the second period of shearing, which may have interrupted deposition of the early minerals.

The second period of shearing mylonitized the northern parts of the veins, producing poorly defined planar structures that cut at an acute angle from the footwall to the hanging wall. Subsequently, sphalerite, arsenopyrite, galena, tennantite, sparse chalcopyrite, sericite, and probably pyrite, ankerite, and quartz were deposited in the fabric produced by the later period of shearing. The similarity of distribution of zinc plus lead and gold plus silver (figs. 31, 32, 33) indicates that all productive veins had identical histories of mineral deposition and probably all formed simultaneously.

North-end quartz largely escaped base-metal mineralization possibly because of its monomineralic and more massive character. Quartz "noses" were present before the ore-forming minerals, for the quartz is cut by veinlets containing ore minerals and the texture of the quartz is chiefly granoblastic-cataclastic, indicating strong deformation, plate 13*A*.

Locally high precious-metal content in quartz is difficult to interpret. Perhaps the location of greatest concentration of precious metals north of greatest concentration of base metals suggests that the peak of mineral deposition of the precious metals was offset from that of the base metals. There is no compelling evidence to place gold in the base-metal period—silver, providing it is chiefly in tennantite, is definitely associated with galena, hence, came in during the later period.

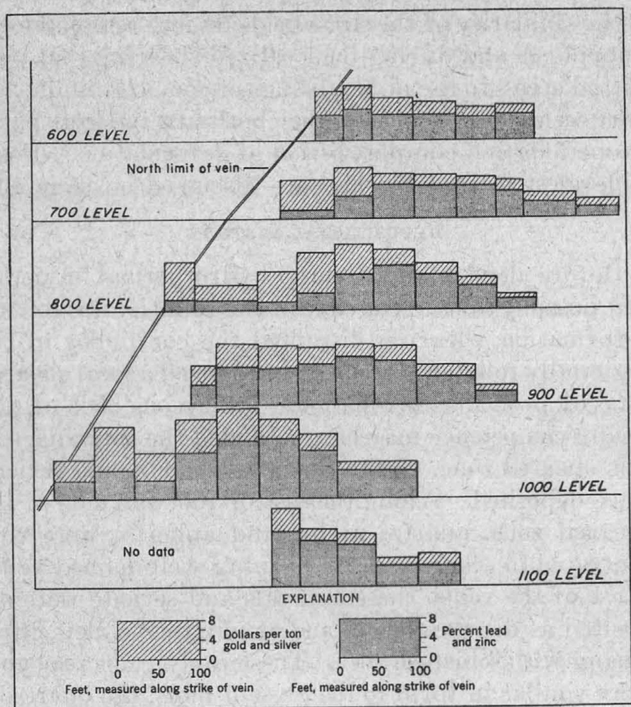


FIGURE 31.—Graph showing grade of ore, *G* vein, Iron King mine. Data furnished by Shattuck Denn Corp.

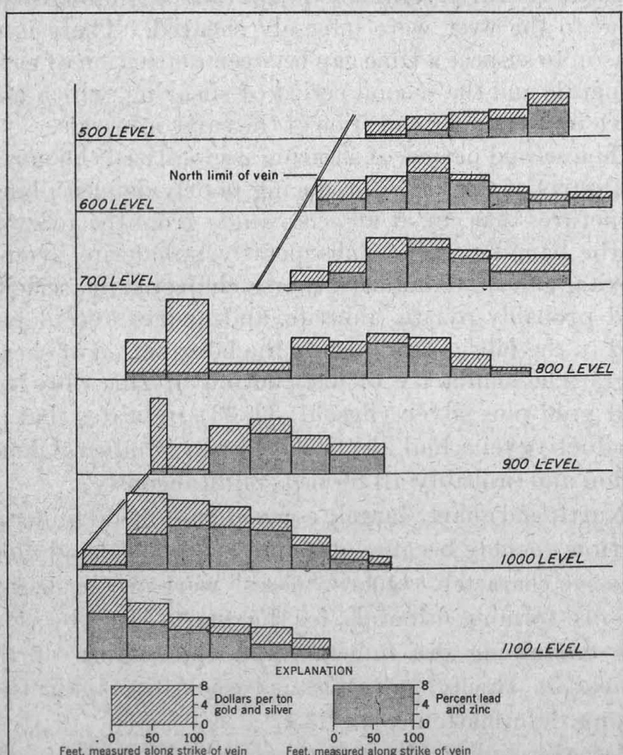


FIGURE 32.—Graph showing grade of ore, *F* vein, Iron King mine. Data furnished by Shattuck Denn Corp.

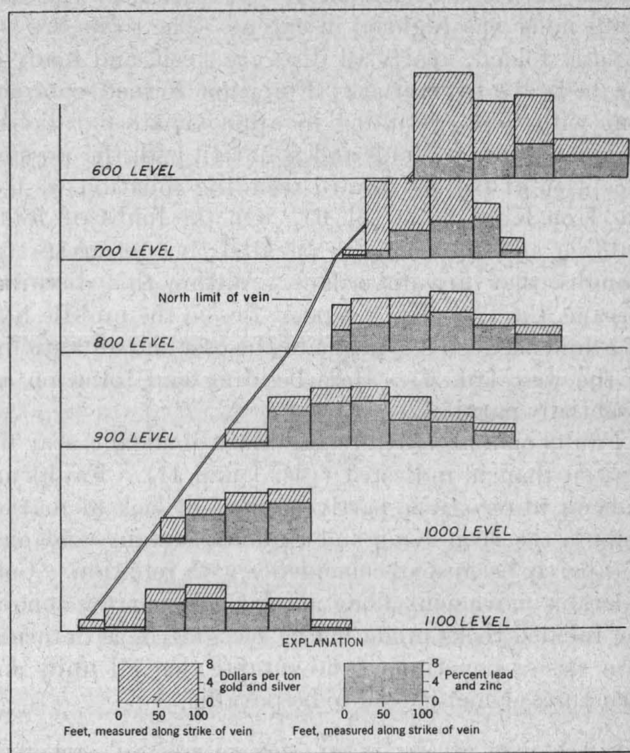


FIGURE 33.—Graph showing grade of ore, *D* vein, Iron King mine. Data furnished by Shattuck Denn Corp.

HYDROTHERMAL ALTERATION

Designation of the early phase of mineral deposition as hydrothermal alteration is arbitrary, but useful in distinguishing between (1) early widespread introduction of gangue minerals and (2) ore-forming minerals concentrated in the veins. Deformation, manifested by shearing, provides the basis for separation, although no break in mineral deposition is implied.

The minerals introduced during hydrothermal alteration are quartz, pyrite, ankerite, sericite, and probably apatite. A second generation of sericite and ankerite, later than the ore minerals, is described in this section for convenience. Quartz occurs in disseminated granoblastic grains as a general silicification and in veinlets associated with pyrite and ankerite. The strong shearing that followed the introduction of the hydrothermal minerals makes it impossible to distinguish introduced quartz, unless it is in veinlets from quartz originally present in the metamorphic rocks, even though quartz is more abundant in the altered rocks. The texture of the quartz in veinlets is largely granoblastic, but a few patches of relict bladed quartz remain.

Pyrite occurs as individual crystals disseminated in the altered rocks and as veinlets associated with other alteration minerals. A series of individual crystals of pyrite along a given "folium" is common in rocks in underground openings of the mine. Brown-stained cavities in outcrops mark the distribution of pyrite in altered rock. Ankerite is abundant, occurring as disseminated grains and as veinlets, commonly associated with pyrite and quartz. Ankerite apparently accompanies both early and late stages of mineral deposition, and it veins the last-stage sulfide minerals.

There are two generations of sericite. The early sericite is disseminated in the alteration zones, and the late sericite, with ankerite, is concentrated locally near the northern parts of the veins. The early sericite is in flakes and "ribbons" concordant with foliation. The "ribbons" anastomose through the rocks, in places dividing and rejoining. The sericite grew with its basal plane parallel to the shear planes that controlled its distribution.

Within the veins, late sericite in microscopic veinlets cuts quartz, pyrite, ankerite, and sphalerite, and individual flakes lie in the cleavage planes in ankerite and in pressure shadows of pyrite, transverse to planar structures in the vein material. Filmlike veinlets of sericite cut the quartz at the north ends of the veins and commonly separate this quartz from the remainder of the vein. Residual screens of wall rock in veins commonly are rich in sericite. Adjacent to the veins, sericite of this generation is restricted to narrow selvages that generally widen around the north ends of the veins to masses as much as 10–20 feet across.

In the wall rocks, spatial distribution is the only basis for distinction between early- and late-stage sericite. The sericite in the veins is clearly younger than the ore minerals, and it is assumed that the local concentrations of sericite adjacent to the veins are of the same age. The sericite disseminated throughout the alteration zone has the same distribution as the pyrite, ankerite, and quartz with which it is assumed to be contemporaneous. No reliable textural criteria were found for distinguishing early from late sericite in wall rocks, for here sericite lies with its basal section parallel to the foliation whether it formed before or after the intramineral deformation that is the basis for distinction between the hydrothermal alteration stage and the ore-forming stage.

Thin sections from outcrops of the hydrothermal alteration zone contain a small amount of a probable clay mineral that has a negative $2E$ of about 35° and a birefringence near 0.010. The indices of refraction could not be determined from thin sections and not enough was found for determination in oil mounts of powdered rocks. The clay(?) mineral occurs as irregular microscopic masses composed of fibers or narrow plates commonly oriented at right angles to the long dimensions of the masses and to the foliation in the rock. Growth of fibers or plates perpendicular to foliation indicates that the clay(?) mineral formed after the last period of deformation. This clay(?) mineral, which is probably from the kaolin group, was not recognized in rocks from underground and accordingly is believed to be a weathering product. The mineral probably formed in an acid environment produced by oxidization of pyrite. Bateman (1927, p. 585) has described kaolinization owing to oxidation of sulfide minerals in sericitic alteration zone near massive pyrite deposits of Rio Tinto, Spain.

Table 25 gives the results of chemical analyses of the fresh and altered tuffaceous rock from the Iron King deposit. Analysis 1 is the relatively unaltered mafic tuff, which is basaltic in composition; 2 is the analysis of the silicified, sericitized, and pyritized rock forming the hanging-wall alteration zone; and 3 is the sericitized and carbonatized rock that encloses the north ends

TABLE 25.—*Chemical analyses of unaltered and altered rocks, in percent*

	1	2	3	4	5
SiO_2	48. 38	59. 12	41. 88	48. 50	58. 70
Al_2O_3	12. 18	12. 13	11. 72	18. 10	20. 45
Fe_2O_3	2. 90	. 29	. 45	4. 66	. 11
FeO	[1] 10. 44	[1] 9. 91	[1] 8. 84	4. 86	2. 05
MnO	. 21	. 16	. 17	------	------
MgO	3. 67	5. 95	4. 33	5. 67	Tr.
CaO	7. 81	1. 11	9. 85	7. 10	. 50
BaO	. 01	. 02	. 09	------	------
K_2O	. 11	1. 45	2. 45	None	1. 88
Na_2O	2. 80	. 48	. 50	6. 64	3. 38
TiO_2	1. 76	. 56	. 51	------	------
H_2O-	. 14	. 12	. 20	------	------
H_2O+	3. 69	3. 70	2. 14	. 38	1. 05
S	. 36	4. 58	1. 07	------	------
P_2O_5	. 30	. 12	. 10	------	------
CO_2	5. 61	1. 51	16. 17	2. 46	. 02
N_2O	------	------	------	. 12	. 14
$BaSO_4$	------	------	------	Tr.	1. 50
FeS_2	------	------	------	. 12	9. 58
$CuFeS_2$	------	------	------	None	. 36
	100. 37	101. 21	100. 47	98. 61	99. 72
Less O for S[2]	. 09	1. 15	. 27		
Total	100. 28	100. 06	100. 20		
Bulk densities	2. 81	2. 78	2. 85		
Powder density	2. 86	2. 87	2. 90		

[1] In the usual method of determining ferrous iron, pyrite is not dissolved and the ferrous iron so present will be missed. In these analyses a correction was made by calculating the ferrous iron in the pyrite from the amount of sulfur present. It was assumed that all sulfur is present as pyrite and that the formula for pyrite is FeS_2.

[2] Based on the assumption that all sulfur is present as pyrite.

1. Unaltered mafic tuff, 900 level, Iron King mine.
2. Altered rock, quartz-sericite-pyrite facies, 900 level, Iron King mine.
3. Altered rock, sericite-carbonate facies, 900 level, Iron King mine. Analyses 1, 2, and 3 by Robert N. Eccher.
4. Fresh uralite-schist from a vertical depth of 420 feet and 100 feet from the Americansky ore body, Ural Mountains, Kyshtim, Russia.
5. Sericite-schist from a vertical depth of 520 feet and 2 feet from the Americansky ore body, Ural Mountains, Kyshtim, Russia. Analyses 4 and 5 after Stickney (1915, p. 630).

of the veins. Figure 34 graphically shows the losses and gains of the altered rocks in milligrams per cubic centimeter in comparison with the relatively unaltered rock.

In the hanging wall, the alteration resulted in addition of SiO_2, K_2O, and S and in leaching of Na_2O and CaO. Comparison of analyses of fresh and altered rock show a slight loss in iron, which probably is within the limits of variation of different samples. The significant point concerning iron is that about half the iron present in silicates and ankerite in the unaltered rock apparently united with sulfur in the altered rock to

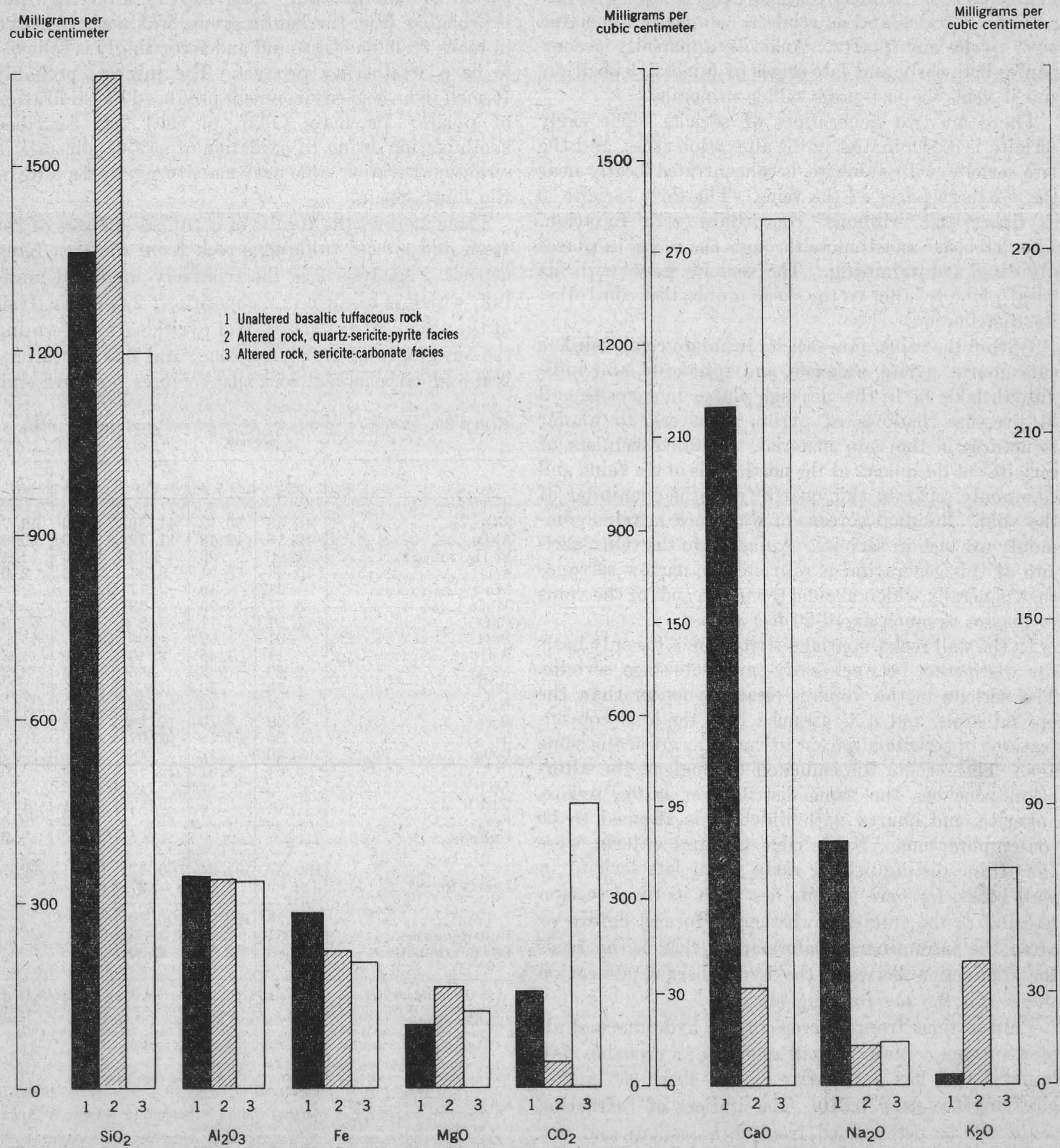


Figure 34.—Graph showing losses and gains of principal constituents in the alteration of the chlorite schist, Iron King mine.

form pyrite; the bulk of the remaining iron remained in the chlorite, for there is little carbonate left in the altered rock, as shown by the low CO_2 content. The introduced K_2O is in sericite. The introduced SiO_2, joined by SiO_2 released by breakdown of silicates, crystallized as free quartz, which occurs in veinlets and in disseminated silicification. The small increase in MgO is probably within the limits of variation from one sample of mafic tuff to another; MgO was probably neither introduced nor removed.

The altered rock surrounding the quartz noses consists chiefly of quartz, ankerite, sericite, and pyrite, locally somewhat stained by iron oxide. The analysis of this rock (table 25, analyses 3) reveals some interesting features. There is more Al_2O_3 than is needed to unite with the K_2O to form sericite. Small amounts of Al_2O_3 probably are combined with Na_2O in soda mica or in residual albite that was not entirely destroyed during the alteration. A small amount of clay minerals might be present, which would account for additional Al_2O_3, but none were recognized in section. The approximate composition of the ankerite was determined by its omega index (1.71–1.70), and all the CO_2 in the analysis was assumed to be in the ankerite. These two assumptions suggest that all the CaO and nearly all the MgO are in the ankerite. The iron content exceeds the amount necessary to fulfill the needs of the ankerite and to combine with the sulfur as pyrite. Some or all the iron above the needs for these two minerals probably occurs as iron oxide, which forms a secondary stain on the foliation planes. Despite the reduction in total SiO_2 from that of the unaltered rock, more than enough SiO_2 is present to supply the needs of the silicate minerals. The remaining SiO_2 forms free quartz, commonly in veinlets, which gives the rock a siliceous appearance.

Stickney (1915) has described a group of massive sulfide veins in the Ural Mountains, Kyshtim, Russia, that are similar in many ways to those in the Iron King deposit. One of these similarities is the character of the hydrothermally altered rocks adjacent to massive sulfide veins. The country rock near the deposits at Kyshtim is "uralite schist." It is composed of andesine usually altered to zoisite and albite, uralite, actinolite, diallage, and some chlorite, epidote, and quartz. Adjacent to the massive sulfide veins, however, this mafic rock is altered to a quartz-sericite-pyrite rock, similar to the hydrothermally altered rock in the Iron King deposit.

Table 25 gives the chemical composition of the unaltered and altered rocks in the Americansky deposit at Kyshtim. The similarity of the losses and gains to the altered rocks at the Iron King is most striking: in both there is a loss of CaO, Na_2O, and CO_2, and a gain of SiO_2 and K_2O. In the Americansky deposit, most of the iron in the original mafic minerals plus a little added iron has been combined with sulfur in pyrite, whereas in the Iron King deposits, iron was not added but the iron in the original mafic minerals is chiefly in pyrite in the altered rock. The most significant difference in the losses and gains is in the MgO. The quartz-sericite-pyrite rocks from the Americansky deposit show a decided leaching of MgO, whereas those from the Iron King do not. In the Americansky deposits, the mafic minerals appear to be more completely altered to sericite, and the carbonates appear to be leached to a greater extent. Loss of MgO would certainly occur in alteration of the mafic minerals to sericite, but would occur in the leaching of the carbonate minerals only if they contained magnesium.

The hydrothermally altered rocks associated with the Iron King deposit were divided into three intensity zones, whose contacts are generally arbitrary (pl. 11). The alteration in zone 1, adjacent to the veins, is most intense, and the rock contains a greater concentration of quartz, pyrite, and ankerite. Along the strike southward, zone 1 grades into 2 in which these minerals are less abundant but still common. Zone 2 grades into 3 southward beyond the limits shown on plate 11. In addition, zone 3 embodies separate belts of altered rocks lying east and west of zones 1 and 2. In zone 3, sericite appears to be the dominant platy mineral; pyrite is very rare; and secondary quartz and ankerite are not megascopically abundant except in local patches.

Zone 1 or the hanging-wall alteration zone is on the west or hanging-wall side of the Iron King deposit. It is the largest zone, ranging on the surface from 100 to 250 feet in width and cropping out for a length of about 2,500 feet. Zone 1 was studied in most detail, owing to more complete exposure by underground openings.

In zones 1 and 2, layers in which pyrite, quartz, and ankerite are more abundant alternate with layers in which these minerals are distributed sparsely and in which the original type of rock (mafic tuff) is apparent through partly altered relics. These alternating layers persist to the walls of the veins, where commonly both grade into sericitic schist. Chlorite is abundant in the layers that contain sparse hydrothermal minerals. In a few thin sections, crosscutting microscopic veinlets of chlorite attest to the mobility of chlorite during the alteration.

It appears that distinct veins formed along the east or footwall side of the sheared zone, while within it (zones 1 and 2), minerals were sporadically introduced along foliation planes and fractures. Quartz, pyrite, and ankerite compose the veins for a short distance south of the ore shoots. Farther south, schistose partings become more abundant. About 400 to 500 feet south of the well-defined veins, the position of the veins can be recognized by layers in which there is a greater concentration of veinlets of quartz, pyrite, and ankerite alternating with wall rocks. Still farther south, these layers pass imperceptibly into altered rocks of zone 1.

Zone 3 is characterized by sericite in which the eastern unit appears to be at a slight angle to bedding, using the nearby rhyolitic tuffaceous bed as a reference (pl. 11). Rocks of zone 3 have a more pronounced foliation than adjacent andesitic tuffaceous rocks, probably because more intense shear localized the alteration and because shearing also took place later. The typical sericitic altered rocks grade into partly altered relics of andesitic tuffaceous rocks through rocks in which both sericite and chlorite are abundant. Foliation in the relic is less pronounced.

An unsolved problem is whether any of the original rocks in the alteration zones were rhyolitic. Most of the partly altered relics indicate an original andesitic or basaltic composition. Especially in rocks of zone 3, sporadic outcrops appear to be rhyolitic. Whether the rhyolitic composition is original or secondary is uncertain, but the possibility of some rhyolitic beds intercalated in the original rock certainly was not eliminated.

Outcrops of the alteration zones are generally white or cream colored and in zones 1 and 2 are stained by iron oxide derived from pyrite. At first, the white color was attributed to abundant sericite, but rocks below the water table are generally green, and thin sections from surface rocks contain abundant pale-green chlorite as well as sericite. Hence the light color probably is due in part to bleaching by sulfuric acid formed by oxidation of pyrite, like that described by Lasky (1936, p. 64) for many veins in the Bayard area, New Mexico. In outcrops of alteration zones 1 and 2, casts after pyrite are common, and sulfuric acid has dissolved most of the carbonate.

SULFIDE VEINS

Two groups of veins are in the Iron King deposit: the well-defined massive sulfide veins, which yielded all but a few tons of the production; and the poorly defined nonproductive ones lying to the west of the massive sulfide. The productive veins comprise the group along the footwall (east side) of the alteration zone. They crop out in an area about 2,500 by 100 feet (pl. 11). By 1948, subsurface openings on the productive veins extended to a depth of about 1,140 feet below the collar of shaft 6, and the vein system had been mined for about 3,400 feet along the strike (pl. 12).

The poorly defined veins, here called nonproductive to distinguish them from the ore veins, crop out erratically in the alteration zone to the west. Their strike lengths are short, and probably they are just as discontinuous with depth. They parallel the foliation, and commonly consist of pyrite, ankerite, and quartz. One of these veins—the copper vein—contains chalcopyrite also. It is the widest and most continuous of the nonproductive veins, but its continuity between its north and south segments is uncertain (pl. 11).

STRUCTURAL CONTROL

Fracturing and shearing controlled spatial relationship, width, length, and to some extent internal structure of the veins and size and shape of the alteration zones. A slight angular discordance between the strike of the veins and the strike of the alteration zones is apparent, as shown by the north ends of the veins terminating in footwall rocks (east of the deposit) and the south ends grading into alteration zone 1. Whether this discordance indicates a difference in age between the shearing that controlled the alteration zones and the shearing that controlled the veins is uncertain. However, early gangue minerals in the veins, although more concentrated, are the same as those sporadically distributed throughout the (hanging-wall) alteration zones, indicating that at the time of deposition of the earliest minerals both structures were present. This does not preclude the possibility of two periods of shearing before mineral deposition. Significance of the slight angular discordance between the strike of the veins and of the alteration zones is difficult to interpret, especially as the rock affected was strongly anisotropic owing to foliation and possibly to beds of different competency. Close spacing of the echelon fractures that control the veins and the relatively wide spacing of similar points of the veins on the levels such as the north ends of the veins suggest that fractures or faults resulted from a shear couple. Lineation (mineral streaking) in the walls of the veins and in the north ends of the veins plunges steeply northward. Judging from the interpretation of the regional geology, this lineation marks the *a* structural coordinate; if so, the direction of relative movement plunged steeply northward.

Strong fracturing and brecciation of early introduced minerals clearly indicate a second period of movement that controlled the localization of ore-forming minerals in the Iron King mine. Distribution of ore-minerals indicates that the later movement took place along fracture zones that extended from footwall to hanging wall of the barren quartz-pyrite-ankerite veins.

The ore deposit at the Eustis mine, Quebec, has a somewhat similar en echelon arrangement of massive sulfide lenses. Stevenson (1937, p. 348) attributes the localizing structure to action of two opposite and tangential forces. In the Flin Flon mine, according to Koffman and others (1948, p. 295–301) massive sulfide ore in sheared limbs of drag folds has an echelon pattern and consistent plunge. Here, shearing occurred along the contact of competent lava flows and more easily sheared pyroclastic and flow breccia. Drag folds were not recognized at the Iron King, but variation in competency of adjacent tuffaceous beds may have localized shearing.

Massive sulfide bodies localized by fractured and brecciated zones have been described by Finlayson (1910, p. 406) for the Huelva deposit, Rio Tinto district, Spain; and by Capps and Johnson (1915, p. 92) for massive sulfide deposit in the Ellamar district, Alaska. Stickney (1915, p. 620) found that the amount of sulfide increased as the schist became more thinly foliated or sheeted. This relationship is also true of the Iron King deposit. Hanson (1920, p. 574–609) studied pyritic massive sulfide deposits in Canada to determine the relationship of form and structure of the ore bodies to enclosing rock. After considering such mines as the Mandy, Manitoba; the Northpines, Ontario; the Flin Flon, Manitoba-Saskatchewan; and the Eustis, Quebec, he concluded that the sulfide resulted from replacement in "zones of more intense shearing and brecciation." The Sullivan deposit, Canada, appears to be an exception, for, according to Swanson and Gunning (1945, p. 651), a stratigraphic zone controls the deposit. However, tourmaline and cassiterite in the deposit indicate a greater depth of origin than for many massive sulfide deposits.

DISTRIBUTION AND CHARACTER OF THE VEINS

The ore deposit consists of 12 veins arranged en echelon, plate 12; individually they strike about N. 22° E. and dip 71° NW. As shown on the map each vein extends farther to the north than the adjacent one on the east. In section, they maintain a similar en echelon arrangement; in any particular vertical section each one to the west extends to a higher altitude than the one on the east. All veins plunge northward, and individually the plunge is commonly constant, the angle ranging between 55° and 60°. Individually the width is commonly constant for short distances but ranges from 1 to 14 feet for different veins; the lengths are measurable in hundreds of feet. From southeast to northwest, the veins are designated as follows: *X*, *Y*, *P*, *A*, *B*, *C*, *D*, *E*, *F*, *G*, *H*, and *I*, plate 12 (*P* vein does not extend to the 900 level; the *B* vein is omitted on some levels).

I vein, although designated as one vein, actually consists of four closely spaced individual ones arranged en echelon, of which the fourth was not exposed completely by underground openings (pl. 12). It is longer than any of the others because of its composite character. Individual echelons of *I* vein have all characteristics of the other veins, such as quartz "noses," consistency of plunge, and characteristic mineral distribution.

Some of the veins deviate from the ideal echelon pattern. On 900 and 700 levels, *X* vein consists of two separated segments, but on 800 level only one vein exists; they must join and split between 700 and 900 levels. *B* and *C* veins, lying between *A* and *D*, are subsidiary structures, as they do not maintain the echelon pattern; *A* vein which probably should be considered as parallel to *B* and *C*, extends as far to the north as *C* and considerably farther than *B*.

P vein is anomalous, for it plunges less steeply than the others and is completely blocked out to its edges within the zone mined. The 25° northward plunge of *P* vein is at least 25° flatter than any other, so that it occupies an intermediate position between *Y* and *A* veins. *P* vein apexes above the 400 level and bottoms a short distance below the 700 level (fig. 35). On the 400 level it is almost a part of *Y* vein; however, in depth it diverges to the north and on 700 level, 250 feet separates *P* vein from the north end of *Y*, where it lies next to and about as far north as *A* vein.

The continuity (except for *P* vein) of veins and schist septa and their general widths are consistent from the surface to 1,100 level; and with rare exceptions, such as the local junction of the north ends of *E* and *F* veins, adjacent veins do not join. The septum between *E* and *F* is commonly not more than 2 feet wide, and the septum separating *H* vein from *G* and *I* is most commonly not more than 5 feet. In places, as on 1,100 level,

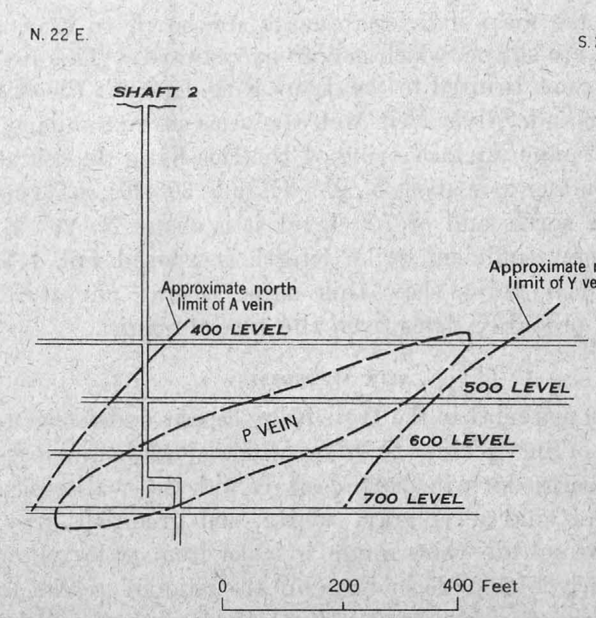


FIGURE 35.—Longitudinal projection, *P* vein, Iron King mine.

faulting after mineral deposition moved the veins together, but these effects are not considered here. Variations in widths of *C*, *H*, *F*, and *G* veins are known. Between 200 and 600 levels *C* ranges in width from 5 to 10 feet, but it is narrow and unproductive on lower levels. *H* vein ranges from 10 to 15 feet in width on 300 and 400 levels and is 10 feet wide on 500 level, but it narrows to about 2 feet between 500 and 700 levels. Below 600 level, *G* increases in width almost commensurate with the decrease in width of *H*. According to Mills (1941, p. 57), *F* changes into a wide low-grade extremely siliceous ore body between 400 and 500 levels, but it narrows to its former width before reaching 600 level.

Thin schist partings or "screens" commonly occur within the veins. The most common type enters from the hanging wall, generally south of ore shoots, and terminates after continuing northward for distances as much as several hundred feet. In places, the last few feet are thin chloritic or sericitic films only a few millimeters thick. Thick schist partings that cross *I* vein divide it into several parts. In a few places narrow partings enter the veins from the footwall, migrate well into them and then back into the footwall tuff. Some veins contain many narrow "screens," ranging in length from a few inches to as much as 100 feet, that on the map are shown entirely enclosed in sulfide. In three dimensions many of these "screens," especially the larger ones, undoubtedly connect to wall rocks.

One of the most striking features of the veins is the abrupt change from massive sulfide to wall rock. In places a knife blade will cover the contact; whereas in others a narrow septum of gouge separates vein from rock.

On the map individual veins are shown to have a gentle arc shape, which is convex eastward. This feature is not limited to the Iron King deposit; the Kit Carson and Silver Belt-McCabe veins curve similarly. The average surface strike of the Iron King deposit at the south end is about N. 25° E. to N. 30° E.; whereas on the north end of 700 level it is about N. 20° E. Wherever sufficient strike length is exposed (pl. 11), individual veins show this same general curvature, which probably dates from the time of origin.

VEIN MATERIAL

Vein material in the Iron King deposit consists generally of fine-grained massive sulfide minerals and massive quartz both in sharp contact with the wall rocks. Massive quartz is gray, white, and greenish gray. Massive sulfide veins range in color from pale yellow to nearly black, depending on the ratio of pyrite to sphalerite and carbonate. Fine banding produced by differences in relative amounts of pyrite, sphalerite, or gangue is almost universally present in the massive sulfide ore (pl. 13*C*, *D*); banding is less marked or absent in nonproductive parts of veins (pl. 13*B*).

The sulfide vein minerals are pyrite, arsenopyrite, sphalerite, chalcopyrite, galena, and tennantite; the gangue minerals are ankerite, quartz, sericite, and a little residual chlorite. Gold and silver constitute the rare metals. Gold is free and, according to Mills (1947, p. 4), is carried largely in pyrite; silver is probably in tennantite. Pyrite is the dominant sulfide and in places makes up about 75 percent of the vein. Quartz and ankerite are the dominant nonsulfide minerals, and locally either may be the more abundant. North ends of the veins are almost exclusively quartz; whereas in the central section, ankerite is commonly more abundant.

The vein material is very fine grained, with most grains between 100 and 300 microns in diameter but ranging from as much as 1.5 millimeters to less than 10 microns. Arsenopyrite grains attain a diameter of 1.5 millimeters, and intergrowths of galena and tennantite form grains 1 millimeter long. Some pyrite crystals, especially in southern sections of the veins, attain diameters of about 300 to 400 microns.

Crystal habits range from idiomorphic to xenomorphic granular. Pyrite commonly has idiomorphic outlines against all other minerals, but aggregates of pyrite etched with nitric acid, reveal xenomorphic outlines. Arsenopyrite shows crystal outline against galena, ankerite, and sphalerite, but not against pyrite or other arsenopyrite. Crystal outlines of sphalerite, galena, and tennantite were not observed; but in places they replace ankerite, retaining the rhombohedral cleavage angle in the outline of the grain. They commonly occur as smaller grains interstitial to pyrite and arsenopyrite.

Banding is common in most massive sulfide deposits. It has been attributed to pseudomorphism of various older structures, such as bedding, fracture, and foliation (pl. 13*C*, *D*). Massive sulfide deposits are characteristically fine grained, thereby favoring preservation of small features by pseudomorphism.

Banding in the massive sulfide from the Iron King deposit probably resulted (1) from deposition of ore-forming minerals (chiefly sphalerite) in fractures or microscopic shear planes in early vein filling and (2) from variation in relative rates of deposition of minerals. The vein material in general consists of bands ranging from 1 millimeter to 10 centimeters in width (figs. 36, 37*A*, *B*). Banding generally parallels vein walls, but in detail is commonly irregular. The irregularities consist of: (1) continuous, wavy bands, (2) discontinuous, nonparallel banding, and (3) irreg-

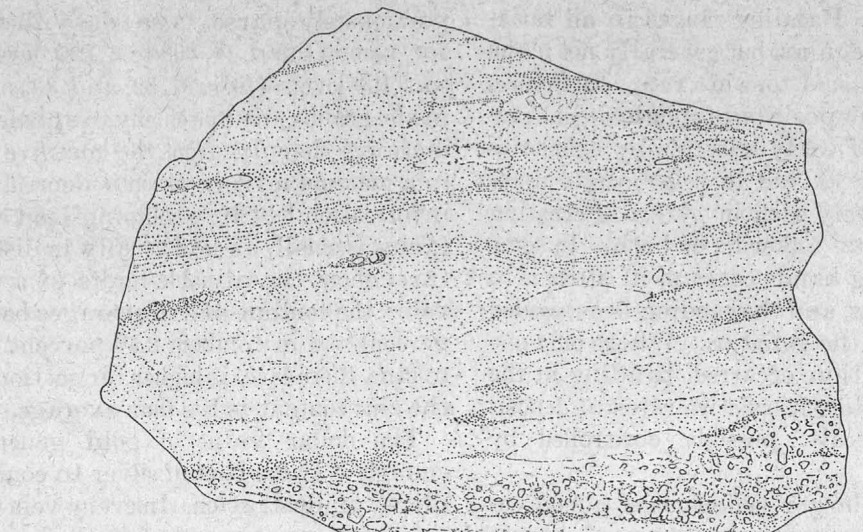


FIGURE 36.—Banded massive sulfide ore, Iron King mine. Dark bands are chiefly sphalerite; light bands, pyrite. Lenses are quartz-ankerite. Note angular discordance between banding in fine- and medium-grained massive sulfide (pyritic). Natural size.

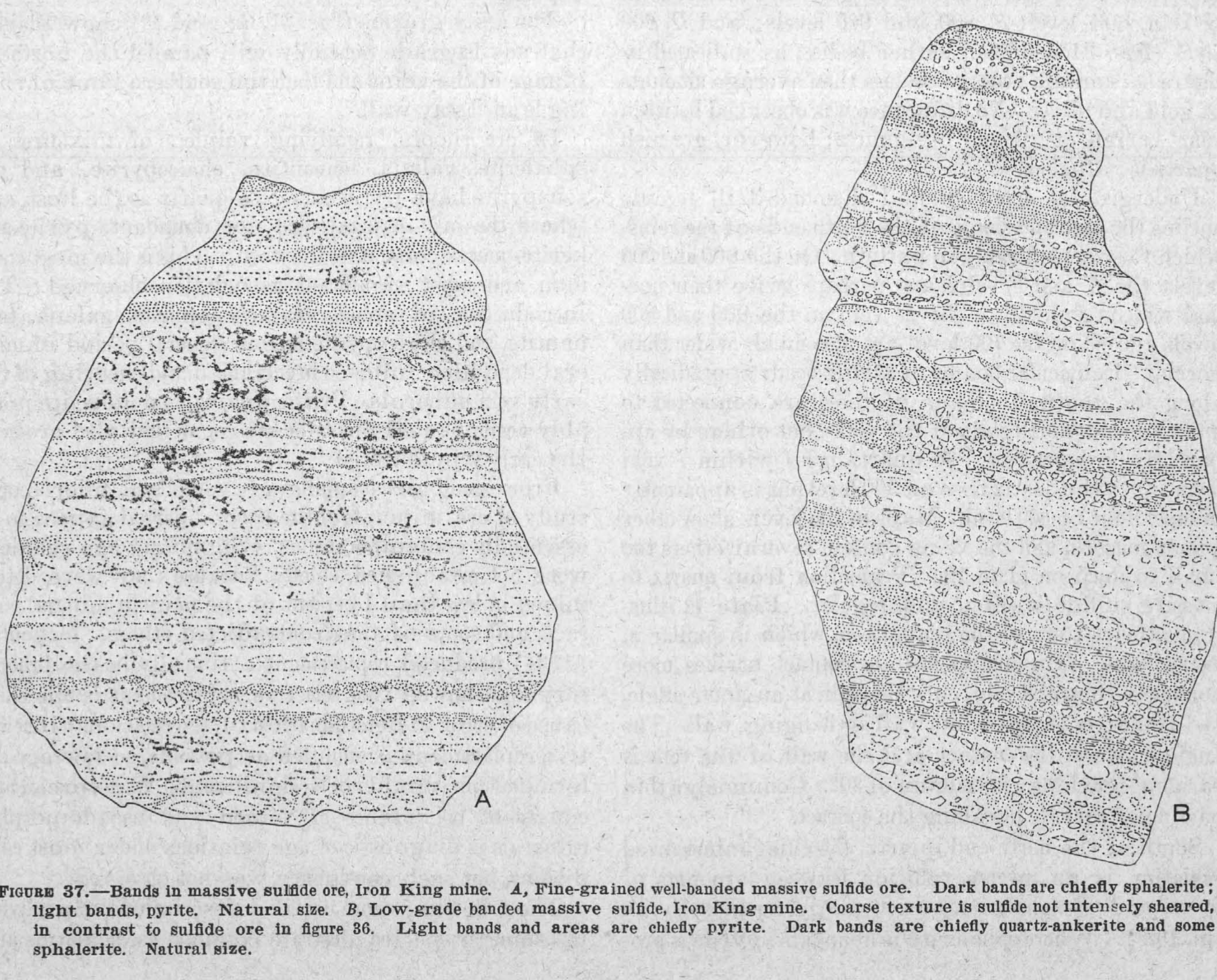


FIGURE 37.—Bands in massive sulfide ore, Iron King mine. *A*, Fine-grained well-banded massive sulfide ore. Dark bands are chiefly sphalerite; light bands, pyrite. Natural size. *B*, Low-grade banded massive sulfide, Iron King mine. Coarse texture is sulfide not intensely sheared, in contrast to sulfide ore in figure 36. Light bands and areas are chiefly pyrite. Dark bands are chiefly quartz-ankerite and some sphalerite. Natural size.

ular fracture networks. Banding ranges in all variations from regular to irregular, but generally not in the same vein or the same general zone in a vein. In the ore, banding is due chiefly to deposition of sphalerite in fractures and replacement of early minerals by sphalerite along microscopic fractures, but in vein gangue it results from bands relatively rich in pyrite alternating with bands rich in quartz, ankerite, or both. In some narrow veins, alternating bands conform in attitude to foliation in the wall rocks, and the banding is as regular and perfectly formed as the foliation. Where only one stage of mineral deposition occurred, banding in the veins may reflect variations in relative rates of deposition of different minerals, possibly controlled by foliation.

North ends of all the larger veins consist almost entirely of greenish to gray quartz that appears almost chalcedonic, plate 13*A*. The quartz contains disseminated idiomorphic pyrite crystals and is cut by ramifying sulfide veinlets and by massive white quartz. In places, massive quartz is rich in gold and silver, as in *G* vein, 800 level; *F*, 800 and 900 levels; and *D*, 600 level (figs. 31 and 32). Other bodies, as indicated in figure 33, contain average or less than average amounts of gold and silver. No difference was observed between some barren quartz and ore-quartz; however, greenish quartz is valueless.

Underground openings and diamond-drill records outline the size and shape of the north ends of the veins, which vary considerably in pattern. On the 800 and 900 levels, the *E* and *F* veins are perhaps twice their normal widths (pl. 12). The *D* vein on the 900 and 800 levels and *G* on the 700 level are also much wider than normal. Lenticular bodies of quartz occur sporadically along the footwall. Some of these are connected to quartz at the north ends of the veins, but others are apparently independent. A quartz mass within *I* vein connects to the quartz nose on 900 level but is apparently independent on 800 level. Maps of the levels show other quartz masses, and the veins contain several others too small to map on plate 12. Transition from quartz to massive sulfide is sharp and regular. Plate 12 illustrates the pattern of the transition, which is similar in every vein. The quartz-sulfide contact strikes more northerly than the vein, cuts the vein at an acute angle, and transgresses from footwall to hanging wall. The angle between the contact and the wall of the vein is variable, reaching a maximum of 30°. Commonly a thin parting of sericite lies along the contact.

South of the north-end quartz, the chief mineralized variation is an inverse relation between amounts of pyrite and of sphalerite, which partly replaces pyrite (pl. 13*D*). Where sphalerite is abundant, pyrite is proportionately sparse. Assay data illustrate these changes for veins *D* and *G*, 600 to 1,100 levels, and for *F*, 500 to 1,100 levels (figs. 31, 32, and 33). Variations shown in the graphs are due chiefly to sphalerite content, which increases sharply from the massive quartz southward to a maximum from which it decreases gradually. The information lost by combining lead and zinc in the diagrams is small, as lead usually is distributed uniformly throughout the minable limits of a vein. In *D* and *F* veins, the content of lead averages between 1.50 and 1.75 percent and in *G* about 2.50 percent. The ratio of lead to zinc, therefore, is higher for sections of the vein where the zinc content is less than average.

The dollar value of gold generally is consistent enough at twice that of silver to combine them for simplicity of illustration. In every vein the gold plus silver maximum occurs north of lead plus zinc, but not so far north that no overlap exists. The dollar value of the gold plus silver is high at the lead plus zinc maximum, but it is waning. This is a consistent feature of the deposit.

The assay graphs (figs. 31, 32, and 33) show plainly that any isograde generally will parallel the northern plunge of the veins and that the southern limit of mining is an "assay wall."

In ore shoots, ramifying veinlets of mixtures of sphalerite, galena, tennantite, chalcopyrite, and arsenopyrite have pyrite-ankerite-quartz as the host, and where the ore minerals are not abundant, pyrite-ankerite-quartz constitute the vein. This is the most common and most significant association observed. The introduction of sphalerite, arsenopyrite, galena, tennantite, and chalcopyrite in one general period of mineral deposition followed brecciation and shearing of the early vein minerals. Pyrite, quartz, and ankerite probably accompanied this later stage, as they also crosscut the early vein material.

From geologic mapping of veins and microscopic study of ore, minerals of the second period appear to be essentially contemporaneous. Significant age relations were not established, chiefly because they were determined in less than 1 percent of the pairs in mutual contact, and some of these contradicted others. Schouten (1934) produced replacement artificially in the laboratory and showed that selective replacement is the chief cause of error in determination of age relations; if selective replacement is admitted as possible, so few age determinations would not be significant. Widespread and consistent occurrence of veined and pseudomorphic minerals is diagnostic of age relations under most conditions, but such consistency was not observed.

The following more detailed descriptions of individual mineral species illustrate common associations and occurrences of minerals. Inferred age relations are stated as a matter of record. Two types of sphalerite occur, rosin and brown. Brown sphalerite is earlier than the rosin, and in places the rosin variety cuts it. Brown sphalerite is most abundant, constituting more than 90 percent of the sphalerite. An analysis of the brown variety by the American Cyanamid Co. showed zinc 63.5 percent, iron 3.2 percent, and sulfur 33.3 percent, which corresponds to 95 percent zinc sulfide and 5 percent iron sulfide. Brown sphalerite occurs chiefly as streaks or bands of relatively pure mineral, which contributes greatly to banded structure of the veins (pl. 13*D*). In part, these bands represent replacement features, as residual pyrite grains are dispersed irregularly through them in various stages of replacement; whereas on either side of the veinlet, idiomorphic pyrite occurs (fig. 38*A*). Commonly brown sphalerite is interstitial to pyrite that shows little or no modification of crystal outlines (fig. 38*B*). Such a relationship could mean either (1) simultaneous deposition of pyrite and sphalerite, (2) selective replacement of early quartz-ankerite by sphalerite, or (3) replacement of sphalerite by pyrite. Sphalerite occurs as microscopic veinlets in quartz, ankerite, chalcopyrite, arsenopyrite, and galena. It is cut by veins of galena and is included as small grains in chalcopyrite and in pyrite. Idiomorphic arsenopyrite occurs in a matrix of sphalerite, but locally sphalerite embays the crystal outline of arsenopyrite. In places sphalerite replaces ankerite, retaining the rhombohedral angle in the outline of the grain. Parts of veins enriched in brown sphalerite are enriched also in tennantite, galena, and arsenopyrite.

Rosin sphalerite is in late crosscutting veinlets associated with clear quartz; to a lesser extent it occurs with ankerite and tennantite and as disseminated crystals whose age relations are obscure. Nests of rosin sphalerite, perched on comb quartz, occur rarely in late crosscutting fractures. Brown and rosin sphalerite occur together in a few crosscutting veinlets. Their age relations were not discerned in these veinlets, but rosin sphalerite only occurs in late crosscutting veinlets that are younger than the bulk of the brown sphalerite.

Galena rarely constitutes more than 4 percent of the vein, yet is in every polished specimen examined from productive veins. Galena and tennantite are associated closely and are generally in contact but no evidence of an age difference between them was seen. Galena, tennantite, and chalcopyrite also make a common associa-

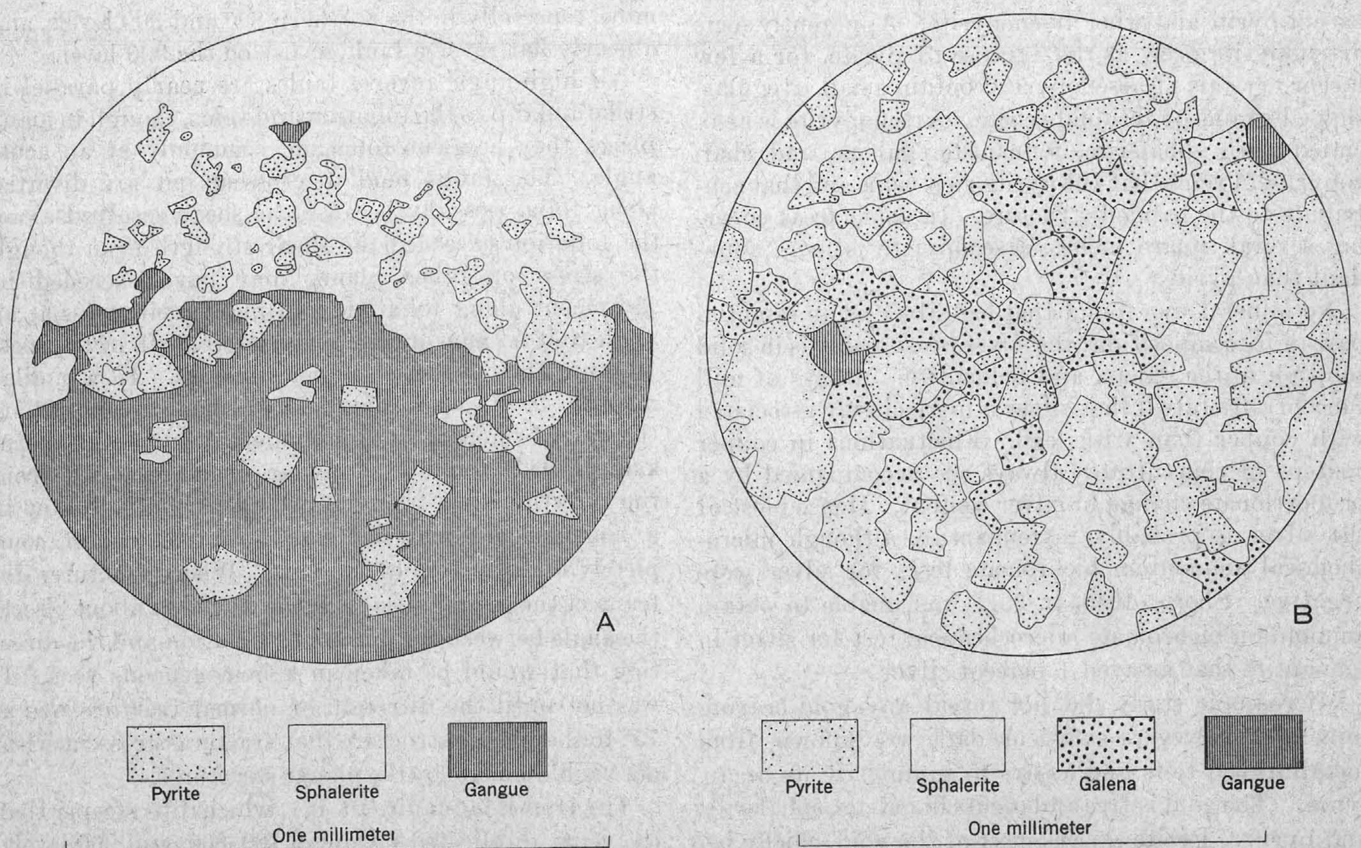


FIGURE 38.—Drawings of polished thin sections, Iron King mine. *A*, **Illustrates character of pyrite on either side of contact of a band rich in sphalerite.** *I* **vein, 700 level. In upper part of field, sphalerite partly replaces pyrite; pyrite in gangue is unmodified.** *B*, **Sphalerite interstitial to pyrite that shows no modification of crystal form,** *H* **vein, 900 level.**

tion. Galena is interstitial to pyrite and arsenopyrite; veins of galena cut sphalerite and arsenopyrite, and veins of sphalerite cut galena. In a few open fractures, galena, rosin sphalerite, and pyrite are perched on comb quartz. Galena and associated tennantite are commonly in pyrite-free zones of quartz and ankerite that form part of the megascopic banded structure. They also occur as large grains at the ends of ankerite augen and, where more abundant, rim the augen completely. In a few places galena replaced pyrite, as indicated by small irregular enclosed residuals of pyrite. Had the pyrite been younger, it most certainly would be idiomorphic because the power of crystallization of pyrite is many times that of galena. The distribution and occurrence of tennantite is similar to that of galena.

Chalcopyrite, which occurs only in very small amounts in the productive veins is in small irregular independent grains; in small masses associated with tennantite; and in microscopic blebs in sphalerite. Microscopic veins of chalcopyrite cut pyrite, arsenopyrite, and quartz ankerite, and veins of sphalerite cut chalcopyrite.

Arsenopyrite is abundant in massive sulfide, particularly in the ore. It commonly has crystal outlines, chiefly diamond shaped in section, against all minerals except pyrite and other arsenopyrite. Apparently some arsenopyrite grew at the expense of pyrite, for a few larger crystals of arsenopyrite contain small irregular-shaped grains of residual pyrite. Arsenopyrite is associated with sphalerite, tennantite, galena, and chalcopyrite in veins that cut pyrite-rich veins and that contribute to the banded structure. In some areas covering several square inches, arsenopyrite is more abundant than pyrite.

No mineral was found that has silver as an essential part of its composition; the silver presumably is in solid solution in the galena and tennantite. Assays of mill concentrates reveal that silver is more closely associated with copper than with lead. Fluctuations in copper content of concentrates always are accompanied by a proportionate change in silver content. Hence most of the silver is probably in tennantite, although microchemical ammonium bichromate tests for silver were negative. Short (1940, p. 201) was unable to obtain ammonium bichromate microchemical test for silver in tennantite that assayed 1 percent silver.

Microscopic study did not reveal any gold-bearing minerals; however, sufficient data are known from metallurgical tests and assays to summarize its occurrence. The gold is free and occurs in galena, sphalerite, and pyrite. Pyrite carries most of the gold, chiefly because pyrite is more abundant. Figures 31, 32, and 33 indicate the distribution of gold in three veins. The ratio of precious metals to base metals is higher in the quartz at the north ends of veins than for the massive sulfide. The greatest concentrations of precious metals also occur in quartz "noses." Precious metals, like the base metals, gradually decrease in content southward.

Ankerite is the carbonate of the veins and hydrothermally altered rocks. It was identified through index of refraction, microchemical tests, and slow effervescence with dilute acid. Ankerite forming knots and vein-filling interstitial to sulfide minerals has an omega index of 1.710 indicating a composition of 65 percent dolomite ($CaMgC_2O_6$) and 35 percent ferrodolomite ($CaFeC_2O_6$) (Winchell, 1933, p. 74). Ankerite from a small quartz-ankerite-chlorite veinlet cutting andesitic tuffaceous rock south of the mine has an omega index of 1.725 indicating equal amounts of dolomite and ferrodolomite.

POST-MINERAL STRUCTURES

Younger structures consist of faults, joints, and probably fracture cleavage. Larger faults that offset veins are reverse strike faults. Those that dip steeper than veins produce an overlap; those that dip less steeply produce a gap. Other strike faults whose direction of relative displacement is not known also occur in the mine, especially in the northern 800 and 900 levels, and a nearly flat reverse fault occurs on the 900 level.

All high-angle reverse faults are nearly parallel in strike and dip to the foliation and veins, though in many places they crosscut foliation, commonly at an acute angle. The faults tend to crosscut but are diverted along folia, possibly because the shear resolved along the foliation exceeded the shear strength even though the stress on other planes may have exceeded it. Movement along foliation continued until stress at an angle to it became greater than the strength of the rock. Rupture then occurred across foliation. In a similar manner, faults were diverted for some distance along the wall of veins. In a scale-model experiment, Ekkernkamp (1939) found that planar structure at 20° from the direction that fractures would normally follow in a homogeneous material would control almost completely the direction of fracture. Where fractures did transect the planar structure, the direction about bisects the angle between the normal to foliation and the direction that would be taken in a homogeneous rock. It was not until the direction of normal fracture was at 75° to the planar structure that fractures crosscut without visible control by the planar structures.

The Iron King fault (pl. 12), which dips steeper than the veins, duplicated *I* vein on 700, 800, and 900 levels; on 1,000 level it is between *I* and *H* veins, which are separated by about 1 foot of gouge. This fault dies out both northward and southward from a point located at 4,175 E.–4,040 N., 800 level, where the vertical separation is about 120 feet (pl. 12). Three reverse faults, having vertical separations of less than 50 feet, occur south of the Iron King fault. Two of these dip less steeply than the veins, producing small gaps in vein continuity, the other dips more steeply, overlapping the vein.

Faults on the north 800 and 900 levels, which have gouge zones about 1 foot wide, do not displace the *I* vein, although a small displacement would not have been noticeable at the stage of development in 1948. By analogy to the other faults of similar attitude, these probably are reverse faults.

Small faults that range in strike from N. 85° W. to N. 80° E. occur sporadically in some veins and dip southward at about 80°. These faults generally stop at the walls of veins, yet they contain gouge zones as much as 6 inches wide, composed of pulverized vein filling. Generally the faults occur as several closely spaced parallel breaks. In several places they extend into wall rock and have a small horizontal separation indicating that the north wall moved eastward relative to the south wall. Displacement on these faults is probably small, as they do not mark changes in grade or appearance of ore. Where the faults do not cut the wall rocks, they may represent minor adjustments to post-mineral deformation, wherein the vein moved slightly within the confines of its walls.

Flat joints, essentially at right angles to the dip of the veins, are abundant throughout all veins. They are spaced only a few feet apart vertically.

In the fine-grained well-foliated hydrothermal alteration zones in the Iron King area, fracture cleavage cuts the dominant foliation. The fracture cleavage has two distinct forms, (1) a series of V-shaped minor folds broken by a fracture that bisects the fold, and (2) sigmoid folds broken by fractures that bisect the folds.

As the attitude of the fracture cleavage is variable, 58 attitudes from outcrops scattered at random throughout the alteration zones were measured, plate 11. Only one of a particular direction of fracture was recorded at any one outcrop. Poles to planes of cleavage plotted on an equal area net revealed a 17 percent concentration at N. 50°–65° W., 80° SW., and a 12 percent concentration at N. 70°–80° E., 75° SE. The sigmoid folds indicate that the north sides of both the northwestward and northeastward-trending fracture cleavage moved southward relative to the south side. Thus the movement on the fracture cleavages is in the proper direction to be members of a conjugate set of shears.

Because the two directions of fracture cleavage are about symmetrical to the strike of veins, it might be assumed that the fracture cleavage was formed by the deformation that localized the fractures or shears now occupied by veins. But this is not correct. Two shear planes of different altitude, but related to the same stresses, must have the same deformation plane (ac plane of the structural coordinate system), and the deformation plane for the sheared zone localizing the veins does not coincide with that for the fracture cleavage. Structural coordinates for the sheared zones that localized the ore deposit are obtained by assuming that lineation (mineral streaking at 60° N.) in the walls of the veins and the parallel northward plunge of the veins is either *a* or *b*. Assuming the lineation is *a*, the deformation plane is nearly N. 58° W., 65° N.; assuming it is *b*, the deformation plane is about N. 80° E., 33° S.

The deformation plane for the fracture cleavage is based on the assumption that the intersection of the two slip planes delineated *b*, a valid assumption as indicated by Cloos (1946, p. 19), and others. Using the average attitude for the two directions of fracture cleavage, *b* plunges S. 20° E. at 75°, and the deformation plane, lying perpendicular to *b*, strikes N. 70° E. and dips 15° northward. The dissimilarity in attitude of deformation planes indicates that the fracture cleavage is probably postmineral in age, possibly owing to the deformation that produced postmineral faults in the ore deposit.

ORE DEPOSITS ALONG THE SILVER BELT–McCABE VEIN

The Silver Belt-McCabe vein was traced as a continuous zone for about 14,000 feet from a point about 1,500 feet west-northwest of the Iron King mine southwestward to the corner of the Jerome area (pl. 1). Northeastward, the structure disappears beneath the gravel of the Hickey formation in Lonesome Valley; and southwestward, the vein passes from the Jerome area in the quartz diorite. The Rebel mine, which is about a mile southwest of the McCabe mine, is reported to be on the structure. The strike ranges from N. 65° E. in the southern sector to N. 30° E. in the northern sector; the dip ranges from 70° NW. to 80° SE.; and the width ranges from 6 to 15 feet.

The vein is almost entirely within the breccia facies of the Spud Mountain volcanics. Chlorite and probably some sericite, lying with their basal sections essentially parallel to the strike of the vein, characterize the fissile, sheared zone comprising the vein; whereas the wall rocks, especially those on the hanging wall (west side), are foliated but not fissile, and are characterized by actinolitic hornblende.

The vein structure appears to have been mineralized only locally, and ore has been found only near the mines described in this section. The ore shoots occur as lenses or pods that rarely, if at all, occupy the entire width of the vein.

The age of the deformation that produced the sheared zone cannot be definitely established. Because of the parallelism between the structures produced by the later periods of Precambrian deformation and the Silver Belt-McCabe vein, and because of the micaceous character of the sheared zone comprising the vein structure, a Precambrian age is most likely. The ore shoots, however, did not necessarily form penecontemporaneously with the deformation that produced the sheared zone.

The unoxidized sulfide ore minerals occur as coarsely crystalline, drusy masses that filled open spaces. This is in marked contrast to the massive sulfide veins in the Iron King deposit, which is believed to have formed nearly contemporaneously with intense deformation at considerable depth. The ore shoots along the Silver Belt-McCabe vein probably formed later than the last period of strong Precambrian deformation, and sufficiently later so that pressure conditions permitted open spaces, perhaps as much as several inches wide. This, however, does not necessarily preclude a Precambrian age for the mineralization.

The character of the ore along the strike of the Silver Belt-McCabe vein varies, suggesting lateral zoning. Silver and lead characterized the Silver Belt deposit, at the north end of the known zone. In the Arizona National mine, to the south of the Silver Belt, the content of lead and silver was lower; but the ore contained zinc and iron, chiefly as sphalerite and pyrite. The ore in the Lookout mine, to the south of the Arizona National, was complex and contained lead, zinc, iron, copper, silver, and gold. The silver content was lower than in the Arizona National, but the copper and gold content was higher. The McCabe-Gladstone mine is south of the Lookout; and like the Lookout, its ore was complex and contained copper, lead, zinc, iron mostly as sulfides, and gold and silver. In the McCabe-Gladstone the content of iron, copper, and gold was higher than that in the Lookout, but lower in lead and probably in silver.

SILVER BELT MINE

The old Silver Belt mine, which is about 5,500 feet southwest of the Iron King mine, has been inactive for many years, and the workings are all inaccessible. The following data are, in large part, abstracted from Lindgren (1926, p. 128–129). So far as is known, the Silver Belt is the oldest mine in the Jerome area. It was located about 1870, and worked from 1870 to 1880. The ore was freighted to Ehrenberg, and from there shipped down the Colorado River and to San Francisco for treatment. Later the ore was smelted at Humboldt. In 1906, the mine was reopened, and the shaft deepened by about 80 feet. But this later work did not produce much ore.

The property was explored by four shafts, one of which is reported to be 400 to 480 feet deep. The amount of lateral workings from the shafts is unknown.

Ore was mined from the surface to the 250 level, figure 39, where it occurred in ore shoots ranging from 3 inches to 3 feet in width, but the vein in this locality ranges from 8 to 12 feet in width. It is reported that the ore was chiefly oxidized, and contained much manganiferous ankerite and barite and minor amounts of galena and sphalerite. The oxidized material contained much silver and some lead. Elsing and Heineman (1936, p. 101) list the production from 1870 to 1880 as 1,000,000 pounds of lead, and silver valued at $300,000. Lindgren estimated the silver production at 300,000

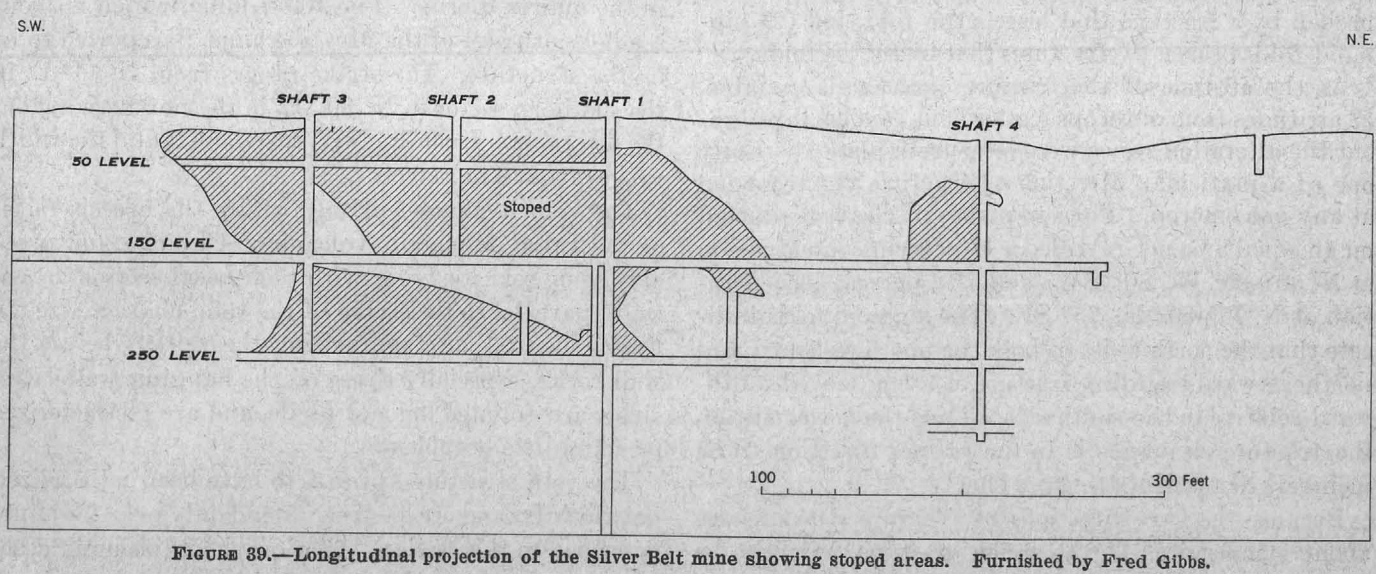


FIGURE 39.—Longitudinal projection of the Silver Belt mine showing stoped areas. Furnished by Fred Gibbs.

ounces, and local estimates were as high as 700,000 ounces.

ARIZONA NATIONAL MINE

The Arizona National mine is about half a mile southwest of the Silver Belt on the same vein. At the time of Lindgren's visit in the Jerome area in 1922, the Arizona National was operating, and had been since 1915. The property at that time was equipped with a 50-ton ball mill and concentrating tables. The mine at present is inaccessible.

The deposit was developed by two shafts, one about 520 feet deep, and by lateral workings at seven levels extending off the shaft (fig. 40). The lateral workings are separated vertically from 40 to 110 feet. Ore was mined between the surface and the level 7, which is about 500 feet below the surface (fig. 40).

The occurrence of the ore is essentially the same as at the Silver Belt mine. The vein strikes N. 20° E., and dips 70° W., and ranges in width from a few inches to several feet. Lindgren (1926, p. 129) reported, "The ore contains a little drusy milky-white quartz, some calcite, much pale brown ankeritic carbonate, with manganese and some barite." Galena and sphalerite comprise the megascopic ore minerals but include minor amounts of pyrite and chalcopyrite. Microscopic argentite and tetrahedrite were disseminated throughout the galena.

Data on production of the Arizona National mine were collected from several sources, which accounts for the overlap in time. Presumably, the data are accurate for the periods designated, but where there is an overlap, the data cannot be added to the total production of the deposit. Elsing and Heineman (1936, p. 101) report that between 1921 and 1926 the deposit yielded 1,000,000 pounds of lead, and silver valued at $60,000. The following production data were furnished by Fred Gibbs, Prescott, Ariz. From October 1915 to June 1923, F. M. Anderson recovered 2,068 tons of concentrate that averaged 103 ounces of silver per ton, 26.9 percent lead, 11.9 percent zinc, about 0.3 percent copper, and about 0.03–0.02 ounce of gold per ton. Production from October 1922 to January 1925 was about 3,600 tons of ore that yielded 70,850 ounces of silver and 228,713 pounds of lead. The grade of this ore was about 20 ounces per ton of silver and about 3 percent lead. Presumably some zinc and a small amount of copper were also present, although they were not mentioned. From October 1928 to February 1931 the Double O Metals Co. produced 377 tons of concentrate that averaged 114 ounces per ton of silver, 32 percent lead, 10 percent zinc, 0.5–1 percent copper, and about 0.03 ounce per ton of gold. So far as known, the Arizona National has been inactive since 1931.

LOOKOUT MINE

This mine is on the Silver Belt-McCabe vein about 1,000 feet southwest of the Arizona National. Little is known of the history, development, and production of the Lookout. It was in operation in 1922 when Lindgren visited the mine, but presumably was closed shortly thereafter. The property was reopened for a short period during 1948 and 1949; and at that time a few tons of high-grade ore—consisting chiefly of galena, sphalerite, and pyrite—was piled on the dump. In 1952 there was no activity and it is not known if the underground openings were accessible.

The ore is a complex deposit of sulfide minerals, chiefly galena, sphalerite, pyrite, and chalcopyrite, and also contains a little gold—perhaps one-eighteenth to one-twelfth ounce per ton—and some silver. The silver content is reported to be less than that at the Arizona National. So far as known, there has been little production from the Lookout. Lindgren (1926, p. 130) reported that a mill test on 180 tons of ore yielded 8 tons of concentrate valued at $80 per ton at the current metal prices of that time.

McCABE-GLADSTONE MINE

The McCabe-Gladstone mine is in Galena Gulch about 1.2 miles southwest of the Lookout mine. It is one of the deepest mines and has produced more ore than any other mine on the vein system. The mine was operated from 1898 to 1913, but has not been active since.

The property consists of two mines, the McCabe on the east, and the Gladstone on the west. It was developed by two shafts 800 feet apart: the Gladstone, 1,100 feet deep; and the McCabe, 900 feet deep. The lateral workings extend along the vein from 200 to 600 feet on every 100-foot level, the total exploration aggregating several miles (fig. 41).

The vein strikes N. 55° E. and dips 80° SE.; the width averages 3½ feet. Lindgren (1926, p. 130–132) reported, "there are five shoots along the vein, each of which has a stope length of 200 to 500 feet. At least two of the shoots appear to reach the 1,100-foot level in the Gladstone mine. These shoots pitch steeply toward the west—and average less than a foot wide." Jaggar and Palache (1905, p. 10) say:

> "the vein is a series of lenses which are characterized by band and ribbon structure, the metallic contents being largely confined to the center of the vein. Open vugs lined with large crystals of quartz and arsenopyrite are common. Arsenopyrite with pyrite and chalcopyrite carry the values, which are largely gold with some silver. Galena is sparingly present."

The gold to silver ratio is inverse to that of the mines northward on this vein (table 26).

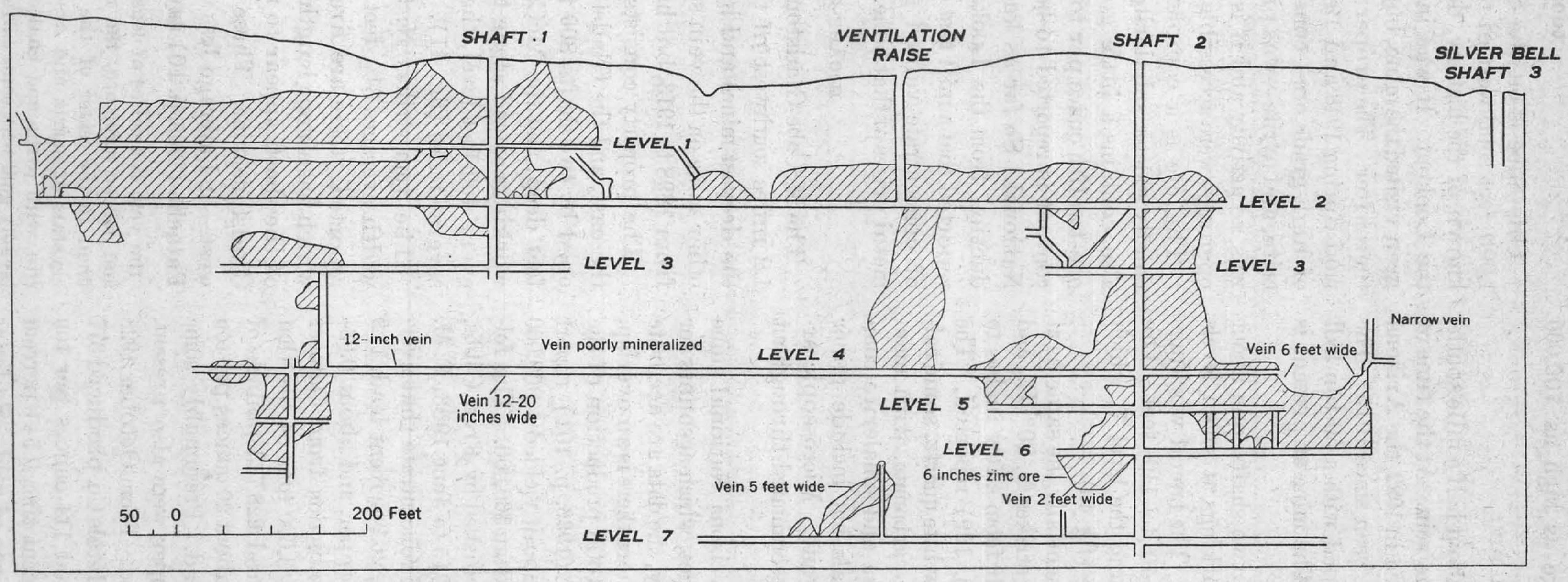


FIGURE 40.—Longitudinal projection of the Arizona National mine showing stoped areas. Furnished by Fred Gibbs.

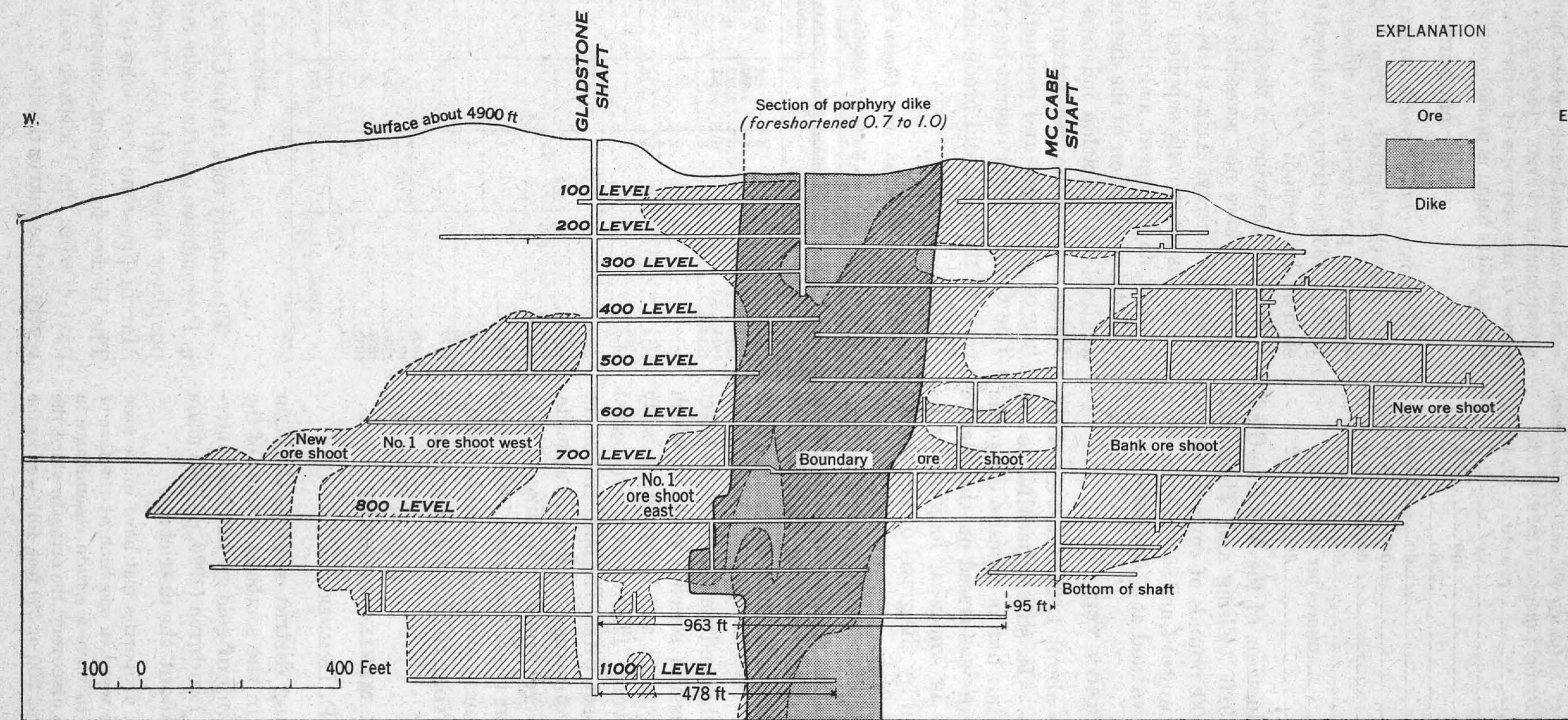


Figure 41.—Longitudinal projection of the McCabe-Gladstone mine showing stoped areas. After Lindgren (1926, p. 131).

TABLE 26.—*Average analysis of shipping ore and concentrates, McCabe-Gladstone mine. From Lindgren (1926, p. 132)*

Silica, percent	31.4
Copper, do	2.0
Lead, do	2.1
Zinc, do	4.7
Iron, do	24.6
Arsenic, do	3.9
Antimony, do	1.0
Sulfur, do	20.4
Gold, ounces per ton	1.6
Silver, do	10.2

The approximate production of the McCabe-Gladstone mine from 1880–1926 (Elsing and Heineman, 1936, p. 101) was 1,200,000 pounds of copper, 500,000 pounds of lead, $2,200,000 in gold, and $600,000 in silver. The total production was valued at $3,000,000.

KIT CARSON VEIN

The Kit Carson vein is about 1,500 feet west of the Silver Belt-McCabe vein. It strikes parallel to the Silver Belt-McCabe vein, but has an opposite dip to the east. The Kit Carson vein was traced on the surface for about 4,000 feet, but is somewhat longer, for its northern extent is overlain by the gravel of the Hickey formation in Lonesome Valley. A short segment near 1,268,000 N.–388,500 E. may be the southward continuation of the vein. Little is known about the Kit Carson vein. It appears to resemble the Silver Belt-McCabe vein in structure, alteration, and character of the mineralized zone.

The vein consists of a sheared zone as much as 5 feet wide, characterized by fissile, sericitic rock in which local stringers of comb quartz and boxwork, possibly after ankerite, were observed. The vein was prospected by eight shafts and prospect pits. The material on the dumps of these openings contains considerable ankerite, but no sulfide minerals were found. The size of some of the dumps indicates that these shafts are 100 or more feet deep, or that short lateral workings extend off shallow shafts. Production from the Kit Carson vein has not been recorded.

CHERRY CREEK MINING DISTRICT

By R. E. LEHNER

The Cherry Creek mining district occupies the basin drained by Cherry Creek in the southeast corner of the Jerome area (pl. 1). Mining of gold ore has been intermittent since about 1880. Lindgren (1926, p. 104) made the following statement about the district:

> The district contains many properties that have made some production, and some of them were in operation at the time of visit. Many of them appear to have a certain resemblance in their history. There was the discovery, the arrastre stage, the sinking of a shaft to a depth of 200 or 300 feet, followed by the erection of a small mill, and next usually a prolonged rest, with a watchman in charge. The pockety character of the ore is the cause of this stoppage of exploration. Whether any large ore shoots will be found is probably doubtful.

PRODUCTION

Economic conditions in large part have controlled activity in the district. From 1917 to 1920, a period of economic prosperity, no mines were active; but from 1930 to 1934, activity is related to the economic depression of that period.

Most of the mines in the district were visited briefly, but many were not accessible for examination. Hugh Allen of Cherry, Ariz., a life-long resident of the district, has generously supplied information on the past history, development, and production of the mines.

Total production of the district is not known, but all available information indicates that it is not large. Table 27 gives the best summary available on the number of producers and production from 1908 to 1933. The Cherry Creek district has yielded less than 1 percent of the lode-gold production of Arizona (Wilson, 1942).

TABLE 27.—*Production from Cherry Creek mining district, 1908–33*

[From Elsing and Heineman (1936, p. 83)]

Year	Producers	Tons	Gold (value)	Silver (ounces)	Copper (pounds)	Total
1908	6	464	$5,775	86	---------	$5,821
1909	4	330	7,646	242	---------	7,772
1910	6	1,332	6,352	93	394	6,452
1911	4	531	---------	---------	---------	9,402
1912	3	---------	---------	---------	---------	---------
1913	2	---------	---------	---------	---------	---------
1914	4	---------	---------	---------	---------	2,866
1915	5	86	---------	---------	---------	958
1916	2	---------	---------	---------	---------	---------
1917	---------	---------	---------	---------	---------	---------
1918	---------	---------	---------	---------	---------	---------
1919	---------	---------	---------	---------	---------	---------
1920	---------	---------	---------	---------	---------	---------
1921	1	---------	---------	---------	---------	---------
1922	---------	---------	---------	---------	---------	---------
1923	1	---------	---------	---------	---------	---------
1924	---------	---------	---------	---------	---------	---------
1925	2	---------	---------	---------	---------	---------
1926	2	---------	---------	---------	---------	---------
1927	---------	---------	---------	---------	---------	---------
1928	---------	---------	---------	---------	---------	---------
1929	---------	---------	---------	---------	---------	---------
1930	3	201	1,897	74	4,155	2,465
1931	1	40	---------	---------	---------	---------
1932	6	223	3,023	96	968	3,111
1933	14	327	9,214	423	1,969	9,488
Total	---------	3,524	$33,907	1,014	7,484	$48,335

GEOLOGY

The country rock in the Cherry Creek mining district is Precambrian quartz diorite cut by a few granodiorite porphyry dikes (pl. 1). Tapeats sandstone(?) and Martin limestone cap some of the ridges and peaks. The Hickey formation, comprising lava and gravel, in part overlies the Paleozoic rocks and in part rests directly on the quartz diorite.

The veins are abundant but discontinuous, and generally are uniform in character. They occur as lenses or pods in sheared zones of quartz diorite and granodiorite porphyry. Their width ranges from 1 inch or less to 6 feet, but average about 1–2 feet. Where the strike changes or the dip flattens the thicknesses appear to be above average. The veins range in strike from north to N. 45° E., but most lie between N. 15° E. and N. 35° E.

The vein filling is chiefly milky-white quartz, but in a few places is stained on weathered surfaces by limonite. Locally it contains vugs, lined with quartz crystals. Minor constituents are gold, tourmaline, pyrite, and, according to Lindgren (1926, p. 103), small quantities of chalcopyrite, bornite, sphalerite, and galena. The tourmaline occurs as minute needles in the quartz, and the pyrite as irregular grains intergrown with quartz. Some gold is free and may be megascopic, but some is derived from oxidized sulfide minerals. Gold and sulfide minerals are associated in most of the ore shoots. This spatial coincidence suggests contemporaneous deposition.

Adjacent to the quartz veins, limonite has stained the quartz diorite and granodiorite porphyry dikes orange and rusty brown. Mafic minerals are absent, and the plagioclase is sericitized and altered to albite. Farther from the veins, chlorite has replaced biotite and hornblende, the plagioclase is saussuritized, and epidote veins are locally present.

The limitation of the quartz veins and alteration zones to the quartz diorite and granodiorite porphyry dikes and their absence in the overlying Paleozoic sedimentary rocks proves that the gold-bearing quartz veins in the Cherry Creek district are of Precambrian age.

LEGHORN MINE

One of the northernmost mines in the district, this mine is developed by an inclined shaft 600 feet deep, but was inaccessible in 1951. The vein cannot be traced at the surface, but at the portal of the adit, the vein strikes N. 65° E. and dips 25° W. According to reports most of the ore came from the hanging-wall side of the vein which is stoped from the 400 level to near the surface for several hundred feet. Production from the Leghorn is reported to be among the largest in the district.

SITTING BULL MINE

The Sitting Bull mine is about 300 feet east of the Leghorn mine at a higher altitude, and both mines may be on the same vein or on parallel veins of the same system. Three adits within a vertical range of about 60 feet crosscut the vein and some ore has been mined from underhand and shrinkage stopes. The underground workings are within the oxidized zone of the vein. The width of the vein ranges from small stringers to 2½ feet; the average strike is about N. 40° E. and the dip ranges from 25° to 45° W. The ore shoots occurred in the more gently dipping parts of the vein. About $11,000 of gold was produced in 1940, and an unknown amount was produced earlier.

FEDERAL MINE

The Federal mine is about a mile southeast of the Leghorn mine, and the vein, averaging 2 feet in width, strikes N. 45° E. and dips 50° W. Lindgren (1926, p. 107) states that the mine was active about 1907, and was developed by an inclined shaft, 260 feet deep. An exploratory adit 1,000 feet long was driven, and a mill costing $100,000 was built, but no ore was found.

GOLD BULLION MINE

The Gold Bullion mine is about a mile northwest of Cherry. Trenching and bulldozing have exposed about 350 feet of vein striking N. 15° E. and dipping 45° W. The underground workings, filled with water in 1951, consist of an inclined shaft 100 feet deep connecting with extensive drifts along the vein. Gold ore was shipped to the smelter at Clarkdale, but the amount of production is not known.

BUNKER MINE

Extensive underground workings were driven in an attempt to find ore shoots in a shear zone that is essentially barren. One small ore shoot, 3 feet wide, was found at the end of one of the exploratory drifts. The surface was scraped by mule teams in the early history of the district, and it is claimed that $100,000 worth of gold was produced about 1880. The mine, which is about 1½ miles north of Cherry, was reported to be one of the three largest producers in the district.

SUGAR BOWL MINE

The Sugar Bowl mine is about a mile north of Cherry, on the road leading to the Bunker mine. A shaft 30 feet deep connects with a drift along the vein, from which some ore has been stoped. An adit crosscuts the vein 30 feet from the portal, and some ore was mined from connecting drifts. The vein, ranging from 2 to 18 inches in width, strikes N. 25°–45° E. and dips from 25° to 45° W. It is reported that about 20 carloads of gold ore ranging in value from $66 to $88 per ton have been shipped.

GOLDEN IDOL MINE

The Golden Idol mine is more than a mile northeast of Cherry. An inclined shaft 400 feet deep was sunk on one of the veins on the property, but was inaccessible in 1951. The vein that was mined is about 18 inches wide, and strikes N. 35° E. and dips 45° W. Lindgren (1926, p. 106) states that a stamp mill and cyanide plant were on the property in 1922, but they were operated only from 1907 to 1910, on ore worth $7 to $12 to the ton. It is reported that the best ore was near the surface.

BLACK HAWK MINE

The old workings of the Black Hawk mine are 1 mile northeast of Cherry. An inclined shaft 200 feet deep was sunk on a vein striking N. 45° E. and dipping 55° W. The shaft is now filled with water. It has been claimed that 30 cars of gold ore averaging $25 per ton were shipped.

GOLD EAGLE MINE

The Gold Eagle mine is about 2 miles northeast of Cherry. An inclined shaft 100 feet deep connects with drifts along a vein striking N. 35° E. and dipping 5°–35° W. This mine has produced about 10 to 15 cars of ore according to unsubstantiated reports; some was reduced in arrastres and some was shipped.

WOMBACHER MINE

The Wombacher mine which is about 1½ miles east of Cherry, consists of a shaft 80 feet deep that connects with short drifts at the bottom. At a depth of 30 feet, a 10-foot crosscut connects to the vein, and below this level, the shaft follows the vein downward. The shaft cut through an ore shoot but the drifts were in barren rock. The mine is reported to have produced between $5,000 and $10,000 in gold ore; some ore was reduced in arrastres and some was shipped.

DOVE MINE

This mine which is about 100 feet west of the Wombacher mine, in 1951 consisted of a vertical shaft 70 feet deep, sunk in the vein. The operators planned to sink the shaft below the level of the Wombacher workings and run a drift eastward on the vein, which strikes N. 35° E. and dips 70° W. to vertical. This is one of the steepest veins in the district.

SUNNYBROOK MINE

The Sunnybrook mine, which is less than a mile west-southwest of Cherry, consists of an incline shaft sunk on the vein. The depth of the shaft is unknown. About 65 feet below the collar, short drifts connect to the shaft, and in 1951 ground water stood at the drift level. The vein strikes N. 15° W. and dips 55° W.; the average width is 18 inches. The vein wedges out at the face of the drift southwest of the shaft, and the gold content and the dip of the vein are reported to decrease with depth.

LOGAN MINE

This mine, 2 miles southeast of Cherry, is one of the deepest in the district. An inclined shaft on the vein is 600 feet deep and connects to three levels; at 60, 160, and 400 feet below the surface. The shaft was filled with water in 1951 to within 50 feet of the surface. Ore was not found below the 400 level. The vein ranges from 1 to 5 feet in width and strikes N. 40° W. and dips 35° W.; the northwest strike is unique in the district.

Gold worth about $14,000 was mined from the 160 level and smelter return sheets show that the ore averaged about $30 per ton. A northwest drift 350 feet long on the 400 level produced ore worth about $25 per ton 175 feet from the shaft and near the end of the drift. Lindgren (1926, p. 107) stated that a mill was on the property in 1922, but it was gone in 1951.

BLACK HILLS MINING DISTRICT

This mining district is on the western slope of the Black Hills and extends eastward along the south margin of Mingus Mountain to near Cherry. Many scattered prospects are in this district, but only one mine, the Yaeger, has had any appreciable production. Small showings of copper occur in many parts of the district, but most prospecting has been disappointing. The district includes much of the quartz diorite in the southern part of the Bingus Mountain quadrangle and much of the Ash Creek and Alder groups. The age of mineral deposition is presumably Precambrian, because of the general similarity to the veins in the Cherry district that are definitely of Precambrian age. Although mineral deposition in the Yaeger mine cannot be proven positively to be of Precambrian age, the absence of mineralized faults and fractures in the nearby Paleozoic rocks is strongly indicative.

YAEGER MINE

The first production from this mine which is located about a mile south of the Prescott-Jerome highway next to the Shylock fault apparently was in 1890. According to Elsing and Heineman (1936, p. 102), 10,000,000 pounds of copper, $52,000 of gold and $50 of silver, having a total value of $1,500,000, were produced from 1890 to 1922. Much of this production must have been before 1904, as subsequent production from the Black Hills district totals less than $300,000. The mine has been inactive since 1923, except for a few attempts to mill some of the dump ore.

The mine is developed by an inclined shaft to the 1,300 level, with drifts extending mostly to the east for a maximum of 750 feet. The mine is now inaccessible.

The Yaeger mine is in a lithic tuff member of the

Grapevine Gulch formation cut by a few narrow diorite porphyry dikes. The vein strikes east and dips 35° S. Apparently, it does not extend westward from the Shylock fault. According to Lindgren (1926, p. 98), the vein locally is 7 feet wide, containing 3 feet of solid bornite. The ore generally consists of calcite, quartz, bornite, and tennantite, and a little pyrite. Secondary chalcocite, azurite, and malachite are also present. Large aggregates of bornite and tennantite are common. Near the surface, oxide copper ore is present, but no well-defined chalcocite zone was found. The ore was reported to contain about 0.65 ounce of silver to the ton and 1 percent of copper, and was chiefly high grade. The ore shoot raked to the east, beginning near the collar of the shaft, and apparently ranges from 200 to 300 feet in length on the middle levels but becomes small on the 1,300 level.

SHYLOCK MINE

The Shylock mine is along the western front of the Black Hills about 3 miles south of the Yaeger mine. The Shylock fault is west of the shaft. It is not known whether shipments of ore have been made, but the mine is explored by an inclined shaft reported to be 1,053 feet deep with drifts totaling 2,000 feet. The country rock is the bedded tuffaceous member of the Grapevine Gulch formation. The shaft was sunk on a vein striking east-northeast and dipping 60° S. The vein was not found west of the Shylock fault.

The gangue in the vein is chiefly massive white quartz, but includes some ankerite, and tetrahedrite, galena, and sphalerite irregularly distributed through it. The ore is in part oxidized, and cinnabar has been recognized in the oxide zone. According to Lindgren (1926, p. 100), decomposition of mercurial tetrahedrite probably resulted in the deposition of the cinnabar, which occurs as coatings, and fracture fillings. On the two upper levels, the width of the quartz vein reached 5 to 6 feet. Benedict (quoted by Lindgren, 1926, p. 100) believes that the deposit was essentially a quartz lens that pinched out in both directions from the shaft.

BRINDLE PUP MINE

The Brindle Pup mine is about midway between Black Canyon and Ash Creek, south of Mingus Mountain. Two small prospect pits were sunk in Buzzard rhyolite beneath a capping of Tapeats sandstone(?). The main workings, however, are in the wide granodiorite porphyry dike that cuts the Deception and Buzzard rhyolite masses (1,327,500 N.; 441,800 E.). The shaft is caved and no information is available as to the extent of the underground workings. On the dump, quartz veins in granodiorite porphyry fragments contain streaks and aggregates of pyrite. Lindgren reports (1926, p. 100) that the ore is massive, and contains quartz, ankerite, pyrite, galena, and sphalerite.

COBALT PROSPECT

A small cobalt prospect is located about half a mile southeast from the Shylock mine in a tributary to Grapevine Gulch (1,315,000 N.; 422,000 E.). The country rock is a small patch of gabbro separating the granodiorite to the south from Grapevine Gulch formation to the north. An opencut 28 feet long leads to an 18-foot adit. A 20-foot winze was sunk at the portal which exposed a small vein striking N. 30° E. and dipping 60°–70° W. The vein ranges in width from a knife-edge to 14 inches, and is about 15 feet long. It pinches out before reaching the face of the adit, and is not exposed on the southwest side of the winze. The vein material is partly oxidized altered gabbro containing relics of sulfide, possibly cobaltiferous arsenopyrite. The vein in the adit is covered with erythrite (cobalt bloom).

PROSPECTING OPERATIONS IN THE BLACK HILLS DISTRICT

The Black Hills district may be divided into two areas. Many prospect pits, shafts, and cuts have been made in a belt along the Shylock fault, both within the Alder group and in the granodiorite, particularly where it is sheared. From the Shylock fault eastward, to the Cherry district, prospecting operations have been widely scattered in the granodiorite and Ash Creek group.

Along the Shylock fault zone, much of the prospecting has been along quartz veins ranging from 1 inch to 2 feet in width. The average width is about 3–4 inches. The trend of most of these veins ranges from N. 20° W. to north, but a few trend northeastward and eastward. Many of the veins contain some carbonate minerals (dolomite?, ankerite?), and surface croppings contain scattered films of malachite and azurite. Very little galena, pyrite, and chalcopyrite were observed on some dumps from the deeper shafts.

Where these narrow quartz veins cut the purple slate member of the Texas Gulch formation, the trend of the veins truncates the strike of the foliation, and bleached zones as much as 3 feet wide parallel the veins.

On the ridge east of the Yaeger mine in the Grapevine Gulch formation, some prospecting was done in 1946 along quartz veins striking north-south to N. 20° E. Galena, pyrite, bornite, anglesite, and azurite are exposed in shafts and on the dumps. An adit was driven 240 feet to the west without intersecting the vein zone, and it is reported that a diamond-drill hole from the face of the adit cut through 40 feet of low-grade mineralized rock.

Silicified zones produce prominent ribs that stand out above the adjacent rocks in the Alder group west of the Shylock fault (pl. 1). Some of the silicified rock forms irregular blebs, but most of the zones are linear and are arranged en echelon or branch. They cut across lithologic contacts, thus proving that they are not quartzite interbeds. The width of the silicified ribs ranges from a few feet to more than 100 feet. Most of the silicified rocks are dark from a coating of iron and manganese oxides. Some probably contain magnetite as the compass needle is deflected near them. In places, the quartz is white and barren. Several prospect holes have been driven into these silicified zones with unsatisfactory results. A deep shaft was sunk on one of the silicified ribs, and a fair-sized dump indicates lateral workings (1,301,800 N.; 415,500 E.). Most of the rock on the dump is gray slate from the adjacent Texas Gulch formation, but some quartz fragments contain scattered pyrite coated with chalcocite.

The scattered prospect pits and shafts east of the Shylock fault zone are confined chiefly to northeastward-trending orange-brown shear zones in the granodiorite. The quartz veins in the shear zones generally parallel the shear zones, but locally some strike northwest. The dips of the veins are generally moderate, that is from 30° to 60°. Ankerite and (or) dolomite are common accessory minerals in the gangue. The veins are commonly stained red and brown from iron oxide, and malachite, azurite, and chrysocolla films are present. On some of the dumps, limonite pseudomorphs after pyrite were observed. The dump from a shaft (pl. 1), 1,293,400 N.; 432,000 E., has fragments of quartz-ankerite vein material containing bornite, as well as the carbonates of copper.

A few prospect shafts have been sunk along quartz veins in the Ash Creek group north of the granodiorite. Quartz, copper stains, and a little chalcopyrite are found on the dumps of some of these prospects.

Molybdenite was observed in a quartz vein in Burnt Canyon, half a mile northwest of the Brindle Pup mine (1,327,800 N.; 438,700 E.). The country rock is a small body of granodiorite porphyry, and the vein strikes N. 20° W. and dips 70° E. The width of the vein is about 1 foot. Scattered molybdenite crystals and coatings of ferrimolybdite, malachite, and limonite are present. A short adit was driven to explore the vein, but the grade of molybdenite is too low to encourage additional prospecting.

LITERATURE CITED

Anderson, C. A., 1927, Voltaite from Jerome, Ariz.: Am. Mineralogist, v. 12, p. 287–290.

——— 1933, The Tuscan formation of northern California, with a discussion concerning the origin of volcanic breccias: Calif. Univ., Dept. Geol. Sci. Bull., v. 23, p. 215–276.

——— 1951, Older Precambrian structure in Arizona: Geol. Soc. America Bull., v. 62, p. 1331–1346.

Babenroth, D. L., and Strahler, A. N., 1945, Geomorphology and structure of the east Kaibab monocline, Arizona and Utah: Geol. Soc. America Bull., v. 56, p. 107–150.

Barker, L. M., 1930, Concentrating plant of United Verde Copper Co.: Min. Cong. Jour., v. 16, p. 363–367.

Bartlett, Katharine, 1942, Notes upon the routes of Espejo and Farfan to the mines in the sixteenth century: N. Mex. Hist. Rev., p. 21–36.

Bateman, A. M., 1927, Ore deposits of the Rio Tinto (Huelva) district, Spain: Econ. Geology, v. 22, no. 6, p. 569–614.

Benson, Lyman, and Darrow, R. A., 1944, A manual of southwestern desert trees and shrubs: Ariz. Univ. Biol. Sci. Bull. no. 6, 411 p.

Billings, M. P., 1942, Structural geology: New York, Prentice-Hall, Inc., 473 p.

——— 1950, Stratigraphy and the study of metamorphic rocks: Geol. Soc. America Bull., v. 61, p. 436–448.

Blandy, J. F., 1883, The mining region around Prescott, Ariz.: Am. Inst. Min. Metall. Eng. Trans., v. 11, p. 286–291.

Bramlette, M. N., 1946, The Monterey formation of California and the origin of its siliceous rocks: U. S. Geol. Survey Prof. Paper 212, 57 p.

Brownell, G. M., and Kinkel, A. R., 1935, The Flin Flon mine, geology and paragenesis of the ore deposit: Canadian Inst. Min. Metall. Trans., v. 38, p. 261–286.

Butler, B. S., and Wilson, E. D., 1938, General features of some Arizona ore deposits: Ariz. Bur. Mines, Bull. 145, p. 9–25.

Campbell, Ian, and Maxson, J. H., 1938, Geological studies of the Archean rocks at Grand Canyon, Ariz.: Carnegie Inst. Washington, Year Book 37, p. 359–364.

Capps, S. R., and Johnson, B. L., 1915, The Ellamar district, Alaska: U. S. Geol. Survey Bull. 605, 125 p.

Childs, O. E., 1948, Geomorphology of the valley of the Little Colorado River, Ariz.: Geol. Soc. America Bull., v. 59, p. 353–388.

Clarke, F. W., 1924, Data of geochemistry: U. S. Geol. Survey Bull. 770, 841 p.

Clarke, F. W., and Washington, H. S., 1924, The composition of the earth's crust: U. S. Geol. Survey Prof. Paper 127, 117 p.

Cloos, Ernst, 1946, Lineation, a critical review and annotated bibliography: Geol. Soc. America Mem. 18, 122 p.

Cloos, H. 1930, Zur Experimentellen Tektonik: Die Naturwissenschaften, Jhg. 18, p. 714–747.

Cooke, H. C., 1947, The Canadian shield *in* Geology and economic minerals of Canada: 3d ed., Canada Geol. Survey Econ. Geology ser. 1, p. 11–97.

Cowley, J. F., and Quayle, T. W., 1930, Development and mining methods, United Verde Copper Co.: Min. Cong. Jour., v. 16, p. 313–325.

Creasey, S. C., 1950, Iron King mine, Yavapai County, Ariz., *in* Arizona zinc and lead deposits: Ariz. Bur. Mines Bull. 156, p. 112–122.

——— 1952, Geology of the Iron King mine, Yavapai County, Ariz.: Econ. Geology, v. 47, p. 24–56.

Daly, R. A., 1933, Igneous rocks and the depths of the earth: New York, McGraw-Hill, 598 p.

D'Arcy, R. L., 1930, Mining practice and methods at the United Verde Extension Mining Co., Jerome, Ariz.: U. S. Bur. Mines Inf. Circ. 6250, 12 p.

Darton, N. H., 1910, A reconnaissance of parts of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, 88 p.

——— 1925, A résumé of Arizona geology: Ariz. Bur. Mines Bull. 119, 298 p.

Darton, N. H., and others, 1924, Geologic map of the State of Arizona: Prepared by the Arizona Bureau of Mines in cooperation with the U. S. Geological Survey.

Davis, E. F., 1918, The radiolarian cherts of the Franciscan group: Calif. Univ. Dept., Geol. Sci. Bull., v. 11, p. 235–432.

Denny, F. W., 1930, Cottrell plant of the United Verde Copper Co.: Min. Cong. Jour., v. 16, p. 370–375.

Dewey, H., and Flett, J. S., 1911, On some British pillow-lavas and the rocks associated with them: Geol. Mag., v. 8, p. 202–209.

Ekkernkamp, M., 1939, Zum Problem der altern Anlagen in Bruchgebieten: Geol. Rundschau 30, p. 713–764.

Elsing, M. J., and Heineman, R. E. S., 1936, Arizona metal production: Ariz. Bur. Mines Bull. 140, 112 p.

Fearing, J. L., Jr., 1926, Some notes on the geology of the Jerome district, Ariz.: Econ. Geology, v. 21, p. 757–773.

Fearing, J. L., Jr., and Benedict, P. C., 1925, Geology of the Verde Central mine: Eng. and Min. Jour., v. 119, p. 609–611.

Finlay, J. R., 1918, The Jerome district of Arizona: Eng. and Min. Jour., v. 106, p. 557–562; 605–610.

Finlayson, A. M., 1910, The pyrite deposits of Huelva, Spain: Econ. Geology, v. 5, no. 5, p. 357–372; 403–437.

Fuller, R. E., 1931, The aqueous chilling of basaltic lava on the Columbia River plateau: Am. Jour. Sci., v. 21, p. 281–300.

Gavelin, S., 1939, Geology and ore of the Malanas district, Vasterbotten, Sweden: Sveriges geol. undersökning, Årsbok v. 33, no. 4, 198 p.

Gidley, J. W., 1922, Preliminary report on fossil vertebrates of the San Pedro valley, Ariz., with descriptions of new species of Rodentia and Langomorphia: U. S. Geol. Survey Prof. Paper 131–E, p. 119–131.

——— 1926, Fossil Proboscidea and Edentata of the San Pedro valley, Ariz.: U. S. Geol. Survey Prof. Paper 140–B, p. 83–95.

Gilbert, G. K., 1875, Report on the geology of portions of New Mexico and Arizona: U. S. Geog. and Geol. Survey, W. 100th Mer. Rept., v. 3, p. 503–567.

Gill, J. E., 1948, The Canadian Precambrian shield, *in* Structural geology of Canadian ore deposits: Canadian Inst. Min. Metallurgy, Geology Div., p. 20–48.

Graton, L. C., 1909, The occurrence of copper in Shasta County, Calif.: U. S. Geol. Survey Bull. 430–B, p. 71–111.

Grubenmann, U., and Niggli, P., 1924, Die Gesteinsmetamorphose: Bornstraege, Berlin, 539 p.

Gunning, H. C., 1937, Cadillac area, Quebec: Canada Geol. Survey Mem. 206, 80 p.

Gunning, H. C., and Ambrose, J. W., 1940, Malartic area, Quebec: Canada Geol. Survey Mem. 222, 142 p.

Gutschick, R. C., 1943, The Redwall limestone (Mississippian) of Yavapai County, Ariz.: Plateau, v. 16, no. 1, p. 1–11.

Hamilton, Patrick, 1883, Resources of Arizona: 2d ed., San Francisco, A. L. Bancroft and Co., 275 p.

——— 1884, Resources of Arizona, 3d ed.: San Francisco, A. L. Bancroft and Co., 414 p.

Hansen, M. G., 1930, Geology and ore deposits of the United Verde Mine: Min. Cong. Jour., v. 16, p. 306–312.

Hanson, G., 1920, Some Canadian occurrences of pyrite deposits in metamorphic rocks: Econ. Geology, v. 15, p. 574–609.

Heineman, S. R. E., 1938, Summary of mining history in Arizona: Ariz. Bur. Mines Bull. 145, p. 26–31.

Hendericks, H. R., 1947, Milling lead-zinc ores at the Iron King mine, Prescott, Ariz.: Am. Inst. Min. Metall. Eng., Min. Tech., v. 11, no. 4, Tech. Paper 2191, 5 p.

Heyl, G. R., 1948, Foothill copper-zinc belt of the Sierra Nevada, Calif.: Calif. Div. Mines, Bull. 144, p. 11–29.

Hinds, N. E. A., 1936, Uncompahgran and Beltian deposits in western North America: Carnegie Inst. Washington Pub. 463, p. 53–136.

Huddle, J. W., and Dobrovolny, E., 1945, Late Paleozoic stratigraphy and oil and gas possibilities of central and northeastern Arizona: U. S. Geol. Survey Oil and Gas Investigations, Prelim. Chart 10.

——— 1952, Devonian and Mississippian rocks of Central Arizona: U. S. Geol. Survey Prof. Paper 233–D, p. 67–112.

Huff, L. C., 1955, A Paleozoic geochemical anolomy near Jerome, Arizona: U. S. Geol. Survey Bull. 1000–C, p. 105–188.

Hughes, P. W., 1949, History of the Supai formation in the Black Mesa, Yavapai County, Ariz.: Plateau, v. 22, no. 2, p. 32–36.

——— 1952, Stratigraphy of Supai formation, Chino Valley area, Yavapai County, Ariz.: Am. Assoc. Petroleum Geologists Bull., v. 36, p. 635–657.

Ingalls, W. R., 1931, World survey of the zinc industry: Min. Met. Soc. America, N. Y., 128 p.

Jaggar, T. A., and Palache, Charles, 1905, Description of Bradshaw Mountains quadrangle, Ariz.: U. S. Geol. Survey Geol. Atlas, folio 126, 11 p.

James, H. L., 1954, Sedimentary facies of iron-formation: Econ. Geology, v. 49, p. 236–293.

Jenkins, O. P., 1923, Verde River lake beds near Clarkdale, Ariz.: Am. Jour. Sci., 5th ser., v. 5, no. 25, p. 65–81.

Keefe, P. C., 1930, Smelter crushing plant: Min. Cong. Jour., v. 16, p. 361–362.

Knechtel, M. M., 1936, Geologic relations of the Gila conglomerate in southeastern Arizona: Am. Jour. Sci., v. 31, p. 81–92.

Knopf, E. B., and Ingerson, E., 1938, Structural petrology: Geol. Soc. America Mem. 6, p. 270.

Koffman, A. A., Price, R. L., Cairns, R. B., Ogoyzl, L. W., and Stockwell, C. H., 1948, Flin Flon mine: Structural geology of Canadian ore deposits: 1st ed., p. 295–301.

Kumke, C. A., and Mills, H. F., 1950, Mining methods and practices at the Iron King mine, Shattuck-Denn Mining Corp., Yavapai County, Ariz.: U. S. Bur. Mines Inf. Circ. 7539, 17 p.

Kuzell, C. R., 1930, Blast furnace smelting: Min. Cong. Jour., v. 16, p. 374–378.

Lanning, J. F., 1930, Historical growth of the United Verde Smelting plant at Clarkdale, Ariz.: Min. Cong. Jour., v. 16, p. 354–360.

Laskey, S. G., 1936, Geology and ore deposits of the Bayard area, Central mining district, N. Mex.: U. S. Geol. Survey Bull. 870, 144 p.

Lausen, Carl, 1928, Hydrous sulphates formed under fumarolic conditions at the United Verde mine: Am. Mineralogist, v. 13, p. 203–225.

——— 1930, The pre-Cambrian greenstone complex of the Jerome quadrangle: Jour. Geology, v. 38, p. 174–183.

Leith, C. K., 1923, Structural geology: New York, Holt and Co., 390 p.

Leith, C. K., Lund, R. J., and Leith, Andrew, 1935, Pre-Cambrian rocks of the Lake Superior region: U. S. Geol. Survey Prof. Paper 184, 34 p.

Lindgren, Waldemar, 1905, The copper deposits of the Clifton-Morenci district, Ariz.: U. S. Geol. Survey Prof. Paper 43, 375 p.

——— 1926, Ore deposits of the Jerome and Bradshaw Mountains quadrangles, Ariz.: U. S. Geol. Survey Bull. 782, 192 p.

——— 1933, Mineral deposits, 4th ed.: New York, McGraw-Hill Book Co., 930 p.

Lindgren W., and Irving, J. D., 1911, The origin of the Rammelsberg ore deposit: Econ. Geology, v. 6, p. 303–313.

Little, W. W., 1950, Radial blast holes for drilling an irregular ore body: Min. Engineering, p. 463–465.

McKee, E. D., 1937, Triassic pebbles in northern Arizona containing invertebrate fossils: Am. Jour. Sci., v. 33, p. 260–263.

——— 1940, Three types of cross-lamination in Paleozoic rocks of northern Arizona: Am. Jour. Sci., v. 238, p. 811–824.

——— 1945, Cambrian history of the Grand Canyon region: Carnegie Inst. Washington Pub. 563, 232 p.

——— 1951, Sedimentary basins of Arizona and adjoining areas: Geol. Soc. America Bull., v. 62, p. 481–506.

McNair, A. H., 1951, Paleozoic stratigraphy of part of northwestern Arizona: Am. Assoc. Petroleum Geologists Bull., v. 35, no. 3, p. 503–541.

Mahard, R. H., 1949, Late Cenozoic chronology of the Upper Verde Valley, Ariz.: Denison Univ. Sci. Lab. Bull., v. 41, p. 97–127.

Merriam, C. W., 1940, Devonian stratigraphy and paleontology of the Roberts Mountains region, Nev.: Geol. Soc. America Spec. Paper no. 25, 114 p.

Mills, H. F., 1941, Ore occurrence at the Iron King mine: Eng. and Min. Jour., v. 142, no. 10, p. 56–57.

——— 1947, Occurrence of lead-zinc ore at the Iron King mine, Prescott, Ariz.: Am. Inst. Min. Metall. Eng., Min. Tech., v. 11, no. 4, Tech. Paper 2190, 4 p.

Mooney, F. X., 1930, Reverberatory smelting: Min. Cong. Jour., v. 16, p. 379–381.

Newhouse, W. H., and Flaherty, G. E., 1930, The texture and origin of some banded or schistose sulphide ores: Econ. Geology, v. 25, p. 600–620.

Nichol, A. A., 1937, The natural vegetation of Arizona: Ariz. Univ., College Agriculture Tech. Bull. no. 68, p. 181–222.

Noble, L. F., 1922, A section of the Paleozoic formations of the Grand Canyon at the Bass Trail: U. S. Geol. Survey Prof. Paper 131–B, p. 23–73.

Noble, L. F., and Hunter, J. F., 1917, A reconnaissance of the Archean complex of the Granite Gorge, Grand Canyon, Ariz.: U. S. Geol. Survey Prof. Paper 98–I, p. 95–113.

Palache, Charles, Berman, Harry, and Frondel, Clifford, 1944. The system of mineralogy, 7th ed., v. 1, New York, John Wiley & Sons, 834 p.

Parsons, F. H., 1930, The roaster plant: Min. Cong. Jour., v. 16, p. 369.

Peterson, N. P., Gilbert, C. M., and Quick, G. L., 1951, Geology and ore deposits of the Castle Dome area, Gila County, Ariz.: U. S. Geol. Survey Bull. 971, 134 p.

Price, Peter, 1934, The geology and ore deposits of the Horne mine, Noranda, Quebec: Canadian Inst. Min. Metall. Trans., v. 36, p. 108–140.

Price, W. E., Jr., 1950, Cenozoic gravels on the rim of Sycamore Canyon, Ariz.: Geol. Soc. America Bull., v. 61, no. 5, p. 501–508.

Provot, F. A., 1916, Jerome mining district geology: Eng. and Min. Jour., v. 102, p. 1028–1031.

Pullen, J. B., 1941, Modified mining methods in the United Verde mine: Am. Inst. Min. Metall. Eng., Tech. Paper 1273, 18 p.

Ralston, O. C., 1930, Possibilities of zinc production in Arizona: Min. Jour., v. 14, p. 11.

——— 1930a, Research at the United Verde: Min. Cong. Jour., v. 16, p. 384–385.

Ransome, F. L., 1903, Geology of the Globe copper district, Ariz.: U. S. Geol. Survey Prof. Paper 12, 168 p.

——— 1904, The geology and ore deposits of the Bisbee quadrangle, Ariz.: U. S. Geol. Survey Prof. Paper 21, 168 p.

——— 1916, Some Paleozoic sections in Arizona and their correlation: U. S. Geol. Survey Prof. Paper 98-K, p. 133–166.

——— 1919, The copper deposits of Ray and Miami, Ariz.: U. S. Geol. Survey Prof. Paper 115, 192 p.

——— 1932, General geology and summary of ore deposits, *in* Ore deposits of the Southwest: 16th Internat. Geol. Cong. Guidebook 14, Excursion C–1, p. 1–23.

Reber, L. E., Jr., 1922, Geology and ore deposits of Jerome district: Am. Inst. Min. Metall. Eng. Trans., v. 66, p. 3–26.

——— 1938, Jerome district: Ariz. Bur. Mines Bull. 145, p. 41–65.

Reid, J. A., 1906, Sketch of the geology and ore deposits of the Cherry Creek district, Ariz.: Econ. Geology, v. 1, p. 417–436.

Rice, Marion, 1920, Petrographic notes on the ore deposits of Jerome, Ariz.: Am. Inst. Min. Metall. Eng. Trans., v. 61, p. 60–65.

Rickard, T. A., 1918, The story of the U. V. X. bonanza: Min. Sci. Press, v. 116, p. 9–17; p. 47–52.

Robinson, H. H., 1913, The San Franciscan volcanic field, Arizona: U. S. Geol. Survey Prof. Paper 76, 213 p.

Rubey, W. W., 1929, Origin of the siliceous Mowry shale of the Black Hills region: U. S. Geol. Survey Prof. Paper 154–D, p. 153–170.

Sandell, E. B., and Goldich, S. S., 1943, The rarer metallic constituents of some American igneous rocks: Jour. Geology, v. 51, p. 167–189.

Satterly, J., 1941, Pillow lavas from the Dryden-Wabigoon area, Kenora district, Ontario: Toronto Univ. Studies, Geol. ser. no. 46, p. 119–136.

Schouten, C., 1934, Structures and textures of synthetic replacement in "open space": Econ. Geology, v. 29, no. 7, p. 611–658.

Schwartz, G. M., 1938, Oxidized copper ores of the United Verde Extension mine: Econ. Geology, v. 33, p. 21–33.

Short, M. N., 1940, Microscopic determination of the ore minerals: U. S. Geol. Survey Bull. 914, 314 p.

Stevenson, J. S., 1937, Mineralization and metamorphism at the Eustis mine, Quebec: Econ. Geology, v. 32, p. 335–363.

Stickney, A. W., 1915, The pyritic copper deposits of Kyshtim, Russia: Econ. Geology, v. 10, no. 7, p. 593–633.

Stoyanow, A. A., 1926, Notes on recent stratigraphic work in Arizona: Am. Jour. Sci., v. 12, p. 311–324.

——— 1936, Correlation of Arizona Paleozoic formations: Geol. Soc. America Bull., v. 47, p. 459–540.

——— 1942, Paleozoic paleogeography of Arizona: Geol. Soc. America Bull. 53, p. 1255–1282.

Swanson, C. O., and Gunning, H. C., 1945, Geology of the Sullivan mine: Canadian Inst. Min. Metallurgy Trans., v. 48, p. 645–667.

Taliaferro, N. L., 1933, The relation of volcanism to diatomaceous and associated siliceous sediments: Calif. Univ. Dept. Geol. Sci. Bull., v. 23, p. 1–55.

Tally, R. E., 1917, Mine-fire methods employed by the United Verde Copper Co.: Am. Inst. Min. Metall. Eng. Trans., v. 55, p. 186–202.

Tenney, J. B., 1935, The copper deposits of Arizona *in* Copper resources of the world: 16th Internat. Geol. Cong., v. 1, p. 167–235.

Tovote, W. L., 1918, Notes on certain ore deposits of the southwest: Am. Inst. Min. Metall. Eng., Bull. 142, p. 1599–1612.

Tyrrell, G. W., 1929, The principles of petrology: New York, Dutton and Co., 349 p.

——— 1931, Volcanoes: London, Thornton Butterwork, Ltd., 252 p.

Walcott, C. D., 1890, Study of a line of displacement in the Grand Canyon of the Colorado, in northern Arizona: Geol. Soc. America Bull., v. 1, p. 49–64.

Williams, David, 1934, The geology of the Rio Tinto mines, Spain: Inst. Min. Metallurgy Bull. 355, 48 p.

Williams, J. J., 1930, Converter department of the United Verde Copper Co.: Min. Cong. Jour., v. 16, p. 382–383.

Wilson, E. D., 1939, Pre-Cambrian Mazatzal revolution in central Arizona: Geol. Soc. America Bull., v. 50, p. 1113–1164.

——— 1942, Arizona lode gold deposits, *in* Ore deposits as related to structural features, edited by W. H. Newhouse: Princeton Univ. Press, p. 242–243.

Wilson, M. E., 1941, Noranda district, Quebec: Canada Geol. Survey Mem. 229, 162 p.

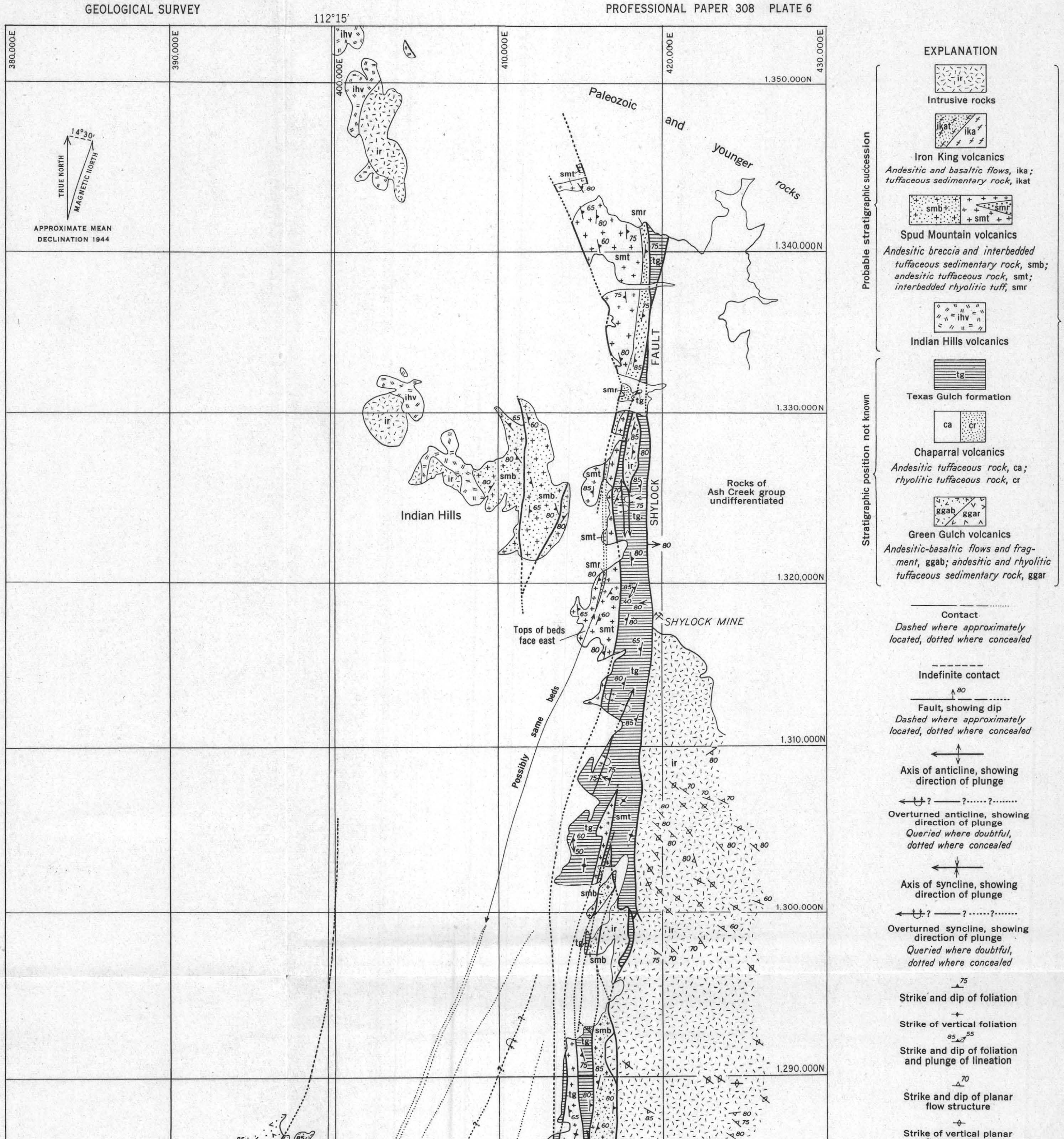
Winchell, A. N., 1933, Elements of optical mineralogy: 3d ed., 459 p.

——— 1936, A third study of chlorite: Am. Mineralogist, v. 21, p. 642–651.

Young, H. V., 1930. Historical sketch of the United Verde Copper Co.: Min. Cong. Jour., v. 16, p. 303–305.

INDEX

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY



INTERPRETATIVE STRUCTURAL MAP OF ALDER GROUP, YAVAPAI COUNTY, ARIZONA

0 1 3 Miles