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BOTTOMING OF THE UNITED VERDE SULPHIDE PIPE

By
Paul F. Yates

PHELPS DODGE CORPORATION
UNITED VERDE BRANCH
JEROME, ARIZONA

ARIZONA SECTION
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PHELPS DODGE CORPORATION

UNITED VERDE BRANCH

MINES DIVISION

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INTRODUCTION

Ninety-five percent of the copper production of the United States has come from sixteen districts, of which Jerome ranks sixth.* The United Verde sulphide pipe has been responsible for giving the Jerome district this rank. The United Verde Extension production was from a down-faulted segment of the upper part of the sulphide pipe. Production from other sources in the district is comparatively negligible.

It is estimated that the original sulphide mass had a total of more than 130 million tons and a vertical extent of over 8300 feet. The United Verde Extension segment accounts for approximately 1120 feet, and the United Verde, to the 4800 ft. level, 4770 feet. The balance was lost by erosion before and after the displacement of the United Verde Extension portion of the sulphide pipe.

Of the twenty most productive western metal mining districts, Billingsley and Locke in 1938,# listed eleven as having been bottomed, or thoroughly explored to the maximum justifiable depth. Four, including the Jerome district, were listed as not having been bottomed. The Jerome district must now be deleted from this latter category.

Production from the United Verde Extension ceased in 1937. Present production from the United Verde is largely from cleanup operations. Extensive exploration to a depth of 1500 feet below the lowest stoping level in the United Verde mine has shown this great sulphide pipe diminishing into roots that are almost negligible.

The Jerome mining district is located on the northeasterly slope of the Black Hills in central Arizona with the two principal mines, the United Verde and the United Verde Extension, close to the town of Jerome near the north end of the district. The geology of the district has been described by several writers.** Here it will suffice to review the more salient features pertaining to the environment of the United Verde sulphide pipe.

*Copper Mining in North America, U.S.B.M. Bull. 405, p.2-8.
U.S.B.M. Minerals Yearbook, 1944.

#P. Billingsley and A. Locke, "Structures of Ore Deposits in the Continental Framework". A.I.M.E. Trans. 144, p. 9-64, 1941.

**See list of references.

GEOLOGY

The geological record begins well back in pre-Cambrian time with a vast outpouring of volcanic material of widely varying composition. This has been termed the greenstone complex and includes much rhyolitic flow and some fragmental material. Overlying this is the bedded sediments formation in which bedded volcanic tuffs and sedimentary material predominates. During a period of deformation the material was consolidated, folded, faulted and titled steeply to the northwest.

Rhyolitic (Cleopatra) quartz porphyry was then intruded as a large, somewhat tabular mass approximately along the greenstone-bedded sediments contact. The United Verde diorite followed in the form of a tabular blunt-nosed expanding plug roughly on the quartz porphyry-bedded sediments contact. Often a remnant of the sediments was left between the porphyry and diorite. Locally the diorite cuts across porphyry tongues.

A series of mineralizing solutions followed the intrusion of the diorite, coming up through the marginal zone of the quartz porphyry. These solutions were controlled by the concave configurations of the overhanging diorite and the schistosity and fracturing in the quartz porphyry. The United Verde sulphide pipe was formed by replacement of part of the remnants of the sediments and much of the quartz porphyry by sulphides, quartz and ferruginous chlorite. After the formation of the sulphide pipe the region was subject to dynamic forces which resulted in major faulting. One of these faults, the Verde, which strikes northwesterly and dips to the east, resulted in the placement of the United Verde Extension orebody. It is estimated that the vertical displacement on this fault in pre-Cambrian time was something like 2400 feet.

Following a long period of erosion and peneplanation, the middle Cambrian (Tapeats) sandstone was deposited as a thin blanket (0-100 ft.) of ferruginous beach sand and pebbles which tended to fill the minor irregularities of the pre-Cambrian surface. Overlying the basal sandstone in the Jerome area are from 300 to 500 feet of Devonian limestone, 300 to 500 feet of Mississippian (Redwall) limestone, and from nothing to 500 feet of red (Supai) sandstone and shale of Permian age. The deposition of each of these periods was preceded and followed by periods of uplift and erosion. Later an outpouring of Tertiary lavas (Malpais) formed a covering mantle. Damming of the Verde Valley by the lavas and contemperaneous subsidence permitted the deposition of over 2000 feet of impure while calcareous seidments (Verde formation).

Pre-lava erosion was evidently very active. A deep stream channel cut through the Paleozoic formations and partly exposed the gossan of the United Verde Extension segment of the sulphide pipe. This channel is now filled with Tertiary gravel and lava.

After the outpouring of the Tertiary lavas there occurred a period of normal faulting which relatively uplifted the west side of the Verde Valley in the neighborhood of 5000 feet. The added displacement on the Verde Fault as indicated by the relative positions of the base of the Paleozoic formations in the vicinity of the sulphide pipe measures approximately 1600 feet. The upthrust block containing the lower, or United Verde mine portion of the sulphide pipe, is bounded by four normal faults. The Verde to the east, the Warrior to the west, the Haynes to the north, and the Hull to the south. Post pre-Cambrian displacement on the Haynes Fault was 500 feet, the Warrior Fault 200 feet, and a comparatively small amount on the Hull Fault. In addition to the pre-Cambrian movement on the Verde Fault some evidence exists that there was also pre-Cambrian movement along the other three faults.

The uplifted scarps of the principal faults were especially subject to erosion with the resultant exposure of a strip of pre-Cambrian rocks paralleling the Verde Fault. The proximity of the exposed ore zone to the fault scarp induced rapid erosion which resulted in a comparatively shallow gossan zone above the United Verde mine. The secondary copper found in the fault zone and near the surface to the east was evidently transported from the top of the sulphide pipe during this period.

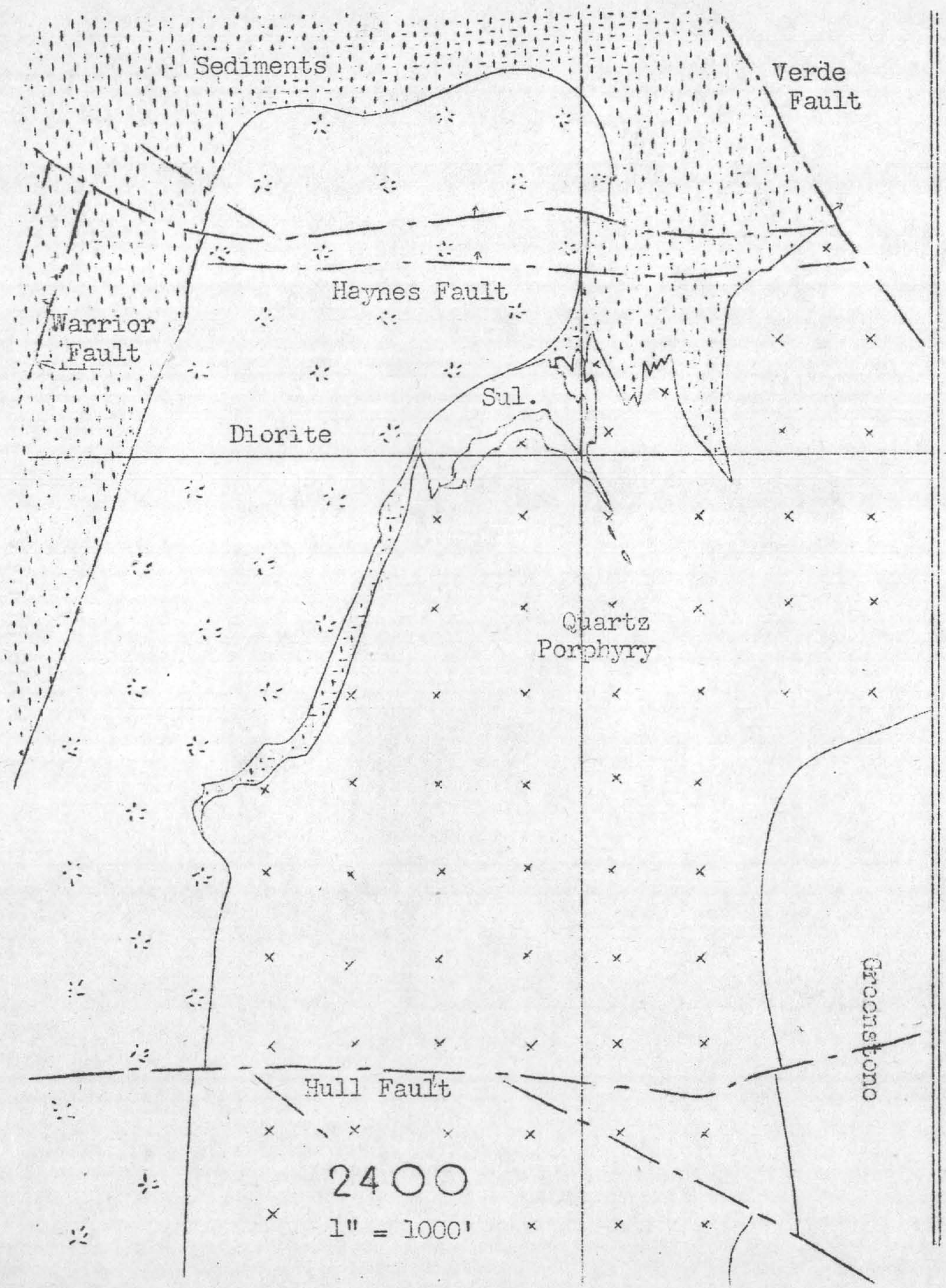
SULPHIDE PIPE

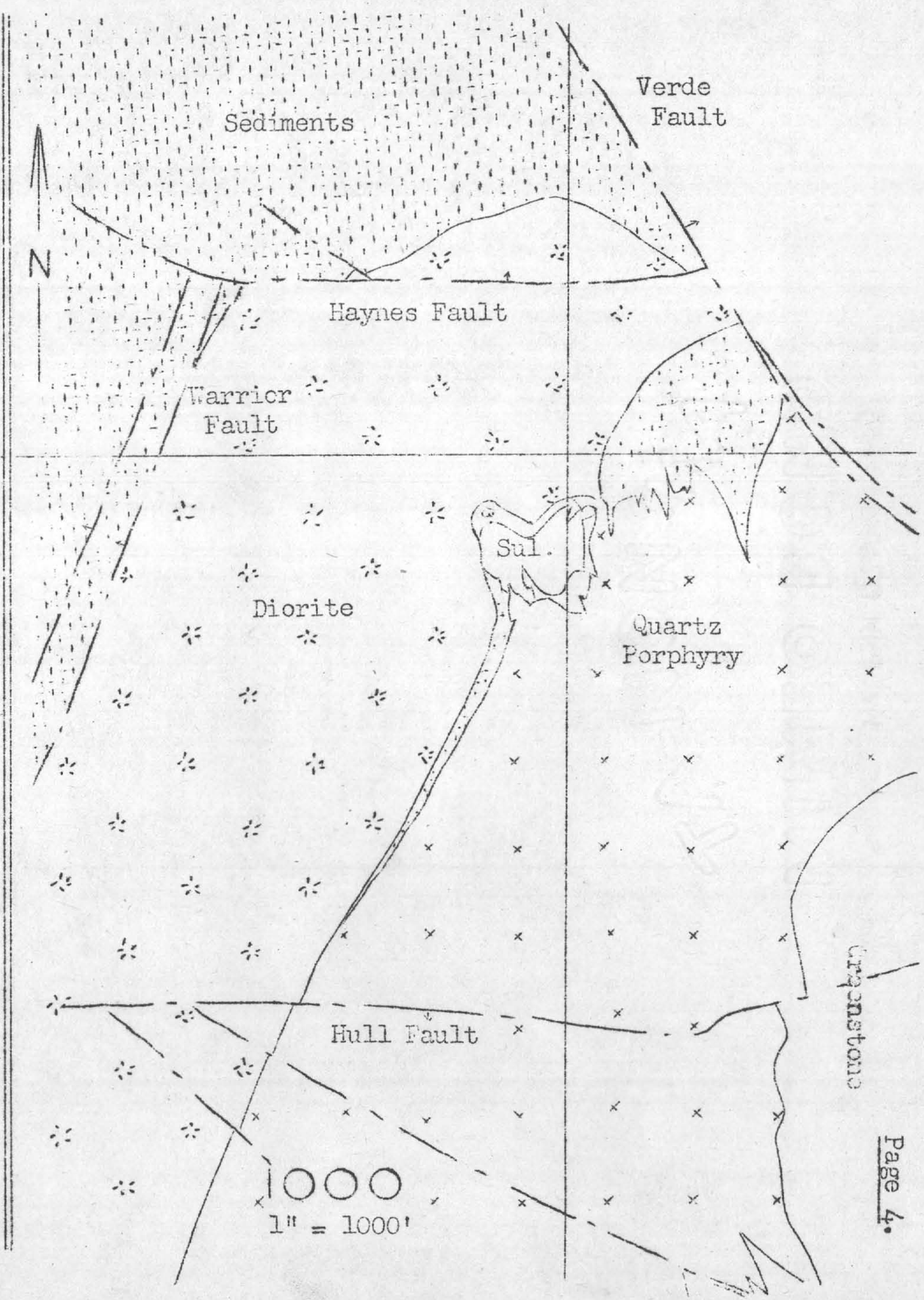
Localization

The United Verde mineralized zone is located in the vicinity of a change in the original trend of the greenstone-bedded sediments contact. (See page 4). To the south from the mineralized zone the contact is in a nearly north-south direction and is comparatively regular. To the north the contact swings to the northeast and is very irregular and interfingering, also to the north near the ore zone, the bedded sediments show many small drag folds evidently related to the plane of weakness along the greenstone-bedded sediments contact. This crumpling is more intense in the upper part of the mine than in the deeper levels. It is believed that the major structure is a large drag fold which plunges steeply to the north-northwest, is more open with depth, and becomes progressively tighter and stronger with increased elevation. The attitude of the minor drag folds support this hypothesis. Much of the evidence along this contact has been destroyed by the intrusion of the quartz porphyry and diorite. The form of these intrusives was affected by the steeply pitching folds, particularly in the case of the quartz porphyry.

The porphyry shows a variable schistosity or parting that is believed to be the result of differential pressure before the rock was completely solidified. The relatively local zones of more intense schistosity were formed later. To the south and east the schistosity strikes west of north and dips to the east. Near the mineralized zone it strikes in a broadly curving arc tending to parallel the surface of the over-riding diorite. The variable schistosity, with zones of greater shearing permitting greater penetration of mineral solutions, is responsible for the irregular footwall of the mineralized zone. In general the amount of shearing near the mineralized zone increases with elevation.

The diorite came in pushing upward and to the northeast, and when it had expanded sufficiently, wrapped around the bend in the porphyry contact. On the bottom levels the east diorite contact is in a north-south line with a bulge or flare to the east near the northern part. Below the


Sediments
Verde Fault
Haynes Fault
Warrior Fault
Sul.
Diorite
Quartz Porphyry
Greenstone
Hull Fault
2400
1" = 1000'


N
Sediments
Verde Fault
Haynes Fault
Warrior Fault
Sul.
Diorite
Quartz Porphyry
Greenstone
Hull Fault
1000
1" = 1000'

3000 ft. level the contact dips to the east to parallel the schistosity of the porphyry. Above the 3000 ft. level, as the diorite expands, the dip is to the west or across the schistosity of the porphyry. As higher elevations are reached, the bulge to the east becomes progressively more prominent. In the middle levels it forms a gently curving arc, and in the upper part of the mine a point swings to the south to form an inverted structural trough. (See plans and vertical section). The plunge of the trough is northerly conforming to the general plunge or the axes of the minor drag folds in the sediments.

Minor Faults and Breaks

The quartz porphyry near its margin with the diorite is cut by an irregular branching pattern of faults. In the upper part of the mine they are either weaker or obscured by mineralization and are hard to trace. In the lower part of the mine they can be traced over considerable distances. These faults appear to have acted as a partial control for the mineralizing solutions. It is significant that the sulphide masses are on the hangingwall side of the breaks, or between the breaks and the diorite. The solutions which formed the black schist penetrated to a certain extent into the footwall side of the breaks, though cross breaks or fracturing associated with the cross breaks. These faults are presumed to have been formed by the forces associated with the intrusion of the expanding diorite as it pushed or wrapped around the bend in the porphyry contact.

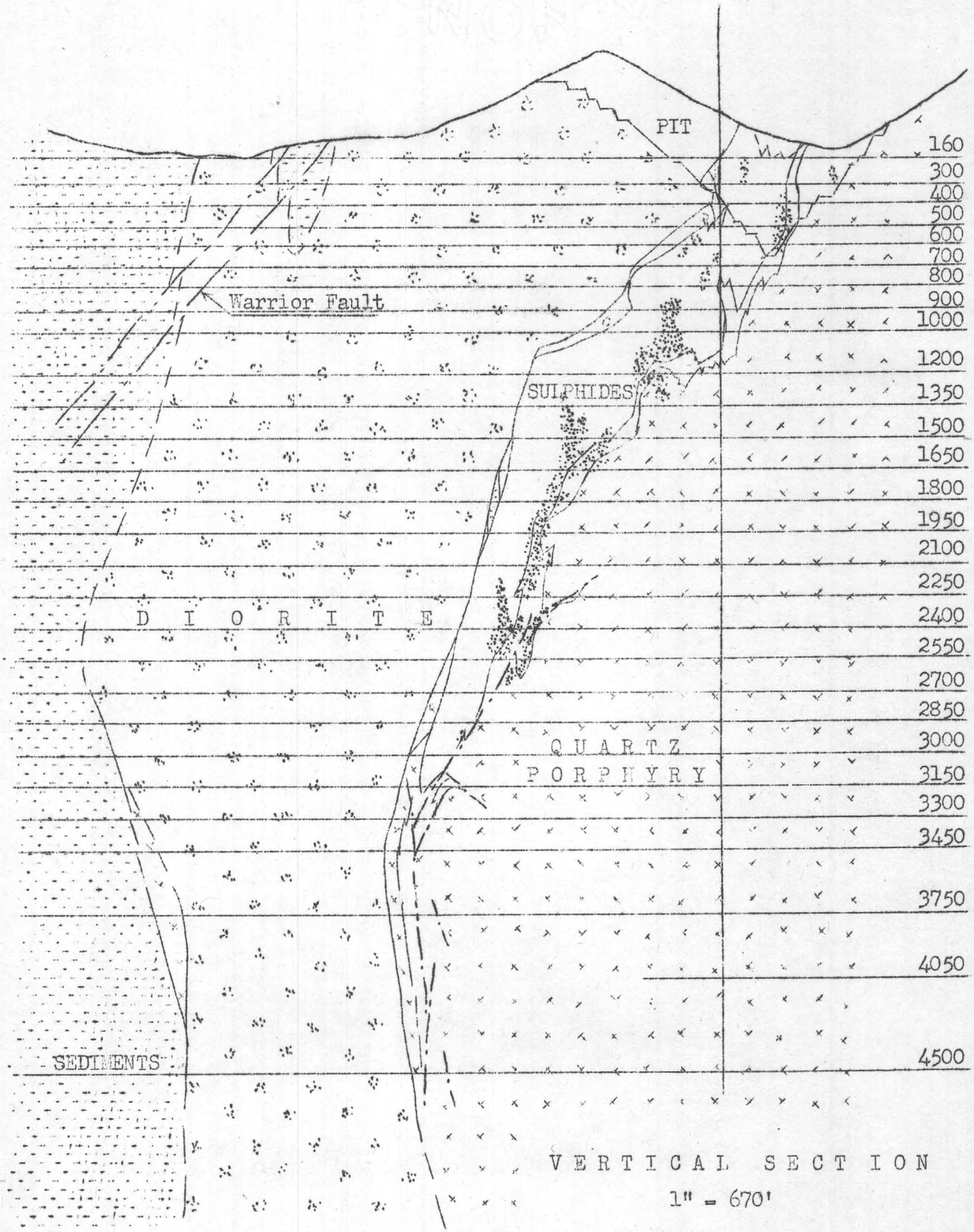
The principal breaks of this fault pattern strike northeasterly and are found starting near the diorite to the south and diverging from it as they skirt the footwall of the sulphide with some branches swinging more to the east and others back toward the diorite. They dip to the northwest at a flatter angle than the diorite-porphyry contact and thus as higher elevations are reached, the space between the breaks and the diorite increases, but still dip toward the contact. (See vertical section Page 6).

A second, less important series, strike in a northwesterly direction and dip to the northeast. In several places the breaks of this series appear to be responsible for the localization of mineralization in the quartz porphyry footwall. Breaks of this series also conform to the southwesterly boundary of the northeast portion of the main mineralized zone.

Faults of both series throw out complicated spurs and branches. The breaks vary in width from a few inches to as much as two or three feet, with crushed rock, quartz, carbonate and gouge filling. They are locally, if not usually, mineralized with pyrite ranging from scattered crystals to streaks and patches. In a number of cases dikes have followed these breaks. The faults are definitely earlier than the intrusion of the dikes and the later mineralization and are believed to be entirely pre-mineral. It is probable that the forces which produced these faults, fractured the already schistose porphyry located between the breaks and the diorite thus forming a more favorable host for the mineralizing solutions.

Dikes

Numerous nearly vertical dioritic dikes cut through the orezone and surrounding rocks in a general east-west direction. In width they generally vary from a fraction of an inch to about three feet. However, there are a number six to eight feet wide, with exceptional cases of



VERTICAL SECTION
1" = 670'

greater width. In some places they are quite regular, in others irregular and broken. The increase in number and local bunching of the dikes, near copper bearing areas, is noticeable with depth. A series of larger dikes starting near the 1500 ft. level cut through the sulphide mass roughly paralleling the diorite contact. With depth they pass towards the footwall of the mineralized zone and on the 3300 ft. level are almost entirely in the chlorite schist and porphyry.

The smaller dikes are usually very fine grained and in places altered or partially altered. The larger dikes are usually fresh and of a coarser texture. Most of the dikes appear to have been intruded following the principal stage of copper mineralization, and before the later stages. There is a possibility that some of the dikes in the lower part of the mine are older.

Mineralization

The United Verde mineralized zone consists of a very irregular pipelike body of massive sulphide, quartz and mixed sulphide and rock with a steep north-northwesterly plunge. It is clearly of the schist replacement type, with replacement of schistose quartz porphyry and a part of the fringe of the bedded sediments. Replacement has been so complete that the relative amounts of the two rocks cannot be determined exactly, but the available evidence indicates that the porphyry was in considerable excess. The cross section of the mineralized zone varies throughout the mine. From the surface to the 1200 ft. level, the horizontal cross section averages about 250,000 square feet. From this horizon to the 1650 ft. level it averages about 500,000 square feet. From the 1800 to the 3000 ft. level it averages a little over 400,000 square feet. From the 3150 ft. level down, the total area decreases rapidly and at the 4500 ft. level it only totals 37,000 square feet, of which 9700 square feet is massive sulphide.

The sulphide zone is limited to the north and west by the impervious diorite, and to the south and east by an irregular border of black chlorite schist. The most abundant primary gangue mineral is pyrite which makes up the great bulk of the sulphide mass. With it are associated large quantities of quartz, chlorite and dolomite. Chalcopyrite is by far the principal copper bearing mineral. Less important associated minerals are sphalerite (marmatite), tennantite, bornite, galena and specularite. The minerals of the oxide zone and zone of a secondary enrichment have been included in earlier reports and are not repeated here.

Several stages of mineralization are recognized and are briefly described as follows*:

1. The first solutions followed the relatively permiable shear zones in the porphyry adjacent to the overhanging diorite, replacing much of the intervening porphyry and portions of the fringe of bedded sediments. These solutions deposited large quantities of quartz with very minor quantities of pyrite and chalcopyrite.

*L. E. Reber, "Jerome District", Some Arizona Copper Deposits, Arizona Bureau of Mines Bull. 145, Pages 41-65, November, 1938.

2. Solutions of the second period deposited much pyrite with important quantities of marmatite, a little chalcopyrite and probably local quartz and dolomite. This period is responsible for the major part of the sulphide zone and probably much of the zinc.

3. In the third period solutions working out from the footwall of the pyrite replaced large quantities of porphyry with a nearly black, high iron variety of chlorite.

4. The fourth period of mineralization was responsible for most of the commercial ore and consisted largely of chalcopyrite with minor pyrite and a little intergrown marmatite and galena. The chalcopyrite appears to have favored the replacement of the chlorite schist.

5. Solutions of the fifth period brought in small quantities of quartz, in part associated with bornite and probably other sulphides.

6. The sixth period of mineralization was characterized by the deposition of intergrown quartz and dolomite with associated chalcopyrite, pyrite, tennantite and sphalerite. These minerals are normally found in the chlorite schist near its footwall contact with the porphyry and most abundantly in the lower stoping levels. In this period mineral deposition by replacement was followed by deposition in fractures and gash veinlets. This mineralization has added materially to the schist ore in certain localities.

7. The latest phase of mineralization resulted in widespread deposition of quartz and dolomite with sparse pyrite in small veins and gash veinlets.

The products of each succeeding phase of the mineralization cycle built up on the footwall of the previous phase, and while rock replacement was most important, some of the products of the preceding phase were nearly always replaced.

In the lower levels of the mine the diorite and bedded sediments parallel the schistosity of the quartz porphyry and the ore zone consists of a few disconnected sulphide-schist lenses. These lenses are in the porphyry near its margin. Two of these are most significant. The lense north of the bulge in the diorite is most extensive on the 4500 ft. level. It is a sulphide-schist lense 280 feet long by about 45 feet wide, with a tail stringing out to the north. Its cross section nearly doubles by the time it reaches the 4050 ft. level, continues about the same to the 3750 ft. level, and then decreases rapidly to pinch out under the expanding diorite just below the 3300 ft. level. The ore in this lense is limited to a cross section of 800 square feet on the 4500 ft. level, increases to 1300 square feet on the 3750 ft. level, then decreases rapidly above this horizon.

Immediately south of the bulge in the diorite on the 4500 ft. level, opposite a rather sharp embayment in the contact, is a lense of quartz, sulphide and schist, 150 feet long by about 30 feet wide. This lense rakes sharply upward to the south, increases rapidly in size to the 3750 ft. level, continues about the same size to the 3450 ft. level. It then decreases up to the 3300 ft. level with a part continuing above the 2700 ft. level. There is very little copper in the massive sulphides in this lense. The copper ore is in the chlorite schist localized along one of the branching faults and separated from the massive sulphides by a band of quartz porphyry, or altered material, transitional between porphyry and chlorite schist. The principal ore body in this lense extends from the 3300 to the 2700 ft. level. There are other mineable bodies of limited size between the 3450 and the 3150 ft. levels.

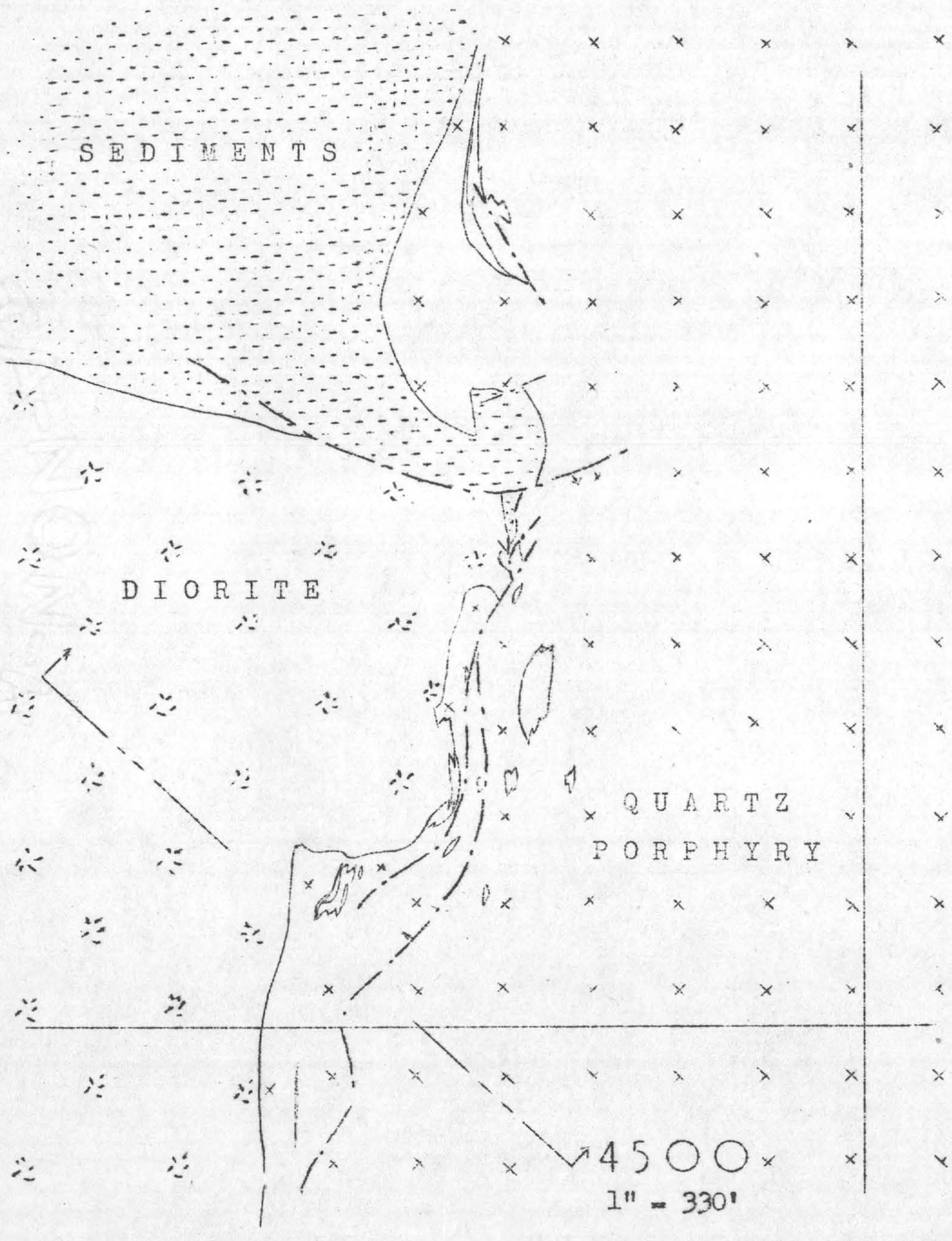
There is a small low grade irregular pipe-like lense of quartz, massive sulphide and mineralized schist associated with quartz-porphyry in a sharp embayment on the west side of the diorite. The material differs only from that of the main ore zone in the presence of visible magnetite and pyrrhotite. This lense pinches out against the overhanging diorite above the 2700 ft. level. It plunges easterly toward the main ore zone, suggesting that it is a small branch comparable to the "north lense".

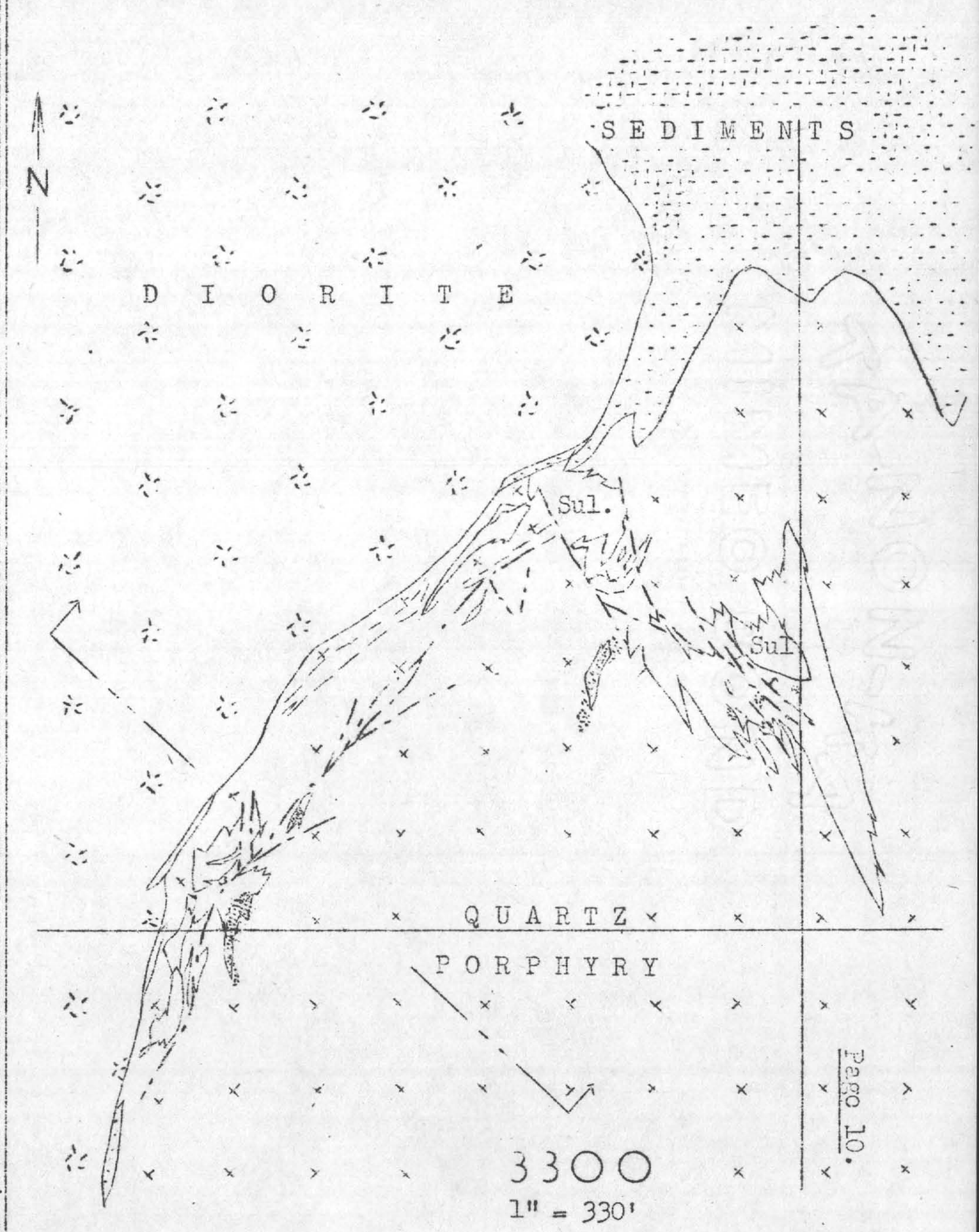
The intervening diorite makes the upper part of the north lense a distinct branch or spur of the mineralized zone, while the south lense may be looked upon as an offset portion of the main ore zone with a vertical overlap of more than 1000 feet on the main sulphide pipe.

On the 4500 ft. level, scattered schist areas with minor sulphide, underlie the main sulphide mass. They extend upward, become stronger and make the bottom of the deepest element of the main sulphide mass, which comes in some distance below the 3750 ft. level. The east element extends from below the 3300 ft. level to join the main mass near the 3150 ft. level; the south element, from below the 3150 ft. level to join the mass near the 2850 ft. level. From the 2850 ft. level upward, the sulphide pipe is continuous.

The start and upward expansion of the east element of the main sulphide body is related to a band of increased schistosity in the quartz porphyry, which grows progressively stronger upward. This zone of schistosity, when combined with the control effected by the expanding bulge in the diorite, accounts for the formation of the crescent shaped sulphide mass in the middle levels. As the diorite continues to expand and over-ride the porphyry, the mineralizing solutions are progressively more confined until in the upper levels, the sulphide is nearly eliptical in form, with the major axis almost perpendicular to the crescent.

Copper. Since the copper mineralization appeared near the close of the mineralizing cycle, most of the ore occurs on the underside or footwall of the sulphide mass. In the lower horizons there are only minor spots. The copper mineralization becomes more effective as the higher elevations in the mine are reached, and on the 3300 ft. level, there are three mineable bodies and the bottom of a fourth. In the lower stoping levels most of the copper is found in the chlorite schist. In the upper levels the amount of copper in the schist decreases and progressively more is found in the massive sulphide. On the 2850 ft. level the copper mineralization was more widespread than below, but the larger stopes are in the chlorite schist near the split in the sulphides. Above this horizon the ore bodies become progressively more continuous and on the 2100 ft. level the ore band is 15 to 90 feet wide and 800 feet long. The flattening of the overhanging diorite permitted increased mineralization near the 1800 and 1650 ft. levels. In the upper horizons of the mine the heavy pyrite stage of mineralization left unreplaced stringers of rock extending far out into the sulphide. Thus with the more constricted diorite trough and a more intense zone of shearing in the porphyry, the heavy chalcopyrite mineralization penetrated nearly to the diorite hangingwall, as well as extending far out into the quartz porphyry footwall.


SEDIMENTS
DIORITE
QUARTZ
PORPHYRY
4500
1" = 330'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QUARTZ
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3300
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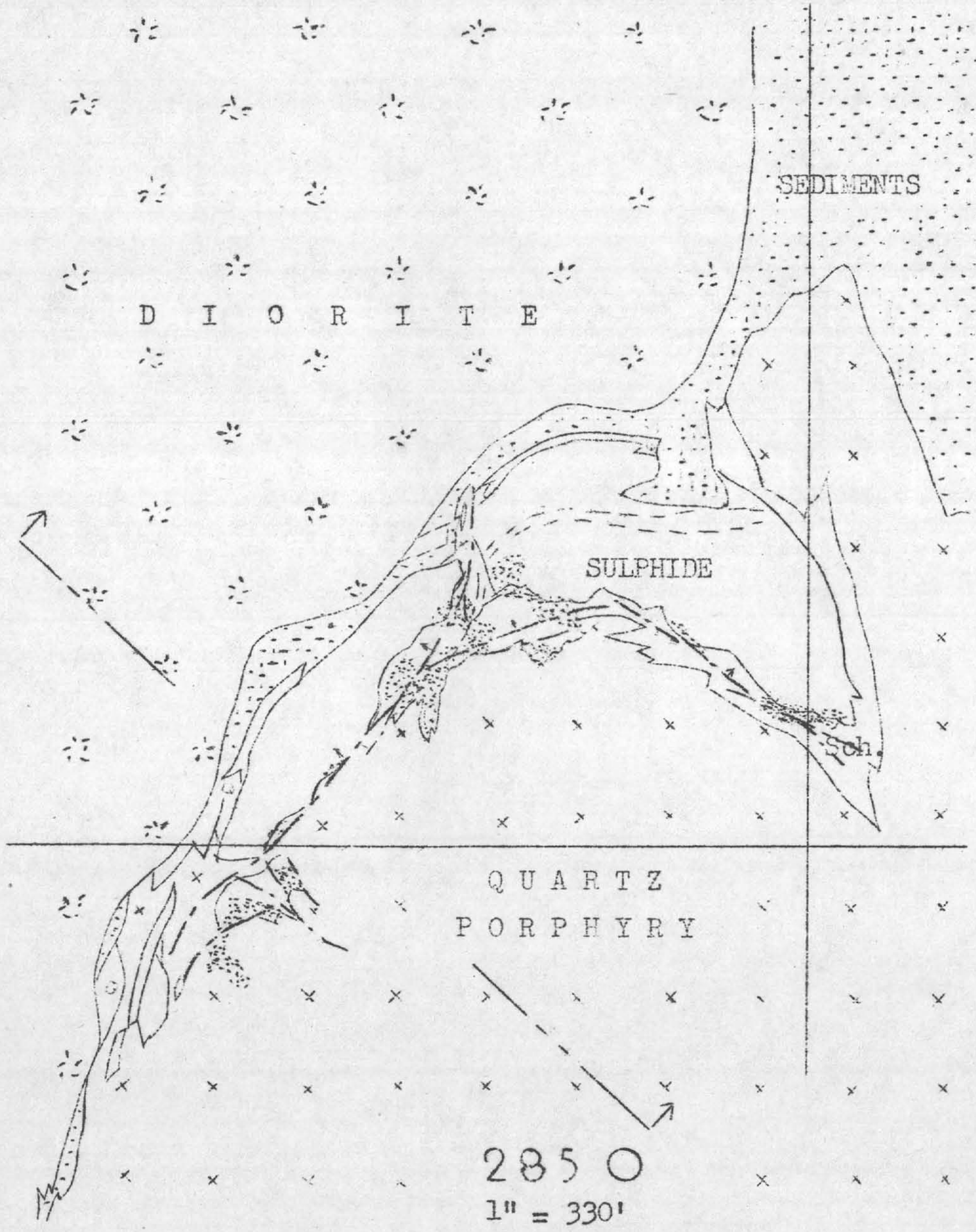
SEDIMENTS
D I O R I T E
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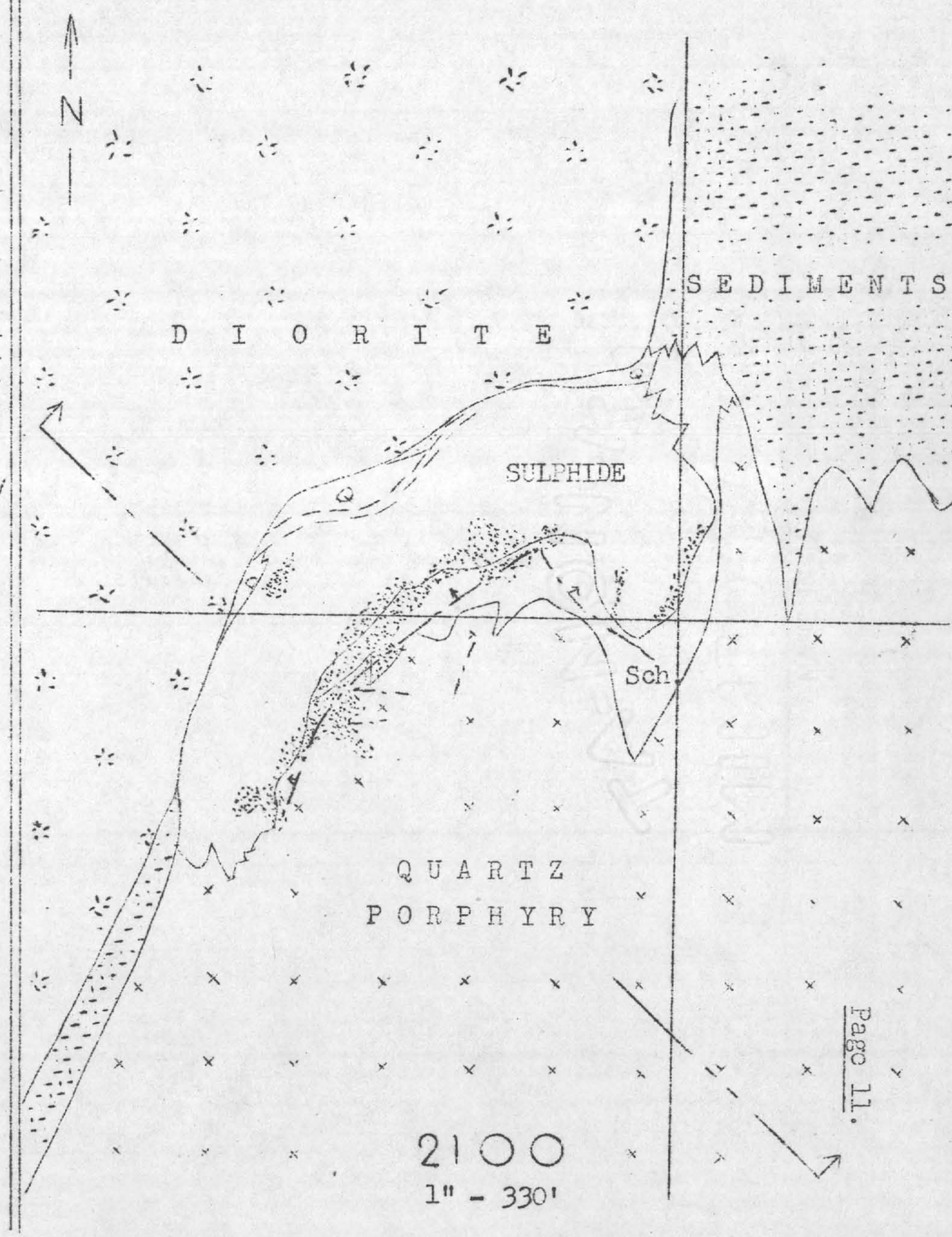
2850
1" = 330'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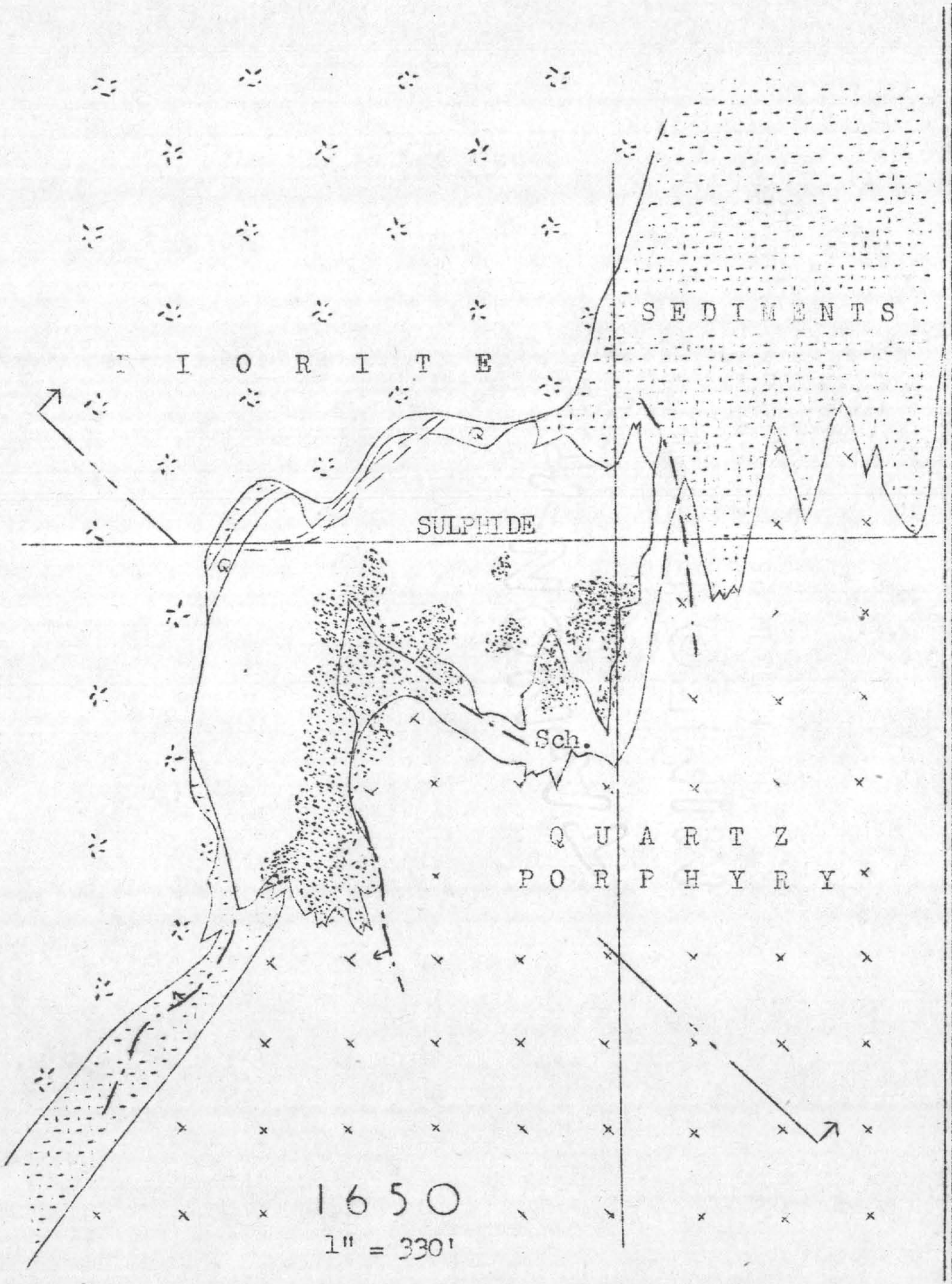
S E D I M E N T S
I O R I T E
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SULPHIDE
Q
Sch.
Q U A R T Z
P O R P H Y R Y
1650
1" = 330'

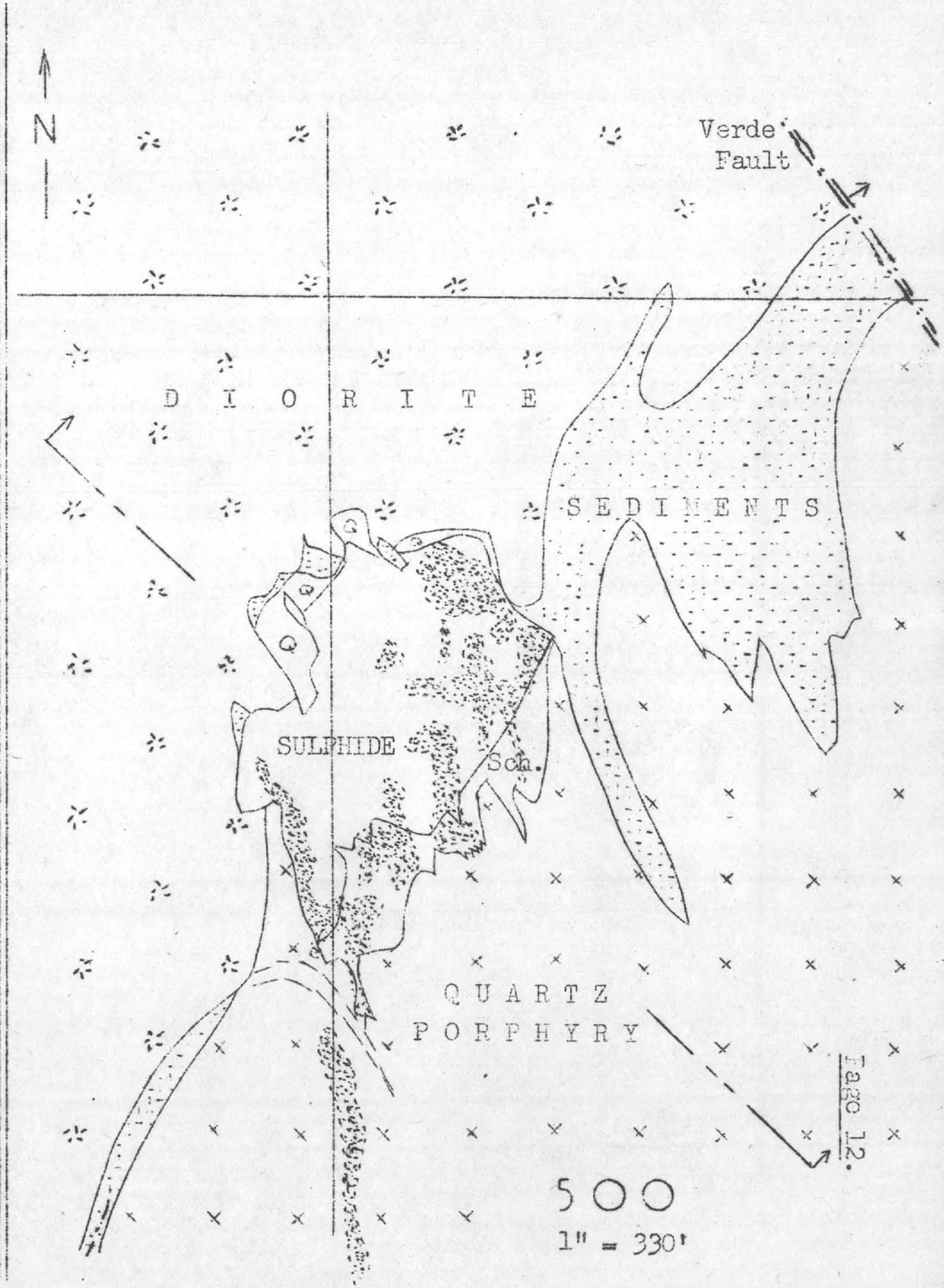
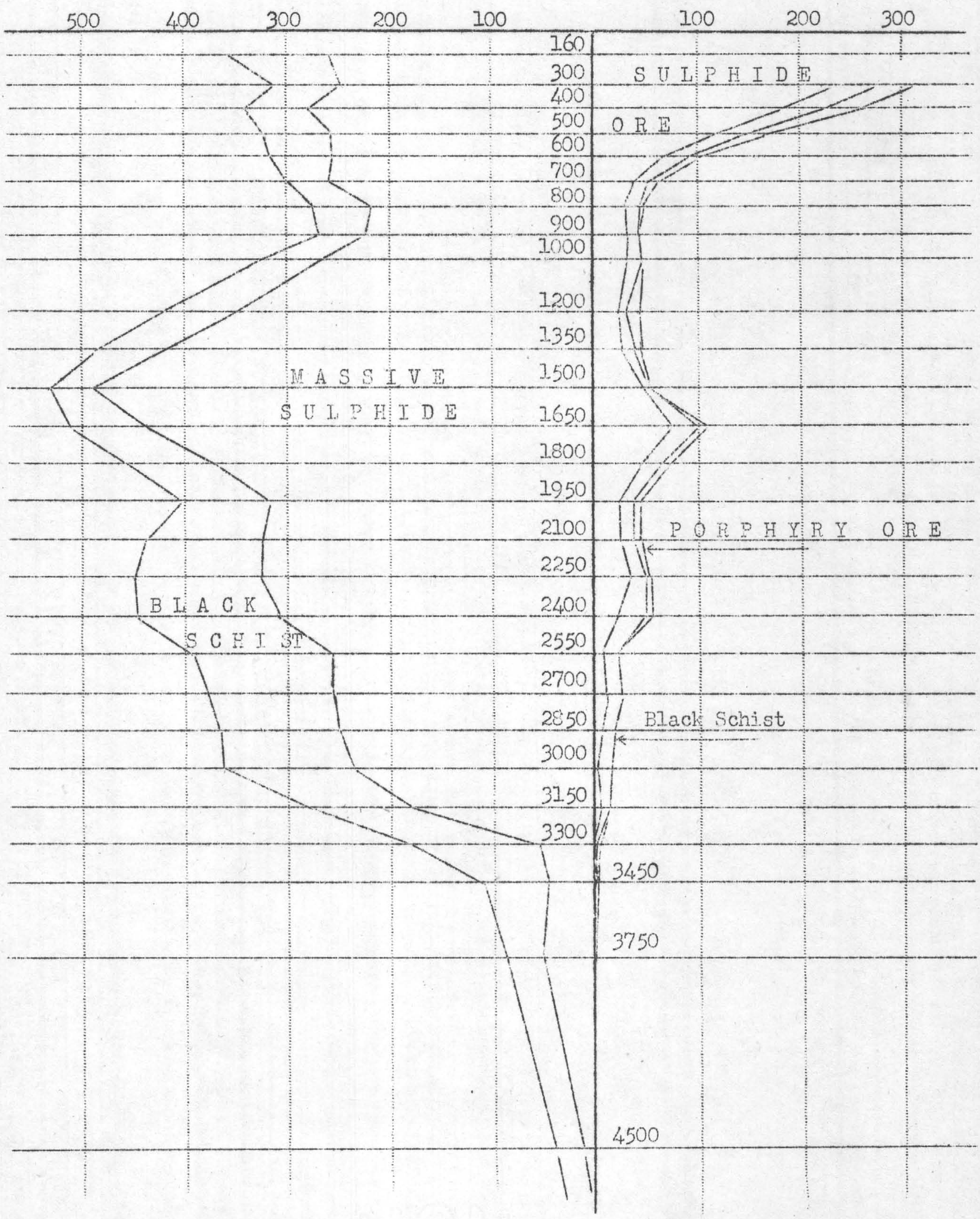

N
Verde
Fault
D I O R I T E
S E D I M E N T S
Q
Q
SULPHIDE
Sch.
Q U A R T Z
P O R P H Y R Y
500
1" = 330'

CHART OF MINERALIZED AREAS

Thousands of Square Feet



Zinc. As already stated most of the zinc is associated with the principal stage of pyrite deposition before the significant copper deposition. It is found in the massive sulphide between the zone of copper deposition and the diorite hangingwall. The greater concentration of zinc is found in the upper levels with scattered spots down to the 3000 ft. level. Below this, relatively high zinc values are limited to part of the north sulphide lense between the 3750 and the 4500 ft. levels.

Development of the low grade zinc ore disclosed that it is quite irregular and discontinuous. Much of the best of the zinc has either been removed in the open pit operation or is involved in the general mine subsidence. The intimate mineralogical composition indicates a difficult metallurgical separation. These factors combine to preclude any present possibility of commercial zinc production from the United Verde mine.

Precious Metals. The best primary gold and silver values are associated with relatively siliceous material. A number of the massive sulphide copper ore bodies terminate in siliceous material, with relatively high gold and silver values. There are also localized gold-silver values in the comparatively narrow transition zone between lean sulphide and quartz. The average ores carry in the neighborhood of .015 ounces of gold per ton and a little over an ounce of silver. Increased gold may go to as much as .10 ounces and silver to two or three ounces. Occasionally much higher values have been found. Silver averaging about two ounces is found in schist ores with comparatively abundant tennantite.

Chlorite Schist. In the upper and middle levels the preponderance of the chlorite schist is nearly pure ferruginous chlorite and almost black in color. In the lower stoping levels and progressively below, the amount of material that is transitional between the quartz porphyry and the chlorite schist continues to increase. There are sizeable areas where it is nearly impossible to tell whether chlorite schist or porphyry predominates. It is probable that in the lower horizons the paths of the mineralizing solutions were more scattered and hence much of the porphyry was only partially replaced. In the middle and upper levels, structural conditions led to a greater concentration or localization. There is a progressively marked lessening of the amount of chlorite schist developed on each of the succeding levels from the 3300 ft. level down.

Quartz. The large masses of quartz found underlying the diorite hangingwall are normally quite dense and commonly jaspery in texture. It is suggested that this earlier quartz assisted in rendering the hangingwall impervious. Other quartz masses are found throughout the sulphide. In general, as the diorite contact is approached, the amount of quartz increases. On the bottom development levels, there is a notable increase in the amount of quartz as compared to the heavy sulphide. Jaspery quartz lenses, varying from a fraction of an inch to several feet in thickness, are often found in the quartz porphyry underlying the sulphide masses and in shear zones adjacent to some of the minor faults. These lenses are usually mineralized with scattered pyrite and a very little chalcopyrite.

ORIGIN AND CONTROL OF MINERALIZATION

General knowledge of metalliferous ore deposits makes it practically certain that the United Verde sulphide pipe was formed by solutions related to igneous rocks or an igneous magma reservoir, though the particular magmatic source to which the mineralizing solutions owes their origin is speculative. The location of the Jerome district with respect to the Bradshaw granite area to the south and southwest, and the granitic areas to the west and northwest, makes the Bradshaw granite magma the most plausible source of the mineralizing solutions.*

It appears that the mineralizing solutions were introduced through the same channel or zone along which the quartz porphyry and diorite were intruded. As the north end of the diorite continues to recede to the south with depth, it exerts less and less control on the deposition of the solutions. There is every indication that at some depth below the 4500 ft. level the mineralizing solutions were introduced along a nearly north-south striking shear or break that is on or close to the bedded sediments-quartz porphyry contact.

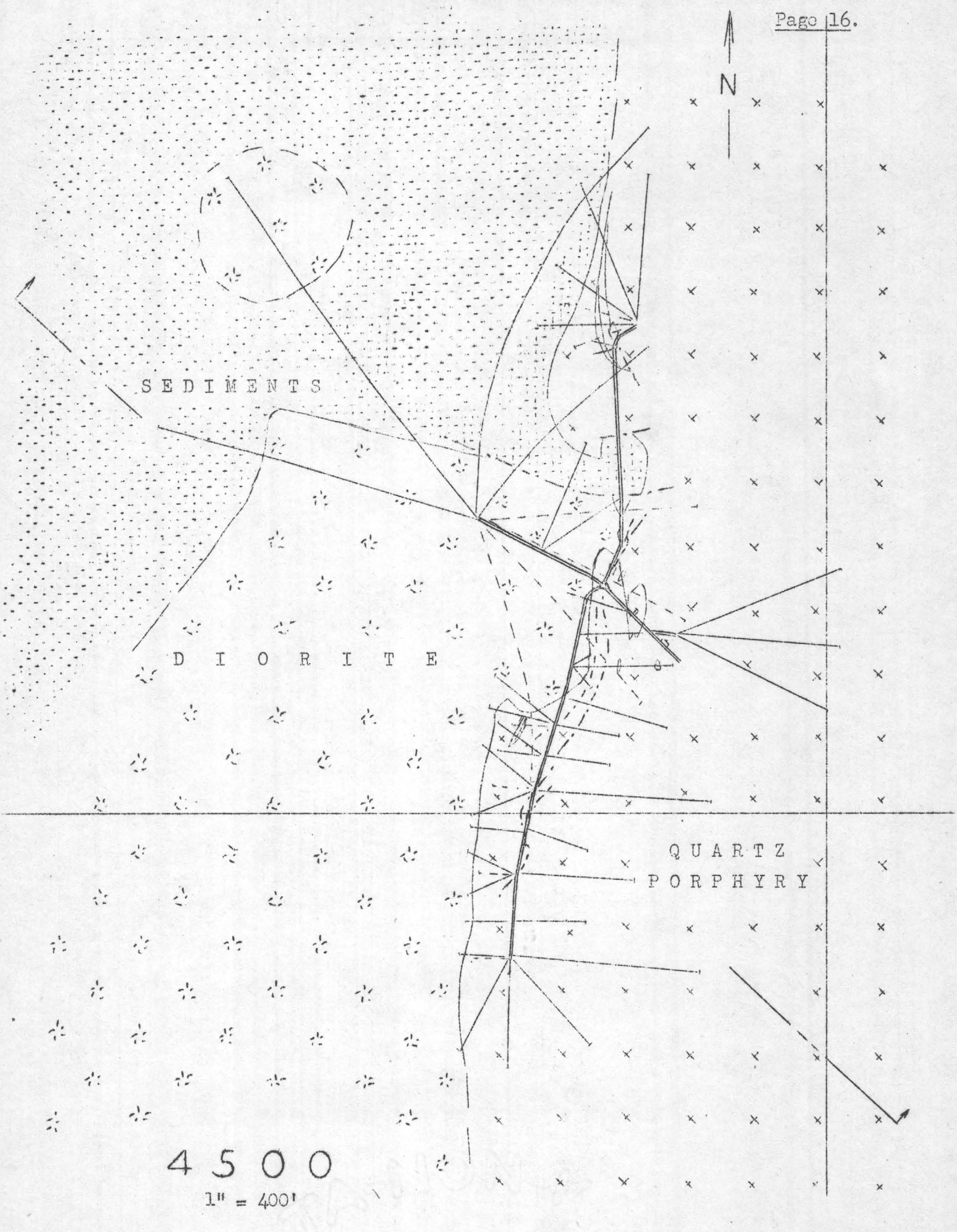
It is believed that the breaks of the minor fault pattern related to the intrusion of the diorite, were most significant in the control of the mineralizing solutions between the postulated major break at depth and the zone of effective mineral deposition. Various unfavorable factors, such as the weakness or fluidity of solutions, tightness of channels, and lack of the damming effect of the overhanging diorite, prevented more than a limited amount of deposition in the bottom levels of the mine. With increased elevation the more sheared and fractured porphyry, coupled with the changing composition of the solutions, and the increased damming effect of the diorite permitted more and more material to be deposited. The diorite, the fringe of sediments and the earlier quartz, combined to form a dam that was impervious to the later phases of the mineral solutions. The changes in the contour of the diorite, the variable degree of schistosity in the porphyry, and the habit of the breaks all combined to effect changes in the form of the mineralized zone so that no two levels are the same.

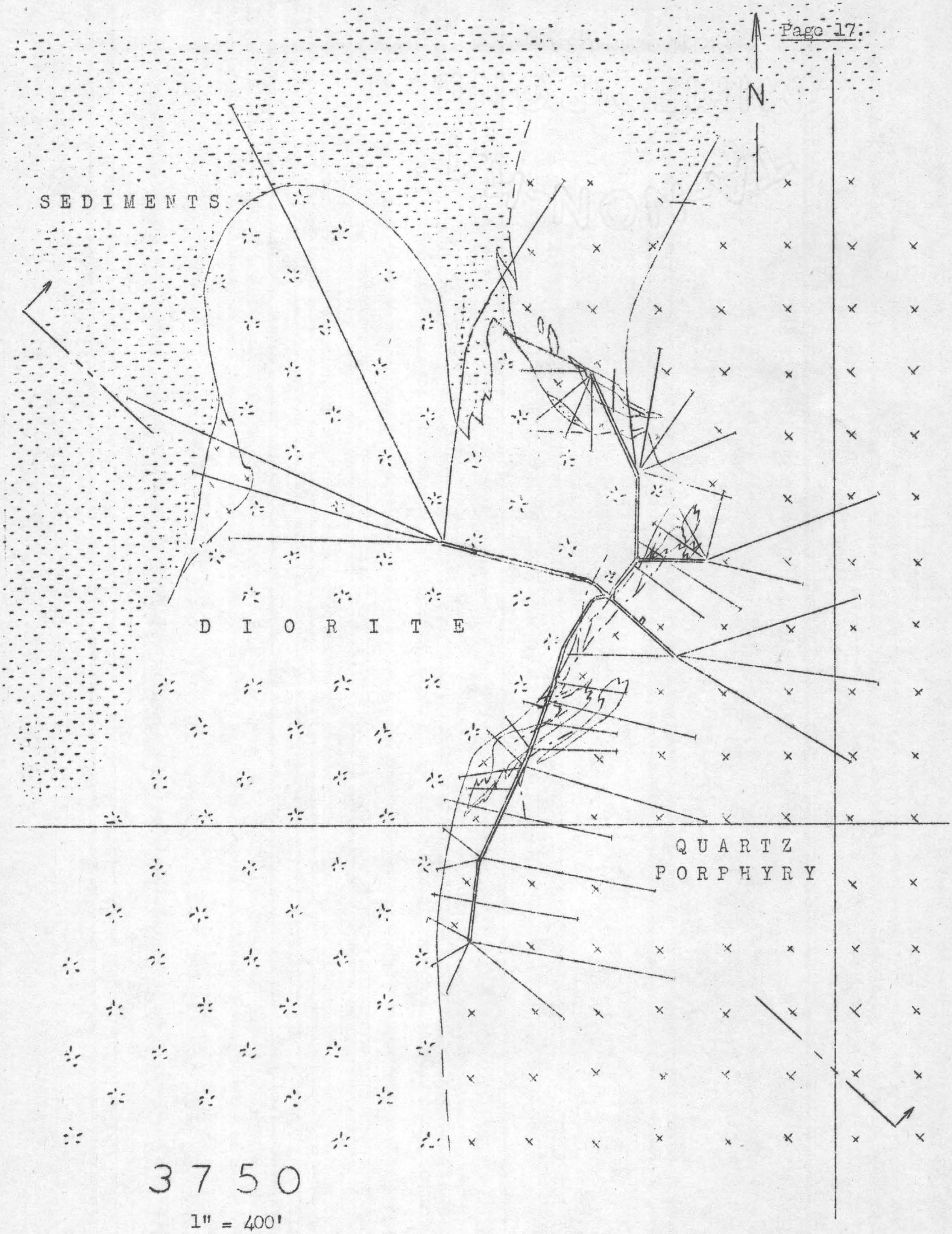
DEEP LEVEL EXPLORATION

When underground operations were resumed in 1937 as the open pit was being completed, the lowest stoping was on the 2550 and 2700 ft. levels, the 2850 and 3000 ft. levels were only partially developed, and drifting had just been started on the 3300 ft. level. The necessity for additional exploration was apparent if the proposed mining schedules were to be maintained.

Preliminary drifting on the 3000 ft. level was completed, and the heading on the 3300 ft. level was being continued along the sulphide-schist contact. An extensive diamond drilling program on the 3000 ft. level indicated a decrease in the area of mineable ore as compared to the levels immediately above. As the 3300 drifting progressed, attendant drilling soon indicated an apparent breaking up of the sulphide mass, with conspicuously little copper mineralization. This suggested the possible termination or bottoming of the sulphide pipe.

*L. E. Reber, op. cit.


N
SEDIMENTS
DIORITE
QUARTZ
PORPHYRY
4500
1" = 400'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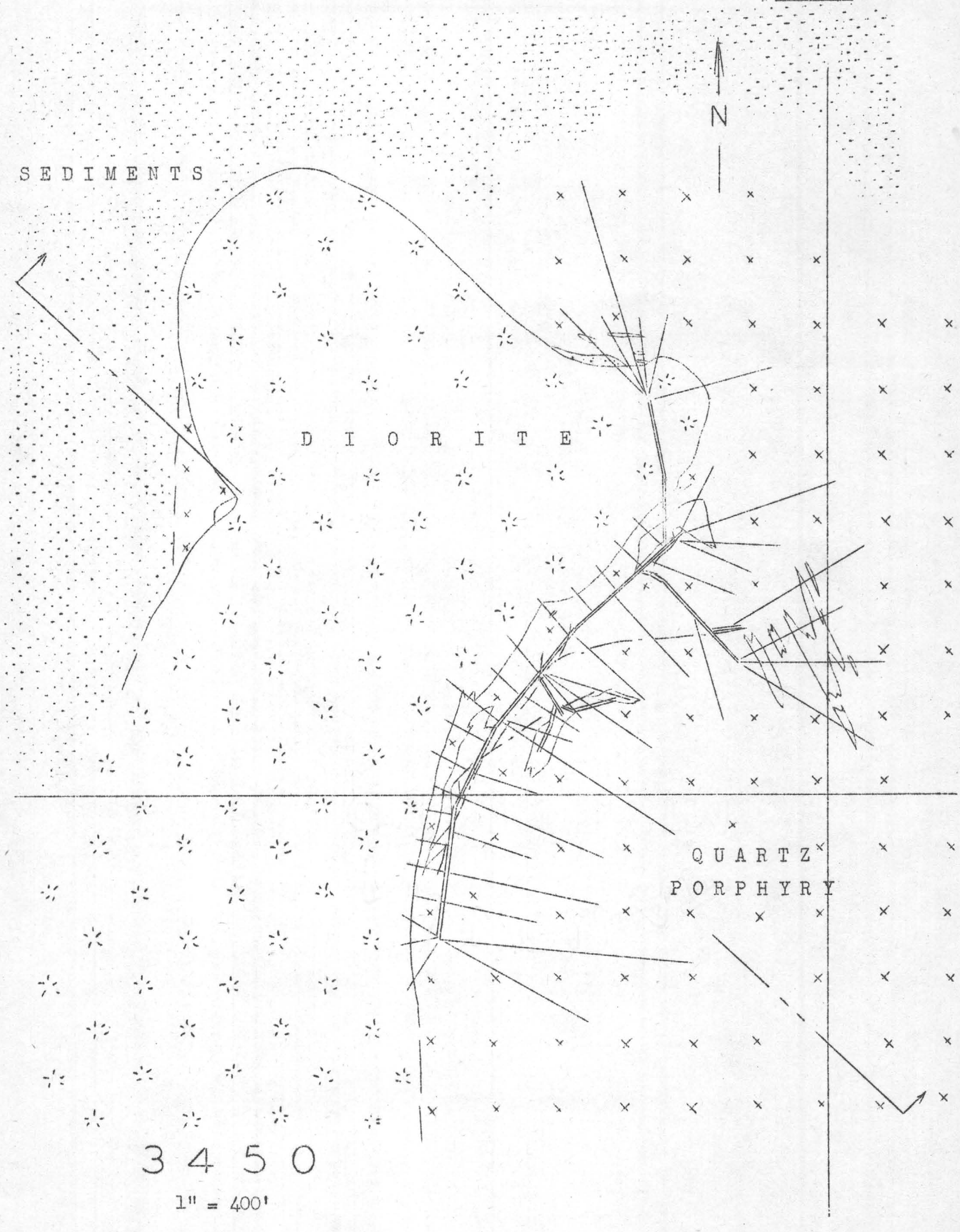
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An intensive exploration and development program was essential to delineate mineable ore areas below the 3000 ft. level and to determine whether or not the ore zone had definitely bottomed. A study of geological data indicated the split in the sulphide mass as the most favorable location for a development shaft. A new shaft was necessary because the existing shafts were at an excessive distance from the mineralized zone and because the hoisting equipment was inadequate for development at the desired depths. The new, No. 8 Shaft, was started from the 3000 ft. level in September 1939, and completed at the 4631 ft. level in August 1942.

Exploration levels were established on the 3450, 3750 and 4500 ft. levels and later an intermediate on the 4050 ft. level. The extensive development and the areas prospected on the 3450, 3750 and 4500 ft. levels are shown on pages 16, 17, and 18. Development from January 1940, to October 1946, has included 10,230 feet of drifts, and nearly 17 miles of diamond drilling. The No. 8 Shaft exploratory program will be completed early in 1947 at a total cost of approximately $1,000,000.

The elevation of the 4500 ft. level is 1030 feet above sea level. Rock temperatures encountered as the development headings on this horizon were being extended were 110° F.

CONCLUSION

It is believed that the great United Verde sulphide pipe has bottomed, that an extensive exploration program was entirely justified, and that it has been diligently carried out. Probably the one outstanding feature of the whole exploration program has been the succession of negative results obtained. The minor spots of mineralized material encountered are a part of the progressive breaking up and diminution of mineralization below the 2400 ft. level. The present exploration program has included a vastly extended area for a vertical distance of over 1500 feet below the lowest stoping horizon with essentially negative results. The chances are exceedingly remote for a change in structural conditions which would permit the deposition of mineral solutions at some deeper horizon.

Mining operations are now essentially confined to the cleaning up of ore in the vertical and horizontal pillars left by earlier mining, to remnants around the borders of existing stopes, and the completion of a few open stopes on the 3150 and 3300 ft. levels. The combined segments of the United Verde sulphide pipe, (United Verde and United Verde Extension), have produced 34,550,000 tons of ore from which has been extracted 3,551,000,000 pounds of copper, 53,420,000 ounces of silver, and 1,462,000 ounces of gold. This vast ore zone, with over sixty years of active productivity, can now be said to be effectively bottomed.

APPRECIATION

The writer is greatly indebted to Dr. Louis E. Reber, Chief Geologist of the Phelps Dodge Corporation, for his generous assistance in the editing of this paper. To Mr. J. B. Pullen, General Superintendent, and Mr. C. E. Mills, Mine Superintendent, of the United Verde Branch, Phelps Dodge Corporation, for their criticism and help; to Dr. C. A. Anderson, Geologist, United States Geological Survey, for his criticism. Acknowledgement is also due the officials of the Phelps Dodge Corporation for permitting the publication of this paper.

Roland,
Best wishes,
Doug.

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Mt Isa – reconstruction of a faulted ore body

By D. Dunnet
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A major geological problem in the Mount Isa District is the significance of the flat greenstone contact which underlies the copper ore bodies at the Isa Mine. Recent structural studies have shown this surface to be one of a set of curved normal faults which flatten in depth and are termed spoon faults.

Displacement on the spoon faults ranges upward of 2 km and total extension for the spoon fault domain exceeds 80 km. The domain is bounded by tear faults of which the Mount Isa fault is an example.

Reconstruction of the spoon fault domain gives insight to the sedimentary basin which originally included the Mount Isa ore bodies. The reconstruction indicates Isa and Hilton to be two faulted parts of the same ore basin and probably of the same ore body. It also strongly suggests a central concealed part to occur between Isa and Hilton.

The extreme extension of the spoon fault domain coupled with the thick basic volcanic section suggests that the domain represents an ancient zone of crustal tension initiated by shear along a curved cratonic boundary.

Introduction

One of the major problems confronting Australian mine and exploration geologists and those interested in base metal sulphide genesis is the significance of the greenstone 'basement' which underlies the Mt Isa ore bodies. The stratiform lead-zinc and copper lodes of the Isa mine dip steeply westwards terminating abruptly against basic volcanics and arenites on an irregular, low angle surface (figure 1). This plane has been variously referred to as an unconformity, an intrusive contact or a fault. The most reasonable interpretation is a low angle fault which displaces the down dip extensions of the ore bodies. With such a large, faulted and concealed target as incentive, Anaconda Australia personnel have directed their attention to a structural synthesis of the Mt Isa area in recent years.

This paper is a synthesis of results from considerable regional and detailed field work undertaken by staff geologists between 1969 and 1973. The author devoted over twelve months to mapping and analysis of information specifically to determine the geometry of faulting and to test if a concealed, faulted segment of the Isa ore body did exist.

Stratigraphic setting

The regional geology of the Mt Isa District has been described by Carter *et al.* (1961) and more detailed descriptions have been given by Carter (1953), Murray (1961), Bennett (1965, 1970), Smith (1969) and others.

The Middle Proterozoic (Carpentarian) sequence which includes Mt Isa rests uncomfortably on Lower Proterozoic crystalline rocks. The Carpentarian rocks are essentially unmetamorphosed and consist of four major units. A basal arenite sequence, the Mt Guide quartzite, is overlain conformably by a sequence of interbedded arenites and tholeiitic basic volcanics termed the Eastern Creek Volcanics. A third sequence of quartz sandstone, siltstone and conglomerate termed the Myally Beds, locally and unconformably overlie the volcanics.

The upper unit consists of siltstone shale and thinly bedded, fine-grained dolomitic sediments which unconformably rest on either the Eastern Creek Volcanics or Myally Beds. In the vicinity of Mt Isa, this sequence is termed the Mt Isa Group where it locally contains a formation of

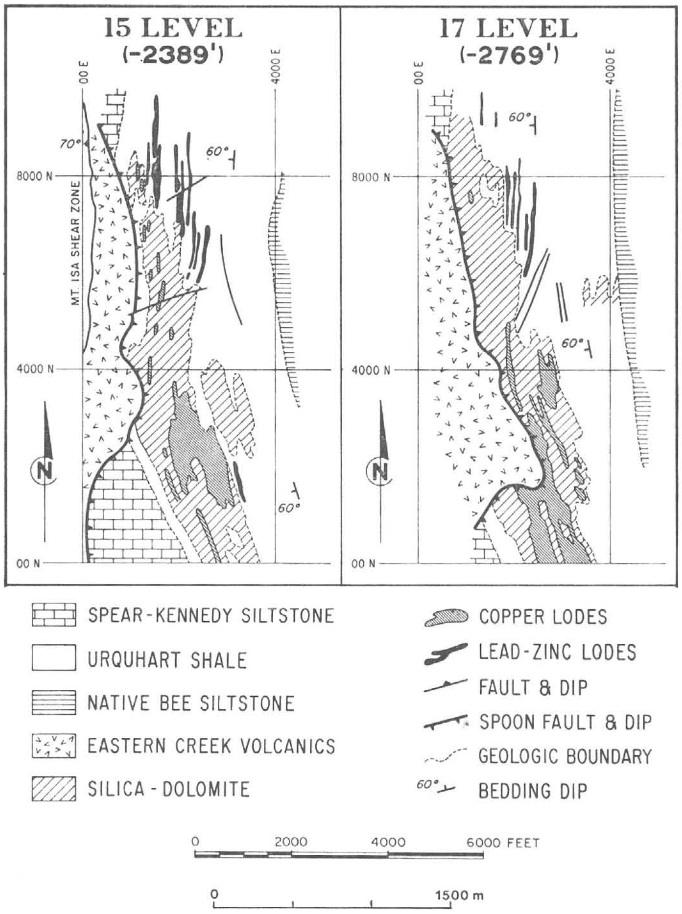

FIGURE 1. Relation of the basal fault to the ore sequence at Mt Isa. Compiled from information released by Mt Isa Mines Ltd.

carbonaceous shale, potassic tuffite, dolomitic siltstone, framboidal pyrite and the base metal sulphides of the Urquhart Shale. The Mt Isa Group ranges in thickness from some 3600 m at Mt Isa to less than 2000 m at the Hilton Mine, 20 km north of Mt Isa. Rocks of the Mt Isa Group form the top of the preserved Carpentarian sequence in the area. They are believed to occupy an isolated basin, but are loosely correlated with the Gunpowder and Paradise Creek formations to the northwest (DeKeyser 1958) and the Surprise Creek beds and Corella Formation to the northeast and east.

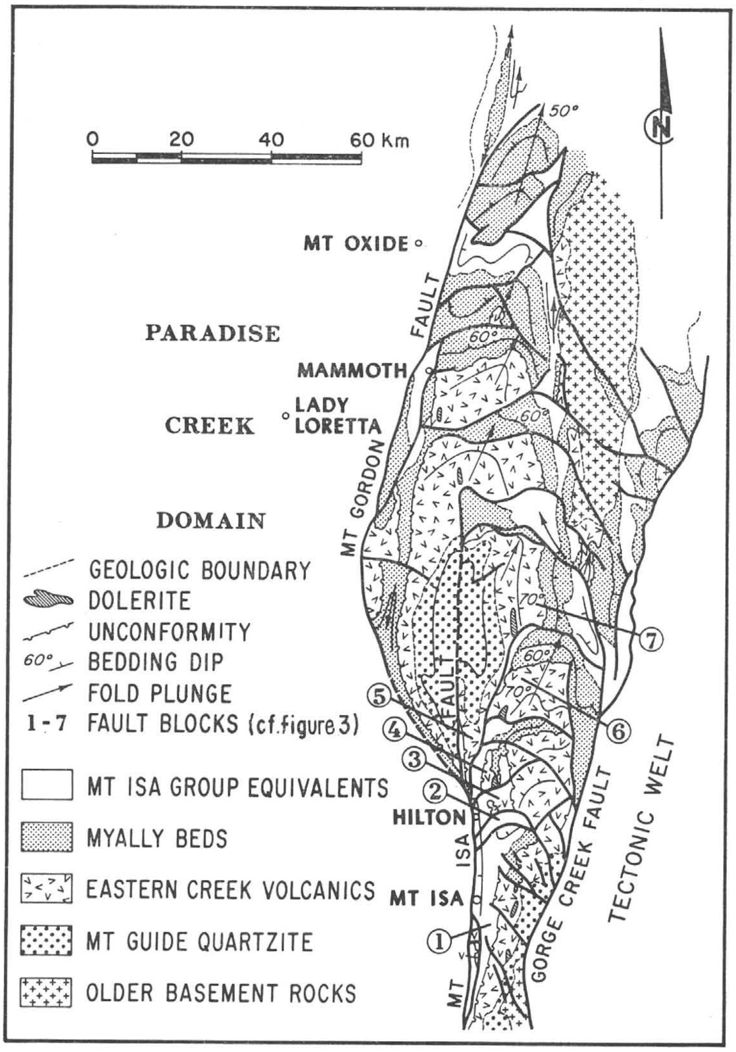

FIGURE 2. General geological map of the Mt Isa spoon fault domain. Data derived from Carter *et al.* (1961) and additional field mapping by the author.

BASE METAL DEPOSITS

The Isa Mine has proven reserves of 57 million tonnes of lead-zinc ore in laminate beds which form a number of discrete stratiform lenses interbedded with low grade pyritic shale. The lenses are separated spatially from the huge copper lodes, with reserves in excess of 142 million tonnes of 3 % copper ore which occur down dip from, and are both laterally equivalent to and immediately above the lead-zinc lodes (figure 1). The copper lodes occur within a sheath of 'silica-dolomite' – a crystalline dolomite with associated fractured and siliceous shale.

Two other major lead-zinc deposits are known in the region. The Hilton Mine about 20 km north of Mt Isa occurs in the Urquhart Shale, and Lady Loretta, situated some 100 km to the northwest of Mt Isa (figure 2), which lies within the Paradise Creek Formation.

A major copper deposit is being mined at Mammoth and copper occurs near Lady Loretta and Mt Oxide. No significant copper is known at Hilton. Recent information released by Mt Isa Mines indicates significant deep extensions to the copper at Mt Isa. These extensions, termed the 3000 ore body by Mt Isa Mines Ltd, will be shown to equate with the faulted central portion of the ore basin, termed Isacon in this paper.

Most workers now concede that the lead-zinc deposits are exhalative-sedimentary, but the origin of the copper remains enigmatic. Some authors believe the copper is also syngenetic, though modified by local tectonics (Solomon 1965; Bennett 1970). Bennett (1970) considers the silica-dolomite to be a shallow water facies of the lead-zinc bearing shales which includes recrystallized algal mats or reefs forming against an active pene-contemporaneous fault line. The algal activity would have controlled the Eh-pH environment to cause exclusive precipitation of copper as distinct from lead-zinc in the deeper water shale environment.

Others, notably Murray (1961) and Cordwell *et al.* (1963), support a separate, epigenetic origin. Conclusions from recently published geochemical investigations by Smith & Walker (1971) suggest copper may be derived, together with other elements, from the deeply leached greenstones beneath the ore bodies.

The following analysis suggests a primary exhalative-sedimentary origin for all the base metals in a symmetrically zoned Py–(Pb–Zn–Ag)–Cu ore basin. Pore fluids associated with the movement on the fault separating Hilton and Mt Isa are believed to extensively recrystallize and locally redistribute the copper ore and associated silica-dolomite.

Structural analysis

The Mt Isa region has undergone a long and complex structural history. The density of faulting is clearly shown on published maps and, in particular, on the excellent set of 1:100000 maps recently available from the Bureau of Mineral Resources.

Analysis of such a complex, heterogeneous fault pattern can be attempted by grouping relative ages, orientations, style, sense and magnitude of movement. This has been attempted previously by Cordwell *et al.* (1963) with limited success. Smith (1969) demonstrated normal and rift faulting contemporaneous with sedimentation. Neither author undertook analysis of faults on the basis of style and magnitude.

Where all minor faults are ignored and faults with displacement in excess of 1000 m only are considered, a relatively simple picture emerges (figure 2). A regional anticline, plunging 60° north is repeated in a number of fault blocks for over 160 km north of Mt Isa.

The Isa and Hilton ore bodies occur within separate fault blocks, but in similar positions on the 60° west dipping limb of the regional anticline.

Each fault block is bounded by a curved fault plane which cannot be followed clearly to the east, but progressively merges westwards with one of two major bounding faults. The Mt Gordon fault is a complex zone of brittle failure, whereas, the Mt Isa fault is a ductile shear zone. Both structures are tear faults with displacement on the Mt Isa fault ranging from zero to over 4000 m down throw on the eastern side. The Mt Gordon fault separates the relatively undeformed Paradise Creek domain from the Mt Isa domain. In the east, the Gorge Creek fault similarly separates the basement 'tectonic welt' from the Mt Isa domain.

The curved cross faults are commonly quartz-filled and brecciated with marginal quartz-fibre filled extension gashes, which would suggest tensional structures. Fault plane dips are difficult to determine, but generally are moderate to steep southerly. Locally (in the Paroo Range area), the fault bounding block 4 (figure 2) dips shallowly (15–40°) south. Stratigraphy indicates normal fault displacement.

The faults have a strong curved trace in plan. It will be shown that despite their steep surface dips, they must be curved in section to flatten with depth and, thus, can be termed spoon faults. The spoon shape is the general form of failure in land slides and is common in the basin-range normal faulting of Nevada (Proffett 1971).

Sediments between the spoon faults are weakly to moderately cleaved except adjacent to the bounding faults. The relative lack of cleavage indicates an absence of strong compressive strain across the spoon fault domain (Dunnet 1969). The open folds with consistently steep north plunges (60°), despite weak internal deformation, suggest substantial rotation of the fault blocks. These observations are important in defining a mechanism of faulting.

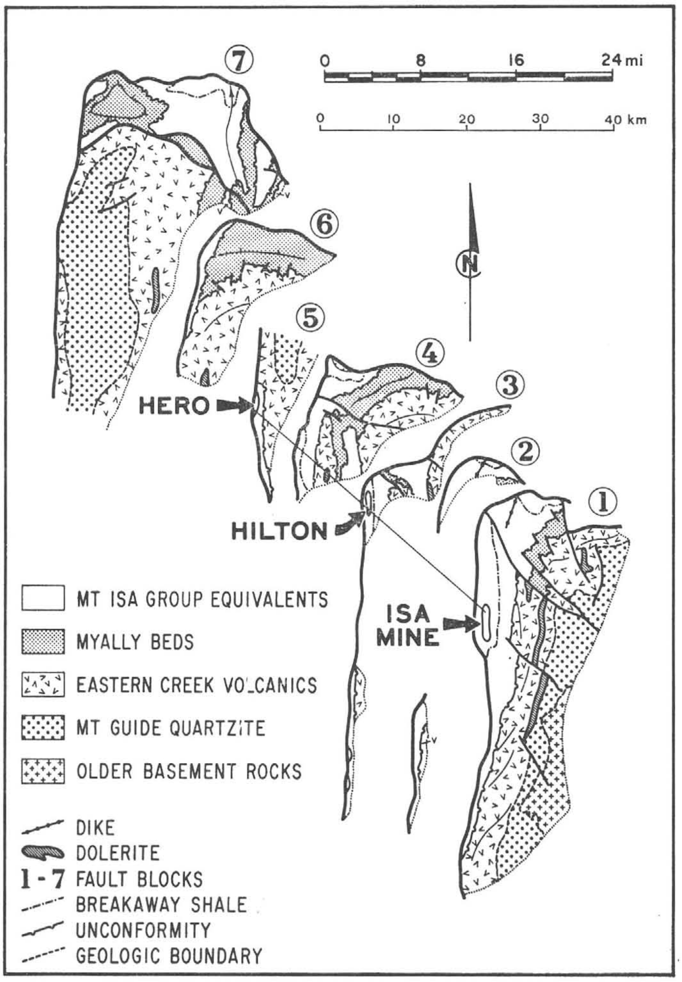

FIGURE 3. Southern part of the map area of figure 2 showing major fault blocks expanded to produce a tectonic profile of the regional anticline. Distance between fault blocks greatly exaggerated.

STRUCTURAL RECONSTRUCTION

Any attempt at reconstruction of the unfaulted sedimentary sequence and calculation of displacement on the spoon faults requires establishment of points common to adjacent fault blocks.

The surface plans of the southern seven fault blocks (1–7, figure 2) are shown in figure 3, where each block has been relocated in space to produce a tectonic profile viewed along the major anticline. Each block has the form of a serial section through the relatively unfaulted, but internally deformed sedimentary pile.

The continuity of features from one block to the next is strikingly apparent in this diagram and supports the hypothesis that the spoon faults bound narrow fault slices which dip shallowly to the south.

The pinch-out of Myally beds on the unconformity at the base of the Mt Isa Group is a line recurrent in blocks 1, 3, 4 and 6. This pinch-out lineation plunges approximately 60° NW in each fault block. The lineation is known to be formed by a pene-contemporaneous fault bound margin to Myally sedimentation in macrolithon 1 (Smith 1969) and, thus, prior to spoon faulting, it can be assumed a continuous, approximately straight linear element through the sedimentary pile (1–7).

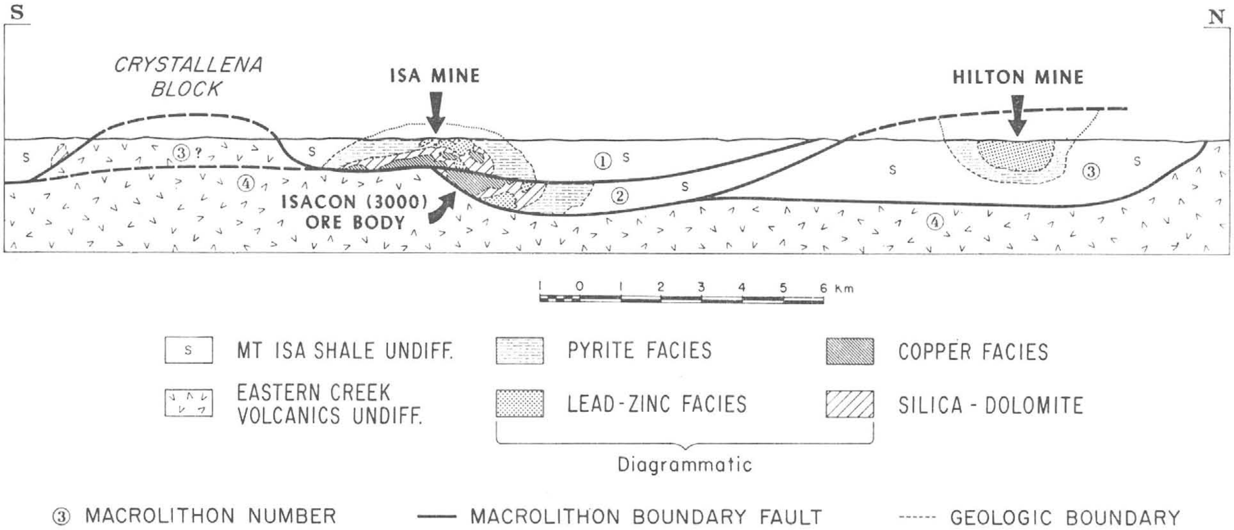

FIGURE 4. Geological long section between Mt Isa and Hilton showing the three slices of the ore body.

Reconstruction of the lineation to a continuous line element necessitates a north–south displacement direction. The observed horizontal offsets of such a steep plunging lineation requires displacement on shallowly south-dipping fault planes.

This general reconstruction shows that the dolorite bodies in blocks 1, 3, 4, 6 and 7 are probably not separate sills, but faulted slices of the same sill.

The most striking deduction from the reconstruction is that the Isa ore body in block 1 is a faulted part of the Hilton ore body in block 3 or at least that they are two ore bodies originally in very close proximity to one another. It must be concluded also that if Isa and Hilton were continuous, a totally concealed ore body slice, termed Isacon, exists beneath block 1 in block 2 between Isa and Hilton.

The striking similarity between lead-zinc ore stratigraphy at Hilton and at Isa, described by Bennett (1970) and Mathias *et al.* (1971), strongly supports not two separate ore bodies, but two faulted slices through the same huge base metal deposit.

A unique solution for the position of the concealed Isacon ore body can be obtained with reasonable accuracy. A dyke common to blocks 1 and 2 is shown on Bennett's (1965) map in the area south of Lake Moondara (figure 3). The triple plane intersection of this dyke with the basal Breakaway Shales and the spoon fault plane is a unique point in each fault block. Horizontal displacement of this point in block 1 relative to 2 is approximately 2000 m in a north–south direction. Because of the steep plunge of the dyke-bedding intersection, this solution is relatively independent of the dip of the spoon fault plane. The displacement sense and direction is consistent with that deduced from the pinch-out lineation solution.

Thus, Isacon should be some 2000 m north of and beneath Isa. A deep intersection of the no. 14 lead-zinc ore body at 12000 N on the Isa Mine grid, some 2000 m north of the last known no. 14 lode position, is believed to be part of the Isacon slice. Current deep diamond drill intersections of copper ore in the 3000 ore body beneath and north of the Isa Mine are also believed to be faulted extensions of the 1100 ore body in block 2.

The shape and orientation of the basin

The argument presented below suggests that the ore in the three fault slices of Isa/Isacon/Hilton represents the major portions of an original continuous ore body. The present position and geometry of the ore is shown diagrammatically in figure 4, a long section between Isa and Hilton.

Reconstruction of this configuration to the original deposition orientation requires three discrete translations.

1. Reconstruction of the fault slices to obtain a subcircular ore body.
2. Rotation of the regional anticline plunge to a subhorizontal attitude.
3. Rotation of the anticlinal limbs to a subhorizontal position to 'unroll' the regional anticline.

This procedure is an approximation of a probably continuous deformation event and does not account for internal strain during deformation. It indicates, however, that the current surface of Isa was originally the southern or southeastern margin of the ore body.

In the upper levels of Isa, individual lead-zinc ore lenses tend to culminate, which suggests the present ground surface is close to the original southeastern margin of the ore basin.

The Isacon slice has not been eroded and probably represents the rich, thick core to the basin. The thickness of block 2 is some 1000 m at ground level, and assuming this thickness continues at depth, the possible volume of ore in Isacon can be very substantial indeed.

Very little information has been published on the shape of the Hilton ore body. Bennett (1970) implies a gradation from silica-dolomite marginal lithologies at Hilton into lead-zinc lodes and probably into pyrite facies with depth. Mathias *et al.* (1971) refers to the strong similarity between ore lenses 1 to 3 at Hilton and the Black Star lodes (1–5) at Isa as distinct from lenses 4 through 7 at Hilton which resemble the Racecourse (6–14) lodes at Isa. The thin enclosing sedimentary sequence at Hilton relative to Isa (Mathias 1972) and lack of known ore in block 4 suggest that, at depth, Hilton will merge into pyrite facies of the nothwestern basin margin.

Low grade disseminated copper mineralization occurs at the Hero prospect in block 5 (figure 3). The copper occupies a fault breccia and the matrix of a fault scarp conglomerate in a sequence which apparently represents the thin marginal sandy facies to the Mt Isa ore basin. The mineralization is associated with alkali-rich hydrothermal alteration and may be a vent for hot springs feeding brine to the ore basin. No other ore source has been recognized to date.

Thus, the total reconstructed Isa/Isacon/Hilton ore basin is believed sub-circular and some 4000 m in diameter. Copper lodes and copper beds tend to occupy the centre and top of the ore basin, with surrounding and lower silver-lead, zinc and marginal pyrite beds. This reconstruction of Isa/Isacon/Hilton conforms to the general basinal geometry of Sullivan (Freeze 1966) Meggan (Ehrenberg *et al.* 1954) and Rammelsburg (Kraume 1960).

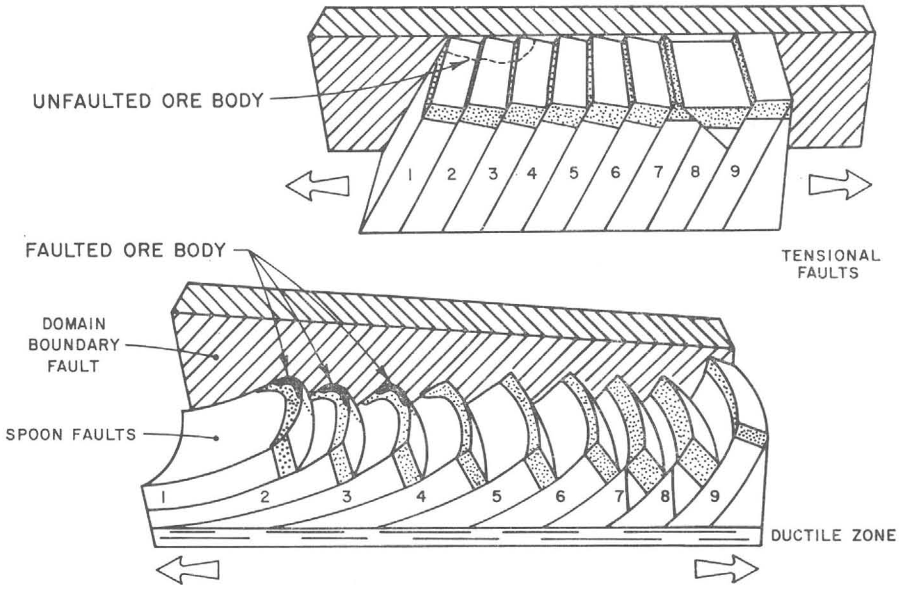

FIGURE 5. Representation of faults in the spoon fault domain initiated as tensional normal faults which progressively rotate due to extension at depth.

Mechanism of faulting

The consistent 60–70° north dips and plunges on bedding and folds in each fault block gives insight to the mechanism of spoon faulting. Bedding can be assumed sub-horizontal before faulting and is thus rotated during faulting. The consistent curved nature of the spoon faults in plan is probably reflected in section so that faults flatten with depth and merge with a decollement where deformation is more ductile (figure 5). A number of deformation mechanisms could fit this picture and could be analysed as shown by Ramsay & Graham (1971). However, the generally small magnitude of compressive strain within fault slices indicates a discontinuous simple shear model is applicable as a first approximation. The fault planes are initiated steeply in tension, but as extension proceeds, they become shear planes such that the blocks passively rotate and bedding becomes progressively steeper. This model requires considerable reduction in crustal thickness between the tear-type domain boundary faults analogous to the Mt Isa and Mt Gordon faults.

Discussion

A mechanism involving large extensions in the crust has been shown to markedly effect the Carpentarian rocks at Mt Isa. The extension domain is separated by sigmoidal faults from a domain of minor deformation to the west and one of major ductile deformation to the east. The deep seated nature of the extension domain structure is indicated by the localization of a thick sequence of basic volcanics within the extension zone. The occurrence of a major base metal deposit in this domain cannot be considered fortuitous and both the plumbing for ore solutions and the establishment of euxinic deposition sites is a direct consequence of the movements.

The sygmoidal nature of domain boundary faults is indicative of a faulting mechanism. A shear couple acting along these faults will produce tension in the crust in the region of boundary fault curvature. There is evidence of markedly different physical properties in the two bounding domains, in their regional gravity patterns, structural and metamorphic styles and degree of igneous intrusion. The western Paradise Creek domain is part of the North Australian Proterozoic platform, whereas, the Tectonic Welt and Cloncurry Belt to the east have characteristics of a mobile belt. The shear and separation is thus believed to have localized along a primitive plate boundary and at a triple junction site. This is discussed more fully in a companion publication (Dunnet 1975).

The tectonic process outlined above gives a ready mechanism for remobilization of copper adjacent to the spoon faults. Movement can only be maintained on such flat faults where the pore fluid pressure is high. In this environment suitable for pressure solution, moderately elevated P/T conditions will permit carbonates, silica and copper sylphides to be readily soluble and be redistributed along the fault plane.

Such a mechanism does not uniquely define the origin of the copper. The 1100 ore body of Isa has moved over at least 2 km of greenstone and probably much more. The movement would allow a progressive solution and recrystallization of primary copper bearing 'silica-dolomite'. It would, equally, permit progressive replacement of primary pyrite by more chalcophile copper leached from the greenstones. Either mechanism could account for the greenstone leaching observed by Smith & Walker (1971).

In a recent paper, Jolly (1974) presented a model for leaching of copper from Keewanawan volcanics during low grade metamorphic dehydration reactions and migration of copper rich fluids to lower temperature environments. Such reactions in the Eastern Creek volcanics would make copper bearing fluids available along fault planes to the sedimentary environment during deposition or during faulting of the Mt Isa ore basin. The thermal gradient around the late tectonic granites (Sybella granite) may localize dehydration reactions and fluid migration.

Future work must show whether greenstones along the displacement path of the Isa and Hilton ore bodies show higher grade, dehydrated mineral assemblage and metal leaching not observed elsewhere in the region.

In view of the presence of copper in similar stratigraphic positions at Isa and Hilton and the hydrothermal mineralization at Hero, the author tends to favour a synchronous exhalative sedimentary origin for the copper and lead-zinc mineralization from fluids of metamorphic dehydration origin.

Considerable credit must go to the Anaconda Company former chief geologist, John Hunt, who initiated the search for a concealed Mt Isa and my associate, Gorol Dimo, whose enthusiasm assisted in the solution.

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Discussion

P. F. WILLIAMS (*Geology Department, University of Lieden, Holland*). I accept Dr Dunnet's interpretation of the geometry of the faults of the Mt Isa region and in fact proposed the same geometrical interpretation in a report to Mt Isa Mines Ltd in 1971. However, I cannot accept the remainder of Dr Dunnet's structural interpretation.

Within his central domain there are folds with an axial plane cleavage that are locally tight to isoclinal. These folds vary in orientation and are refolded by a second generation of northerly plunging folds. This history is best demonstrated in the field but can also be seen on the 'Geological map of Mt Isa district' (Battey 1962).

East of the Mt Isa Fault the map shows two large folds; a synform, with its axial plane trace passing through Mt Isa, and an antiform which exposes basement rocks along the eastern side of the map. These two large folds have approximately north–south striking axial planes and plunge northerly. They are second generation folds (B_2). In the hinge of the antiform, near

Transport Bay, the map shows a fold (37 000 E, 51 000 N) with an east–west trending axial plane that is obviously being refolded by the antiform. In the field this first generation fold (B_1) is seen to be tight to isoclinal and to have an axial plane cleavage. The cleavage is best seen in the Moondarra siltstone and is parallel to layering, except in the B_1 hinge. It is folded by the B_2 antiform.

Such B_1 folds are not common in the Mt Isa group but other examples can be seen on the map and more can be found in the field. Furthermore, the very common parallelism of cleavage and bedding in rocks that are known to contain isoclinal folds is strongly indicative of widespread isoclinal folding.

The faults described by Dr Dunnet appear to be folded by the B_2 folds and have therefore been interpreted as pre-B_2 by the writer. The possibility that they developed as curved 'spoon faults' cannot be eliminated but if so they developed with an axis of curvature that lies in the B_2 axial surface. However, these faults certainly post-date B_1; they are unaffected by B_1 folding and they cut the B_1 folds and axial plane cleavage.

Thus the structure and history are more complicated than proposed by Dr Dunnet. The possibility of the faults being penecontemporaneous with sedimentation is not eliminated since the folds may also be penecontemporaneous but the arguments presented by Dr Dunnet are invalid and any such interpretation is therefore pure speculation.

This of course does not detract from Dr Dunnet's important economic argument that the mineralization may be repeated in every fault slice. His recognition of the existing repetition, is, in my opinion, an important contribution to the search for new ore-bodies in the Mount Isa district.

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D. Dunnet. The local, early (B_1) folds were first brought to my attention by Dr B. P. Walpole in 1962 and subsequently discussed with Dr Williams in 1969. I fail to see how they invalidate the observations and interpretation summarized in this paper. The folds are non-penetrative features and as Dr Williams states are 'not common'. There is certainly no evidence for widespread megascopic isoclinal folding of this period. I believe these folds result from soft sediment slumping. The presence of associated cleavage does not invalidate their early genesis.

Unfortunately Dr Williams has not considered the compelling evidence for penecontemporaneous faulting in the Mt Isa region. He also makes the common error of assuming superimposed structural criteria to represent separate and unrelated deformation events rather than sequences in a rotational developing tectonic cycle. The sequence of events proposed by Dr Williams is essentially similar to my own and I believe is the response to right lateral wrench faulting on the Mt Isa fault system.

I proposed four recognizable events:

1. Early normal faulting which strikes west-northwest and is penecontemporaneous with Myally Beds through at least Urquhart Shale deposition time. Locally the faults control Myally Beds conglomerate and sand filled troughs as in the Gum Creek area (Smith 1969). At Hero Bore, 40 km north of Mt Isa, a rapid facies change of Breakaway Shale and Native Bee Siltstone equivalent to conglomerate marks the edge of the Mt Isa Shale basin and is coincident with

their overlap across a growth fault directly onto Eastern Creek Volcanics. Similar compelling evidence for fault controlled sedimentation can be seen in the Crystal Creek and Mammoth areas further north.

2. Local slumping and soft sediment deformation shows as response to the early faults. The fold at 37000 E, 51000 N (Mt Isa Mine grid) and a nappe structure with similar vergence at 32000 E, 48000 N are believed to represent slumps of the basal Mt Isa Group sediments into the still active Gum Creek trough.

3. Continuation of movement leads early normal faults to progressively merge into spoon faults. Late flat normal faults locally cut and rotate early normal faults. The gross effect is a north–south extension and major translation to the south.

4. Compression across the spoon fault domain during later stages of faulting accentuates the initial spoon fault curvature. It produces B_2 folds of Williams in quite penetrative deformation adjacent to the Mt Isa fault. Deformation is less intense towards the centre of the spoon fault domain as expected in compression resulting from inhomogeneous shear tectonics.

The sequence of events proposed by Dr Williams correspond to 2, 3 and 4 above. His suggestion that B_1 folds are a separate and unrelevant event, and thus early normal faults are unrelated to spoon faults, is possible but unlikely considering the parallelism and similarity of fault style. Undoubtedly the tectonic picture is more complex than that proposed but I believe it will fit the broad framework outlined above.

1946

BOTTOMING OF THE UNITED VERDE SULPHIDE PIPE

By
Paul F. Yates

PHELPS DODGE CORPORATION
UNITED VERDE BRANCH
JEROME, ARIZONA

ARIZONA SECTION
A. I. M. E.
TUCSON - OCTOBER 26-28, 1946

PHELPS DODGE CORPORATION

UNITED VERDE BRANCH

MINES DIVISION

"BOTTOMING OF THE UNITED VERDE SULPHIDE PIPE"

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INTRODUCTION

Ninety-five percent of the copper production of the United States has come from sixteen districts, of which Jerome ranks sixth.* The United Verde sulphide pipe has been responsible for giving the Jerome district this rank. The United Verde Extension production was from a down-faulted segment of the upper part of the sulphide pipe. Production from other sources in the district is comparatively negligible.

It is estimated that the original sulphide mass had a total of more than 130 million tons and a vertical extent of over 8300 feet. The United Verde Extension segment accounts for approximately 1120 feet, and the United Verde, to the 4800 ft. level, 4770 feet. The balance was lost by erosion before and after the displacement of the United Verde Extension portion of the sulphide pipe.

Of the twenty most productive western metal mining districts, Billingsley and Locke in 1938,# listed eleven as having been bottomed, or thoroughly explored to the maximum justifiable depth. Four, including the Jerome district, were listed as not having been bottomed. The Jerome district must now be deleted from this latter category.

Production from the United Verde Extension ceased in 1937. Present production from the United Verde is largely from cleanup operations. Extensive exploration to a depth of 1500 feet below the lowest stoping level in the United Verde mine has shown this great sulphide pipe diminishing into roots that are almost negligible.

The Jerome mining district is located on the northeasterly slope of the Black Hills in central Arizona with the two principal mines, the United Verde and the United Verde Extension, close to the town of Jerome near the north end of the district. The geology of the district has been described by several writers.** Here it will suffice to review the more salient features pertaining to the environment of the United Verde sulphide pipe.

*Copper Mining in North America, U.S.B.M. Bull. 405, p.2-8.
U.S.B.M. Minerals Yearbook, 1944.

#P. Billingsley and A. Locke, "Structures of Ore Deposits in the Continental Framework". A.I.M.E. Trans. 144, p. 9-64, 1941.

**See list of references.

GEOLOGY

The geological record begins well back in pre-Cambrian time with a vast outpouring of volcanic material of widely varying composition. This has been termed the greenstone complex and includes much rhyolitic flow and some fragmental material. Overlying this is the bedded sediments formation in which bedded volcanic tuffs and sedimentary material predominates. During a period of deformation the material was consolidated, folded, faulted and titled steeply to the northwest.

Rhyolitic (Cleopatra) quartz porphyry was then intruded as a large, somewhat tabular mass approximately along the greenstone-bedded sediments contact. The United Verde diorite followed in the form of a tabular blunt-nosed expanding plug roughly on the quartz porphyry-bedded sediments contact. Often a remnant of the sediments was left between the porphyry and diorite. Locally the diorite cuts across porphyry tongues.

A series of mineralizing solutions followed the intrusion of the diorite, coming up through the marginal zone of the quartz porphyry. These solutions were controlled by the concave configurations of the overhanging diorite and the schistosity and fracturing in the quartz porphyry. The United Verde sulphide pipe was formed by replacement of part of the remnants of the sediments and much of the quartz porphyry by sulphides, quartz and ferruginous chlorite. After the formation of the sulphide pipe the region was subject to dynamic forces which resulted in major faulting. One of these faults, the Verde, which strikes northwesterly and dips to the east, resulted in the placement of the United Verde Extension orebody. It is estimated that the vertical displacement on this fault in pre-Cambrian time was something like 2400 feet.

Following a long period of erosion and peneplanation, the middle Cambrian (Tapeats) sandstone was deposited as a thin blanket (0-100 ft.) of ferruginous beach sand and pebbles which tended to fill the minor irregularities of the pre-Cambrian surface. Overlying the basal sandstone in the Jerome area are from 300 to 500 feet of Devonian limestone, 300 to 500 feet of Mississippian (Redwall) limestone, and from nothing to 500 feet of red (Supai) sandstone and shale of Permian age. The deposition of each of these periods was preceded and followed by periods of uplift and erosion. Later an outpouring of Tertiary lavas (Malpais) formed a covering mantle. Damming of the Verde Valley by the lavas and contemperaneous subsidence permitted the deposition of over 2000 feet of impure while calcareous seidments (Verde formation).

Pre-lava erosion was evidently very active. A deep stream channel cut through the Paleozoic formations and partly exposed the gossan of the United Verde Extension segment of the sulphide pipe. This channel is now filled with Tertiary gravel and lava.

After the outpouring of the Tertiary lavas there occurred a period of normal faulting which relatively uplifted the west side of the Verde Valley in the neighborhood of 5000 feet. The added displacement on the Verde Fault as indicated by the relative positions of the base of the Paleozoic formations in the vicinity of the sulphide pipe measures approximately 1600 feet. The upthrust block containing the lower, or United Verde mine portion of the sulphide pipe, is bounded by four normal faults. The Verde to the east, the Warrior to the west, the Haynes to the north, and the Hull to the south. Post pre-Cambrian displacement on the Haynes Fault was 500 feet, the Warrior Fault 200 feet, and a comparatively small amount on the Hull Fault. In addition to the pre-Cambrian movement on the Verde Fault some evidence exists that there was also pre-Cambrian movement along the other three faults.

The uplifted scarps of the principal faults were especially subject to erosion with the resultant exposure of a strip of pre-Cambrian rocks paralleling the Verde Fault. The proximity of the exposed ore zone to the fault scarp induced rapid erosion which resulted in a comparatively shallow gossan zone above the United Verde mine. The secondary copper found in the fault zone and near the surface to the east was evidently transported from the top of the sulphide pipe during this period.

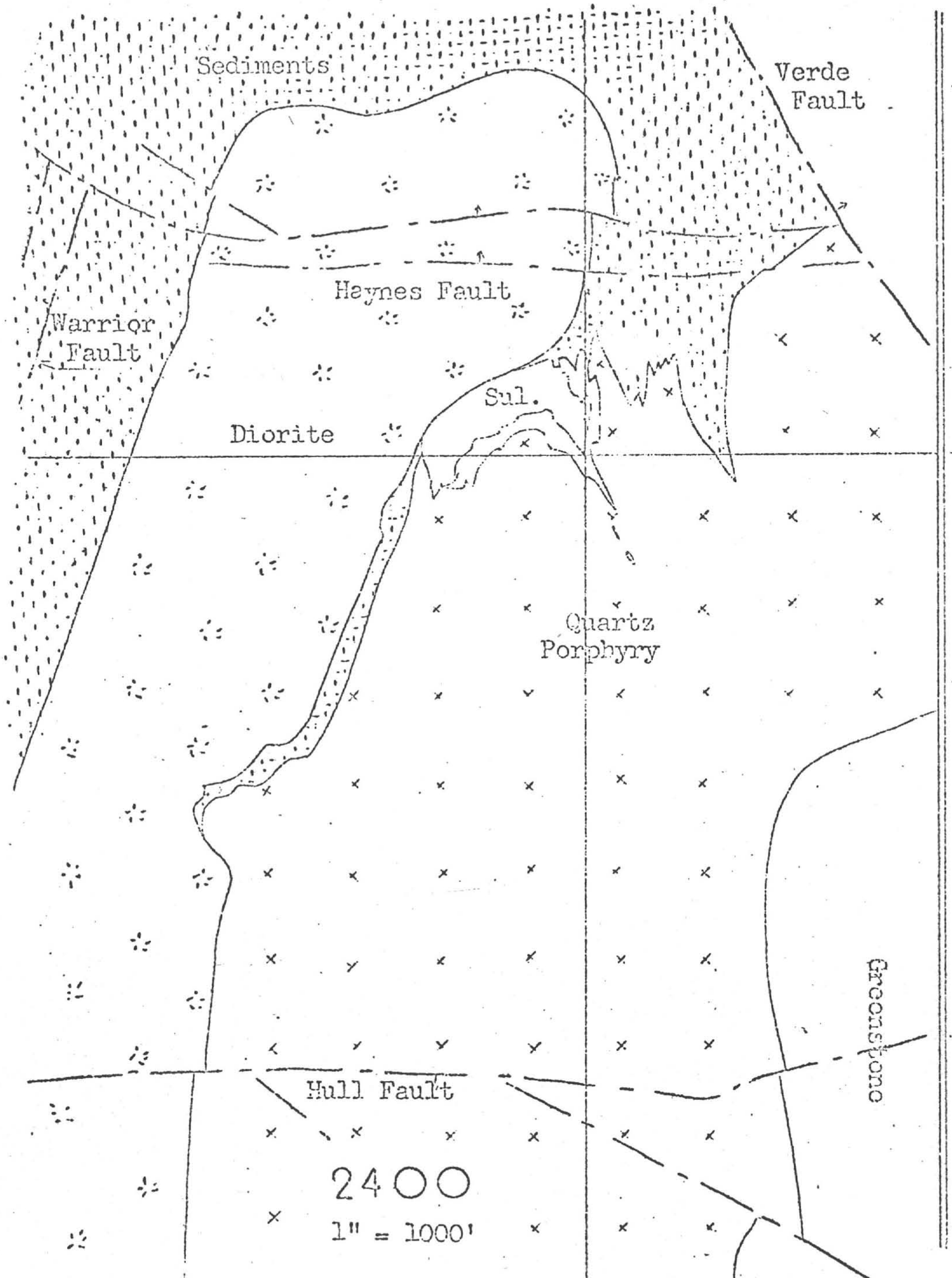
SULPHIDE PIPE

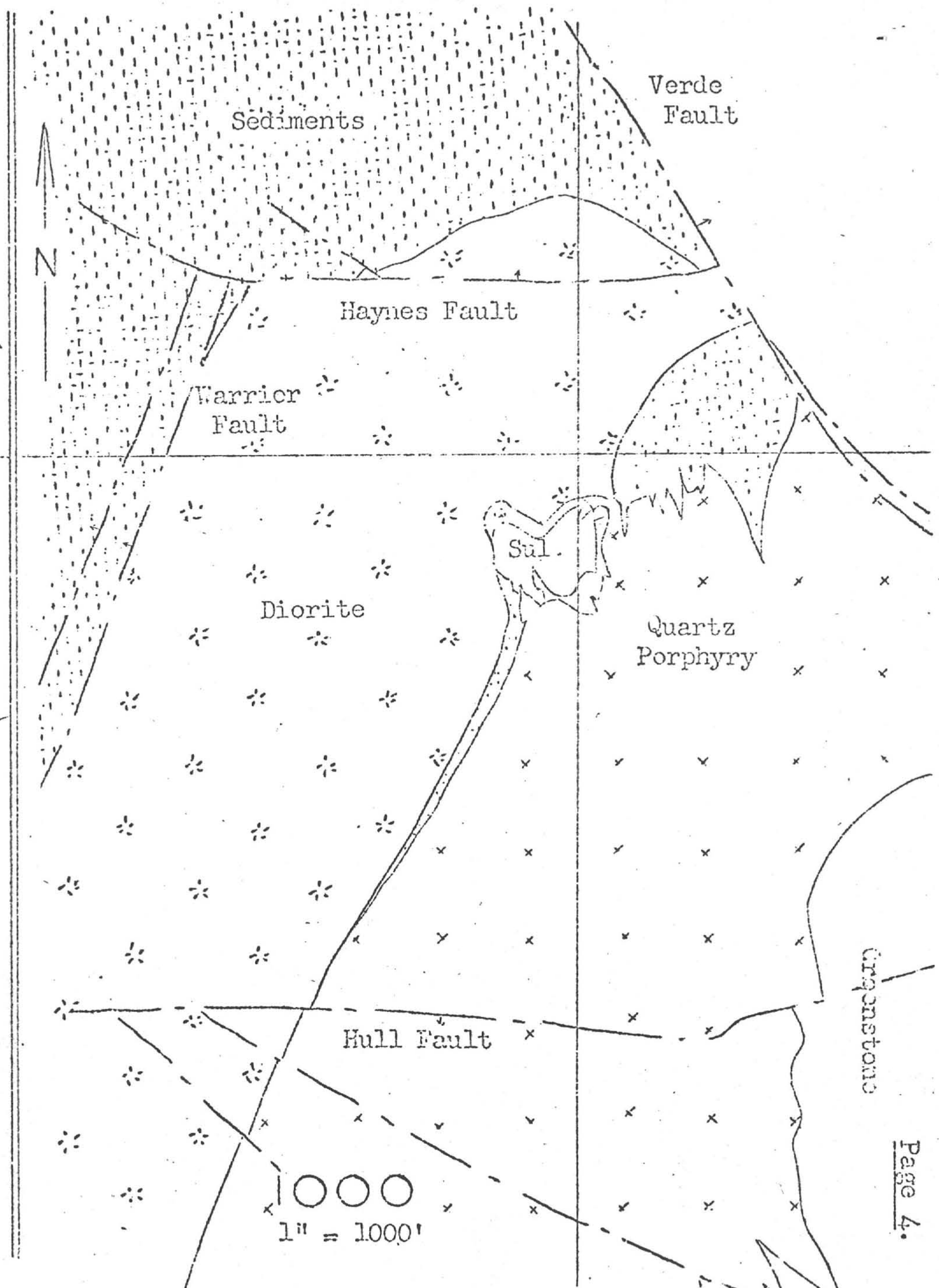
Localization

The United Verde mineralized zone is located in the vicinity of a change in the original trend of the greenstone-bedded sediments contact. (See page 4). To the south from the mineralized zone the contact is in a nearly north-south direction and is comparatively regular. To the north the contact swings to the northeast and is very irregular and interfingering, also to the north near the ore zone, the bedded sediments show many small drag folds evidently related to the plane of weakness along the greenstone-bedded sediments contact. This crumpling is more intense in the upper part of the mine than in the deeper levels. It is believed that the major structure is a large drag fold which plunges steeply to the north-northwest, is more open with depth, and becomes progressively tighter and stronger with increased elevation. The attitude of the minor drag folds support this hypothesis. Much of the evidence along this contact has been destroyed by the intrusion of the quartz porphyry and diorite. The form of these intrusives was affected by the steeply pitching folds, particularly in the case of the quartz porphyry.

The porphyry shows a variable schistosity or parting that is believed to be the result of differential pressure before the rock was completely solidified. The relatively local zones of more intense schistosity were formed later. To the south and east the schistosity strikes west of north and dips to the east. Near the mineralized zone it strikes in a broadly curving arc tending to parallel the surface of the over-riding diorite. The variable schistosity, with zones of greater shearing permitting greater penetration of mineral solutions, is responsible for the irregular footwall of the mineralized zone. In general the amount of shearing near the mineralized zone increases with elevation.

The diorite came in pushing upward and to the northeast, and when it had expanded sufficiently, wrapped around the bend in the porphyry contact. On the bottom levels the east diorite contact is in a north-south line with a bulge or flare to the east near the northern part. Below the


Sediments
Verde Fault
Haynes Fault
Warrior Fault
Sul.
Diorite
Quartz Porphyry
Greenstone
Hull Fault
2400
1" = 1000'


Sediments
Verde Fault
N
Haynes Fault
Warrior Fault
Sul.
Diorite
Quartz Porphyry
Greenstone
Hull Fault
1000
1" = 1000'

3000 ft. level the contact dips to the east to parallel the schistosity of the porphyry. Above the 3000 ft. level, as the diorite expands, the dip is to the west or across the schistosity of the porphyry. As higher elevations are reached, the bulge to the east becomes progressively more prominent. In the middle levels it forms a gently curving arc, and in the upper part of the mine a point swings to the south to form an inverted structural trough. (See plans and vertical section). The plunge of the trough is northerly conforming to the general plunge or the axes of the minor drag folds in the sediments.

Minor Faults and Breaks

The quartz porphyry near its margin with the diorite is cut by an irregular branching pattern of faults. In the upper part of the mine they are either weaker or obscured by mineralization and are hard to trace. In the lower part of the mine they can be traced over considerable distances. These faults appear to have acted as a partial control for the mineralizing solutions. It is significant that the sulphide masses are on the hangingwall side of the breaks, or between the breaks and the diorite. The solutions which formed the black schist penetrated to a certain extent into the foot-wall side of the breaks, though cross breaks or fracturing associated with the cross breaks. These faults are presumed to have been formed by the forces associated with the intrusion of the expanding diorite as it pushed or wrapped around the bend in the porphyry contact.

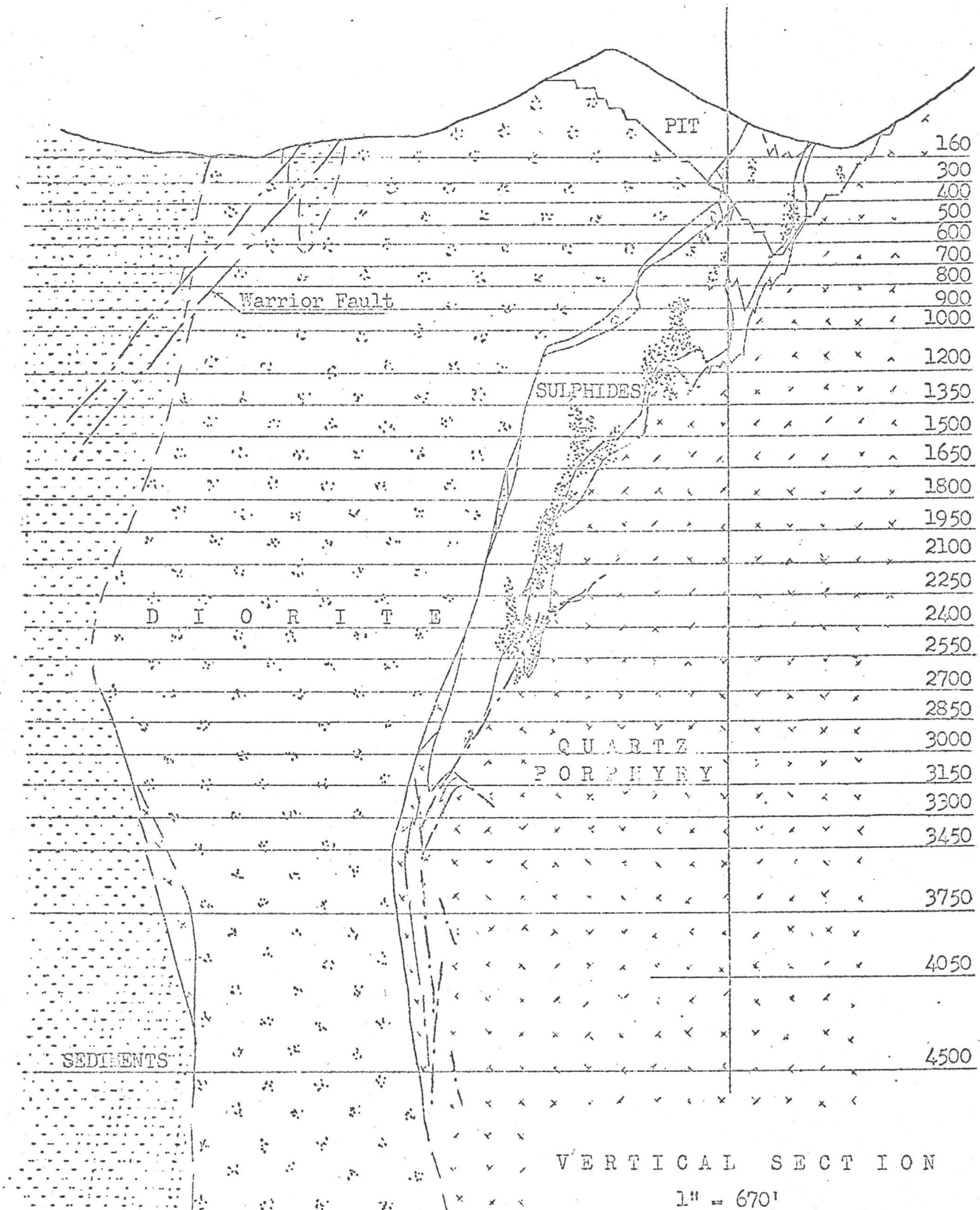
The principal breaks of this fault pattern strike northeasterly and are found starting near the diorite to the south and diverging from it as they skirt the footwall of the sulphide with some branches swinging more to the east and others back toward the diorite. They dip to the northwest at a flatter angle than the diorite-porphyry contact and thus as higher elevations are reached, the space between the breaks and the diorite increases, but still dip toward the contact. (See vertical section Page 6).

A second, less important series, strike in a northwesterly direction and dip to the northeast. In several places the breaks of this series appear to be responsible for the localization of mineralisation in the quartz porphyry footwall. Breaks of this series also conform to the southwesterly boundary of the northeast portion of the main mineralized zone.

Faults of both series throw out complicated spurs and branches. The breaks vary in width from a few inches to as much as two or three feet, with crushed rock, quartz, carbonate and gouge filling. They are locally, if not usually, mineralized with pyrite ranging from scattered crystals to streaks and patches. In a number of cases dikes have followed these breaks. The faults are definitely earlier than the intrusion of the dikes and the later mineralization and are believed to be entirely pre-mineral. It is probable that the forces which produced these faults, fractured the already schistose porphyry located between the breaks and the diorite thus forming a more favorable host for the mineralizing solutions.

Dikes

Numerous nearly vertical dioritic dikes cut through the orezone and surrounding rocks in a general east-west direction. In width they generally vary from a fraction of an inch to about three feet. However, there are a number six to eight feet wide, with exceptional cases of



VERTICAL SECTION

1" = 670'

greater width. In some places they are quite regular, in others irregular and broken. The increase in number and local bunching of the dikes, near copper bearing areas, is noticeable with depth. A series of larger dikes starting near the 1500 ft. level cut through the sulphide mass roughly paralleling the diorite contact. With depth they pass towards the footwall of the mineralized zone and on the 3300 ft. level are almost entirely in the chlorite schist and porphyry.

The smaller dikes are usually very fine grained and in places altered or partially altered. The larger dikes are usually fresh and of a coarser texture. Most of the dikes appear to have been intruded following the principal stage of copper mineralization, and before the later stages. There is a possibility that some of the dikes in the lower part of the mine are older.

Mineralization

The United Verde mineralized zone consists of a very irregular pipelike body of massive sulphide, quartz and mixed sulphide and rock with a steep north-northwesterly plunge. It is clearly of the schist replacement type, with replacement of schistose quartz porphyry and a part of the fringe of the bedded sediments. Replacement has been so complete that the relative amounts of the two rocks cannot be determined exactly, but the available evidence indicates that the porphyry was in considerable excess. The cross section of the mineralized zone varies throughout the mine. From the surface to the 1200 ft. level, the horizontal cross section averages about 250,000 square feet. From this horizon to the 1650 ft. level it averages about 500,000 square feet. From the 1800 to the 3000 ft. level it averages a little over 400,000 square feet. From the 3150 ft. level down, the total area decreases rapidly and at the 4500 ft. level it only totals 37,000 square feet, of which 9700 square feet is massive sulphide.

The sulphide zone is limited to the north and west by the impervious diorite, and to the south and east by an irregular border of black chlorite schist. The most abundant primary gangue mineral is pyrite which makes up the great bulk of the sulphide mass. With it are associated large quantities of quartz, chlorite and dolomite. Chalcopyrite is by far the principal copper bearing mineral. Less important associated minerals are sphalerite (marmatite), tennantite, bornite, galena and specularite. The minerals of the oxide zone and zone of a secondary enrichment have been included in earlier reports and are not repeated here.

Several stages of mineralization are recognized and are briefly described as follows*:

1. The first solutions followed the relatively permiable shear zones in the porphyry adjacent to the overhanging diorite, replacing much of the intervening porphyry and portions of the fringe of bedded sediments. These solutions deposited large quantities of quartz with very minor quantities of pyrite and chalcopyrite.

*L. E. Reber, "Jerome District", Some Arizona Copper Deposits, Arizona Bureau of Mines Bull. 145, Pages 41-65, November, 1938.

2. Solutions of the second period deposited much pyrite with important quantities of marmatite, a little chalcopyrite and probably local quartz and dolomite. This period is responsible for the major part of the sulphide zone and probably much of the zinc.

3. In the third period solutions working out from the footwall of the pyrite replaced large quantities of porphyry with a nearly black, high iron variety of chlorite.

4. The fourth period of mineralization was responsible for most of the commercial ore and consisted largely of chalcopyrite with minor pyrite and a little intergrown marmatite and galena. The chalcopyrite appears to have favored the replacement of the chlorite schist.

5. Solutions of the fifth period brought in small quantities of quartz, in part associated with bornite and probably other sulphides.

6. The sixth period of mineralization was characterized by the deposition of intergrown quartz and dolomite with associated chalcopyrite, pyrite, tennantite and sphalerite. These minerals are normally found in the chlorite schist near its footwall contact with the porphyry and most abundantly in the lower stoping levels. In this period mineral deposition by replacement was followed by deposition in fractures and gash veinlets. This mineralization has added materially to the schist ore in certain localities.

7. The latest phase of mineralization resulted in widespread deposition of quartz and dolomite with sparse pyrite in small veins and gash veinlets.

The products of each succeeding phase of the mineralization cycle built up on the footwall of the previous phase, and while rock replacement was most important, some of the products of the preceding phase were nearly always replaced.

In the lower levels of the mine the diorite and bedded sediments parallel the schistosity of the quartz porphyry and the ore zone consists of a few disconnected sulphide-schist lenses. These lenses are in the porphyry near its margin. Two of these are most significant. The lense north of the bulge in the diorite is most extensive on the 4500 ft. level. It is a sulphide-schist lense 280 feet long by about 45 feet wide, with a tail stringing out to the north. Its cross section nearly doubles by the time it reaches the 4050 ft. level, continues about the same to the 3750 ft. level, and then decreases rapidly to pinch out under the expanding diorite just below the 3300 ft. level. The ore in this lense is limited to a cross section of 800 square feet on the 4500 ft. level, increases to 1300 square feet on the 3750 ft. level, then decreases rapidly above this horizon.

Immediately south of the bulge in the diorite on the 4500 ft. level, opposite a rather sharp embayment in the contact, is a lense of quartz, sulphide and schist, 150 feet long by about 30 feet wide. This lense rakes sharply upward to the south, increases rapidly in size to the 3750 ft. level, continues about the same size to the 3450 ft. level. It then decreases up to the 3300 ft. level with a part continuing above the 2700 ft. level. There is very little copper in the massive sulphides in this lense. The copper ore is in the chlorite schist localized along one of the branching faults and separated from the massive sulphides by a band of quartz porphyry, or altered material, transitional between porphyry and chlorite schist. The principal ore body in this lense extends from the 3300 to the 2700 ft. level. There are other mineable bodies of limited size between the 3450 and the 3150 ft. levels.

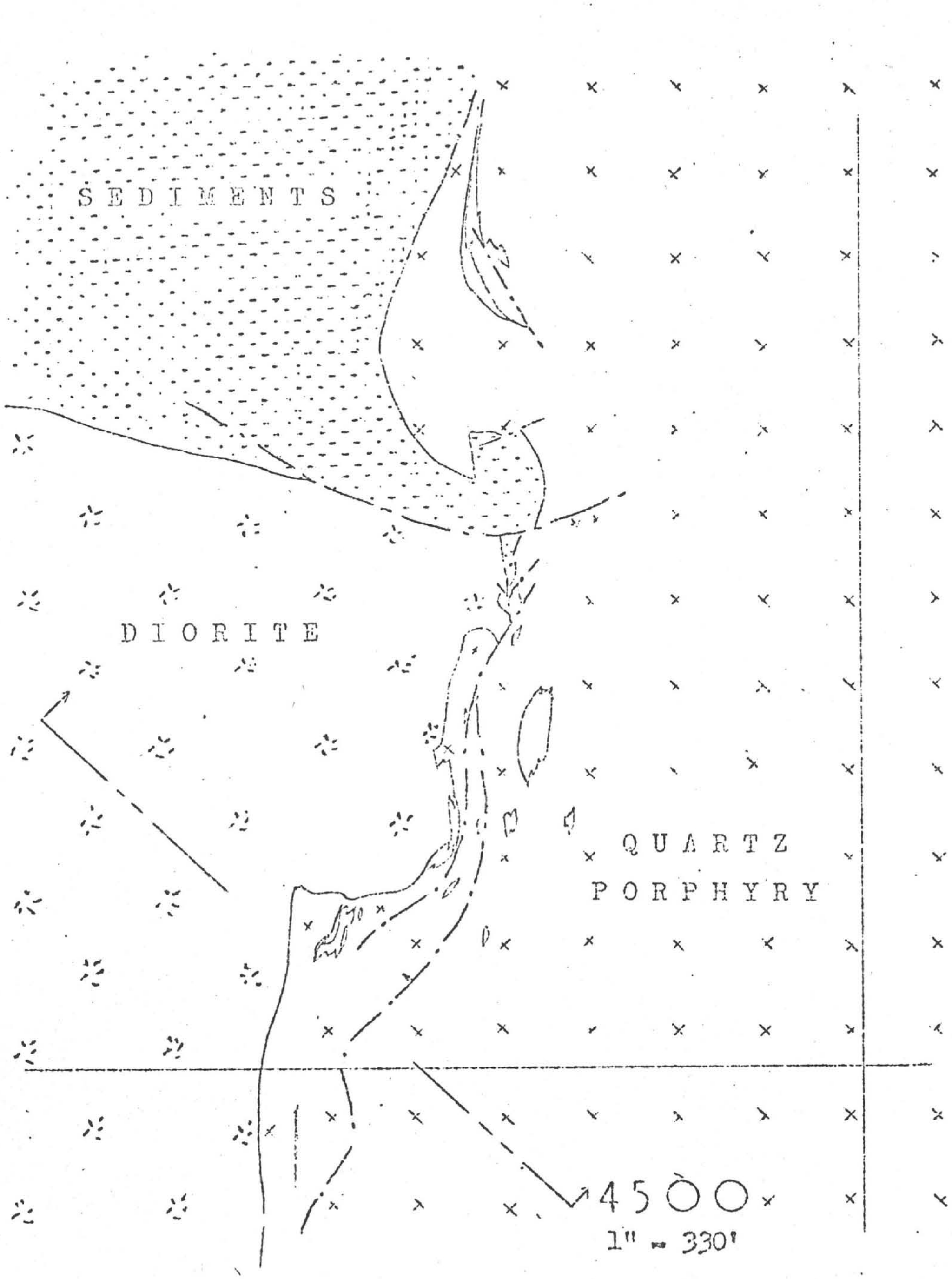
There is a small low grade irregular pipe-like lense of quartz, massive sulphide and mineralized schist associated with quartz-porphyry in a sharp embayment on the west side of the diorite. The material differs only from that of the main ore zone in the presence of visible magnetite and pyrrhotite. This lense pinches out against the overhanging diorite above the 2700 ft. level. It plunges easterly toward the main ore zone, suggesting that it is a small branch comparable to the "north lense".

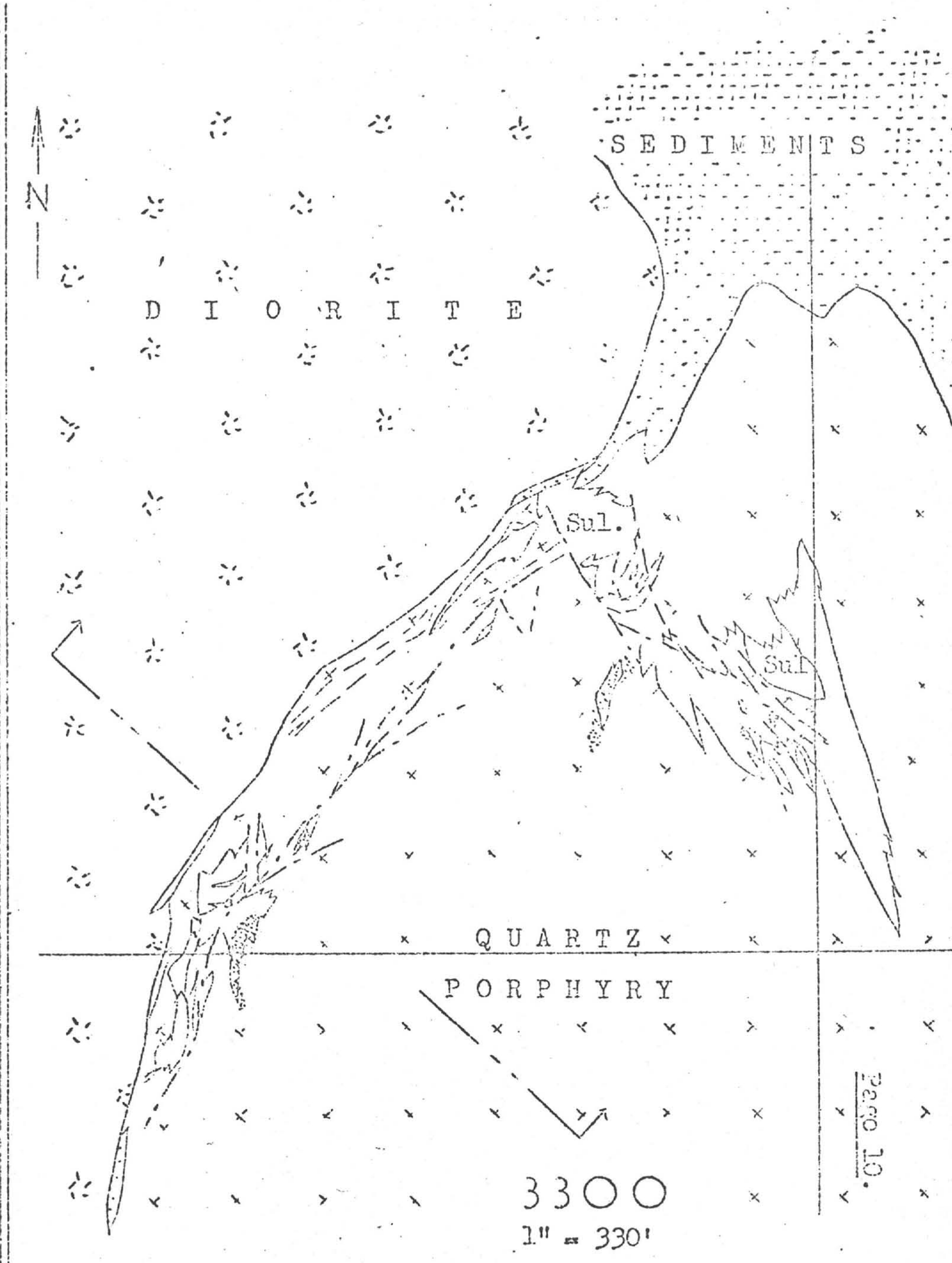
The intervening diorite makes the upper part of the north lense a distinct branch or spur of the mineralized zone, while the south lense may be looked upon as an offset portion of the main ore zone with a vertical overlap of more than 1000 feet on the main sulphide pipe.

On the 4500 ft. level, scattered schist areas with minor sulphide, underlie the main sulphide mass. They extend upward, become stronger and make the bottom of the deepest element of the main sulphide mass, which comes in some distance below the 3750 ft. level. The east element extends from below the 3300 ft. level to join the main mass near the 3150 ft. level; the south element, from below the 3150 ft. level to join the mass near the 2850 ft. level. From the 2850 ft. level upward, the sulphide pipe is continuous.

The start and upward expansion of the east element of the main sulphide body is related to a band of increased schistosity in the quartz porphyry, which grows progressively stronger upward. This zone of schistosity, when combined with the control effected by the expanding bulge in the diorite, accounts for the formation of the crescent shaped sulphide mass in the middle levels. As the diorite continues to expand and over-ride the porphyry, the mineralizing solutions are progressively more confined until in the upper levels, the sulphide is nearly eliptical in form, with the major axis almost perpendicular to the crescent.

Copper. Since the copper mineralization appeared near the close of the mineralizing cycle, most of the ore occurs on the underside or footwall of the sulphide mass. In the lower horizons there are only minor spots. The copper mineralization becomes more effective as the higher elevations in the mine are reached, and on the 3300 ft. level, there are three mineable bodies and the bottom of a fourth. In the lower stoping levels most of the copper is found in the chlorite schist. In the upper levels the amount of copper in the schist decreases and progressively more is found in the massive sulphide. On the 2850 ft. level the copper mineralization was more widespread than below, but the larger stopes are in the chlorite schist near the split in the sulphides. Above this horizon the ore bodies become progressively more continuous and on the 2100 ft. level the ore band is 15 to 90 feet wide and 800 feet long. The flattening of the overhanging diorite permitted increased mineralization near the 1800 and 1650 ft. levels. In the upper horizons of the mine the heavy pyrite stage of mineralization left unreplaced stringers of rock extending far out into the sulphide. Thus with the more constricted diorite trough and a more intense zone of shearing in the porphyry, the heavy chalcopyrite mineralization penetrated nearly to the diorite hangingwall, as well as extending far out into the quartz porphyry footwall.


SEDIMENTS
DIORITE
QUARTZ
PORPHYRY
4500
1" = 330'


N
SEDIMENTS
DIORITE
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PORPHYRY
3300
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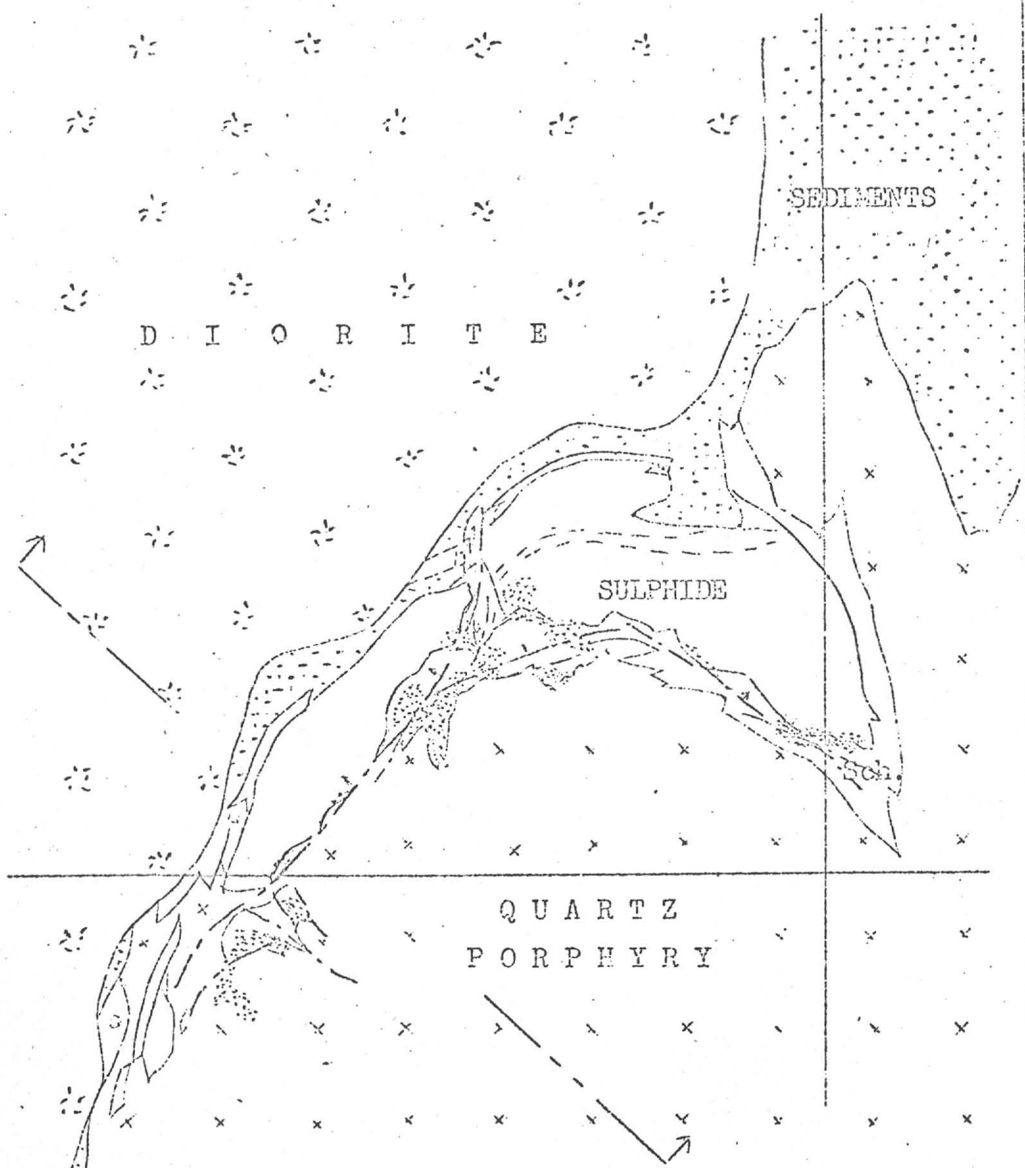
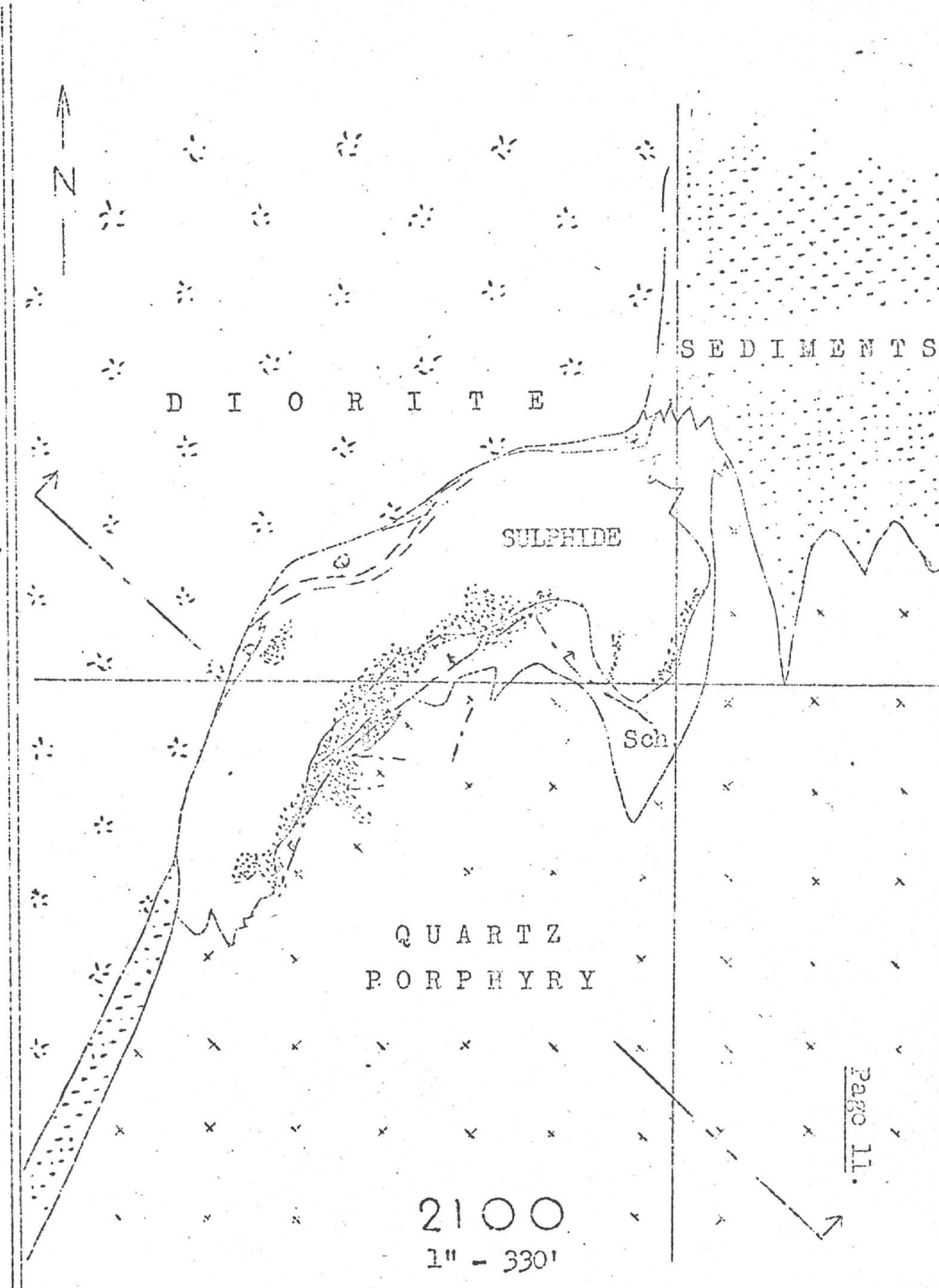
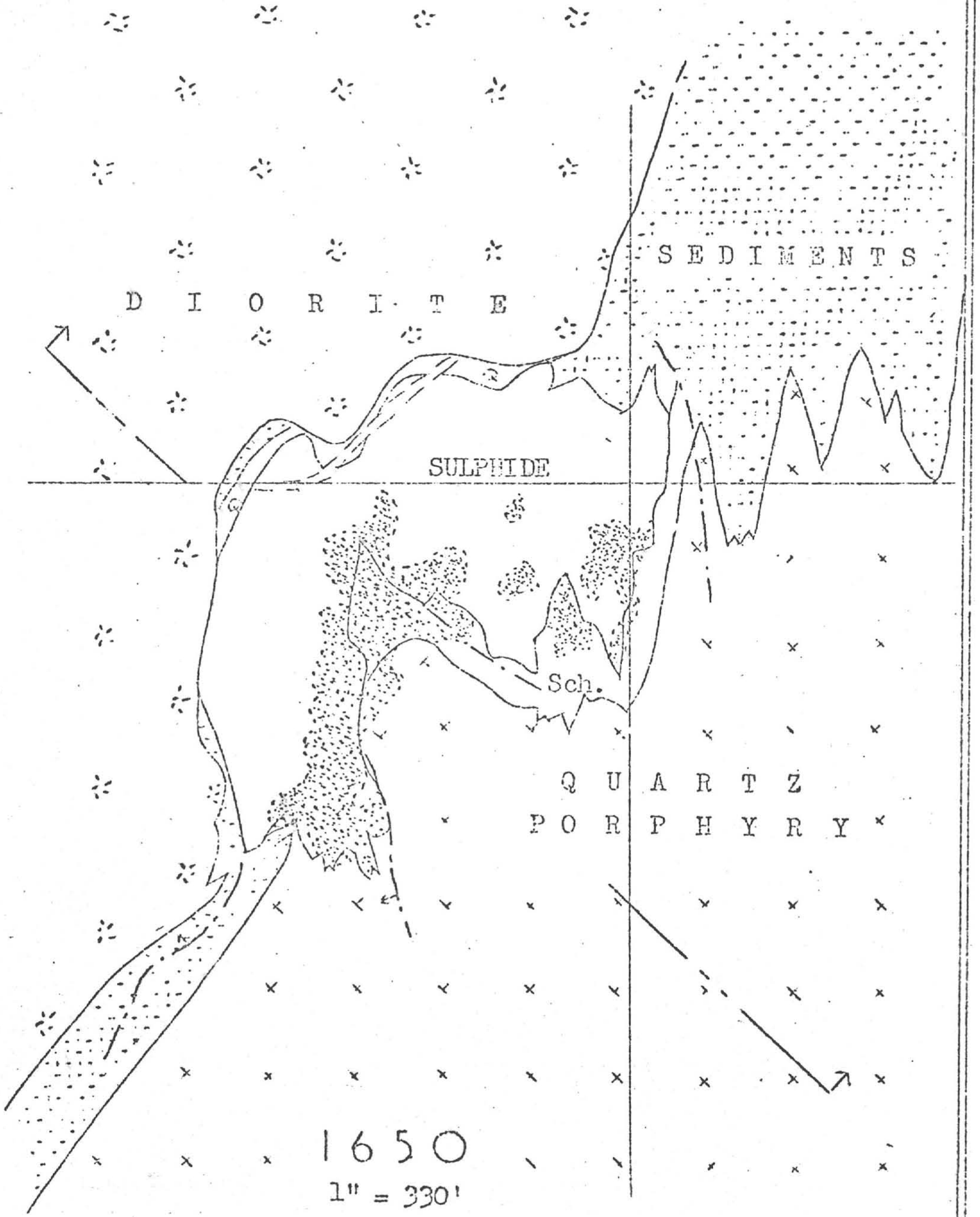


2850
1" = 330'



2100
1" - 330'


DIORITE
SEDIMENTS
SULPHIDE
Q
Sch.
QUARTZ PORPHYRY
1650
1" = 330'

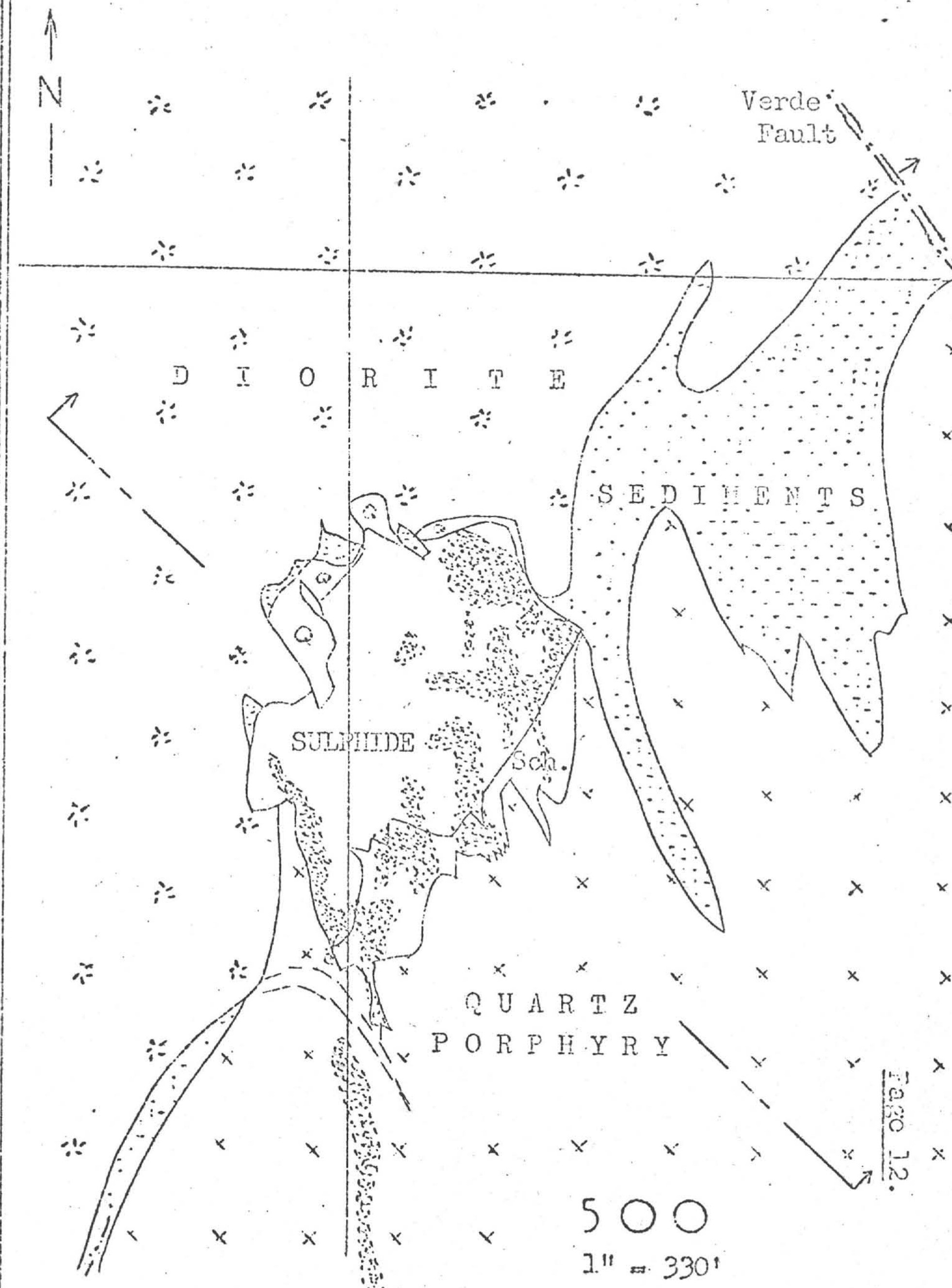
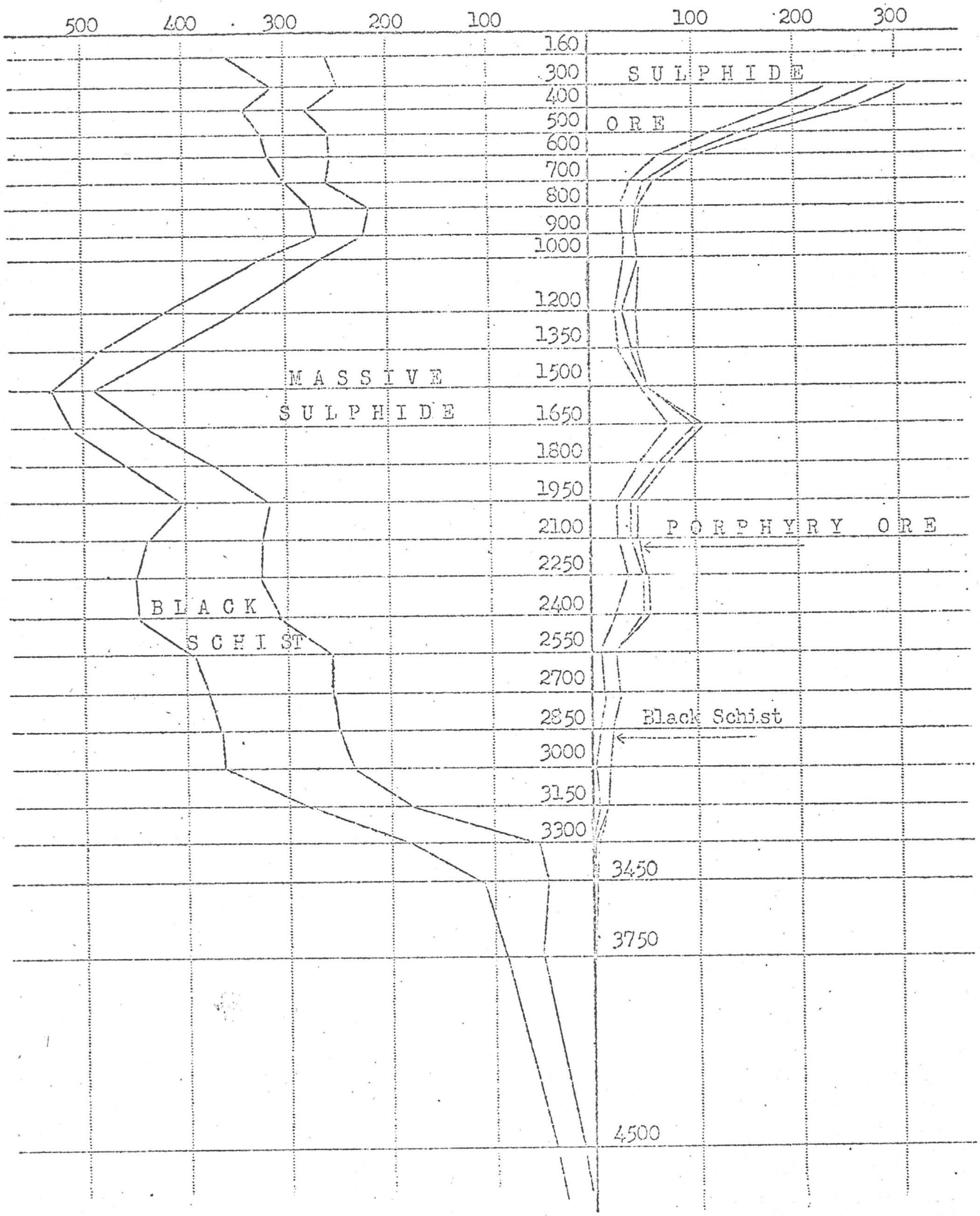

N
Verde Fault
DIORITE
SEDIMENTS
SULPHIDE
Q
Sch.
QUARTZ PORPHYRY
500
1" = 330'

CHART OF MINERALIZED AREAS

Thousands of Square Feet



Zinc. As already stated most of the zinc is associated with the principal stage of pyrite deposition before the significant copper deposition. It is found in the massive sulphide between the zone of copper deposition and the diorite hangingwall. The greater concentration of zinc is found in the upper levels with scattered spots down to the 3000 ft. level. Below this, relatively high zinc values are limited to part of the north sulphide lense between the 3750 and the 4500 ft. levels.

Development of the low grade zinc ore disclosed that it is quite irregular and discontinuous. Much of the best of the zinc has either been removed in the open pit operation or is involved in the general mine subsidence. The intimate mineralogical composition indicates a difficult metallurgical separation. These factors combine to preclude any present possibility of commercial zinc production from the United Verde mine.

Precious Metals. The best primary gold and silver values are associated with relatively siliceous material. A number of the massive sulphide copper ore bodies terminate in siliceous material, with relatively high gold and silver values. There are also localized gold-silver values in the comparatively narrow transition zone between lean sulphide and quartz. The average ores carry in the neighborhood of .015 ounces of gold per ton and a little over an ounce of silver. Increased gold may go to as much as .10 ounces and silver to two or three ounces. Occasionally much higher values have been found. Silver averaging about two ounces is found in schist ores with comparatively abundant tennantite.

Chlorite Schist. In the upper and middle levels the preponderance of the chlorite schist is nearly pure ferruginous chlorite and almost black in color. In the lower stoping levels and progressively below, the amount of material that is transitional between the quartz porphyry and the chlorite schist continues to increase. There are sizeable areas where it is nearly impossible to tell whether chlorite schist or porphyry predominates. It is probable that in the lower horizons the paths of the mineralizing solutions were more scattered and hence much of the porphyry was only partially replaced. In the middle and upper levels, structural conditions led to a greater concentration or localization. There is a progressively marked lessening of the amount of chlorite schist developed on each of the succeeding levels from the 3300 ft. level down.

Quartz. The large masses of quartz found underlying the diorite hangingwall are normally quite dense and commonly jaspery in texture. It is suggested that this earlier quartz assisted in rendering the hangingwall impervious. Other quartz masses are found throughout the sulphide. In general, as the diorite contact is approached, the amount of quartz increases. On the bottom development levels, there is a notable increase in the amount of quartz as compared to the heavy sulphide. Jaspery quartz lenses, varying from a fraction of an inch to several feet in thickness, are often found in the quartz porphyry underlying the sulphide masses and in shear zones adjacent to some of the minor faults. These lenses are usually mineralized with scattered pyrite and a very little chalcopyrite.

ORIGIN AND CONTROL OF MINERALIZATION

General knowledge of metalliferous ore deposits makes it practically certain that the United Verde sulphide pipe was formed by solutions related to igneous rocks or an igneous magma reservoir, though the particular magmatic source to which the mineralizing solutions owes their origin is speculative. The location of the Jerome district with respect to the Bradshaw granite area to the south and southwest, and the granitic areas to the west and northwest, makes the Bradshaw granite magma the most plausible source of the mineralizing solutions.*

It appears that the mineralizing solutions were introduced through the same channel or zone along which the quartz porphyry and diorite were intruded. As the north end of the diorite continues to recede to the south with depth, it exerts less and less control on the deposition of the solutions. There is every indication that at some depth below the 4500 ft. level the mineralizing solutions were introduced along a nearly north-south striking shear or break that is on or close to the bedded sediments-quartz porphyry contact.

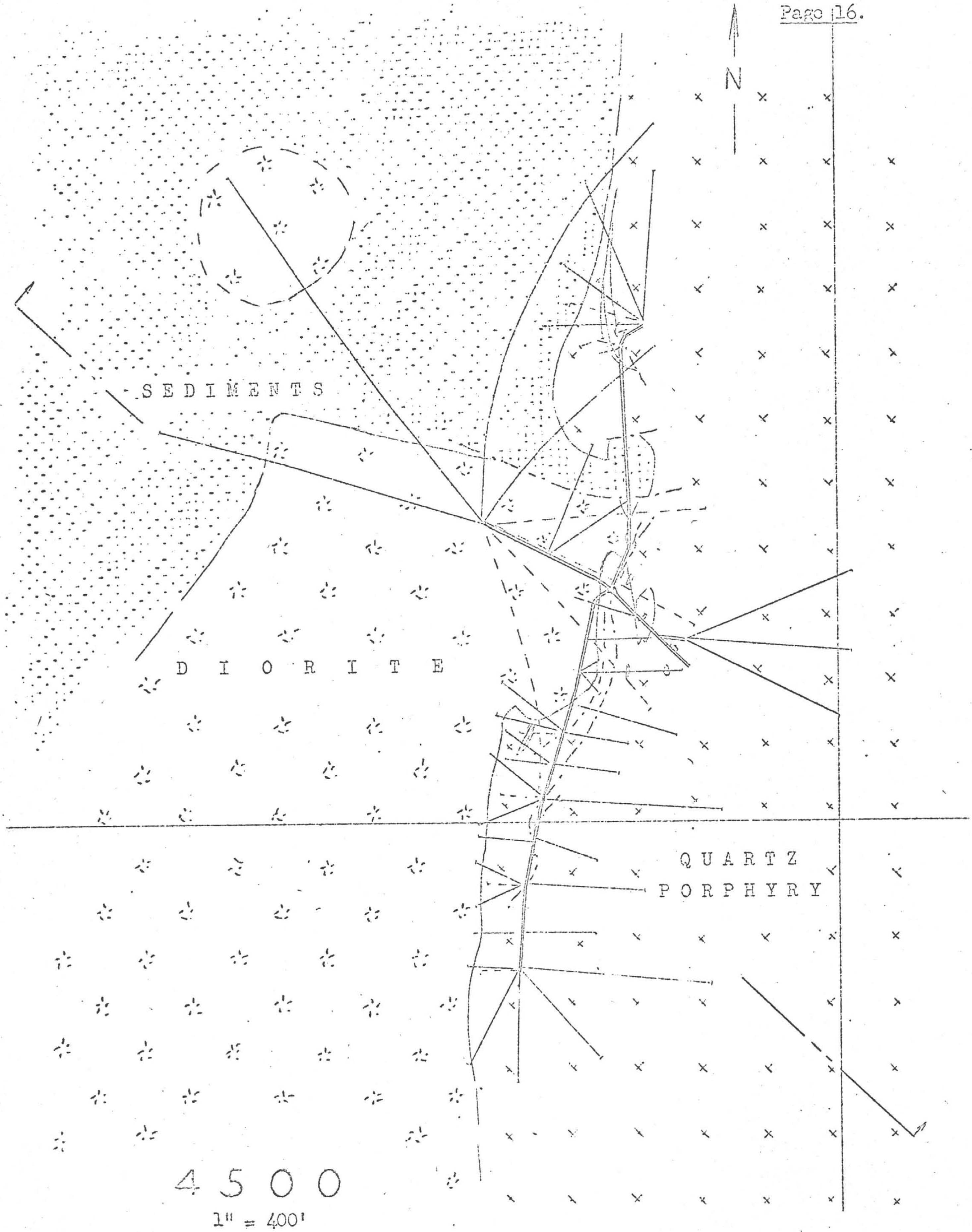
It is believed that the breaks of the minor fault pattern related to the intrusion of the diorite, were most significant in the control of the mineralizing solutions between the postulated major break at depth and the zone of effective mineral deposition. Various unfavorable factors, such as the weakness or fluidity of solutions, tightness of channels, and lack of the damming effect of the overhanging diorite, prevented more than a limited amount of deposition in the bottom levels of the mine. With increased elevation the more sheared and fractured porphyry, coupled with the changing composition of the solutions, and the increased damming effect of the diorite permitted more and more material to be deposited. The diorite, the fringe of sediments and the earlier quartz, combined to form a dam that was impervious to the later phases of the mineral solutions. The changes in the contour of the diorite, the variable degree of schistosity in the porphyry, and the habit of the breaks all combined to effect changes in the form of the mineralized zone so that no two levels are the same.

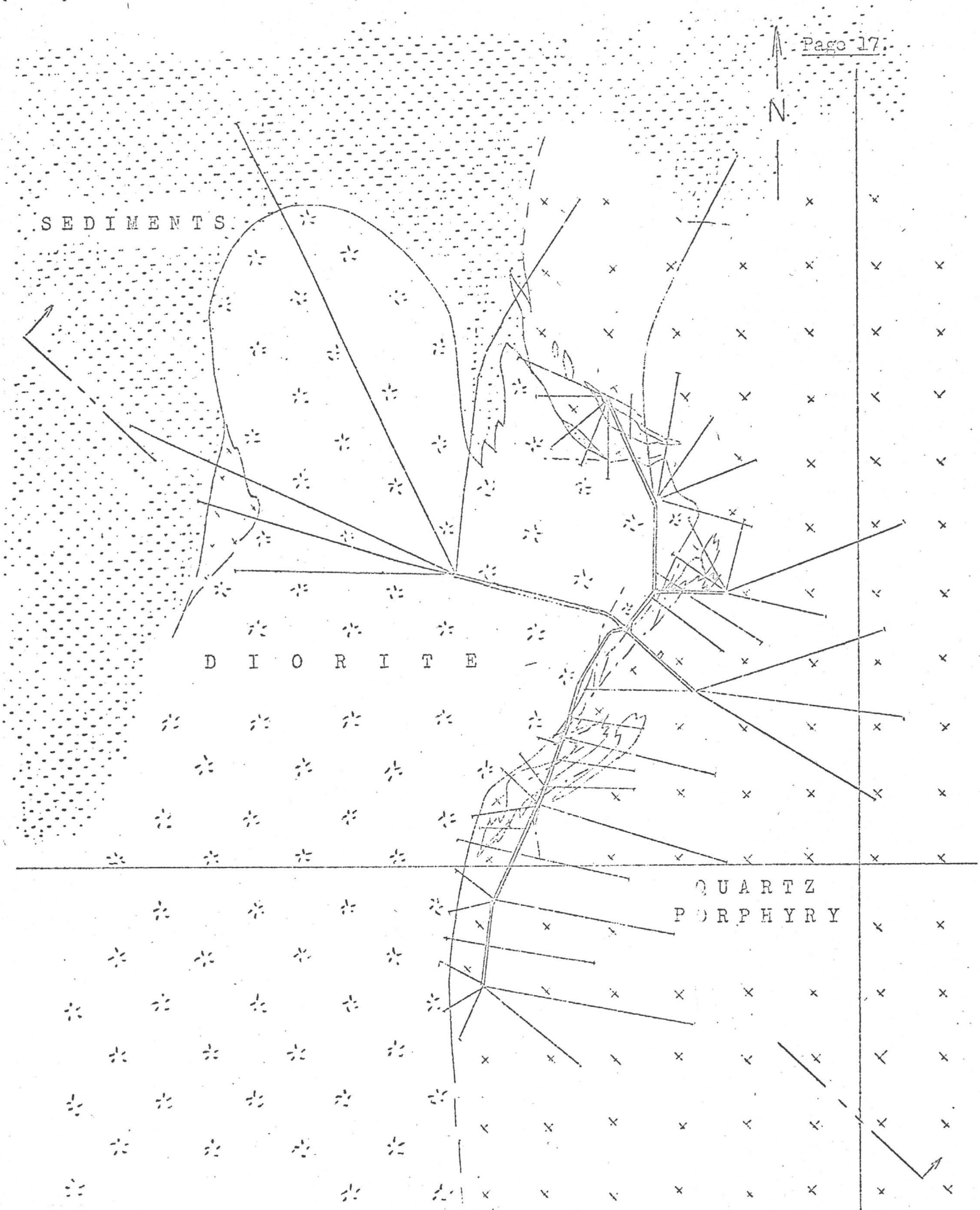
DEEP LEVEL EXPLORATION

When underground operations were resumed in 1937 as the open pit was being completed, the lowest stoping was on the 2550 and 2700 ft. levels, the 2850 and 3000 ft. levels were only partially developed, and drifting had just been started on the 3300 ft. level. The necessity for additional exploration was apparent if the proposed mining schedules were to be maintained.

Preliminary drifting on the 3000 ft. level was completed, and the heading on the 3300 ft. level was being continued along the sulphide-schist contact. An extensive diamond drilling program on the 3000 ft. level indicated a decrease in the area of mineable ore as compared to the levels immediately above. As the 3300 drifting progressed, attendant drilling soon indicated an apparent breaking up of the sulphide mass, with conspicuously little copper mineralization. This suggested the possible termination or bottoming of the sulphide pipe.

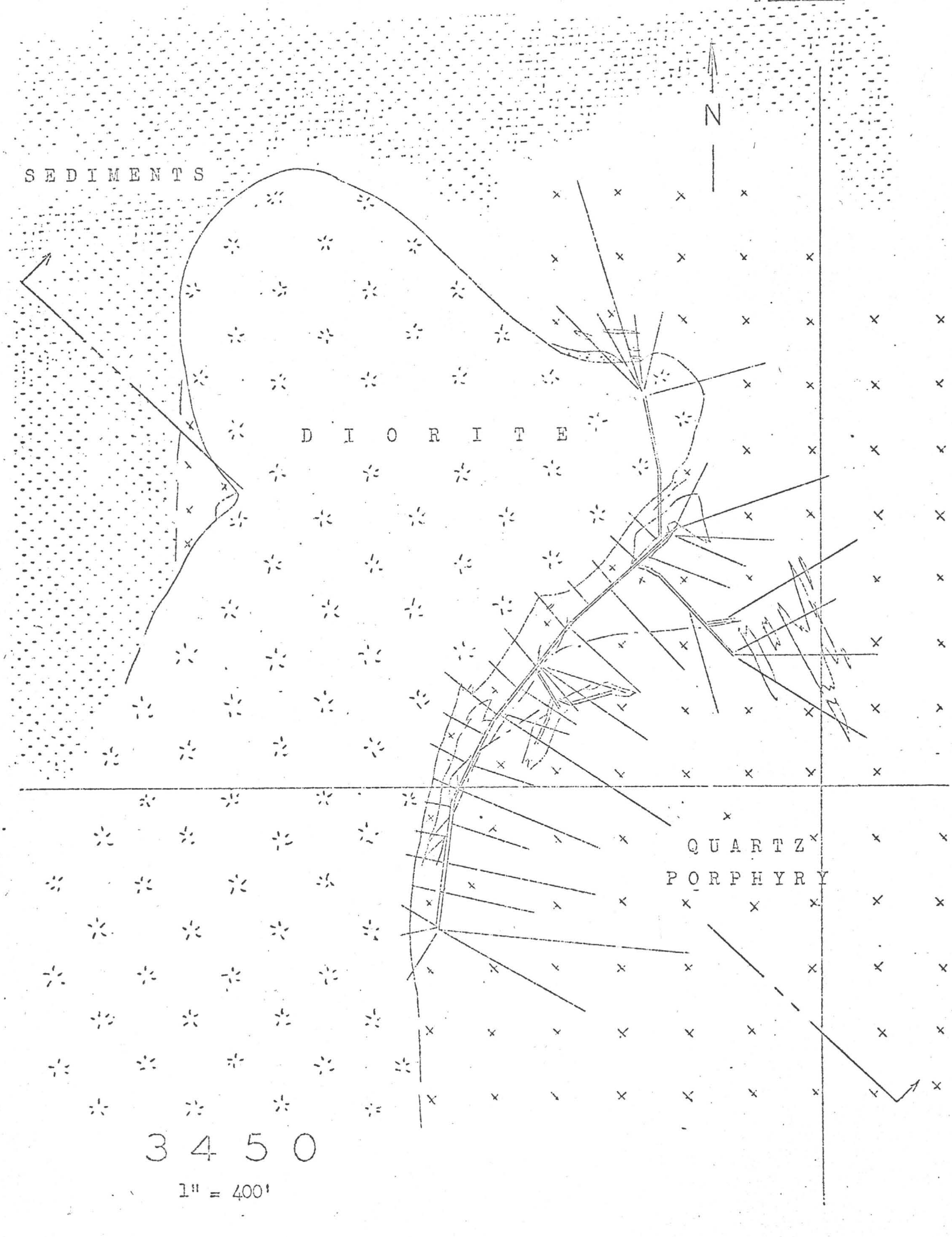
*L. E. Reber, op. cit.


N
SEDIMENTS
DIORITE
QUARTZ
PORPHYRY
4500
1" = 400'



3750

1" = 400'


N
SEDIMENTS
DIORITE
QUARTZ
PORPHYRY
3450
1" = 400'

An intensive exploration and development program was essential to delineate mineable ore areas below the 3000 ft. level and to determine whether or not the ore zone had definitely bottomed. A study of geological data indicated the split in the sulphide mass as the most favorable location for a development shaft. A new shaft was necessary because the existing shafts were at an excessive distance from the mineralized zone and because the hoisting equipment was inadequate for development at the desired depths. The new, No. 8 Shaft, was started from the 3000 ft. level in September 1939, and completed at the 4631 ft. level in August 1942.

Exploration levels were established on the 3450, 3750 and 4500 ft. levels and later an intermediate on the 4050 ft. level. The extensive development and the areas prospected on the 3450, 3750 and 4500 ft. levels are shown on pages 16, 17, and 18. Development from January 1940, to October 1946, has included 10,230 feet of drifts, and nearly 17 miles of diamond drilling. The No. 8 Shaft exploratory program will be completed early in 1947 at a total cost of approximately $1,000,000.

The elevation of the 4500 ft. level is 1030 feet above sea level. Rock temperatures encountered as the development headings on this horizon were being extended were 110° F.

CONCLUSION

It is believed that the great United Verde sulphide pipe has bottomed, that an extensive exploration program was entirely justified, and that it has been diligently carried out. Probably the one outstanding feature of the whole exploration program has been the succession of negative results obtained. The minor spots of mineralized material encountered are a part of the progressive breaking up and diminution of mineralization below the 2400 ft. level. The present exploration program has included a vastly extended area for a vertical distance of over 1500 feet below the lowest stoping horizon with essentially negative results. The chances are exceedingly remote for a change in structural conditions which would permit the deposition of mineral solutions at some deeper horizon.

Mining operations are now essentially confined to the cleaning up of ore in the vertical and horizontal pillars left by earlier mining, to remnants around the borders of existing stopes, and the completion of a few open stopes on the 3150 and 3300 ft. levels. The combined segments of the United Verde sulphide pipe, (United Verde and United Verde Extension), have produced 34,550,000 tons of ore from which has been extracted 3,551,000,000 pounds of copper, 53,420,000 ounces of silver, and 1,462,000 ounces of gold. This vast ore zone, with over sixty years of active productivity, can now be said to be effectively bottomed.

APPRECIATION

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Jerome, Arizona
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