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REPORT ON THE PROPERTIES

of the

UNITED VERDE EXTENSION MINING COMPANY

at

JEROME, ARIZONA.

by

Waldemar Lindgren

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by

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Introduction

At the request of Mr. J. S. Douglas, President of the United Verde Extension Mining Company, I spent a month examining the mine of the Company at Jerome for the purpose of investigating the geological features. The objects were to ascertain the nature of the deposit, its probable continuation in depth, the possibility of recovering the faulted part and also to consider the likelihood of finding other deposits in the area controlled by the Company.

The principal property containing the deposits consists of a compact area of claims on the slope below the town of Jerome, comprising about 200 acres. There are also several outlying mining claims, like the Haynes group to the northwest of the United Verde Mine, and some other areas in various parts of the district, which, however, have no present definite value for mining purposes. The Company also controls the claims of the Jerome Verde Development Company, adjoining their mine on the north and in which much development work has been done. Most of these properties are outlined on Plate 1 accompanying this report.

Mining Developments

The main features of the mining and geology of the district have been rather fully treated in several publications[1] so that this part of the discussion may here be cut short.

Of the two principal mines in the district the United Verde is the older and has yielded the greater production. It is situated on the west side of the great Verde fault, which divides the district in two structural parts, and consists of a large pipe of sulphide ore plunging North Northwest and which has been followed to a depth of 3,000 feet, vertically.

The second is the United Verde Extension Mine, which is situated about half a mile to the East of the first mentioned mine and which was discovered by underground workings about 1917. It is now developed to a vertical depth of 1,700 feet from the collar of the Edith shaft (Elev. 4,908 feet) to the 1,900 foot level (Elev. 3,209 feet), and by very extensive workings on all levels from the 550 foot level down. The developments began from the Little Daisy shaft, now in disuse.

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Reber, L.E. Jr.: Geology and ore deposits of the Jerome District. Am.Inst.Min. & Met. Eng., Trans., vol. 66, pp. 3-26, 1922.

Finlay, J.R.: The Jerome district of Arizona. Eng. & Min.Jour.-Press, Sept.28 and Oct. 5, 1918.

Lindgren, Waldemar: Ore deposits of the Jerome and Bradshaw Mountains Quadrangles, Arizona. Bull.782, U.S.Geol. Survey, Washington, 1926.

The elevation of its collar was 5,048 feet; it intersected the fault, and it is about 800 feet deep.

About all of the developments are contained in the March, Main, Conglomerate, Carbonate, Bitter Creek and Florencia claims. The Haynes group is developed by a short tunnel and by the Haynes shaft, situated half a mile Northwest of the United Verde outcrops, and 1,200 feet deep. The Jerome Verde Development Company's property is developed from the now abandoned Columbia shaft 1,350 feet deep but mostly from the different levels of the Edith shaft.

All the various elevations of the levels are entered on ~~Plate 3~~ page 36 accompanying this report.

The Geological Formations

As the ores are found in the old pre-Cambrian rocks the other younger formations are of subordinate interest. They consist of a thick series of approximately horizontal limestones, and they were deposited on the even surface, worn down by erosion, of these pre-Cambrian rocks. A brown basal sandstone, usually called the "Tonto" forms the bottom layer; it is about 40 feet thick.

Still later than the limestones is a conglomerate deposited on their eroded surface in temporary rivers of Tertiary age. Above the limestones and conglomerates are generally spread out thick flows of basaltic lava also of Tertiary age.

The pre-Cambrian formations are complex but consist of the following main elements:

1. Diorite and diabase. These are the youngest rocks of the pre-Cambrian series. They are dark green, granular rocks usually greatly altered and filled with secondary zoisite. There are several areas of these in the vicinity of the orebodies, and they are in the main identical with the United Verde diorite. They are usually massive though in places changed by pressure to dark green schists.

2. Cleopatra quartz porphyry. This is a grey quartzose fine-grained rock showing quartz crystals. It is schistose in places and usually contains much sericite.

3. Deception quartz porphyry. This is also a fine-grained grey rock with very small quartz crystals and forms a large mass south of the Cleopatra porphyry. Its exact age is not established. While it is apparently massive the microscope shows that it has been affected by incipient schistosity.

4. Greenstone series. This is a usually schistose green rock which forms a large area of complex composition. A large part of it is chloritic schist, composed mainly of quartz and chlorite. It is derived by alteration and pressure from volcanic rocks in part basic in part acid. To a small extent it is interbedded with metamorphic generally siliceous sediments, but there is much less of these here than near the United Verde Mine. The Greenstone series frequently contains dikes of Cleopatra porphyry.

In the United Verde Mine the pre-Cambrian rocks enumerated are cut by many dikes of diorite porphyry, the youngest of all rocks of the old series. Few of them are found in the United Verde Extension, and they are here of little importance for the mineralization.

The Distribution of the Rocks

Within a rectangle 3,200 by 3,600 feet, forming the surrounding of the orebody a certain fairly regular arrangement of the formations may be noted. The rectangle is divided in two parts by the great Verde fault, the orebody of the United Verde Extension Mine lying in the hanging wall of this fault. To the west of the fault the principal rocks are the Cleopatra porphyry, with some intrusions of diorite. The southern part of this area is occupied by Deception porphyry.

To the east ofthe fault the area may be roughly divided in two parts. The southern part is mainly occupied by Cleopatra porphyry. To the north of the orebody the greenstone schists prevail with some intrusions of diorite and many smaller dikes and masses of Cleopatra porphyry. The rough outlines of these two areas are the same as all levels hence the boundaries are approximately vertical.×

The orebody lies between the quartz porphyry on the south and the diorite and greenstone schists on the north. The surface geology is shown on Pl. 2.

× The geological level maps made for the Company by Mr. Fearing are in the main correct and the determination of the rocks is also generally satisfactory

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Structure

The structure of the pre-Cambrian rocks is emphasized by the lines of schistosity which run North Northwest or Northwest with a steep easterly dip. In most of the quartz porphyry and diorite the structure is poorly developed.

This schistosity which in part is followed by the veins was developed strongly in early pre-Cambrian time, the effects of pressure growing less after the intrusion of the quartz porphyry and the diorite.

Structure later than the pre-Cambrian is emphasized by the faulting which took place on a large scale at the close of the Tertiary or at the beginning of the Quarternary period.

The whole rock series, including the pre-Cambrian, the limestones and the lavas (Malapais) was then divided into parallel North Northwest trending blocks and successively sank down to form the broad Verde Valley.

There are at least three of these blocks: The highest now forms the Mingus Mountain, Woodschute Mountain, and Cleopatra Mountain mass. It is bounded on the east by the Verde fault, and it contains the United Verde and Verde Central orebodies. The dip of the Verde fault is about 57° East Northeast.

The second block lies between the Verde fault and the Bessie fault, the latter showing in the United Verde Extension transportation tunnel and the ore bins at the foot of the old tramway. It contains the main ore-body of the United Verde Extension.

The third block lies underneath the Verde Valley between the Bessie fault and an unknown fault line below the valley. At Clemenceau the basal sandstone apparently lies about 1,000 feet below the Verde River.

While the first block is cut by several minor faults or branches of the main fault such as the Haynes, the Warrior, and the Dillon, it lies on the whole about 2,000 feet higher than the second block. The second block lies about 600 feet higher than the third, which
and the first block at least 1400 feet higher than the second.
has sunk down at least 1,400 feet lower, the basal sandstone at Clemenceau lying probably at an elevation of 2,300 feet.

The Verde Fault

The total dislocation along the Verde fault may be measured by assuming that the basal sandstone rested about 100 feet above the present top of Cleopatra Mountain. Now, projecting the slight dip of the basal sandstone as found in the Audrey shaft to the fault the following elevations are obtained:

	Feet
Top Cleopatra Mountain	6,052
Probable elevation of base of sandstone once resting on top of Cleopatra Mountain	6,150
Elevation of base of sandstone in Audrey shaft	4,336
Assumed elevation of same close to fault	4,530
Vertical throw 6,150-4,530	1,620

This calculation agrees quite well with the statement of Mr. Reber that the vertical throw is about 1,700 feet. Measured on the surface of the fault and parallel to the dip (the dip-slip) the movement would be about 1,900 feet, that is, the hanging wall has moved down 1,900 feet relatively to the footwall.

In a fault of this magnitude some horizontal movement has undoubtedly taken place. I understand that this horizontal component has been estimated by Mr. Fred Searles to the amount of 1,500 feet south, i.e., the hanging wall has moved southward relatively to the footwall. I believe he arrived at this conclusion by attempting to match the various areas of rocks in the hanging and in the foot walls.

While there is some regularity in the arrangement of the rocks in the United Verde Extension area the persistence of these pre-Cambrian contacts is not to be relied on. For instance, while the porphyry-greenstone contact in the United Verde Extension area trends East-West the trends in the United Verde area are strongly oblique to the fault. I consider this method unreliable.

In many places the walls of the fault show striations but in all cases I have seen these striations are vertical or quite steep apparently precluding any such large horizontal movement as Mr. Searles assumes.

The slab of ore mined in the fault zone on the 500 United Verde on the Hermit claim is pretty surely drag from the lower pyritic orebody of the United Verde

Extension. It is not drag from the main body for in that case it would have been richer. It could not possibly have been moved from the Main Top orebody for this is located on a minor hanging slip of the fault. The distance of this drag from the lower part of the sulphide body, measured along the fault plane, is 1,900 feet or practically the same as the figure arrived at before for the dip-slip. The horizontal component indicated by this drag is 300 to 400 feet, the hanging wall having moved to the south. The total slip of the fault (measured on the fault planes) is, therefore, from 1,900 to perhaps 2,000 feet, the direction inclining slightly southward. (See Plate 4.).

In a fault of this magnitude the dislocation is rarely confined to one plane. In most places in the United Verde Extension there is a minor hanging wall slip which follows some orebodies. Then about 150 feet to the west lies the main fault which usually is a greatly crushed and sheared zone from 20 to 100 feet wide. In some places there are three distinct planes within a distance of 100 feet.

Naturally the oxidation has been more energetic along the fault plane than in other places and down to the 1,400 or 1,500 foot levels the gouge is usually colored more or less deep red. Slickensides are common on the fault gouge with striations vertical or dipping slightly to the south. In places real grooves are seen - rock riffles which point in the same direction. As a rule there is no ore along the fault except where orebodies have been cut or drag carried along. There is no indication of a post-fault mineralization. Only where copper-bearing waters have been seeping along the dislocation a little malachite or chrysocolla may be seen.

The Florencia and Dillon Faults

When blocks of this size sink down aross fractures more or less perpendicular to the main faults are likely to be observed. Such a fracture is the Florencia fault, which is traceable on the surface in the malapais and limestone of the second block. The first place where it is definitely located on the surface is in Bitter Creek below Douglas house where conglomerate is faulted up against malapais. From there it continues East Northeast faulting the various limestone members about 100 feet, the downthrow being on the south side. The fault is exposed on various levels to the Northeast of the orebody, particularly on the 1,400 and 1,700 foot levels, where it has been followed for over 2,000 feet in an East Northeast direction finally turning to N. 80° E. It is a sharply defined fracture with 6 to 8 inches of red gouge. The striations dip towards the east about 55° on the fault plane. The Florencia fault is followed into the main orebody, but it is believed that it stops on the hanging wall seam when the movement becomes negligible. There is no mineralization along the fault except a little close to the orebody. It is a post-mineral fault of the same age as the main fault, and it is a coincidence that it cuts into the orebody.

The Dillon fault is a similar cross fracture well shown in the Dillon tunnel and probably also in the sag just west of Cleopatra Mountain. Here also the downthrow is on the south side, and it amounts to not more than 200 feet. The strike is East Northeast and the dip 75°S. It has been suggested that the Dillon fault is the continuation of the Florencia, but I do not believe this to be a fact. Both are cross faults and post-mineral, but this ends the relationship.

There are many other small faults at various places on the surface and underground but none of them are of much importance. Nearly all are of post-mineral and probably Tertiary age.

Geological History

In order to understand the development of the mineralization it is necessary to review briefly the geological history of the district.

The events may be divided in three sharply defined periods:

1. The pre-Cambrian period of intense igneous action, including intrusions, lava flows and volcanic tuffs in the order indicated on page 4. There was some subordinate sedimentation, resulting in cherts and shales. The last feature of this period was the intrusion of vast amounts of granite, the so-called Bradshaw granite, which occupies large areas in the southern part of the Black Hills but which is not represented in this district. The nearest granite is found on the upper Black Canyon and near the Shylock Mine, several miles away.

At this time the pre-Cambrian rocks formed mountains probably many thousands of feet in height.

Then began a long period of erosion which gradually wore down the range, by long continued erosion, to an almost level plain.

The epoch of mineralization began in later pre-Cambrian time though before the period of erosion. It is believed that it was induced by the intrusion of the vast masses of granite in the region. Hot solutions emanating from deepseated magmas found their way up along fracture zones or along chimneys formed by the intersection of fracture zones. Thus were formed the United Verde and the United Verde Extension orebodies. These deposits extended far above the erosional surface on which now the basal, brown sandstone rests, and it is likely that the upper part amounting to several thousand feet of these deposits have been removed by the pre-Cambrian erosion.

During this erosion, which was necessarily accompanied by oxidation and descending copper waters, deep chalcocite zones were formed, and they were heavily enriched by repeated oxidation and concentration. The upper 200 or 300 feet now formed a siliceous leached gossan with but little copper.

2. Now followed, beginning with the Cambrian or the early Paleozoic, a long period of sedimentation, during which the deposits were covered by several thousand feet of sandstones and limestones, deposited in the advancing sea. This period continued to the end of the

Paleozoic era and probably well into the Mesozoic. The deposits were sealed up and little or no change took place in the ore deposits.

3. The last period was one of faulting and erosion and began at the end of the Mesozoic. Following a general uplift erosion began to attack the accumulated sediments; but it took a very long time to remove the heavy masses of sediments. Towards the close of the Tertiary period, basalt flows (Malapais) were poured out over the eroded sediments. Faulting and lava flows began almost simultaneously but the faulting continued long after the lava flows had ceased.

During the early part of this succession of events the outcrops of the United Verde deposit were uncovered and the gravel, now so well shown on the 550 foot level was deposited in a stream of moderate grade. This gravel contains abundant well rounded pebbles of limestone, chert, gossan, pre-Cambrian rocks as well as a few pebbles of Malapais. The stream in this vicinity ran about parallel to the fault, and it just trenched the gossan of the United Verde Extension orebody as shown on the 800 foot level.

During this epoch much copper solution was carried down from the decomposing and eroded chalcocite zone of the United Verde. The gravels in places contain chrysocolla, malachite and azurite, and these minerals also descended on fissures into the underlying limestone. Soon the gravel was covered by repeated flows of Malapais and the faulting continued at intervals probably well into the Quarternary period.

A certain amount of oxidation with accompanying deposition of chalcocite below must have accompanied the third period, but the United Verde Extension deposit, except for a brief period, was so well sealed up that these changes probably amounted to little, compared to the main enrichment of pre-Cambrian time.

Groundwater

As well known there is very little water in the lower levels of the United Verde Mine; some oxidation and deposition of gypsum is observed along the dikes in that mine down to a depth of 2,400 feet or more. In the United Verde Extension Mine there is more water because the workings drain a large territory. Most of the water comes from the principal water horizon of the district, that is, the brown, basal sandstone of the Paleozoic series. The main fault also carries considerable water in places but there is not a very active circulation along it. When the fault was cut on the 1,800 foot level it readily drained the water standing in the two or three levels above. Occasionally water courses are cut but in most cases they seem to be pockets which soon are drained. Most of the workings are dry.

Such water as is encountered is fairly pure and contains very little, if any, copper.

General Features of Mineralization

No mineralization, except from infiltering surface waters, is found in the malapais, conglomerate, or limestone.

The mineralization of the pre-Cambrian rocks while intense in certain places is not general or widespread. Even disseminated pyrite is extremely scarce. In the extensive exploration work in the Jerome Verde Development Company no disseminated pyrite was observed outside of the few orebodies, except near Columbia shaft on the 14th level. The Deception porphyry, the greenstone series, the diorite and the quartz porphyry is as a rule barren of pyrite. On the other hand, the Cleopatra porphyry to the west of the fault generally contains some finely disseminated pyrite. This means, of course, that the country was not permeated by the mineralizing solutions except near the main channels of metallization. This points to deepseated processes and impermeable rocks.

The ore deposits close to Jerome are either fracture zones or pipe-like bodies. Of the former the "veins" in the United Verde Extension Mine, or the Verde Central are examples. They strike in a northerly or north westerly direction, dip steeply, and the mineralization consists of a replacement of the rock by quartz, pyrite, and chalcopyrite.

The pipe-like bodies are more important and have probably been caused by the converging of two or more fracture zones. The United Verde deposit is a large pipe with a diameter of 500 to 700 feet in the upper levels and plunging North Northwest at an angle of about 70°. It is contained in quartz porphyry and metamorphic sediments while its hanging is formed by a hard concave diorite contact.

On the lower levels (Plate 1) there is a tendency of the massive deposit to become elongated Northeast-Southwest, and on the 2,400 foot level the ore-bearing area is about 600 feet long in this direction. In the main it is a replacement of quartz porphyry and schist by quartz, calcite, dolomite, pyrite, chalcopyrite and sphalerite with minor quantities of galena, arsenopyrite and tetrahedrite. The ore is massive and fine-grained, averaging well over 4 per cent.

The United Verde Extension deposit is a similar pipe here more distinctly caused by the converging of two fracture zones. In its upper part it is nearly vertical, or dipping steeply eastward. On many levels it is irregular with rounded projections into the surrounding rocks. Seen in cross section (Sections 2 and 8) it has a somewhat canoe-shaped form tapering below to a keel. From the 1,400 foot level down it acquires a decided plunge in a northerly direction and the outlines of the sulphides become irregular. At present the lowest point on which it has been developed is the 1,900 foot level.

The upper four hundred feet of the deposit contains siliceous leached material or gossan with some residual ore. The chalcocite ore occupies the levels from 1,250 to 1,500. Below the 1,500 foot level the deposit contains mostly massive, poor, pyritic sulphide. The area occupied by the deposit varies from 100 by 100 to 300 by 300 feet; on the 1,700 foot level it is 100 by 100 feet. On the 1,800 and 1,900 foot levels it is not fully developed. The gossan is poor with a few residual orebodies. The chalcocite zone from the 1,250 to the 1,400 foot level is rich with ore running up to 40 per cent copper, but becoming poorer and more pyritic on the 1,500 and 1,600 foot levels. The sulphides on the three lowest levels are mainly pyrite with less than 1 per cent copper. There is thus a considerable similarity in origin and structure of the United Verde and the United Verde Extension orebodies, though the latter is considerably smaller.

The United Verde Extension Orebody in More Detail

The United Verde Extension orebody does not outcrop at the surface. It is located in the second block, which is slightly tilted to the east, and it is covered by 500 to 800 feet of limestone, conglomerate, and malapais as shown in the eight sections accompanying this report. For a very brief interval, while the stream bed now filled with conglomerate was being excavated a part of the croppings were exposed to the surface but was soon sealed again and covered by conglomerate and malapais.

At the Edith shaft basal brown sandstone lies 574 feet below the surface on the 800 foot level; the 800 foot level shows in some places the conglomerate overlying the pre-Cambrian rocks; the 550 foot level shows only sandstone, limestone and conglomerate.

As a whole the orebody forms a compact mass of irregular outline but with a tendency to extend East Southeast or Southeast. It has a distinct, though steep dip to the Northeast. Aside from some residual ore the distance between the 800 and the 1,250 foot levels contains only siliceous gossan making rather sharp contacts with the kaolinized country rock. Chalcocite ore, more or less pyritic occupies the space between the 1,250 and the 1,600 foot levels; on the 1,500 and 1,600 foot levels the ore is poorer and tends to form a canoe-shaped keel extending for 300 or 400 feet Northwest.

From the main orebody extend two fractured and schistose veins, irregular in strike and mineralization; the converging of these veins has evidently caused the favorable locus for deposition. One of these, striking N. 50° W. may be termed the Maintop vein; the other, striking N. 20° W. may be called the Gold Stope vein. During the early exploration work these veins were the "leaders" which eventually led to the discovery of the main mass.

Speaking broadly, the orebody lies between quartz porphyry on the south and diorite on the north. Most of the deposit is contained in quartz porphyry but some of the lower poor sulphide bodies enter into the diorite.

The veins are contained in the greenstone series and in special belts of schistose greenstone, and they show a tendency to wrap around and follow the outlines of the main northern diorite area. Nevertheless they enter in part into the diorite and therefore this diorite is earlier than the mineralization.

The orebodies are shown in horizontal projection on Pl. 5, and in vertical projection on Pls. 6-14.

The Main Top Vein

The relations of the Main Top vein to the main body are well shown on the 800 foot level. From the main mass of gossan, that is quartz, brecciated and stained with limonite, a branch extends out Northwest for several hundred feet, containing several masses of rich residual chalcocite ore. After an interval of several hundred feet more the Main Top vein has again been intersected by drifts from the Little Daisy shaft. Here it is small and barren and is followed more or less closely by the subordinate hanging wall fault which lies about 100 feet or more to the east of the main fault.

On the 950 foot level the continuation of the Main Top vein is clearly shown; it follows a schist belt and dips about 60°N.E. The Main Top stopes below is indicated by a 100 foot long quartz lens containing $3 to $0.15 oz
$4 in gold and silver.

On the lower levels the interval between the Main Top stope and the main orebody has not been fully explored but the Main Top stope extends for 50 feet above the 1,100 foot level down to the 1,300, and is about 150 feet long and several sets wide. The ore is rich, very rich in part, and is partly oxidized chalcocite with some pyrite. This stope is cut by the boundary line of the Jerome Verde Company and was partly mined by that Company.

The exploration on the lower levels, 1,300, 1,400 and 1,500 shows plainly the projection of the Main Top vein from the main orebody to a distance of several hundred feet. Some of these orebodies are low grade and pyritic but in other places a strong enrichment has taken place.

On the 1,400 and the 1,700 foot levels the work has been carried out 2,400 feet or more from the main body along the Main Top vein but without successful results. The zone of schistosity continues but there is little quartz and no ore.

On the whole the Main Top vein is very poor, the mineralization localized and I consider that the prospects of finding new orebodies below the 1,300 foot level, except near the main body, are poor. Anyway, such bodies would surely be pyritic, of low grade, and small extent.

The Gold Stope Vein

The Gold Stope vein is clearly shown on the 800 foot level projecting from the main orebody a distance of 1,500 feet North Northwest. It is indicated by schist, jaspery quartz, and gossan. No orebodies occur though to the west and southwest of the Edith shaft there is some indication of mineralization. The vein ranges up to 50 feet wide. It occurs in greenstone schist. Seven Hundred feet North Northwest of Edith shaft is a winze with copper stains and there is also some disseminated mineralization of oxidized copper ores in the vicinity. The outlook for finding bodies of value is small. At the Morgan winze sunk to the 1,100 foot level there is some mineralization with quartz and native copper but the outlook in this vicinity also is poor. This is probably a branch of the Gold Stope vein.

On the 950 and 1,100 foot levels the vein is very clearly indicated. It dips steeply to the east and follows a belt of schist. Gossan and quartz are present all along from near the main orebody to a point Southwest of the Edith shaft. From then on North Northwest the explorations have been continued in Jerome Verde ground for 700 feet but without results except some schist, occasional quartz streaks and copper stains.

On the 950 foot level, for 250 feet south from a point 400 feet Southwest of the Edith shaft, extend the gold stopes. These continue for several sets above the 950 and about half ways down to the 1,100. They are three sets wide or in places 20 feet and contain sugary crushed quartz without much limonite. The ore yields from $3 to $10 in gold and 0 to 4 ounces of silver. There are no copper stains. Evidently this is a thoroughly leached and crushed gossan in which secondary enrichment of gold has taken place. On the 1,100 foot level the same vein shows with little or no ore and little gold. The vein here distinctly joins the main orebody.

0.145 to 0.48oz

On the 1,300 foot level the vein turns to a steep westerly dip and breaks across the diorite to join orebodies projecting from the main body between the two veins. The vein is narrow and contains chalcocite and oxidized ore. On this level the vein extends for about 500 feet north of the main orebody.

The Gold Stope vein does not continue on the lower levels though the belt of schist which it follows

how know?

in the upper levels still persists downward. (See Section 3).

Smaller Orebodies above the 1,250 Level

The main chalcocite body below the gossan begins quite sharply at the 1,250 sub-level. Among the smaller residual orebodies above that level those belonging to the Main Top and the Gold Stope veins have already found mention. The most important among these residual bodies is the rich mass containing two hundred thousand tons, which begins 50 feet above the 800 foot level and extends somewhat below the 950 foot level. It lies at the contact of the gossan and quartz porphyry, is at most 200 feet long and contains very rich chalcocite ore, in part oxidized. In part it is bounded by the hanging wall slip. Several other bodies not yet fully developed are found on the 800 foot level a few hundred feet to the Northwest of the main orebody. Another body of rich oxidized drag ore lies above the main orebody from the 1,100 to the 1,300 foot levels. It lies along the main fault and runs up to a point about the 1,100 foot level. There are possibilities of more of these smaller orebodies being found on the 800 and 950 foot levels, both to the Northwest and Southwest of the main body.

The Main Body

The general outline of the main body has already been described. In the upper levels it consists mainly of an iron-stained cherty quartz or jasper, sometimes brecciated. The brecciation is probably caused by the collapse owing to the leaching of pyrite and chalcocite. The outlines of this body are generally sharp and well marked. Sometimes a little disseminated pyrite is seen in the adjacent, more or less kaolinized rock. Near the 1,250 level pyrite becomes more abundant in the lean and quartzy rock and some copper is found as chalcocite. The main body of the chalcocite ore begins sharply at the 1,250 foot level and its top is almost horizontal (see sections). The richest ore was found on the 1,300 and 1,400 foot levels. All of the ore contains fine-grained pyrite except that which has become wholly oxidized, usually in the outskirts of the orebody. The pyrite is mostly arranged in narrow lines or bands which indicate replacement along sheared or schistose structures. Oxidized chalcocite ore is found in places from the 800 foot level down but on the whole there is little in the ore except quartz, pyrite and chalcocite. The chalcocite is fine-grained and has dull metallic lustre. Little of it is real sooty chalcocite. Towards the bottom or keel of the orebody on the 1,500 foot level the easterly half of the elongated orebody is low grade, say 5 to 6 per cent copper while the westerly part is high grade. On the 1,600 foot level the body is smaller, say 200 feet long and 50 feet wide and generally highly pyritic and in part of too low grade to be stoped, say containing less than 3 per cent copper. The surrounding rocks, mainly quartz porphyry are more or less schistose and bleached. The drift run below the orebody on the 1,700 foot level shows mainly white, soft quartz porphyry and no ore except some seams of chalcocite in 1,720 drift.

The Ore

This large and compact body of chalcocite ore contained in all about 2,000,000 tons of high grade ore averaging from 10 per cent to 20 per cent copper. Practically all of the ore contains much residual pyrite, quartz, and secondary chalcocite. The chalcocite replaces pyrite, quartz, and another mineral which was chalcopyrite or zincblende. I am sure, however, that there was never any great amount of chalcopyrite in the ore. It was probably low grade, say with 1 per cent to 3 per cent chalcopyrite. It must be remembered, however, that the deposit originally extended far up above the pre-Cambrian surface and that the deposition by ascending copper waters occurred during the long time when the upper part was removed by erosion and copper sulphate steadily descended. The present chalcocite zone is, therefore, the product of a very long concentration. The earlier and poorer chalcocite zone was subjected to oxidation and re-deposition and advanced in depth gradually becoming greatly enriched. It is, of course, possible that the upper, now eroded part of the deposit was richer in copper than the lower part.

The chalcocite ore is low in silver, lower than the ore of the United Verde but for a few feet above the top of the chalcocite zone there is a silver enrichment when the ore contains from 10 to 20 ounces of silver.

There is also a distinct tendency to enrichment in gold in the siliceous masses above the ore. The "Gold Stopes" mentioned above are examples of this and elsewhere it is not uncommon to find siliceous gossan with from $1 to $3 in gold per ton. 0.05 to 0.145 oz/ton

The Pyritic Bodies of Lower Levels

On the 1,500 foot level 150 feet Northwest of the main body there begins an irregular area of low grade sulphide which lies between quartz porphyry on the south and diorite on the north. On the 1,600 foot level the same body lies up against the main fault and has in part been cut off by it. It is an irregular area from 100 to 200 feet in diameter and connects with the area on the upper level, the mass plunging steeply to the North.

The same body has been exposed on the 1,700 foot level and is here a rounded mass with a diameter of about 100 feet. On this level it does not quite reach the fault. It is also in part developed on the 1,800 foot level but has not yet been opened on the 1,900.

Though this body does not quite connect with the upper orebody yet it can not be doubted that it belongs to the same deposit, and that it forms part of the vent through which the mineralizing solutions ascended.

The pyritic body thus plunges to the north, and it dips steeply to the east so that it has not yet been cut off by the fault except in part. From present indications it may continue in the hanging of the fault for some distance below the 1,900.

It lies in greatly crushed chloritic schist which in part strikes Northeast while the normal strike should be Northwest on the outskirts of the ore and in it also is much fine-grained siliceous rock; evidently the whole body is a schist replacement. In large part, however, it is poor in silica and carries a carbonate gangue. It is fine-grained often with parallel streaks of pyrite. Along with the pyrite is a little chalcopyrite, though rarely reaching 1 per cent copper. There is also several percent of zincblende and occasionally a little galena. This low grade ore is the primary ore of the deposit; it is in structure and composition entirely similar to the low grade pyrite of the United Verde deposit. At the latter mine, it should be remembered, it is not at all uncommon to find the gangue made up almost entirely of calcite and dolomite.

While only small parts of this body now constitute ore it is quite possible that it may contain more chalcopyrite in depth, and it should be followed by a winze below the 1,900 foot level when the outline of the ore on that level has been determined.

Conclusion as to the United Verde Extension Deposit

The United Verde Extension deposit forms a pipe of sulphide ore, which is entirely similar in geological situation, composition and structure to the United Verde deposit, though it is much smaller and poorer. It has received an extraordinary strong chalcocite enrichment between the 1,250 and the 1,600 foot levels. The siliceous capping from the 800 to the 1,250 foot levels indicates the leached part of the chalcocite zone. No enriched ore may be expected below the 1,500 or 1,600 foot levels. It is possible that in depth the pipe may contain bodies with enough chalcopyrite to make the ore payable but on the whole I consider this rather unlikely.

Exploration Work

A great deal of exploratory work has been carried on by the United Verde Extension, consisting in drifts, crosscuts, and diamond drilling. This work has been concentrated on the 800, 1,200, 1,400, and 1,700 foot levels. In large part this work has been done on the property of the Jerome Verde Development Company to the north and east. Other objectives have been to develop the veins or fracture zones like the Main Top and the Gold Stope veins, and finally to explore the main fault in order to find the location of possibly faulted portions of the United Verde Extension orebody. With the exploratory work should also be classed the Bitter Creek tunnel driven to the fault from the surface and the No.7 tunnel driven north along the fault from Deception Gulch near where it is crossed by the main road from Jerome to Clarksdale.

These extensive workings have enabled me to draw certain conclusions which will now be presented:

1. Exploration of Jerome Verde ground Northwest of Main Top orebody. These explorations on the 800, 950, 1,100, 1,200, 1,400, and 1,700 foot levels have been generally unsuccessful, and I recommend no more work in that direction. No chalcocite ore would hardly be expected below the 1,400. The mineralization is weak, spotted, and irregular.

2. Exploration of Jerome Verde ground north and northeast of the Edith shaft. These explorations, mainly on the 1,400 foot level have disclosed no indications of mineralization and should be discontinued.

3. Exploration of United Verde Extension and Jerome Verde ground east of the Edith shaft. This development work has been carried out over 2,000 feet to the east on the 1,400 and 1,700 foot levels along the Florencia fault and in the vicinity of the Columbia shaft of the Jerome Verde Company. They have disclosed no promising indication except a very slight pyritic dissemination near Columbia shaft and should also be discontinued. I consider it useless to drift further along the Florencia fault on the 1,400 and 1,700 foot levels. The fault is entirely of post-mineral age and would not be likely to lead to any orebodies. I class under the same heading the suggested drift along the Bessie fault from the Transportation tunnel (on the 1,300 foot level) to the vicinity of the old ore bins at the foot of the abandoned tramway. The Bessie fault also is post-mineral and is not likely to lead to any orebody. The whole distance exposed by the Transportation tunnel shows no indications of mineralization towards the east. It is true that it is impossible to predict what lies below an area covered by later formations. But when fairly extensive development work has shown an absence of all mineralization of any importance it would seem to be the part of wisdom to quit.

4. Explorations to the Southwest in United Verde Extension Ground. Drifting and diamond drilling has been carried on in this direction on the 800 and 1,200 foot levels and also from the No.7 tunnel. The work has intersected the fault and penetrated far into the quartz porphyry and the Deception porphyry on the west side of the fault. Nothing of importance has been found and there seems to be no reason for continuing in this direction. As the fault is post-mineral it would have no relations to ore deposit, except by chance. As the movement along the fault would have carried smaller faulted fragments of the orebodies up to the northwest there would be scarcely any such fragments along it to the south.

5. Explorations along the Main Fault Northwest of the Orebody. These explorations have for purpose the finding of faulted portions of the orebody. It should be remembered that only relatively small portions of the ore has been cut by the fault. The extent to which the main chalcocite body has been cut is indicated on Plate 3. The faulted part has not yet been found. Above the faulted part is drag which extends in a steeply dipping direction to the 1,100 foot level. The position of the drag confirms the view already expressed that the movement of the fault has been mainly vertical, dipping steeply to the southeast. Likewise the sulphide body on the 1,600 foot level has been cut by the fault, and it is believed that the slab ore mined from the 500 foot level United Verde is this fragment of pyritic ore which has been in part enriched

since the faulting owing to its exposed condition comparatively near the surface. This ore it is said averaged 10 per cent copper. The lower part that I saw was mainly pyritic and seemed to contain about 5 per cent copper.

It is possible, however, though not probable, that this faulted slab may represent a part of the main orebody. At any rate the distance from the source is just about 1,900 feet which is the amount considered to be the total slip along the fault plane. In the vicinity of this slab the up-faulted conglomerate is also considerably permeated by oxidized copper minerals and forms low grade ore in part. Evidently, the horizontal distance between Sections 2 and 5 from the main orebodies up to the body on the 500 foot level United Verde is possible ore ground, though no large bodies need to be expected.

The explorations in United Verde Extension ground comprise the Bitter Creek tunnel; this should be extended Northwest along the fault with crosscuts to the fault at intervals. There will probably be no great amount of backs above this tunnel in United Verde Extension ground.

Further explorations are confined to the vertical distance between the 1,000 foot level United Verde (Elev. 4,525) and the 1,500 foot level United Verde Extension (Elev. 3,609) on the 800, 950, 1,100, 1,200, 1,300, and 1,400 foot levels. In all cases these explorations are most detailed about 2,000 or 2,500 feet to the Northwest of the main orebody; this is in my opinion too far to the Northwest as the total horizontal throw of the fault was probably not more than 500 feet. On the 1,400 and the 1,700 foot levels the fault has been most carefully prospected to the Northwest; in both cases without success. On the 1,700 the fault has been crossed and some explorations undertaken in the porphyry of the footwall. The United Verde Company are now drilling north in that vicinity. I consider the probabilities of finding ore here are extremely slim.

On the whole I doubt whether any ore along the fault, if found, will pay for the great amount of explorations undertaken.

6. Explorations immediately Northwest of Orebody. Generally speaking the development work in this direction has not been sufficient. It is true that there is here an area of diorite between the Main Top orebody and the main orebody while diorite is not exactly the most favorable country rock yet there may be ore in it along belts of schist, along the hanging wall seam and along the main fault. Exploratory work is, therefore, urged between the main orebody and the Main Top orebody on the 800, 950, 1,100, 1,200, 1,300, and 1,400 foot levels.

7. Explorations to the Southeast of the main orebody across Florencia claim. For well known reasons ? little or no development work has been undertaken in the Florencia claim. Considering that the main orebody is formed by the intersections of two zones of shearing and fracturing extending Northwest and North Northwest it seems most probable that their continuation with possible orebodies would be found in the Florencia claim. For this

reason I advocate careful exploration of this part of the property, across and beyond the Florencia claim with dirfts in a Southeast direction from the main orebody and frequent crosscuts from these drifts. Work of this kind is suggested on the following levels: 903 (Slab level), 950, 1,100, 1,200, 1,300, and 1,400. While it is possible that some part of the orebody has dropped on the south side of the Florencia I hardly expect to find any ore in the Florencia on or below the 1,500 foot level.

The principal country rock would be quartz porphyry and I expect rather several smaller orebodies in the Florencia than any new large mass but the claim deserves quite careful exploration. Such work as has been done already looks promising.

8. The Lower Sulphide Bodies. I have already stated my belief that, after the low grade sulphide has been explored on the 1,900 foot level, a winze should be sunk to a depth of 200 or 300 feet in this body, the winze to have an inclination northward parallel to the plunge of the pyrite.

The Haynes Group.

Location and Geology

The Haynes Group forms an area of fifteen claims elongated north-south and adjoining the United Verde Mining Company on the west. Almost the whole of this area is covered by the limestones to the west of the fault, and it is of course entirely problematical whether any ore deposits are contained in the underlying pre-Cambrian rocks.

A few hundred feet south of the area the Verde Grande shaft has been sunk to a depth of 800 feet, just below the brown basal sandstone. Nothing of value is reported except a little pyrite and chalcopyrite on or near a contact. Near Haynes shaft there is an area of pre-Cambrian rocks: Greenstones, quartz porphyries and sedimentary metamorphic rocks, and these extend up into the gulch adjoining the shaft to the south. In this gulch about 200 feet above the shaft a 300 foot long tunnel has been driven in a westerly direction in metamorphic rocks, but no mineralization is disclosed. At the end of the tunnel is an east dipping slip, striking northerly and evidently a post mineral dislocation.

The Haynes shaft, at the base ball grounds, has a collar elevation of 5,416 feet and is located in the Southeast corner of the Contention claim just below the brown basal sandstone. It is 1,200 feet deep, vertical with several hundred feet of drifts on the 700 and 1,200 foot levels. Nothing of value has been disclosed; no mineralization shows on the dump and the shaft is inaccessible.

Close by the shaft courses a compound dislocation, called the Haynes' fault, the north side of which has been thrown down, not more than 300 feet. It probably dips 70° North and will probably intersect the United Verde orebody on or about the 3,000 foot level, though there is a possibility that, becoming flatter in depth it may parallel the hanging of this orebody.

Apex Rights in the Haynes Group

There is evidently no present value in the exposures so far made but the question of apex rights with reference to the United Verde orebody should be considered. It will be seen from Plate 1 that the 2,400 foot level of the United Verde lies about 500 feet Southeast of Haynes shaft and the 3,000 foot level would probably be 400 feet from the same point. The orebody has here a more elongated form and it enters in fact for some distance in the Warrior claim on the 2,400 foot level. About the 4,000 or 4,500 foot level if the orebody maintains its attitude it may enter the Southeast part of the Contention claim. If the tendency to elongation East-West continues it may even enter the Contention claim at a higher level than that just indicated.

The outcrops of the United Verde orebody lie on the Eureka and Chrome Southwestern claims, and I believe that a lode line or apex may be established across the side lines of these claims. The apex law would then consider the side lines to be end lines and the side lines would govern the extralateral sweep.

It will be seen from Plate 1 that this sweep would be entirely in the United Verde property, and that it could not possibly cover any part of the Haynes group.

On the other hand, as far as now known, there are no apex rights in the Haynes group, and I conclude from this that the common law of surface properties would govern.

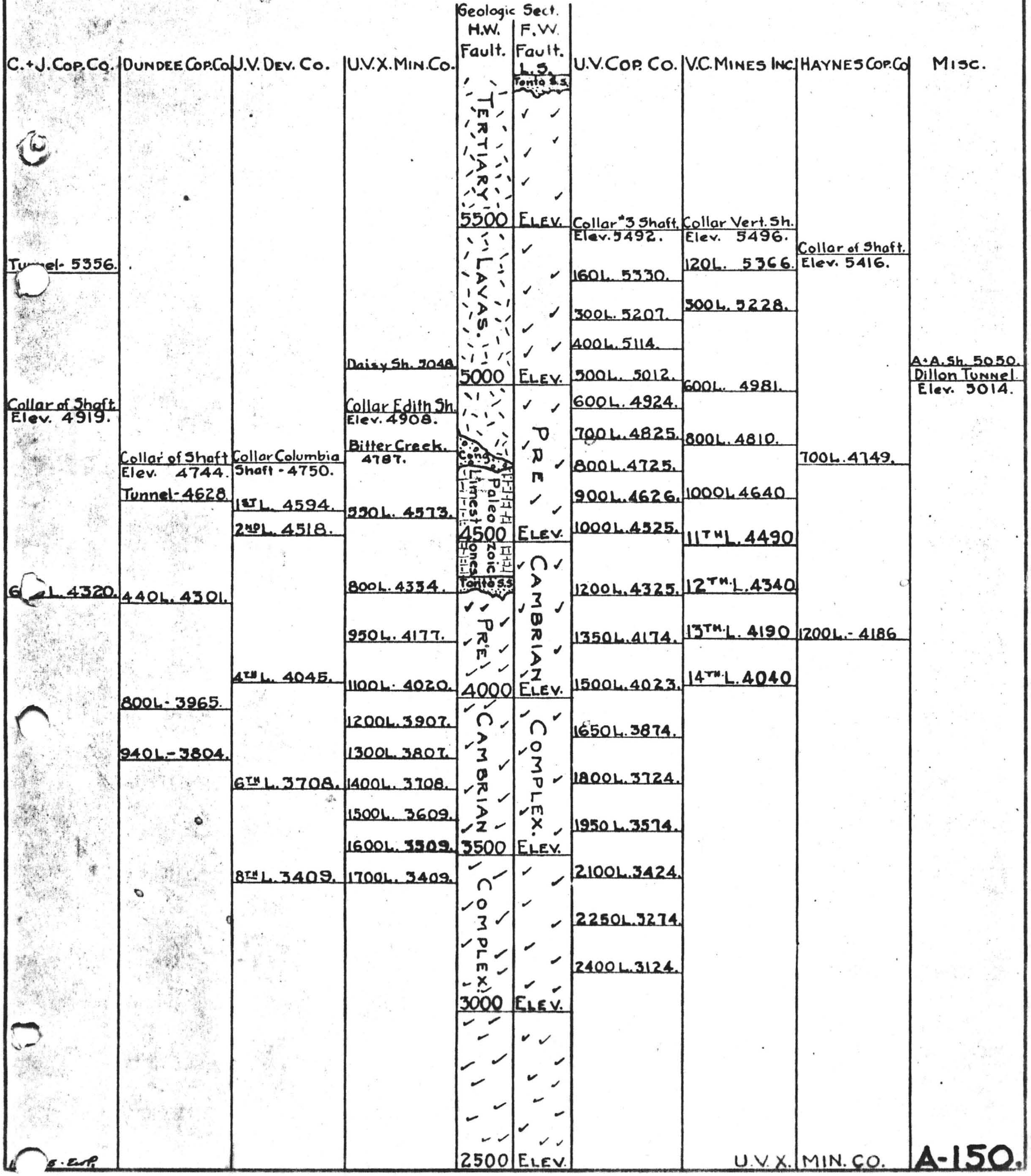
In other words, the boundary planes would be vertical and the United Verde have no rights if any of their orebodies should cross these vertical planes into the Haynes group.

Respectfully submitted,

Waldemar Lindgren

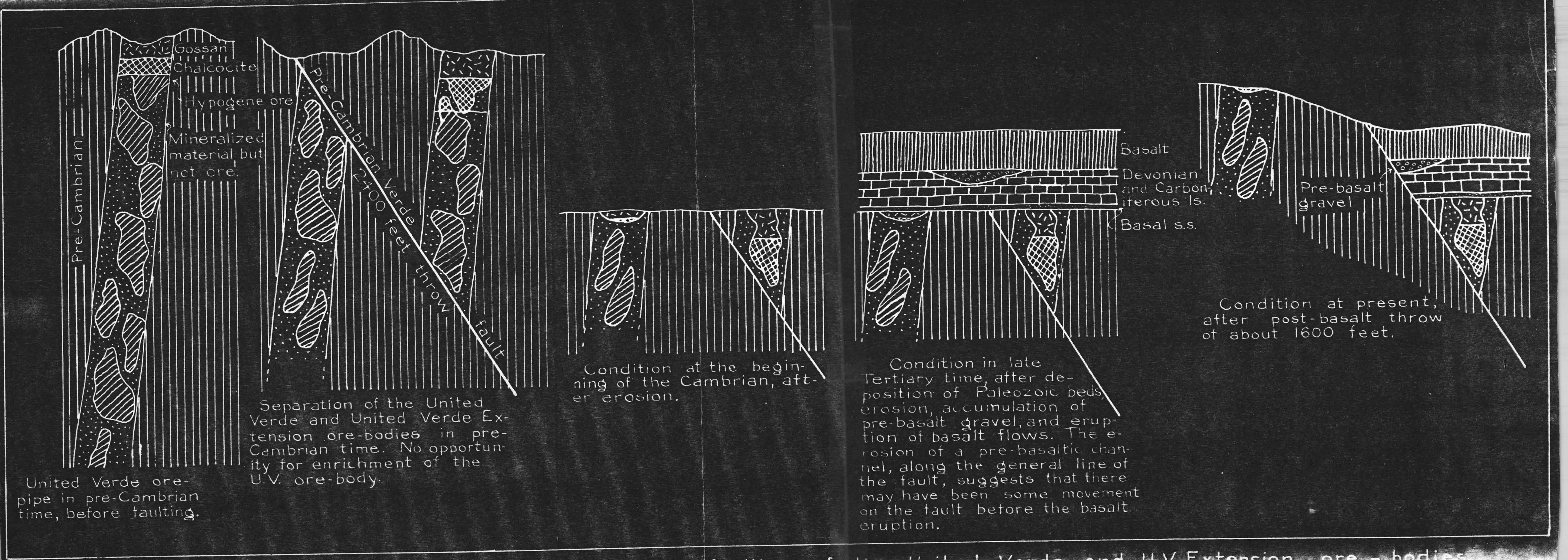
Cambridge, Mass.,
August 10, 1926.

ELEVATIONS OF MINE WORKINGS
JEROME DISTRICT.



U.V.X. MIN. CO. A-150.

Figure 3.



Diagrammatic representation of probable stages in the faulting of the United Verde and U.V. Extension ore-bodies

Scale about 1 inch=1000 feet

I. C. 6250

February, 1930

Department of Commerce

UNITED STATES BUREAU OF MINES
Scott Turner, Director

INFORMATION CIRCULAR

MINING PRACTICE AND METHODS AT THE UNITED VERDE EXTENSION MINING COMPANY, JEROME, ARIZ.

BY

Richard L. D'Arcy

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February, 1930.

INFORMATION CIRCULAR

DEPARTMENT OF COMMERCE - BUREAU OF MINES

MINING PRACTICE AND METHODS AT THE UNITED VERDE EXTENSION MINING COMPANY, JEROME, ARIZ.[1]

By Richard L. D'Arcy[2]

INTRODUCTION

This paper describing the mining practice and methods at the United Verde Extension mine, Jerome, Ariz., is one of a series of papers in preparation by the Bureau of Mines presenting the mining methods used in various mining districts of the United States.

The United Verde Extension mine is a massive, high-grade deposit of copper sulphide containing some gold and silver and is mined almost exclusively by the conventional square-set method with some local modifications.

About 450 men are employed underground and 1200 tons of direct smelting ore is produced per day. Figure 1 is a surface map of the Jerome district.

ACKNOWLEDGMENTS

The author acknowledges the assistance of Olaf Hondrum, chief engineer, and Roy H. Marks, efficiency engineer, United Verde Extension Mining Co., and also that of E. D. Gardner, supervising engineer, and C. H. Johnson, assistant mining engineer, U. S. Bureau of Mines, Tucson, Ariz.

HISTORY OF DISTRICT

The development of the Jerome mining district as an important source of copper, gold, and silver dates from the development of the mine of the United Verde Copper Co. This mine was located in 1876 and worked in a small way at shallow depth for its gold-silver values until purchased in 1889 by Senator W. A. Clark of Montana. Production from this mine increased steadily, especially after 1894, when the narrow-gauge railroad from Jerome Junction was built. From 1900 to 1918, inclusive, the mine produced slightly over 7 million

1 - The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6250."
2 - One of the consulting engineers, U. S. Bureau of Mines, General Superintendent, United Verde Extension Mining Co.

tons of ore containing 750,000,000 pounds of copper, 12,374,000 ounces of silver, and 403,000 ounces of gold. Recovery per ton for this period was about 100 pounds of copper, 1.75 ounces of silver, and 0.057 ounces of gold. From 1918 to date the United Verde has been one of the most important mines in Arizona, and the total metal value of its product probably has been greater than that of any other mine in the State.

The success of this mine encouraged capitalists to attempt to find other important ore bodies in the district; this led to the development of the United Verde Extension, the second large mine of the district.

The United Verde Extension mine was brought to successful production through the efforts of James S. Douglas and associates, who assumed the financing of the property from the time when it was a small prospect. Their efforts were rewarded in December, 1914, by the discovery of a small high-grade vein of chalcocite. Finally in January, 1916, a big lens of high-grade chalcocite was opened up on the 1400 level. This lens, when fully outlined on this level, proved to be oval, with a maximum length of 500 feet and a maximum width of 300 feet. Virtually all of the lens was clean, high-grade ore. From then on the mine rapidly became an important producer.

Production started in 1915 and has been maintained ever since. From 1915 to 1928, inclusive, the mine produced slightly over 2,000,000 tons of ore containing approximately 535,000,000 pounds of copper, 4,100,000 ounces of silver, and 76,000 ounces of gold, with a gross metal value of approximately $98,000,000.

GEOLOGY

The geology of the Jerome district has been described in detail by L. E. Reber, jr.[3] The Verde fault is perhaps the most striking structural feature of the district. This fault strikes about N. 40° W. and can be traced on the surface for miles. The dip is about 59° to the northeast. It is a normal fault, and has a known vertical downthrow of approximately 1,600 feet.

The United Verde mine is immediately west of the fault; that is to say, it is located in the footwall, while the United Verde Extension mine is close to the fault in the hanging wall.

The fault is directly responsible for the discovery of the United Verde mine. It cut through the mineralized zone, dropping the section to the east 1,600 feet, as has been stated, leaving the greater portion of the zone in the footwall but exposing it in the newly-formed hillside.

The geologic section (fig. 2) at right angles to the fault shows the sequence of the geological formations. The United Verde Extension shafts go through lava, conglomerate,

3 - Reber, L.E., Jr., Geology and Ore Deposits of the Jerome District: Min. and Met., May, 1920.

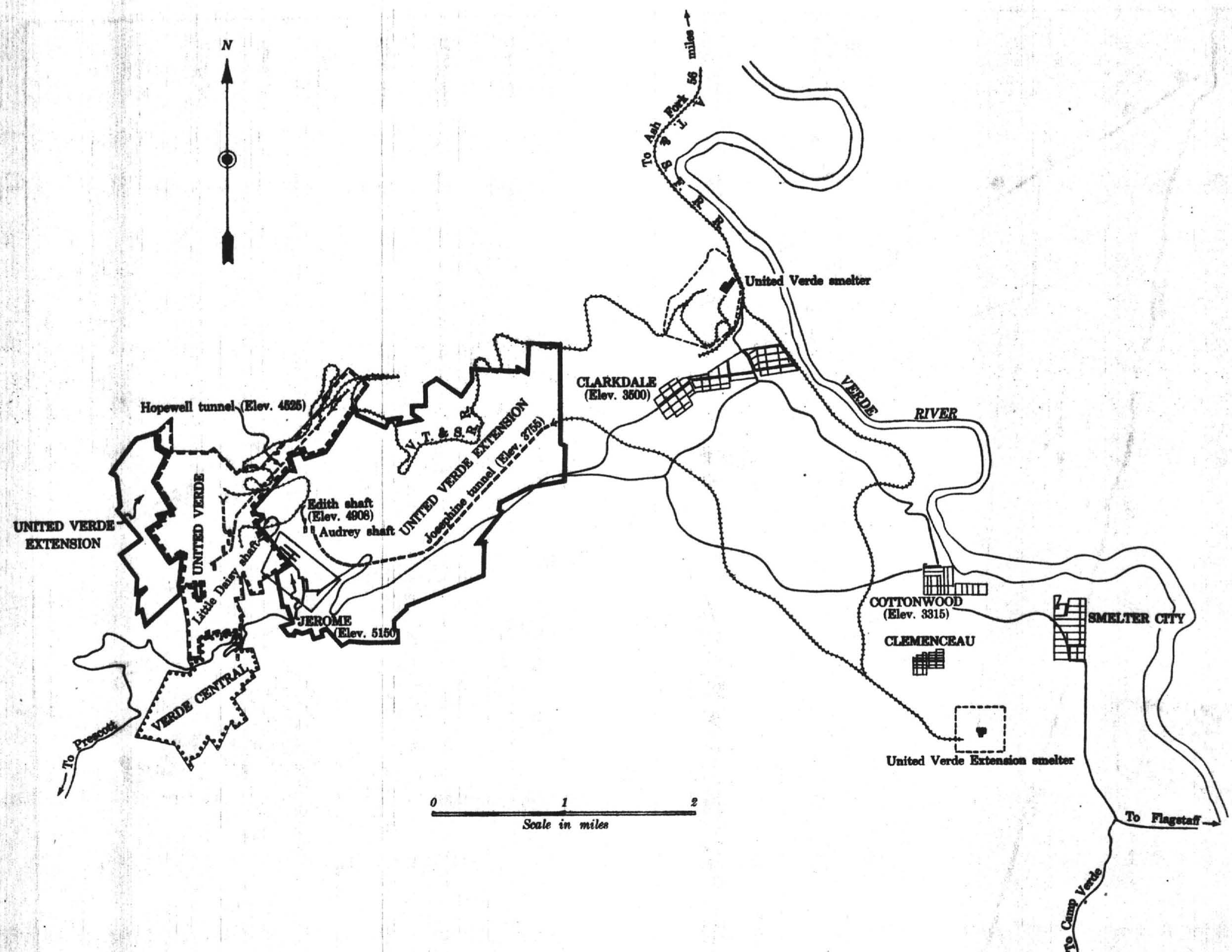


Figure 1. - Map of Jerome district

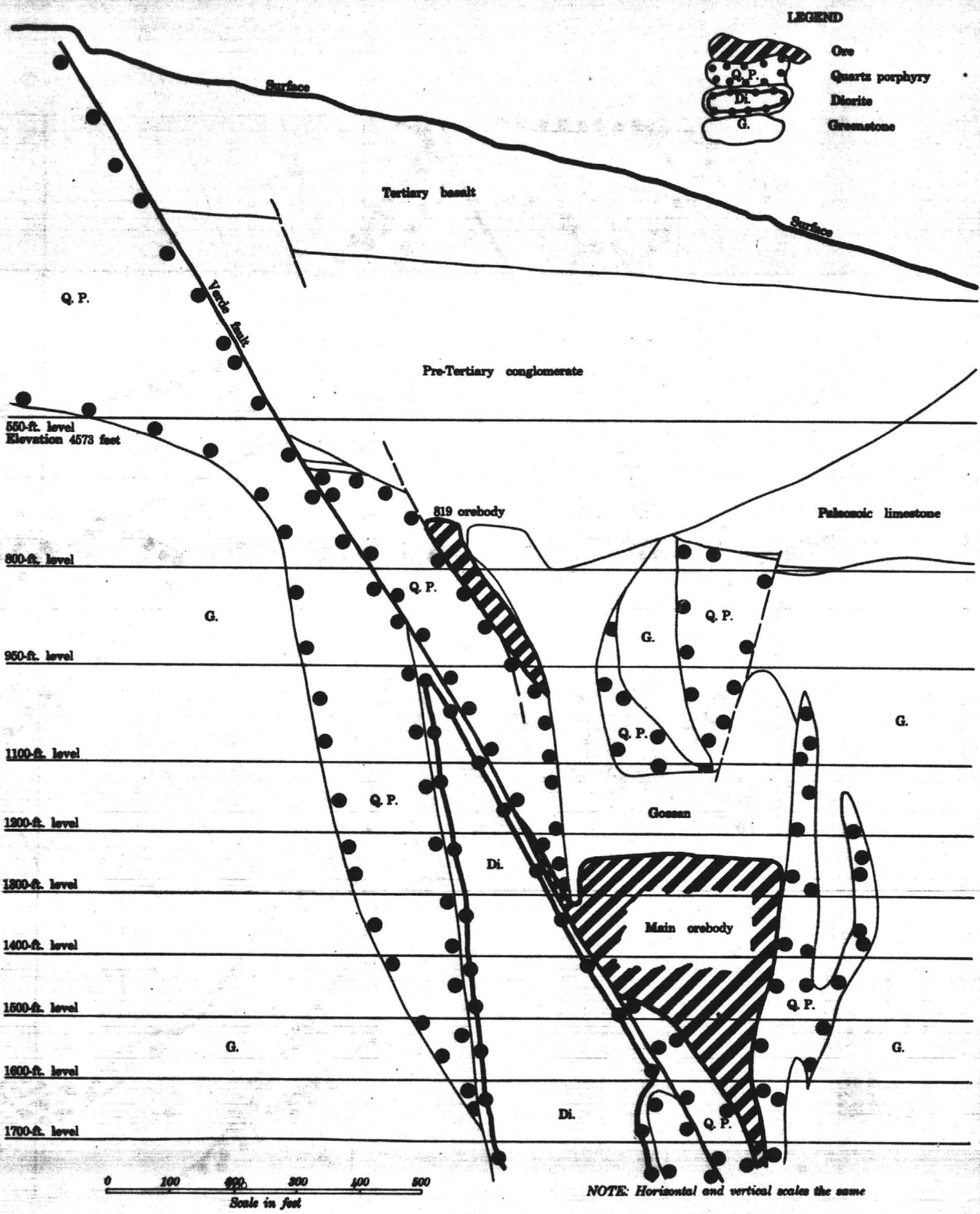


Figure 2. – Vertical geologic section (N. 45° E.) through main orebody

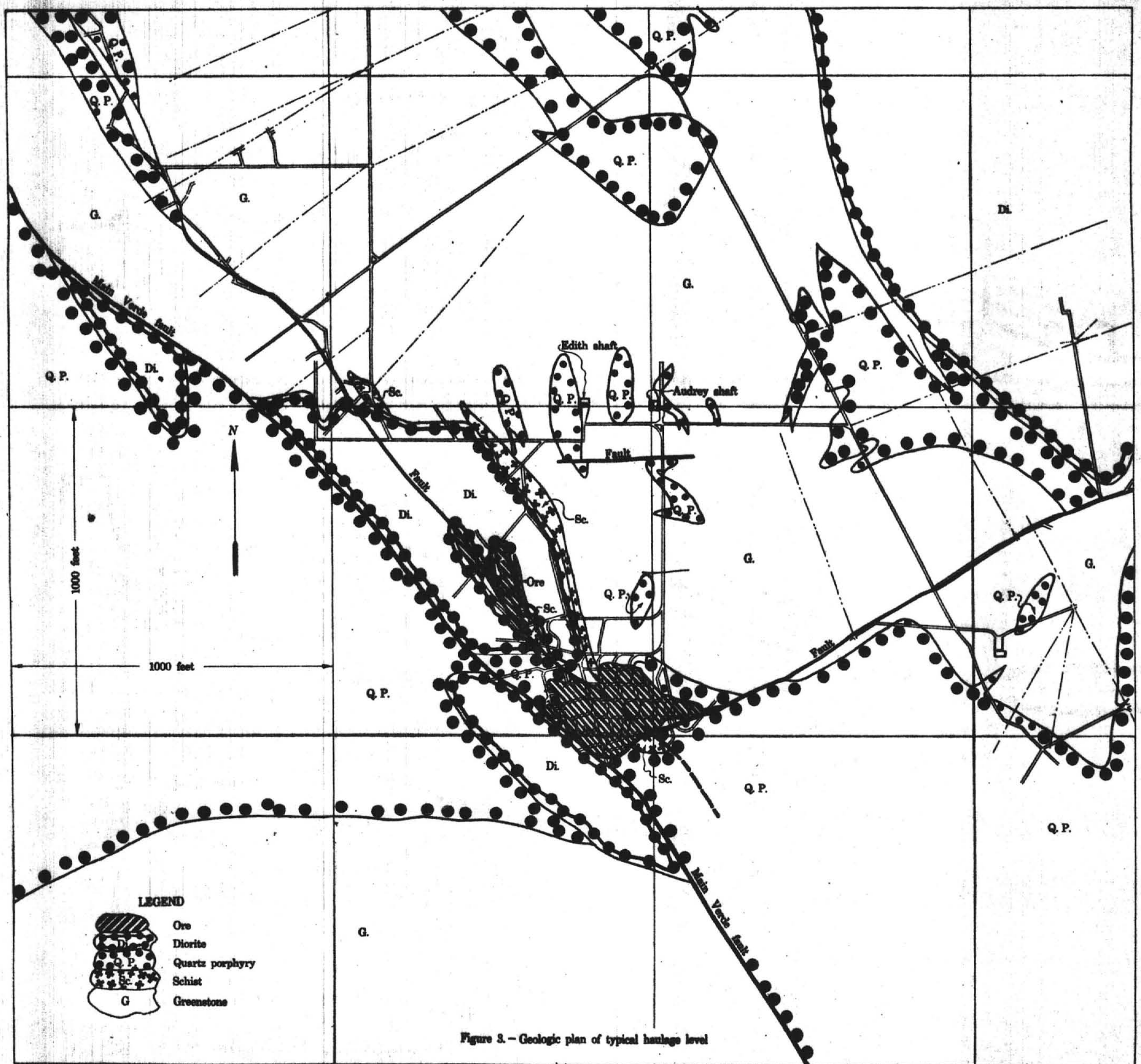


Figure 3. – Geologic plan of typical haulage level

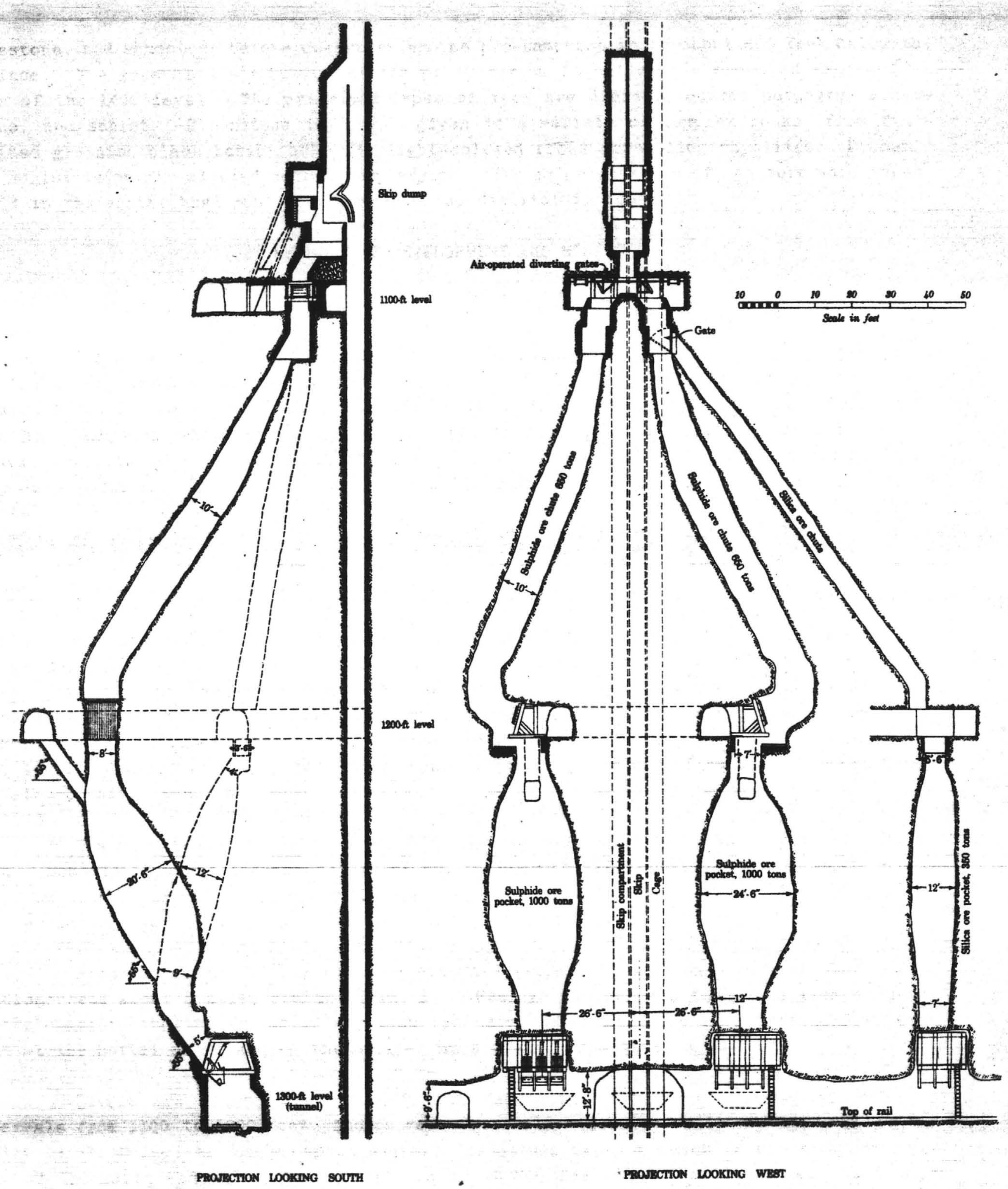


Figure 4.– Loading pockets at Audrey shaft

limestone, and sandstone before encountering the pre-Cambrian rocks about 600 feet below the surface. The general distribution of the pre-Cambrian formations is shown in Figure 3, a plan of the 1400 level. The principal types of rock are diorite, quartz porphyry, greenstone, and schist. Greenstone is a name given to a variety of complex rocks, from fine-grained greenish black basic rocks, to light-colored rocks resembling rhyolites. Probably the schist is mainly altered quartz porphyry and altered greenstones of the more acid types. It is in the schist that most of the ore in the district is found.

METHODS OF DEVELOPMENT AND MINING

Development

The mine is operated through two vertical 3-compartment shafts and a large cross-section haulage adit connecting both shafts on the 1300 level. Both shafts are of concrete, located about 200 feet apart and 1,000 feet north of the main ore-bearing zone. This location has been very satisfactory because the shafts have been in firm rock from collar to bottom; conditions have been ideal for the rather elaborate system of ore and waste pockets, skip-dump pockets, transfer raises, and tunnel-loading pockets immediately adjoining the shafts.

The layout of ore pockets at the Audrey shaft is shown in Figure 4. Ore from below the tunnel level is hoisted in 3-ton skips running in counterbalance to a point above the 1100 level; the skip is dumped by movable guides which show red lights in front of the hoisting engineer when in dumping position and green lights when the shaft is clear. The ore passes from the dumping point to an air-operated deflecting door on the 1100 level, which turns the ore one way or the other as desired. Three converging pockets meet just below this deflector, two for sulphide ore and one for silica converter ore. From these pockets the ore is loaded into trains of standard-gauge cars in the main haulage adit on the 1300 level. Control at this point is by means of finger gates made from bent 70-pound rails operated by air cylinders.

The main tunnel is 2-1/4 miles long and approximately 10 by 10 feet in cross section. Some sections of the tunnel are of solid-concrete arch construction, and others are timbered with 12 by 12 inch sets on 5-foot centers. About 4,000 feet is rock section with gunite coating, and the remainder is unsupported rock section.

From the portal of the tunnel a standard-gauge railroad connects with the smelter at Clemenceau about 5 miles distant (fig. 1). Haulage through the tunnel is with a 25-ton electric motor handling trains of eight 30-ton cars, which are made into trains of 16 cars each at the portal and taken to the smelter by a steam locomotive.

Levels are run on the 550, 800, 950, and 1100 foot elevations and on 100-foot intervals from 1100 to 1900 feet, inclusive. These elevations refer to distances below the collar of the Daisy, an old prospect shaft. The actual depth of each level below the collars of the Edith and Audrey main shafts is about 200 feet less than indicated. The main producing levels in the big ore lens are the 1300, 1400, 1500, and 1600. Production from outlying smaller ore bodies extends from the 550 to the 1700 levels.

Development details

Shafts

As stated before, both main shafts, known as the Audrey and Edith, are of solid concrete. The Audrey is the ore-hoisting shaft, while the Edith is used for handling men and supplies and development waste. The Audrey is operated one shift and the Edith three shifts per 24 hours. The Audrey shaft was equipped after the ore was found and was concreted immediately, but the Edith was sunk for prospecting purposes and was at first timbered. Later, it was concreted, and Figure 5 shows a cross section of the completed concrete. The changing of this shaft from timber to concrete was done partly on a cost-plus basis with a contractor in charge of the job, and partly by a picked mine crew working under a bonus agreement. A comparison of these two methods is rather instructive and is favorable to the bonus work, where each man participated in the benefits. Shaft-sinking has since been done under a similar agreement, with very satisfactory results.

Following are details of the shaft concreting costs:

Edith shaft concreting

Three-compartment shaft (2 hoisting compartments 4 feet by 5 feet 6 inches, and 1 manway and pipe compartment 5 feet 2 inches by 5 feet 6 inches), shaft wall containing 6 pipes in sizes varying from 2 to 8 inches.

Shaft concreted from 1400 level to surface, a distance of 1205 feet, including 7 stations.

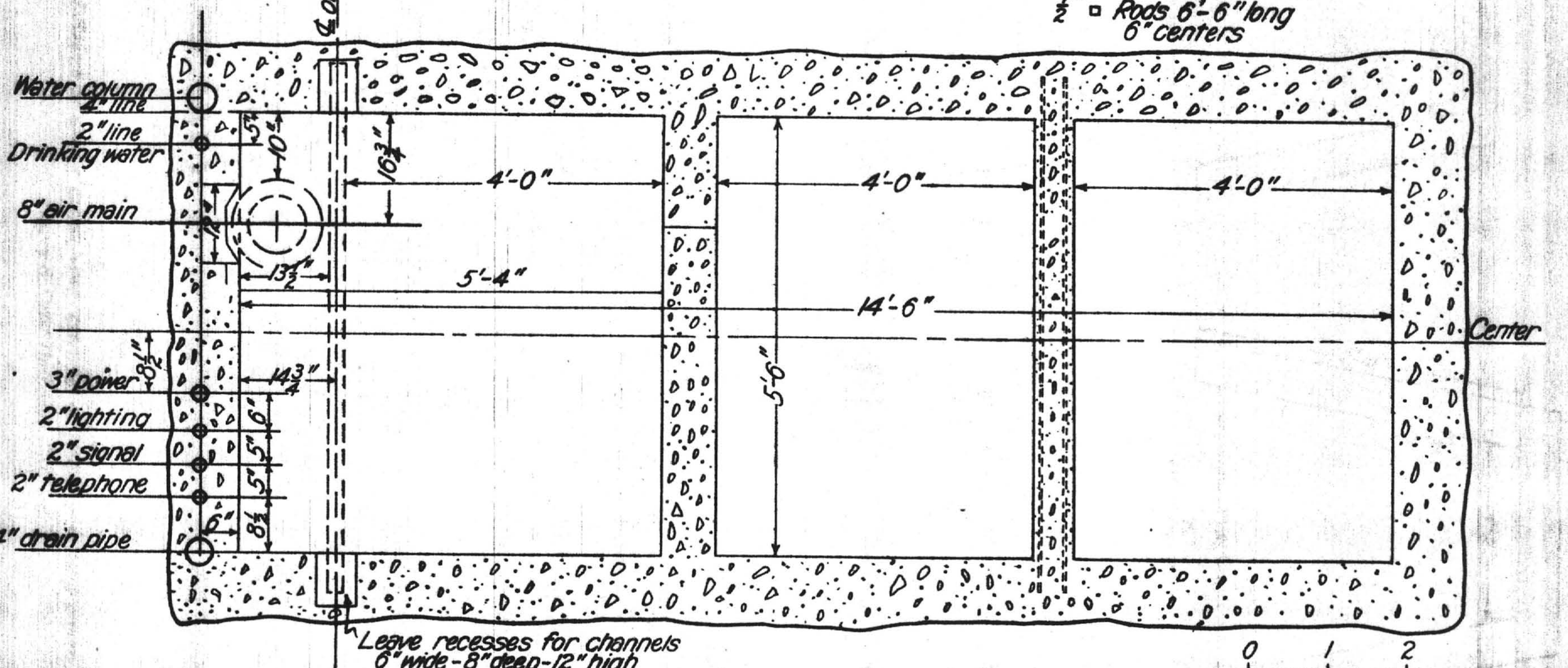
Work started February 1, 1921; completed July 25, 1921.

Work was done in two sections; first section from 800 to surface, 575 feet on contract basis, second section, 1400 level to 800 level, 630 feet, was done on bonus basis on footage made per day.

The actual cost of mixing and placing the concrete in each section, not considering the preliminary cost of installing the crushing plant, removing old pipe lines, and placing guides and chairs in the concreted sections, was in each instance as follows:

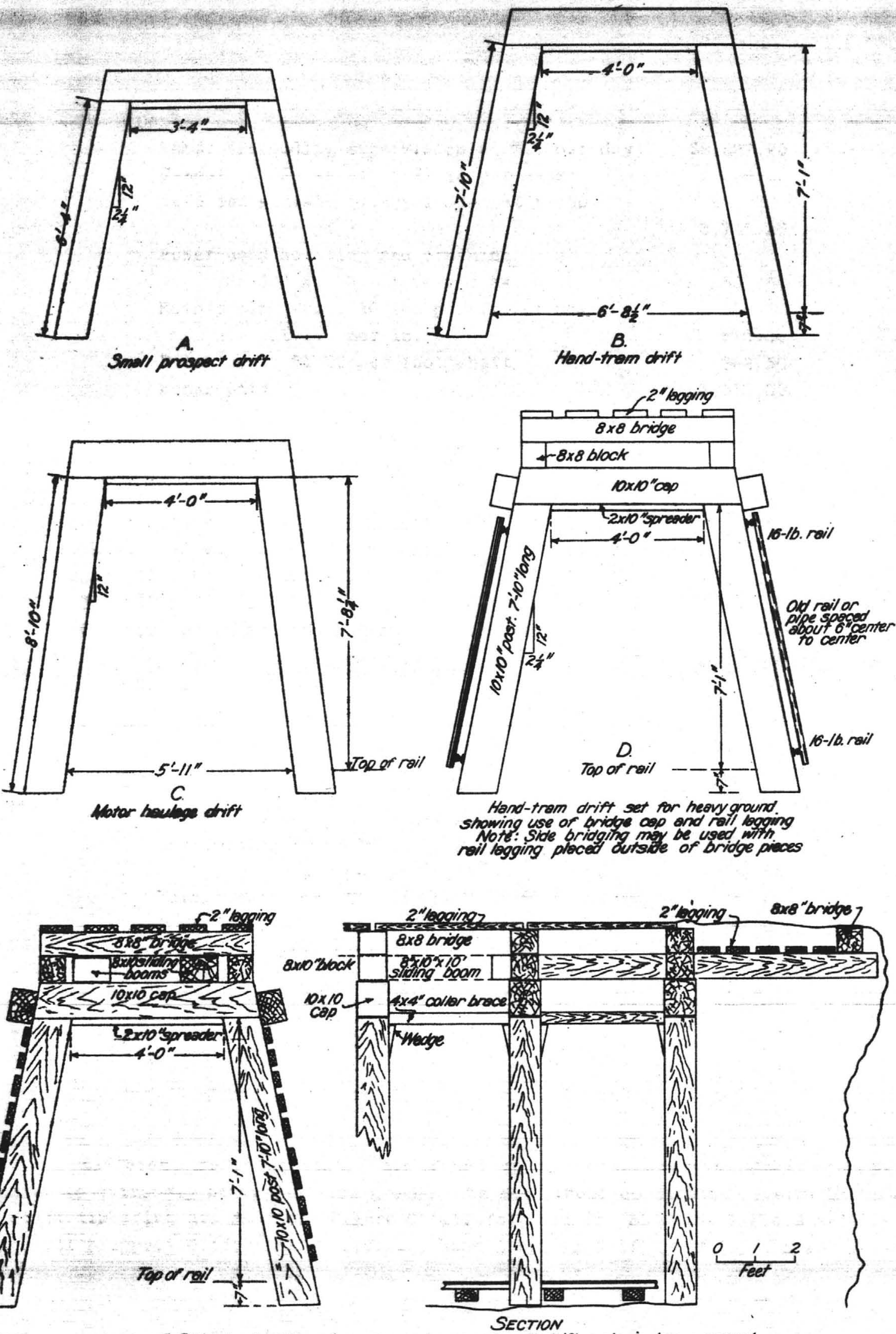
1st section

575 feet, including 2 stations.
Work started February 1, 1921; finished
April 21, 80 days.
Average advance, 7.19 feet per day.



STATION SIDE

Figure 5.-Section of concrete, Edith Shaft



E: Sketch of sliding booms used over top of drift sets in heavy ground

Figure 6.-Drift Timbers

Costs

Labor (including supervision at $10 per day)	$8,827.20
Cement (6,564 sacks at $1.10 per sack)	7,220.40
Sand and gravel, (1,498.1 yds. at $2.50 per yd.)	3,745.25
Power used hoisting and crushing (25,380 kw. h. at 2¢ per kw. h.)	507.60
Reinforcing iron, 10 lb. per ft. of shaft at 10¢ per lb.	575.00
Form lumber $1.50 per foot shaft	862.50
Bonus paid	3,075.00
Total cost for 575 feet	$24,812.95
Cost per foot	$43.14

2d section

Distance concreted, 630 feet, including 5 stations.
Work started May 1, 1921; finished July 25, 1921, 86 days.
Actual time of concreting this section of shaft, after deducting the time lost in cutting new stations, was 69 days, or an average per day of 9.13 feet.

Costs

Labor (including supervision at $225 per mo.)	$5,068.50
Cement used (6,256 sacks at $1.10 per sack)	6,881.60
Sand and gravel (1,434.5 yds. at $2.50 per yd.)	3,586.25
Power used hoisting and crushing (29,310 kw.h. at 2¢ per kw.h.).	586.20
Reinforcing iron, 10 lb. per ft. of shaft, at 10¢ per lb.	630.00
Form lumber (640 ft. of shaft at $1.50 per ft.)	945.00
Bonus paid	2,056.50
Total cost of completing section	$19,754.05
Cost per foot	$31.35

Mixture used was 1 part cement, 2 parts sand, 5 parts crushed rock, or 5-1/3 sacks of cement, 10 cubic feet fines, and 23 cubic feet crushed rock per yard of concrete in place.

Drifts

Many different rock conditions are found in the mine, varying from very hard quartz gossan to extremely heavy swelling ground. To meet these conditions several kinds of standard drift timbering are in use. Figure 6 (a), (b), and (c) show the various sets used for (a) a small prospect drift, (b) an ordinary hand-tramming drift, and (c) a motor drift;

also (d) shows the use of old rails or pipe in place of lagging in ground that is very soft and inclined to swell. It has been found that by using rail lagging in swelling ground the soft ground squeezes through between the rails, and very little pressure develops on the set itself. Figure 6 (e) shows a method of timbering in soft ground which is not bad enough to require spilling and still needs some support overhead. This is provided by carrying sliding booms over the sets which are pushed ahead as needed.

In the main haulage tunnel several different types of support were used, two of which are shown in Figures 7 (a) and (b).

Guniting

Guniting was used very successfully in a section of the main tunnel 4,000 feet long. This part of the tunnel was through an old recemented river-channel conglomerate, which was comparatively hard when first broken but after exposure to air and moisture tended to slack and slough. Had this not been gunited it would have needed timbering through the entire section. The gunite has now held for over 10 years. If this section had been supported by timber it would have needed at least one complete renewal of the timber. Gunite has been applied in other sections of the mine with little success, due to slight ground movements, that break the gunite and render it useless in a very short time.

A record of the cost of guniting this 4,000-foot section of the main tunnel follows.

Size of tunnel	10 by 10 feet
Footage gunited	4,098
Mixture used	1 cement to 3 sand
Applications	2 coats

Costs

Labor	$2,581.29
Cement (2,056 sacks at $1.10 per sack)	2,250.60
Sand (263 yds. at $2.50 per yd.)	657.50
Machinery repairs and supplies	282.84
Total cost	$5,772.23
Cost per linear foot of tunnel	1.40
Cost per sq. ft., approximately	.046

Bulkhead drift sets

A system of holding extremely heavy gangways through the pillars in the main ore body is shown in Figure 8. It has been found that solid timber bulkhead built as shown, using the waste ends of timber that accumulate in a mine of this kind, will hold a ground pressure that would break ordinary heavy timber sets several times a year. In fact, on one level a section of this kind of bulkheading put in on one side of a drift opposite a solid

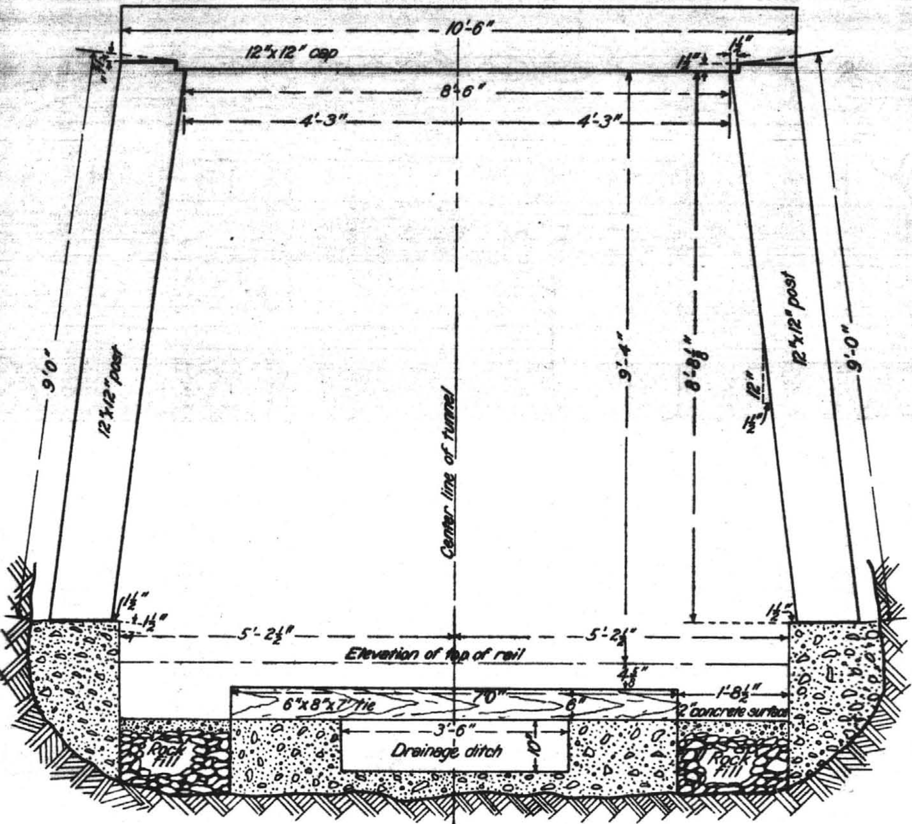


Figure 7-A.-Standard 12"x12" Tunnel Timber

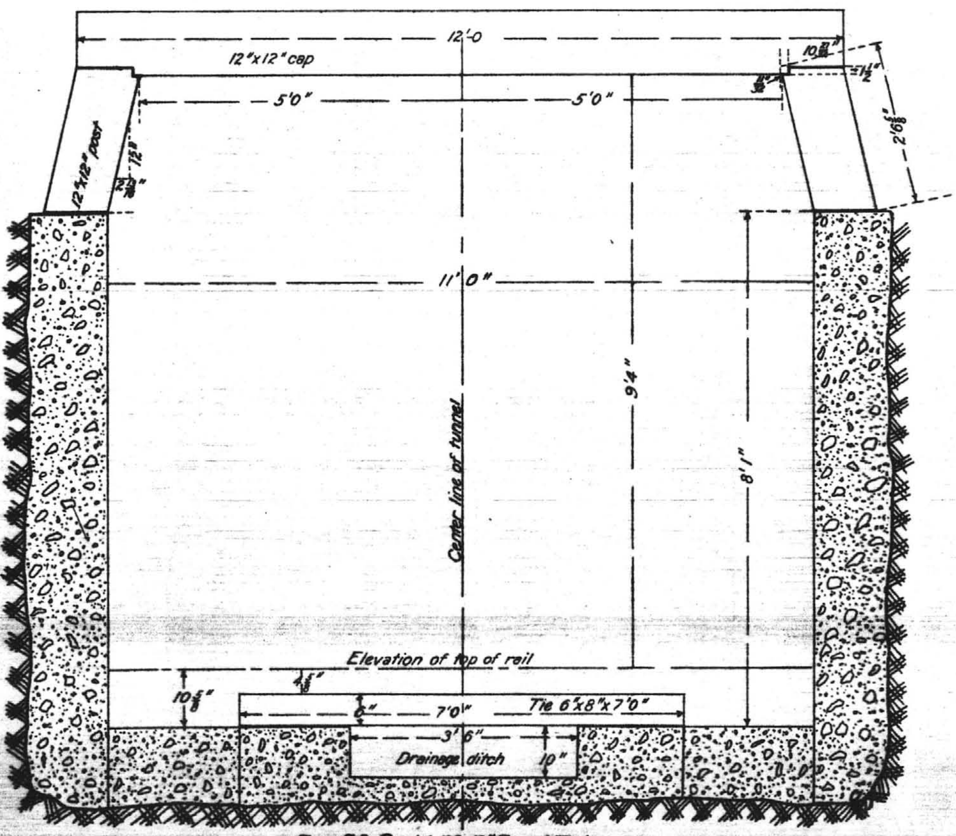


Figure 7-B-Special 12"x12" Tunnel Timber

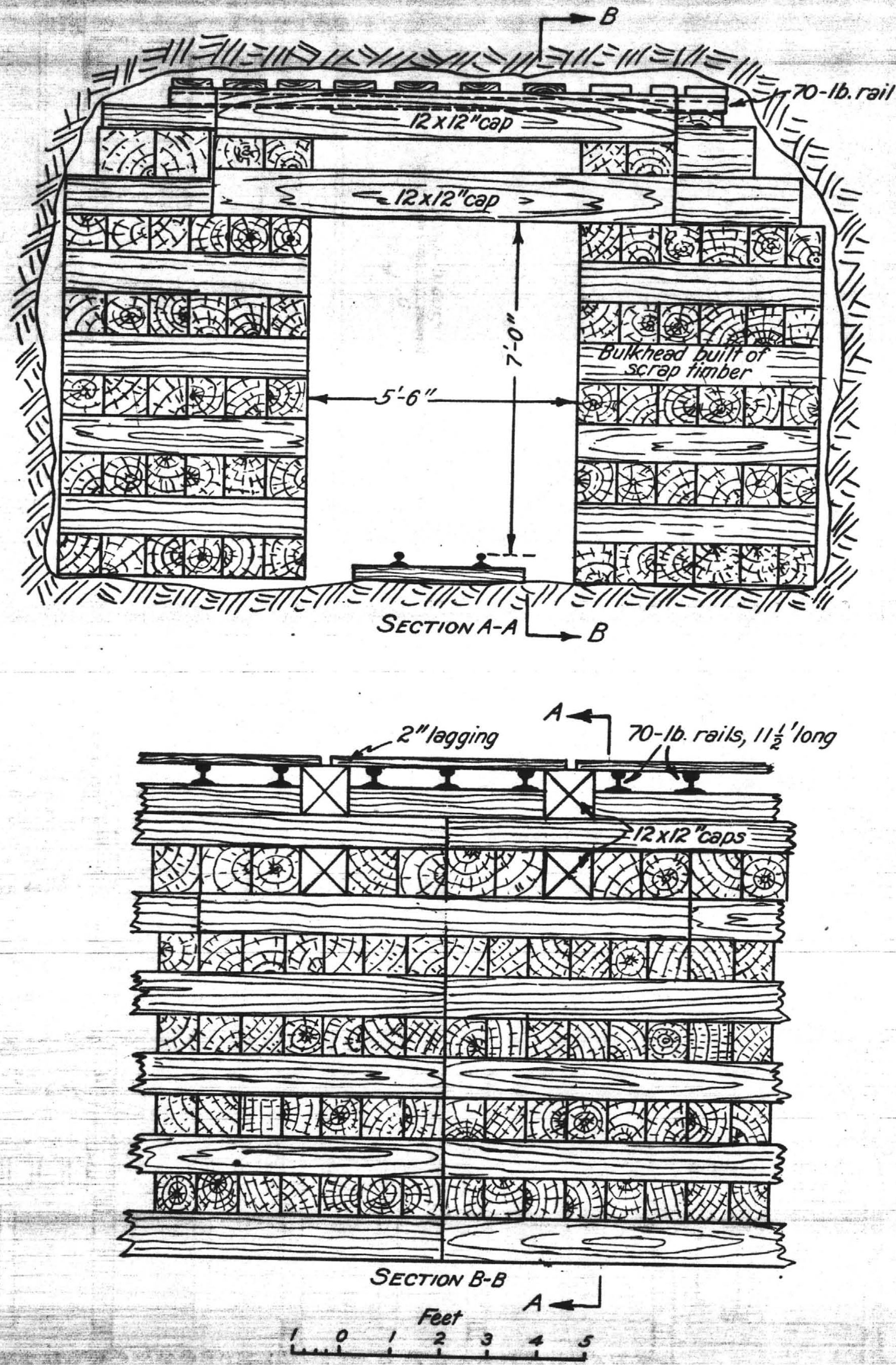


Figure 8.- Timber Bulkhead

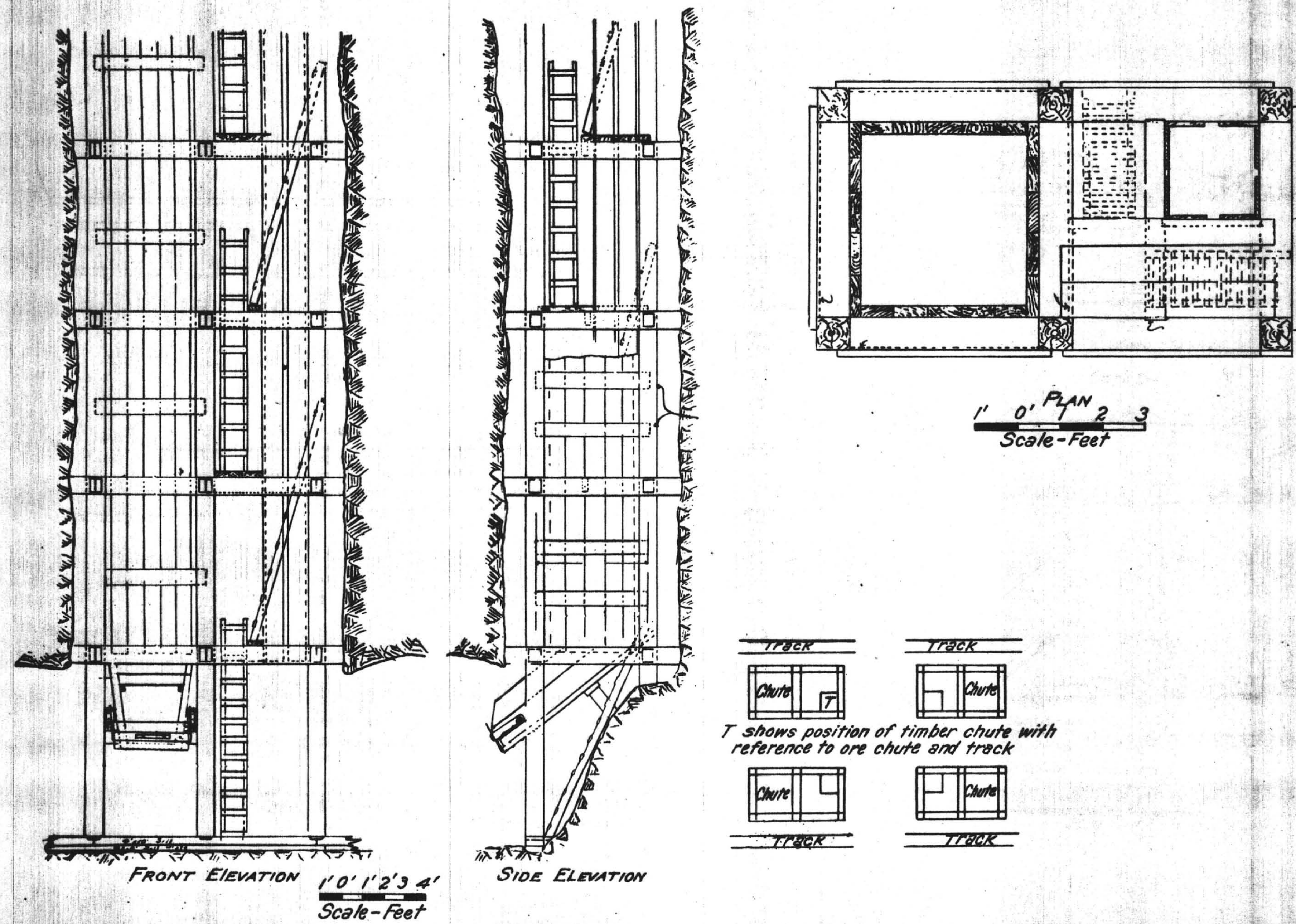
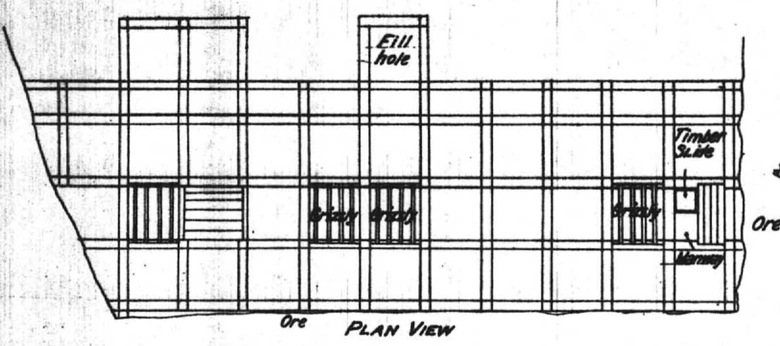


Figure 9. - Standard six post squares raise with safety manway



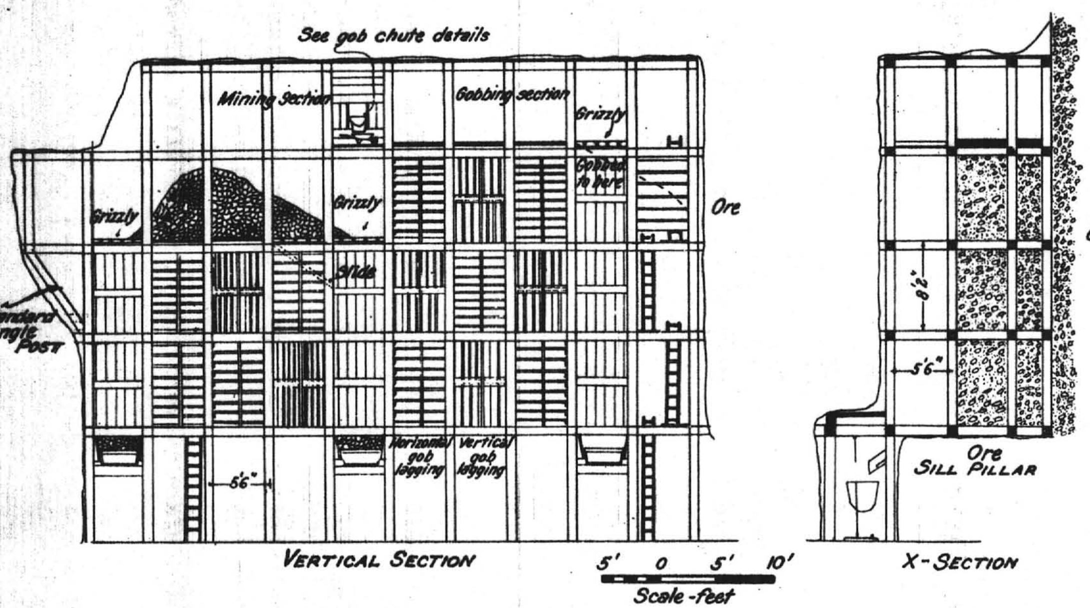


Figure 10-A: Typical Square Set Stoping Method

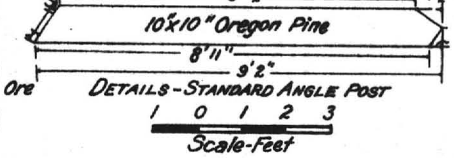


Figure 10-C

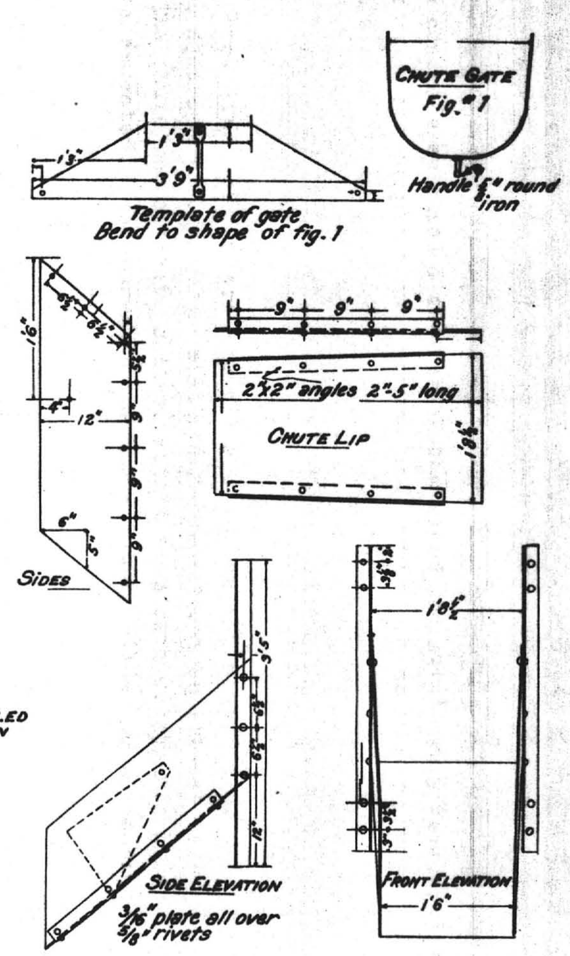


Figure 10-B: Gob Chute Details

reinforced concrete bulkhead 5 feet thick has stood the strain very well, while the concrete has been forced out of place and cracked and has had to be blasted away to make clearance for gangways.

Raises

Three kinds of timbered raises are run in the mine. Wherever the work is to be followed by square-set stoping the standard 2-compartment square-set raise shown in Figure 9 is used. The chute compartment is lined with 2 or 3 inch Oregon fir lining, depending upon the service expected. The manway provides a timber slide in one corner and has landing platforms on each floor. In addition to the square-set raise two kinds of cribbed raises are in use. The smaller raise is timbered with 3-inch Oregon fir cribbing, giving two compartments 3-1/2 by 3-1/2 feet in the clear. For heavier use cribbing is made of 6 by 8 inch material and compartments are 4 by 4 feet in the clear.

Stoping

Because of the heavy massive nature of the main ore body, the richness of the ore, and the necessity for mining in such a way that no blocks of sulphide ore are allowed to move and generate heat only the square-set system of mining with stopes tightly filled with waste has ever been used in the main sulphide lens. By using the square-set system of mining with stopes tightly filled with waste complete extraction of the main ore body has been possible with practically no dilution. Moreover, this system has allowed careful prospecting of the walls, which has resulted in finding many small rich lenses of ore that would otherwise have been missed.

A typical stope is shown in plan and section in Figure 10 (a). The stope sections are usually 3 sets wide in fairly solid ore and 2 sets wide in the heavier ground. If the ore is very badly broken it is sometimes removed in slices a single set in width. Slices are taken 100 feet high, as that is the interval between levels throughout the mine. The length of the slice may be anything to suit the conditions, usually being from 10 to 20 sets. Ore chutes are placed in about every fourth set, and alternate chutes have manways beside them. By spacing chutes in this manner and leaving slides with grizzlies in adjoining sets as shown the shoveling of ore into chutes is virtually eliminated. If no weight develops on the timbers after one floor is removed another is removed and sometimes several more before filling with waste. This reduces the cost of mining, as most of the ore rolls to the chutes, and a large part of the fill can be run into place by gravity. When several floors are mined before filling the timber is protected from the fall of the blasted ore by placing grizzlies of 70-pound rails, 6 feet long, held in metal holders, immediately below the mining floor. By using metal holders the grizzlies are moved very readily and placed where needed. After one section is finished it is filled entirely, except the chutes and manways needed for entrance to and mining of the next slice. The chutes also serve for fill holes for running waste into the new section. By having a fill hole in about every sixth set and mining several floors before filling there is very little shoveling of waste fill. If conditions are such that the waste will not spread a light metal gob chute is placed in the fill hole and the waste spread with a car or wheelbarrow. Figure 10 (b) shows the details of the chute gate.

All timber used in stoping is standardized (fig. 11). Figure 10 (c) shows a standard angle post for offsetting a set. In the heavier sulphide stopes nearly all timber is 10 by 10 Oregon fir, but in the lighter ground much 8 by 8 Oregon fir is used. In the heaviest sill-floor gangways all timber is of 12 by 12 dimensions.

Although the general method of mining used is the well-known square-set system several modifications have been developed locally to apply to conditions existing in this particular ore body. A general technique of mining under this system has been developed, which has an all-important bearing upon the efficiency and safety of the mining, especially in holding the unmined pillars so that there is no movement of ore, with resultant heat and danger of fire.

A system of mining badly broken pillars by stoping up through the center with small square-set cuts, then tying across the top with timber stringers and slicing the sides downward, has been quite successfully used. This method is shown in Figure 12. On most of the producing levels in the main ore body the mining has been done in such a way that pillars usually about six sets wide have been left over the main extraction gangways, extending vertically from level to level. These pillars have been standing for many years while the ore on both sides and on the level above has been removed. Resultant movement has in many instances thoroughly broken these pillars so that they would be very difficult to mine by ordinary square-setting from the bottom upward. Moreover, the gob lining between the pillars and old stope sections is often found to be rotten and broken. By taking a small square-set slice up through the middle of the pillar, using as a cutting point the old chute and manway in the section previously mined and filled, then tying across the top under the old filled level above and coming down with a series of 10 by 10 timber stringers from pilot sets to the old gob line, it has been found that these pillars can be removed very effectively. Quite often this ore between the sets and the old gob can be taken down by the use of a bar alone, without using explosives at all. If the old gob line is broken or rotten it is braced back by stulls between the stringers and new cross lagging. After one-half is finished it is filled with waste dumped in from the level above and the other half mined the same way. After all the mining is completed everything is filled except a chute and manway on the advancing side to be used as a cutting point for the next slice.

Underground transportation

Main haulage levels in the main ore body are maintained on the 1400 and 1600 levels, and the ore from the levels above is passed through a series of transfer raises. Haulage on these levels is done with 5-ton trolley locomotives running on tracks with 30-pound rails and minimum curves of 25-foot radius. The car used in this haulage is the 30 cubic foot side-dump car shown in Figure 13. Cars of this type have been in continuous operation for 12 years and have proved satisfactory. Chute doors used throughout the mine are illustrated in Figure 14. This type of chute door was copied from one used in the United Verde mine. The same type of door, operated by an air cylinder, is in use on most of the main haulage transfer chutes. A 16-cubic foot car used for hand tramming is also shown in Figure 14.

On other levels where the tonnage produced is much less and where the working

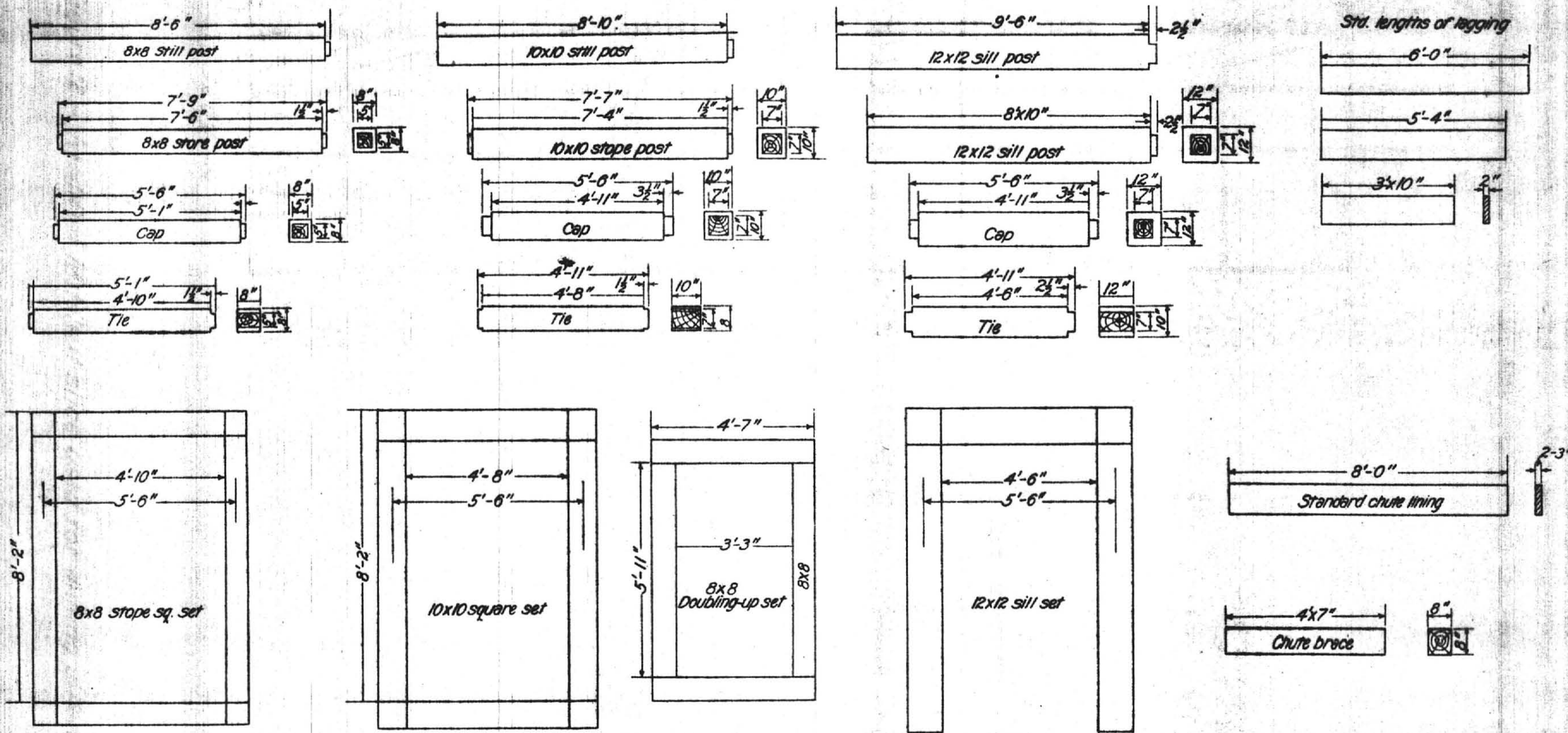


Figure 11. - Standard Stope Timber

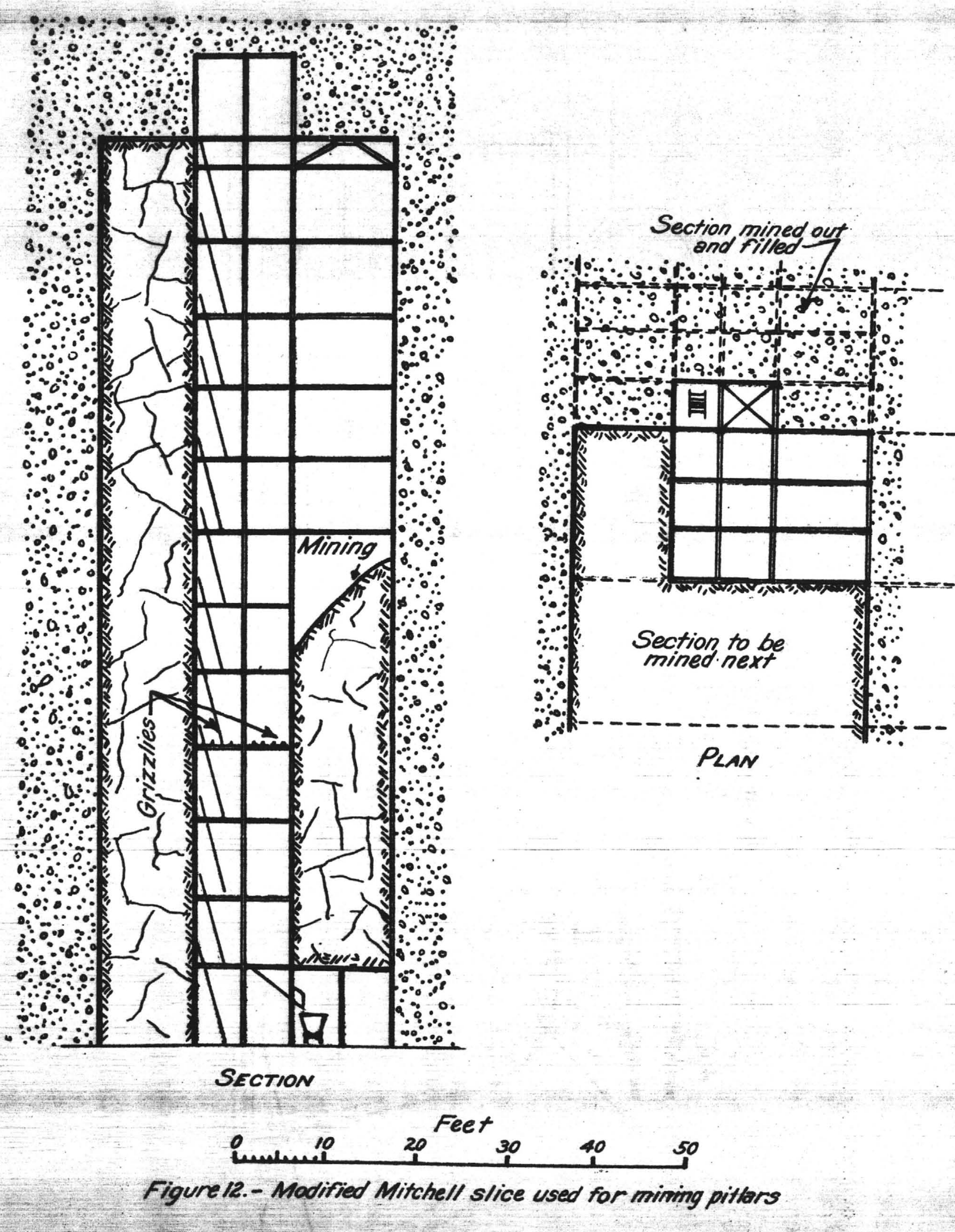


Figure 12.- Modified Mitchell slice used for mining pillars

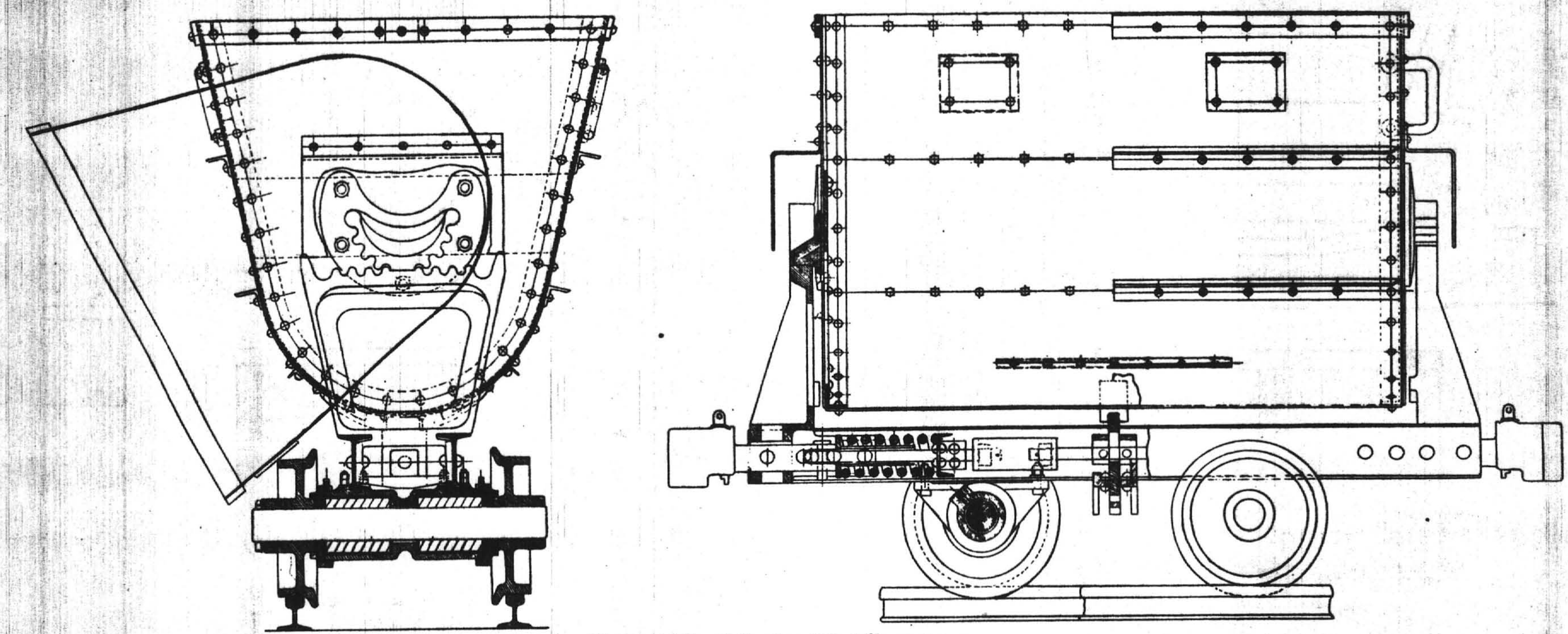


Figure 13.- 30-Cu.Ft. Mine car

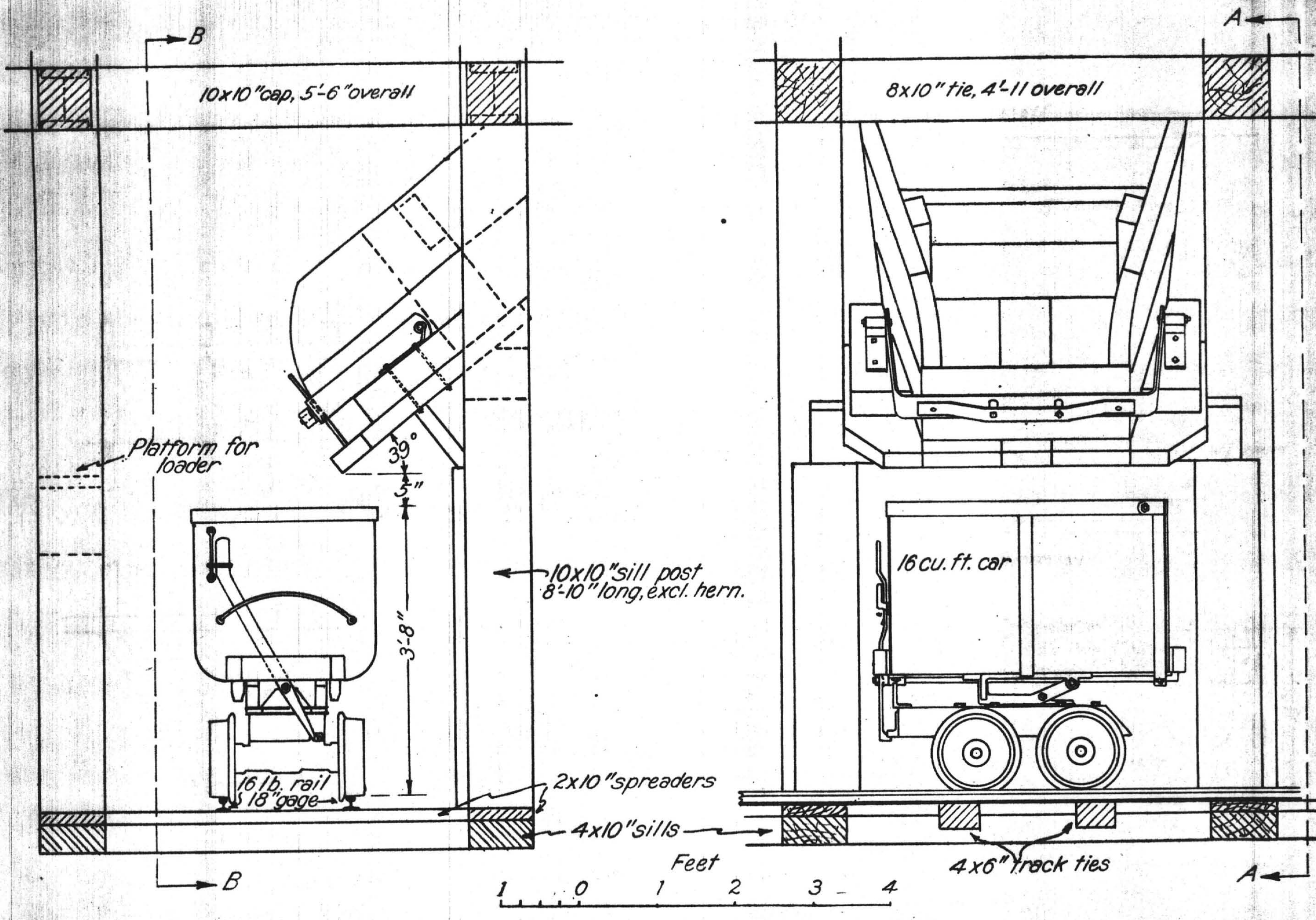


Figure 14. - United Verde Chute Gate and 16-Cu. Ft. Car

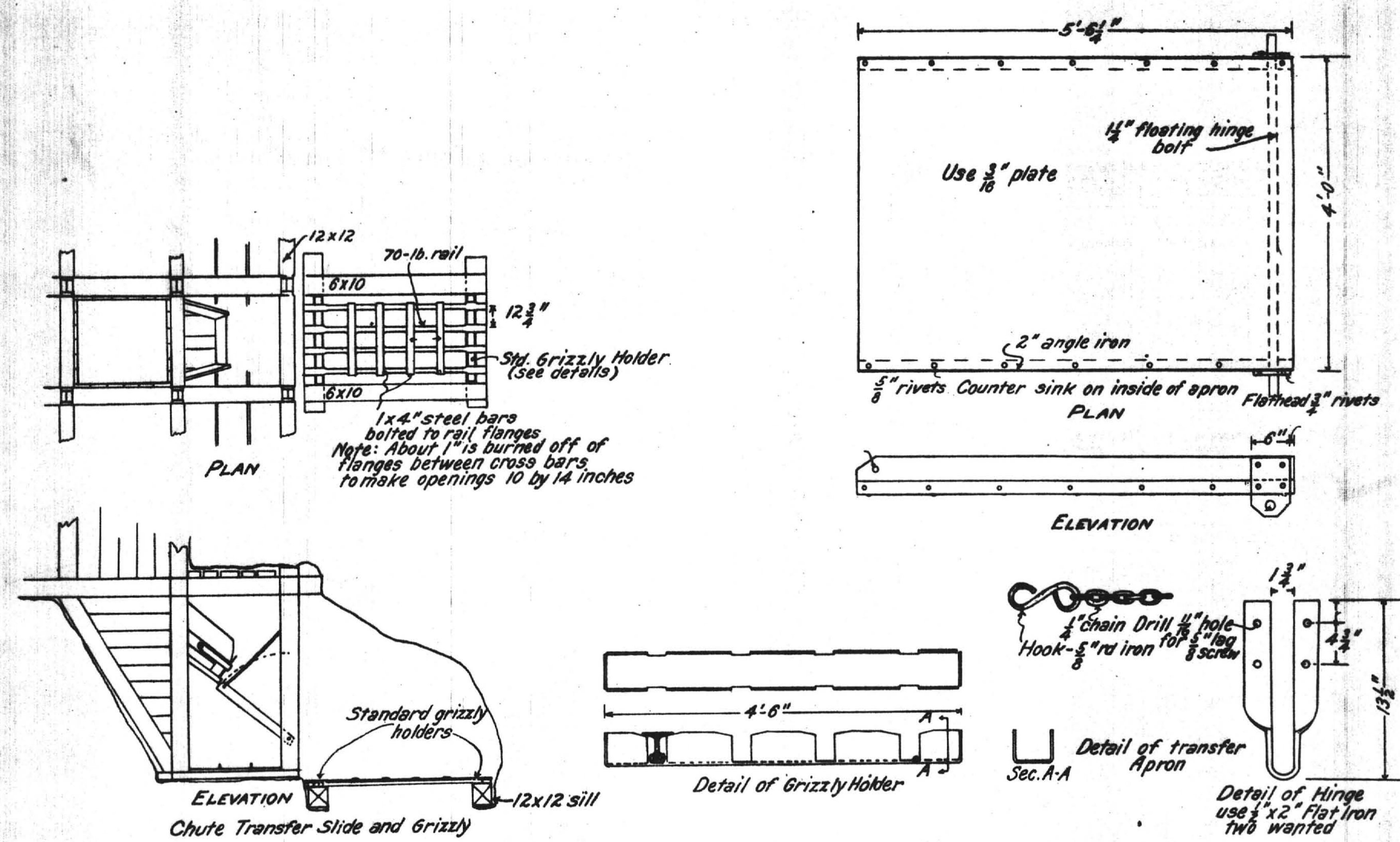


Figure 15.- Chute Transfer Slide and Grizzly

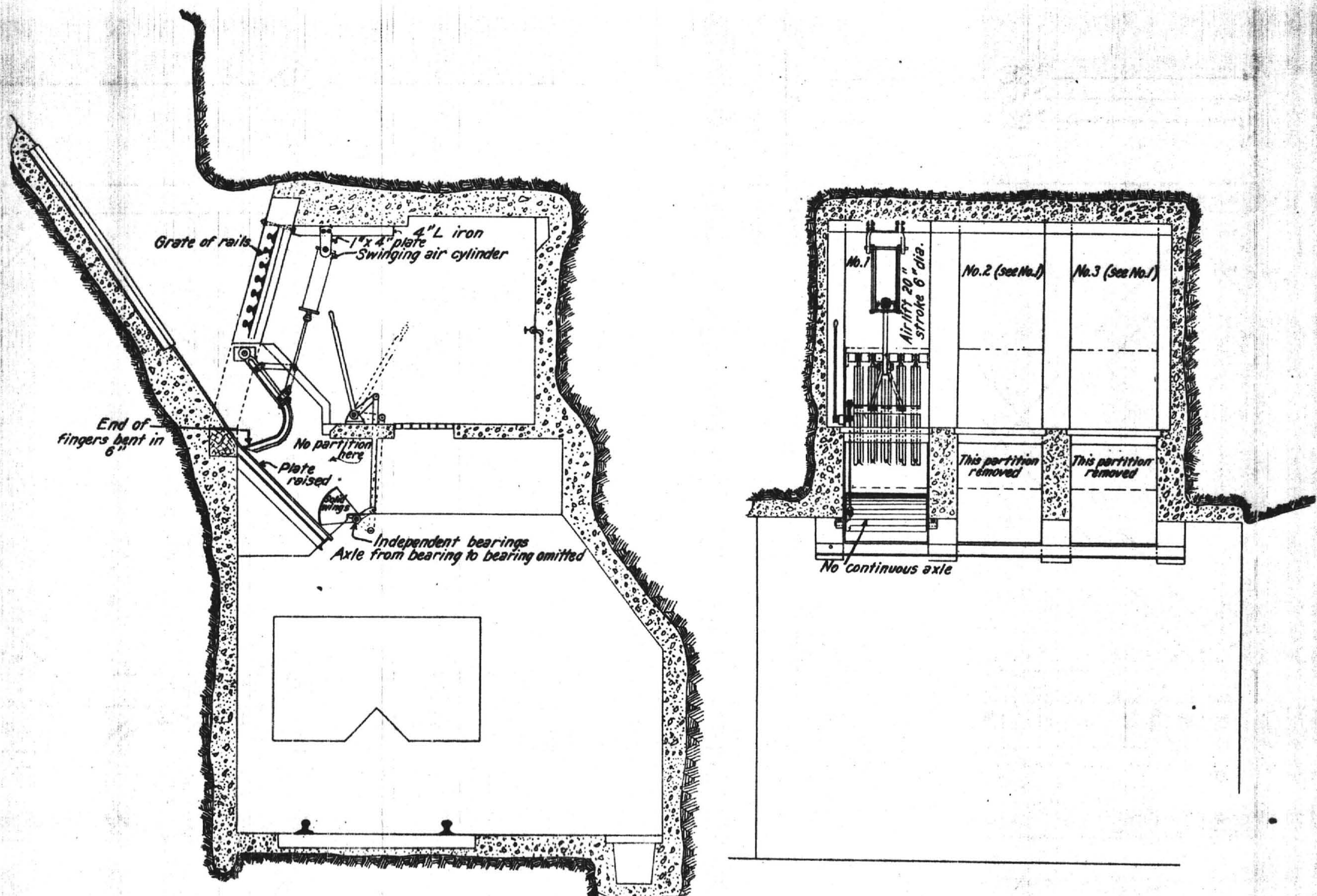


Figure 16.- Loading gates Main Ore Pocket

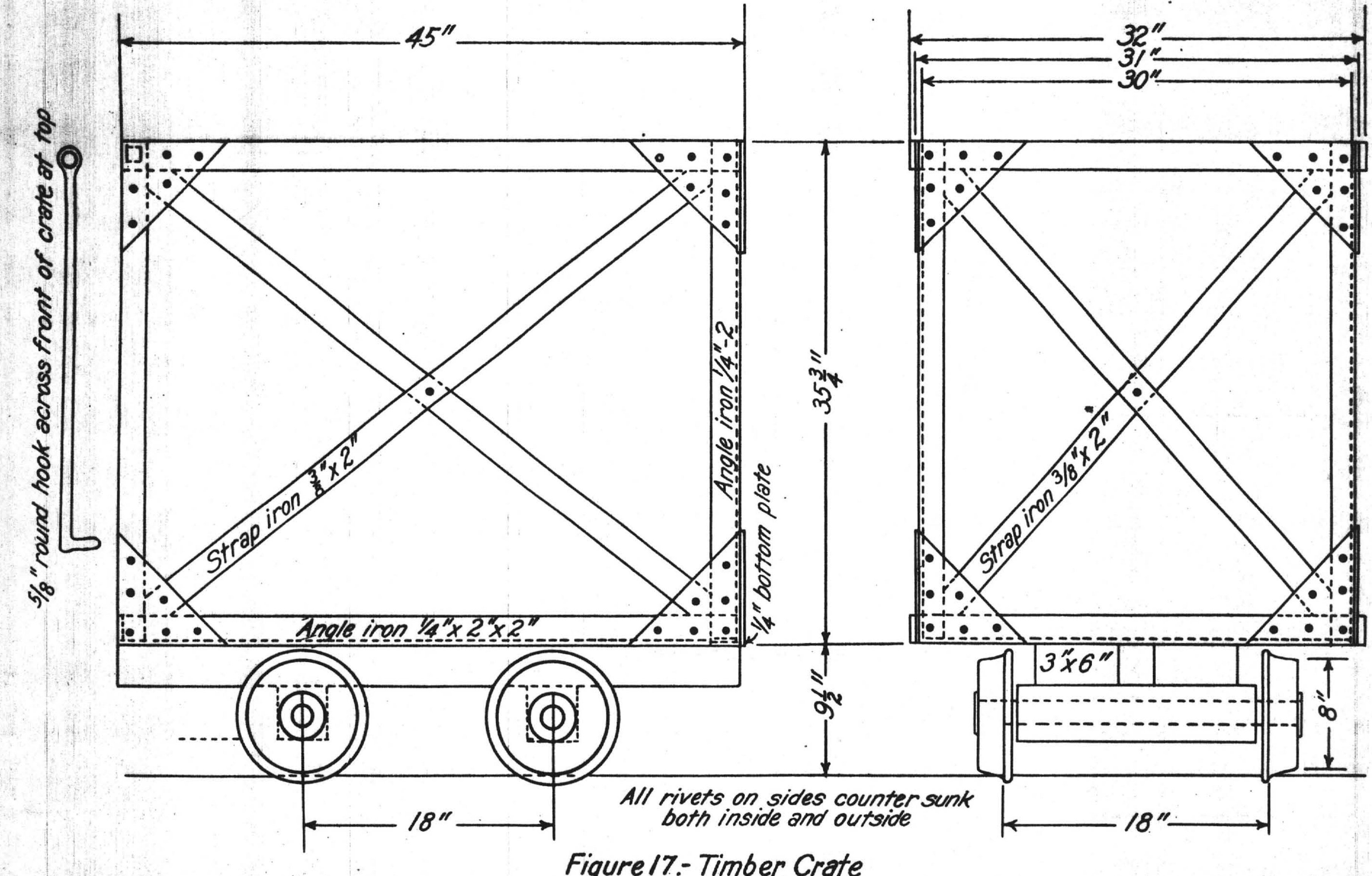


Figure 17.- Timber Crate

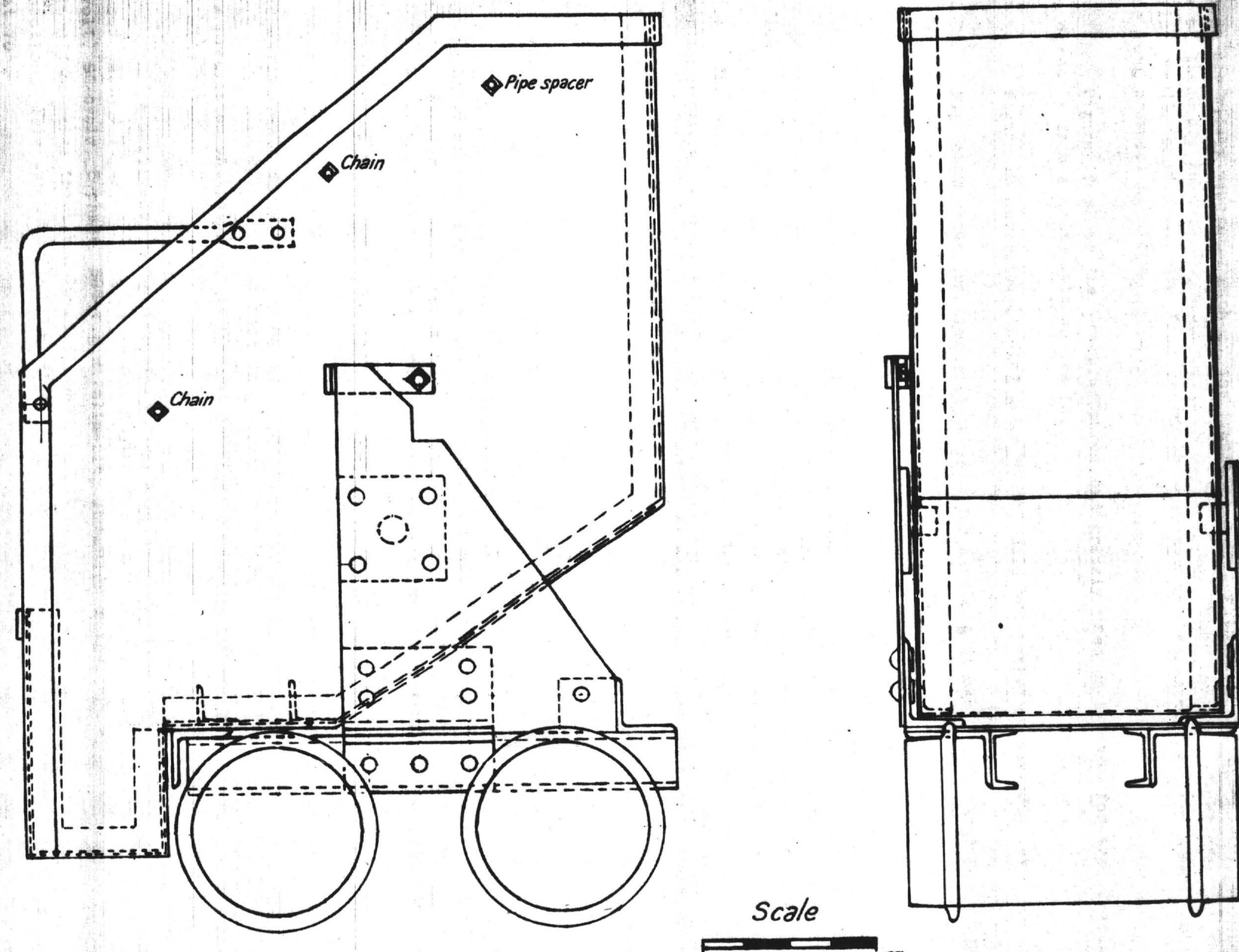


Figure 18.-Car for drill steel

places are widely separated much of the tramming is done with small storage-battery motors. Six of these are in use in various sections of the mine. They have proved satisfactory for moving small tonnages of ore from scattered workings and for handling development waste from long prospect headings.

Figure 15 shows the transfer apron and grizzly used on a level for transferring ore directly from a chute into an ore pass.

Figure 16 shows the loading gates of the main ore pocket on the 1300 level.

Figure 17 shows the timber crate used for handling timber in the cages and Figure 18 the details of the car for handling drill steel in the mine.

CONTRACTS

In an effort to obtain better progress and more efficiency drifting and raising are generally done on contract. All contracts are let directly through the superintendent's office. In a raise the contract specifies the footage to drive to the next level. In drifting the footage is generally limited to 100 feet, although contracts have been let for more. The contract stipulates the price per foot, the price per set of timber, the size of opening required, and, in a raise, the kind of timbering. The contractor pays for all explosives used. The contractor gets his regular day-pay check on pay days, and settlement on his contract is deferred until the first of the month. Settlement is then made according to the engineer's measurement and payment made on the 15th of the month.

Drifting contracts may run for months. When a contract is completed the contractor obtains settlement immediately, if he so requests.

Bonus work was tried out some years ago. In the stopes it resulted in hurried and consequently poor mining. The saving effected was not considered enough to compensate for this disadvantage. In drifting and raising difficulty was experienced in setting rates. The straight contract system was decided upon as being more acceptable to the workmen.

VENTILATION

The mine is ventilated mechanically by a surface exhaust fan installed at the top of a return-air system extending to the 1200 level. Rock temperatures are not very high, but a considerable amount of heat is generated by oxidation and timber decay, and the system is predicated entirely upon providing comfortable working conditions and control in case of a mine fire.

A multivane, forward-curved blade, single-inlet, single-width, centrifugal fan is used, with a 78-1/2-inch rotor operated at 346 r.p.m. by belt drive from a 250-hp., 2,200-volt, 60-cycle, 3-phase, 585-r.p.m. slip-ring induction motor. It exhausts from a 6.33 by 15.0 foot raise through a 10-foot concrete duct on a 30-degree slope and 4.5 by 5.5 feet in section. This fan is at present exhausting 100,000 cubic feet per minute of air saturated at 70°.

A single-inlet, single-width, multivane, forward-curved blade centrifugal fan, with 52-3/8 inch rotor, is connected to the opposite end of the air raise by a similar concrete duct; this is an auxiliary installation and is installed to operate at 590 r.p.m. by belt drive from a 75-hp., 2,200-volt, 875-r.p.m. induction motor. Each fan duct has a winch-operated door hinged to the floor and held in place both by fan pressure and gravity.

All long development headings are ventilated by fan-pipe installations, using small air or electrically-operated blowers, with 10-inch galvanized-iron piping.

FIRE HAZARDS

On account of the heavy ground in the mine considerable timber is required. Due to this and to the fact that the main ore body carries a high sulphur content a fire menace is always present. Timber bulkheads are used to maintain haulage and extraction drifts in various parts of the stoping sections of the mine. To control any fire starting from the above conditions fire hydrants and standpipes are placed at all places where hazards exist.

A fire patrol is maintained on the graveyard shift, and all hazardous places are wet down two and three times a week. In addition, large independent fire lines are maintained on the main working levels. These lines are direct-connected to the pump columns where a large source of water would be available if needed. In addition to this, all air lines can be converted into water lines in a few minutes by the use of installed by-passes.

In the timbered section of the Edith shaft sprays are placed at 300-foot intervals, and the timbers in this shaft are wet down at least three times a week.

FIRE-FIGHTING EQUIPMENT

A complete mine rescue station is maintained with all the necessary fire-fighting equipment. Figure 19 illustrates a small portable disk fan. This type of fan has proved successful in other parts of the Southwest in fighting fires. The fan is equipped with a 110-volt, alternating-current, single-phase, 60-cycle, 850 revolutions per minute, General Electric repulsion motor. It is mounted on a mine truck with a reel carrying 1,000 feet of No. 14 duplex rubber cable that can be connected to the lighting circuit. The fan and reel are mounted on a turntable and can be locked in any position desired. Figure 20 shows an emergency tool truck for fire-fighting.

Sets of oxygen breathing apparatus and gas masks are kept on hand, and men have been trained in their use. Fifteen active rescue men are required to practice rescue and fire-fighting at least twice a month. These practices are followed by occasional maneuvers in which all apparatus men participate. Apparatus men practice on company time and are paid a bonus of $7.50 a month.

All shift bosses, jigger bosses, and tool nippers are trained in first aid, and first-aid stations or cabinets are maintained on all active levels. The training of apparatus and first-aid men is in charge of the safety engineer, who is also responsible for the maintenance of the rescue station.

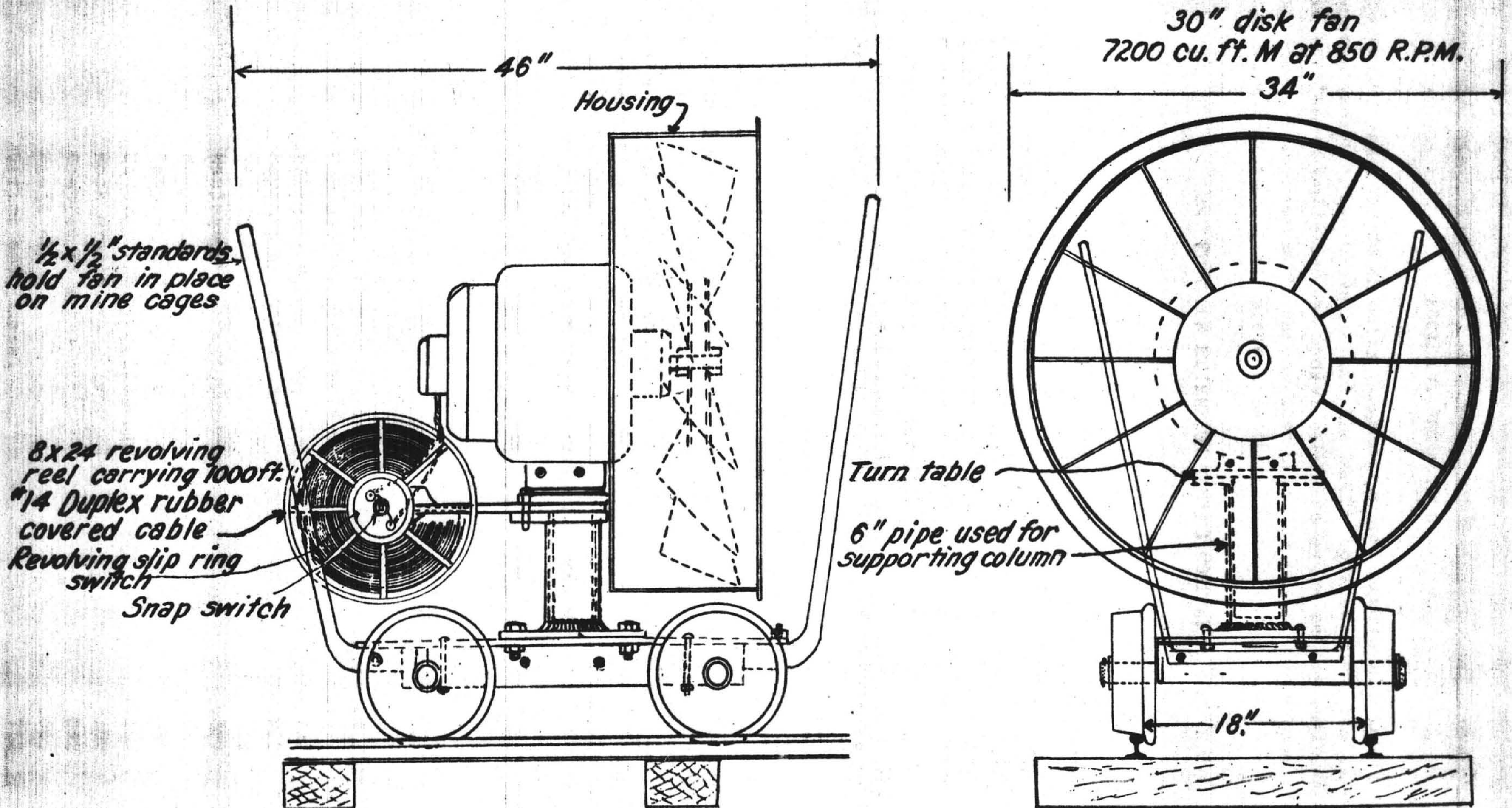


Figure 19 — Portable Ventilation Fan Used for Mine Fire Fighting

ACCIDENT PREVENTION

The safety engineer makes daily inspections and reports all unsafe conditions to the mine superintendent, mine foreman, and the shift boss on each run visited. Safety propaganda in the form of bulletins and individual talks by the safety engineer on inspection trips through the mine impresses the safety idea upon the men. Safety committees have been tried and abandoned in favor of the present method.

UNITED VERDE EXTENSION MINING COMPANY

EFFICIENCY DATA

YEAR 1928

Tons mined per man (stoping shifts)	4.84
Tons mined per man (underground shifts)	2.47
Tons mined per man (total shifts)	2.00
Feet advanced per man (development shifts)	1.17
Mine timbers and handling cost (per 1000 board feet)	36.24
Mine timbers and handling cost per ton	.67
Mine timbers (board feet per ton)	16.82
Total board feet used per ton	18.53
Pounds power per foot advanced	6.14
Feet fuse per foot advanced	19.10
Number caps per foot advanced	3.29
Pounds carbide per underground shift	.85
Pounds powder in stope per ton	.39
Feet fuse in stope per ton	1.93
Number caps in stope per ton	.35

UNITED VERDE EXTENSION MINING COMPANY

MINING COSTS

YEAR 1928

Tons shipped during period: 275,212

	Cost per ton
Prospecting and development	$0.611
Extraction	1.710
Repairs and maintenance	.260
Ventilation	.068
Haulage	.357
Hoisting	.151
Pumping and drainage	.039
Underground miscellaneous	.107
Rock drills	.152
Compressed air	.092
Waste pit	.005
Office and general	.738
TOTAL COST PER TON	$4.286

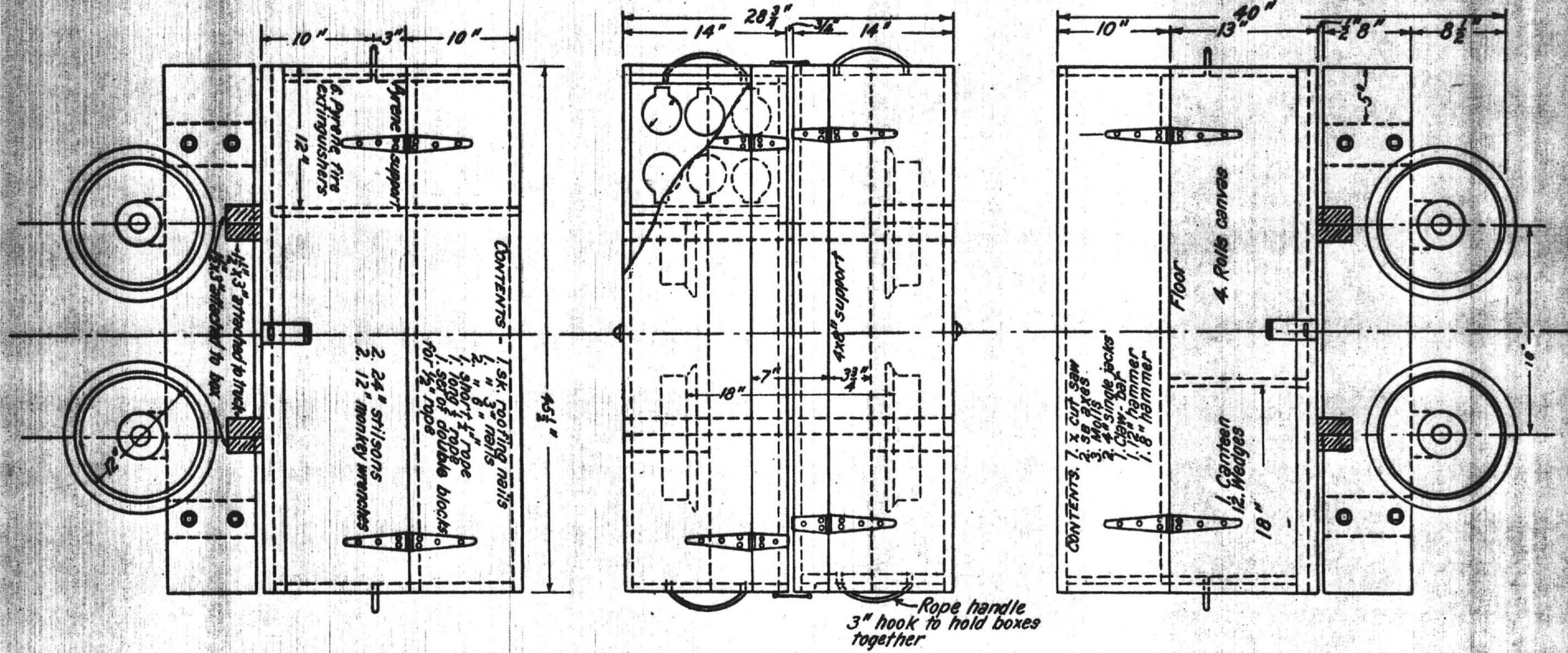


Figure 20.- Emergency Tool Truck for Helmet Teams United Verde Extension Mining Co. Jerome, Ariz.

DMEA

GEOLOGICAL REPORT

on the

UNITED VERDE EXTENSION MINE

by

J. L. FEARING, JR.

JANUARY 5, 1926

INDEX

REPORT
ON THE
UNITED VERDE EXTENSION MINE

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J. L. FEARING, JR.

INTRODUCTION.

Purpose of geology. The aim of a mine geologist is to confine prospecting to those places which are favorable for ore deposition. By so doing he not only may locate new orebodies, but also may save a large sum of money which ordinarily would be spent exploring worthless areas. To be of any real value, geological work must be thorough and accurate, and the conclusions which follow must be in accord with indisputable facts.

Status of geological work at the U.V.X. I believe that the geological study of the United Verde Extension mine has reached the stage where certain conclusions are definitely established as facts and of much practical value. Therefore, I submit this report on my findings together with certain prospecting recommendations to be used as a guide to future work.

PART 1.

GEOLOGY.

Outline of district geology. The oldest rocks in the Jerome district are a series of volcanic flows and fragmentals and bedded sedimentaries, locally termed "greenstone". They are intruded by two quartz porphyry sills, the older of which is called Deception porphyry, and the younger and uppermost, Cleopatra porphyry. During this period of large-scale intrusion, the greenstones were folded and made schistose, while at its close the whole series was tilted down to the north very abruptly. Many plugs and dikes of diorite then cut all of these formations, and they comprise the youngest of the pre-Cambrian rocks. The pre-Cambrian surface was then leveled by erosion and covered by Palaeozoic sediments and Tertiary basalt, which to this day are flat and undisturbed except by faulting.

Orebodies. The orebodies of the district were formed soon after the diorite intrusion and long before any of the palaeozoic sedimentary rocks were laid down. The ore solutions, however, are more closely related structurally to the Cleopatra quartz porphyry.

This is probably due to the fact that the solutions could find no channel in the diorite, which is massive and impervious. The orebodies were formed by replacement of certain favorable greenstone schists, but there are some bodies of commercial ore in the porphyry itself. The primary ores are sulfides in which pyrite predominates, and chalcopyrite is the chief primary copper mineral.

<u>Faulting</u>. The most prominent of the post-Tertiary faults, which is known as the Verde fault, strikes northwesterly in the vicinity of the mines and dips northeast at 60 degrees. This fault has shifted the formations on its northeast side down 1700 feet, measured in a vertical plane, and to the southeast horizontally about 1500 feet. The result of the weathering of the fault scarp produced is that in the footwall the pre-Cambrian rocks are exposed at the surface, while in the hanging-wall they are overlaid by 800 feet of Palaeozoic and later rocks.

<u>Relation of U.V.X. orebody to the Verde fault</u>. The relation of the United Verde Extension Main orebody to the Verde fault has always been more or less of a mystery to many who visit the mine. A conclusion that is quite commonly

arrived at is that the ore will follow the fault downward instead of being cut off by it. The argument is that even if there were no movement on the fault in pre-Cambrian time, a line of weakness existed up which the ore solutions came and near which they acted most effectively.

<u>Verde fault is not the ore channel.</u>

There are several reasons why such an hypothesis is unlikely. In the first place, it is known that the ore is cut off by the fault in two places. Secondly, if the line of weakness existed in pre-Cambrian time, it would be reasonable to expect to find other orebodies along the Verde fault. A considerable amount of work has been done on the fault in various prospects both north and south of the United Verde Extension mine, and no mineralization has ever been found. It is much more reasonable to assume that the orebody, with its altered and softened surrounding rocks, formed a line of weakness for the subsequent faulting. The Tunnel and the Bessie faults, lieing a half of a mile and a mile respectively east of the Verde fault, are similar breaks in every way. If the lines of weakness are of pre-Cambrian age, these faults should also be mineralized, and, so far as is known, they are not. Thirdly, I have arrived at the conclusion that the Main orebody is not in any fault zone. This is an important conclusion, because it has always been thought that the hanging-wall gouge passed through the orebody, but it is not an essential part of the argument against the orebody being localized by the fault zone. The orebody is vertical and the fault, dipping into it at 60°, diverges from it going up so that the gossan, or upper manifestation of the orebody is beyond any question outside of the fault zone entirely from the 1100 level up. These points are well brought out in the vertical section attached hereto. The United Verde and United Verde Extension orebodies are similar in every way and it does not seem reasonable to assume that they were formed under wholly different circumstances. The United Verde orebody certainly was not formed at the intersection of any line of weakness with favorable formations.

Ore localization.
A. Hart's theory.

R. W. Hart came to the conclusion that the United Verde Extension ores were localized by the intersection of the Florencia fault with a mass of schistose Cleopatra quartz porphyry. This idea is no longer held because the following observed facts make it untenable:

1. The Florencia fault is distinctly of post-Tertiary age.

2. The ores are largely greenstone, rather than quartz porphyry, replacements.

Ore localization.
B. Present theory.

My study leads to the opinion that the United Verde and United Verde Extension ore-bodies were formed under similar circumstances. It is my belief that the three following factors not only controlled their formation, but are pre-requisite for the finding of other orebodies of major importance:

1. Proximity to the upper, or north, contact of the Cleopatra quartz prophyry sill.

2. Easily replaceable, schistose green-stones in contact with the quartz porphyry.

3. Close foldings of the greenstones with the development of favorable structures in them, and interfingerings with tongues of schistose quartz porphyry.

An impervious hanging-wall, such as the diorite provides, though probably not essential for ore deposition, undoubtedly plays an important role in concentrating ore solutions.

Importance of porphyry.

The importance of having an underlie-ing mass of Cleopatra quartz porphyry can hardly be over emphasized. There is little doubt that the ore solutions came up through schistose portions of the porphyry. Rising in the porphyry, they would be concentrated at its upper edge. They would tend to show greater concentrations at any outward bulges in this upper contact. If the adjoining rocks happendd to be favorable for replacement, ore deposits would be likely to result; but if they happened to be unfavorable, the ore solutions would be likely to travel up the contact and be wasted.

Favorable greenstones. What are the easily replaceable greenstones? Detailed study along all possible lines has lead to the conclusion that the rocks favoring replacement, in addition to the porphyry itself, are the bedded sedimentaries and adjacent acid volcanic fragmentals. A schistose condition appears to be the most important prerequisite. The increased permeability which it gives the rocks aids the attack of the mineralizing solutions. The basic volcanic greenstones appear to afford a wholly unfavorable environment. The difference in the replaceability of these various rocks is believed to be due not so much to their unlike chemical natures as to the fact that the acidic rocks are brittle and crack easily, giving ready access to ore solutions, while the basic rocks, when subjected to stresses, do not crack but compress and, by the process known to geologist as "plastic deformation", are made even less permeable than they originally may have been.

<u>Favorable structures.</u> The brecciation which is attendent upon folding of the greenstones makes them more accessible to mineralizing solutions. The United Verde orebody is probably localized in the crest of a northward plunging anticlinal fold in the favorable greenstones. This structure, in addition to the arched-shaped hanging-wall of diorite, has, beyond a doubt, been responsible for the great size and persistence of the United Verde sulfide pipe. The United Verde Extension orebody is localized in a syncline. The anticlinal and synclinal bends undergo the most fracturing, which is important. Another favorable structure is found in outward bulges along the upper edge of the Cleopatra sill, and it acts much like those mentioned above in that it causes a concentration of solutions.

<u>Chances of finding new ore zones.</u> Enough work has been done in the Verde district to make it seem unlikely that any new ore zones, comparable to those of the United Verde and United Verde Extension mines, will be found unless a duplication of structural condi-

tions can be approximated, and, so far as is now known, these conditions are non-existent elsewhere.

<u>Verde Central type of mineralization.</u> Perhaps the most convincing argument in support of the idea that the Cleopatra quartz porphyry is the rock most closely related structurally to the mineralization is the fact that throughout the district a certain amount of sulfide is usually found along its margins. This contact mineralization generally results in lenses of primary ore which are too small to be commercial. But even in the absence of those conditions which are believed to be necessary for the formation of large orebodies, small but commercial, copper sulfide lenses may be developed.

To date the Verde Central subsidiary of the Calumet and Arizona Mining Company has been the most promising of the "contact" prospects; but the profit that will result from mining the ore now developed or partially developed will not offset the amount of money that has been spent in its development. Although the actual ore area on the bottom level is less than it is on several of the upper levels, the total pyritized areais larger. So the Verde Central looks encouraging enough to warrant deeper work in anticipation of having the ore area get larger with depth as it has done several times in the United Verde Mine.

Secondary enrichment. The United Verde once must have had an enriched zone as extensive as that of the United Verde Extension. Numbrous pieces of "float" found along the hill side from the mine workings to the Verde valley point to such a probability. Structurally, there is no evidence that would preclude its having existed. Whatever in the nature of a chalcocite zone that did exist has been almost entirely wasted away by the post-Tertiary erosion. The chalcocite zone of the Extension has been protected by its covering of Palaeozoic sediments at least since Devonian time, and the importance of this protection is the better appreciated when we resort to a post-mortem of what would have been without it. Assuming that the orebodies of the two mines were similar in their makeup, which is reasonable, and that there were no secondary enrichment, the Extension would have produced only one-fifteenth as much copper as it will produce - 20,000 tons against 300,000.

Recommendations. Looking ahead to the future, it is apparent that there is considerable geological work yet to be done in connection with the many holdings of the United Verde Extension Mining

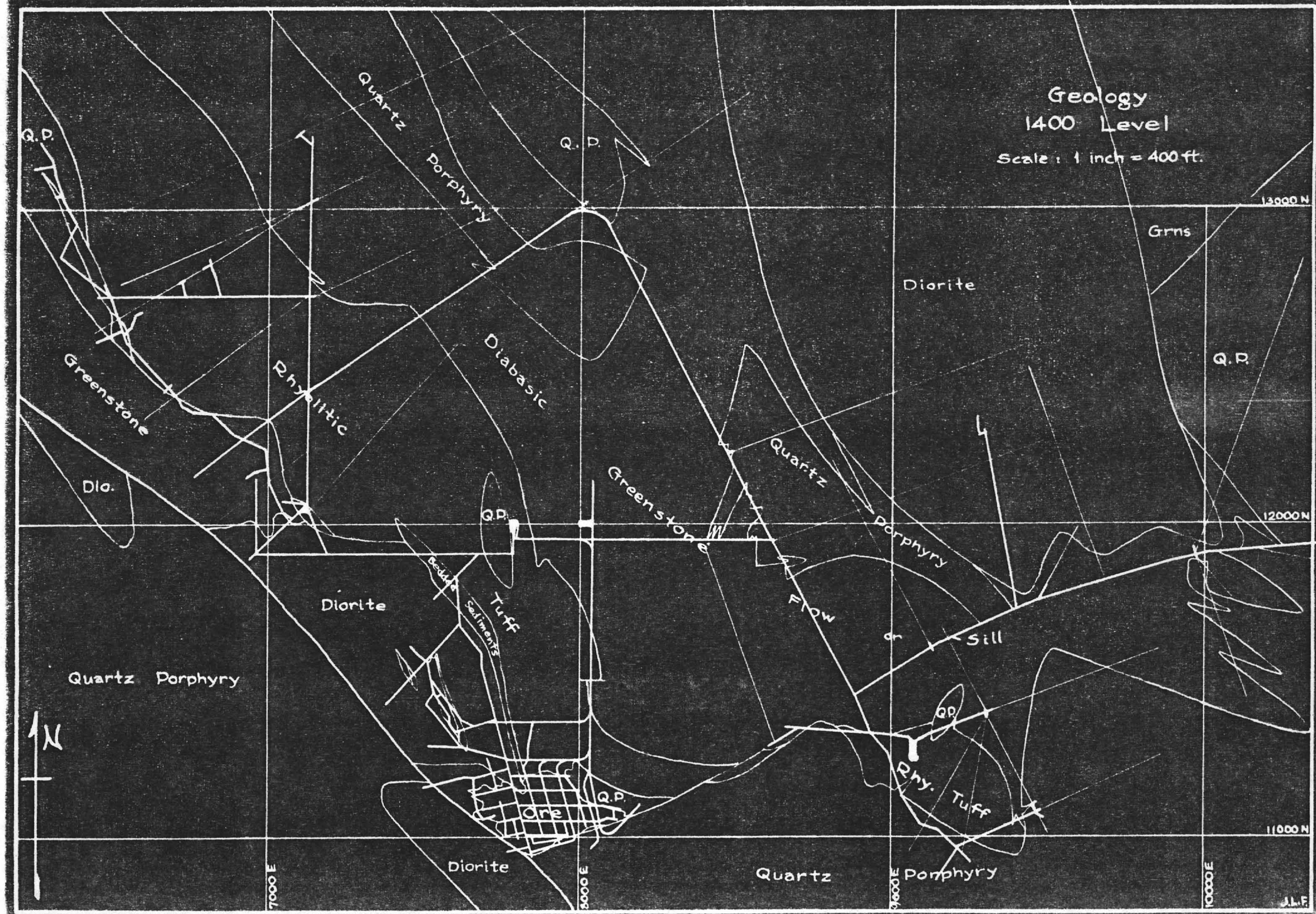
Company. I feel that a resident geologist should be kept by the company for at least two years to see that the work is completed, now that a good start has been made. The work that should be done is as follows:

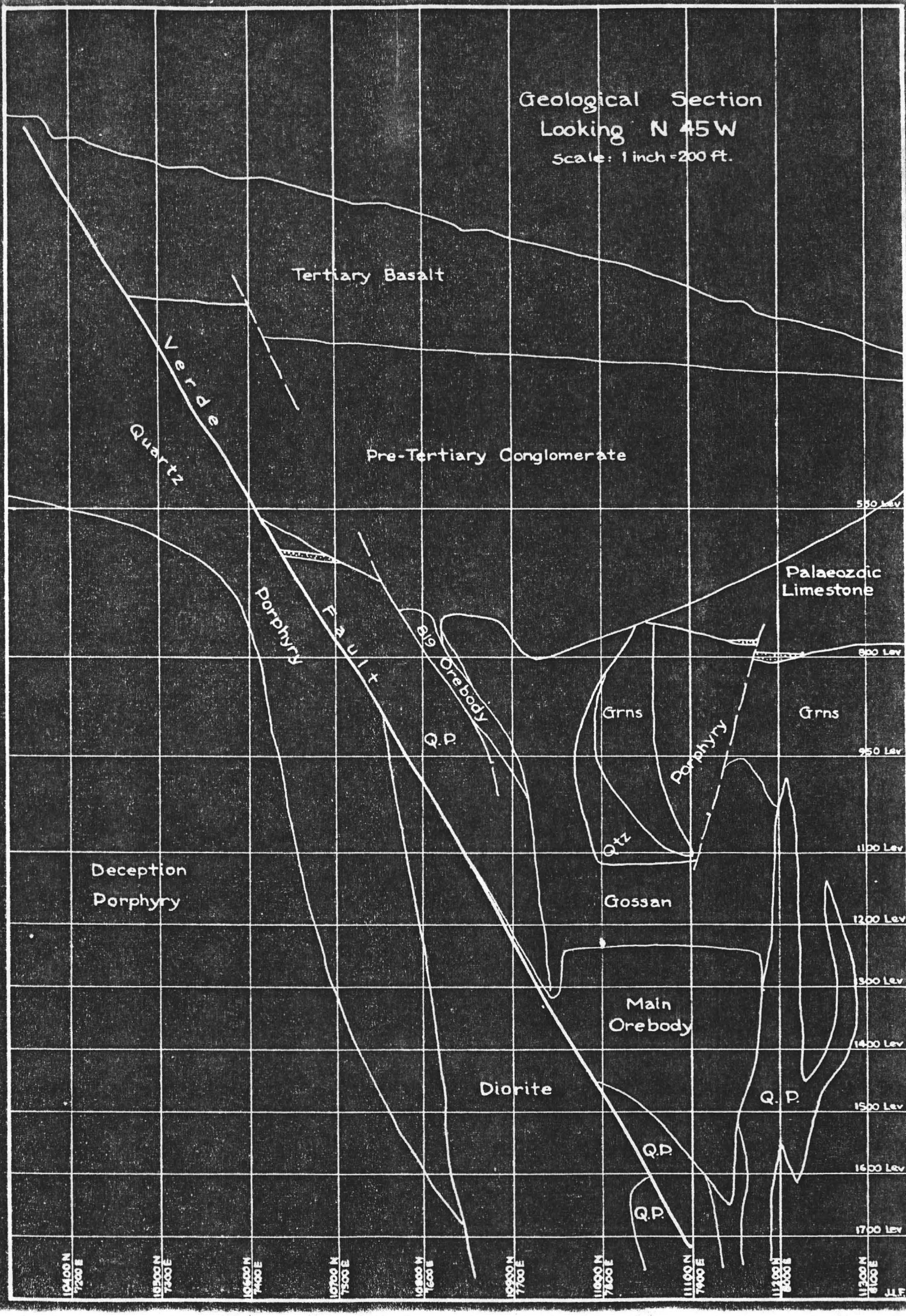
1. Mapping the surface particularly on those holdings which have the pre-Cambrian rocks exposed.

2. Making of sections through the ore zones and favorable areas.

3. Keeping the present geological maps up to date.

4. Making 40-scale geological level maps showing assays.


Geology
1400 Level
Scale: 1 inch = 400 ft.
13000 N
12000 N
11000 N
7000 E
8000 E
9000 E
10000 E
Q.P.
Quartz
Porphyry
Q.P.
Grns
Diorite
Q.P.
Greenstone
Rhyolitic
Diabasic
Quartz
Porphyry
Dio.
Q.P.
Greenstone
Diorite
Bedded
Sediments
Tuff
Flow
or
Sill
Quartz Porphyry
N
Q.P.
Rhy. Tuff
Q.P.
Ore
Diorite
Quartz
Porphyry
J.L.F.


Geological Section
Looking N 45 W
Scale: 1 inch = 200 ft.
Tertiary Basalt
Verde
Quartz
Pre-Tertiary Conglomerate
550 Lev
Palaeozoic
Limestone
Porphyry
Fault
Big Orebody
800 Lev
Grns
Grns
Q.P.
950 Lev
Porphyry
Qtz
1100 Lev
Deception
Porphyry
Gossan
1200 Lev
1300 Lev
Main
Orebody
1400 Lev
Diorite
Q. P.
1500 Lev
Q.P.
1600 Lev
Q.P.
1700 Lev
10400 N 7200 E
10500 N 7300 E
10600 N 7400 E
10700 N 7500 E
10800 N 7600 E
10900 N 7700 E
11000 N 7800 E
11100 N 7900 E
11200 N 8000 E
11300 N 8100 E
J.L.F.

PART 11.

EXPLORATION

General — With the geology accurately unraveled, it is not difficult to determine the places that should be prospected and to eliminate those that are without prâmise. The geological maps show that the only place that fulfills the conditions I have outlined above as essential for ore deposition is at the site of the present known orebodies. This does not mean that there is not a good chance of finding more ore. Numbrous places in the ore zone have not been prospected, while the complications resulting both from the post-Tertiary faulting and erosion afford additional areas worth testing.

For convenience and clearness, I have divided the following discussion of future exploration work into three groups, depending on its location with respect to the Verde, or Main, fault, as follows:

1. The hanging wall country
2. The fault zone.
3. The foot wall country.

Hanging wall country. — 1. The most favorable place to prospect in the hanging wall country is in gossan areas.

In the past few years, these areas have added considerable tonnage to the ore reserves and undoubtedly they will add more as prospecting continues.

2. The quartz porphyry and greenstone schists south of the Main orebody, both inside and outside the Verde fault zone, deserve to be prospected thoroughly. It is likely that enough tonnage of lower grade carbonate ores will be found to warrant the installation of a leaching mill.

3. It is a fact that the Florencia fault cuts off the eastern tip of the Main orebody. This faulted-off tip probably is not large though it might prove to be large enough to mine at a good profit. The only drawback against blocking out this ore is that it lies in the Florencia claim.

4. Some prospecting is warranted near the surface in limestone areas. The 502-Stope orebody occurs in brecciated limestone on top of a small slip which acted as a guide for the copper-bearing solutions. Considering the small size and apparent unimportance of the shear zone that was responsible for the 502 orebody, it is not impossible that the Florencia fault, with its larger shear zone, should be the locus for a similar carbonate orebody. The distance from the stope to the Florencia fault is about 50 feet.

<u>Summary of Recommendations.</u> With reference to the hanging wall region, the following recommendations are offered:

1. Gossan areas
   a. Continue 821, 824, 902-W, 903-Int., and 911.
   b. Go North and South on the vein gossan from 806 drift.
   c. Go North along vein from 1340.

2. Region South of Main orebody
   a. Continue 1119-B and 903-Int.
   b. Go east from 822 face.

3. Florencia fault
   a. Go Northeast along Florencia fault starting at intersection of fault with 1520-S drift.

4. Favorable limestone areas
   a. Crosscut North from 502-Stope to the Florencia fault.

The following headings are outside of favorable areas and should be discontinued permanently:

1. 909-N, 909-E, 909-W, and 909-Crosscut.

2. 1413 and 1415.

3. 1520-S.

4. 1713 and 1713-W.

5. 1715.

<u>Fault zone country.</u> In view of the information which we now have concerning the movement along the Verde fault, prospecting in the fault zone should be limited to the region between the Florencia claim and the North

corner of the Little Daisy fraction. A large part of this country has been well prospected, but there remain a few places which justify additional work. It is certain that we have never looked in the right place for the downward extension of the United Verde Hermit orebody or for the faulted-off portion of our vein orebody.

1. The United Verde Hermit orebody is believed to be a faulted-off sliver from the United Verde Extension Main orebody. It is possible that this valuable ore-shoot, which is developed on the 500 level of the United Verde mine, may continue downward far enough on its dip to get into Extension ground, and this possibility is worth testing. But it is probable that it may never have been big enough to have extended to such depth. The gamble is worth while regardless of theory because one guess is as good as another, and if the ore should be found, the reward would be large.

2. In 1425- Crosscut, which extended part way through the fault zone, a ten foot width of low grade massive pyrite was found lieing just west of the hanging wall gouge of the Main fault. There is a good chance that this represented the southern tip of the faulted-off part of the Vein

orebody. Whether this proves out to be correct or not, it is certain that the proper place to look is the fault zone Northwest of the place at which it lies along the hanging wall gouge. More prospecting should be done North of 1425 crosscut.

3. Other favorable areas in the fault zone are to be found in the sheared rocks more or less near the Main orebody or gossans, such as the 1119-B country. In these places secondary copper minerals have been deposited by solutions which came from above and found the fault zone as good channel in which to circulate.

Recommendations. With respect to work in the fault zone, the following recommendations are offered:

1. Hermit orebody
   a. Continue 824-Crosscut to the fault.

2. Vein orebody
   a. Go Northwest from 1425-Crosscut, along the hanging wall gouge of the Main fault.

3. Other areas
   a. Go South from 822 and 906-S faces.
   b. Go Southwest to the fault from 1208.
   c. Prospect fault zone between 1246-Stope and 1221 crosscut. Also Southeast of 1246-Stope.

Footwall country. The country West of the Main fault is not at all promising as far as United Verde Extension ground is concerned, but there are three pieces of work that are certainly justifiable.

1. The root of the Main orebody probably lies on the Daisy claim of the United Verde Copper Company. However, so little is known about the various rock contacts in that vicinity that we are justified in doing some work on the Windlass claim on the 1700 level. If the diorite here has a big embayment in it, as is possible, there is a likelihood that this root may at some place pitch through United Verde Extension ground.

2. The tongue of black schist on the Copper Chief claim should be prospected in depth in spite of the fact that it shows no mineralization at the surface, because black schist occurrences are so often related to orebodies that the same solutions which furthered their formation were responsible for the orebodies of the district.

3. The work which aims to find the intersection of the Hull fault with the Main fault will definitely settle whether or not the Hull and Florencia faults were once the same. If they were the same, there is a chance of finding ore.

Recommendations. The following recommendations dealing with work in the footwall of the main fault, are offered:

1. Root of the main orebody
   a. Continue 1716 work.
   b. Continue 1210-N work.

2. Copper Chief black schist area
   a. Continue 1221-A but turn it to go Southwest, or else diamond drill the favorable ground.

3. Hull fault
   a. Continue the No. 7 Tunnel drift along the Verde fault.

The following headings are thought to be in unfavorable ground or duplicating other headings and should be discontinued:

1. All 819 work.
2. 1221-C
3. 909-South and 908-North.
4. 1210-South.
5. No. 7 Tunnel crosscut.

Report

on the Geology of the

UNITED VERDE EXTENSION MINE

By

F. L. RANSOME

1928

Consulting Geologist
1201 E. California St.
Pasadena, California.

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ILLUSTRATIONS

REPORT ON THE UNITED VERDE EXTENSION MINE

By F. L. Ransome

PURPOSE AND SCOPE OF THE EXAMINATION

At the request of Mr. J. S. Douglas, President of the United Verde Extension Mining Company, I arrived in Jerome early in July, 1927 and, with the exception of about 28 days occupied by two trips to Oregon, was continuously at work, until the middle of December, engaged in a study of the United Verde Extension Mine and the immediately surrounding district. The particular purposes of the examination were: (1) to ascertain whether there is any probability of a downward continuation of the main ore body within the boundaries of the Company's property; (2) to appraise the possibility or probability of the existence of other ore bodies of comparable size within the Company's ground; and, finally, (3) to suggest directions for future major development. No detailed instructions were drawn up for this work and no time limit was placed upon it.

It appeared to be the opinion of Mr. Douglas, with which I concurred, that the members of the resident mine staff were fully capable of finding all of the ore within the known ore-bearing territory of the mine, their intimate knowledge of the workings and of the behavior of the known ore-bodies being such as no new-comer, occupied for only a few months with the broader geological features, could hope to attain. Nevertheless, it was reasonable to expect that there would result fron my work at least some suggestions concerning what may be termed minor or secondary exploration and these I shall make in the appropriate place. Inasmuch as I hope later to publish a paper on the geological features of the Jerome district, I shall confine myself in the present report to a brief outline of those conditions that have a direct bearing upon the practical questions with which the report is primarily concerned.

In the present study of the mine, none of the previous geological work was accepted without verification. I examined all accessible parts of the underground working, in the hope that in the generally more or less schistose rocks, some structure might be recognized, which would prove to have a significant relation to ore deposition. This hope was only partly fulfilled. I found that, in general, the earlier mapping has been faithfully and accurately carried out. Where there is disagreement with it, this is usually a question of interpretation rather than of record. In my opinion, however, the 100-foot-scale geologic level maps, in general use in the Company's office, embody far too extensive imaginative projection into areas where there are no underground workings. Such maps, displaying much that is conjectural without distinction from what is fairly well established, may be useful for special purposes but are likely to be misleading as general working guides.

In the course of the mine examination a collection was made of over 400 specimens, chiefly rocks. The specimens have been labelled, cataloged and indexed and should be useful in future geological and developmental work, especially as some of them come from places that will soon be no longer accessible.

No geological level-maps have been prepared to accompany this report as such work would require considerable time and can, in the light of my report and collection, be done by members of the regular staff, if desired. If the Company wishes, however, I will willingly undertake to prepare revised geologic maps or to render such aid as may be necessary for their preparation.

Throughout my stay at Jerome I enjoyed the most cordial cooperation on the part of all connected with the United Verde Extension mine and acknowledge with particular appreciation the helpfulness of Mr. Olaf Hondrum, chief engineer, and the members of his staff.

GENERAL GEOLOGY OF THE DISTRICT

The most comprehensive and detailed account of the geology of the Jerome district is that by Reber [1], which has been supplemented by later papers by Fearing [2], and Lindgren[3].

It suffices here to state that the fundamental rocks of the district constitute a complex of schists and intrusive rocks of pre-Cambrian age which had their present characteristics imposed upon them by the folding and metamorphism of that early era. They constitute the roots of pre-Cambrian mountains, which, however, had been worn down by erosion to a nearly level surface at the beginning of the Cambrian. The principal ore deposits were formed before the completion of this period of erosion.

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[1] Reber, L. E., Geology and ore deposits of Jerome district: American Inst. of Min. and Met. Engineers, Trans. vol. 66, pp. 3-26, 1922.

[2] Fearing, J. L. Jr., Geology of the Jerome district, Arizona; Economic Geology, vol. 21, pp. 757-773, 1926.

[3] Lindgren, W. Ore deposits of the Jerome and Bradshaw Mountains quadrangles, Arizona; U.S. Geol. Survey, Bull. 782, pp. 54-97, 1926.

In Cambrian time, the region sank below the sea and was covered successively by the dark red basal sandstone of the region, which is here supposed to be the equivalent of the Cambrian Tapeats sandstone of the Grand Canyon, altho some geologists consider that it may be of Devonian age.[1] The basal sandstone, of variable thickness but attaining a maximum of about 100 feet, is overlain successively by from 600 to 1000 feet of Devonian and lower Carboniferous limestone and by red sandstones and shales, up to 500 feet thick, of Permian age - the Supai formation.

After a long period of erosion, the region was covered in late Tertiary time by basaltic flows, which accumulated to a thickness of over 700 feet. The eruption of the basalt was followed by normal faulting and by the erosion that has shaped the topography of today.

The primary or hypogene mineralization, which produced the ore bodies of the United Verde and United Verde Extension mines in their original form, and practically all of the downward or supergene enrichment, which resulted in the remarkable main ore body of the United Verde Extension mine, took place before the deposition of the basal sandstone. The ores of these mines are consequently pre-Cambrian or pre-Devonian, according to the opinion held as to the age of the sandstone.

Inasmuch as the stratigraphy of the Paleozoic formations has no bearing on the problems dealt with in this report, no particular study was made of these rocks.

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[1] See Fearing, J. L. Geology of the Jerome district, Arizona; Ec. Geol., vol. 21, pp. 758-759, 1926.

The general surface distribution of the more important rock units or groups in the part of the Jerome district adjacent to the principal mines, is shown in Plate I.

PRE-CAMBRIAN FORMATIONS

With few exceptions the pre-Cambrian rocks are more or less schistose and have been considerably metamorphosed by the close folding and compression and by the igneous intrusions of pre-Cambrian time. Some of them are completely recrystallized into fine-grained schists that contain no vestige of their original texture or mineral composition. Consequently it is not surprising that various geologists, attempting to subdivide them, have differed in opinion as to their original character and appropriate nomenclature. As a whole they belong to the group of rather diverse metamorphic rocks that on general maps of the region have been designated Yavapai schist. They are so represented, for example, on the geological maps of the Jerome and Bradshaw Mountain quadrangles, which accompany Lindgren's[1] recent report on those areas.

Locally, attempts have been made to divide the pre-Cambrian rocks at Jerome into a number of units.

Reber, in the paper previously referred to, divides the principal pre-Cambrian rocks as follows, the younger rocks being at the top:

(4) United Verde diorite. (Intrusive)

(3) Quartz porphyry. (Later known as Cleopatra porphyry. Intrusive)

(2) Bedded sediments.

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[1] Lindgren, W., Ore deposits of the Jerome and Bradshaw Mountain quadrangles, Ariz., U.S. Geol. Survey, Bull. 782, 1926.

(1) Greenstone complex. (Includes what was later called "Deception porphyry" by Finlay.)

Reber considered the "greenstone complex" as consisting chiefly of metamorphosed volcanic flows and pyroclastic rocks with minor bodies of intrusive rock. His "bedded sediments" are described as consisting of a great variety of materials, among which he mentions quartzites, slates, conglomerates and one bed of "limestone or marble" up to 20 feet thick. The "quartz porphyry" he regarded as intrusive and probably an offshoot from the Bradshaw granite, which is extensively exposed south of the Jerome district. The "United Verde diorite" is characterized as an "augite diorite with diabasic phases."

Fearing, in the paper previously cited, maintains that the "Deception quartz porphyry" should not be included in the "greenstone complex" but, like the "Cleopatra quartz porphyry" is an intrusive sheet or sill, the "Deception quartz porphyry" being the older of the two. He divides the remainder of the "greenstone complex" as follows:

Basic tuff - - - - - - - - - - - - - - - - -	Not fully exposed.
Diabase flow or sill, often of dioritic texture - - - - - - - - - -	- 1200 feet.
Andesitic or diacitic tuff - - - - - - -	0 - 200 feet.
Rhyolite tuff - - - - - - - - - - - - - -	- 600 feet.
Bedded shale or ash - - - - - - - - - - -	0 - 70 feet.
Basic tuff - - - - - - - - - - - - - - -	Not fully exposed.

I regret to state that, in my opinion, this section is wholly unreliable. It appears to have been based on measurements across the prevailing <u>schistosity</u> in a c ross-cut in the United Verde mine, but this cross-cut affords no satisfactory basis for the nomenclature or thicknesses given by Mr. Fearing. His statement that these divisions have been mapped in the workings of the United Verde Extension mine is not supported by any maps known to me. They certainly do not all appear in the figure to which he refers on page 763 of his paper, which is a map of the 1400 level of that mine, altho in that illustration he represents as "rhyolitic tuff" rock which on the maps prepared by him for the company he shows as "acid volcanics".

Enough has been presented to indicate that there is considerable diversity, if not confusion, in the nomenclature applied to the pre-Cambrian rocks (See figure 1.)

My own observations lead to the conclusion that there are five, possibly six, major groups of rocks involved in the pre-Cambrian complex as exposed in the central part of the Jerome district. These, beginning with what is probably the oldest are as follows:

(1) <u>WALNUT SPRINGS GREENSTONE</u>. The rocks of what it is here proposed to name the <u>Walnut Spring Greenstone</u> are typically exposed at and near the swimming pool near Walnut Spring. They comprise two principal varieties, both greenish gray on fresh exposures. One variety is fine-grained, more or less schistose rock, which is characterized by wavy, discontinuous banding. The other variety is coarser-grained, less noticeably banded and shows grains or phenocrysts of quartz. The two varieties are intimately associated, and the coarser variety near the contact with the finer-grained variety, contains fragments of the latter. Other varieties of the Walnut Spring greenstone, especially when weathered, have some resemblance to altered tuffs.

Under the microscope, the fine-grained variety is recry-

Nomenclature of rocks in the Verde District, Ariz.

Present report.	Reber, 1920.	Fearing, 1926.	Current usage, United Verde Mine.	Current usage, U. V. X. Mine.
Walnut Spring greenstone. (Banded rhyolite flows).	Bedded sediments.	Greenstone, including some sedimentary material.	Bedded sediments.	Greenstone; Quartz porphyry in part.
Gold Hill rhyolite. (Felsitic rhyolite flow or flows. Few or no quartz phenocrysts.).	Greenstone.	Greenstone.	Greenstone.	Greenstone; Acid volcanics. "Bedded sediments" where greatly sheared.
Deception rhyolite. (Flow or flows. Quartz phenocrysts small and sparse).	Greenstone.	Deception quartz porphyry (Intrusive.)	Fragmental greenstone.	Deception porphyry.
Cleopatra rhyolite. (Probably mainly a flow or flows. Quartz phenocrysts abundant)	Quartz porphyry. (Intrusive).	Cleopatra quartz porphyry.	Quartz porphyry.	Quartz porphyry. Cleopatra porphyry.
Verde diorite. (Intrusive)	United Verde diorite. (Intrusive).	United Verde diorite. (Intrusive).	United Verde diorite.	Diorite.
Diabase.	Greenstone.	Diabasic greenstone. (Flow or sill).		Greenstone.

stallized to a finely crystalline aggregate of quartz, sericite and some epidote and chlorite. It is more siliceous than might be supposed from the general appearance of the rock and contains (Spec. U. V. X. 8) 72.4 per cent of $Si\ O_2$ and 1.8 per cent of $Ca\ O$.[1] The coarser variety (Spec. U. V. X. 143) contains quartz phenocrysts as large as those commonly present in the Cleopatra rhyolite. The texture of the rock, as seen under the microscope, suggests the possibility that it may be a tuff but field relations indicate that it probably is a devitrified glassy rhyolite with abundant included fragments - a flow breccia.

This rock contains 73.2 per cent of $Si\ O_2$ and 2.6 per cent of $Ca\ O$.

On the supposition that the banding of these rocks is indicative of sedimentary bedding, they were termed "bedded sediments" by Reber and are so mapped in the United Verde mine. In the United Verde Extension mine, the finer-grained variety has generally been mapped as "greenstone" and the coarser-grained variety, at least in part, has been mapped as "quartz porphyry". I regard them as metamorphosed rhyolite flows, the banding being interpreted as flow-lines in an originally glassy lava. The inclusions of the finer grained variety in the coarser variety are not readily explainable if these rocks are sedimentary but can be accounted for, if the rocks are rhyolite, as fragments of previously solidified lava caught up in parts of the flow that congealed later or in a subsequent flow.

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[1] These and other chemical determinations cited in this report were made by Mr. S. H. English, chemist at the United Verde Extension smelter, at Clemenceau.

The name <u>greenstone</u> is commonly applied to altered volcanic rocks of more basic composition than the rocks here described but the name is appropriate so far as color is concerned and has become a familiar term in the district. These considerations appear to justify its retention.

(2) <u>GOLD HILL RHYOLITE</u>. The formation termed in this report the <u>Gold Hill rhyolite</u> is exposed in Deception Gulch from near the Gold Hill tunnel, whence it derives its name, for a distance of about 1000 feet eastward. The rock of this area generally weathers brown and is brownish gray on fresh fracture. As a rule, it is not noticeably schistose, but locally some schistosity is developed and in such places the rock may be greenish gray. Contorted flow lamination is conspicuous in some exposures in Deception Gulch. Quartz phenocrysts are rare or absent but the microscope shows abundant quartz in the groundmass of the rock. Small phenocrysts of orthoclase or sanidine are fairly abundant, usually associated with phenocrysts of a sodic plagioclase. The rock is a more or less altered glassy rhyolite, probably erupted as a flow or flows. In places it shows distinct flow brecciation.

The Gold Hill rhyolite does not appear to have been distinguished previously as a separate formation and is known at the surface only at the type locality in Deception Gulch. It is in every respect, however, identical with the rock that, in the United Verde Extension mine has usually been mapped as "acid volcanics", when any separation of the "greenstones" has been attempted. Chemical determinations on a specimen (U. V. X. 168) from the United Verde Extension mine gave 71.4 per cent of $Si\ O_2$

and 0.9 per cent of Ca O.

(3) <u>DECEPTION RHYOLITE</u>. The rock described in this report as <u>Deception rhyolite</u> is typically exposed in the rugged gorge through which Deception or Walnut Creek flows east of the Verde Central mine. It is separated from the Gold Hill rhyolite by a belt of Cleopatra rhyolite (next to be described) which in Deception Gulch is about 2500 feet wide from east to west.

The Deception rhyolite is generally a rather roughly schistose rock which is greenish gray on fresh fracture and weathers brown. As a rule it contains small, rather sparsely distributed and somewhat angular phenocrysts of quartz. Near the contact with the Cleopatra rhyolite, as may be seen on the pipe-line on Cleopatra Hill, it has a distinctly brecciated character which is strongly suggestive of flow brecciation. There is no evidence that the Deception rhyolite is intrusive but much to suggest that it is an originally glassy rhyolite flow which has been rendered schistose and has undergone considerable metamorphism. In microscopic character and in many exposures underground it closely resembles the Gold Hill rhyolite and may be a more metamorphosed variety of that rock. Chemical determinations made on a specimen of Deception rhyolite (U.V.X. 72) gave 75.6 per cent of Si O_2 and 0.3 per cent of Ca O. On another specimen (U.V.X. 49) the results were Si O_2 74.0 per cent, Ca O 0.3 per cent.

The Deception rhyolite was included in the "greenstones" by Reber, altho he remarks that its character is open to question. Finlay named it "Deception porphyry" and Fearing, in the paper previously referred to, designates it as "Deception porphyry" and "Deception quartz porphyry". He regards it as an intrusive sill. Mr. Hansen, chief geologist of the United Verde mine, maps it as "fragmental greenstone", his view apparently being that the small quartz phenocrysts are fragmental grains and not true phenocrysts.

(4) CLEOPATRA RHYOLITE. The Cleopatra rhyolite is typically exposed on Cleopatra Hill and in Deception Gulch, in the general vicinity of the Verde Central mine. It is the "quartz porphyry", "Cleopatra quartz porphyry", or "Cleopatra porphyry" of the various reports on the Jerome district and of the geologic maps of the mining companies.

This rock shows considerable variation from place to place but its distinguishing characteristic is its abundance of easily visible quartz phenocrysts. In places, as on the east slope of Cleopatra Hill, the rock is schistose. In other places it is massive, the conspicuous quartz phenocrysts lying in a very fine-grained brown matrix that has every appearance of havine once been largely volcanic glass altho this glass has devitrified or become a very fine-grained aggregate of quartz and feldspar. In a number of places, particularly in Deception Gulch, along the western margin of the mass, between the Verde Central Mine and Walnut Spring, the rock is unquestionably a flow-breccia, in which fragments of previously solidified porphyritic rhyolite have caught up and carried along in still-liquid portions of the mass. Even where Cleopatra rhyolite shows no distinct brecciation, it exhibits streaky variations in texture that are strongly suggestive of movement in a viscous lava flow. In short, the Cleopatra rhyolite, as exposed on the surface, has the characteristics of a thick viscous flow certainly not those of a deep-seated intrusive mass.

In the mines, the apparent occurrence of some of the Cleopatra as lenses or isolated masses in the other pre-Cambrian rocks suggests that the rhyolite is intrusive. No convincing evidence of intrusion was found, however, and it is certain that some of the isolated bodies shown on some mine maps as "quartz porphyry" are not the Cleopatra rhyolite. It is entirely possible, moreover, that the main body of Cleopatra rhyolite may have been erupted as a flow while, at the same time, portions of the rhyolitic magma may have been intruded into the older rocks as dikes.

The eruption of the Cleopatra rhyolite probably occured long before the deposition of the ore bodies and consequently is not responsible for the copper mineralization in the Jerome district.

(5) VERDE DIORITE. It is generally accepted in the district that the Verde diorite is an intrusive mass altho this conclusion rests chiefly upon the character of the rock and its general relations to the other rocks rather than upon direct evidence of intrusion. The rock is a massive medium-grained angite diorite, which as a rule is considerably altered. Generally, as the rock is found in the mines, the augite has been altered to amphibole or to epidote, chlorite and carbonates, the feldspars are decomposed and considerable secondary quartz is present. As a rule the diorite is not schistose altho schistosity may be locally developed at its margins. Chemical determinations made on a specimen of fairly fresh diorite from the United Verde open pit (specimen U. V. X. 1) gave 49.8 per cent of $Si\ O_2$ and

8.6 per cent of Ca O.

(6) DIABASE. The rock here designated diabase has not been recognized at the surface and in the United Verde Extension mine is not present in the vicinity of any known ore body. Large masses of it have been penetrated, however, in the long exploratory drifts to the east and north of the Audrey shaft, in Jerome Verde ground, on the 1400 and 1700 levels. On the mine maps it has generally been shown as "greenstone" altho on his published map of the 1400 level (Economic Geology, vol. 21, P. 763, 1926) Fearing terms it "diabasic greenstone flow." The diabase is a generally massive rock of rather fine texture and greenish color. In thin section, under the microscope, it shows the characteristic ophitic texture of diabase with abundant augite. The plagioclase feldspars are decomposed and the rock contains much secondary epidote and chlorite. Chemical tests (U.V.X. 233) showed 46.2 per cent of $Si\ O_2$ and 5.6 per cent of Ca O. Without insistence upon any high accuracy for these determinations, it is clear that the rock is much more basic than the rhyolitic "greenstones" of the mine and is fairly close to the Verde diorite in composition. I could find no evidence for regarding it as a flow and am inclined to believe that it is intrusive and rather closely related to the Verde diorite.

It appears from the foregoing that the principal pre-Cambrian rocks of the central part of the Jerome district comprise 4 rhyolitic formations, namely, the Walnut Spring greenstone, the Gold Hill rhyolite, the Deception rhyolite, and the Cleopatra rhyolite, all of which are believed to have been erupted at the surface as flows, and two basic igneous rocks, namely the Verde diorite and the diabase, of which the diorite is intrusive and the diabase may be intrusive. So far as my observations go, there are no sedimentary rocks in the pre-Cambrian of the central part of the Jerome district. Certainly conglomerates, sandstones, shales and limestones are absent and it is at least doubtful whether any bedded tuffs are present.

Occasionally, in the following pages it will be convenient to refer collectively to the Walnut Spring greenstone, the Gold Hill rhyolite and the Deception rhyolite. Generally when the terms "greenstone" and "rhyolitic greenstone" are used they are to be understood as referring to any or all of the three rocks mentioned, without any attempt to distinguish between them.

By way of summary it may be stated, that in pre-Cambrian time the Jerome area was covered by a series of rhyolitic lava flows, erupted over a surface of older rocks which are not anywhere exposed in the district. Possibly some of the earlier flows were intruded by dikes, or even by larger bodies, of the magma that solidified as the Cleopatra rhyolite but that rhyolite as a whole is believed to have congealed on or very close to the surface as it existed at that time.

PRE-CAMBRIAN STRUCTURE

All of the pre-Cambrian rocks, except the Verde diorite and some of the diabase appear to have been closely folded in pre-Cambrian time. This folding was accompanied or followed by intense compression along nearly east-west lines so that the rocks were rendered schistose. It is, in general, this schistose structure, striking nearly north and standing nearly vertical, that is the most conspicuous structural feature of the rocks. Whatever original layering may have been present in the succession of rhyolitic flows has been obliterated or greatly obscured.

It is possible on the various levels of the United Verde Extension mine to map separately the Walnut Spring greenstone, the Gold Hill rhyolite, the Deception rhyolite, and the Cleopatra porphyry. When, however, an attempt is made to utilize these level-maps for the construction of geological cross-sections thru the mine, the distribution of these rocks is so different on successive levels as to exclude any simple structural explanation. The observed relations suggest that the rocks were intricately folded and perhaps faulted before they became schistose but it is very doubtful whether it would be practicable to show this structure in sections other than in a much generalized and largely imaginary fashion. It is to be remembered that all of these rocks are rhyolite, that they never had the regular stratification of sedimentary beds, that there are no persistent, readily recognizable "key" layers that would give a clue to the structure, and finally that the differences in character brought about in any one rock by the imposed schistosity are, as a rule, far more conspicuous than the original differences between the individual members of the rhyolitic series. Prolonged study might overcome the difficulties referred to, but it does not appear that the occurrence of ore is dependent upon these earlier and obscure structures in the "greenstones" and consequently there is no economic justification for persistency in an attempt to decipher them.

From the economic point of view the significant lithologic units are: (1) the rhyolitic "greenstones" as a whole (including the Walnut Spring greenstone, Gold Hill rhyolite, and Deception rhyolite), (2) the Cleopatra rhyolite, and (3) the

Verde diorite. It is the relative distribution of these three units, in conjunction with certain zones of shearing, that has determined the place of ore deposition.

LOCAL MODIFICATIONS OF THE PRE-CAMBRIAN ROCKS

Black schist - A large part of the ore of the United Verde mine occurs in a dark, schistose rock commonly referred to as "black schist". It is very fine-grained and much of it resembles a slate rather than an ordinary crystalline schist.

Reber described this rock, in his paper previously referred to, and apparently regarded it as a member of his "bedded sediments", altho he also states that it is probably a product of alteration by magmatic solutions that may have been closely related to ore deposition. Fearing[1] refers to the black schist as being almost entirely composed of ferruginous chlorite and states that the "Cleopatra porphyry", the "Deception porphyry", the "rhyolite tuff" and the "bedded sedimentaries" have all been "observed grading into black schist". Lindgren[2] ascribes the ferriferous chlorite of the black schist to the action of ascending solutions connected with ore deposition but suggests that the black schist may have been originally a slate of sedimentary derivation.

My own observations have convinced me that most of the black schist is intensely sheared and metamorphosed Cleopatra rhyolite. Some of it still retains residual phenocrysts of quartz and in a number of places all gradations can be found

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1 Loc. cit., p. 762

2 Loc. Cit., pp. 72 and 74

between Cleopatra rhyolite and black schist. The dark color is due to the development of the ferruginous chlorite referred to by the writers mentioned, this development being a phase of the same process of mineralization to which the formation of the hypogene ore was due. Possibly the other rhyolitic formations may, in places, have been altered to black schist. Such change would not be improbably, altho I have not seen any evidence of it.

Contact schist - In the United Verde Extension mine there is exposed on all of the main levels a belt of very fissile schistose rock which extends generally in a north-northwest direction from the main ore body and intervenes between the Verde diorite on the west and the Gold Hill rhyolite ("acid volcanic greenstone") on the east. This is the "bedded sediments" of the company's geological maps and the "schist related to ore deposition" of Mr. Lindgren's map.

This rock has generally been regarded as a distinct member of the pre-Cambrian group but, in my opinion is a local modification of the Gold Hill rhyolite and possibly, to a minor extent, of other members of the rhyolitic "greenstones". As a rule, it grades into the Gold Hill rhyolite with no definite contact, the fissile, crumpled "bedded sediments" gradually being succeeded by the more moderately schistose "greenstone". In a few places in the mine the Gold Hill rhyolite shows local schistose portions that undoubtedly would have been mapped as "bedded sediments" did they occur in the position where the main belt of this fissile is normally found. It is fairly certain that the "bedded sediments" of the United Verde Extension mine is merely a very strongly sheared portion of the Gold Hill rhyolite and, because of that shearing, the rock has been a path for oredepositing solutions. The rock has not only been squeezed to a finely laminated schist, in which all original texture has been obliterated, but on account of its thinly laminated character has been a zone of weakness along which later movement has taken place, as shown by the prevalent crumpling and distortion of the laminations.

As previously mentioned, the contact schist ("bedded sediments") generally follows the contact with the relatively massive diorite. It is believed to owe its structure to that fact, the Gold Hill rhyolite having yielded most readily to pressure where it was squeezed against the resistant diorite mass. Whether the Verde diorite exerted this pressure at the time of intrusion or was merely a passive mass against which the older rhyolitic rock was molded by regional pressure, I am unable to say. The fact that, at a few places, the contact schist does not appear to occur exactly at the contact with the diorite does not, I believe, invalidate this general explanation of its origin. It records zones of maximum yielding to stress with the accompaniment of rock flowage thru the development of an exceptional degree of schistosity.

GENERAL CONDITIONS THAT DETERMINED HYPOGENE ("PRIMARY") ORE DEPOSITION. 26

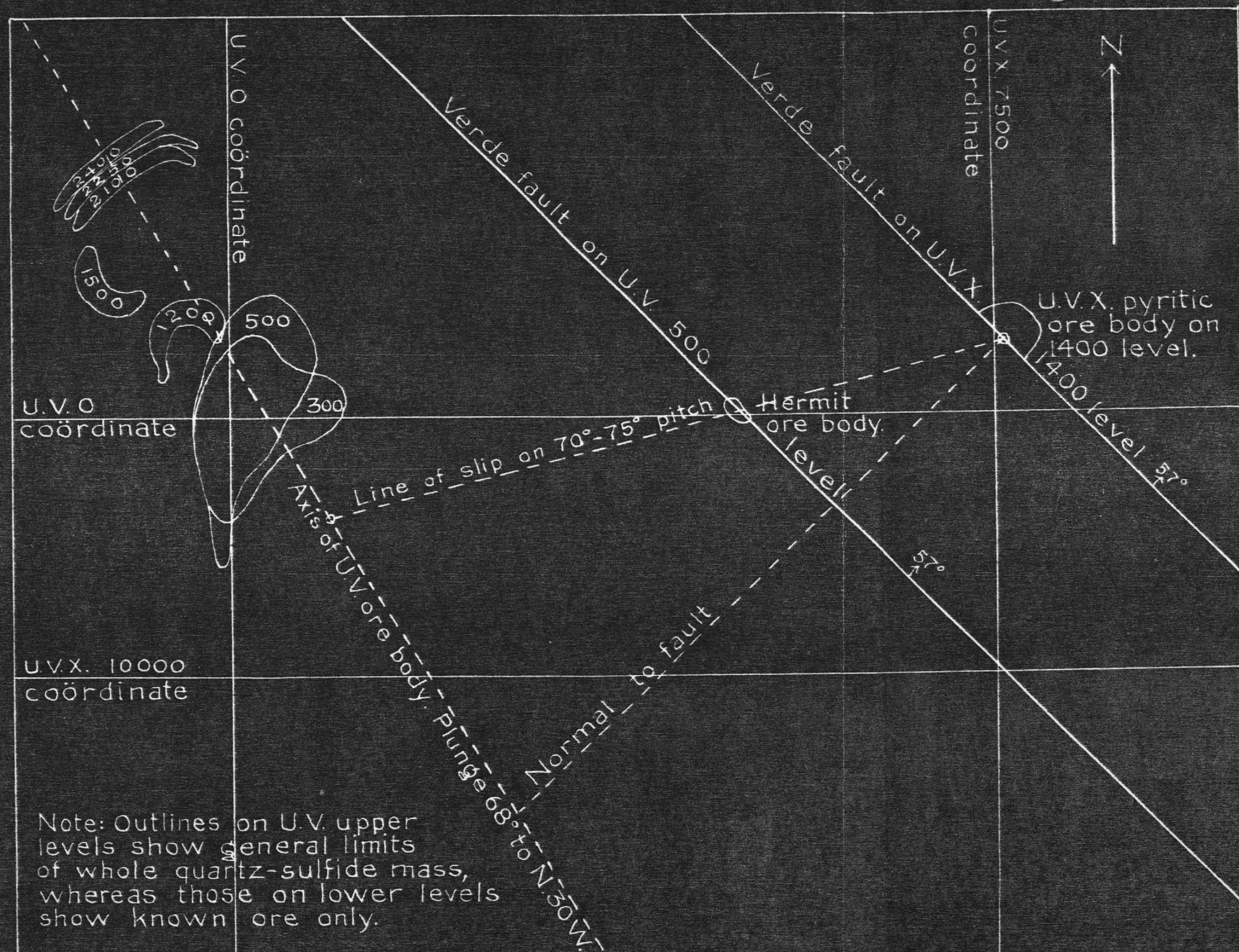
Examination of the general geologic map of the central part of the Jerome district shows that the ore body of the United Verde mine occurs where Verde diorite, Cleopatra rhyolite, and one or more of the rhyolitic greenstones come together. In a general way the United Verde ore body is limited on the northwest and west by the Verde diorite, on the south by the

Cleopatra rhyolite, and on the northeast by "greenstone". Examination of the map further shows that there is only one place in the district where the three rocks mentioned have this relative position. It is a highly suggestive fact that the only other large ore body found in the district, that of the United Verde Extension mine, has roughly the same general relation to the Verde diorite, the Cleopatra rhyolite and the "greenstone". As is well known, the two ore bodies lie on opposite sides of the great Verde fault, the United Verde ore-body in the footwall, to the west and the United Verde Extension ore body in the hanging wall, to the east.

Both ore bodies occur chiefly in Cleopatra rhyolite or in black schist, which is for the most part a local modification of the Cleopatra rhyolite. Of all the rocks in the district, the Cleopatra rhyolite appears to have been most susceptible to extensive replacement by ore, particularly where it has been sheared or fractured and where it is adjacent to the Verde diorite. That the diorite was an essential factor in the mineralization is certain. To the presence of the diorite mass were probably due the shearing and fissuring which gave passage to the ore-bearing solutions; the body of diorite, as a whole impervious and massive, forced the solutions to travel along its margin; finally, it is probable, altho not demonstrable, that the deeper portions of the dioritic magma, before its consolidation, supplied the iron, copper and zinc of the present ore bodies.

In the United Verde Extension ground the zone of contact schist represents the most important and continuous belt of shearing along the margin of the Verde diorite. It furnished a passage for the ore-bearing solutions and itself contains

Figure 2.



Horizontal projection on United Verde Extension 1400 level.

500 FEET TO 1 INCH

important ore bodies. The main ore body, however, was formed where this zone of shearing entered the Cleopatra rhyolite,

It happens, as is plainly shown on the mine maps, that this ore body lies, in a general way, at the intersection, and mainly within the angle, of the Verde and Florencia faults. These faults, however, appear to be wholly later than the original or hypogene mineralization altho they may have controlled to some extent the supergene enrichment that transformed the United Verde Extension ore body from what was probably a low-grade pyritic mass into the present large, compact and high-grade deposit of chalcocite.

RELATIONS OF THE UNITED VERDE AND UNITED VERDE EXTENSION ORE BODIES TO THE VERDE FAULT.

The course of the Verde fault (or, as it is sometimes called, the Jerome fault) is generally nearly northwest and southeast. The United Verde and United Verde Extension ore-bodies lie approximately on an east-west line, on opposite sides of the fault. The United Verde ore body, exposed at the surface, lies about 2000 feet west of the fault, in the footwall, the fault dipping to the northeast at about 57 degrees. The United Verde Extension ore body, as projected vertically to the surface, lies about 1500 feet east of the fault. (See figure 2)

The original exploration of the United Verde Extension ground appears to have been suggested by the conjecture that there might be, in the hanging wall of the fault, a segment sliced off from what was originally the upper part of the United Verde ore body. Later, however, geologists found that if the down-thrown block, containing the United Verde Extension ore-body, were slipped back until the base of the Paleozoic beds in the down-thrown block was restored to the same level as the base of the same beds in the footwall block, this movement, equivalent to a dip-slip of about 1900 feet or a throw of 1560 feet,[1] was not sufficient to place the United Verde Extension ore-body above the United Verde ore-body. Inasmuch as the faulting has been supposed to have occurred wholly in late Tertiary or Quaternary time, obviously the throw could have been no greater than the 1560 feet required to restore the base of the Paleozoic sedimentary beds to their original continuity of level. Therefore, it was argued, the two ore-bodies can never have been continuous and it followed that, somewhere in the footwall must be the downward continuation of the United Verde Extension ore-body, below the fault.

Drill-holes, cross-cuts and drifts in the footwall in the general latitude of the two ore bodies, failed to find the ore body sought. The idea was then advanced that the Verde fault might have a large horizontal component of movement. Mr. Searls, for example, thought that the hanging-wall block might have moved some 1500 feet southeast of its original position. Work done in accordance with this hypothesis also failed to find any ore in the footwall country. In this connection it may be pointed out that attempts to determine the horizontal component of the fault movement by matching particular rock masses on opposite sides of the fault can scarcely be successful. In the first place, the distribution of the various rocks in foot and hanging wall is not accurately known and, in the

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1 This is my estimate. Lindgren makes the throw 1620 feet and it has generally been considered to be about 1600 feet. F.L.R.

second place, the rock masses are of irregular form and their outlines, say on the 1500 level in the footwall, are likely to be considerably different from those 1560 feet higher, on the same side of the fault, with which the outlines on the 1500 level, in the hanging wall, must be compared to ascertain horizontal displacement.

Before further consideration of the possible relation of ore bodies on opposite sides of the fault, two questions should be answered. The first is - What is the relation of the main ore body of the United Verde Extension mine to the low-grade pyritic ore body of the lower levels? The second question is - Does the Verde fault cut off the United Verde Extension ore body as a whole?

With respect to the first question, it may be pointed out that on the 1500 level, the uppermost level on which the pyritic ore body has been approximately outlined, it is separated from the main ore body by about 120 feet. This intervening ground, however, has not been explored and the two ore bodies may actually join. This ground, moreover, is greatly disturbed and faulted and the apparent separation of the two ore bodies may be due to faulting. In any case, even if no considerable body of sulfides connects the main ore body with the pyritic ore body, it is reasonable to regard them as portions of one general zone of mineralization. I consider it highly probable, moreover, that the pyritic ore body represents the original character of the main ore body, before enrichment took place. Originally therefore, the path of the hypogene mineralizing solutions was upward thru the ground now occupied by the pyritic mass, into the ground now occupied by the main ore body. Both masses are parts of one great ore zone which as a whole pitches to the north or north-north-west, as shown in the projection of the ore bodies on the plane of the fault, which accompanies the report of Mr. Lindgren.

With respect to the second question, I believe that the United Verde ore zone, as a whole, is cut off by the Verde fault. Parts of the main ore body and of the pyritic ore body rest directly upon the gouge of the main fault and are obviously cut off. Other portions appear to die out before reaching the main fault and there is even a suggestion that the ore on the lower levels may be dipping to the northeast and continuing downward in approximate parallelism with the fault. This appearance is probably deceptive. It is evident on all the levels of the mine that the hanging-wall country for 100 to 150 feet northeast of the main gouge of the Verde fault is a zone of intense shearing and faulting, in which the relative displacement has been generally down, to the northeast. It is due to the complicated movements in this shear zone that portions of the main ore body disappear before they reach the main Verde gouge. They are cut off by minor faults within the shear zone. Furthermore, as the general pitch of the ore bodies as a whole is more northerly than the strike of the Verde fault, the south end of the ore body, which was also the enriched portion, was the first part to be cut off by the fault and does not appear on the 1700 level. The low-grade pyritic mass is at least about 230 feet long and 160 feet wide on the 1700 level and the body is known on the 1800 and 1900 levels but has not been developed fully on the latter two levels. If the northern limit of the mass, its dip and its pitch, were all known, some prediction might be made as to the probable extent of the pyritic body below the 1900 level and as to the position and attitude of the section along which it must be finally cut off by the Verde fault. These data, however, are not available. That the whole of the United Verde Extension ore zone is cut off by the Verde fault at generally increasing depths northward appears to be fairly certain.

If the United Verde Extension ore bodies are parts of one general zone of mineralization which rests as a whole on the footwall of the Verde fault, where is the continuation of this zone in the footwall country?

Mr. Lindgren, in his report to the company, expresses the opinion that the movement on the Verde fault is not far from a slip straight down the dup and that consequently the horizontal component is small. I fully agree with this. All exposures of the fault that I have seen show grooves and striations that pitch approximately 75 degrees to the south. He also consideres that the body of crushed, enriched ore mined in the United Verde mine on the 500 level, under the Hermit claim, is a fragment from the pyritic ore body of the United Verde Extension mine that has been left behind in the fault zone. This is highly probable. If so, it establishes the general direction of movement on the fault and shows the path that the United Verde Extension ore bodies must have followed in their descent from relatively higher levels at the time of faulting. That path points to a position south of the United Verde ore body but high above the present surface. In his published report[1] Lindgren says:

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[1] U. S. Geolog. Survey, Bull. 782, p. 87.

The suggestion has often been advanced that the large ore body may be the downfaulted upper part of the United Verde; but, as pointed out by Rickard and Finlay, this is improbable, because its trend and plunge are different and its projection upward, after allowing for the 1700 foot slip along the main fault, would bring it above the town of Jerome, or a long distance south or southeast of the United Verde body.

Quite true; but the United Verde ore body itself plunges 68 degrees to the north northwest and, if projected upward, to an intersection with the fault, would also be considerably south of its position at the present surface. We must consider, not the present top of the United Verde ore body, but the <u>former</u> top, now eroded away, where it was cut off by the fault.

It is highly significant that the general geological environment of the United Verde ore body is the same as that of the United Verde Extension ore body and that this association of rocks occurs nowhere else in the district. When this particular grouping of "greenstone", Cleopatra rhyolite and Verde diorite is found on opposite sides of a great fault it is difficult to avoid the conclusion that the duplication of conditions is due to the separation by faulting of what was once continuous.

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The United Verde Extension ore body was plainly cut off from its former downward continuation. Extensive exploration of the footwall, extended far northwest and southeast of the region of its probable occurrence, has failed to discover any other root than the United Verde ore body. Furthermore, very extensive exploration in all directions from the United Verde Extension ore body has not brought to light any down-faulted top of the United Verde ore body, unless it be the Extension ore body itself.

The main ore body of the United Verde Extension mine, having undergone extensive supergene enrichment to a mass now largely chalcocite, is of course very different from the hypogene, enriched ore of the United Verde; but the low grade pyritic ore body, with considerable sphalerite, is identical in character with much low-grade material to be found in the United Verde mine. It is to be remembered that the great sulfide mass of the United Verde is only in relatively small part ore. Moreover, it is reported that some of the upper levels of the United Verde mine contained little but such lean sulfides. Consequently, the fact that the pyritic ore body on the lower levels of the United Verde Extension mine is not as rich in copper as the ore of the United Verde is no proof that both bodies could not have originally been parts of the same continuous sulfide mass.

In order to test the suggestion that the United Verde Extension ore body has been faulted off from the top of the United Verde ore body, and to check rough calculations previously made, a simple model of paper and cardboard was constructed to the scale of 500 feet to the inch. The base of the model was taken as the 1700 level of the United Verde Extension, elevation 3409 feet. It was assumed that the Verde fault is a plane and that its trace on that level is a straight line coursing north 45 degrees west. It was assumed that the pyritic ore body on the 1700 level is about one half of the area before faulting and consequently that a point at coordinates 11400 N. and 7550 E. could be taken as the center point of this particular horizontal section of the original pyritic ore body. The fault was assumed to have a uniform dip of 57 degrees. The plunge of the United Verde ore body (the vertical angle between a horizontal plane and the longest axis of the ore body) was taken as 68 degrees. The direction of plunge was estimated at north

30 degrees west. Of course these various assumptions are not strictly accurate and take no account of possible variations in the dip and strike of the fault or in the angle and direction of plunge of the United Verde ore body. Furthermore, the position of the inclined axis of so irregular a body as the United Verde sulfide mass is not a matter susceptible of precise determination. On the whole, however, the assumptions made appeared to be as close approximations to fact as could be represented in a simple model.

It was found, under these conditions, that the Verde fault cut the inclined axis of the United Verde ore body at a point about 4000 feet above the 1700 United Verde Extension level, or at an elevation of 7409 feet. Projected downward, this point would fall about 600 feet southeast of United Verde zero coordinate point. This would require a throw on the Verde fault of about 4000 feet. A line drawn from this point of intersection of the Verde fault with the axis of the United Verde ore body to the assumed central point of the pyrtic ore body on the 1700 United Verde Extension level, obviously defines the direction of slip, in the plane of the fault. (See figure 2) It was found to have a pitch between 70 and 75 degrees, to the southeast, which accords closely with actual observations on the fault striations. Furthermore, this line passes directly thru the plotted position of the Hermit ore body of the United Verde mine, thus not only confirming the suggestion made by Mr. Lindgren, that this body is "drag" from the United Verde Extension pyritic ore body, but also showing that it may be regarded as ore faulted down from a part of the United Verde ore body that has long since been removed by erosion.

In addition to the direct evidence presented for the original continuity of the United Verde and United Verde Extension ore bodies, there is another consideration that has weight as one link in a chain of cumulative evidence. On opposite sides of the strongest fault in the Jerome district occur the only two large ore bodies known in the district. They were originally of similar character and have a similar relation to adjacent rocks. The one in the hanging wall is plainly cut off by the fault and is in such a position that it may have been faulted off from the ore body in the footwall. It would certainly be a remarkable coincidence if the only two great ore bodies in the district had such a suggestive relationship and were nevertheless entirely independent of each other.

Up to this point, all of the evidence considered indicates that the United Verde ore body and the United Verde Extension ore body were once continuous. There is one feature, however, that may, by some, be regarded as antagonistic to this view. This is the necessity of accepting the view that the movement on the fault took place at two widely separated periods. It has been shown that a reversal of throw on the fault, of about 1600 feet, would restore the base of the Paleozoic sandstone in the down-dropt block to the position of its original continuity with the same sandstone, above the United Verde pit. Consequently, the post-Paleozoic (presumably late Tertiary or ~~Ea~~Quaternary) faulting is limited to a throw of 1600 feet. On the other hand the throw necessary to replace the United Verde Extension ore body on top of the United Verde ore body, is at least 4000 feet. The only escape from this dilemma is to concede that the fault began in pre-Cambrian time, with a total throw of 2400 feet.

It was apparently immobile thruout Paleozoic and Mesozoic time but was revived in Late Tertiary or ~~In~~Quaternary time, after the basaltic eruptions, and acquired a further throw of 1600 feet.

That such behavior is possible is shown by the Bright-Angel fault in the Grand Canyon, which was described by me in 1908.[1] This fault, in pre-Cambrian time, had a throw of at least 300 feet, the block on the west being dropt relatively to that on the east. After the deposition of the whole Paleozoic series there was a smaller movement on the fault, this time in the reverse direction. Other faults are also known in the Grand Canyon region which show a similar renewal of movement after long periods of quiescence.

The supposition that there were two distinct periods of movement on the Verde fault, separated by a period of inactivity finds some additional support from the occurrence at two places, one on the 500 level of the United Verde, the other on the 1900 level of the United Verde Extension, of calcitic vein material that appears to have replaced ~~cruslit~~ crusht diorite. This vein material may represent the original pre-Cambrian gouge, of which only fragments have survived the c rushing and grinding of the later period of movement.

On the whole, altho there is admittedly an element of improbability in the explanation of two-period faulting, this element is believed to be outweighed by the evidence previously adduced in support of a throw of 4000 feet.

It is concluded that the United Verde and United Verde Extension ore bodies were originally one and that they have been separated by a throw of about 4000 feet on the Verde fault.

[1] Science, vol. 27, pp. 667-669, 1908.

PRACTICAL CONSEQUENCES OF THE CONCLUSION THAT THE TWO ORE BODIES WERE ORIGINALLY ONE.

The most direct and obvious conclusion to be derived from the foregoing discussion is that the United Verde Extension mine, so far as concerns known ore bodies, has a definite bottom on the Verde fault. Furthermore, the conclusion that the district contained originally only one large ore body, which occurred where the rocks have a certain unique relative distribution, diminishes the probability that other large bodies will be found in depth, within the United Verde Extension ground. The company's territory northeast of the Verde fault is covered by Paleozoic beds, overlain in part by basalt. The character and distribution of the pre-Cambrian rocks in this area are imperfectly known. Nevertheless it is traversed by the Josephine tunnel and by a number of long drifts and c ross-cuts, none of which has shown any important mineralization. While no one can be certain that long-range underground prospecting from the United Verde Extension mine may not open up an ore body, I can see no probability of such an event. By "long-range prospecting" is meant such work as the 1904 and 1320 S. drifts, not to mention many drifts previously run to the north, east and south, particularly on the 1200 and 1400 levels. Apparently the best chance of adding to the known ore reserves lies in continued exploration of the Cleopatra rhyolite ground south of the Florencia fault with a view to picking up offshoot or fringing bodies from the main ore body; in searching for residual masses of chalcocite in the great gossau areas of the upper levels; in more thoro exploration of the margin of the main diorite mass; and possibly by following down the pyritic ore body below the 1900 level in the hope of finding some chalcopyrite ore above the Verde fault. I should expect to find this pyritic plunging steeply to the north-northeast. Whether it will be advisable to follow it down to the fault by an inclined winze from the 1900 level or by sinking the Edith shaft another 100 feet and cross-cutting, is a question to be determined by the engineering staff.

MISCELLANEOUS SUGGESTIONS FOR PROSPECTING

The contact schist ("bedded sediments") has been found to contain important vein-like ore bodies on levels above the 1400 level. The recognition of this schist as a local modification of the "greenstones" around the margin of the diorite, rather than as an original distinct formation, having no genetic connection with the diorite, leads to the suggestion that the principal zone of this rock, instead of continuing northwestward as indicated on the company's geological maps, may curve around the northern end of the diorite mass (for example, in the regions 11900 N. and 7000 to 7300 E. on the 950 and 1100 levels; 1200 N. and 7100 - 7200, on the 1200 level; 11,900 N. and 7100 E. on the 1300 level; and 12000N. and 7200 to 7400 E. on the 1400 level,) and contain one or more ore bodies. In general it will probably be advisable to leave no large portion of the margin of the principal diorite mass, including,the rock adjacent to the contact, unexplored. The greater number of the important ore bodies found in the United Verde Extension mine, as well as in the United Verde, have had a marginal position with reference to the diorite or have occurred in shear zones within it. There are certainly very few that are not at some point in contact with or very near that rock.

The ore bodies that occur within the diorite mass, such as 1407 and 1307 A. are generally in such crushed and disturbed ground that it is difficult or impossible to determine whether they are replaced sheared diorite or replacements of masses of other schistose rock included in the diorite. These ore bodies have generally a southwesterly dip and appear to be cut off below by northeasterly-dipping gouges. Thus they wedge out below. How much of their apparent southwesterly dip is due to shearing along northeasterly-dipping fault planes and how much may be an original inclination, I was unable to determine. Owing to the generally crushed and broken character of the ground in which they lie and the absence of any datum bed or layer by which displacement might be measured, I was also unable to gain any clear idea of the details of the structure in the vicinity of these ore bodies. Presumably, where ore bodies such as 1307 are cut off below by a northeasterly-dipping fault, there should be, in the footwall, another segment of what was originally the same ore body. Probably 1307-A, on the 1300 level, is such a segment, which was once continuous with 1307 ore body. The ore body stopped at 1307-A may itself be a down-dropped mass, once part of an ore body of which another segment may be found west of it, between 1307-A and the main Verde fault. As a general guide to prospecting for faulted segments of ore bodies in the zone of disturbance along the northeast side of the main Verde fault, I can only offer the suggestion that the direction of slip on the subsidiary faults, like that on the main fault, was probably steeply down the dip, with a pitch of 75 degrees or more, to the southeast. I agree with Mr. Lindgren that more development might be carried out in the country between the known ore bodies and the main Verde fault. The extension of cross-cut 1204, which was in progress when my examination was concluded in December, 1927, and was showing abundant native copper, is in line with this suggestion.

On the 1300 level, it would be advisable to explore the country west of 1307-A stope, to the fault.

On the 1400 level, 1425 cross-cut, which I was unable to examine, is reported to have cut some pyritic material west of the 1407 ore body. This suggests that enrichment, in this particular part of the mine, did not extend to the 1400 level and consequently that there is not much chance of finding any but low-grade pyritic material, such as is known to be present on the 1500 level, in this part of the mine.

Development during recent years has led to the discovery of a number of bodies of residual chalcocite ore in the extensive mass of gossan above the 1300 level. This suggests that the gossan mass should be rather thoroly explored. At present there appear to be no particular clues to the position of the residual ore bodies but such clues may become apparent when the ground is better known.

Some specific recommendations for development, level by level, are submitted for consideration, as follows:

800 level. Drive north from 807 or south from 806, with a view to exploring the diorite contact in 7100-7300 E. and 11,700 11,800 N.

Drive northeast from 824 N. into 7000-7100 E. and 11,400-11,500 N.

Explore gossan in 7500-7600 E. and 11,000 to 11,100 N.

Explore country southeast of 827, into 10,800-10,900 N. and 8,100-8,200 E.

950 level. Explore north contact of diorite, near 11,900 N. and 7100 E.

Explore south contact of diorite and gossan area between 902 W. and 906.

The possible occurrence of ore in 10,900-11,000 N. and 7,800-8000 E. is worthy of consideration.

1100 level. It would probably be well to explore the north contact of the diorite, between the Edith shaft and the Main Top ore body, altho this might await the result of similar work on levels above or below.

There is a large block of unexplored ground on this level south of the long west cross-cut that begins at 7600 E. 11,600 N. There may be ore in this area but, if so, it will probably be indicated by the developments from 1204, on the level below.

1200 level. Explore north of 1202 W., between 7100 and 7200 E., for example, by a cross-cut north on 7175 E.

There is apparently some chance for ore between 11,200-11,400 N. and 7,500 - 7,600 E.

1300 level. The ore zone followed in 1354 N. appears to swing westward at 1160 - 1200 N. following the north contact of the diorite, towards the Main Top. It should be followed in this direction. Drift 1354 N. north of 1200 N. appears to be entirely north of the mineralized zone, which I suspect runs nearly east and west here.

Some attempt should probably be made to ascertain whether there may not be ore along the line joining the 1307 A body and

I suggest some exploration to the vicinity of 7500 E. 11,700 N.

<u>1800 level</u>. If there is any ore on this level, it is probably in 7400 - 7600 E. and 11,700 - 11,800 N.

<u>1900 level</u>. The two sulfide bodies on the 1900 level are so small, so low in grade and so close to the Verde fault, that it is doubtful whether it is worth while to sink on them or to run a deeper level to them from the Edith shaft. My own inclination would be to abandon them, particularly when it is considered that any deeper work on them would pass into the greatly disturbed ground between the main Verde fault and its hanging wall branch.

Elsewhere, also, the 1900 level, in my opinion, offers no inducement to further exploration.

THE HAYNES GROUND

The Haynes shaft is reported to be 1200 feet deep, with levels at 700 and 1200 feet. There is no record of any ore having been found in these workings and there is nothing at the surface or on the dump to indicate the existence of any significant mineralization. Whatever value the Haynes ground may have is dependent upon the possibility that the United Verde ore shoot may extend, at depth, partly into the United Verde Extension ground.

On the 1950 level, the known ore of the United Verde is said by Mr. Hansen, chief geologist for that company, to extend about 50 feet into the eastern side of the Warrior claim but it swings east again and, down to the 3000 level, lies just east of the Warrior east side-line. The geologists of the United Verde consider that their ore body below the 3000 level, probably lies wholly to the east of the Warrior claim. On the 3000 level, the ore body lies about 1000 feet southeast of the southeast corner of the Contention claim, on which the Haynes shaft is situated. At the 4000 to 4500 levels, the ore body, if its western boundary follows the direction expected, will still be separated from the Contention claim by the full width of the Warrior claim. There does not, therefore, appear to be much chance that any part of the United Verde ore body will, at any point enter the Contention claim. There is, of course, a possibility that the ore body may so change in shape and direction below the 3000 level, as to enter the Contention claim but there is no reason for expecting it to do so.

I regard the Haynes ground as having some, rather vague, speculative value but in my opinion this is not sufficient to justify its exploration, either now or in the near future.

If ore should ever be found in the Contention claim, the only apex that the United Verde could claim would be, at the most, on the Silver Giant, 1888, Eureka and Chrome Southeastern claims. Side lines of these claims would become legal end lines and the sweep of extralateral rights would be limited, on the west, by the vertical plane thru the western sideline of the Silver Giant. This would pass well to the east of the Contention claim. This question, should it become important, should of course be submitted to the Company's counsel as it is more legal than geological.

The same general argument against undertaking deep prospecting on the Contention claim applies also to the Granny and other claims of this group.

F. L. Ransome

Pasadena, Calif., March 15, 1928.

Yavapai
Carole

Economic Geology
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OXIDIZED COPPER ORES OF THE UNITED VERDE EXTENSION MINE.*

G. M. SCHWARTZ.

ABSTRACT.

The ores of this deposit show an unusual amount of oxidation and secondary enrichment believed to have taken place during pre-Cambrian time. The ore minerals approximately in order of abundance are: chalcocite, cuprite, malachite, azurite, native copper, chrysocolla, pyrite, chalcopyrite, black oxide, covellite, and bornite. Primary sulphides are pyrite, chalcopyrite, and presumably bornite. The secondary sulphide ore is almost entirely chalcocite, but a little bornite and covellite are found. Malachite commonly replaced chalcocite directly but also replaced cuprite and occurs as nodular and boulder-like masses as well as in streaks in kaolinite. Azurite formed with malachite apparently in much the same sequence except that it was not found replacing sulphides. Cuprite directly replaces sulphides and is commonly replaced by malachite. Chrysocolla occurs mainly with malachite, and native copper also formed at places during oxidation.

No peculiarities or changes were noted that might be attributed to the pre-Cambrian age of the oxidation. The minerals, their sequence and textural relations seem entirely normal.

INTRODUCTION.

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No peculiarities or changes were noted that might be attributed to the pre-Cambrian age of the oxidation. The minerals, their sequence and textural relations seem entirely normal.

[redacted]

Prescott
5-11-85

Ben + Carol,

The USGS Report is an as yet unpublished work now in progress by the Denver office. Paul Handverger got me a copy. The other items are from files kept at Paul's home.

All's well; regards,

Don

Send a copy
to Hoddos
"FYI"

GOLD IN THE UNITED VERDE MASSIVE SULFIDE DEPOSIT
JEROME, ARIZONA

Ed DeWitt, U.S. Geological Survey, Denver, Colorado

Jerome Waegli, Phelps Dodge Corporation, Morenci, Arizona

INTRODUCTION

Location

The United Verde mine and the surrounding Verde mineralized district (Keith and others, 1983, 1984) are on the eastern slope of the Black Hills, near Jerome, Arizona, about 140 km north of Phoenix and 64 km southwest of Flagstaff (fig. 1). Small massive sulfide deposits extend 9 km south-southeast from Jerome, but over 98 percent of the production from the Verde district has come from the United Verde and United Verde Extension mines at Jerome. Although other deposits will be referenced, only the massive sulfide deposit of the United Verde mine will be discussed in this report.

History

Prehistoric Indians and Spaniards in the late 1590's discovered the deposits at Jerome and recovered some copper by surface mining, but the modern history did not begin until 1876-1877 with the location of claims that would later become the holdings of the United Verde Copper Company (Hamilton, 1884; Rickard, 1918). Senator W. A. Clark of Montana purchased the United Verde holdings in 1888 and operated the United Verde mine until 1935, when Phelps Dodge Corporation purchased the property. The mine closed in 1953, but has been leased to several parties conducting small-scale surface mining and leaching.

Production

Production records of the Phelps Dodge Corporation indicate that from 1889 until 1974 the United Verde mine produced nearly 33,000,000 tons of ore that yielded over 2,921,000,000 pounds of copper, 52,891,000 pounds of zinc, 49,279,000 ounces of silver, and 1,350,000 ounces of gold (table 1). Unpublished data from the Arizona Bureau of Geology and Mineral Technology indicate that from 1883 until 1975 an additional 459,000 pounds of lead were produced and approximately 4,000,000 pounds of copper were extracted. From 1920 through 1940 the open pit operations produced 9,708,923 tons of ore that contained 674,734,000 pounds of copper, 20,529,100 ounces of silver, and 689,260 ounces of gold (Alenius, 1930, 1968, fig. 2A) From 1900 through 1975 the silver grade of ore decreased from over 4.0 oz per ton to 1.0 oz per ton (fig. 2B). During the same time gold grades decreased from approximately 0.085 oz per ton to 0.010 oz per ton, resulting in an increase of the Ag/Au ratio from 25 to 75 (fig. 2C). From 1889 through 1974 the ore averaged 1.49 oz per ton silver and 0.041 oz per ton gold, and had a Ag/Au ratio of 36.3. From 1903 through 1953 the gold grade of the ore had a crude positive correlation with copper content (fig. 3); the highest grade copper ores of 1903-1911 contained the highest gold values, and the lowest grade copper ores of 1940-1953 contained the lowest gold grades. This correlation is partly an artifact of the mining or oxidized ores (high gold content) early in the history of the deposit. Gold grades from 1960 through 1975 did not follow the crude positive correlation with copper content, as much of the mining during that time was heap leaching and reprocessing of old ores.

The Ag/Au ratio of the ore has varied over time and with the tonnage of ore produced (fig. 4). From 1901 through 1920, Ag/Au ratios increased with increasing underground production; as tonnage increased the gold grade decreased faster than the silver grade (figs. 2A, B) 2). When open pit production began in 1920 and overtook underground production in 1922-1923, the Ag/Au ratio stabilized at 30 to 40 and was independent of tonnage produced through 1939 (fig. 4). From 1940 through 1944 the Ag/Au ratio increased to 50 to 70 and was inversely related to production; gold grades decreased faster than silver grades (figs. 2B, C). When zinc production began in 1944-1945, the Ag/Au ratio stablized at about 50 and was independent of tonnage produced. Notably, the gold grade increased slightly from 1945 through 1953 (fig. 2C), and zinc-rich ore contained as much gold as copper-rich ore (fig. 5).

Because only the copper-rich portion of the massive sulfide lens and surrounding rock was mined at the United Verde, a very large tonnage of low grade, probably subeconomic, ore remains in the ground. Reber(1922, 1938) estimated that only 14 to 20 percent of the original 90,000,000 ton ore body was of commercial grade (greater than 2 percent copper). Both Paul Handverger (written commun., 1974) and Paul Lindberg (written commun., 1977) estimated the deposit contained 80,000,000 to 100,000,000 tons of mineralized material, 75 percent of which remains in the ground. If the areas in figure 14 of Anderson and Creasey (1958) are used to calculate tonnages, approximately 115,000,000 tons of low-grade massive sulfide ore and 38,000,000 tons of mineralized 'black schist' remain in the United Verde mine from the surface to the 4500 level. The grade of the massive sulfide material is unknown, but a conservative estimate, based on past production data, would be 0.5 to 1.0 percent copper, 2 to 4 percent zinc, traces of lead, 0.01 to 0.015 oz per ton gold, and 0.5 to 1.0 oz per ton silver. McIlroy and others (1974) show a resource estimate of 24,681,942 tons of ore that average 0.52 percent copper, 0.90 percent lead, 4.72 percent zinc, and 2.05 oz/ton silver, but give no values for gold grade.

Similar Deposits

The ore in the United Verde mine is interpreted to be a stratiform syngenetic deposit associated with rhyolitic submarine volcanism and hydrothermal alteration (Anderson and Nash, 1972). The orebody and associated volcanic rocks are very similar to Archean massive sulfide deposits of the Canadian shield (Hutchinson, 1973; Sangster, 1980; Franklin and others, 1981) and the Miocene Kuroko deposits of Japan (Ishihara, 1974). In the southwestern United States similar deposits of Proterozoic age are noted near Pecos, New Mexico (Krieger, 1932; Robertson and Moench, 1979), and in central and western Arizona (Anderson and Guilbert, 1979; Gilmour and Still, 1968; DeWitt, 1979; Baker and Clayton, 1968; Anderson, Scholz, and Strobell, 1955; Stensrud and More, 1980; and Donnelly and Hahn, 1981). In central and western Arizona similar volcanogenic massive sulfide deposits include the Iron King, Zonia, United Verde Extension, Old Dick-Bruce, Bluebell, Copper Chief, Desoto, and numerous smaller deposits.

GEOLOGY

Stratified Metavolcanic and Metasedimentary Rocks

The United Verde massive sulfide deposit lies at the top of a sequence of interbedded rhyooltic to basaltic volcanic rocks which have been metamorphosed to lower greenschist facies. Mixed sedimentary and volcaniclastic rocks overlie the massive sulfide deposit. Because original volcanic textures and structures are well preserved and deformation has not obliterated stratigraphic relations, the metamorphosed lithologies will be described by their protoliths. Detailed stratigraphy is described in Anderson and Creasey (1958) and Anderson and Nash (1972).

According to data in Anderson and Creasey (1958), volcanic rocks older than the massive sulfide deposit are a bimodal suite of basalt and basaltic andesite (40%) and rhyolite (55%), with only minor amounts (5%) of andesite and dacite (fig. 6). The mafic rocks include the Gaddes Basalt and Shea Basalt, both of which are pillowed lava flows with minor tuff and rhyolite breccia beds. The intermediate rocks are represented only by the Brindle Pup Andesite, a flow unit containing intercalated basalt and rhyolite flows. The felsic rocks include the Buzzard Rhyolite, dacite of Burnt Canyon, and Deception Rhyolite and allied minor intrusive rocks. These felsic extrusive units consist of flows, flow breccias, jasper-rich flows, and crystal and lithic tuffs. Porphyritic rhyolite (Cleopatra quartz porphyry) once thought to intrude the Deception rhyolite (Reber, 1922; Anderson and Creasey, 1958) is now included as an extrusive unit within the Deception (Anderson and Nash, 1972).

The chemical analyses in Anderson and Creasey (1958, tables 2, 4, 5, 6, 7, and 11), however, do not indicate such a bimodal suite. Their major element data are plotted on a classification grid (fig. 7; De la Roche and others, 1980) where the rock units are classified by their major element chemistry, not by their published name. In other words, even though a unit may have been named the Brindle Pup Andesite, the rock can be shown to be a rhyodacite because of its position on figure 7. The one analysis of Gaddes Basalt turns out to be a dacite, and the four analyses of Shea Basalt are actually a dacite, an andesite, and two andesitic basalts (figure 7). The analysis of Brindle Pup Andesite is a rhyodacite. The Buzzard and Deception Rhyolites are truly rhyolites, but the quartz porphyries range in composition from rhyodacite to alkali rhyolite. The chemical data, even though there are only 17 analyses of fresh, unaltered rocks in the Jerome area, indicate that there is a complete range of compositions from basalt to rhyolite, and not a bimodal suite.

The pre-ore deposit volcanic rocks are subalkaline (combined Na_2O plus K_2O; Anderson, 1983) as shown on figure 8A. The Shea and Gaddes units are low-K rocks (fig. 8B) and the rest of the units are medium-K rocks according to the classification of Peccerillo and Taylor (1976). All rocks with greater than 56 percent SiO_2 are slightly to strongly peraluminous (Shand, 1927). These rocks do not contain abnormally high concentrations of aluminum, but rather are slightly depleted in calcium, sodium, and potassium compared to metaluminous rocks with comparable silica. Based on their Fe/Mg ratio (fig. 9), all the pre-ore deposit units are tholeiitic (Miyashiro, 1974). The quartz porphyries exhibit a range from tholeiitic to calc-alkalic, but the trend toward calc-alkalic character may be a function of increasing magnesium enrichment during mineralization. The pre-ore deposit suite is calc-alkalic with a Peacock (1931) index of SiO_2 = 56-60.

Metasedimentary and metavolcanic units that are syn- or post-massive sulfide deposit include coarse- and fine-grained tuffaceous rocks, volcanic breccia, chert and jasper beds, and dacite and andesite of the Grapevine Gulch Formation. Chemically the dacite in the Grapevine Gulch is a rhyolite (fig. 7). Crystal tuffs are locally abundant in the upper part of the Grapevine Gulch Formation, indicating that rhyolitic volcanism continued after deposition of tuffaceous rocks, minor limestone, and some agglomerate (Reber, 1922). Breccia beds in the basal Grapevine Gulch contain mineralized fragments of Deception rhyolite (Anderson and Nash, 1972).

The pre- and post-ore deposit rocks have been described as having formed in a volcanic environment (Anderson and Creasey, 1958), in a greenstone belt (Anderson and Silver, 1976), and in volcanic arcs with distinct polarities and chemical evolution (P. Anderson, 1978).

Intrusive Rocks

All metavolcanic and metasedimentary units have been intruded by minor quartz porphyry dikes, an extensive gabbro (United Verde Diorite of Reber, 1922), and later andesite(?) porphyry dikes. In the southern part of the Jerome area a 1740 $\pm$ 15 Ma quartz diorite pluton (Anderson and Creasey, 1967; Anderson and others, 1971; date recalculated using decay constants in Steiger and Jaeger, 1977) intrudes those units. The gabbro in the United Verde mine area intruded as a sill near the contact of the Grapevine Gulch Formation and Deception Rhyolite, and locally cut out and isolated pieces of the massive sulfide deposit (Haynes orebody; plate 7 and figure 24 of Anderson and Creasey, 1958; Plate X of Reber, 1938; Anderson and Nash, 1972). The gabbro was emplaced late in the deformational history of the stratified rocks but was metamorphosed to the same degree as the stratified rocks. Chemically, the gabbro has been extensively altered (high H_2O, CO_2, Al_2O_3) and cannot be chemically named as other rock units are on figures 7, 8, and 9.

A swarm of east-trending, low-grade metamorphosed andesite(?) dikes intrudes the gabbro and massive sulfide lens in the United Verde mine (Provot, 1916; Reber, 1922). The dikes are undeformed but do contain sparse pyrite and chalcopyrite (Anderson and Creasey, 1958). Apparently the dikes were emplaced after regional deformation ceased, and the heat from the dikes caused very local remobilization of sulfide minerals.

Regional Structure and Age of Metamorphism and Deformation

The stratified volcanic sequence that underlies the massive sulfide deposit has a minimum age of 1,770 to 1,780 Ma, the U-Pb zircon date of the Cleopatra member of the Deception Rhyolite (L. T. Silver, personal commun.,, 1982). Regional deformation and low grade metamorphism of this 1,770-1,780 Ma sequence, along with the younger Grapevine Gulch Formation and gabbro, occurred between 1,770 Ma and 1,740 $\pm$ 15 Ma, the age of the post- to late-tectonic quartz diorite batholith south of Jerome (fig. 6) The syngenetic stratiform massive sulfide deposit in the United Verde mine is therefore about 1,770 to 1,780 Ma.

Varied structural interpretations of the Jerome area have been proposed by Anderson and Creasey (1958), Anderson and Nash (1972), Lindberg and Jacobsen (1974), and Norman (1977) that involve from one to three major deformational events. The interpretation favored in this report incorporates much of Anderson and Nash's (1972) stratigraphy and follows Lindberg and Jacobsen's (1974) model for two generations of folding (figs. 6 and 10). In the area south of Jerome the northwest-trending Jerome anticline (F1) has been cross folded about west-northwest-trending axes (figure 6). The regional foliation in the metamorphosed lithologies parallels the second generation of folds (F2). Locally, as near the United Verde mine, F1 and F2 structural features are parallel and the effects of refolding are not apparent.

ORE DEPOSITS

Structure

The United Verde massive sulfide body is localized near the top of the Cleopatra rhyolite member of the Deception rhyolite, and in the overlying Grapevine Gulch formation (fig. 10) The sulfide deposit and country rocks have been folded about north-northwest-trending axes, resulting in a pipe-shaped stratiform deposit that trends N20W and plunges 65 degrees to the north, parallel to minor folds and axial plane lineations (Anderson and Creasey, 1958). The plunge of the sulfide body increases with depth. Above the 1100 level the plunge averages 45 degrees; from the 1100 level to the 3300 level it averages 70 degrees; and from the 3300 level to the 4500 level it is vertical or reverses plunge to the southeast. After some of the folding, but before the end of regional metamorphism, a sill-like body of gabbro which isolates and cuts off portions of the top of the ore body (see Plates 7 and 10 of Anderson and Creasey, 1958) was emplaced along the Deception rhyolite-Grapevine Gulch Formation contact.

The deposit is zoned from stratigraphic bottom (Cleopatra rhyolite member of the Deception Rhyolite) to top (Grapevine Gulch Formation) and consists of: 1) chloritized rhyolite or quartz porphyry; 2) copper-rich 'black schist', a hydrothermal alteration product containing massive chlorite derived from rhyolite; 3) copper-rich massive sulfide containing variable amounts of zinc; 4) copper-poor, zinc-rich massive sulfide that forms most of the massive sulfide deposit; and 5) jaspery chert lenses (Reber, 1922; Anderson and Creasey, 1958). The black schist ranges from 0 to 60m thick, the massive sulfide from 0 to 120m thick, and the chert from 0 to 40m thick. The massive sulfide grades downward into 'black schist' and ultimately rhyolite, but its upper contacts with chert, Grapevine Gulch rocks, or rhyolite are sharp and discrete. Laterally, the massive sulfide grades into and is interbedded with rhyolite and Grapevine Gulch lithologies.

The sulfide mass is exposed from the surface to the 4500 foot level of the mine, and undoubtedly once extended from the surface upward to the overlying Cambrian Tapeats Sandstone, an additional vertical distance of 120m. The sulfide body therefore had a minimum length of 1600m. The massive sulfide portion of the deposit varies in thickness from 12 to 18m on the 4500 level to over 120m on the 1650 level. It ranges in width from discontinuous zones 75 to 160m long on the lower levels of the mine to a continuously mineralized zone over 420m long on the 3000 level. The massive sulfide is approximately pipe- or molar-shaped from the surface to the 1650 level, crescent-shaped from there to the 3300 level, and lens-shaped in the lowest parts of the mine (Anderson and Creasey, 1958, Plate 7). This variation in shape reflects both the original configuration of the deposit and the effects of folding.

Wallrock Alteration

Both the Cleopatra rhyolite member and tuffaceous lithologies of the Grapevine Gulch Formation below and adjacent to the massive sulfide lens have been variably chloritized and sericitized. Chloritization has created the 'black schist' in the mine area and is probably the product of hydrothermal alteration of the rhyolite by seawater brine (Anderson and Nash, 1972). Sericitization of the rhyolite is more widespread than chloritization, but is not as pervasive and may not be totally related to the ore-forming process. Instead, some of the sericite may represent pre-metamorphic devitrification and alteration of glass and pumice within the rhyolite (Anderson and Creasey, 1958). Microprobe analyses indicate that chlorite in the 'black schist' from the United Verde mine is ripidolite with a Fe/Fe+Mg ratio that ranges from 0.37 to 0.49 (Nash, 1973). The magnesium content of the ripidolite in the Cleopatra rhyolite member increases, from south to north, in proximity to the United Verde mine. Similar magnesium-rich chlorite (Fe/Fe+Mg ratio of 0.31 to 0.56) has been reported from the alteration pipe of the Bruce massive sulfide deposit near Bagdad, Arizona (Larson, 1984).

Mineralogy

The original mineralogy of the United Verde deposit is simple and has been modifed only slightly by weathering or supergene processes. Ore minerals in the massive sulfide lens are, in decreasing order of abundance, pyrite, sphalerite, chalcopyrite, bornite, arsenopyrite, galena, tennantite, and gold (probably electrum). Gangue includes quartz, carbonate minerals, chlorite, sericite, and minor hematite. The same minerals, in about the same relative abundances, occur in the 'black schist' ore and Cleopatra Rhyolite ore, but chalcopyrite and bornite are more abundant than sphalerite in these ores. The chert that overlies the massive sulfide lens contains less pyrite and more chalcopyrite, sphalerite, hematite, and magnetite than the other ores. Naturally oxidized ores above the 160 level and ores oxidized by mine-fires down to the 600 level contained cuprite, chalcocite, azurite, malachite, native copper, wire silver, minor copper hydroxide minerals, limonite, and hydrous copper sulfate minerals (Reber, 1922; Lindgren, 1926; Anderson and Creasey, 1958).

Pyrite, sphalerite, and chalcopyrite in the massive sulfide lens and 'black schist' are intergrown in a banded to massive texture that ranges in average grain size from 1 mm to less than 0.02 mm (Lindgren, 1926; Ralston, 1930; Slavin, 1930). Galena is normally finer-grained than the other sulfide minerals and is interstitial to pyrite and sphalerite. The overlying chert and underlying 'black schist' ores are slightly coarser, but very fine-grained. This fine-grained and intergrown nature of the ore made high recoveries of both base and precious metals difficult (Barker, 1930).

Gold is apparently present as electrum in microscopic inclusions within most sulfide minerals, and the gold may contain significant silver. Unfortunately no studies have been made of the mineralogy or occurrence of gold and silver. Much silver is present in late-stage tennantite in quartz-carbonate veins and carbonate-rich massive sulfide (Anderson and Creasey, 1958, table 16). This tennantite also contains significant gold, most probably as microscopic inclusions.

Lead Isotope Data

Galena from the United Verde deposit was reported by Stacey and others (1976) to have the following lead isotopic ratios: $^{206}Pb/^{204}Pb$ = 15.725; $^{207}Pb/^{204}Pb$ = 15.270; $^{208}Pb/^{204}Pb$ = 35.344. On a $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ diagram, this galena falls on a 1,645 Ma model isochron (Stacey and Kramers, 1975), which is about 130 Ma younger than the preferred age of the host rocks. The lead isotope ratios have been interpreted by Stacey and others (1976) to indicate that during formation of the deposit lead from the mantle was mixed with lead from an orogenic or marine source that was of a slightly more radiogenic nature than the mantle lead. This mixing model does not account for the 130 Ma age discrepancy, however. An explanation for the anomalously young model galena date of 1645 Ma is that nonradiogenic lead in the deposit was homogenized with radiogenic lead from the surrounding Cleopatra Rhyolite during regional metamorphism and protracted cooling of the metavolcanic terrane.

Gold-Silver Zonation

As previously noted, the most obvious change in content of precious metals in the deposit is from unoxidized to oxidized ore, where gold and silver grades increase by almost an order or magnitude (Au, 0.03 oz per ton in unoxidized ore to 0.2 oz per ton or greater in oxidized ore; Ag, 1.2 oz per ton in unoxidized to 15.0 oz per ton or greater in oxidized). However, gold and silver contents also vary considerably within the unoxidized ore where their grades are related to the type of ore. Smith and Sirdevan (1921, table 3) were perhaps the first to show that silica-rich (converter) massive sulfide ore contained more gold and silver than normal massive sulfide (iron) or chlorite schist (silica) ore. Subsequently, Hansen (1930), Barker (1930), and Ralston and Hunter (1930) enlarged upon these findings and indicated that the ore ranged from low precious metal contents (qurtz porphyry, chlorite schist ore) to high contents (massive sulfide, siliceous massive sulfide ore). Their data suggested that the deposit was zoned and that precious metal contents were greatest at the stratigraphic top.

This variation of gold and silver within ore types is further quantified by using the data of Storms (1955) for various levels within the United Verde deposit. Massive sulfide ore on the 700 level averages 10 times as much gold and 4-5 times as much silver as chlorite schist ore (table 2). Massive sulfide ore on the 3000 level averages 3-4 times as much gold and 2 times as much silver as chlorite schist ore. Gold and silver grades range from 0.002 oz per ton and 0.71 oz per ton, respectively, in chlorite schist ore to 0.116 oz per ton and 4.0 oz per ton in chert ore on the 4500 level. Clearly the content of precious metals is highest at the stratigraphic top of the deposit and gold is more enriched than silver near the top.

Correlations between precious and base metals in the deposit are not obvious if ore types are not differentiated (fig. 11A-F). Copper, zinc, gold, and silver analyses for a suite of samples on the 2400 level show no high positive or negative correlations among the four variables (fig. 11). An important feature to note from figure 11 is that the gold and silver grades, although not positively correlated with either copper or zinc content, are just as high in zinc-rich ore (fig. 11B, F) as in copper-rich ore (fig. 11C, D).

If the various ore types are separated and the data in Storms (1955) is plotted, correlations are noted (fig. 12, table 3). The Ag/Au ratio and precious metal grades vary with location in the deposit (fig. 12A). In the chlorite schist ore the Ag/Au ratio is highest (average 170-400) and gold content lowest (Au, about 0.005 oz per ton). The Ag/Au ratio decreases to 30-100 (average for unoxidized ore about 55) and the gold grade increases to about 0.04 oz per ton. Chert ore has the lowest Ag/Au ratio (30) and the highest gold grade (0.10 oz per ton). Positive correlations of gold with zinc and gold with combined zinc and copper are noted for massive sulfide ore (fig. 12B, C, table 3). The best correlation between precious and base metals in massive and siliceous massive sulfide ore is between gold and combined copper plus zinc (0.570 for 106 samples). Except for data from the 3000 level the correlation between zinc and gold is as good or better than that between gold and combined zinc plus copper (table 3). Gold distribution is not well correlated with copper except on the 3000 level. The addition of silver to gold decreases the correlation with combined copper plus zinc, indicating that silver must be present in another mineral besides the assumed electrum, most reasonably galena.

CONCLUSIONS

Distinguishing Characteristics

The deposit at the United Verde mine is very typical of Archean, Proterozoic, and Phanerozoic volcanogenic massive sulfide deposits (Ohmoto and Skinner, 1983; Franklin, Lydon, and Sangster, 1981; Sangster, 1980 and 1972; Ishihara, 1974; Hutchinson, 1973; and Gilmour, 1965). It occurs at the top of a submarine rhyolite dome and flow breccia unit (Cleopatra member of the Deception rhyolite; Anderson and Nash, 1972) that is part of and overlies a predominantly tholeiitic, medium-K, calc-alkalic suite of rhyolite to basalt. The deposit is zoned from the top to bottom and consists of capping chert and siliceous massive sulfide ore, zinc- and copper-zinc-rich massive sulfide, chloritic stringer ore and chloritized Cleopatra rhyolite ore. Gold and silver are present in all ore types but are concentrated at the stratigraphic top, in massive sulfide, siliceous massive sulfide (both zinc- and copper-rich), and chert ore. The grade of precious metals in the deposit (Au, 0.045 oz per ton; Ag, 1.61 oz per ton) is comparable to other volcanigenic massive sulfide deposits in Arizona (DeWitt, 1983) and was exceeded only by the Iron King mine near Humboldt, Arizona (Au, 0.073 oz per ton; Ag, 2.67 oz per ton; Arizona Bureau of Geology and Mineral Technology, unpublished production data). The deposit is the largest volcanogenic massive sulfide in the United States (33 million tons mined; minimum of 50-70 million tons of low-grade material remaining) and one of the largest in North America. Only the Kidd Creek (Walker and others, 1975) and Brunswick 12 deposits (Sangster, 1984; McAllister and others, 1980) have greater reserve plus production tonnages.

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Ore Controls

The localization of the stratiform massive sulfide body was controlled by a hydrothermal conduit now represented by the chlorite schist and chloritic alteration pipe in the Cleopatra rhyolite. No paleotopographic controls, such as basins, sides of domes, etc., have been recognized in the Jerome area although they could have existed and have been masked by the deformation of the metavolcanic rocks. Why such a large sulfide body was localized at the top of the Deception rhyolite, as opposed to lower in the volcanic pile, is unknown, but the genesis of the deposit must have been intimately associated with the evolution of the submarine volcanic suite.

The deposit is overlain by a sequence of volcaniclastic sediments, tuffs, cherty sediments, and jasper-rich beds (Grapevine Gulch formation) that are compositionally unlike the underlying flows, breccias, domes, and intrusives. Therefore, formation of the masive sulfide deposit appears to have ended the period of submarine calc-alkalic volcanic activity and signaled the beginning of volcaniclastic activity that may have had a different geochemistry (data lacking to evaluate this possibility) and was certainly of a different nature (partly subaerial; tuffs and immature sedimentary rocks dominant instead of flows).

Base and precious metals are zoned within the deposit; the alteration pipe contained average to high copper but very litte zinc, gold, or silver. The massive sulfide had average to high copper, zinc, gold, and silver. The capping siliceous massive sulfide and chert had base and precious metal contents that overlapped the highest massive sulfide ores. If all the metals were transported through the alteration pipe to the paleosurface by hydrothermal solutions, zinc and gold were retained in solution longer than copper and silver, and were precipitated only opon reaching the seawater-sediment interface. This zonation is consistent with decreased pH, Eh, and temperature of the hydrothermal solution at the inferred top of the deposit.

Origin

The United Verde deposit was formed in a Proterozoic submarine environment during deposition of rhyolite flows, tuffs, and pyroclastic material. The massive sulfide body and underlying chloritic alteration pipe are the end products of a conduit through which hydrothermal solutions enriched in copper, zinc, lead, gold, and silver traveled and ultimately precipitated their sulfide minerals. Chemical studies have not been completed that would indicate the ultimate source of metals in the deposit, whether that source be the underlying volcanic pile (leaching and redistribution of metals) or the magma reservoir of the Deception rhyolite (primary enrichment of metals in the magma).

ACKNOWLEDGMENTS

Phelps Dodge Corporation contributed unpublished production data and assay results from the 2400 level of the United Verde mine. Anna Wilson aided in the computer plotting of the data from Storms (1955). The manuscript was reviewed by . . .

TABLE CAPTIONS

Table 1. Production data for the United Verde mine. Data from 1889 through 1974 furnished by Phelps Dodge Corporation. Data for 1883 through 1888 and for 1975 from unpublished production records of the Arizona Bureau of Geology and Mineral Technology.

Table 2. Summary of metal contents from different ore types within the United Verde massive sulfide deposit. Data from diamond drill core analyses on the 700, 1200, 3000, and 4500 levels of the United Verde mine and the 3000 level of the Haynes orebody (Storms, 1955)

Table 3. Correlation coefficient data for metals in ore types from the United Verde mine. Data from Storms (1955).

FIGURE CAPTIONS

Figure 1. Location map of the Jerome area, north-central Arizona.

Figure 2. Plots of production, copper, silver, and gold grades, and Ag/Au ratios during the lifetime of the United Verde mine. (A), production vs time; (B), copper and silver grades vs time; (C), Ag/Au and gold grade vs time. Data from Table 1 and unpublished data from the Arizona Bureau of Geology and Mineral Technology.

Figure 3. Plot of gold vs copper for different time spans of production in the United Verde Mine.

Figure 4. Plot of Ag/Au vs tonnage for different time spans of production in the United Verde mine.

Figure 5. Plot of gold grade and Ag/Au ratio vs Cu/Zn ratios for ore mined from 1944 through 1953 from the United Verde Mine.

Figure 6. Generalized geology of the Jerome region. Modified from Anderson and Creasey (1958).

Figure 7. Chemical classification diagram (De la Roche and others, 1980) for volcanic units in the Jerome area. Data from Anderson and Creasey (1958). Only those analyses are plotted that contain less than 3.0 percent H_2O, less than 0.5 per cent CO_2, and have total oxide weight percents between 99 and 100 percent.

Figure 8. (A), $Na_2O + K_2O$ versus SiO_2 diagram for volcanic rocks in the Jerome area. Subalkalic versus alkalic field boundary from Anderson (1983); (B), K_2O versus SiO_2 diagram for plutonic and volcanic rocks in the Jerome area. Boundaries for low-, medium-, and high-K fields from Peccerillo and Taylor (1976). Figures 8A, 8B, and 9 use the raw data from Anderson and Creasey (1958), uncorrected for water contents.

Figure 9. SiO_2 versus $FeOt/(FeO_t + MgO)$ diagram for volcanic rocks in the Jerome area. Data from Anderson and Creasey (1958). Boundary separating calc-alkalic from tholeiitic rocks from Miyashiro (1974).

Figure 10. Geology of the United Verde Mine area. Modified from Anderson and Creasey (1958) and Lindberg and Jacobsen (1974).

Figure 11. Plots of Cu, Zn, Au, and Ag in the United Verde massive sulfide deposit. Data from unpublished assay results made available by Phelps Dodge Corporation. Individual ore types are not plotted separately. (A), Cu vs. Zn; (B), Ag vs. Zn; (C), Au vs. Cu, (D), Ag vs. Cu; (E), Au vs. Ag; (F), Au vs. Zn.

Figure 12. Plots of Cu, Zn, Au, and Ag for various ore types in the United Verde massive sulfide deposit. Data from Storms (1955). Individual ore types are plotted separately. (A), Au vs. Ag; (B), Au vs. Zn; (C), Au vs. Cu+Zn.

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Year	Tons Mined	% Cu	% Zn	Oz/T Ag	Oz/T Au	Lbs. Cu	Lbs. Zn	Oz. Ag	Oz. Au	Pb lb
		Average Grade				Metals Recovered				
1834-1888	26,900	12.77		12.0	0.16	6,869,075	-	323,726	4,242	
1889	10,000	9.55		15.4	0.97	1,910,890		154,260	9,697.5	
1890	26,000	10.11		16.3		5,257,421		423,714		
1891	37,000	9.93				7,360,000				
1892	50,000	9.85		2.2	0.05	9,845,666		109,878	2,442.7	
1893	50,000	9.22				9,222,141				
1894	58,990	9.36		4.7	0.13	11,043,542		276,258	7,778.8	
1895	60,201	13.72		4.4	0.08	16,522,181		263,080	4,627.9	
1896	116,994	9.56				22,166,425				
1897	151,266	10.36		2.9	0.065	31,355,027		526,114	9,773.6	
1898	219,831	9.66				42,453,316				
1899	254,138	8.65		1.9	0.055	43,995,733		486,470	13,956.7	
1900	245,352	8.13		2.13	0.065	39,888,472		523,723	15,943	
1901	248,646	6.93		2.03	0.063	34,438,441		504,277	15,695	
1902	133,219	7.28		2.30	0.072	19,407,080		306,784	9,551	
1903	196,970	7.57		2.87	0.096	23,771,597		450,603	15,038	
1904	264,412	5.45		2.49	0.088	29,274,610		668,612	23,762	
1905	273,523	5.97		1.78	0.058	32,683,951		486,041	15,915	
1906	274,181	7.04		1.56	0.047	35,236,441		428,317	12,913	
1907	253,566	6.51		1.41	0.046	33,015,457		356,939	11,734	
1908	241,915	7.48		2.04	0.084	36,183,089		494,574	20,334	
1909	280,534	6.54		1.77	0.061	36,695,455		495,477	17,021	
1910	323,569	5.55		1.74	0.059	38,663,880		563,132	19,267	
1911	304,949	5.07		1.51	0.050	33,164,520		461,168	15,239	
1912	351,817	4.45		1.37	0.043	31,570,152		480,518	15,069	
1913	395,674	4.46		1.62	0.052	35,344,694		641,074	20,666	
1914	397,227	4.14		1.65	0.055	32,448,170		646,573	21,400	
1915	491,992	4.59		1.84	0.057	45,127,832		903,051	28,221	
1916	694,053	5.07		1.76	0.041	58,299,573		1,030,851	26,416	
1917	813,176	5.14		1.65	0.033	71,726,634		1,223,310	29,230	
1918	861,250	5.10		2.06	0.032	77,501,595		1,292,109	29,281	
1919	469,353	5.24		1.60	0.035	42,927,666		665,327	16,838	
1920	718,851	5.10		1.35	0.020	64,952,270		910,345	18,759	
1921	132,353	5.49		1.58	0.027	13,581,488		202,716	4,090	
1922	423,543	5.48		1.45	0.034	40,845,407		554,587	12,603	
1923	1,101,456	4.82		2.06	0.066	97,560,882		2,113,162	67,541	
1924	1,257,714	4.29		1.60	0.043	98,246,081		1,846,621	48,235	
1925	1,289,350	4.93		1.24	0.020	108,210,901		2,108,348	50,196	
1926	1,285,461	4.31		1.76	0.050	107,388,418		2,242,788	55,906	
1927	1,352,387	4.17		1.73	0.046	99,969,654		2,096,681	55,897	
1928	1,580,312	4.14		1.44	0.038	118,151,126		2,113,174	55,395	
1929	1,800,607	4.61		1.30	0.036	142,290,460		2,092,418	62,096	
1930	941,196	4.36		0.79	0.053	70,720,014		1,413,333	42,938	
1931	229,789	3.95		1.37	0.047	19,891,777		309,650	10,350	
1935 U.V. thru 2/18	58,546	4.34		1.20	0.037	4,679,333		66,954	2,154	
1935 P.D. from 2/19	725,020	4.48		1.26	0.038	59,817,830		867,390	27,337	
1936	1,302,974	3.96		1.52	0.052	91,514,608		1,826,875	64,531	
1937	1,433,330	3.41		1.51	0.049	85,290,903		1,907,890	65,743	
1938	772,527	3.98		1.54	0.058	55,579,814		1,040,611	41,877	
1939	740,022	4.06		1.10	0.037	55,417,033		920,091	25,652	
1940	795,784	4.64		1.35	0.026	68,111,011		917,950	17,984	
1941	1,078,462	4.11		1.41	0.028	80,858,441		1,314,725	26,649	
1942	1,212,933	3.90		1.20	0.023	86,554,613		1,279,650	24,011	
1943	882,214	4.16		1.20	0.021	68,192,842		934,927	16,362	
1944	502,247	5.55		1.21	0.018	52,774,095		547,873	8,100	
1945	377,579	5.57		1.29	0.024	39,228,810		463,540	8,475	
1946	336,197	5.01		1.28	0.025	31,485,167		414,387	8,055	
1947	346,311	4.48		1.01	0.014	31,063,498		391,993	7,573	
1948	348,048	4.44	6.8	1.25	0.021	29,833,400		436,721	11,166	
1949	409,313	4.56	7.2	1.52	0.032	33,957,890	8,005,488	485,301	9,497	
1950	351,992	4.12	7.77	1.74	0.044	15,426,569	15,157,169	272,342	6,117	
1951	299,436	3.77	7.49	2.06	0.055	19,830,228	17,915,943	399,689	7,000	
1952	155,642	3.20	5.28	1.98	0.047	10,475,722	9,613,749	249,015	4,300	
1953 End P.D.	29,164	2.20	4.5	1.58	0.041	1,938,803	2,199,620	49,058	1,258	
---- Start										
1954 Big Hole	5,004	6.05		0.72	0.006	605,319		3,604	31.5	
1955	13,447	5.10		0.70	0.006	1,371,056		9,453	77.7	
1956	14,929	5.18		0.73	0.006	1,545,434		10,843	84.0	
1957	12,872	6.39		1.15	0.026	1,644,400		14,773	333.8	
1958	16,010	6.46		1.73	0.037	2,067,960		27,724	586.7	
1959	9,824	4.93		0.98	0.030	969,108		9,627	290.7	
1960	17,010	6.76		1.12	0.006	2,299,801		10,088	101.9	
1961	18,533	6.57		0.87	0.008	2,436,505		16,187	143.2	
1962	10,477	8.45		0.84	0.011	1,770,601		8,794	113.8	
1963	15,076	7.72		0.89	0.012	2,326,437		13,414	179.1	
1964	8,203	5.34		0.97	0.013	876,828		7,974	105.1	
1965	9,577	6.35		1.00	0.016	1,216,466		9,603	152.3	
1966	5,552					543,943		4,174	54.9	
1967	5,006	5.28		0.75	0.010	528,227		3,751	50.1	
1968	5,218	5.42		1.08	0.013	565,219		5,649	68.6	
1969	9,299	6.39		1.07	0.011	1,118,820		9,950	100.8	
1970	11,062	6.29		1.17	0.014	1,392,423		12,946	155.7	
1971	7,238	5.24		1.16	0.015	758,239		8,428	110.1	
1972	6,214	4.95		1.08	0.011	615,609		6,732	69.8	
1973	1,705					173,120		1,829	19.3	
1974	3,923	5.34		1.19	0.014	376,019		4,190	48.6	
1975	598	7.63		1.09	0.01	91,292		654	60	
Total U.V.	20,685,383	5.15		1.75	0.047	1,978,768,862		34,360,185	971,801	
Total P.D.	12,099,195	4.18		1.38	0.036	917,312,277	52,891,969	14,720,036	381,687	
Total Big Hole	206,149	6.13		1.01	0.014	25,201,534		199,793	2,877.7	
Grand Total	32,990,727	4.80		1.49 ~~1.61~~	0.041 ~~0.045~~	2,921,291,673	52,891,969	49,279,954	1,356,366	
Arizona Bureau of Geology & Mineral Technology Totals	32,588,782	4.36		1.53	0.042	2,844,403,043	97,352,100	49,732,425	1,376,108	457,100

Table 2. Average grades of ore types, United Verde Mine

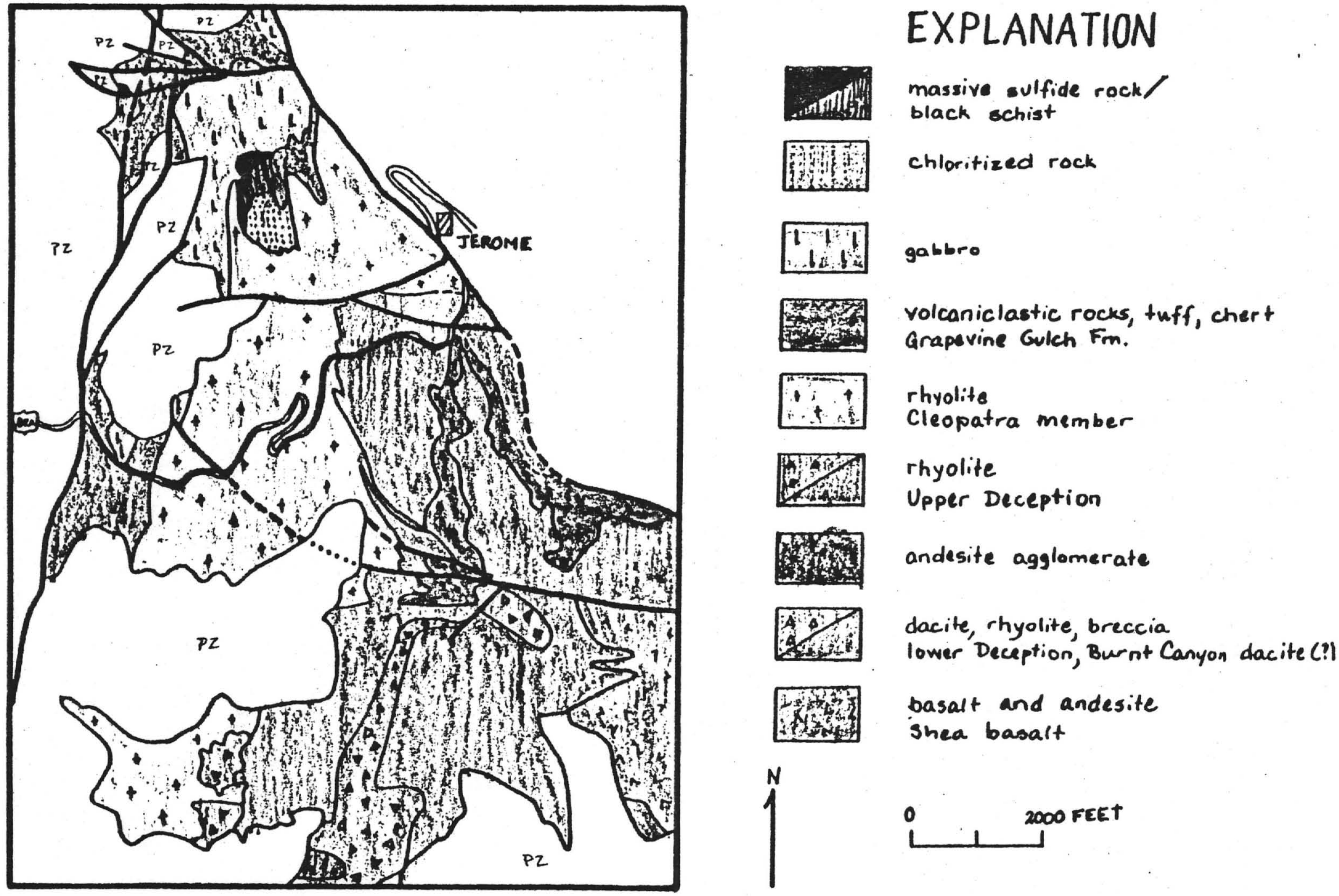
Ore Type	Level	Copper (%)	Zinc (%)	Gold (oz per ton)	Silver (oz per ton)
United Verde ore body					
Massive sulfide	700	1.58 (44)	10.79 (15)	0.053 (14)	3.42 (14)
Chert, siliceous massive sulfide	700	3.45 (16)			
Chlorite schist	700	2.58 (12)		0.005 (34)	0.75 (34)
Massive sulfide	1200	0.55 (88)	3.41 (88)		
Chlorite schist	1200	1.02 (17)	3.21 (17)		
Massive sulfide	3000	1.80 (109)	4.90 (98)	0.020 (43)	1.56 (31)
Chlorite schist	3000	3.38 (109)	1.53 (7)	0.006 (88)	0.91 (78)
Chert	4500	3.70 (4)	2.22 (4)	0.116 (4)	4.00 (4)
Siliceous massive sulfide	4500	3.89 (17)	10.98 (14)	0.109 (17)	3.70 (17)
Massive sulfide	4500	2.25 (62)	9.91 (55)	0.068 (60)	2.22 (56)
Chlorite schist	4500	1.35 (21)		0.002 (9)	0.71 (9)
Haynes ore body					
Massive sulfide	3000	0.49 (37)	4.29 (28)	0.050 (36)	0.50 (36)

(23), number of samples averaged

Table 3. Correlation coefficients for ore types in the United Verde massive sulfide deposit.

Level, ore type	Correlation Coefficients Cu vs Zn	Cu vs Au	Zn vs Au	Cu+Zn vs Au	Ag vs Au	Cu+Zn vs Ag+Au
All levels, massive sulfide (92)	-.400	.024	.475	.528	.385	.232
All levels, siliceous massive sulfide (14)	.090	.398	.514	.610	.335	.470
All levels, massive plus siliceous massive sulfide (106)	-.302	.173	.480	.570	.434	.316
All levels plus Haynes orebody, massive sulfide (120)	-.260	-.007	.256	.260	.209	.337
700, massive sulfide (15)	-.938	-.428	.388	.357	.381	-.471
3000, massive sulfide (29)	-.643	.740	-.480	.475	.150	.221
4500 massive sulfide (48)	-.279	-.104	.484	.477	.486	.264
Haynes 3000, massive sulfide (28)	-.040	.060	-.086	-.071	.127	-.081
All levels, chlorite schist (115)	A	.291	A	A	.426	A
All levels, quartz porphyry (15)	A	.293	A	A	.495	A
All levels, massive sulfide (137)	-.168	B	B	B	B	B
All levels, chlorite schist (22)	-.035	B	B	B	B	B

(22), number of samples; A, no Zn analyses; B, no Au, Ag analyses.


JEROME
PZ
EXPLANATION
massive sulfide rock/
black schist
chloritized rock
gabbro
volcaniclastic rocks, tuff, chert
Grapevine Gulch Fm.
rhyolite
Cleopatra member
rhyolite
Upper Deception
andesite agglomerate
dacite, rhyolite, breccia
lower Deception, Burnt Canyon dacite (?)
basalt and andesite
Shea basalt
N
0
2000 FEET

CHLORITE SCHIST ORES &
CHERT ORE

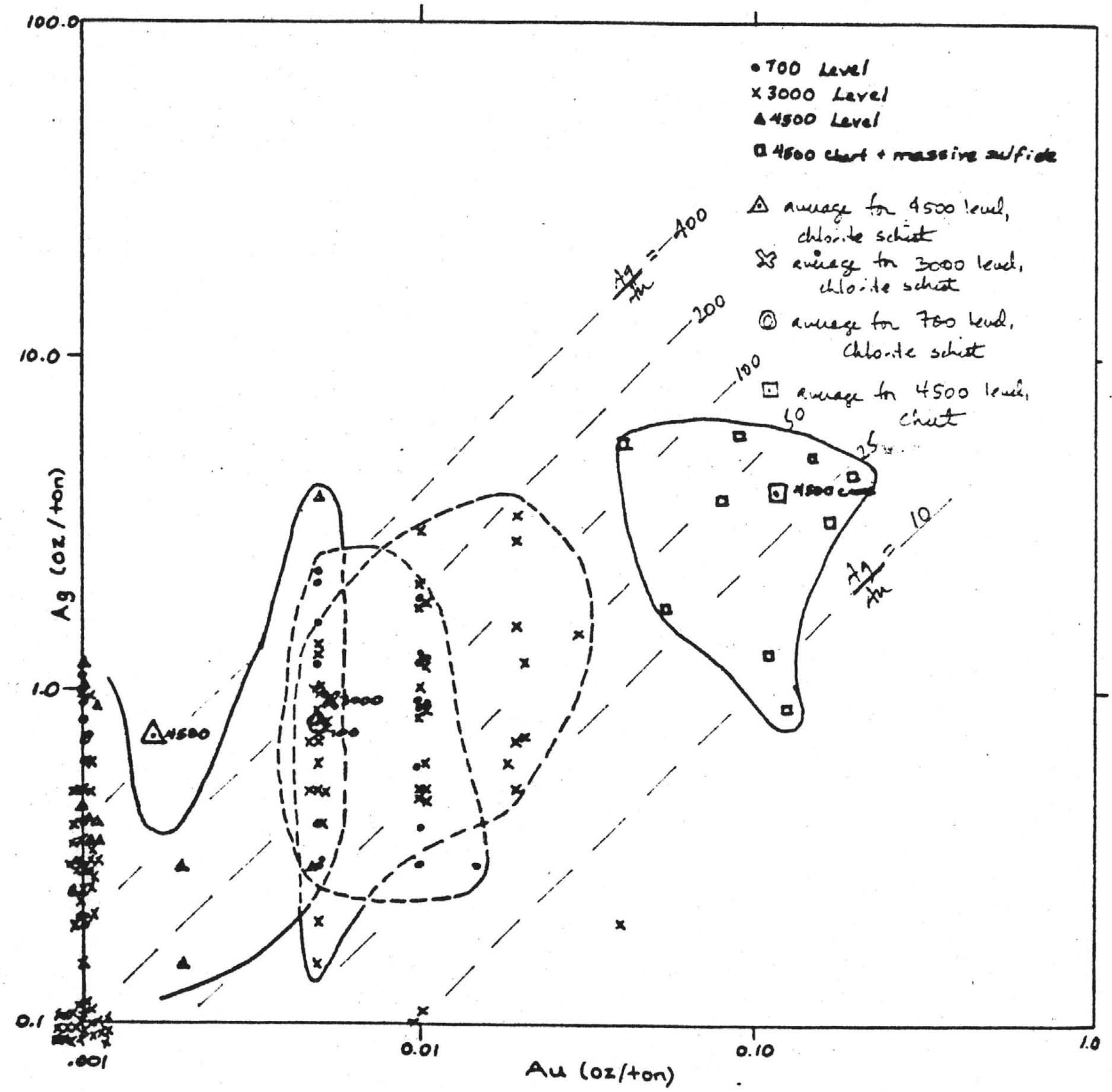
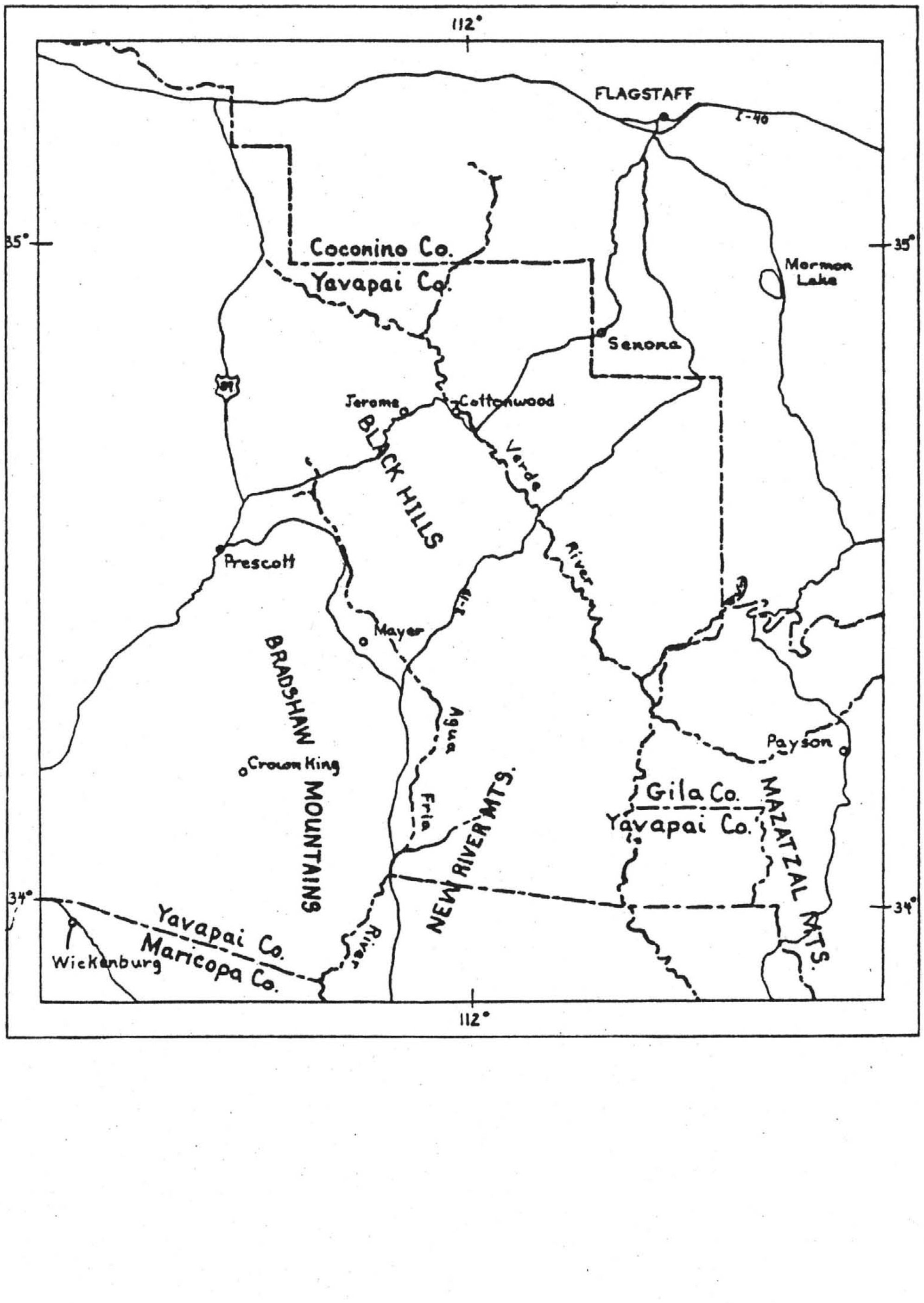
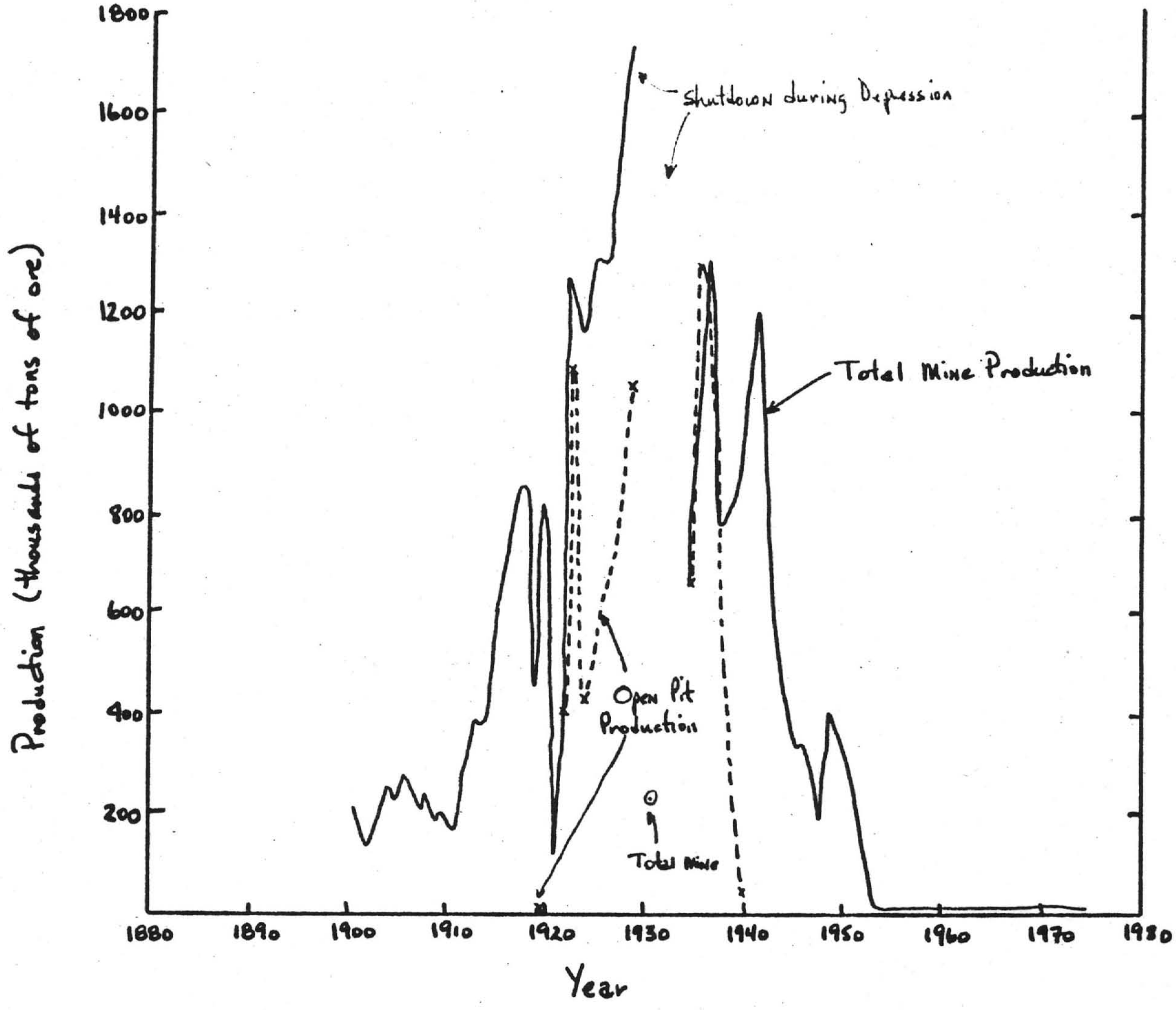


figure 12A



112°
FLAGSTAFF
I-40
35°
Coconino Co.
Yavapai Co.
Mormon Lake
Senona
89
Jerome
Cottonwood
BLACK HILLS
Verde
River
Prescott
I-17
Mayer
BRADSHAW MOUNTAINS
Agua
Fria
Crown King
NEW RIVER MTS.
Payson
Gila Co.
Yavapai Co.
MAZATZAL MTS.
34°
Yavapai Co.
Maricopa Co.
Wickenburg
River

fig 1



Production (thousands of tons of ore)
1800
1600
1400
1200
1000
800
600
400
200
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
Year
Shutdown during Depression
Total Mine Production
Open Pit Production
Total Mine

Fig. 2A

MASSIVE SULFIDE, CHERT ORES

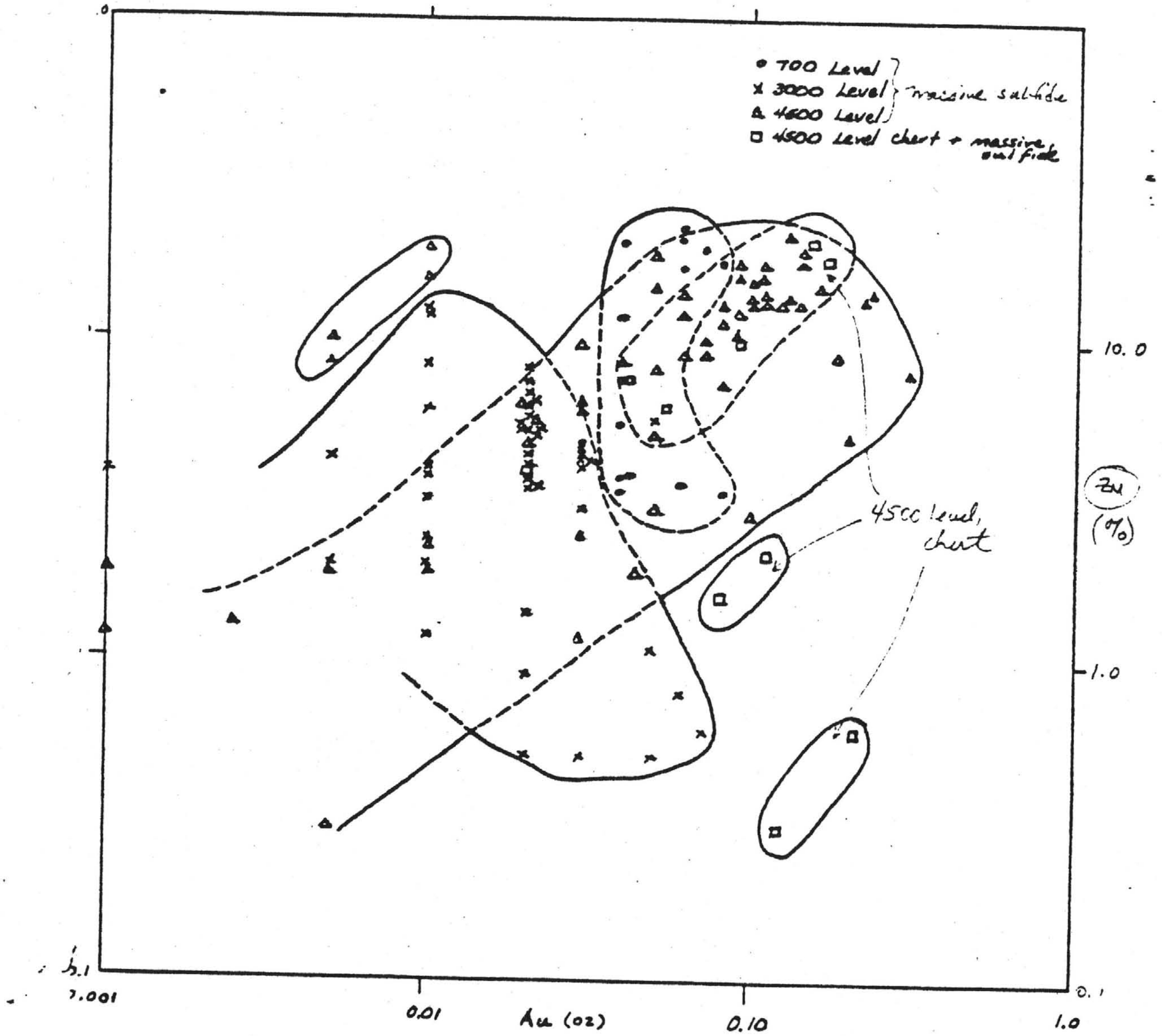
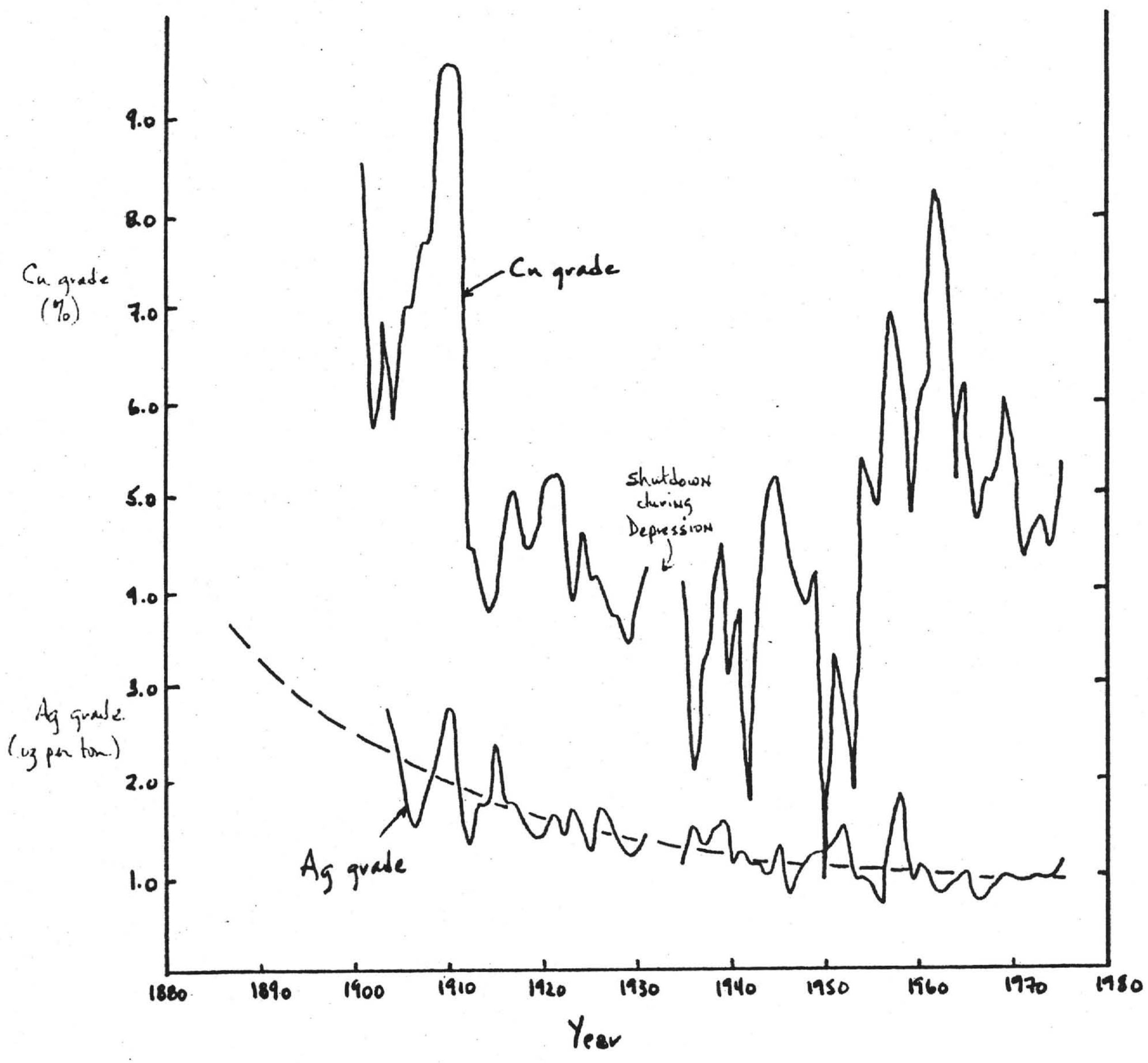
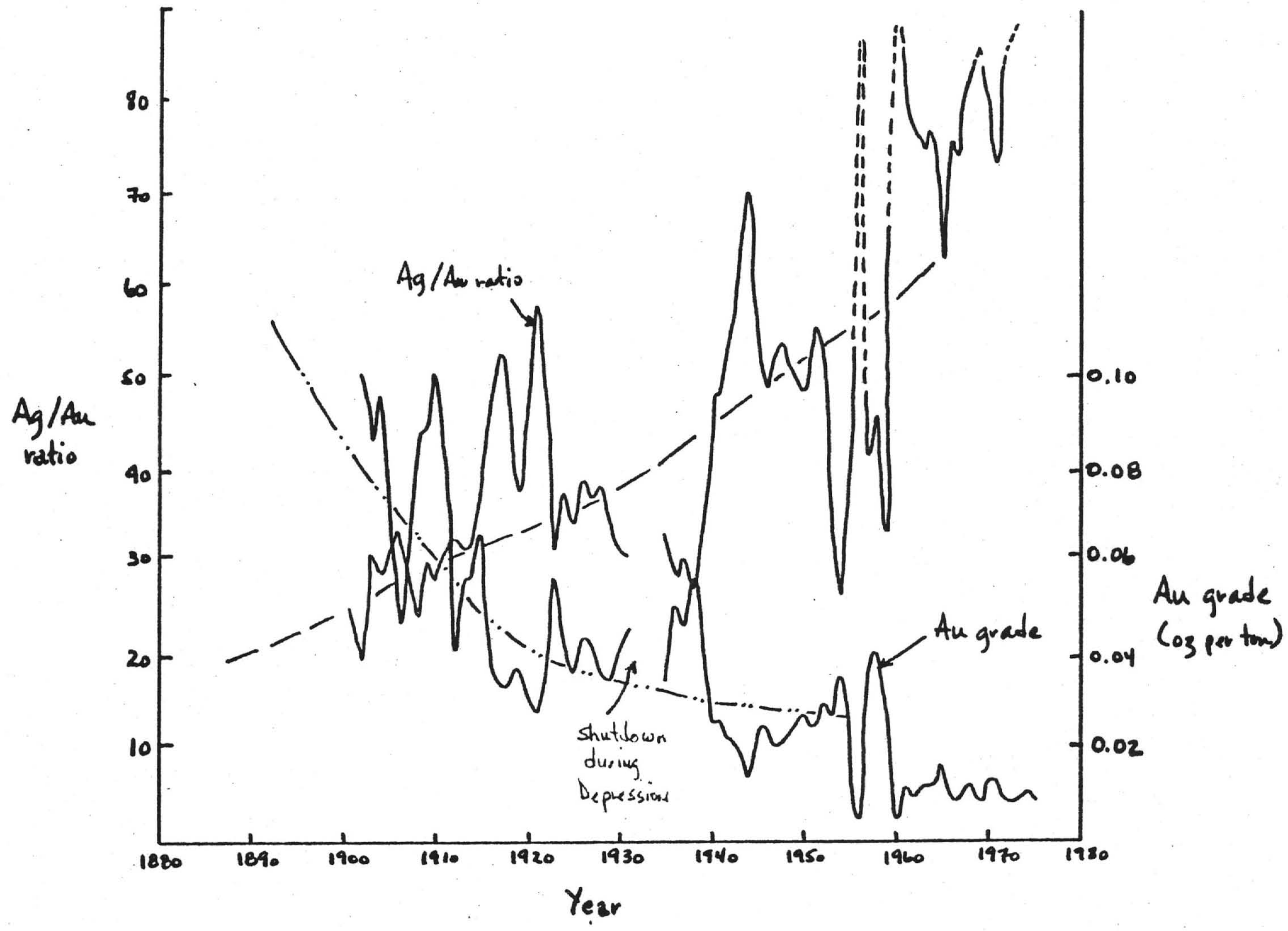


figure 123

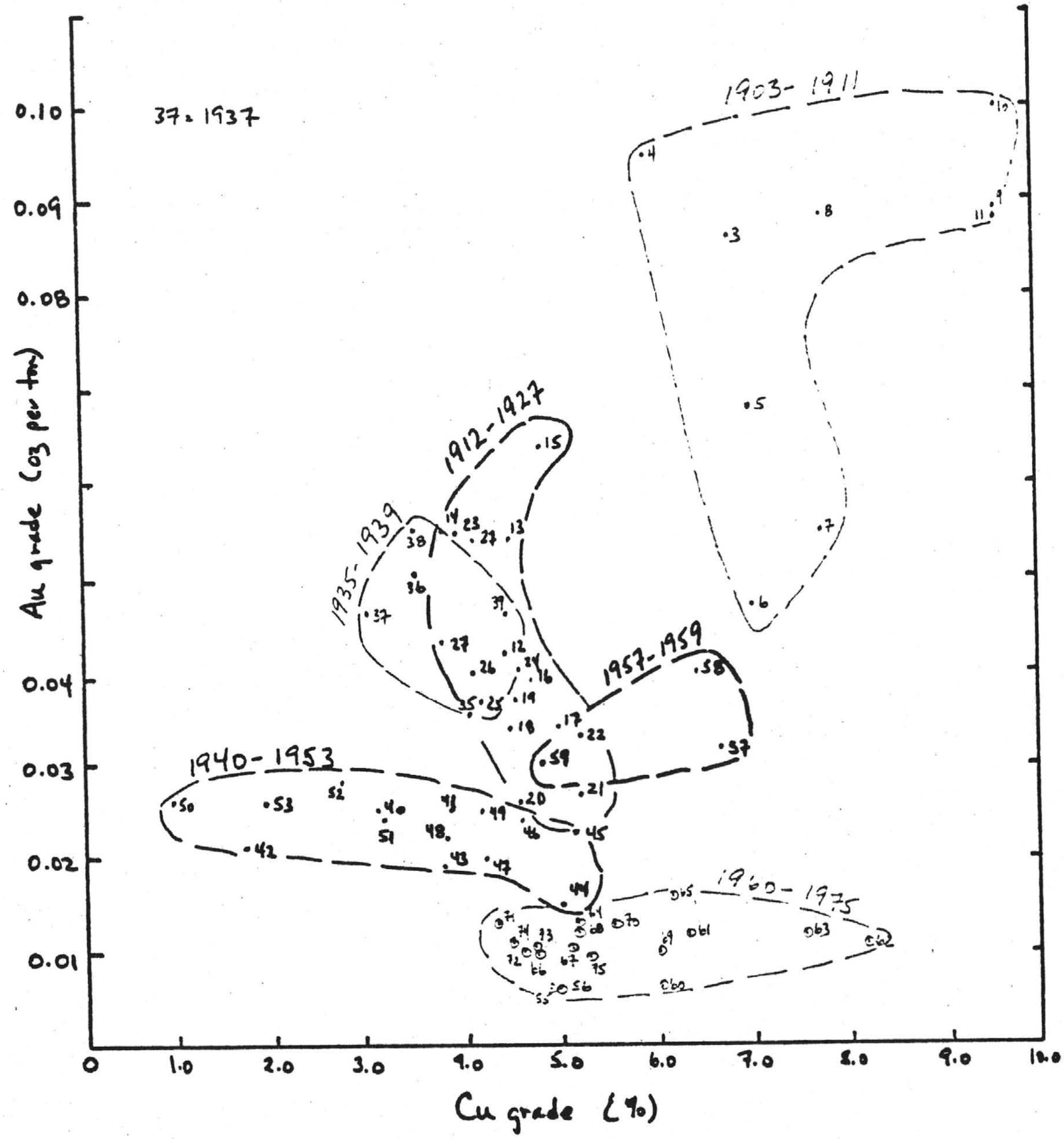


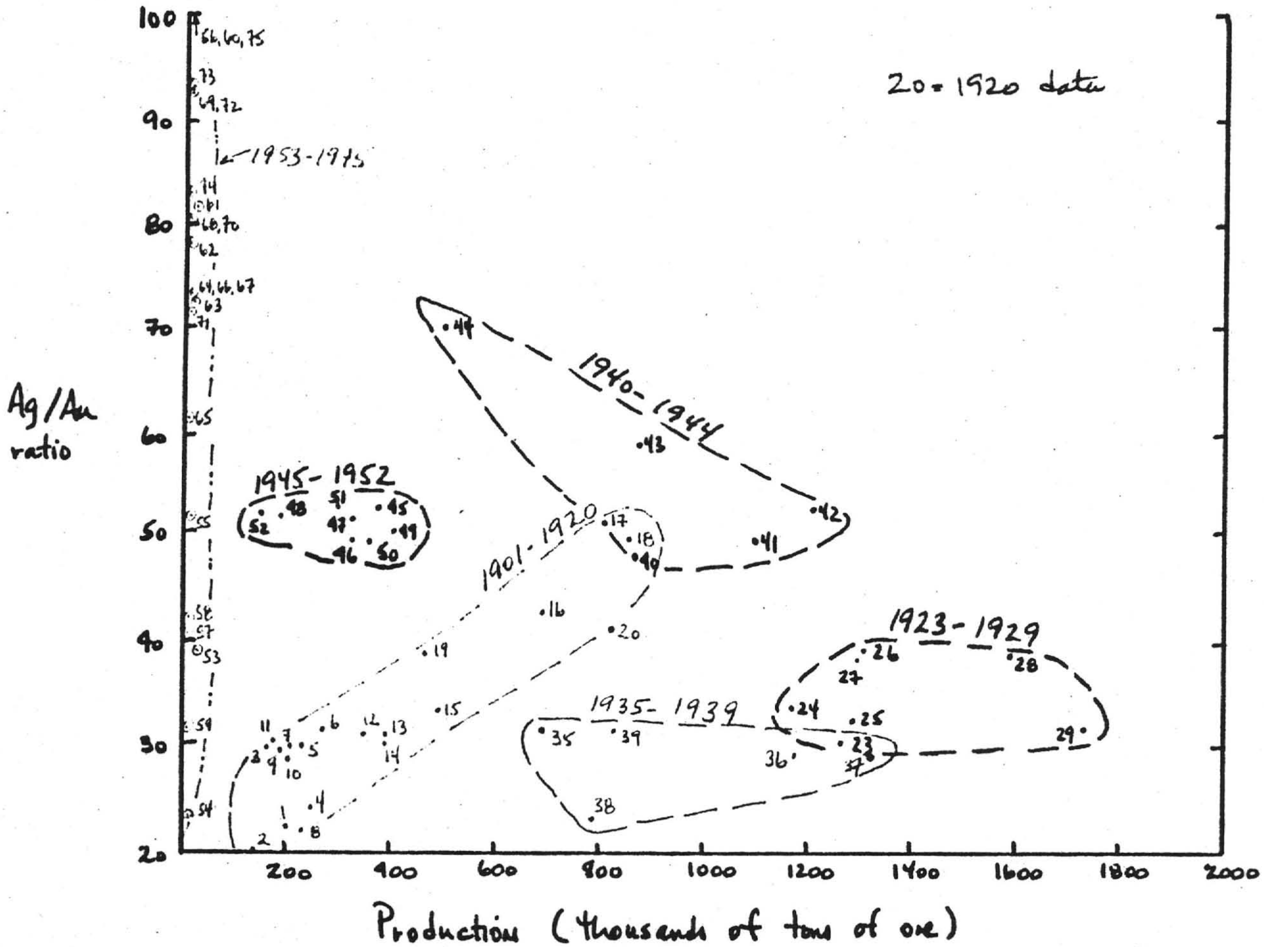
Cu grade (%)
Ag grade (oz per ton)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
Cu grade
Ag grade
Shutdown during Depression
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
Year

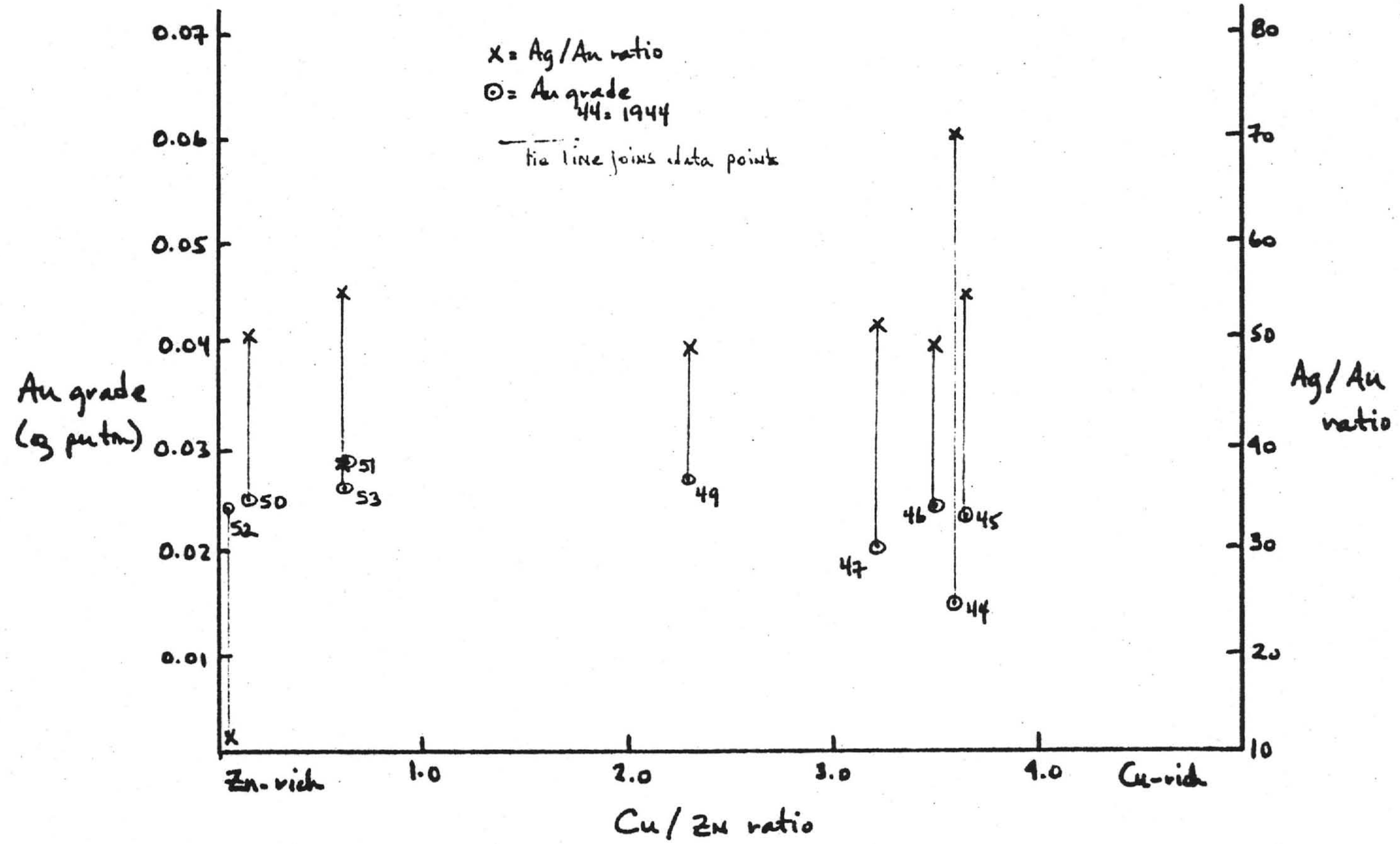


Ag/Au ratio
80
70
60
50
40
30
20
10
0.10
0.08
0.06
0.04
0.02
Au grade (oz per ton)
Ag/Au ratio
Au grade
Shutdown during Depression
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
Year

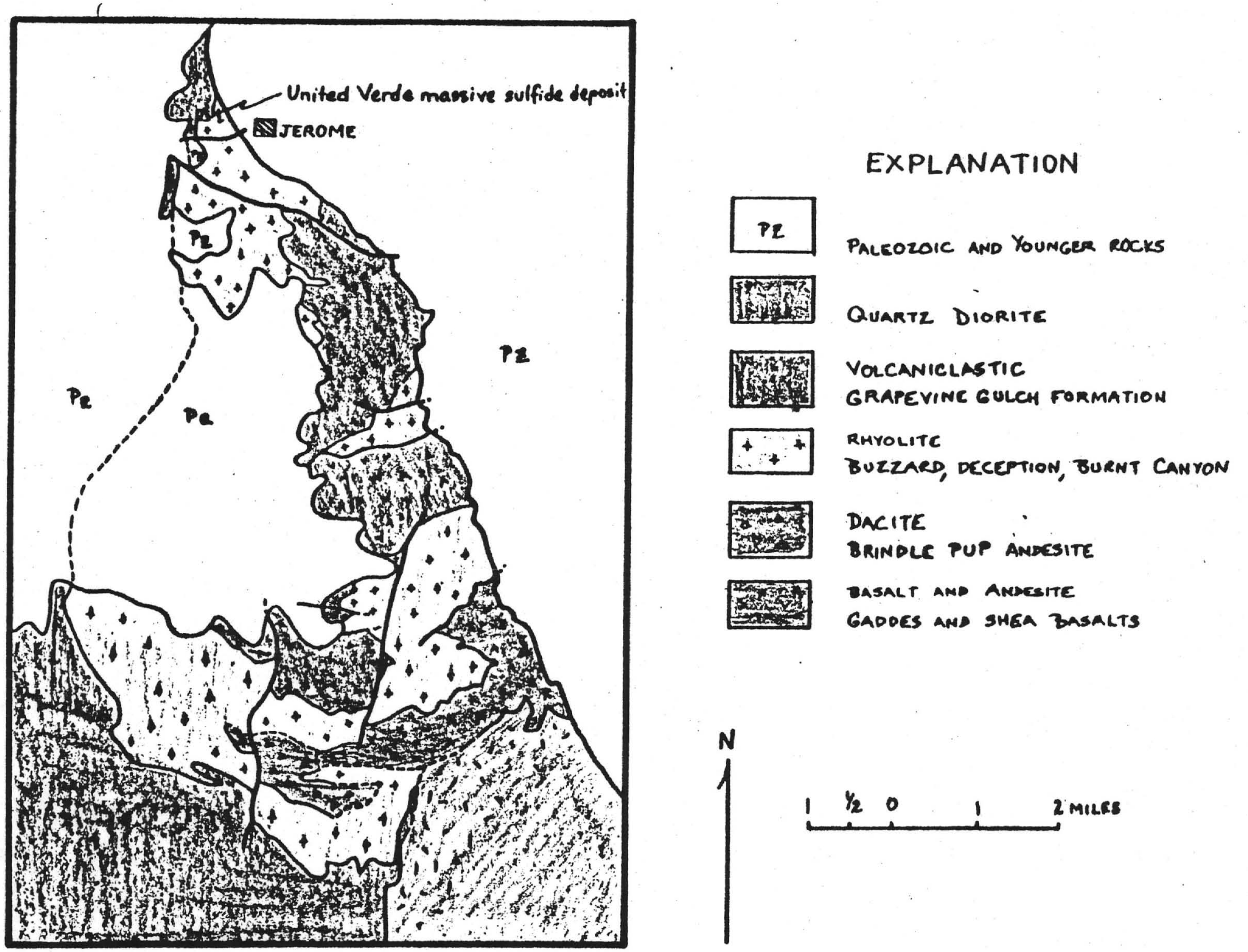
fig 2c

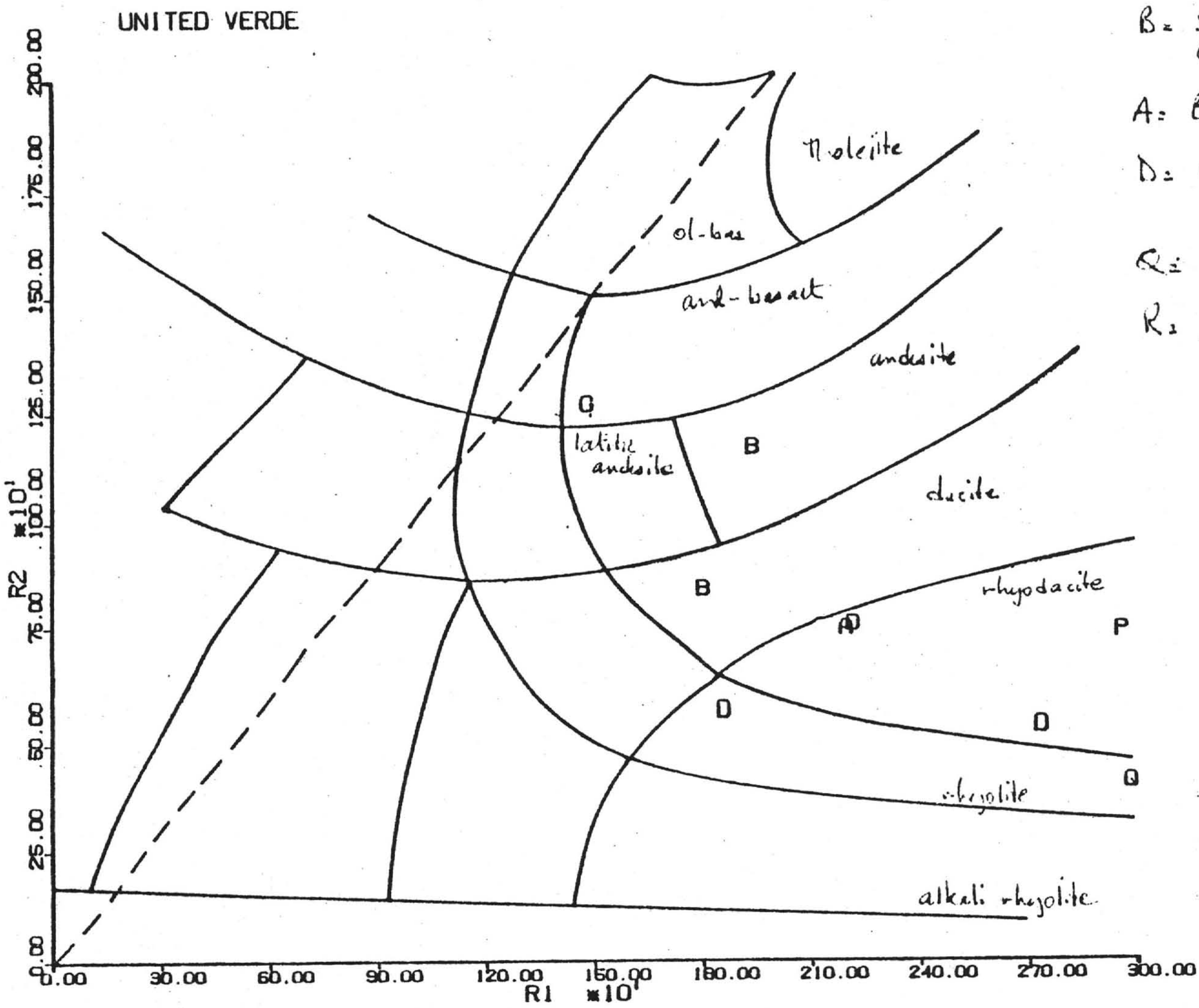

37 = 1937
1903-1911
1912-1927
1935-1939
1957-1959
1940-1953
1960-1975
Au grade (oz per ton)
Cu grade (%)
0.10
0.09
0.08
0.04
0.03
0.02
0.01
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0


Ag/Au ratio
20 = 1920 data
1953-1975
1945-1952
1940-1944
1901-1920
1935-1939
1923-1929
Production (thousands of tons of ore)



X = Ag/Au ratio
⊙ = Au grade
44 = 1944
tie line joins data point
Au grade (g per tm)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
Ag/Au ratio
80
70
60
50
40
30
20
10
Zn-rich
1.0
2.0
3.0
4.0
Cu-rich
Cu/Zn ratio
44
45
46
47
49
50
51
52
53


United Verde massive sulfide deposit
JEROME
Pz
Pz
Pz
Pz
EXPLANATION
Pz
PALEOZOIC AND YOUNGER ROCKS
QUARTZ DIORITE
VOLCANICLASTIC
GRAPEVINE GULCH FORMATION
RHYOLITE
BUZZARD, DECEPTION, BURNT CANYON
DACITE
BRINDLE PUP ANDESITE
BASALT AND ANDESITE
GADDES AND SHEA BASALTS
N
1 ½ 0 1 2 MILES



G = United Verde diorite

B = Shea Basalt,
Gaddes Basalt

A = Brindle Pup Andesite

D = Grapevine Gulch Dacite
Burnt Canyon Dacite

Q = Quartz Porphyry (Cleopatra)

R = Deception Rhyolite

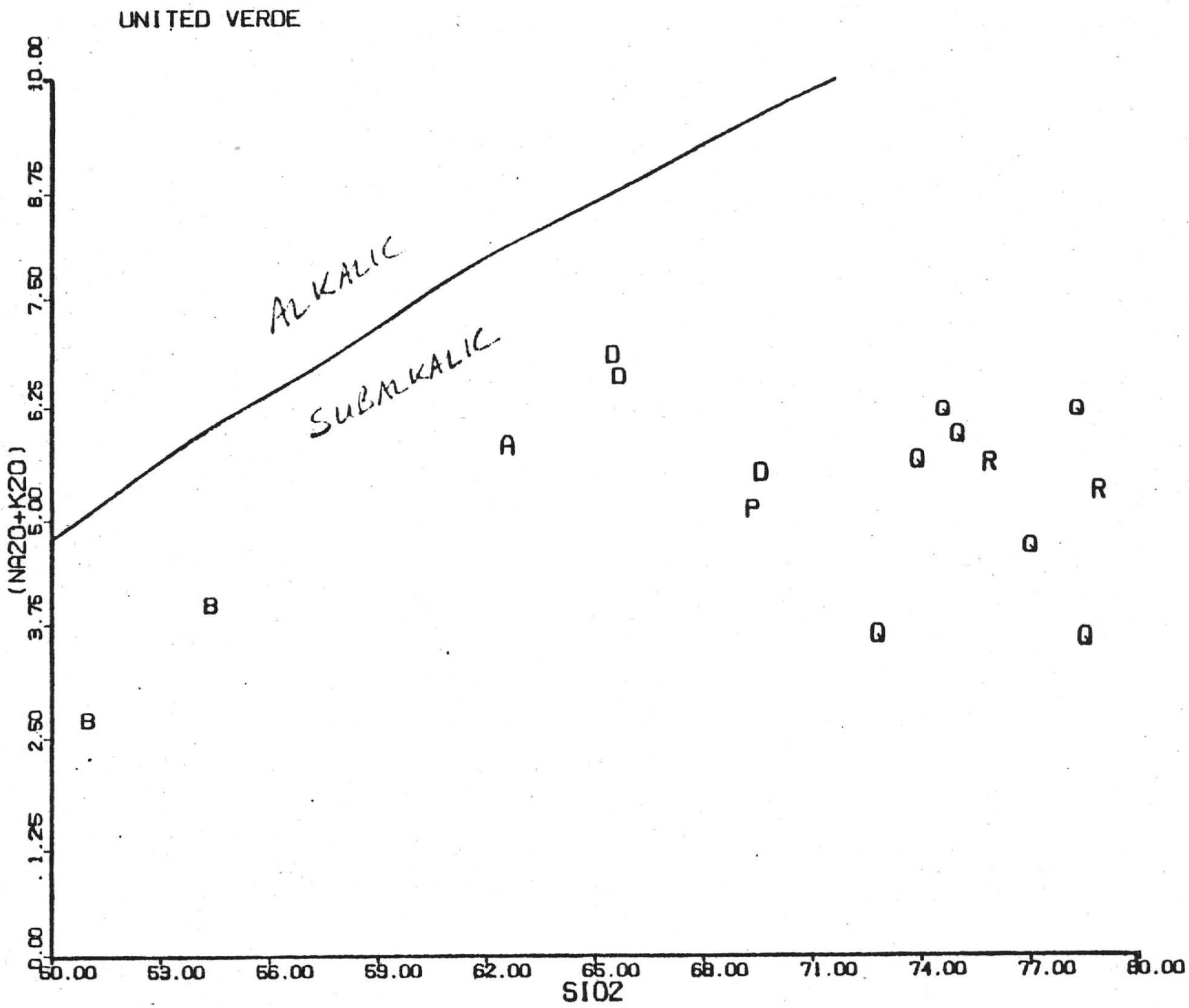
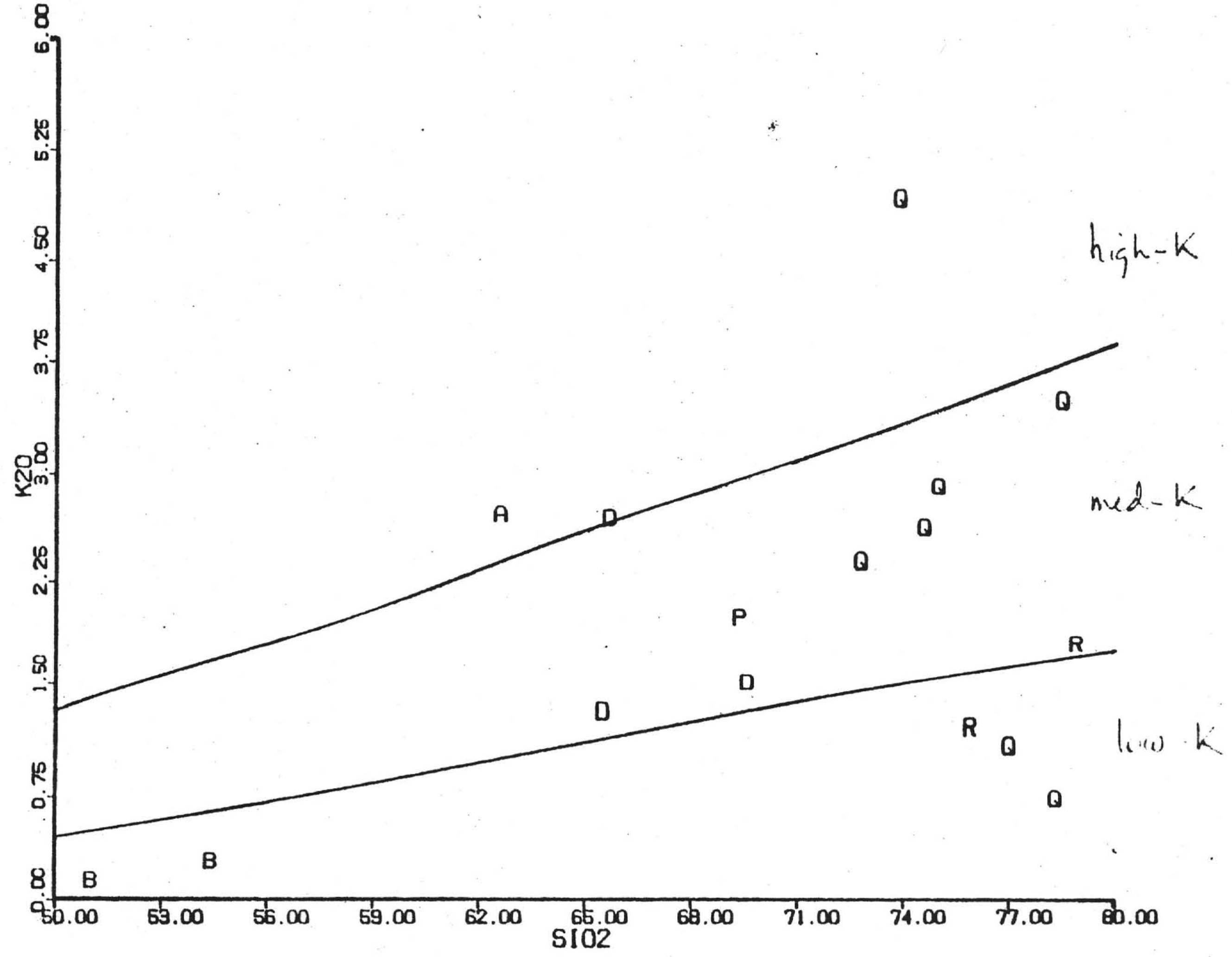
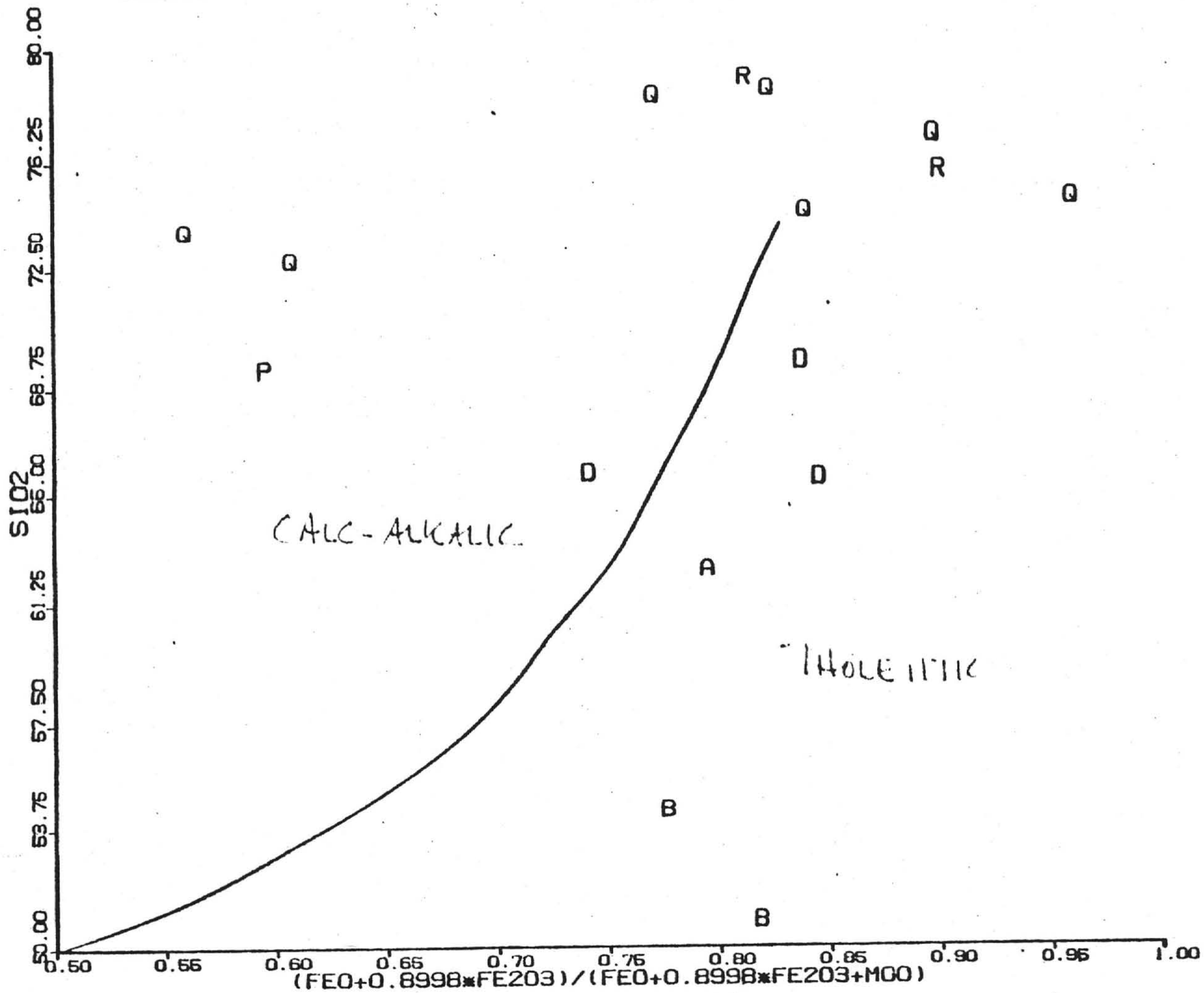

UNITED VERDE
ALKALIC
SUBALKALIC
(NA2O+K2O)
0.00
1.25
2.50
3.75
5.00
6.25
7.50
8.75
10.00
50.00
53.00
56.00
59.00
62.00
65.00
68.00
71.00
74.00
77.00
80.00
SIO2
B
B
A
D
D
D
P
Q
Q
Q
Q
Q
Q
Q
Q
R
R

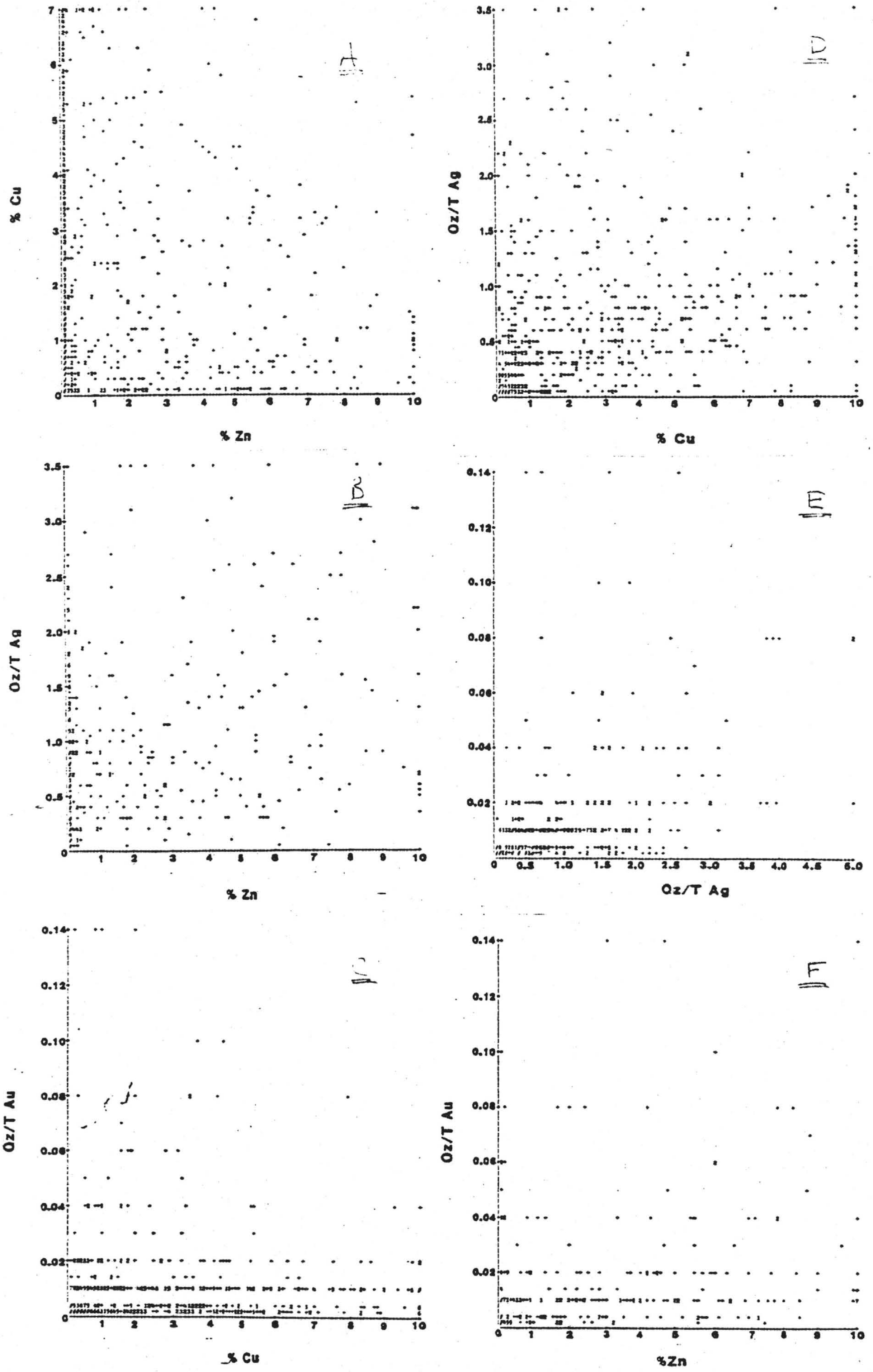
fig 8A

UNITED VERDE



UNITED VERDE





+ = one analysis

2-9 = two or more analyses plot at one point.

= more than nine analyses plot at one point

fig 11

MASSIVE SULFIDE, ~~CHERT~~ ORES

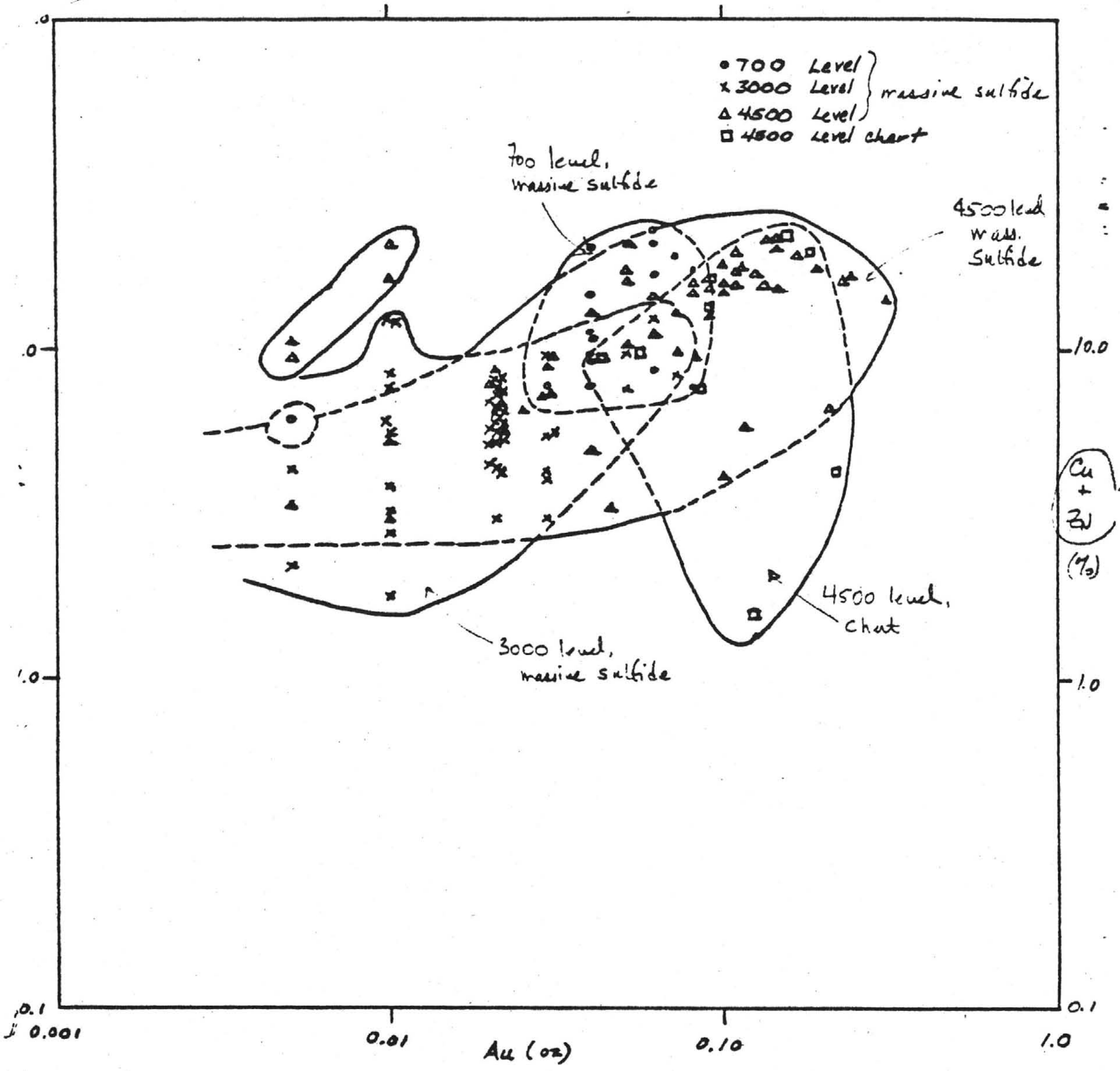


figure 12 c

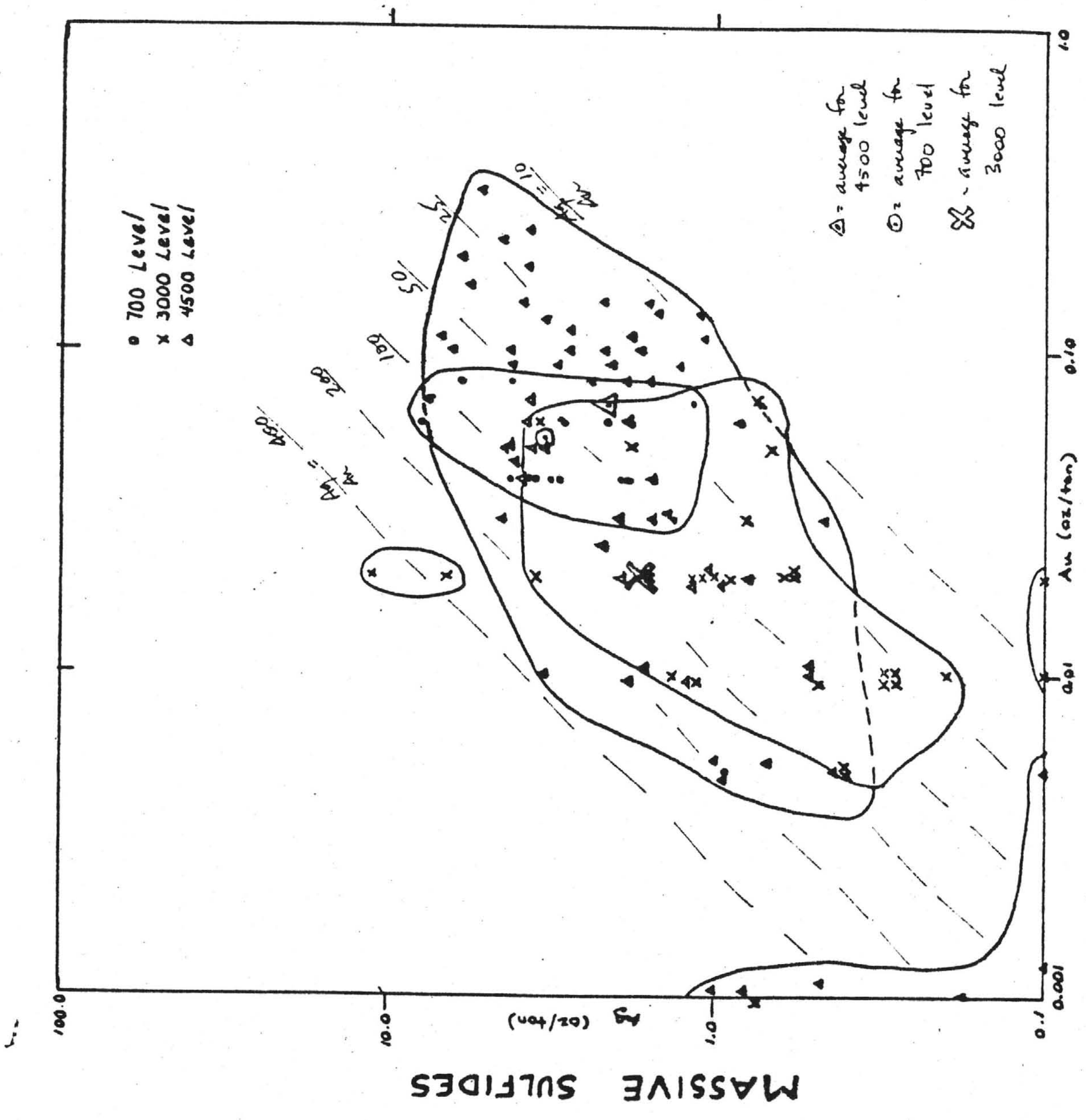


figure 12A (cont

BFD.

A BRIEF GEOLOGIC HISTORY AND FIELD GUIDE TO THE JEROME DISTRICT, ARIZONA

Paul A. Lindberg
205 Paramount Drive
Sedona, Arizona 86336

INTRODUCTION

On May 3, 1986 a post-meeting field trip will tour the Jerome mining district of North Central Arizona. A visit will be made to the United Verde open pit (inactive) and examine the Proterozoic stratigraphy and structure of the pit area and along Highway 89A where the section is well exposed in Deception Gulch and Hull Canyon. Field trip stops are numbered in Figures 1 and 2 and are referred to in the text.

Because of field trip logistical constraints, Stops No. 1 and 2 will be referred to later in the geologic text. Stop No. 3 is at the United Verde open pit and Stops No. 4-11 examine the well-exposed geologic section along Highway 89A.

The guide is designed to give the field trip participant a broader view of the complex geology of the district than the limited field trip exposures can provide. It presents a current interpretation of the geologic history of the northern part of the region which is based on past work but provides new information that has been obtained since 1971. From then to the present day a wealth of additional data has resulted from detailed re-mapping of the surface geology, studies of extensive diamond drill cores which have penetrated to the Proterozoic through Phanerozoic cover rocks, re-examination of underground mine records and rock specimen suites from sites no longer accessible, stratigraphic and structural correlation studies, and the application of modern models for the origin of the Proterozoic massive sulfide ores. The interpretive synthesis prepared by the author is based on team efforts by Verde Exploration Company, the Anaconda Company, CoCa Mines Inc., and Phelps Dodge Corporation.

All mines in the district are now inactive but mineral exploration continues. The United Verde open pit exposes the top 500 feet of an elongate, N.N.W.-plunging orebody which extends for another 4200 feet in elevation below the flat bench leading into the pit area. Gold exploration is currently being conducted within the gossan zone of the nearby United Verde Extension (U.V.X.) mine.

JEROME DISTRICT MINERAL PRODUCTION

The mines at Jerome have provided the major share of Proterozoic massive sulfide ore production from all of Southwestern United States. The United Verde deposit was by far the largest and the entire massive sulfide body was probably in excess of 100 million short tons. It is not known how much more of the body was eroded to its original discovery level. The bulk of the elongate, plunging body is predominantly pyrite which forms the upper portion of the mass. Chalcopyrite and sphalerite occur in the basal portion and comprise the major ore minerals contained in a gangue of pyrite, qyartz, and minor accessory minerals. Small amounts of surficial supergene ore (silver rich) were mined from the topmost part of the United Verde body, but most of the ore represents a primary grade. Production yields of 4.43% Cu, 1.49 oz/t Ag, and 0.041 oz/t Au plus a small amount of by-product zinc were obtained from the basal ore which was mined. There may be zinc reserves left within the United Verde massive sulfide body.

Although the original primary ore mineralogy and grades of the United Verde and U.V.X. massive sulfide bodies were probably very similar, the U.V.X. deposit became highly enriched by subsequent supergene events. Perhaps up to a third of the U.V.X. enrichment dates from Precambrian time, but most of the bonanza ores were generated during Tertiary time as discussed further in the text. As the upper part of the U.V.X. sulfides came in contact with meteoritic groundwaters, copper was carried downward from the oxidizing mass in acidic solution where it replaced chalcopyrite and pyrite in the primary ore. Rich chalcocite ore, some quite massive, was produced by the supergene process. The U.V.X. mine produced 3.9 million short tons of 10.23% Cu, 1.65 oz/t Ag, and 0.046 oz/t Au.

Other mines in the Jerome district included the Copper Chief, Cliff, Verde Central, and Shea. The Copper Chief ores were mainly oxidized but a small amount of copper-bearing sulfide ore was produced. The gossan ores were mined chiefly for their precious metal content. The Cliff mine produced a small amount of high grade Cu-Ag massive sulfide ore. The Verde

Central deposit is reported to have produced 121,000 short tons of ore grading 2.94% Cu. The Shea mine is unique to the district in that it produced small amounts of silver from tetrahedrite ore contained in a quartz-siderite vein (Lindgren, 1926). In addition, there are scores of smaller deposits, some of which had minor production, that are scattered along a relatively narrow zone of Proterozoic rock outcrop for 4.5 miles on the N.E. flank of Mingus Mountain.

PREVIOUS WORK AND ORE-FORMING THEORIES

The literature on the Jerome district up to 1958 is ably summarized in an authoritative U.S.G.S. professional paper by Anderson and Creasey (1958). Their paper was prepared soon after the closure of the mines at Jerome and the theories of ore genesis that they presented were current for that era. It was widely believed that the massive sulfide ores were formed by selective replacement of portions of the Grapevine Gulch sediments and an intrusive quartz porphyry. They reported on the widespread alteration within the Cleopatra quartz porphyry underlying the orebodies but were unable to fully explain the cause.

The 1:24,000 geologic map which accompanies the professional paper incorporated the work of G.W.H. Norman who mapped the Jerome district to the southeast as far as Oak Wash, located about 5 miles from the village of Jerome. His 1:4,800 scale mapping and the abundant mine records by mine staff geologists over the years provided the main data base upon which the Anderson and Creasey (1958) synthesis was made.

Exploration personnel who were active in the area during the 1960's and very early 1970's, however, came to the conclusion that the replacement model for the origin of these Proterozoic massive sulfide deposits was inadequate to explain their formation. By 1971 the volcanogenic concept for explaining massive sulfide origin was becoming accepted in the Jerome area (P.A.Handverger, pers. commun. and private company reports, 1971) and, of course, elsewhere (Sangster, 1972). For more than 15 years the volcanogenic model has played a key role in most massive sulfide exploration programs in the Jerome district.

Anderson and Nash (1972) re-interpreted the model presented earlier by Anderson and Creasey (1958). Their conclusion was in harmony with local geologists who recognized that the important Cleopatra quartz porphyry was not an intrusive, but was a crystal tuff and part of the volcanic stratigraphy. The United Verde and U.V.X. massive sulfide ore deposits rest conformably on the topmost surface of the Clepoatra. Anderson and Nash (1972) re-classified the rhyolite crystal tuff as the Cleopatra Member of the Deception Rhyolite. The present author proposes that the term Cleopatra Crystal Tuff (cct on maps and sections) is more appropriate to describe a discrete formation that is directly related to ore formation and separated from older and younger volcanic strata by unconformable surfaces.

Lindberg and Jacobson (1974) emphasized that the United Verde and U.V.X. deposits lie on opposite limbs of the Jerome anticline. Each of these bodies exhibit opposite-facing stratigraphic tops and its own unique Mg-chlorite footwall alteration (Handverger, 1975). Norman (1977) adheres to the hydrothermal replacement model for ore generation.

GENERAL DESCRIPTION OF THE VOLCANOGENIC MODEL

Within the volcanic and sedimentary rocks of the Jerome district abundant volcanogenic characteristics can be seen that relate to the process of ore formation and rock alteration. Before proceeding further into the details of the local geology, some general aspects of the volcanogenic model will be discussed.

Volcanogenic massive sulfide deposits and their lateral exhalite equivalents should be considered to be part of the stratigraphic succession, albeit a rare and localized type of strata. Modern observations of the deep sea floor within the last decade have at last provided geologists with direct evidence for the previously hypothesized ore-forming process. It needs to be emphasized, however, that modern "black smoker" sulfide accumulations are associated with basaltic crust and many such bodies will ultimately be consumed at a subducting plate margin. Those that are accreted to the land mass would be classified as a Cyprus-type. In contrast, massive sulfide bodies that are formed with an evolved, submarine silicic volcanic pile, such as in an island-arc environment, will stand a much higher chance of being accreted to a continental land mass and preserved in the record. A scenario such as that has been proposed for the Devonian West Shasta massive sulfide district in Northern California (Barker, et al., 1979 and Lindberg, 1985).

The interaction of sea water with hot submarine volcanic rock permits large hydrothermal cells to form in the substratum. Hydrothermal solutions that result from such cells vent onto the sea floor and undergo dramatic temperature reduction and loss of pressure at the rock/water interface. Sulfide crusts are precipitated from mineral-laden hot springs at the vent site. Sulfide stockworks and/or veining will typically form in the immediate footwall of the surface-laid sulfide laminates and masses. Continued hydrothermal attack on the base of the growing sulfide body forms the classic replacement textures that are so often reported in literature on massive sulfide deposits. The highest economic metal values are most often contained near the base of such bodies, while delicate primary sulfide laminations are often preserved toward the top and outer edges of the body.

Footwall rock alteration formed by the hydrothermal cells will vary with the size of the system and the nature and composition of the fractured substrate. Magnesium salts contained within the heated seawater are carried in hydrothermal solution. Most of the metal, sulfur, and silica values can vent to the surface in solution but the magnesium reacts with the footwall rocks where it can be concentrated in impressive amounts (i.e., the "black schist" below the ore deposits at Jerome). The high content of Mg relative to Fe in these chlorites distinguishes them from the iron-rich chlorites formed during regional metamorphism (i.e., greenstone belts).

Siliceous volcanic rocks will often exhibit widespread footwall sericite alteration and may be associated with silicification near the vent site. In some cases silica depletion can occur at the vent itself and be concentrated laterally. An example of a lateral silica enrichment zone occurs immediately southwest of the United Verde deposit where the conspicuous, erosion-resistant Cleopatra Hill presents an anomalous geomorphic feature.

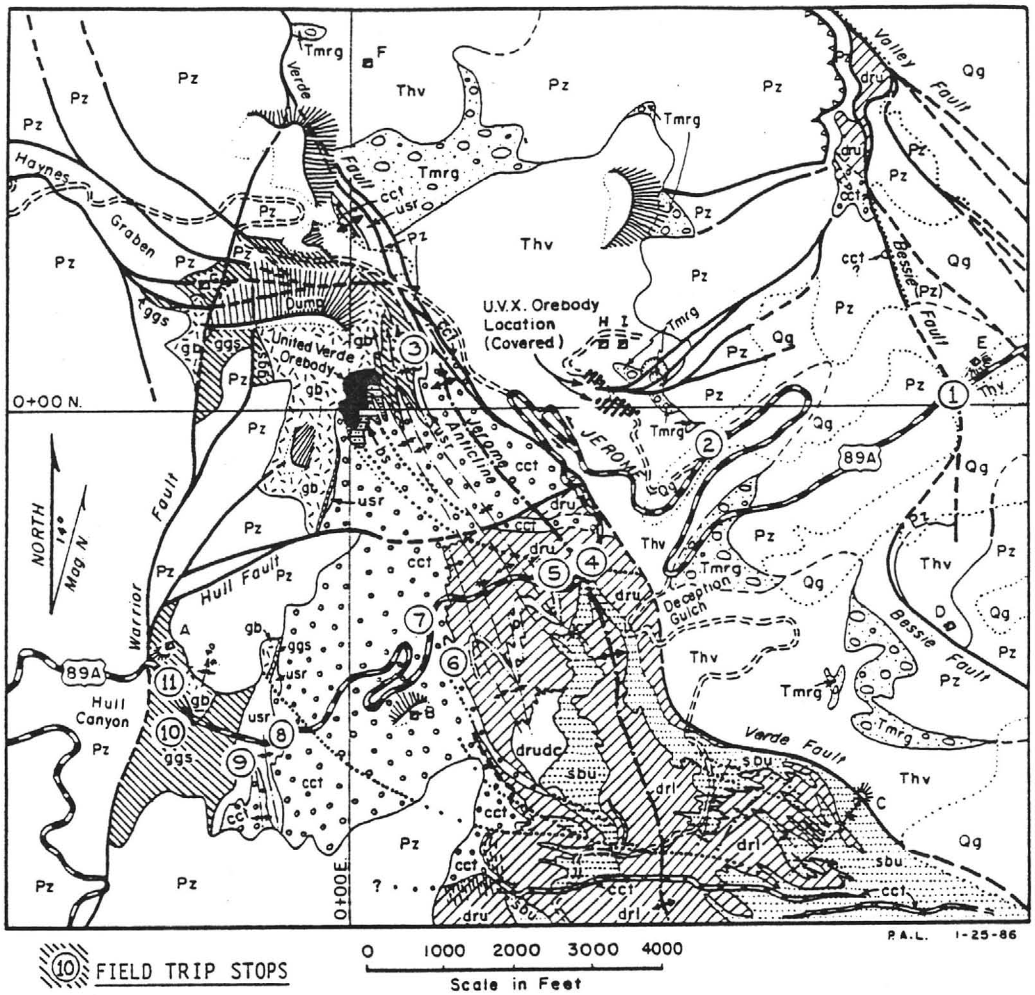


Figure 1. Geologic map of northern part of Jerome district, Arizona. Modified from Anderson and Creasey (1958) with detailed post-1971 mapping by P. A. Lindberg, P. A. Handverger, and C. Meyer.

Rock Types:

Thv Mid.-Late Miocene; Hickey Basalt and included sediment
Tmrg Eocene(?)-Mid. Miocene; Mogollon Rim Gravels
(Laramide Uplift and unconformity)
Pz Paleozoic sediments, undifferentiated
(Major unconformity)

Proterozoic:
gb Intrusive gabbro sills (pre-folding)
ggs Grapevine Gulch formation; volcaniclastic sediments and turbidites; grades to N. and N.E. into andesitic flows and hyaloclastites, basalt flows, and crystal lithic tuffs (see text)
usr Upper Succession Rhyolite; flows, breccias and tuffs
ms Massive sulfide; exposed and concealed (United Verde Horizon); coeval with exh=bedded exhalites and uvs= other minor, non-exhalitive bedded sediments
bs "Black schist" alteration (Mg-chlorite type)
cct Cleopatra Crystal Tuff
ms Massive, semi-massive sulfide (Verde Central Horizon)
dru Upper Deception Rhyolite; flows and breccias; includes polygonal flow marker horizon (p) and dacite (drudc)
sbu Upper Shea Basalt; flows and breccias
drl Lower Deception Rhyolite; flows and breccias
(sbl) (Lower Shea Basalt; inferred beneath drl; not exposed)

Map Symbols:

Mine shafts: A=Jerome Grande, B=Verde Central, C=Verde Combination, D=Gadsden, E=Texas, F=A&A, G=Haynes, H=Edith and I=Audrey (U.V.X.)

Mine dumps

Folds: Primary (N.N.W.) Secondary (E.-N.E.)

Proterozoic cauldron fault zones related to ore formation; pre-folding; some fractures filled by cct feeder dikes

Late Miocene normal faults and re-activated Laramide high-angle reverse faults

Typical footwall alteration of a siliceous volcanic host rock exhibits depletion of Na_2O and enrichment of K_2O and MgO. Beyond the reach of the hydrothermal alteration zone these values remain normal for the particular rock composition in question. The volume of a massive sulfide body is small when compared to the large volume of altered footwall rocks. Sericite (with chlorite and silica) typically forms within a broad zone of alteration in a rhyolitic host rock, for example, while chlorite (with sericite and silica) becomes dominant near the active zone of venting. Depletion of metals from altered footwall rocks accounts for some of the concentrations found in the resulting orebodies.

Submarine vent sites can assume a wide variety of geometries within a volcanic pile. Solutions may vent along pipe-like sites as seen in some Kuroko, Japan examples (Kuroda, 1983). They may also vent from elongate graben fractures in the sea floor as is proposed for the West Shasta district, California (Lindberg, 1985), or they may issue from arcuate cauldron fractures as proposed for some of the Kuroko, Japan deposits (Ohmoto and Takahishi, 1983) and for the United Verde deposit (Lindberg, In press). In the Delta district of Alaska massive sulfide deposits formed in rifted tuff successions with no obvious lava or vent breccia associations (Clynt Nauman, pers. commun.).

There are certain terms, purely relative in nature, that often prove to be very useful in understanding the environment associated with volcanogenic massive sulfide deposits and their associated alteration zones. For example, Meyer (1972, pers. commun. and private company reports) applied the concept of "Lower" and "Upper Succession" to distinguish between altered, ore-associated host rocks of the Jerome district with post-ore cover rocks that are relatively unaltered. These informal terms can often prove helpful in determining stratigraphic tops by the "one-sidedness" of the alteration state at a mineralized contact. In addition, the terms "proximal" and "distal" provide the relative sense of whether the sulfide deposit is close to, or away from, an altered vent site.

NOMENCLATURE IN THE JEROME DISTRICT

Anderson and Creasey (1958) classified the volcanic and sedimentary rocks of the Jerome district as belonging to the Ash Creek group of the Precambrian Yavapai series. A uranium-lead date of 1,820$\pm$10 m.y. old was obtained from zircons contained within the "quartz porphyry facies in the upper part of the Deception Rhyolite" (Anderson, et al., 1971, p. C12).

Post-1971 detailed mapping in the Jerome district discloses that the published stratigraphic nomenclature of Anderson and Creasey (1958) and Anderson and Nash (1972) is in need of severe revision. There are two main reasons for the problems in terminology. In the first place, not all of the effects of folding were taken into account before names were applied to the rock units. Along the Jerome anticline, for example, (Lindberg and Jacobson, 1974) Deception Rhyolite and Shea Basalt interfinger with one another. In the present paper the author has applied the informal names "lower Shea Basalt, lower Deception Rhyolite, upper Shea Basalt, and upper Deception Rhyolite" to the succession seen in Deception Gulch south of Jerome. The second reason for terminology confusion rests with the interpretation of how the "Cleopatra quartz porphyry" of Fearing (1926) fits the stratigraphic succession.

It is beyond the scope of this paper to present all of the evidence and reasons for proposing formal changes in the geologic nomenclature for the Jerome region. The informal stratigraphic succession presented in this paper is compatible with the necessary constraints on the system required by the volcanogenic model. A thorough review of the origin and structural history of the Jerome massive sulfide deposits and proposed nomenclature revisions is currently being prepared by the author (Lindberg, In prep.).

INFORMAL STRATIGRAPHIC SECTION FOR JEROME

The following table presents a simplified stratigraphic section for the northern portion of the Jerome district. Map and cross section rock symbols are also shown as used by the author in Figures 1, 2, 4 and 5. This informal usage is subject to further refinement. Wherever possible the terminology initiated by Anderson and Creasey (1958) has been retained, but it is now clear that major revisions in their nomenclature is required.

Tertiary:

Thv	Mid.-Late Miocene; Hickey Basalt and included sediments
Tmrg	Eocene(?)-Mid. Miocene; Mogollon Rim Gravels
~~	(Major Unconformity)

Paleozoic:

Pz	Paleozoic sediments, undifferentiated; Also includes €t=Tapeats Sandstone, €cv=Chino Valley formation, Dm=Martin Dolomite, PPs=Supai Sandstone
~~	(Major Unconformity)

Proterozoic:

gb	Intrusive gabbro sills
gg	Grapevine Gulch formation; ggs=volcaniclastic sediments and turbidites, ggaf=andesitic flows and breccias, ggah=andesitic hyaloclastites, ggbf=pillow basalt flows, ggclt=crystal lithic tuffs (rhyolite)
usr	Upper Succession Rhyolite; flows, breccias, tuffs
ms	Massive sulfide (United Verde Horizon)
exh	Bedded exhalites; lateral equivalent to ms above and contained in United Verde Horizon
uvs	Minor non-exhalitive sediments contained along United Verde Horizon
bs	"Black schist" footwall alteration to ms (Mg-chlorite)
cct	Cleopatra Crystal Tuff; cctb=internal autobreccia layers, cctc=chloritic alteration, but not to the intensity of black schist
ms	Massive to semi-massive sulfides (Verde Central Horizon)
dru	Upper Deception Rhyolite; flows and breccias
sbu	Upper Shea Basalt; flows and breccias
drl	Lower Deception Rhyolite; flows and breccias
sbl	Lower Shea Basalt; flows, some pillowed, and hyaloclastites (Not exposed below the northern portion of the Jerome district but projected into this position from abundant N.N.W.-plunging exposures southeast of Jerome)

EVOLUTIONARY MODEL FOR THE JEROME VOLCANIC PILE

Figure 2 shows a schematic pre-fold evolutionary model of a portion of the Jerome volcanic pile as seen in cross section. Most of the folds at this locality plunge toward the N.N.W. and there is a progressive younging of outcropping strata from the Copper Chief mine area toward the last Proterozoic exposures found at Jerome, nearly 4 miles to the northwest. In addition, the rhyolitic section thickens appreciably toward Jerome. The submarine basement upon which the Deception Rhyolite was laid is here defined as lower Shea Basalt, and the periodic build-up of rhyolite lava and breccia sheets created a submarine dome that was several thousand feet thick. Collectively, the lower and upper Deception Rhyolite appears to be thickest in the immediate Jerome area, but outcrop limitations and fold geometries do not allow the full areal extent of the unit to be determined toward the west, north, or northeast of Jerome.

Figures 1 and 2 show a northward-thinning wedge of upper Shea Basalt which outcrops between lower and upper Deception Rhyolite. Anderson and Creasey (1958) included this basalt within the Deception, but extensive field studies prove that this rock unit can be traced without interuption from Deception Gulch, just south of Jerome, to the main mass of outcropping Shea Basalt several miles to the southeast. During the recent mapping phase and study of the evolution of the volcanic pile it has become clear that rhyolite eruptions near Jerome interfinger with andesite/basalt emissions from a source located further to the south on the flank of the dome.

A temporary hiatus in volcanic activity occurred at the end of the systematic and slow build-up of the upper Deception Rhyolite. Jasper lenses, chemical exhalites, re-worked volcaniclastic sediments, and local thin conglomerates can be observed on this disconformable surface for some distance. Several prospect cuts have been dug along this prospective contact over the last century. The Verde Central orebody was discovered at this horizon. Rather than occurring at a random position on the topmost surface of the upper Deception Rhyolite, the alteration sites, prospects, and orebody lie on fractures that closely match the same locations where subsequent cauldron fractures of the next cycle of volcanism were about to occur.

Following the generation of the Verde Central ore deposit (and perhaps even during), a catastrophic set of events took place that radically changed the nature of the evolving volcanic dome. Tumescence, or swelling, of the large submarine dome by increasing deep-seated magma pressure triggered the formation of nested, arcuate fractures around the periphery of the volcanic high. Large cauldron subsidence faults formed within the Deception Rhyolite dome and the ruptures acted as feeder channels through which the Cleopatra Crystal Tuff was explosively erupted. Collapse of a central crater by magma withdrawal from a deep chamber was probably commensurate with the rapid surface accumulation of the tuff sheet.

The Cleopatra Crystal Tuff was extruded in massive surges onto the sea floor where thick sheets were accumulated. Irregularly distributed within the uniform sheets are autobreccia layers that exhibit indistinct boundaries, implying that the crystal tuff was consolidated enough between eruptive surges to permit local brecciation. The composition of the crystal tuff is virtually the same from bottom to top of a mass which is conservatively estimated to be 2000 feet thick in the Jerome area. Away from the pervasively altered Cleopatra in the footwall of ore zones the rhyolite exhibits abundant 2-3 mm quartz and feldspar phenocrysts set in a felsic matrix. When altered, the conspicuous and resistant quartz "eyes" remain in a fine-grained matrix often consisting of sericite, quartz, and some chlorite.

Cleopatra Crystal Tuff feeder dikes now occupy some of the cauldron subsidence fractures that cut the upper Deception Rhyolite. Offsets that have been studied on six cauldron faults and/or feeder dikes show consistent down-to-the-north motions, indicating that the collapsed dome lies somewhere to the north of Jerome. Where cauldron fractures are not filled by feeder dike material the original fault gouge has been completely healed by chlorite and other hydrothermal alteration minerals.

Mine exposures and exploration drilling have extended the limited outcrop range of the Cleopatra to a minimum of 5.5 miles in a north-south direction. Because of Phanerozoic cover rocks, complex folds, and the fault-buried northeastern portion, it is virtually impossible to assign an accurate volume to the original Cleopatra Crystal Tuff sheet. It is probable that it covered a diameter of at least 8 miles and had a central thickness of 2000 feet or more. A conservative estimate for the volume would be 6 cubic miles (25 cubic kilometers). This rapid eruption and mass would have been capable of generating an enormous "heat engine" which, along with the energy released from the buried magma chamber, was capable of driving the hydrothermal solutions responsible for massive sulfide generation.

Renewed cauldron fracturing cut the consolidated Cleopatra Crystal Tuff sheet along breaks that were subparallel to the feeder dikes. These late stage subsidence faults were not large, but they allowed the release of trapped hydrothermal fluids to escape to the sea floor along confined channelways. Figure 3 depicts a schematic view of how these hydrothermal solutions vented to the sea floor and deposited the United Verde massive sulfide ore deposit. Continued hydrothermal activity caused extensive high-grade replacement ores to form near the base of the earlier formed, syngenetic sulfide laminates and masses.

Coeval with proximal massive sulfide ore deposition may be distal deposition of bedded chemical exhalites and other minor sedimentary lenses. In the example cited in Figure 3, exhalites extend distally toward the east from the United Verde deposit, but did not breach the sea floor scarp on the western wall. The assymetry of deposition of fluids which escape along the sea floor from a vent area depends upon the irregularity of the volcanic seascape. In some parts of the Jerome district little, or none, of the hydrothermal fluids bled away from the vent site to produce bedded exhalites. They extended for long distances away from the Copper Chief orebody to the southeast, however, where the bedded exhalites are currently being studied by Johnson (In press) for their chemical signatures.

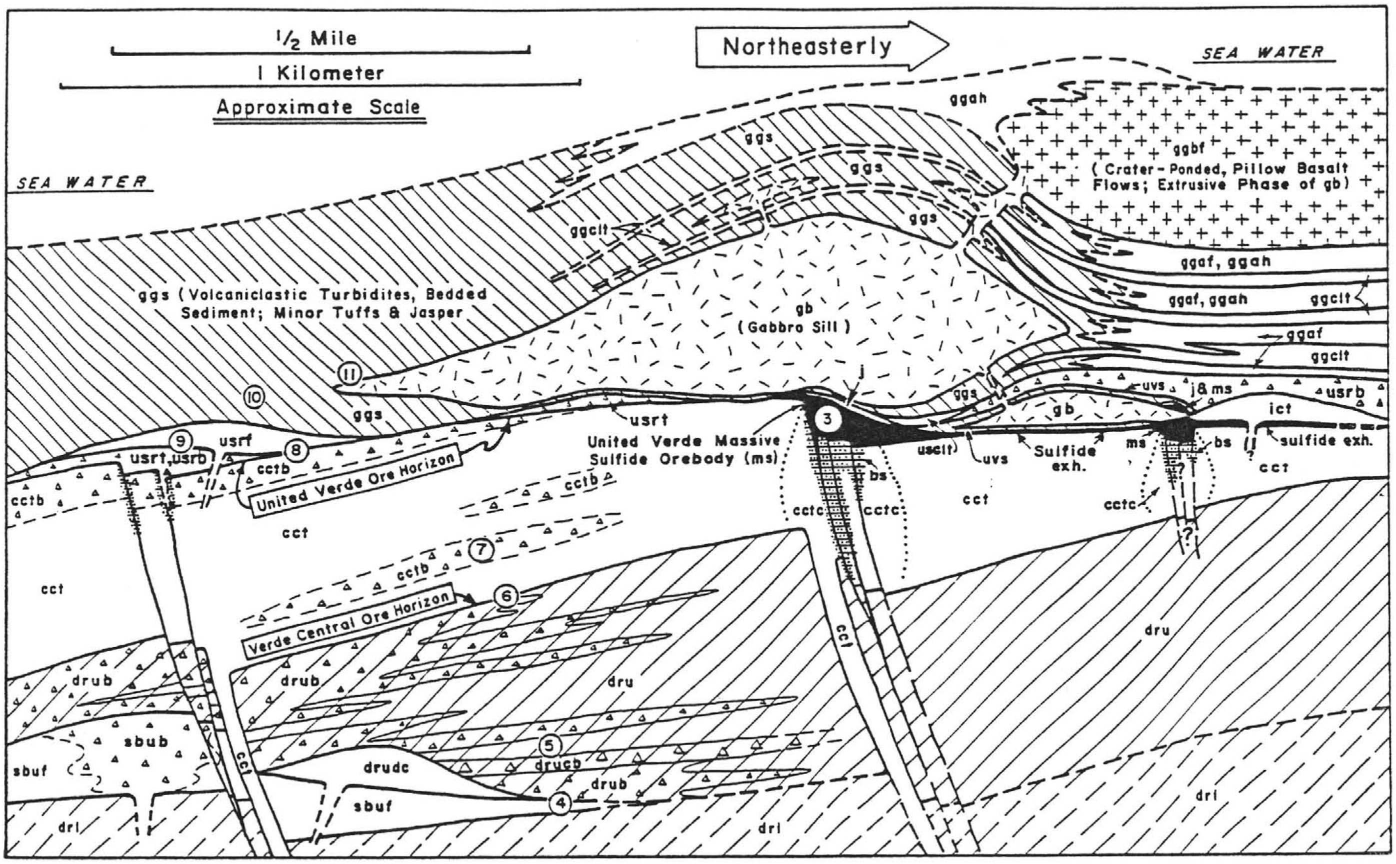


Figure 2. Schematic pre-fold model of the Jerome volcanic pile in cross section. Rock symbols are the same as shown in Figure 1 and the informal stratigraphic section listed in the text. In addition to rock formation names, for example gg for Grapevine Gulch formation, additional letters designate the specific subdivision of that formation. These include: f=flow, t=tuff, b=breccia, h=hyaloclastite, clt=crystal lithic tuff, j=jasper, s=sediment, and c=chloritized. Only a portion of the large Deception Rhyolite dome is shown in this figure. Following ore deposition along the Verde Central Horizon the rhyolite dome is disrupted by cauldron faulting and the explosive eruption of the Cleopatra Crystal Tuff. Post-consolidation cauldron subsidence faults break the tuff sheet and allow hydrothermal solutions to vent to sea floor traps where the massive sulfide bodies accumulated. In time the hydrothermal venting and ore formation subsided along the United Verde Ore Horizon where massive sulfide bodies, bedded exhalites, and other thin sediments mark the upper surface of the Cleopatra. Localized eruptions of Upper Succession Rhyolite lava domes, breccias, and tuffs were laid on top of the horizon. Toward the northeast renewed andesitic and basaltic volcanism, interspersed with thin rhyolitic crystal lithic tuffs, blanketed the high part of the volcanic dome and shed debris down the flank toward the southwest. All of these units are designated as part of the Grapevine Gulch formation. Where they are most readily observed in Hull Canyon along Highway 89A, the rocks are chiefly comprised of turbidites (ggs). Late stage, but pre-folding, gabbro sills cut the upper part of the succession and are probably co-equivalent to the crater-ponded pillow basalt flows shown in the upper right. Field trip stops are indicated by numbered circles. The Cleopatra crystal tuff (cct) is shown at approximately ½ the true thickness. All other strata approximate true thicknesses.

Following the hiatus in volcanism, and massive sulfide ore generation with widespread footwall rock alteration, localized and relatively small rhyolite domes, breccias, and tuffs were laid onto the United Verde Ore Horizon. The rocks are fresh and distinctly post-ore in age and have been given the informal name of Upper Succession Rhyolite.

Above the fresh rhyolites in Hull Canyon (Field Trip Stop No. 10) are a thick series of turbidite sheets (ggs) of the Grapevine Gulch formation. Toward the north, as seen in outcrop, mine workings, and extensive drill holes, these volcaniclastic sediments gradually change into hyaloclastites, breccias, and flows from the higher part of the dome. Interspersed within the abundant Hull Canyon turbidite exposures are bedded jasper horizons which must represent significant time intervals between turbidite surges. In other turbidite sheets there are basal rip-up clasts of tabular jasper laminae.

Gabbro sills intrude the bedded sediment portion of the Grapevine Gulch formation, and may be related to pillow basalt extrusions into the inferred crater region at the summit of the dome. Gabbro sills are pre-folding in age and part of the dome development.

STRATIGRAPHIC SECTION SEEN ON FIELD TRIP

Figures 1 and 2 show the field trip stop numbers in their true plan and idealized section position. Stops No. 4-11 will examine the stratigraphic section from upper Shea Basalt through to the Grapevine Gulch turbidites and intrusive gabbro sill as exposed along Highway 89A in Deception Gulch and Hull Canyon.

Stop No. 4 is situated on the axis of the Jerome anticline at the apex of the upper Shea Basalt amygdaloidal flow. Overlying this for the next 2500 feet to the west along the highway are intensely folded flow and breccia sheets of the upper Deception Rhyolite. The plane of the Verde fault lies a few hundred feet to the northeast.

Stop No. 5 is located at a distinctive marker unit within the upper Deception Rhyolite which helps define the tight folding in this region of the Jerome anticlinorium. Polygonal joints in this unusual flow are considered to be primary cooling fractures that have been distorted during subsequent folding. The rest of the upper Deception Rhyolite is made up of numerous flows with surficial flow rinds that were formerly glassy (now devitrified) and their associated flow breccias. Most of the breccias are composed of relatively small fragments in the range of one-three inches, but between Stops No. 4 and 5 there is a distinctive coarse breccia bed that can be traced through numerous fold closures for several thousand feet.

Stop No. 6 is located at the upper culmination of the monotonous series of flows and breccias that comprise the upper Deception Rhyolite. The distal end of the Verde Central ore horizon is well exposed in a large drag fold near creek level at the western end of Deception Gulch along the contact between the upper Deception Rhyolite and the overlying Cleopatra Crystal Tuff. The contact is marked by a thin layer of greenish-black Mg-chlorite alteration and associated jasper lenses that wax and wane along the prospective ore horizon. Mine tunnels from the Verde Central workings come close to this location and the mine dumps can be seen a short distance upstream. While the Deception Rhyolite is typically devoid of megascopic quartz phenocrysts, the overlying Cleopatra Crystal Tuff contains abundant 2-3 mm semi-rounded crystals set in a felsic matrix. At the base of the Cleopatra is a thin rip-up layer containing rounded jasper clasts and fragments of the Verde Central Ore Horizon sediments.

Stop No. 7, a short distance from the last stop and located along Highway 89A, illustrates the internal features of the Cleopatra Crystal Tuff. On the immediate north side of the highway, in a drainage culvert opening, there is a conformable contact between two possible cooling units formed during eruptive surges. Lying to the west of this location, and well exposed in a highway roadcut, is an autobreccia lens within the crystal tuff. Weathering enhances the fragmental nature of the rock but this feature is often difficult to see on freshly sawn or drilled rock surfaces.

Stop No. 8 is located at the extreme top of the Cleopatra Crystal Tuff at a roadcut in Highway 89A at a point approximately 5000 feet to the W.S.W. of the United Verde orebody. The top 10-50 feet of the Cleopatra is brecciated, with incipient fracturing extending deeper. Multiple folds along the contact exaggerate the thickness of the breccia. The top few feet of the breccia show matrix supported Cleopatra fragments bearing different alteration states as well as foreign jasper and re-worked volcaniclastic fragments caught up in a debris flow. The color of this distinctive horizon takes on a purplish hue from the interstitial hematite staining. Because the same color was seen adjacent to known orebodies in the district the old prospector's term "purple porphyry" was considered as an important exploration guide to ore. The hematite staining is thought to have resulted from deposition of weak hydrothermal fluids that percolated outward from the volcanic edifice and into the surrounding seascape. These rocks are anomalously devoid of sulfur, as are all of the rhyolites seen in Deception Gulch and Hull Canyon. The brick red color that is seen in the rhyolites of Deception Gulch is due to the weathering of chlorite.

From Stop No. 8 due south to creek level in Hull Canyon, the Cleopatra contact can be followed along the purplish color zone. Several excellent drag folds can be observed along the thin bedded sediments of the United Verde Ore Horizon. Just across the stream bed, on the southern side, can be seen some of the least altered Cleopatra Crystal Tuff known to the author.

Stop No. 9 is situated immediately to the west of the previous stop and is located within the Upper Succession Rhyolite. One prominent and unaltered flow exhibits large polygonal joints and is locally called the Bullseye rhyolite from the distinctive iron-stained rings which can be observed within the polygonal fractures. During a 1971 visit to this location Howel Williams referred to these localized rhyolite accumulations as "blister domes," (pers. commun.). The thickness of the Upper Succession Rhyolite varies greatly along strike. It is absent over the western part of the United Verde orebody but thickens considerably in the hanging-wall rocks above the U.V.X. mine. They may reach their greatest thickness in the Copper Chief mine area to the southeast.

Stop No. 10 examines scores of stacked turbidite sheets that range from a few feet to more than 40 feet in thickness. These rocks can either be seen in the weathered outcrops along Highway 89A or to better advantage in the nearby parallel drainage to the south. They form classic Bouma cycles which exhibit coarse, graded volcanic fragments at the base to fine-grained pelites at the top (Bouma, 1962). A few of the pelitic tops show delicate load casts caused by the weight of a subsequent overlying turbidite sheet. Fragments within the turbidites may vary from rhyolitic crystal tuff to andesite and the individual sheets appear to become progressively finer grained upward and more andesitic as the beds become younger. The turbidites are believed to emanate from the summit area of the volcanic dome located somewhere north of Jerome. Submarine erosion, perhaps close to wave level, has removed material from the dome and deposited the thick turbidite accumulations on the southwest flank. These rocks are included in the Grapevine Gulch formation of Anderson and Creasey (1958).

Stop No. 11 is located near the ruins of the Walnut Springs swimming pool. Bedded and tightly folded chert horizons are exposed within pelitic sediments of the Grapevine Gulch formation. Just north of this site is a highway roadcut which exposes the southern tip of a large gabbro sill that extends to the hanging-wall of the United Verde ore deposit. The Warrior fault lies just west of this location and marks the end of Proterozoic outcrops in Hull Canyon.

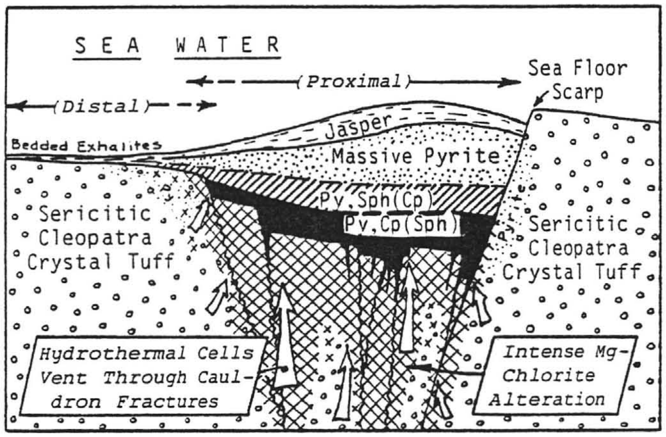


Figure 3. Schematic pre-fold cross section through the United Verde deposit. The view is southerly as one would observe the south open pit wall. Massive sulfides were emplaced over cauldron subsidence faults and lap against a sea floor scarp, giving assymetric distributions. The Cleopatra Crystal Tuff has been intensely altered by Mg-chlorite (Black Schist) in the footwall of the orebody. At depth within the mine the sea floor scarp appears to diminish to zero and the sulfide lenses overlap the fractures. The distal bedded exhalites on the eastern side are now highly folded but persist as thin chemical sediments that extend toward the U.V.X. deposit for several thousand feet.

UNITED VERDE OPEN PIT

Stop No. 3 will be at the United Verde open pit. Except for a small lease operation in the mid-1970's to salvage some footwall stringer ore (chalcopyrite in black schist), the mine has been inactive since 1953. The massive sulfide body is located on patented claims owned by the Phelps Dodge Corporation.

The original small surface cuts, shafts, and very early smelter sites were located well above the large flat bench that now leads into the pit area. This bench was cut into the hill on the United Verde 300 mine level (i.e., 300 feet below the original ore discovery point). The open pit portion of the mine was begun in 1917 but it was not until 1922 that ore was produced. One of the reasons for digging the pit was to remove burning massive sulfide ore that was hindering underground production. After a hiatus during the Depression years the pit continued to produce ore until 1940. The orebody was eventually mined to the 4500 level along the N.N.W.-plunging orebody, or to a depth of 4200 feet below the bench level.

The open pit operation has removed most of the sulfide mass, but the upper barren pyritic massive sulfides can still be seen in the northwestern pit wall. This is overlain by a tightly folded jasper capping and remnants of Grapevine Gulch sediments. The northwestern open pit wall above the sediments has been cut into the gabbro sill. The entire ore system (footwall alteration, massive sulfide ore and barren pyrite, and jasper capping) has a N.N.W. plunge at an average of about 60 degrees. When standing outside the fenced-off pit area, from a vantage point near the old Phelps Dodge office, a view toward the southwest into the pit shows the distinct plunge on the south pit wall where the dark colored chloritic footwall remains beneath the mined away sulfide zone.

The conspicuous high ridge just west of Jerome and immediately south of the pit is Cleopatra Hill. This erosion-resistant hill marks a silica-chlorite alteration zone. Cauldron faults which helped to localize the venting of hydrothermal solutions can be traced from the southwest corner of the pit up and over the high southern ridge, where the heavily chloritized fracture zones pass over the ridge just to the west of the highest part of Cleopatra Hill.

The entire southern wall of the 300 level bench area and open pit is composed of Cleopatra Crystal Tuff, with the exception of two tight synclines of bedded exhalites and post-ore rhyolites just southwest of the shaft. The bedded exhalites are composed of banded cherts and jaspers with sulfide laminates and disseminations. They represent the lateral, or distal, equivalent to the main massive sulfide body to the west as is shown in the pre-fold reconstruction of Figure 3. At this excellent exposure the three dimensional effects of the polyphase folding can be seen in detail. These folds can be traced down plunge to the deepest levels of the United Verde mine workings as well as to the southeast through Deception Gulch and on into Mescal Gulch.

The principal, or primary, folds trend N.N.W. and their axial planes dip steeply to the E.N.E. The secondary cross folds trend east-northeasterly and also exhibit steep axial planes. The interference patterns created by the two superimposed fold effects create the classic "egg crate" pattern seen in outcrop. In the United Verde pit area the primary folds plunge at 60° to the depths of the mine and there the plunge reverses as the system passes through the east-trending Haynes cross syncline. The resultant of polyphase folding generated near-vertical high grade ore shoots where chalcopyrite migrated into the steep axial plane intersection of primary and secondary anticlines.

The tour will examine the south pit wall in some detail to observe the distal and proximal footwall alteration effects in the Cleopatra Crystal Tuff. The pit ramp road along the south wall is an ideal location to observe the effects drawn in Figure 3. To the east of the orebody the thin exhalite strata extend distally away from the chloritic-altered vent area and override the sericitic-altered crystal tuff adjacent to that vent. Dark colored, greenish-black Mg-chlorite alteration formed in the immediate ore footwall. It can be seen in fractures cutting the crystal tuff and replacing the rock.

The miner's term "black schist" was applied the intensely chloritized footwall alteration of the United Verde orebody. Mg-chlorite alteration ranges in intensity from complete replacement of the crystal tuff to a permeation of the rock with indistinct outer boundaries. The strongest concentrations of chlorite occur within the old feeder fractures which channeled large quantities of hydrothermal solution toward the original sea floor. Between major fracture zones are brecciated areas where chlorite envelops and partially bypasses large blocks of lesser chloritized crystal tuff.

Pyrite is not abundant in the footwall rocks of the immediate vent area, but is displaced to the sides of the most strongly chloritic zone where it is associated with abundant sericite. Directly below the massive sulfide body were high grade stringer veins composed of chalcopyrite and intensely chloritic crystal tuff. This constituted a major source of ore produced during the mining operation.

Just west of the main chloritic fracture zone, a prominent pit wall of Cleopatra Crystal Tuff shows strong sericite alteration and pyritic stockworks of a type identical with that seen to the east of the orebody below the bedded exhalites. Chlorite is virtually absent in this zone which is in sharp contrast to the nearby chloritized vent zone. The wall is interpreted by the author to be near the sea floor scarp depicted in Figure 3. It was just off the main point of hydrothermal venting, which accounts for the lack of Mg-chlorite, but was involved within the widespread sericite alteration envelope. There is no evidence that massive sulfide deposition ever breached this sea floor scarp at this point in space. Cauldron faulting formed an effective sea floor ore trap.

In the bottom levels of the pit massive pyrite outcrops beyond the rubble left by mining operations. Delicate primary depositional banding can be seen in the massive pyrite, along with primary chert lenses that become more common upward. Replacement textures are rare to absent this high up on the massive sulfide pile and the economic values are nil. Only the overlying jasper was somewhat recrystallized and partially bleached by the adjacent gabbro sill intrusion. A small amount of pyrite was formed in the chert at the expense of the hematite.

PROTEROZOIC FOLDING

Polyphase folding is seen throughout the Jerome district within the Proterozoic rocks. The dominant folds trend N.N.W. and approach isoclinal conditions in some areas. Drill-indicated primary fold amplitudes of at least 6000 vertical feet are inferred, while secondary cross folds of lesser amplitude are revealed by F_1 plunge reversals seen throughout the district. The principal exposed fold in the Jerome area is the Jerome anticline as shown in Figures 1, 4, and 5. In reality this is axis of an anticlinorium that is about 5000 feet wide. Correlation studies over the last decade and a half of old mine records and new diamond drill data indicate that additional major anticlines and synclines are concealed beneath Paleozoic and Tertiary cover rocks to the northeast of the Verde, Bessie, Valley, and other faults within the Verde Graben. Fold limb attitudes in the Jerome area are steep and trend north-northwest.

Cross folds of lesser amplitude than the primary folds trend irregularly along east-northeast axes, and a few of them are shown in the southeastern portion of Figure 1. Interference patterns between the complex fold sets cause numerous fold plunge reversals and result in "Christmas tree" contact patterns. Both stages of folding are caused by a single deformational event from uniform compressional stress being applied sub-horizontally along an E.N.E. axis. The earlier folds (F_1, N.N.W.) result from initial crustal foreshortening, while the cross folds (F_2, E.-N.E.) result from differential vertical extension and thickening of the crust.

PROTEROZOIC FAULTING

Proterozoic faulting was confined to cauldron-type features that are often arcuate, steep, and are associated with growth features inherent within the development of the volcanic pile. These pre-fold fault zones were healed by hydrothermal solutions that converted fault gouge into alteration minerals such as chlorite and silica. These steep features remain steep and retain their cross-cutting contact relationships during the folding stage because the axes of the folds are also steep. A circular fracture zone with primary steep attitudes will foreshorten in the direction of compression and distort it into an oval shape during the formation of F_1 folds. In the same example the oval-shaped fracture will be distorted again during vertical ductility to flatten the oval even more, and tend to make the fracture zones even steeper during the formation of F_2 folds.

Ransome (1932) maintained that movement must have occurred along the Verde fault in Precambrian time. He believed that the United Verde Extension orebody was the faulted-off apex of the United Verde body, and he was not alone in this belief during the life of the mines. Ransome's concept is illustrated in Bateman (1950, p. 501). A number of other geologists over the years opposed this view for the origin of the U.V.X. deposit as outlined in Anderson and Creasey (1958, p. 7-8).

Exploration programs over the past 4 decades have added a great deal of new information that was not available at the time of the Anderson and Creasey (1958) report. Correlation work by the author on U.V.X. and United Verde mine records show an almost exact fit across the Verde fault plane when displacements are removed. No evidence for a Precambrian age of fault offset could be found, or was necessary. The United Verde and U.V.X. massive sulfide bodies are simply independent and separate deposits that are now located on opposite-facing limbs of the Jerome anticline (Lindberg and Jacobson, 1974; Handverger, 1975). It is equally clear that the extreme supergene enrichment of the U.V.X. body does not date from Precambrian time as proposed by Ransome (1932), simply because normal supergene effects rarely exceed 200 feet below the Paleozoic cover level (The U.V.X. has 450 feet of gossan above it).

PHANEROZOIC FAULTING

Phanerozoic faulting in the Jerome area is restricted to two distinct and separate events. The first involved high-angle reverse faulting associated with the Laramide Uplift of Southwestern Arizona in

Late Cretaceous to Eocene time. The second involved normal faulting that began in Late Miocene time.

High-angle Laramide reverse faulting was widespread in the Jerome area (Lindberg, 1983), in the Grand Canyon region (Huntoon, 1974), and along portions of the Mogollon Rim. Nations, et al. (1982) place the timing of the Laramide Orogeny in Late Cretaceous to Eocene time. The reverse faults seen in the Jerome area accompanied compressional uplift of Southwestern Arizona. Figure 4 depicts a geologic cross section reconstruction of the Jerome mine area just following the Laramide Uplift, reverse faulting, and northeast tilting of the strata on the Verde monocline (Lindberg, Verde Graben abs. in press). Several local gravity slides of detatched Paleozoic strata occurred northeast of Jerome where large blocks de-coupled and slid eastward at a low angle along shaly beds of the Chino Valley formation. Although the mile-wide slab moved only a few hundred feet, the ensuing "pull-away" zone that overlay the U.V.X. orebody adjacent to the Ancestral Verde fault was to become a major factor in the generation of the bonanza ore grades that were about to develop in the deposit. From the time of the Laramide Uplift to Middle Miocene time the eroding, northeast-draining peneplain partially removed the tilted Paleozoic strata from the Jerome area but bared the Precambrian basement in the Mayer-Prescott region to the southwest. Rim Gravels were deposited toward the northeast continuously from Mingus Mountain to the present Colorado Plateau, uninhibited by any intervening valleys or grabens.

Erosion on the northeast-draining peneplain may have lasted for 40-50 million years and resulted in a mature landscape with well defined drainage channels. One such mature channel developed in the "pull-away" zone overlying the U.V.X. deposit. A conglomerate-filled channel, 400 feet deep and 2000 feet wide was carved into the landscape in pre-Hickey Basalt time. Precambrian cobbles, thought to show a Mayer-Prescott area provenance (including several varieties of granitic rocks which are unknown in the Jerome area) were carried toward the plateau in these channels. Hickey Basalt was laid on top of the gravel channels in the Mingus Mountain-Mayer area 14.6 to 10.1 m.y. ago (McKee and Anderson, 1971). Identical gravel-filled channels, buried by 8 m.y. old Slide Rock Basalt, are seen in the eastern wall of Oak Creek Canyon, 30 miles to the northeast (McKee and McKee, 1972). They also occur south of Sedona beneath Hickey age basalt flows and are thought by the author to represent down-faulted gravels and basalt within the Verde Graben (Lindberg, 1983).

The first known normal faulting along the Verde fault system in the Jerome area took place is post-Hickey time, or less than 10.1 m.y. ago. McKee and McKee (1972) believed that 10 m.y. old basalt clasts were still being carried onto the plateau in the vicinity of Oak Creek Canyon. This gives credence to the idea that an important drainage reversal could not have occurred in the Jerome-Verde Valley area, at least before that time. The author concurs in this belief and proposes that the Verde Graben could not have formed before 10 m.y. ago.

Figure 5 shows the geology of the Jerome area following normal faulting associated with the formation of the Verde Graben, beginning about 10 m.y. ago. This section also shows the modern erosional surface along United Verde mine coordinates Zero to 400 North. Field Trip Stop No. 2 presents the surface portion of the cross section to a viewer situated at a Jerome viewpoint on Highway 89A near the old Mingus Union High School (See Figure 1).

THEORIES OF ORIGIN OF U.V.X. OREBODY

The role of faulting was a controversial subject in the Jerome district when it came to searching for additional hidden orebodies. A popular theory early in this century held that the apex of the outcropping United Verde "ore pipe" could have been faulted off and remain hidden below Tertiary and Paleozoic rocks on the northeastern side of the Verde fault (See Anderson and Creasey, 1958, p. 87-89 and 145-149).

Costly attempts to locate a buried orebody by underground searching in the expected location nearly ended in failure when a small pod of 45% copper ore was discovered in late 1914. This, of course, led to the famous discovery of the main bodies of the U.V.X. bonanza-grade Cu-Ag-Au ores. Because the discovery was close to the predicted location for the "faulted-off United Verde apex" theory, it became an accepted model by some (Ransome, 1932).

This concept, however, had its problems when seen in retrospective. The theory demanded a Precambrian age of offset prior to Paleozoic deposition, and another normal offset in Tertiary time along the Verde fault of another 1500 feet. The Precambrian age of movement is no longer regarded as valid, but the Tertiary offsets are well documented. G. W. H. Norman (in: Anderson and Creasey, 1958 and Norman, 1977) has struggled with a U.V.X. fault solution for a long time.

Handverger (1975) and the author conclude that the U.V.X. is a separate and distinct orebody from the United Verde deposit. The two bodies lie on the opposite limbs of the Jerome anticline and each has distinctive footwall and hanging-wall assemblages. While the primary massive sulfides of the U.V.X.were Proterozoic in age, they were largely converted to high grade chalcoite ore during the Tertiary supergene enrichment period and formed at the expense of a much larger orebody.

GENERATION OF THE VERDE GRABEN

The Jerome area marks the southwestern margin of the Verde Graben which involves faulting of the Hickey Basalt that is as young as 10.1 m.y. old. Collective normal offsets on the Verde, Bessie, Valley, and other un-named faults amount to 6100 vertical feet in the area between the Copper Chief mine and the Mingus Union High School south of Cottonwood, Arizona. It is likely that the deepest portion of the graben underlies the present course of the Verde River, but drill holes have not penetrated that deep.

Until recently the role played by the Laramide high-angle reverse faults was not understood. The author has located numerous fault slices of preserved Laramide age offsets, and this ancestral stage nearly always failed again during the Late Miocene tensional regime with its normal faulting.

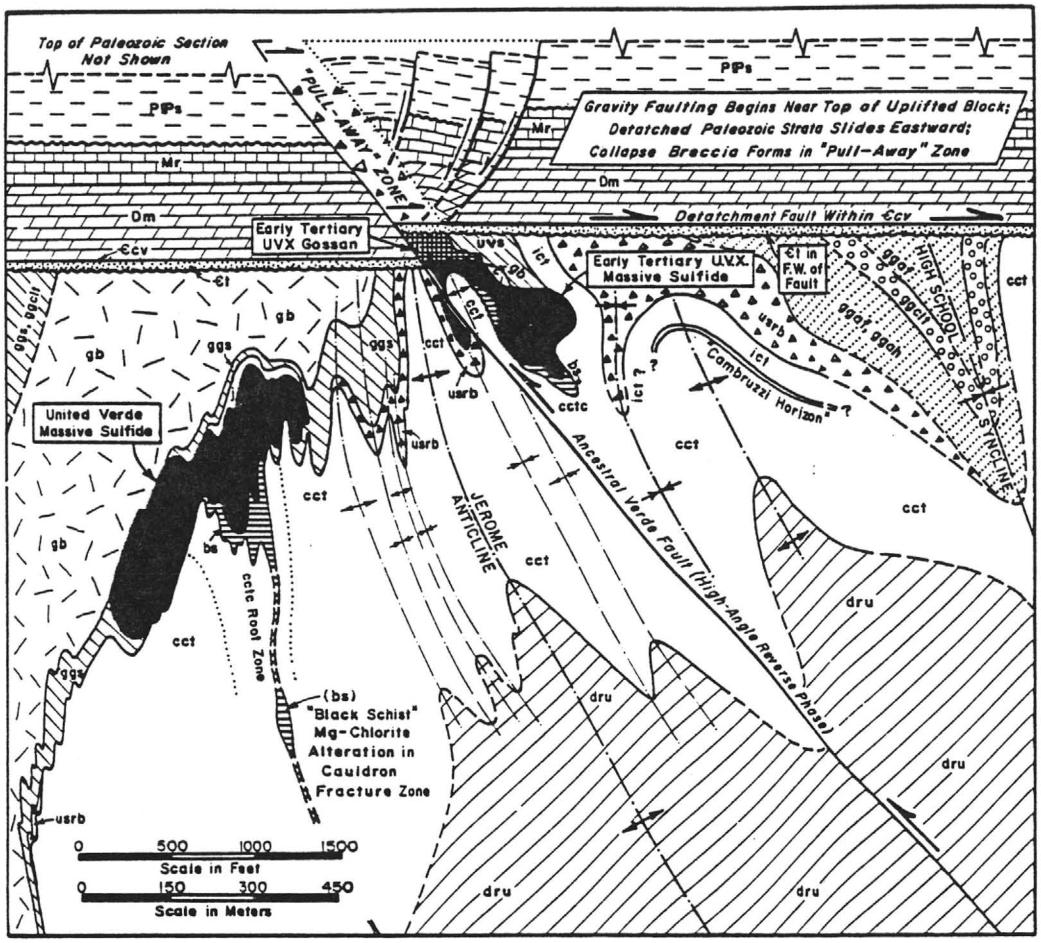


Figure 4. East-west composite cross section through the United Verde (Mine Section 400 North) and U.V.X. (Mine Section Zero North) orebodies as their positions have been reconstructed following the Laramide Uplift and high-angle reverse faulting on the Ancestral Verde fault. The view is looking due North. A "pull-away" zone is created along the fault trace when a large block of Paleozoic strata detatches from the underlying Tapeats Sandstone and slides toward the east on uplifted and gently dipping strata. The Jerome anticline forms the central axis of an anticlinorium that is nearly 5000 feet across. Deep level exploration of the overturned western limb of the anticline was carried out from the United Verde mine to elevations below that shown in this figure. The chloritic root zone below the United Verde orebody follows cauldron fractures that extend through the entire Cleopatra Crystal Tuff (cct). Rock symbols are as shown in Figure 1 and as described in the text. Note the size of the gossan over the U.V.X. orebody. It is expected to not have exceeded more than 200 feet in depth below the Paleozoic strata.

The Laramide and Late Miocene faults are always parallel to the limbs of the primary folds in the Proterozoic basement. The Precambrian influence on the location and dip of Tertiary fault planes in the Jerome district is unmistakable.

The recent understanding that most faults in the Jerome district had a dual history, first compressional and then tensional, has led to a whole new understanding of the complex geometries of the fault blocks in this region. For example, as the Verde fault is traced northward the down-to-the-east motion gradually diminishes to zero and then further on it begins to develop a reverse sense. Britt (1972) discovered that two ages of faulting had taken place and it was not just a simple scissor fault. The first reverse phase (Laramide) affected the entire fault trace from Jerome northward to beyond the Verde River. The later tensional stage (Late Miocene) affected only the southeastern segment of the fault which was re-activated during the generation of the Verde Graben (Lindberg, in press).

The Verde fault forms a clear boundary along the southwestern portion of the graben, but in the vicinity of Jerome additional fault steps along the Bessie (Field Trip Stop No. 1), Valley, and other un-named faults create ever-greater cumulative displacements toward the southeast. The northeastern boundary probably extends into the Sedona area.

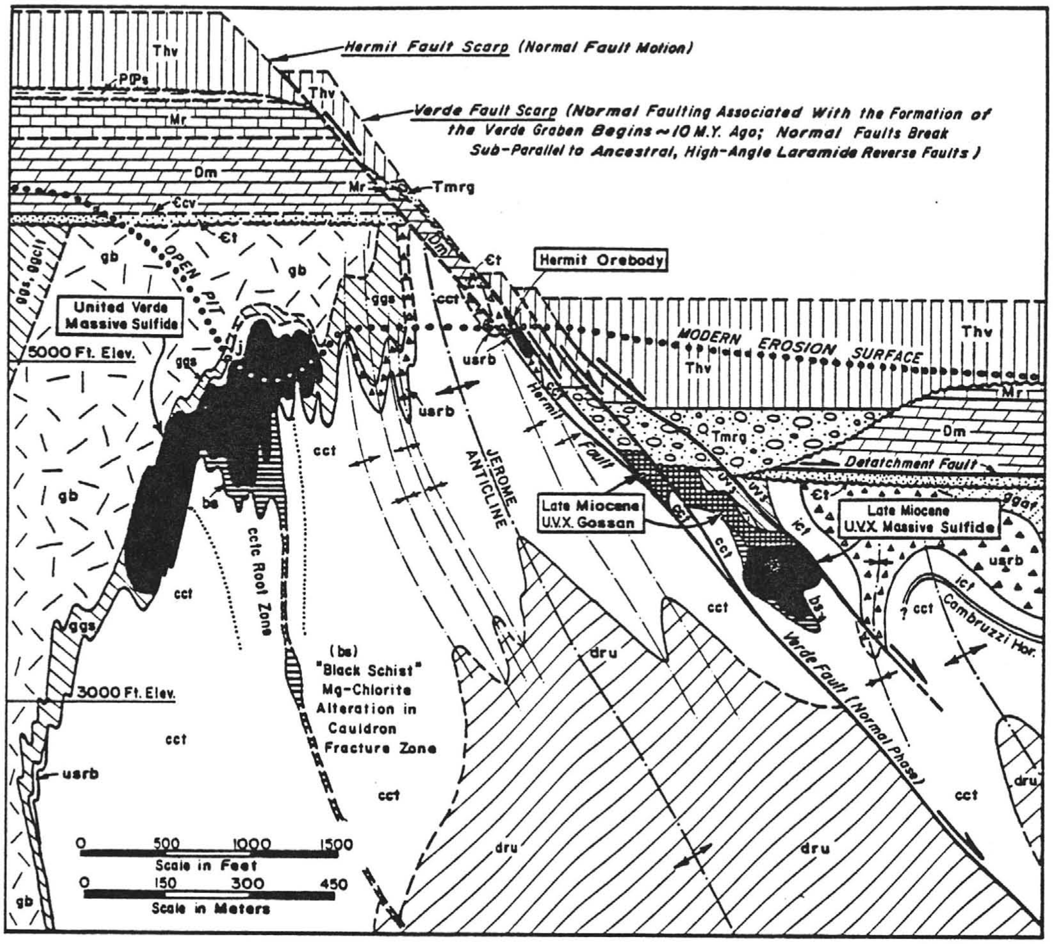


Figure 5. East-west composite cross section through the United Verde and U.V.X. orebodies as their positions have been reconstructed following the period of normal faulting associated with the generation of the Verde Graben approximately 10 m.y. ago. The view is looking due North. A post-Laramide Uplift erosional surface has cut deeply into the Paleozoic surface and left a mature, deep, gravel-filled channel directly overlying the U.V.X. orebody (Compare with Figure 4). The dotted line shows the approximate modern erosional surface across this section. Field Trip Stop No. 2 will view the surface trace of this section from a vantage point along Highway 89A. Using the Tapeats Sandstone as a marker horizon, the Laramide reverse fault stage had lifted the eastern side (Ancestral Verde stage) no more than 400 feet. Then, in Late Miocene time, normal faulting of approximately 1900 feet took place along the Verde fault. The net offset is about 1500 feet. Note the development of basalt lava flows (14.6 to 10.1 m.y. old) that overlie the mature channels filled with Rim Gravels. The normal faulting that accompanied the generation of the Verde Graben has to post-date these lava flows.

The graben gradually diminishes in amplitude toward the northwest, but individual small graben blocks can be seen as far as the entrance to Sycamore Canyon. The graben appears to have attained greatest offset along the former Verde monocline, remnants of which can be seen north of the Phoenix Cement plant near Clarkdale. The Mingus Mountain block is a segment of the Colorado Plateau which the author infers has been detatched during recent crustal extension, with the intervening Verde Graben having been formed as that portion of the plateau floundered. The post-Laramide peneplain affords an excellent marker horizon to measure the amount of graben displacement.

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