CONTACT INFORMATION
Mining Records Curator
Arizona Geological Survey
1520 West Adams St.
Phoenix, AZ 85007
602-771-1601
http://www.azgs.az.gov
inquiries@azgs.az.gov

R. I. 4006 FEBRUARY 1947

UNITED STATES
DEPARTMENT OF THE INTERIOR
J. A. KRUG, SECRETARY

BUREAU OF MINES
R. R. SAYERS, DIRECTOR

REPORT OF INVESTIGATIONS

OLD RELIABLE COPPER MINE

PINAL COUNTY, ARIZ.

BY

THOMAS C. DENTON

REPORT OF INVESTIGATIONS

UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

OLD RELIABLE COPPER MINE, PINAL COUNTY, ARIZONA[1]

By Thomas C. Denton[2]

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ILLUSTRATIONS

INTRODUCTION

The Old Reliable copper mine was first examined by Harlow D. Phelps, an engineer of the Bureau of Mines, in October and November 1942, in compliance with a request from the War Production Board, which furnished copies of assay maps of the 100- and 200-foot levels and requested that they be check-sampled. The author and R. M. Grantham and W. D. Hughes, engineers of the Bureau, made a second and more detailed examination later, after a number of manways had been opened that were inaccessible when the first examination was made.

1/ The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Report of Investigations 4006."

2/ Mining engineer, Bureau of Mines.

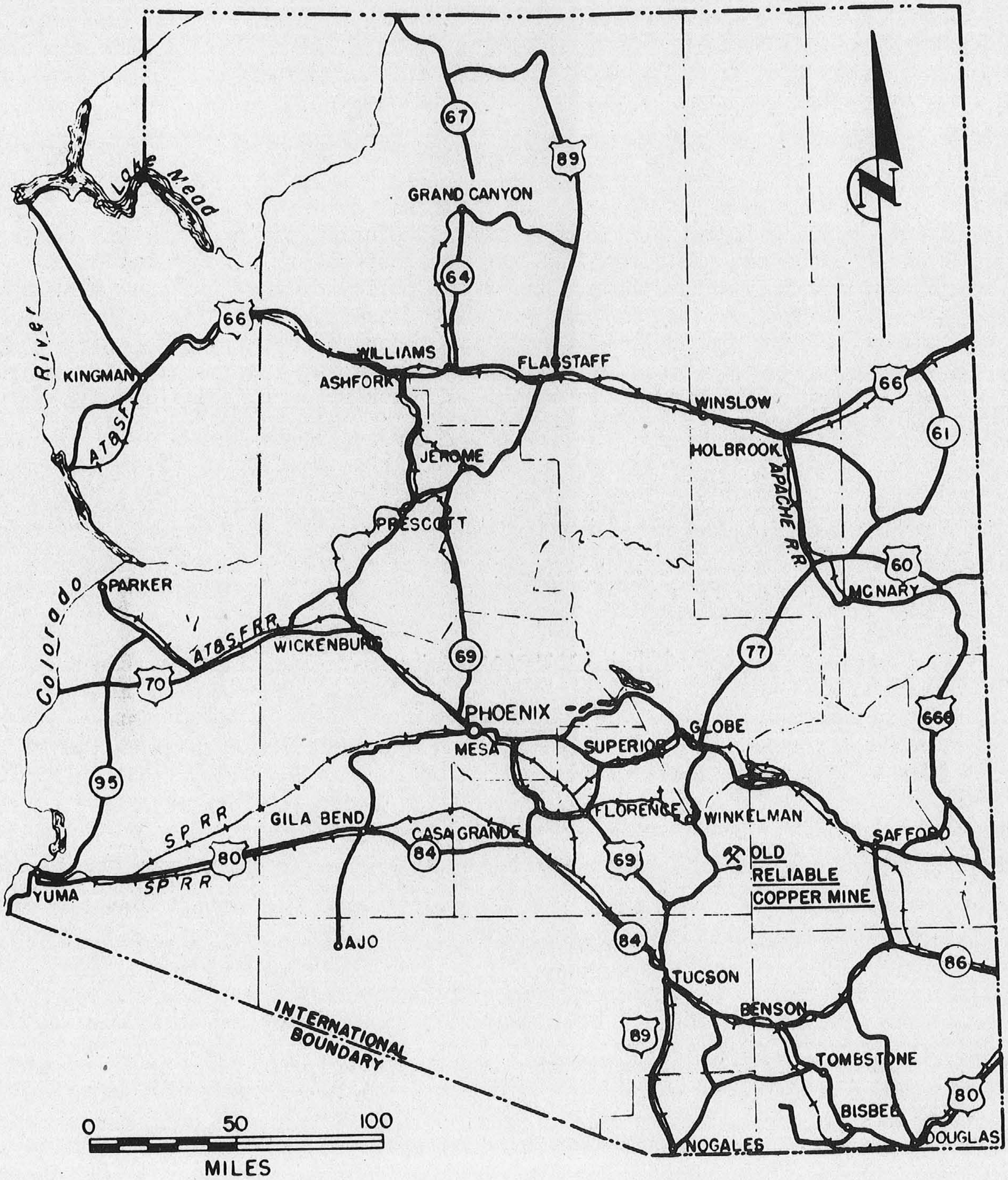

Figure 1.- Location map, Old Reliable copper mine, Pinal County, Arizona.

Copper Creek is the main stream of the area. Ash Creek enters it about $\frac{1}{4}$ mile downstream from the mine. Both creeks occupy narrow, steep, V-shaped canyons.

The climate of the region is semiarid. Rainfall is said to average 18 to 20 inches annually. Recorded temperatures range from 110° F. to 8° F. Snow falls occasionally during the winter. There are no climatic obstacles to year-around operation.

Vegetation is sparse and of a semidesert variety. There is no timber suitable for mine use in the area.

HISTORY AND PRODUCTION

Lode-mining claims were first located in the Copper Creek area about 1863, when rich lead-silver ore from the Blue Bird mine was shipped. In 1863 the region was recorded as the Bunker Hill mining district.

Little work was done until 1893, when the Copper Creek Mining Co. acquired claims along Copper Creek. Acquisition of claims north of the creek in 1907 by the Calumet & Arizona Mining Co. and completion of a wagon road from Mammoth in 1908 started a boom. This latter company explored the Copper Giant, Superior, Globe, Copper Prince, and other properties in the area by underground work and diamond drilling. From 1908 until about 1918, numerous other deposits, including the American Eagle, were worked. A survey for a railroad from Winkleman was made, but construction was not undertaken.

Except on the Childs-Aldwinkle claims, little or no work was done in the area after 1918. This property was exploited primarily for molybdenum, the first work done during World War I. The war ended before production began, but from 1933 to 1938, 329,000 tons of ore was milled and 7,000,000 pounds of MoS_2 was recovered. From 1933 to 1935, the Old Reliable mill was used to treat the ore. Toward the end of 1935, a mill was built on the property, and from then to the end of 1938 a total of 296,652 tons was milled, an average of about 200 tons per day. Maximum production was reached in 1936, when 87,021 tons was milled.

The first corporate owner of the Old Reliable claims was the Copper Creek Mining Co., which by 1908 was controlled by the Minnesota-Arizona Mining Co. The latter company built a steam-electric power plant, a dam, and a mill on Copper Creek, about a mile from the Old Reliable mine, and about $2\frac{1}{2}$ miles of a railroad from the mine to the mill. Ore from other mines in the area was treated in the mill.

In 1910, the Minnesota-Arizona Co. was reorganized under the name Copper State Mining Co., to which company the Old Reliable was transferred. In 1914, the new company replaced the steam plant with a Diesel-electric unit and revamped the mill. Ore from the American Eagle as well as from the Old Reliable was treated. The property operated until about 1919. Later, the mill was dismantled and the machinery was removed.

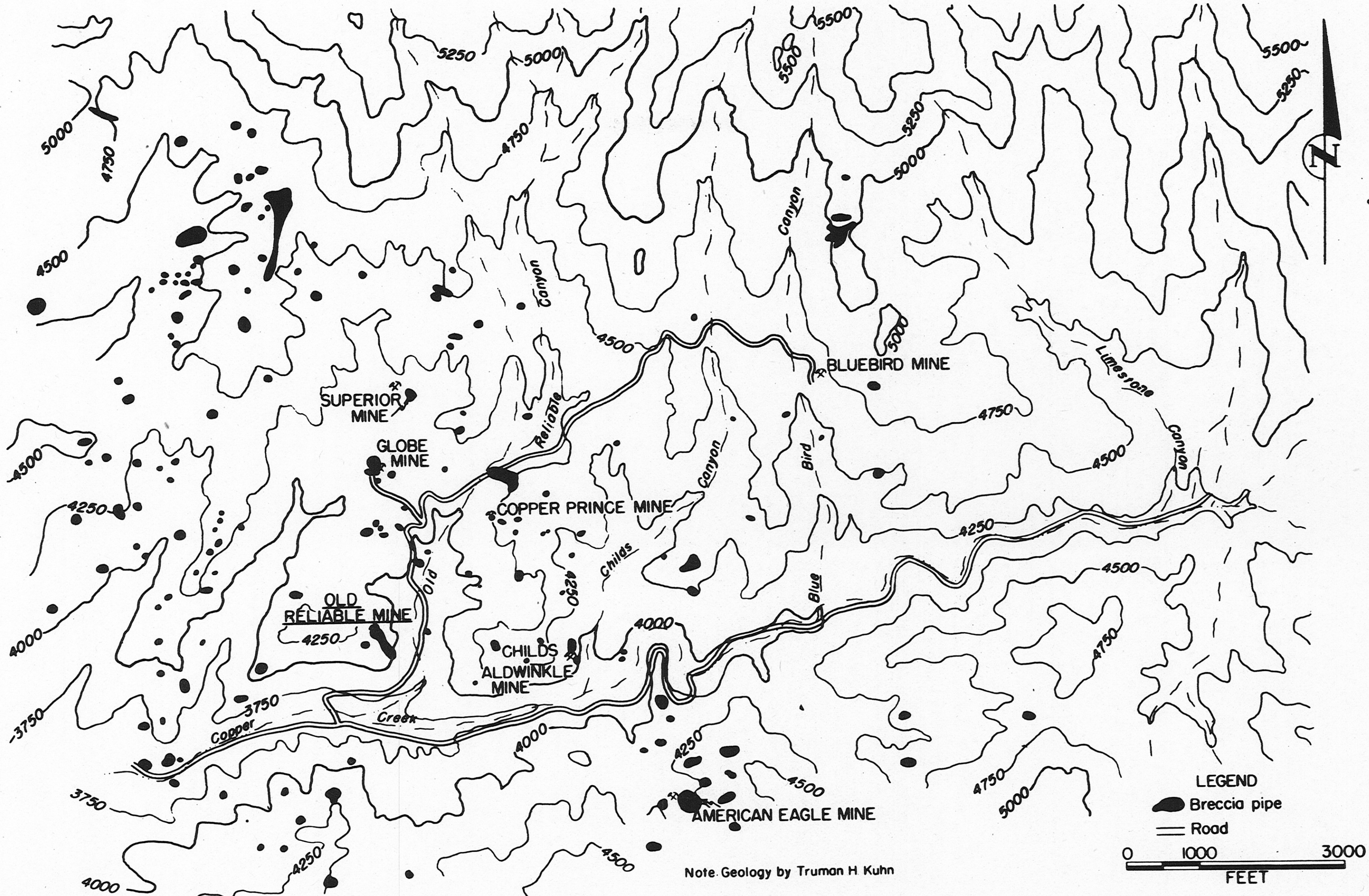

Figure 2.- General map of Copper Creek ore deposits, Pinal County, Arizona.

Although the pipes are found in all the igneous rocks, those that have been productive are in or near granodiorite. The chief producers have been the Childs-Aldwinkle, Copper Prince, Old Reliable, American Eagle, and Globe. The first two are in a large granodiorite mass. The second two, although chiefly in andesitic tuff, are at a granodiorite contact. The Globe is 1,000 feet from a granodiorite contact.

A typical pipe outcrops as a small but prominent pinnacle. In horizontal section, the pipes vary from circular to elliptical and stand vertically or have a steep pitch.

The pipe filling consists of angular, silicified rock fragments cemented chiefly by quartz, sericite and copper minerals.

The outcrops of some copper-bearing pipes, notably the Old Reliable, appear to be leached. Below the leached zone, oxidized copper minerals occur. The transition from oxidized copper minerals to copper sulfides, usually chalcopyrite and bornite, is gradual. Some chalcocite occurs at and near the water table. There is evidence of the occurrence of primary chalcocite. Molybdenum sulfide occurs at the Childs-Aldwinkle mine, and zinc and tungsten minerals have been found in the area.

Few data are available regarding the grade of the copper ore mined from the pipes or of the continuation of ore in depth. The Childs-Aldwinkle pipe was mined to a depth of about 800 feet, where it became small and the molybdenum content low. The copper content of the pipe, however, appears not to have decreased with depth and to have averaged about 2 percent.

The formation of the breccia pipes is believed to be due to intersecting fracture systems, solution of the rock along these fractures and subsequent slumping of unsupported masses.

The Old Reliable pipe is one from which production has been realized. Although molybdenite has been identified, copper is the only metal of consequence in the pipe.

Much of the outcrop is covered by talus. Parts exposed appear silicified and leached.

SAMPLING

Check-sampling 100- and 200-foot Levels

Detailed company assay maps of the 100- and 200-foot levels were furnished the Bureau by the War Production Board. All samples were horizontal channels 5 feet in length and taken at 5-foot intervals.

Five areas on the 100-foot and three on the 200-foot level were selected by the Bureau for check sampling. In all, 64 samples were taken; 37 were channel samples taken from the 100-foot level. Of the remaining 27, which were taken on the 200-foot level, 13 were grab samples of ore left in chutes

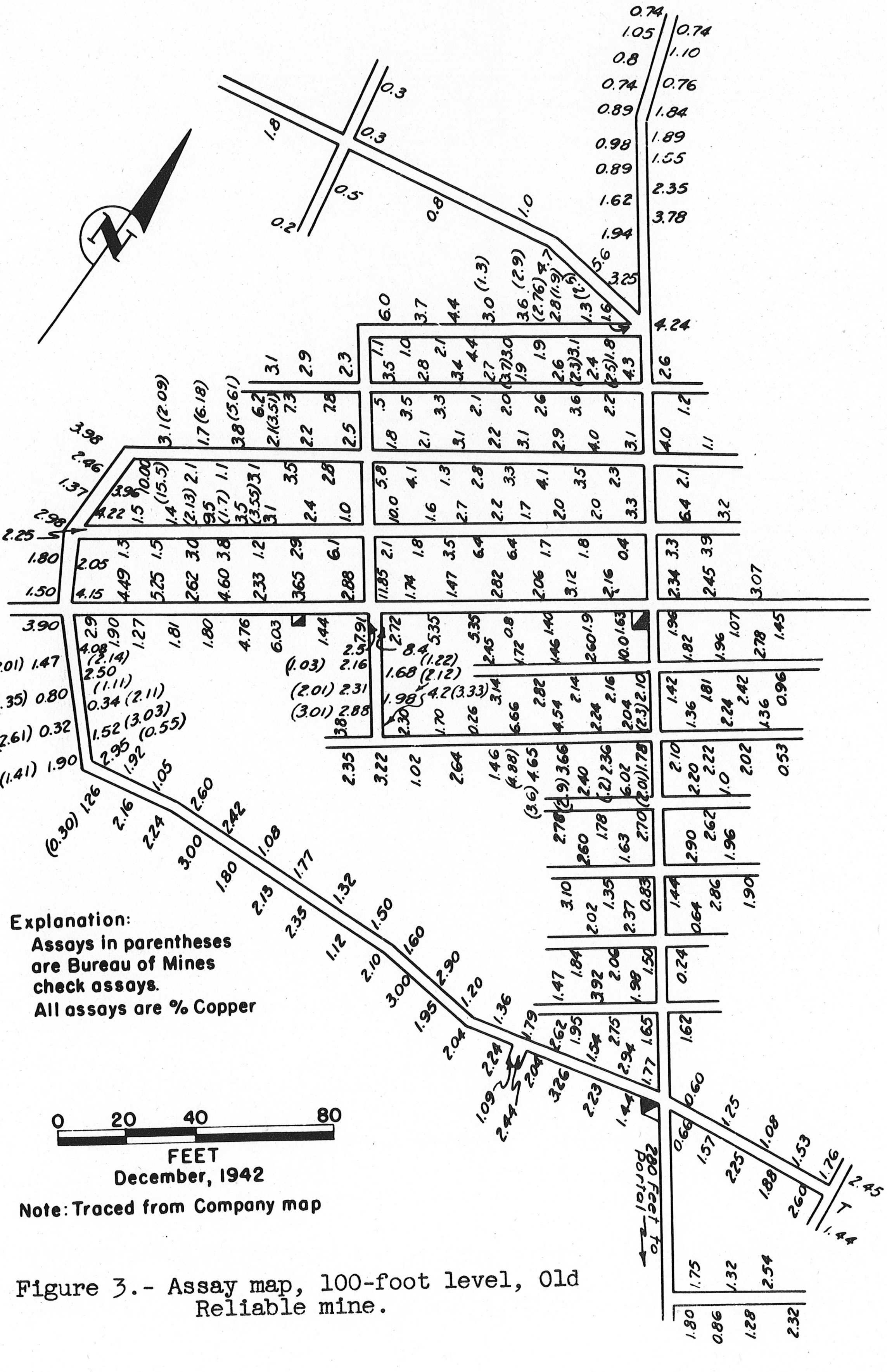

Figure 3.- Assay map, 100-foot level, Old Reliable mine.

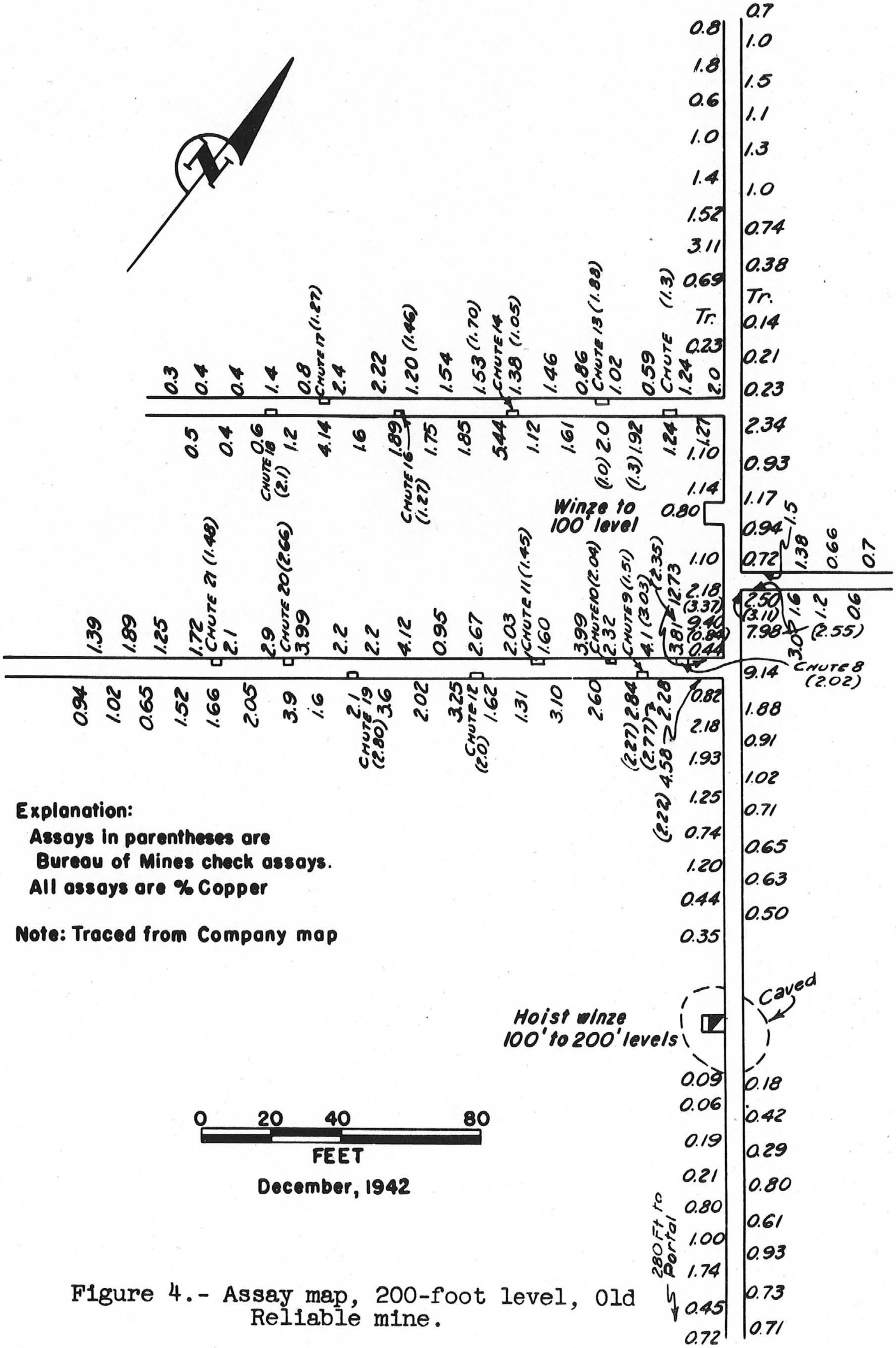

Figure 4.- Assay map, 200-foot level, Old Reliable mine.

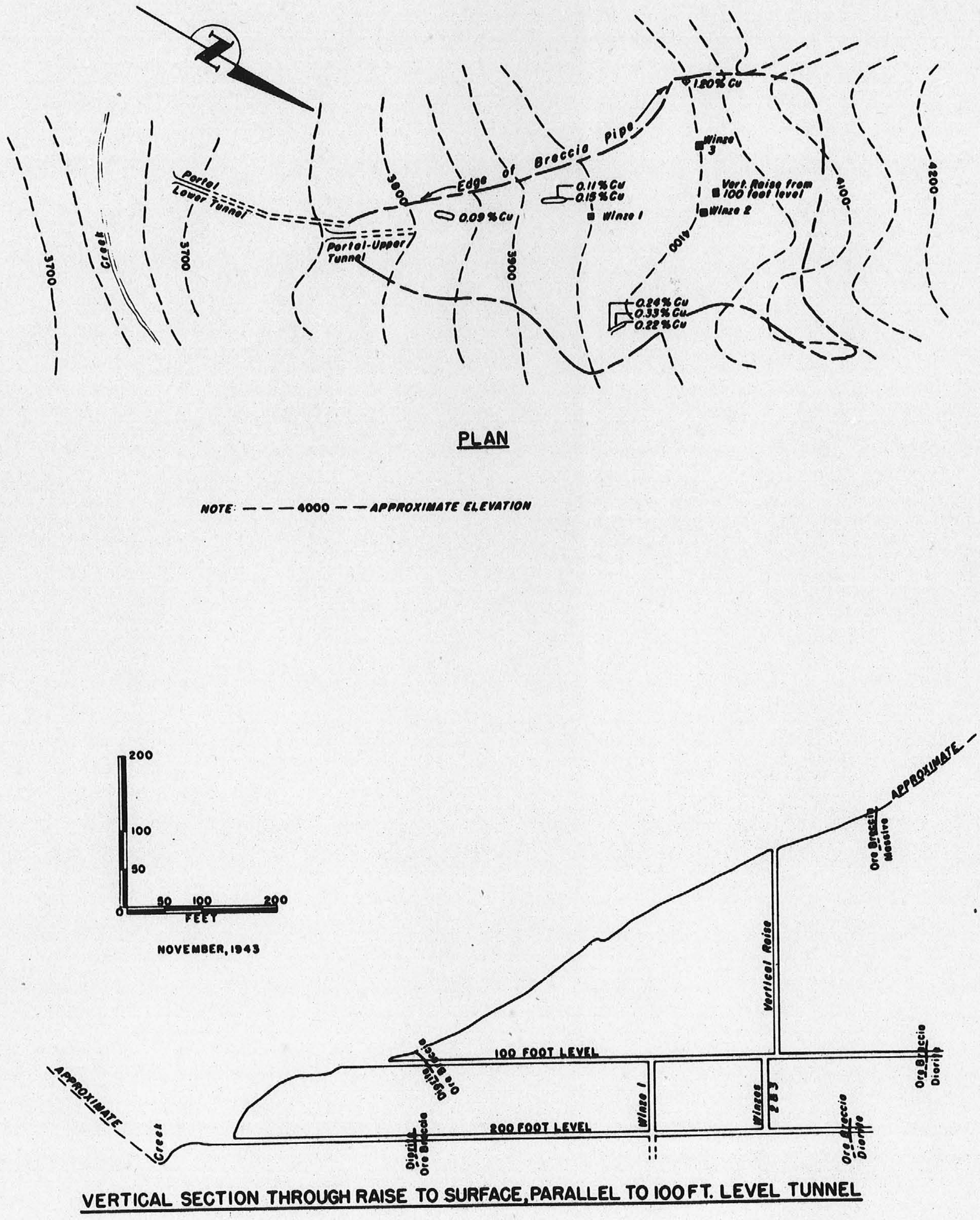

Figure 5.- Surface workings and assays, Old Reliable mine.

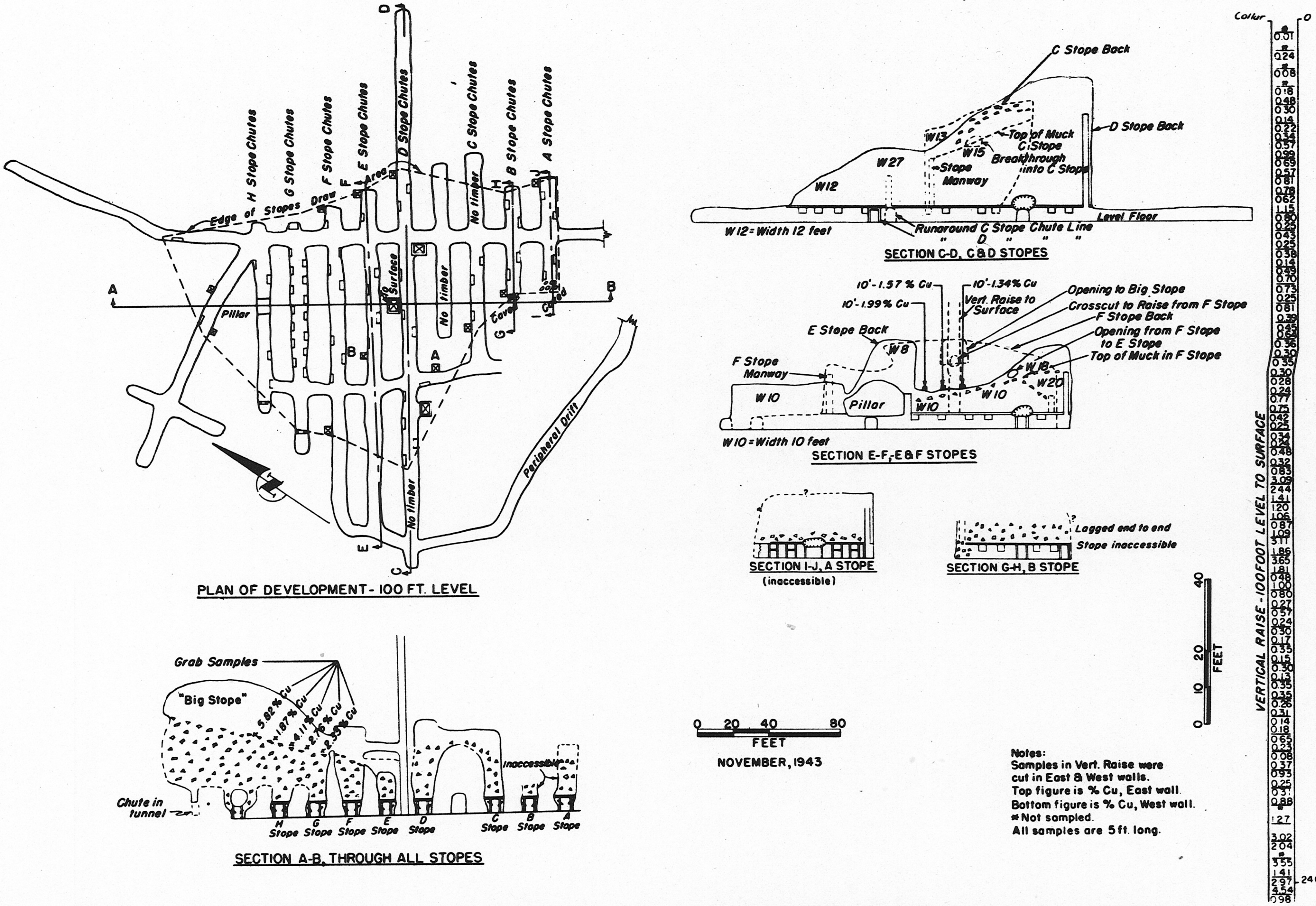

Figure 6.- Development on 100-foot level, stope assays and assays for vertical raise, Old Reliable copper mine, Pinal County, Arizona.

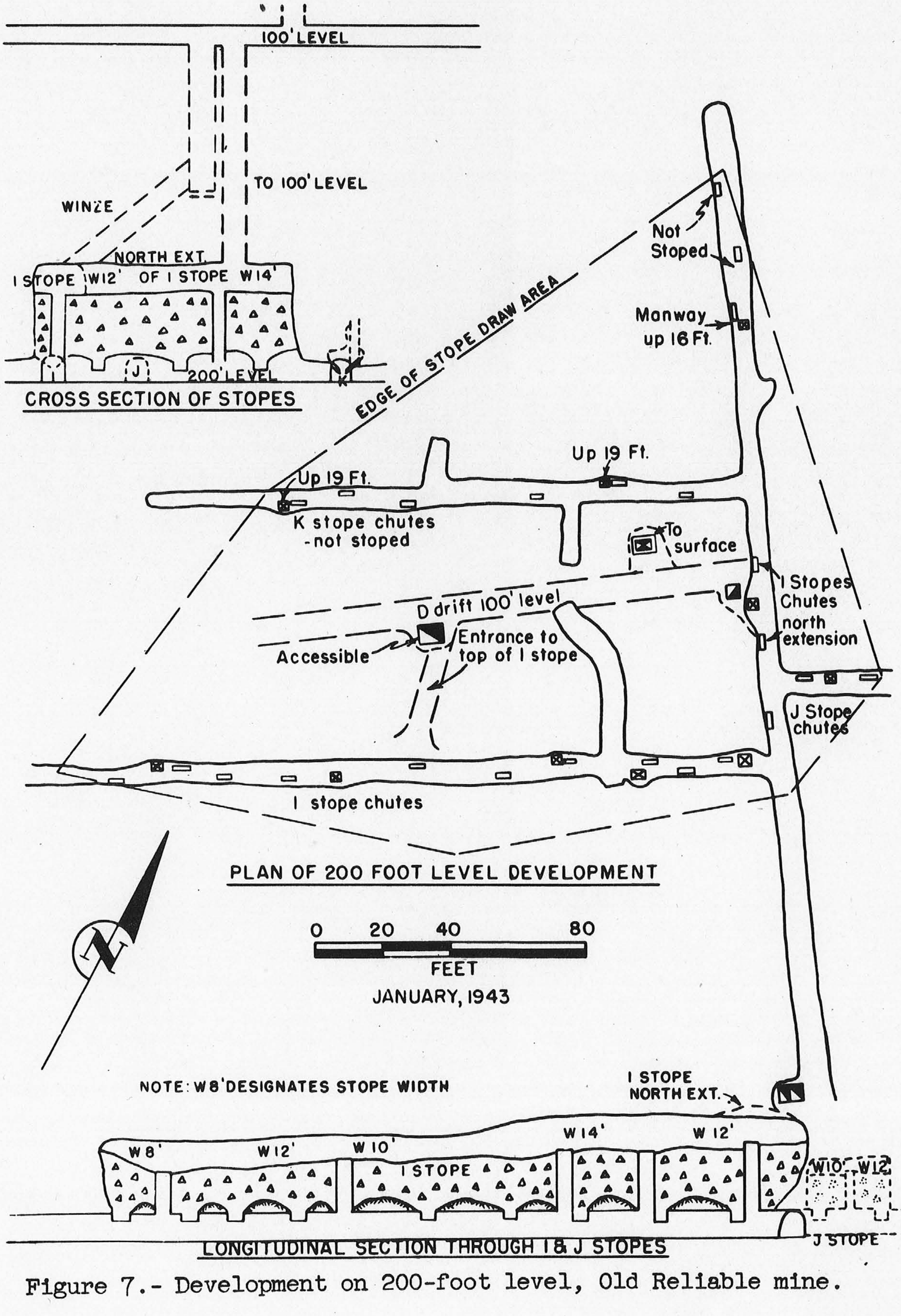

Figure 7.- Development on 200-foot level, Old Reliable mine.

the surface. These levels are connected by three vertical raises. Ore mined from the 200-foot level was hoisted through one of these to the 100-foot level tunnel.

Horizontal development on the 100-foot level consists of parallel chute drifts, for the most part on 20-foot centers at right angles to the direction of the tunnel, and a peripheral drift. In addition, near the tunnel portal are exploratory drifts that make acute angles with the tunnel.

In a number of the chute drifts the backs have been raised, timber and chutes placed, and shrinkage stoping done. The maximum height to which stopes have been carried is 80 feet above the level floor.

Six pillars separating stopes have been broken through, making a stope about 100 feet in diameter at the north end of the mine about 40 feet above the 100-foot level. Farther south, the pillar between "C" and "D" stopes was broken through about 40 feet above the level, making a stope 50 feet wide.

The 200-foot level has not been developed or stoped as extensively as the 100-foot level. Pillars were left above the chute drifts. Only three narrow shrinkage stopes have been started. The maximum height reached in stoping is about 35 feet.

Timber on the 100-foot level is in good condition. Chute-drift sets are tied with girts. In many places these are supported by posts between sets. Most are on 5-foot centers. Posts are 8 feet high. Some round timber has been used, but most of it is 8 by 8 inches square.

Access to the 200-foot level is by either the tunnel or the raise to the 100-foot level. The bottom of the raise is in the back of stope 1. Where stoping has been done, a back pillar has been left over the chute drift. The level makes an insignificant quantity of water.

METALLURGICAL TESTS

Inspiration Copper Company Tests

Preliminary small-scale laboratory tests made by the Inspiration Copper Co. by their continuous, single-stage, leach-float method extracted 96 percent of the copper with a consumption of 98 pounds of 60° Be' sulfuric acid per ton of ore. The concentrate averaged 42.41 percent copper. The tests were made by W. G. Scott, leaching plant superintendent.

The sample tested assayed 4.42 percent copper, about twice the indicated average grade of the ore; 2.01 percent of the copper occurred as oxide and 2.41 percent as sulfide. A qualitative microscopic analysis showed the predominant sulfide mineral to be chalcocite. Some chalcopyrite and covellite and traces of bornite and tetrahedrite were found. The oxidized copper minerals were malachite and chrysocolla.

The Childs-Aldwinkle property, which is nearby, milled 200 to 250 tons of ore per day for several years by utilizing these sources of water. Although the mine appears to have made little water, it is now flooded and is itself a potential source of water.

A reliable source of unlimited water is the San Pedro River. About 10 miles of pipeline would be required, and a static head of approximately 1,400 feet would have to be overcome to utilize this source.

Power. - Power could be obtained by constructing a transmission line from a high-tension hydroelectric-transmission line at a point near Mammoth.

Equipment. - An old-model, 285-horsepower, McIntosh-Seymour full-Diesel engine direct-connected to a Crocker-Wheeler 200-kilowatt, 2,300-volt generator with switchboard is installed at the property. It is said to be in good condition. There are a few buildings at the property, which are in fair condition. Some rail remains at the mine.

Area V

Mineral Resource Office

March 14, 1966

Memorandum

To: W. R. Hardwick, Project Leader

Through: J. H. Soule', Project Coordinator

From: Acting Chief, Mineral Resource Office

Subject: New prints from negative D-608-TU

In accordance with your request of March 7, we are forwarding three 8 x 10 glossy prints of the subject negative. These new prints show everything that was on the original negative.

M. H. Salsbury

Attachments

cc: R. W. Geehan
Paul Zinner

Soule'

Area V

Mineral Resource Office July 14, 1965

Memorandum

To: Paul L. Russell, Physical Scientist

From: Joel N. Van Sant, Chief,
Area V Mineral Resource Office

Subject: A Preliminary Study of the Feasibility of Fracturing the Old Reliable Copper Deposit With Nuclear Explosives

We are enclosing the original and four copies of the subject report.

JOEL N. VAN SANT
Joel N. Van Sant

Attachments

cc: Soule'
Geehan

Area V

Mineral Resource Office
Tucson Field Office

July 12, 1965

Memorandum

To: J. N. Van Sant, Chief, Area V Mineral Resource Office

From: J. H. Soule', Project Coordinator, Tucson

Subject: A Preliminary Study of the Feasibility of Fracturing the Old Reliable Copper Deposit With Nuclear Explosives

Four copies and the original of the subject report are attached for your transmittal to Paul Russell in Washington. An additional copy also is attached for your files.

John H. Soule'

Attachments (6)

cc - Paul Russell
File
DF

JHSoule:rm

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A Preliminary Study of the Feasibility of Fracturing the Old Reliable Copper Deposit with Nuclear Explosives

by

William R. Hardwick

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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ILLUSTRATIONS

A Preliminary Study of Feasibility of Fracturing the Old Reliable Copper Deposit With Nuclear Explosives

by

William R. Hardwick[1/]

INTRODUCTION

Cooperative research by the United States Atomic Energy Commission (AEC) and the United States Bureau of Mines, Department of the Interior, (USBM) under the Plowshare program indicates promise for the application of nuclear explosives to fracture leachable copper ore deposits. Fracturing will permit recovery of the copper by in-situ leaching at a cost estimated to be lower than the cost by conventional methods, and will make possible the economic recovery of copper from the deposits that cannot be mined profitably by conventional methods. Some safety problems are introduced but they are not believed to preclude use of the new method.

Proof of the method for fracturing a deposit and recovering copper can be determined only by a full scale field test. Justification for such a test stems from the fact that there are large reserves of marginal copper ore to which this method may be applicable.

1/ Mining Engineer, U. S. Bureau of Mines, Tucson, Ariz.

This report has been prepared from information in USBM files. The Old Reliable deposit was selected because it is of a representative type, and considerable information was available.

The study is a part of the AEC-USBM cooperative effort to investigate the possible use of nuclear explosives by the mining industry. This report is of a preliminary nature and it is not anticipated that an experiment will be undertaken in the immediate future without further study and cooperation with the property owners and other agencies.

LOCATION

The Old Reliable mine, a copper deposit that may be amenable to nuclear explosive fracturing and subsequent in-situ leaching, is on five patented mining claims in sec. 10, T. 8 S., R. 18 E., in southeastern Pinal County, Arizona.

The mine is about 8 miles east of the San Pedro River, 9 miles from the town of Mammoth, 12 miles from the San Manuel block-caving mine, and 12 miles northeast of the San Manuel concentrator, smelter, and townsite (fig. 1). The Old Reliable mine is at an elevation of about 4,000 feet, the San Pedro River is at an elevation of 2,400 feet, and the San Manuel mine and concentrator on the opposite side of the river are at about 3,100 feet elevation.

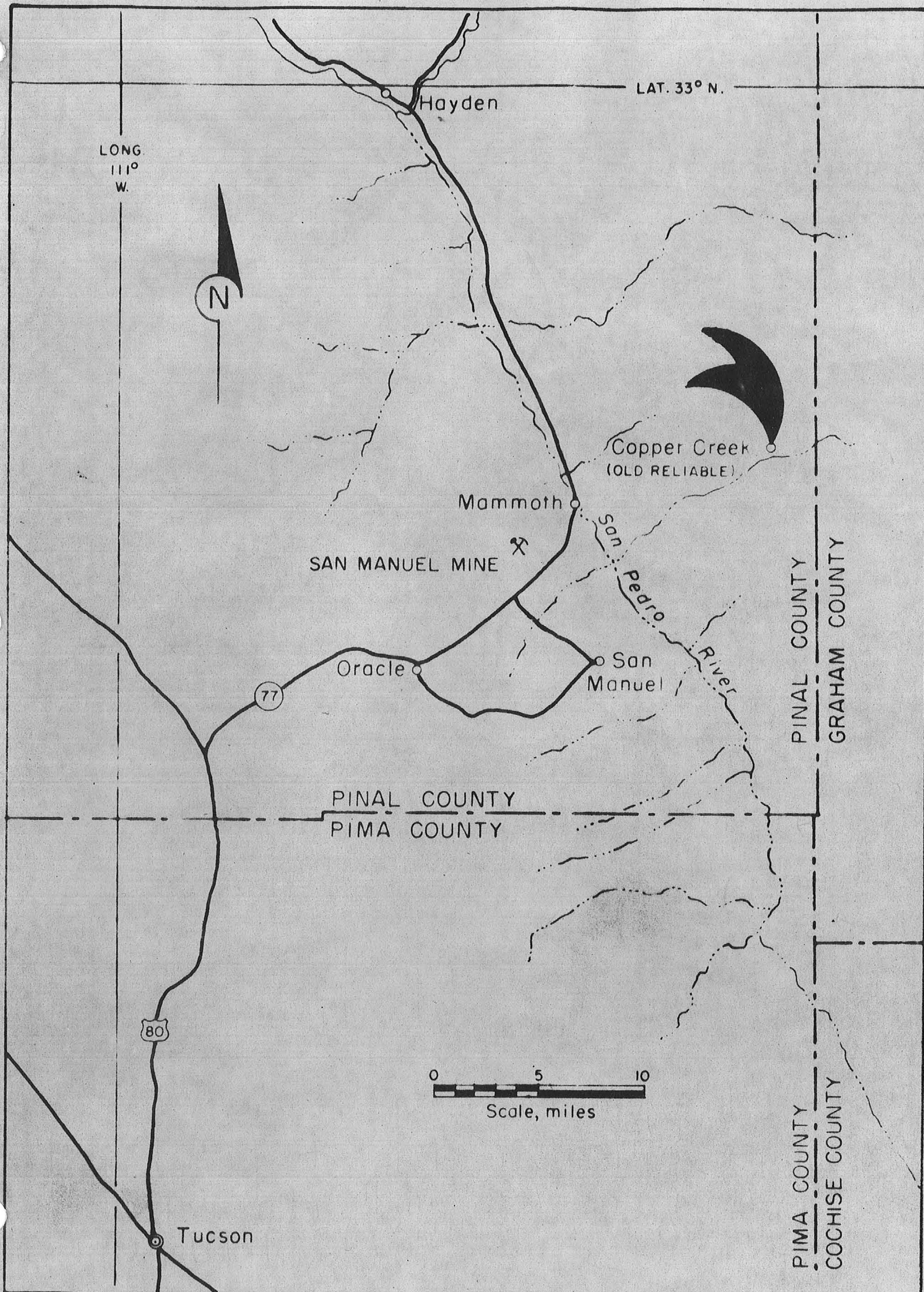

FIGURE 1.- Location Map Showing Old Reliable Mine.

The area is covered by the Mammoth, Holy Joe Peak, Klondyke, and Galiuro Mountains quadrangle sheets published by the U. S. Geological Survey on a scale of 1:62500.

HISTORY

The Old Reliable property, although located about 1880, first was developed by the Minnesota-Arizona Mining Co. in 1907. The mine operated intermittently until 1918 and produced an estimated 700,000 pounds of copper from 30,000 tons of ore. The copper deposit was examined by engineers of the U. S. Bureau of Mines in 1942-43 at the request of the War Production Board. The results are reported in War Minerals Report 275, 1955, and USBM Report of Investigations 4006, February 1947.

The reorganized Copper Creek Consolidated Mining Co. acquired the property, constructed a concentrating plant, and rehabilitated the mine in 1953, but closed after operating about 6 months in 1954. About 6 cars of concentrates containing 200,005 pounds of copper were produced from 5,900 tons of ore. An additional 971 tons of ore was mined and shipped to the smelter at Hayden, Arizona in 1954 and 1955.

Failure of the operation in 1954 was attributed to the hardness of the ore which reduced the capacity of the mill and to low copper recovery by flotation which was believed to be caused by oxidation of the sulfide ore in the stopes.

GEOGRAPHY

The Old Reliable mine is north of the Copper Creek stream on the west side of the Old Reliable Gulch (fig. 2). The mine is reached by a short road which turns north from the Mammoth Copper Creek road, crosses Copper Creek, and winds up the steep bank north of Copper Creek and west of Old Reliable Gulch. Beyond the mine the road continues up Old Reliable Gulch about one-half mile to the Copper Prince mine. About one-half mile beyond the Copper Prince mine the road forks, one branch turns northeast to the Glory Hole mine and the other southeast to the Bluebird mine. From the turnoff to the Old Reliable road the Copper Creek road continues about a mile along the south side of Copper Creek, passes the Childs-Aldwinkle mine (fig. 3) and forms the main street of the now abandoned Copper Creek settlement.

The settlement, about a mile from the Old Reliable mine and about a mile and a half west of the Pinal-Graham County line, was established about 1900 and served numerous prospectors in the district. Activity in the district ceased about 1920 and the settlement has been abandoned except for sporadic periods when one of the mines of the district is temporarily revived. About 2 miles south of Copper Creek a similar settlement, Sombrero Butte, on Mulberry Creek, served the Magna and Bunker Hill mines. Most employees in the district now prefer to live in Mammoth and drive the 12 miles.

FIGURE 8. - Old Reliable Mine

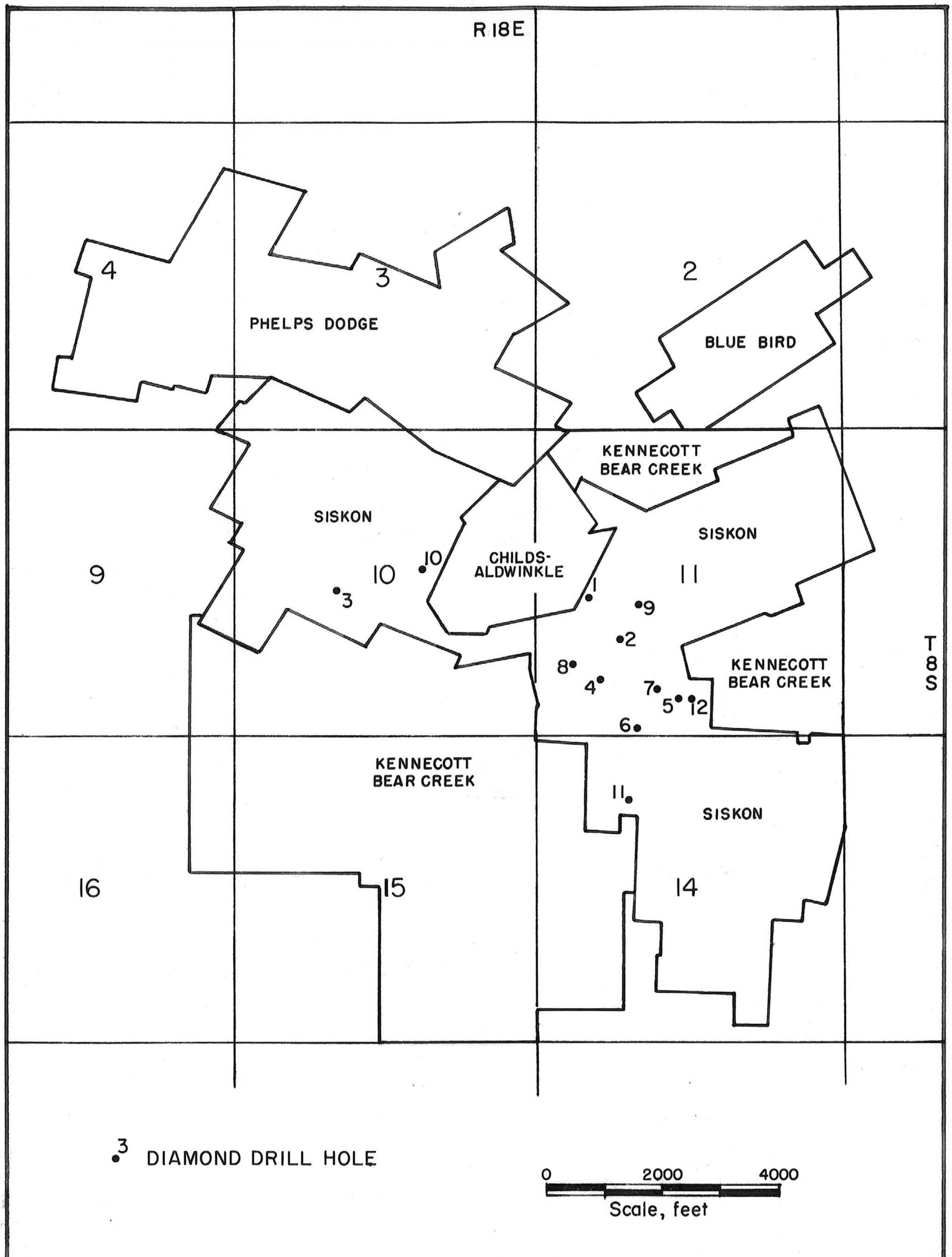

FIGURE Property Boundaries of Copper Creek Area, Pinal County, Ariz.

FIGURE 3. - Childs-Aldwinkle Mine

The area in the vicinity of Copper Creek and east of San Pedro River is very thinly settled but is used to pasture cattle. Numerous watering ponds, springs, and windmills are maintained by ranchers to water cattle. Some of these are along Copper Creek below the Old Reliable mine.

The nearest settlements of significance, Mammoth and San Manuel, are on the west side of the San Pedro River. The nearest major city is Tucson, about 40 miles southwest, air line, or about 75 miles by road. The town of Hayden, where the Kennecott Copper Corp. concentrator and smelter and American Smelting and Refining Co. custom smelter are located, is about 20 miles north.

The topography near the mine is rugged. The slope of the ground at the mine is about 30 degrees. The lower or 200 foot level enters the slope from Old Reliable Gulch at about 3,650 feet and the surface at the top of the rise is about 4,025 feet.

The climate is semi arid. Rainfall is said to average 18 to 20 inches annually, recorded temperatures range from 110° F. to 8° F. Snow falls occasionally in the winter.

Copper Creek is the main stream. It occupies a narrow, steep "V" shaped canyon and flows for periods of 2 to 3 months during rainy seasons. The water, flowing on the surface to the San Pedro River only during flood season, disappears in the gravel of the stream bed west of the mine. The 200 foot level of the Old Reliable mine makes an insignificant quantity of water. The bottom of the ore is below ground water level.

GEOLOGY

The rock of the Copper Creek area in the vicinity of the Old Reliable deposit is a complex series of andesite and dacite flows, rhyolite tuffs, and intrusions. A medium grained rock of variable composition but predominently granodiorite has intruded the series.[2/]

2/ Kuhn, T. H. Pipe Deposits of the Copper Creek Area, Arizona. Economic Geology, v. XXXVI, No. 5, August 1941, pp. 512-538.

Numerous breccia pipes have been found in the area (fig. 4). The pipes vary from circular to eliptical and stand vertically or have a steep pitch. More than 125 pipes are known but only a few have been explored for ore deposits; these indicate that the pipes decrease in size downward.

The Old Reliable pipe is a breccia body that crops out at an elevation of about 4,000 feet near the intersection of Copper Creek and Old Reliable Gulch. The pipe is irregular in shape and about 700 feet long. The ore deposit is about 250 feet in diameter.

Other mines nearby that have produced ore from pipe deposits are: Superior, Globe, Copper Prince, Childs-Aldwinkle, and American Eagle. Several of these, including the Copper Prince and the Globe are very similar to the Old Reliable and may be sites for subsequent operations. Many similar deposits with substantial copper reserves occur in other areas.

GEOLOGICAL STRUCTURE

The San Pedro Valley lies in a large northwest-trending structural depression. It is bounded on the east by tilted fault blocks that form the Galiuro Mountains and on the west by ranges which include the Santa Catalina Mountains and the Black Hills. The down drop basin that forms a trough for the San Pedro River is defined on the east by the Copper Creek and related fault systems and on the west by the Cholla, West Side, and related fault systems.

The central trough of the San Pedro Valley near Mammoth has been filled with sediments resulting from erosion. Deposits on both sides of the San Pedro River are not symetrical and, according to Heindl, this may indicate that the uplift on the two sides of the San Pedro Valley were neither simultaneous nor necessarily of the same magnitude.[3]

3/ Heindl, L. A. Cenozoic Geology in the Mammoth Area, Pinal County, Arizona. U. S. Geol. Survey Bull. 1141-E, Washington, 1963.

The generalized geology from Mammoth to Copper Creek with a schematic section is shown on figure 5.

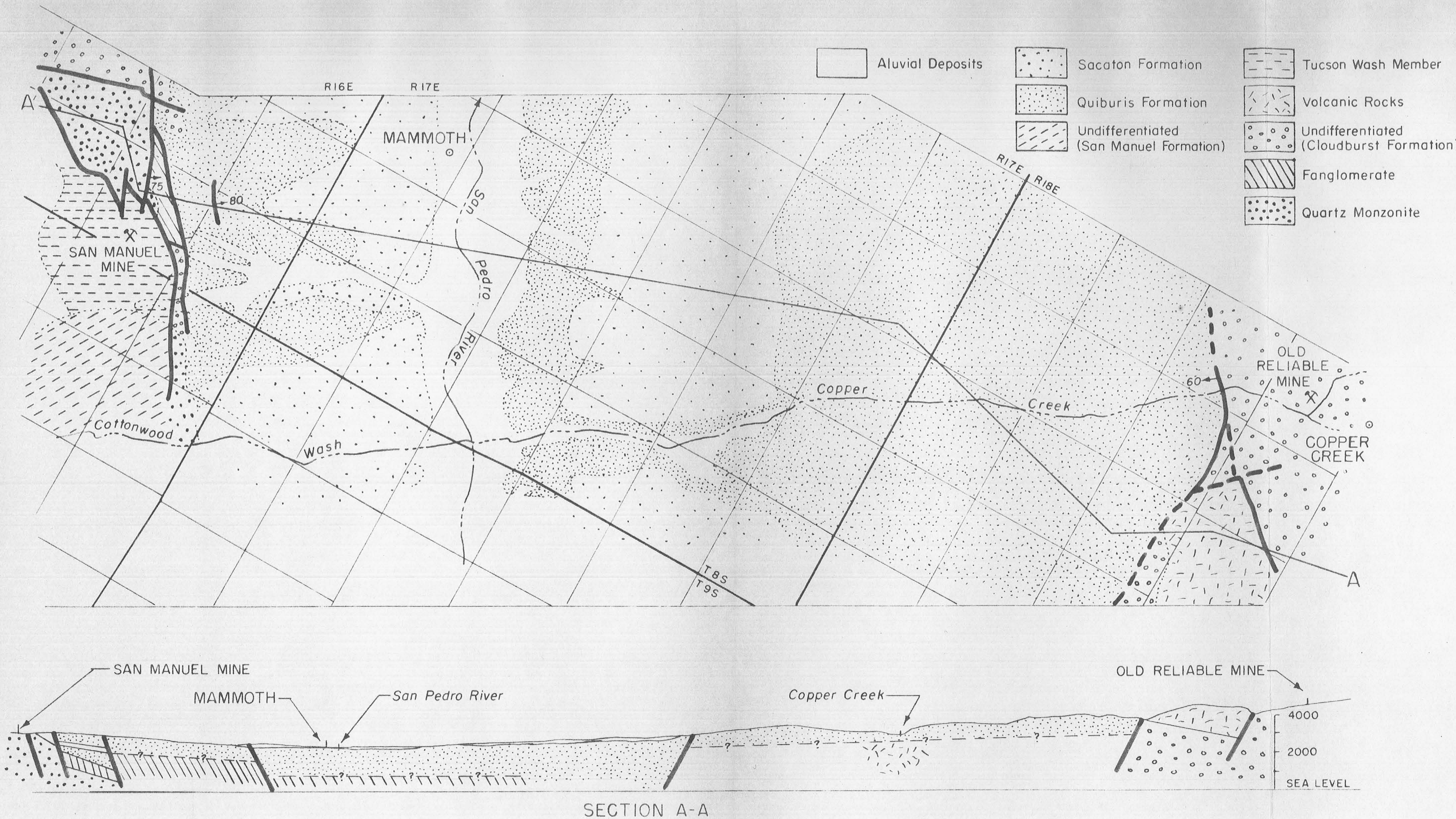

FIGURE 5.- Generalized Geologic Map and Schematic Section from Mammoth to Copper Creek
(Courtesy U.S. Geological Survey Bulletin 1141E)

MINE WORKINGS

The mine has been developed by two levels known as the 100 foot level (fig. 6) and the 200 foot level (fig. 7). Access to each is by adit above Old Reliable Gulch. A third and lower level was started from the Copper Creek side but was abandoned before it reached the ore body. A raise extends from the 100 level to the surface (fig. 8). Chute drifts at right angles to the adit extend to a peripherial drift on the 100 foot level. The two levels are connected by three raises. From some drifts shrinkage stopes have been carried above the 100 foot level. In the upper part of the mine six of the pillars separating shrinkage stopes were broken making a single large 60 x 100 foot stope above the level. The ore above the stope did not cave.4/

4/ Kumpke, C. I. War Minerals Report 275, BuMines, November 1944, p. 8.

Several buildings of a temporary type construction and a concentrating plant with a capacity of about 125 tons per day are at the mine. The concentrating plant consists of crushing, grinding, and flotation equipment. It includes bins, belt conveyers and other auxiliary equipment.

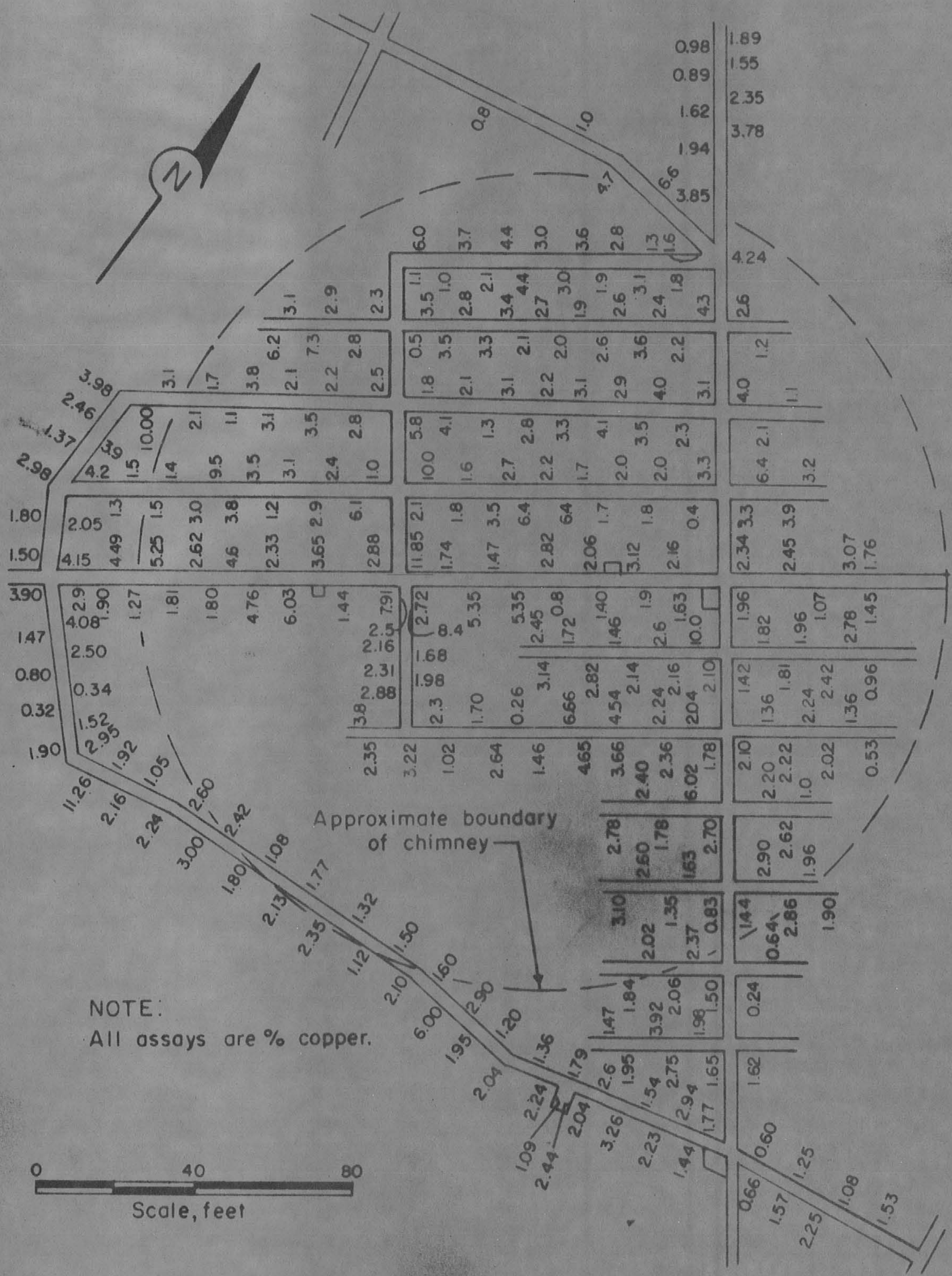

FIGURE 6.-Assay Map, 100-foot Level, Old Reliable Mine.

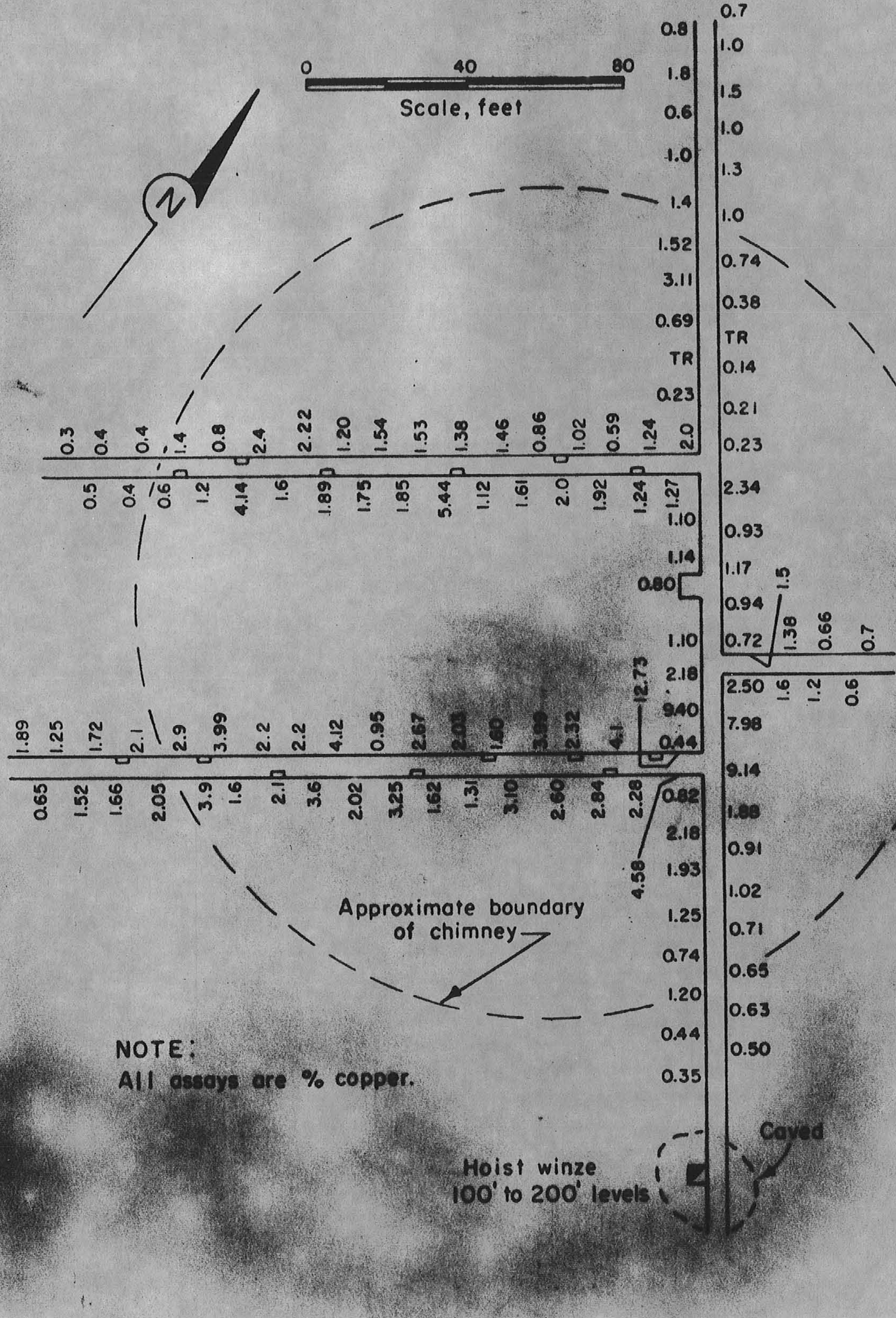

FIGURE 7.-Assay Map, 200-foot Level, Old Reliable Mine.

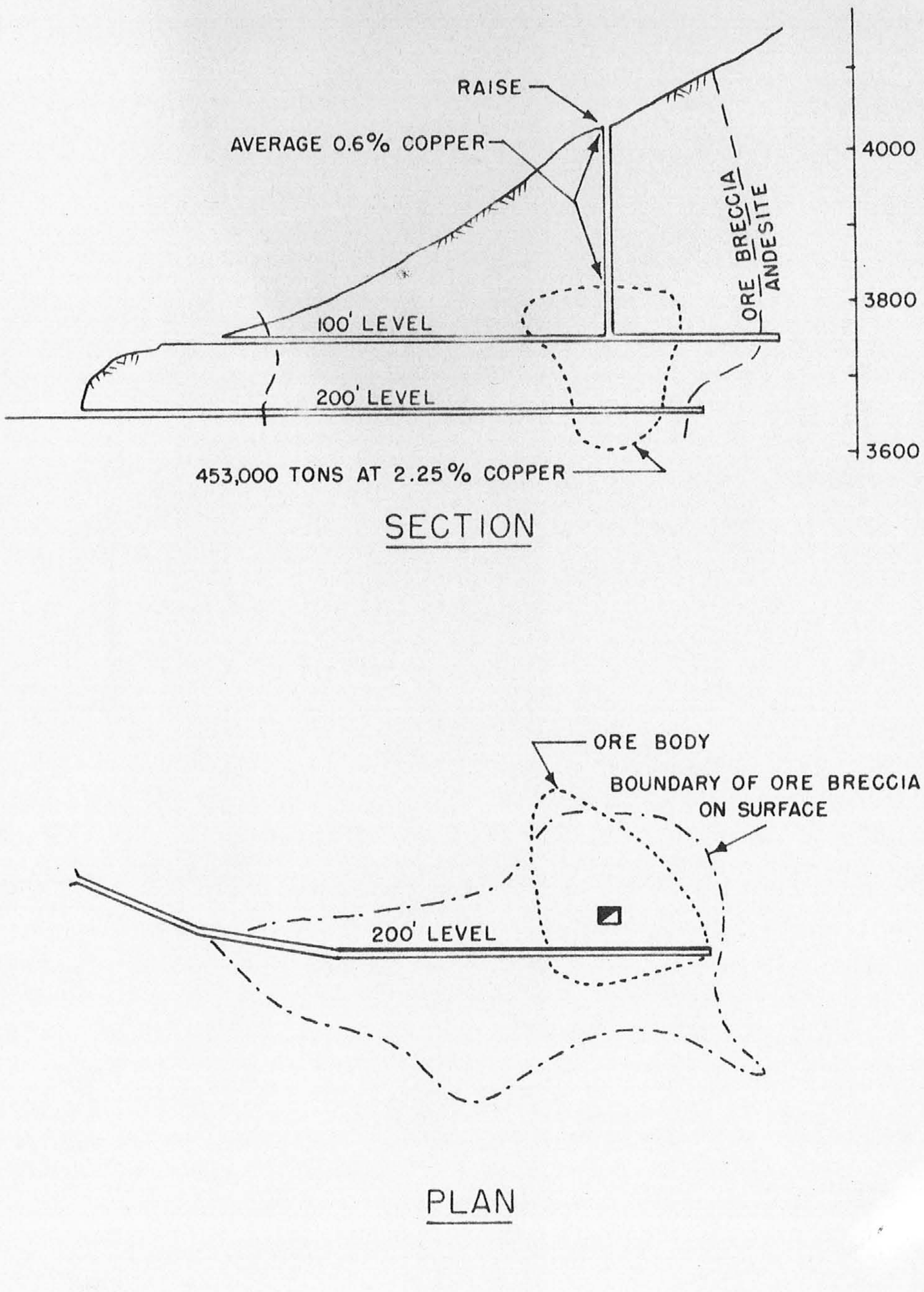

Figure 8.- Plan and Section of Old Reliable Mine.

ORE RESERVES

The drifts and raises in the center of the deposit were sampled. Measured and indicated ore, from 50 feet below the 200 foot level to 60 feet above the 100 foot level, was estimated at 379,000 tons. An additional 73,000 tons of ore was inferred making a total of 453,000 tons at a grade of 2.25 percent copper. Sampling indicated that the copper is about half in oxide and half in sulfide minerals.[5]

5/ Denton, T. C. Old Reliable Copper Mine, Pinal County, Arizona. BuMines Rept. of Inv. 4006, 1947, p. 9.

The material above the back of the stopes was sampled only by a single raise that extends from the 100 foot level to the surface. The average copper content for the upper 217 feet of this raise was 0.6 percent. Assuming 13 cubic feet per ton this sample represents 2,420 tons per vertical foot in a 200-foot diameter column or 525,000 tons for the 217 feet.

On the 100 foot level the measured part of the ore deposit was sampled from cross cuts spaced at 20 feet along the adit. The assay average of the samples inside a 200-foot diameter circle was 2.69 percent copper. The average of the assays in a circle vertically below this area on the 200 level was 1.91 percent copper, and the average for these two circle areas is 2.30 percent copper.

Assuming the influence of the average values for the two levels extends from 43 feet above the 100 foot level to 50 feet below the 200 foot level, a vertical range of 190 feet is represented and at 2,420 tons per vertical foot contains to 467,000 tons. From this must be deducted the ore that has been mined, about 37,000 tons, leaving available 430,000 tons at a grade of 2.30 percent copper.

Other rock surrounding the deposit that may be broken by a 10 kton nuclear explosive is assumed to contain 0.20 percent or 4 pounds of copper per ton.

Assuming a column of material broken from the 430 foot level with a radius of about 100 feet and containing 1 million tons, the ore that will be broken is estimated as follows:

From	To	Tons	Copper-pounds
Surface	217 ft.	525,000	6,300,000
217 ft.	410 ft.	430,000	19,780,000
410 ft.	430 ft.	45,000	170,000
Total		1,000,000	26,250,000

The copper content of this ore is not sufficient to cover the cost of shipping to a smelter, and the tonnage in the deposit is not sufficient to amortize the cost of a conventional concentrating plant with sufficient capacity to operate profitably.

CHARACTER OF THE ORE

A metallurgical test sample assayed 4.42 percent copper, about twice the average grade. In this sample 2.01 percent of the copper occurred as oxide while 2.41 percent occurred as sulfide. A qualitative microscopic analysis showed that the predominant sulfide mineral was chalcocite. Some chalcopyrite, and covellite and traces of bornite and tetrahedrite were found. The oxide copper minerals were malachite and chrysocolla.

INDICATED COPPER RECOVERY

Straight leaching tests, using sulfuric acid, are not available, although they may have been run by the last operating company. A small scale test by the University of Arizona, using the Inspiration single stage leach float method, recovered 90.5 percent of the copper.

For the purpose of calculating it is here assumed that the copper in the form of chalcopyrite, bornite, and tetrahedrite is not recoverable by leaching. As the majority of the copper is in the form of chalcocite and oxide copper minerals; the recovery of total copper by leaching might be 80 percent. Such a recovery would be possible with relatively fine grinding (10 mesh) and leaching with sulfuric acid and ferric sulfate.

Fragmentation by a nuclear explosive will leave many large fragments (fig. 9). Because the solution penetrates these fragments slowly the recovery is further reduced. The same condition is evident at mines when fragmentation is by conventional explosives and the material is placed on a dump or when fragmentation results from subsidence from mining operations. The effect of these large particles is to decrease the recovery and rate at which copper can be extracted. Estimates of total recovery by operating mines range from 25 to 75 percent of the total copper during the first 10 year period.

Assuming a possible metallurgical recovery of 80 percent and a 10 year recovery of 60 percent, a total recovery of 48 percent or about half of the copper may be possible from the 10 year in-situ leaching operation.

If the reserve figure of 26,250,000 pounds of copper is accepted for the Old Reliable deposit the recovery of 48 percent or about 13 million pounds of copper is indicated. Some additional copper may be recovered from fractured rock outside the broken chimney. The total recovery may be increased by extending the operating period beyond 10 years but a rapid decrease in the rate of recovery may be expected beyond that period.

FIGURE 9. - Fragmentation in tuff from nuclear explosive (Courtesy Lawrence Radiation Laboratory UCRL 5757)

DESIGN OF NUCLEAR EXPLOSION

Nuclear explosives have been fired underground to break a column of rock similar to that which includes the Old Reliable ore deposit. One such explosion is illustrated on figure 10; another is illustrated on figure 11. Available experimental data for underground nuclear explosions permits the prediction of cavity size, chimney height, and tonnage of rock broken with considerable confidence.[6] Curves have

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6/ Hansen, S. M. and D. B. Lombard. Completely Contained Nuclear Explosives for Mining by Caving. Proceedings of the Third Plowshare Symposium, TID 7695, AEC, 1964.

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been developed to show chimney parameters plotted against depth of burial for various yields. These can be used to determine the approximate explosion for a mining operation.

FIGURE 10. - Crater formed by nuclear explosion.
(Courtesy Lawrence Radiation Laboratory
UCRL 6251)

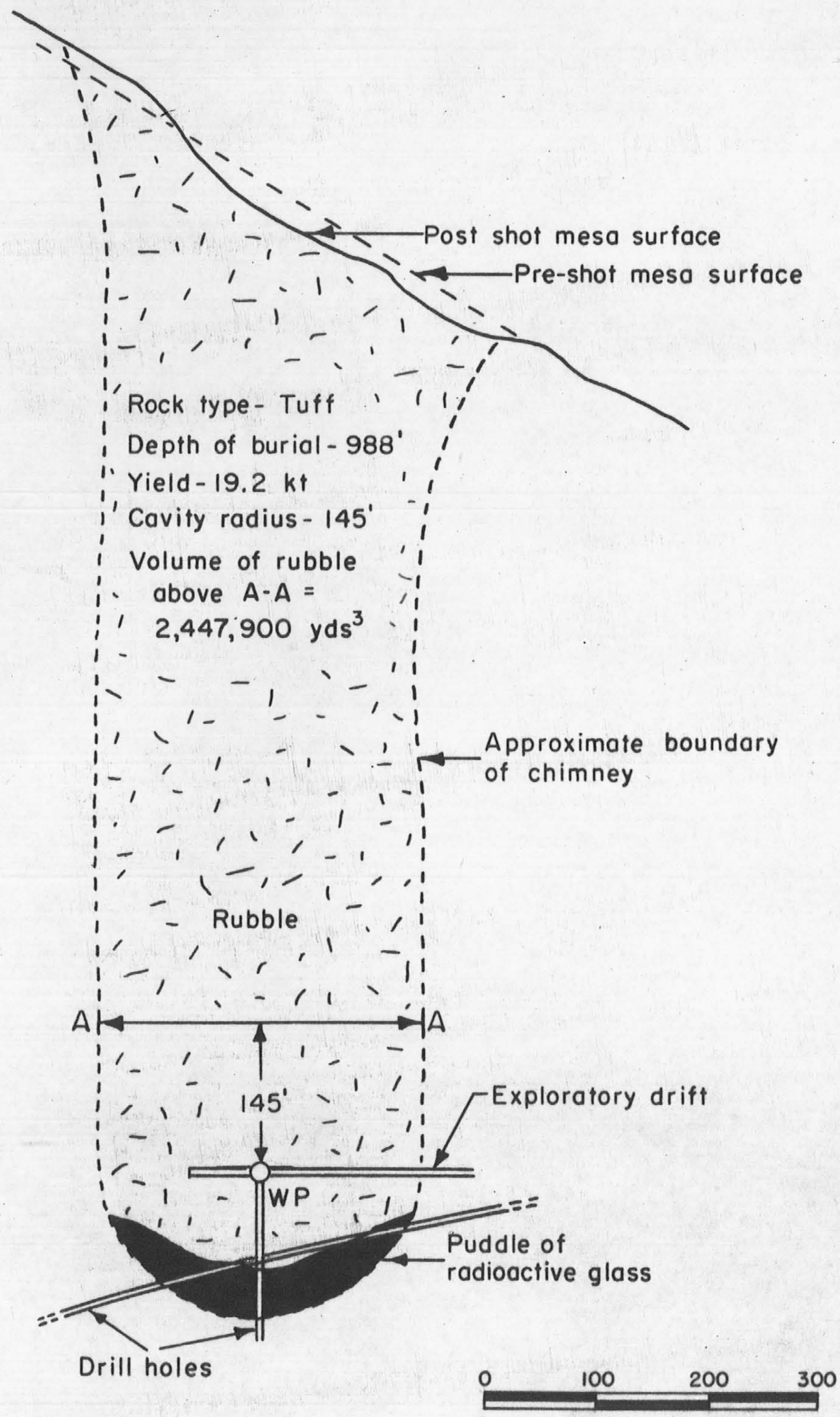

FIGURE 11.- Schematic Cross Section of Rock Broken by Nuclear Explosion.
(Courtesy Lawrence Radiation Laboratory, UCRL 7350)

In the case under consideration, the Old Reliable ore body, it is desirable to break to a radius of 100 feet from a depth just below the ore body, approximately 500 feet beneath the ground surface (fig. 12). Referring to figure 13, a 10 kton explosive appears to satisfy this requirement. At a depth of 500 feet the radius of a 10 kton nuclear explosion is approximately 100 feet. The predicted chimney height from figure 14 is approximately 410 feet and the rock broken is estimated at 1 million tons from figure 15.

The nuclear explosive should be scaled to the ore deposit and designed to produce a crater similar in conformity to that of figure 11. Leach solution would be applied to the broken surface, percolate through the ore, dissolve the copper, and be collected in the 200 level adit, or by a new adit driven into the bottom of the chimney. A pump would be necessary to collect solutions below the adit. Copper would be recovered from the solution in a surface plant and the solutions reused.

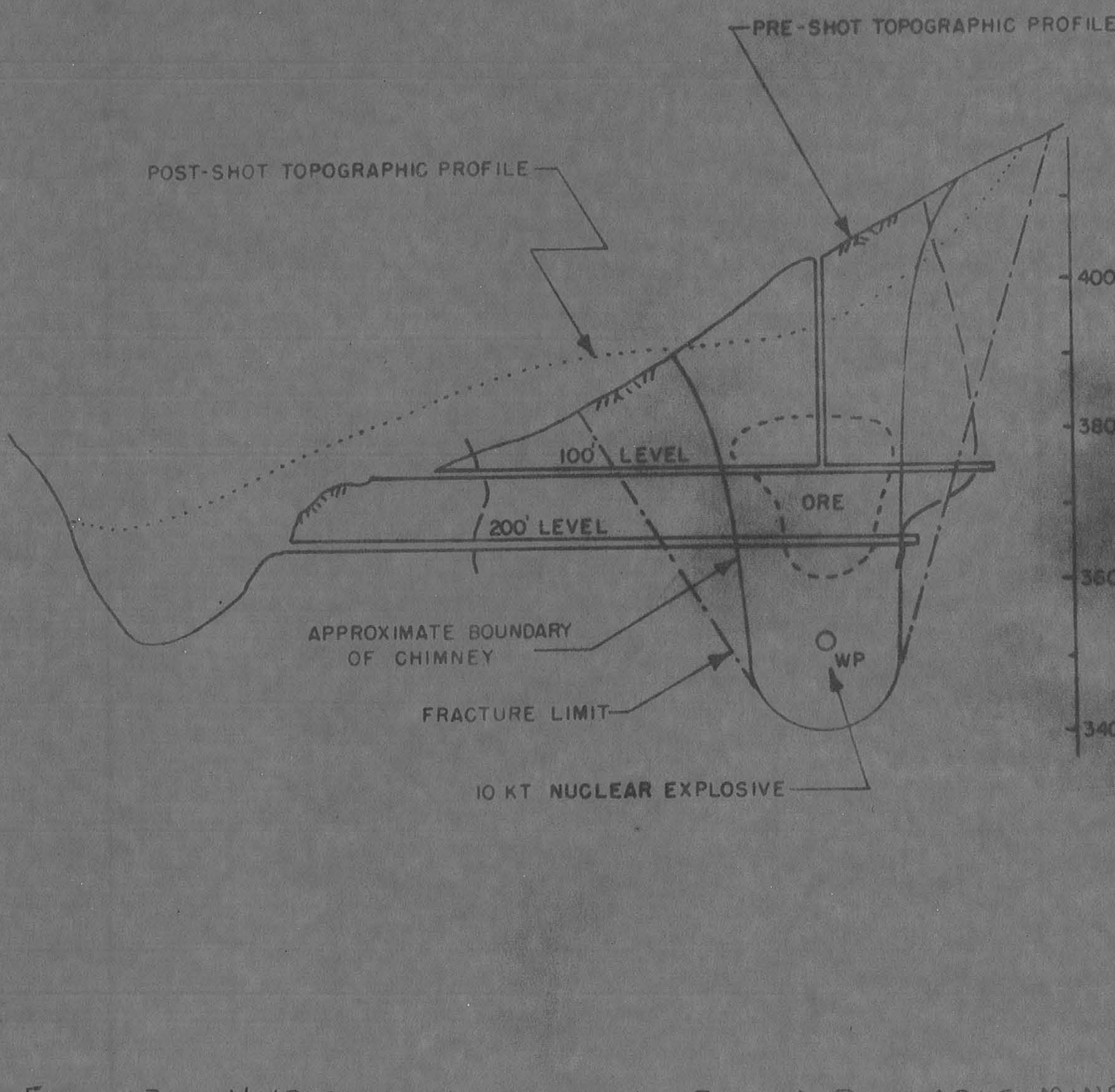

FIG. 12.- HYPOTHETICAL SECTION OF OLD RELIABLE MINE AFTER NUCLEAR EXPLOSION.

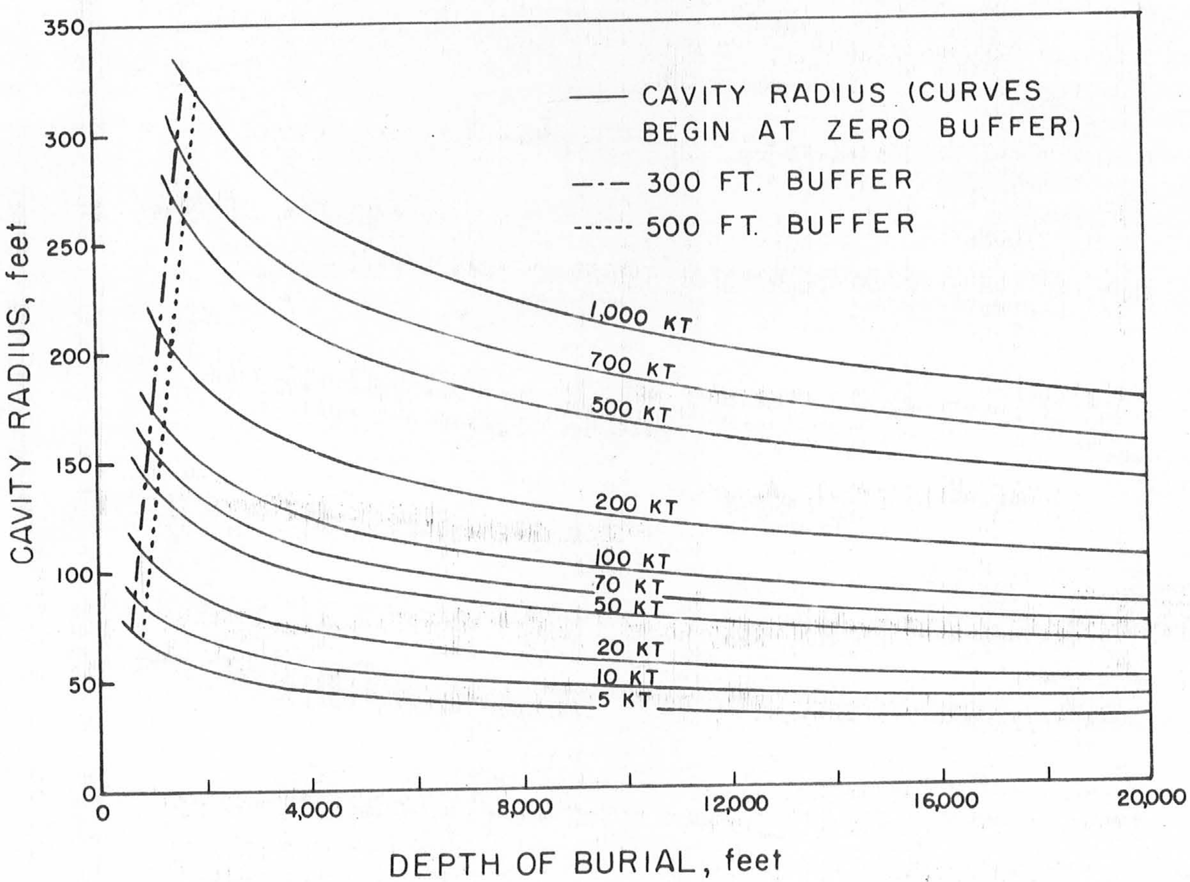

FIGURE 13.- Cavity Radius for Underground Nuclear Explosions in Granitic Rock. (Courtesy Lawrence Radiation Laboratory, TID 7695)

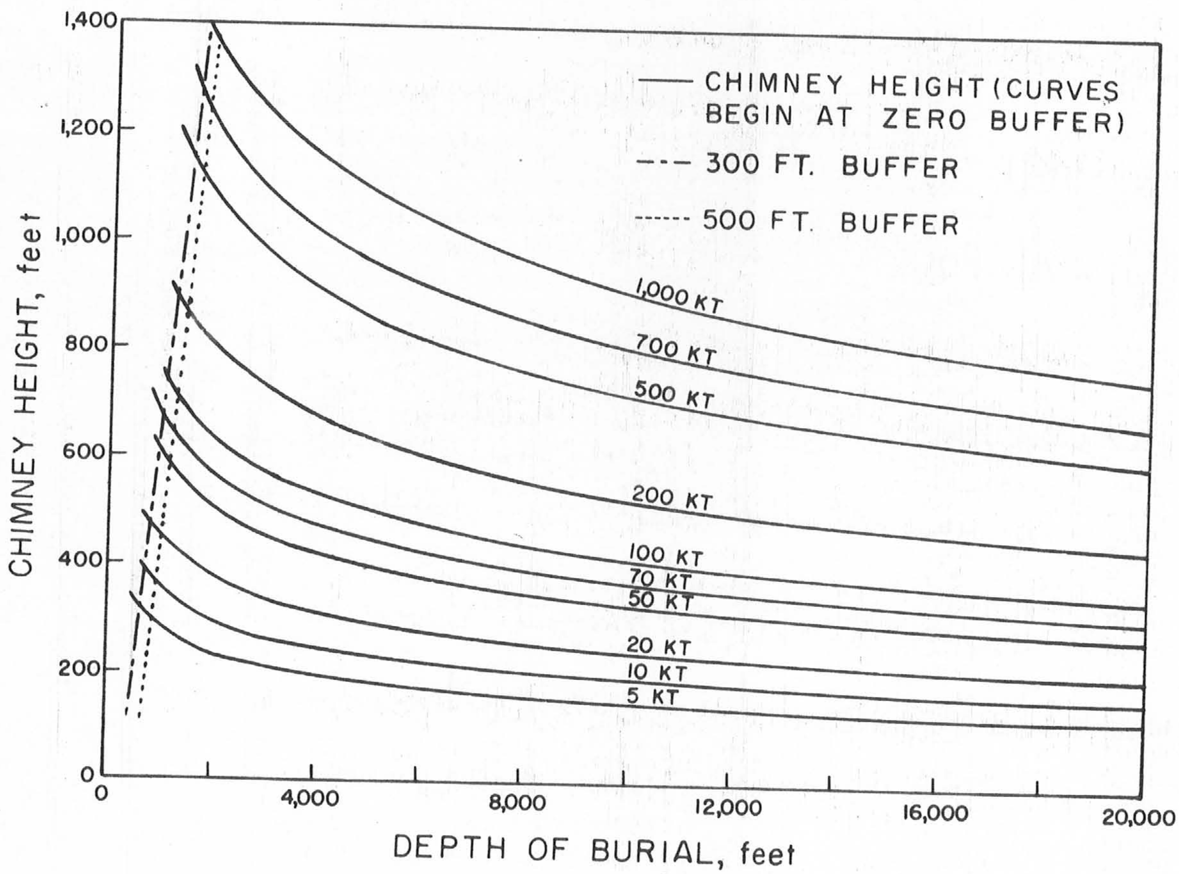

FIGURE 14.- Chimney Height for Underground Nuclear Explosions in Granitic Rock. (Courtesy Lawrence Radiation Laboratory, TID 7695)

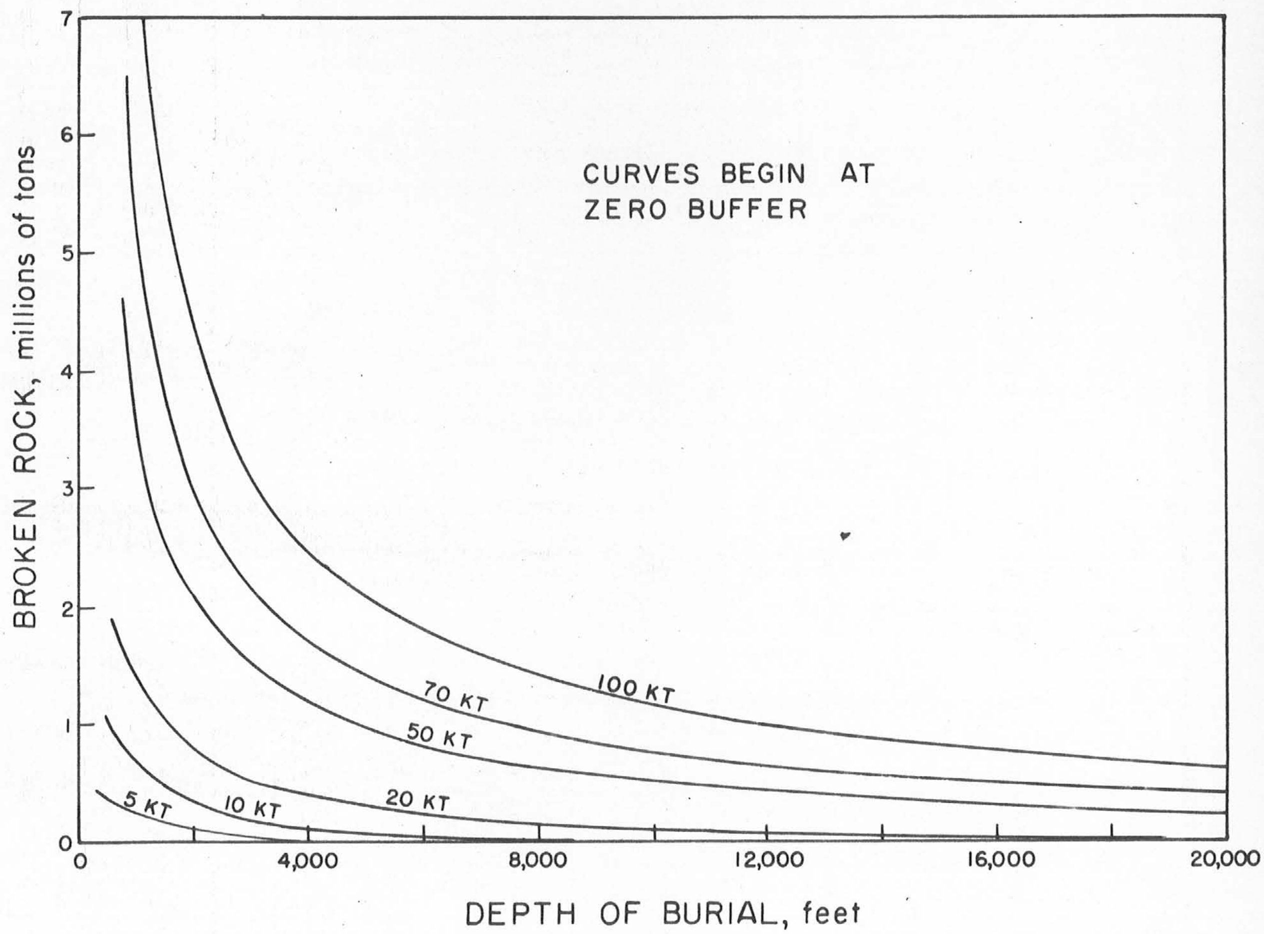

FIGURE 15.-Tonnages of Granitic Rock Broken by Underground Nuclear Explosions.
(Courtesy Lawrence Radiation Laboratory, TID 7695)

ECONOMICS

The current copper price is 36 cents per pound. At this price the indicated 13 million pounds of recoverable copper has a gross value of $4,680,000.

The estimated cost of breaking this deposit with a nuclear explosive and leaching the copper at the rate of 1,300,000 pounds per year is as follows:

Capital Requirement		
Feasibility study	$ 50,000	
Safety preparation	130,000	
Nuclear explosive	350,000	
Emplacement hole	10,000	
Site preparation and support (Inc. security, emplacement, & transportation)	350,000	
Postshot development for leaching	150,000	
Working capital	50,000	
Safety equipment	10,000	
Total capital	$1,100,000	
Cost per pound of copper		$0.085

<u>Operation Requirement</u>

Labor	$ 35,000
Supplies	34,000
Transportation to rail	5,000
Rail transportation	500
Smelting, refining and marketing	48,000
Miscellaneous	20,000
Total cost per year	$142,500
Per pound of copper	$0.119

<u>Administration Requirement</u>

Labor	20,000
Supplies	5,000
Total	$25,000
Per pound of copper	$0.026

<u>Summary - Cost per pound of copper</u>

Capital	$0.085
Operation	0.119
Administration	0.026
Total operating cost	$0.23

<u>Indicated return per pound of copper</u>

Selling price	$0.36
Operating cost	0.23
Indicated return	$0.13

<u>Indicated net profit per pound of copper</u>

Indicated return	$0.13
Estimated taxes, royalty, etc.	0.06
Indicated net profit	$0.07
Net profit per year	$91,000.00

Net incomes as calculated from published reports for several mines are as follows: The two year average net income per pound of copper produced by the San Manuel-Superior mines of Magma Copper Co. in 1962 and 1963 was $0.05. The 1959 and 1960 average net income per pound of copper sold by Inspiration Copper Corp. was $0.06 of which $0.034 was paid in dividends. The 1961 and 1962 average net income per pound of copper produced by the Pima mine was $0.034 of which $0.029 was paid in dividends.

The indicated net profit for an operation at the Old Reliable mine is $0.07 per pound of copper or $91,000 per year profit.

SAFETY PROBLEMS

Safety problems peculiar to mining with nuclear explosives can be divided into three categories. First, those involving air blast; second, those involving ground shock; and third, those involving radioactivity.

Air Blast

The first of these, air blast, results from the rapid expansion of the hot gases at extremely high temperature. This expansion causes a shock wave which forms in the air and moves outward at high velocity. Shock waves move from the center of the blast by two routes, radially along the ground and by reflection from atmospheric conditions overhead. A characteristic of this wave is that pressure rises at the moving front causing an overpressure which may damage structures when it exceeds about one half pound per square inch.

Air blast is attenuated by charge burial.[7] For a cratering

7/ Reed, J. W. Project Stagecoach, Chapter 9, Final Report, TID 4500 (16th ed.), Sandia Corp., Nevada Test Site, May 1942, p. 169.

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explosion most of the blast energy is shot upward through a conical region defined by the true crater slope. Consequently, blast pressures close in and on the ground are much smaller than would be expected from a surface blast. The results of Sedan nuclear explosion, a cratering experiment, show amplitudes for air blast that average about 20 percent as large as expected from a free air burst at ground level and the Danny Boy nuclear explosion data averaged about 10 percent the air blast might be expected from a ground level explosion.

As the blast wave travels in the air away from its source, the overpressure steadily decreases. The variation of the pressure with distances is dependent on energy yield of the explosion, atmospheric conditions, and topography.

Theoretical calculations for the overpressure versus distance relation have been made for certain standard conditions and scaling laws have been derived for extrapolation to other uniform burst conditions. A constant overpressure (shock strain) is obtained when the distance is changed in proportion to the cube root of the new yield and inversely to the cube root of the burst altitude ambient air pressure.[8] For bursts underground, surface overpressures are

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8/ Cauthen, Lewis J., Jr. Survey of Rock Damage to Surface Facilities and Drilled Holes Resulting from Underground Nuclear Explosions. Lawrence Radiation Laboratory, Livermore, Calif. UCRL 7964, 1964, p. 4.

reduced further because much of the initial blast energy is lost in forming the crater. For completely contained explosions a serious air blast may not occur. The proposed experiment will be contained to the extent that air blast is not expected to be critical.

Ground Shock

The second phenomena that may cause damage is ground shock, or particle motion which results when the shock wave caused by an explosion is transmitted outward through the rock. Particle velocity or acceleration in terms of gravity are used to measure particle motion. Particle velocity is the measurable parameter of surface motion which appears to correlate best with surface damage. The measured velocity above which damage will occur to residential type construction is generally defined as 11 cen. per sec.

The approximate distance at which maximum particle veolcity dropped below 11 cen. per sec. for several nuclear explosions in different types of rock is shown below.

Distances at which measured particle velocity dropped below 11 cen. per sec. (Table 9 from UCRL-7350, Rev. 1).2/

2/ Boardman, C. R., D. D. Rabb, and R. D. McArthur. Characteristic Effects of Contained Nuclear Explosions for Evaluation of Mining Effects. University of California, UCRL-7350, Rev. 1, 1963, p. 23.

Explosion	Yield-kton	Rock-type	Distance-ft.
Gnome	3.1	Salt	14,500
Hardhat	5.0	Granodiorite	4,200
Brazos	7.8	Alluvium	3,200
Logan	5.0	Tuff	6,100

Rock of the Old Reliable mine compares most favorably with that of the Hardhat area. Scaling the damage threshold distance for the Hardhat explosion up to 10 kton gives a distance of 5,300 feet. This is the distance at which threshold damage or slight cracking of the plaster may be expected to occur in residential type construction.

Ground shock can also cause damage to underground workings. Tunnel damage data has been tabulated for several explosions. Hardhat workings were damaged to a distance of 535 feet from the explosion center. Using cube root scaling an indication of the threshold damage distance is obtained by the relationship:

$$D_2 = \frac{W_2^{1/3} D_1}{W_1^{1/3}}$$

Substituting D_1 = 535 feet, W_1 = 5 kton, and W_2 = 10 kton, the indicated distance at which tunnel damage may occur is found to be 673 feet. Mine damage could be expected in underground workings at this distance from the Old Reliable mine when a 10 kton explosion is fired. The nearest underground mines are the Copper Prince and the Childs-Aldwinkle, both are more than 3,000 feet distant.

Transmission of semic waves through the ground between shot point and structure is dependent on geological characteristics of the ground through which waves must travel. Transmitted waves are interrupted and attenuated by intervening geological structures. Geological structures shown by the section (fig. 5) between the Old Reliable mine and San Manuel may decrease the effect of ground shock.

The structures of major importance closest to the Old Reliable mine are at San Manuel (fig. 16) about 12 miles distant and include a 500 foot smoke stack. The formula suggested by Coast and Geodetic Survey, U. S. Department of Commerce, for prediction of acceleration and displacement attenuation with distance follows:10/

10/ Carder, D. S., L. M. Murphy, T. H. Pearce, and W. V. Mickey. Surface Motions From Underground Explosions, Operation Hardtack 11. U. S. Department of Commerce, Coast and Geodetic Survey, April 1, 1960.

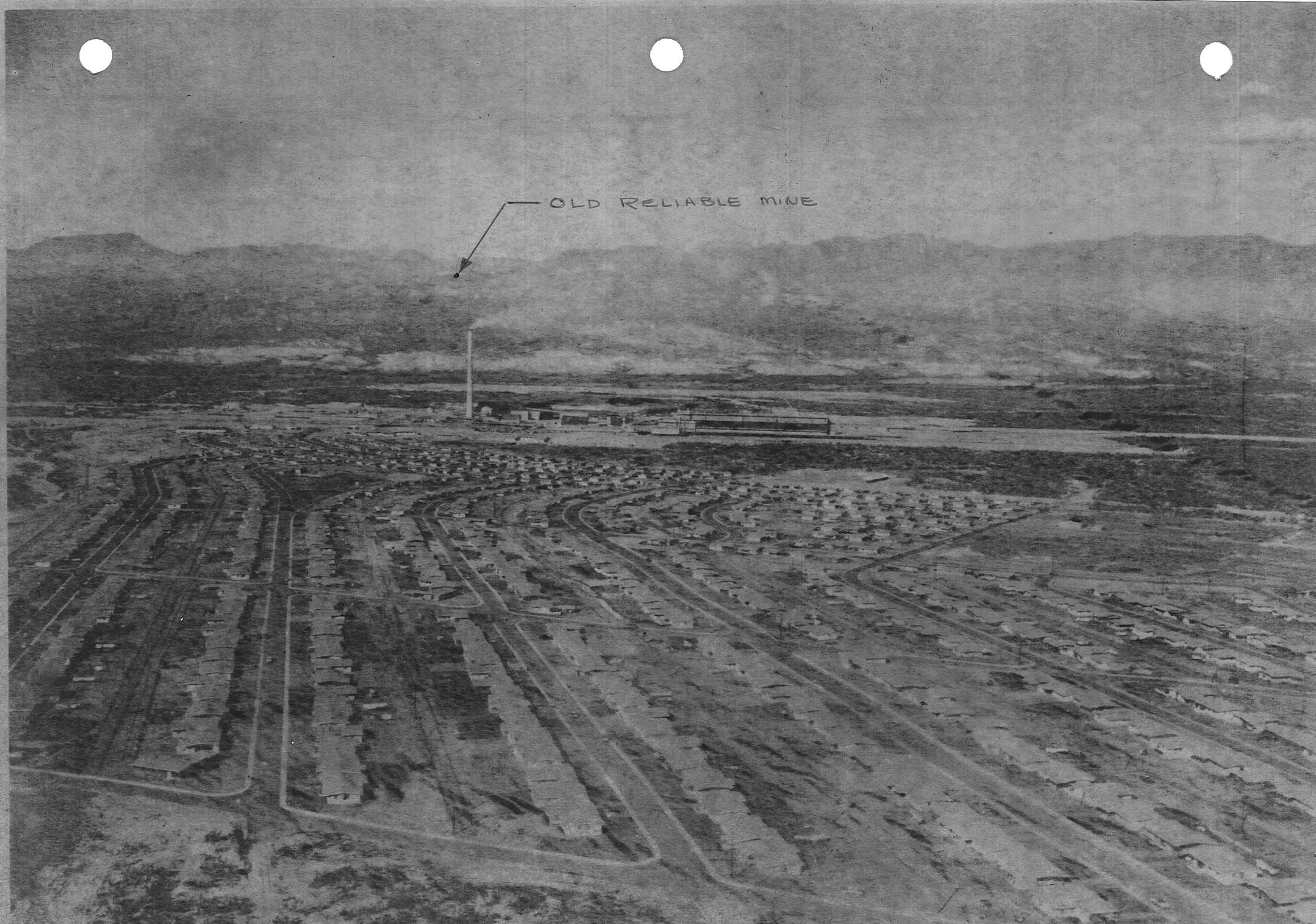

FIGURE 16. - Copper Creek as viewed from San Manuel

$$\text{Log } a = 0.75 \log W + 3.98 - 2 \log D$$

Where:

a = maximum acceleration, single component (gravity)

W = equivalent high explosive (tons)

D = distance to explosion (feet)

Solution of this equation using a shot size of 10 kton and a distance of 12 miles gives an acceleration of .002 g or about 0.06 foot per sec. per sec.

The San Manuel stack was designed for a seismic coefficient a/g of .03 g or an acceleration of about 1 foot per sec. per sec. (fig. 17).

Radioactivity

The third phenomena that may cause damage is radioactivity. Radioactivity may cause hazards from four different aspects:

1. Radioactive fallout if the explosive is near the surface.

2. Radioactive hazards to employees in the operation as from excavation in hot ground or contamination of solutions with which employees come in contact.

3. Contamination of copper produced.

4. Contamination of ground water.

The design of the explosion will be such that only a small amount if any activity escapes. An evaluation of the fallout hazards may indicate removing people from an area ranging up to 25 miles. If the shot is fired when prevailing fallout will be extended in a northeast direction only a few people will be involved.

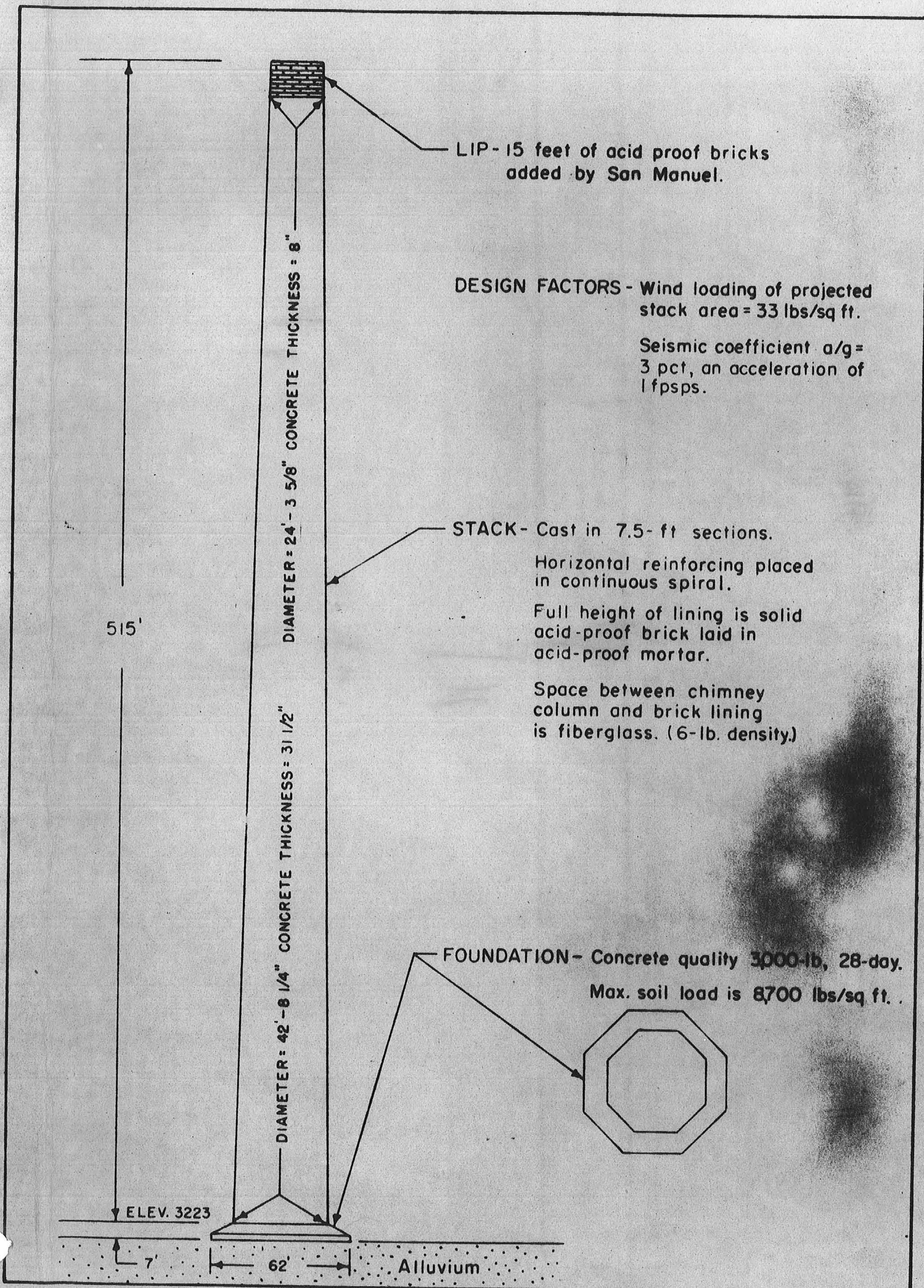

FIGURE 17. - Reinforced Concrete Smelter Chimney, 500' X 20', San Manuel, Ariz.

Soon after the explosion it will be necessary to drive reentry openings into the area of the explosion cavity to provide channels and recover the copper bearing solution. Based on the experience on Nevada Test Site this does not appear to present an unsurmountable problem. Rad-safe protection will be an additional expense.

When solutions are applied to the ore some radioactive isotopes may be leached. The amount and concentration in leach solution is being investigated but is not believed to be such that unsurmountable problems are developed.

Like the hazards from activity and leach solutions the amount of concentration in the copper product is being investigated. Present indications are that it will not present a serious problem.

The amount of contamination in the ground water is dependent on half-life of the isotopes and the rate at which they are leached. Much of the contamination may be removed by process leaching. It may be necessary to discard early solution. If this occurs serious consideration should be given to planning the operation so as to prevent the buildup of disposed contamination in a surface area that may be flooded by flash floods and carried downstream to the San Pedro River.

CONCLUSION

A small deposit, the Old Reliable Copper mine, has been explored sufficiently to estimate the type, quantity, and copper content of the ore. The deposit is typical of many that are not currently economic because the grade of the ore is too low for direct smelting and the reserves are too small to amortize a concentrating plant. Although the reserves in the Old Reliable are less than a million tons some deposits of this type and grade range up to 10 million tons of ore.

The small size of the deposit reduces the cost of many of the problems of an experiment. The deposit is typical and results can be scaled to larger deposits. The Old Reliable deposit is recommended for a detailed feasibility study. A successful experiment is indicated, will provide an incentive at minimum cost, and will illustrate a new application of the in-situ leach mining method.