CONTACT INFORMATION
Mining Records Curator
Arizona Geological Survey
3550 N. Central Ave, 2nd floor
Phoenix, AZ, 85012
602-771-1601
http://www.azgs.az.gov
inquiries@azgs.az.gov

The following file is part of the John E. Kinnison mining collection

ACCESS STATEMENT

These digitized collections are accessible for purposes of education and research. We have indicated what we know about copyright and rights of privacy, publicity, or trademark. Due to the nature of archival collections, we are not always able to identify this information. We are eager to hear from any rights owners, so that we may obtain accurate information. Upon request, we will remove material from public view while we address a rights issue.

CONSTRAINTS STATEMENT

The Arizona Geological Survey does not claim to control all rights for all materials in its collection. These rights include, but are not limited to: copyright, privacy rights, and cultural protection rights. The User hereby assumes all responsibility for obtaining any rights to use the material in excess of "fair use."

The Survey makes no intellectual property claims to the products created by individual authors in the manuscript collections, except when the author deeded those rights to the Survey or when those authors were employed by the State of Arizona and created intellectual products as a function of their official duties. The Survey does maintain property rights to the physical and digital representations of the works.

QUALITY STATEMENT

The Arizona Geological Survey is not responsible for the accuracy of the records, information, or opinions that may be contained in the files. The Survey collects, catalogs, and archives data on mineral properties regardless of its views of the veracity or accuracy of those data.

Bisbee

GEOLOGY AND ORE DEPOSITS OF THE WARREN MINING DISTRICT

BY DONALD G. BRYANT AND HARRY E. METZ

Geology of the Porphyry Copper Deposits, Southwestern North America. Univ of Arizona Press.

Christmas

JER

NEW DEVELOPMENTS AT THE CHRISTMAS MINE

GILA COUNTY, ARIZONA

By

JOHN T. EASTLICK

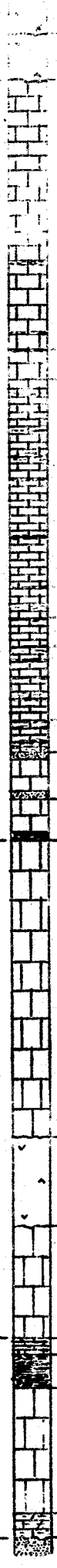
Prepared for presentation at the Annual Meeting
of the Arizona Section of the American Institute
of Mining, Metallurgical and Petroleum Engineers

December 2, 1957

Not to be reproduced in any form without permission
of the Inspiration Consolidated Copper Company.

STRATIGRAPHIC SECTION IN VICINITY CHRISTMAS MINE WEST TO

Compiled from Diamond Drill Hole Data and Surface Geological Mapping.



+1500' Andesite volcanics

60' Medium grained quartz [illegible] persistent throughout most of the area.

400' Thick bedded light to dark gray crystalline limestone with thin shaly layers and local chert nodules and fossils.

NACO LIMESTONE (PENN. & PERMIAN)

500' Thin to medium bedded limestone and shale, locally cherty and abundantly fossiliferous.

63' Thin bands granular quartzite separated by thick bedded gray crystalline limestone with local shaly beds.

50' Fine to coarse grained crystalline limestone, locally cherty with 3—5' dark shale at base.

ESCABROSA LS. (MISSISSIPIAN)

400' Massive, light gray, fine to coarse grained crystalline limestone, locally thin bedded and cherty in the upper part.

120' Coarse grained quartz mica diorite sill persistent over whole area, locally thicker in Christmas vicinity.

130' Light to dark gray, fine to medium grained crystalline limestone.

MARTIN LIMESTONE (DEVONIAN)

20' Thinbedded shaly limestone, silicified near contacts.

45' Argillaceous and calcareous shale, generally highly silicified and altered to hornfels near contacts.

170' Massive light gray, fine grained crystalline limestone, thin quartzite beds in the upper part.

30' Thin bedded shaly and dolomitic limestone.

CAMBRIAN

175' Argillaceous and calcareous quartzite.

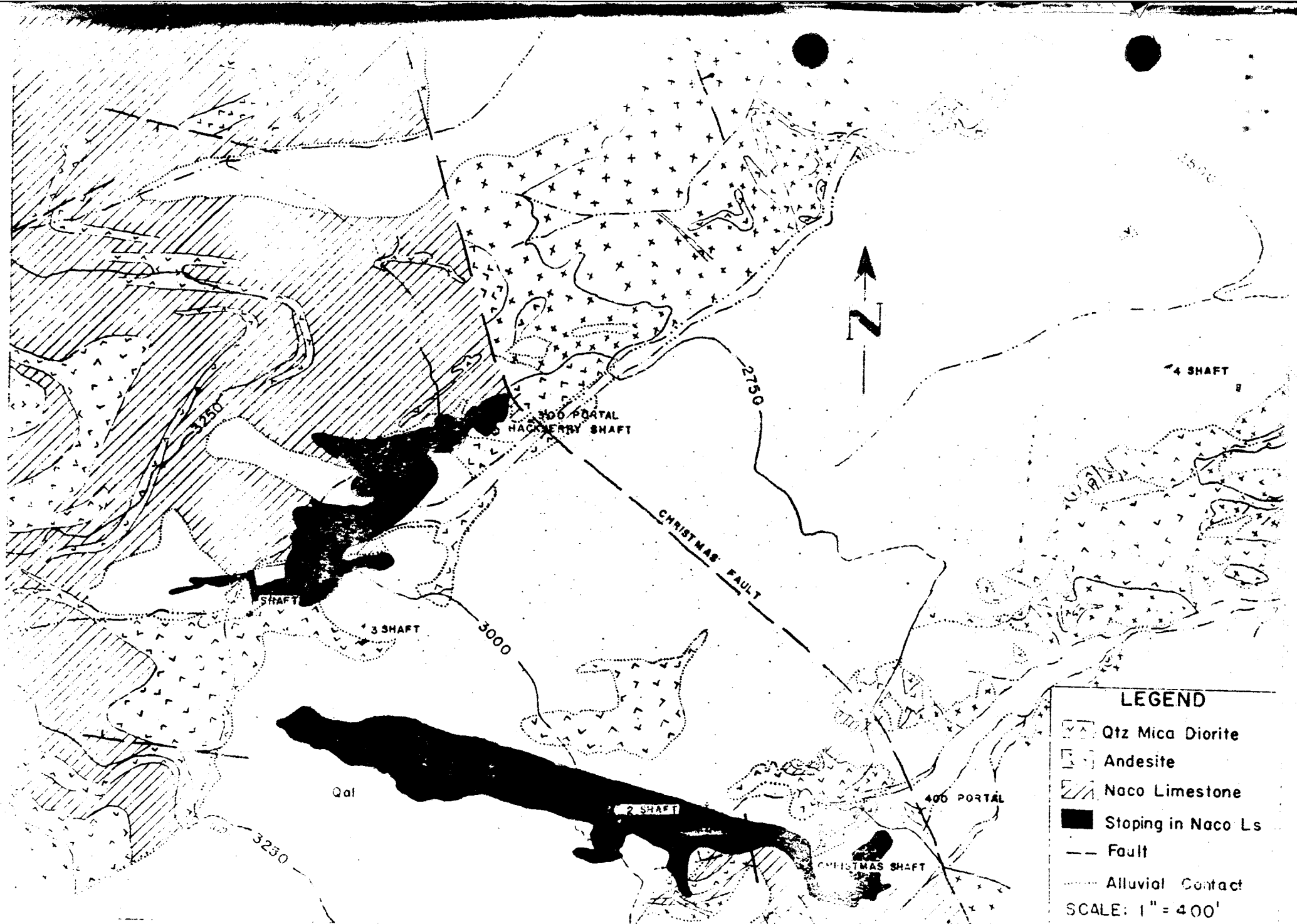


PLATE I, GENERALIZED SURFACE GEOLOGY, CHRISTMAS MINE, I.C.C.COMPANY

...ters ... Swanson, USGS, with additions by Company Geological Staff and ... Exploration Dept.

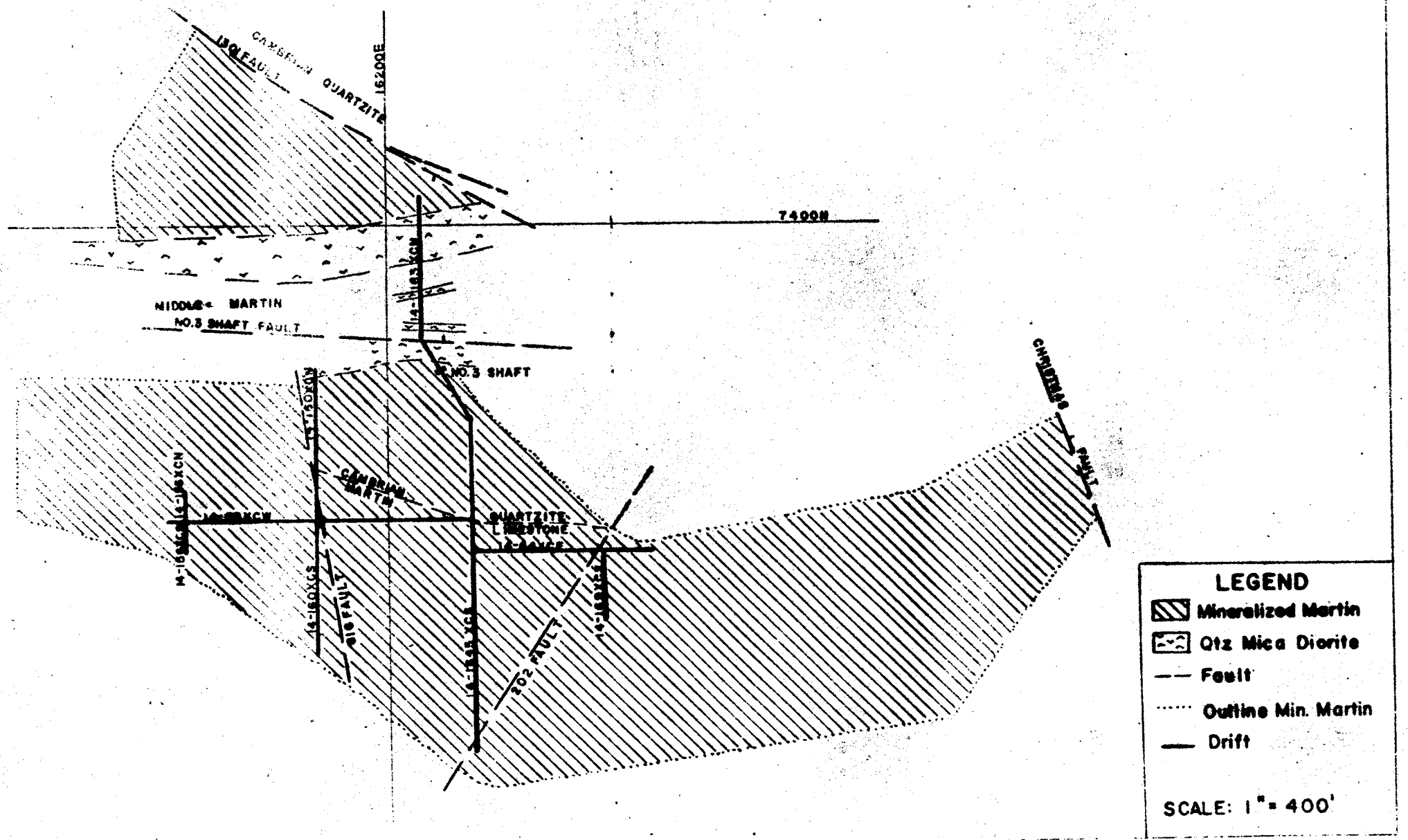


PLATE 4, GENERALIZED 1400 LEVEL GEOLOGY, CHRISTMAS MINE, I.C.C. COMPANY

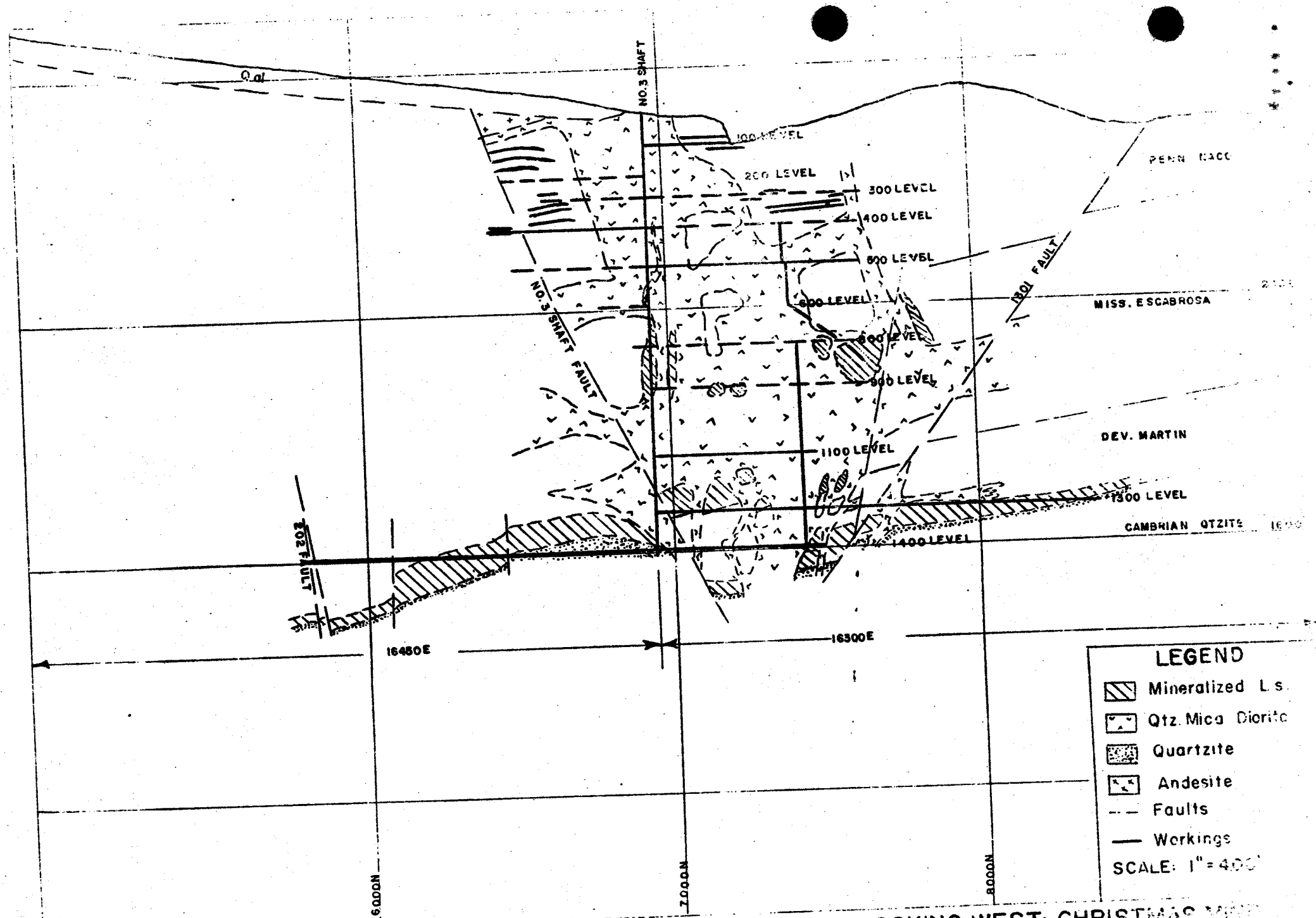


PLATE 5, GENERALIZED N-S SECTION THRU NO.3 SHAFT, LOOKING WEST; CHRISTMAS MINE

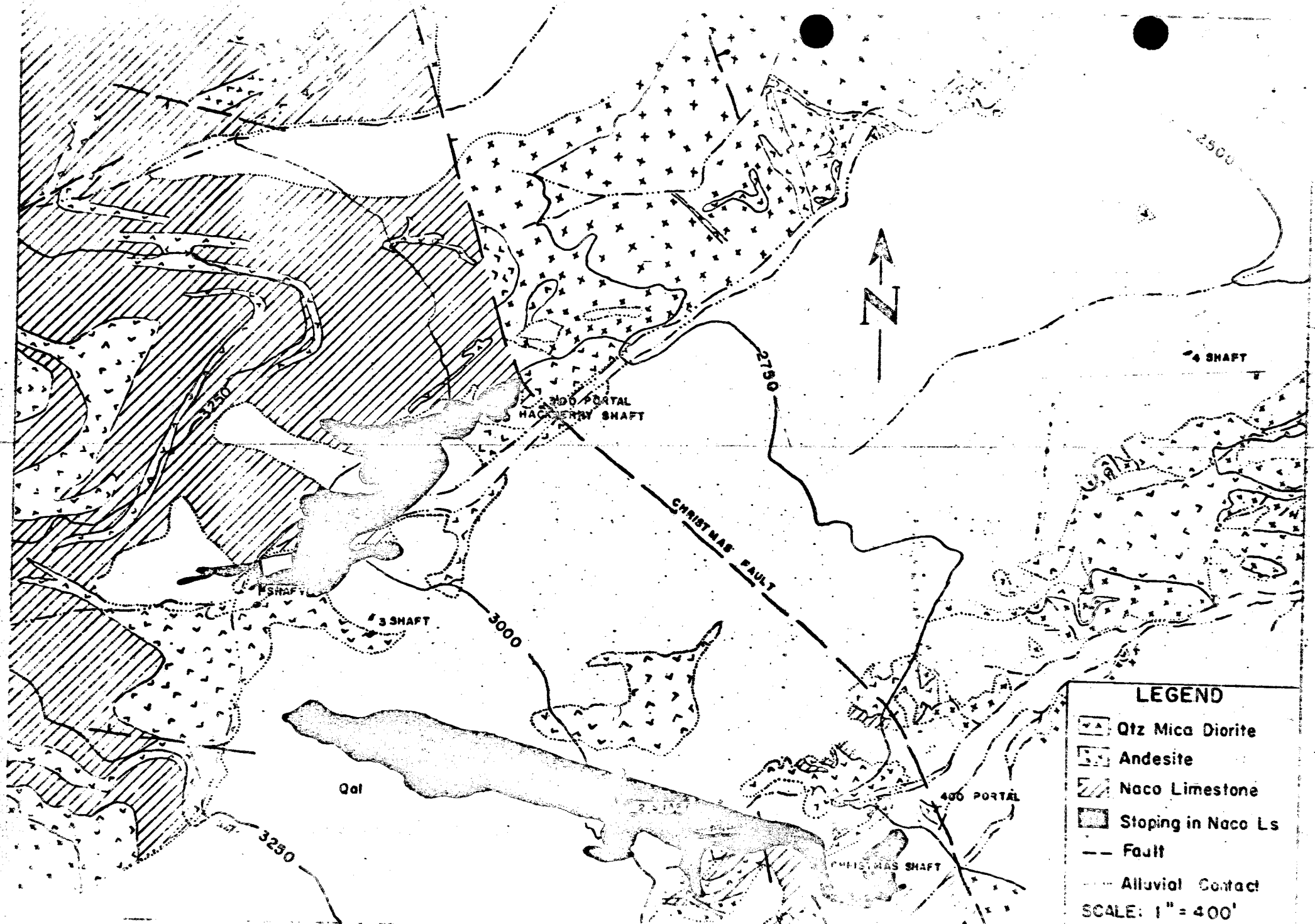


PLATE I, GENERALIZED SURFACE GEOLOGY, CHRISTMAS MINE, I.C.COMPANY

eters[illegible] Swanson, USGS, with additions by Company Geological Staff and Anaconda Exploration Dept.

STRATIGRAPHIC SECTION IN VICINITY CHRISTMAS MINE WEST TO

d from Diamond Drill Hole Data and Surface Geological Mapping.

+1100' Andesite volcanics

60' Medium grained quartz hornblende porphyry, persistent throughout most of the area

NACO LIMESTONE (PENN. & PERMIAN)

400' Thick bedded light to dark gray crystalline limestone with thin shaly layers and local chert nodules and beds

500' Thin to medium bedded limestone and shale, locally cherty and abundantly fossiliferous.

63' Thin bands granular quartzite separated by thick bedded gray crystalline limestone with local shaly beds.

50' Fine to coarse grained crystalline limestone, locally cherty with 3—5' dark shale at base.

ESCABROSA L.S. (MISSISSIPIAN)

400' Massive, light gray, fine to coarse grained crystalline limestone, locally thin bedded and cherty in the upper part.

120' Coarse grained quartz mica diorite sill persistent over whole area, locally thicker in Christmas vicinity.

130' Light to dark gray, fine to medium grained crystalline limestone.

20' Thinbedded shaly limestone, silicified near contacts.

45' Argillaceous and calcareous shale, generally highly silicified and altered to hornfels near contacts.

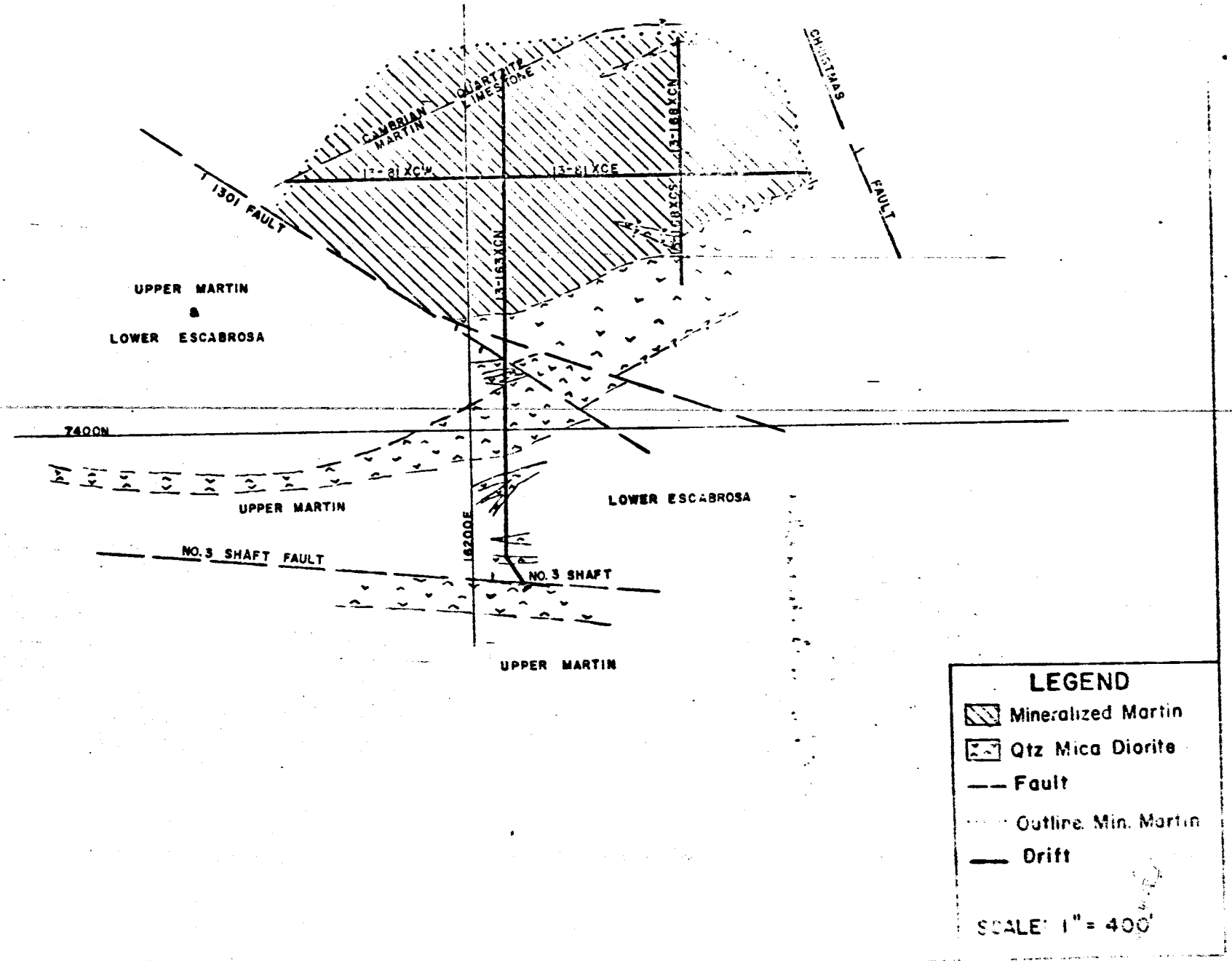
MARTIN LIMESTONE (DEVONIAN)

170' Massive light gray, fine grained crystalline limestone, thin quartzite beds in the upper part.

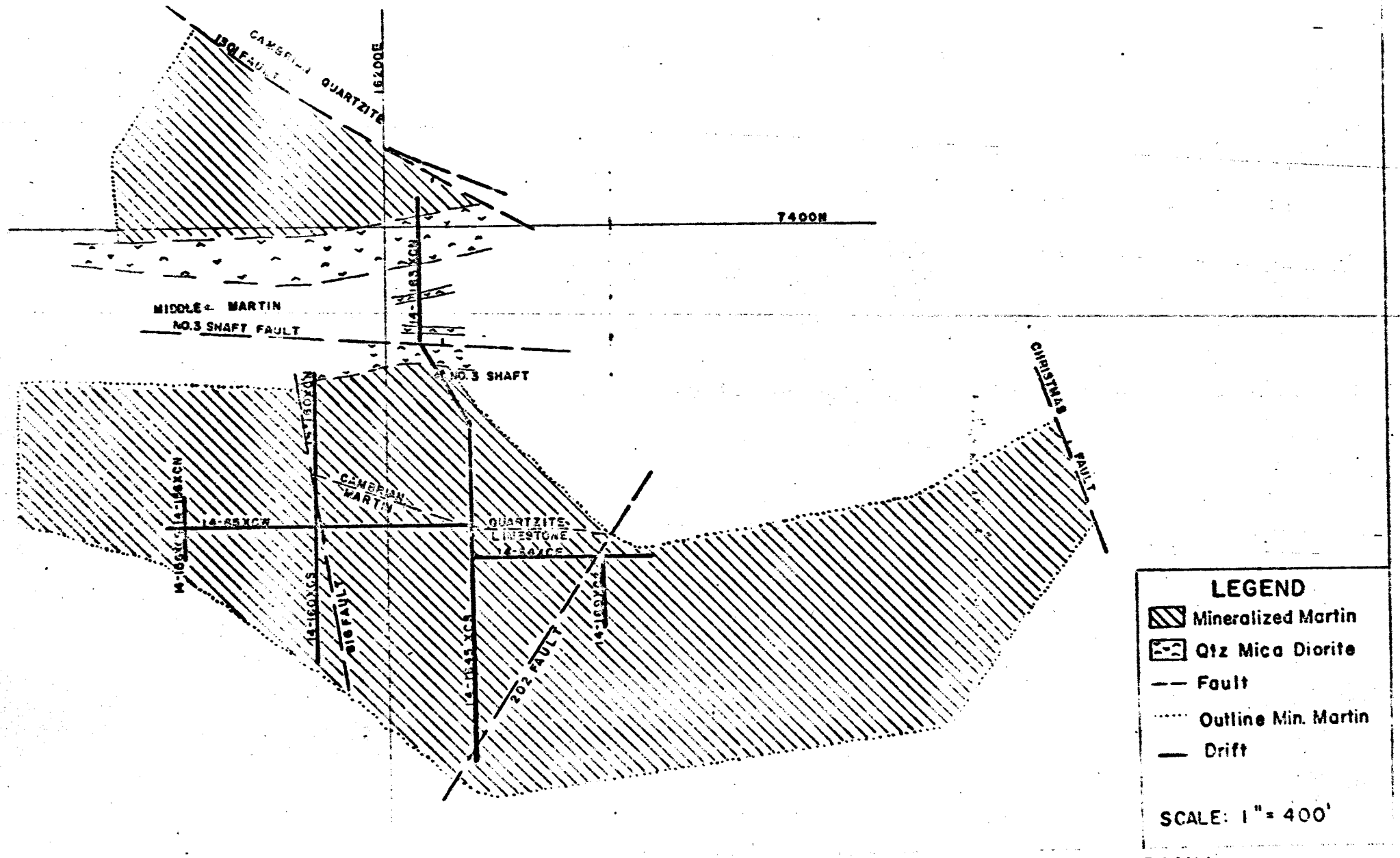
30' Thin bedded shaly and dolomitic limestone.

CAMBRIAN

175' Argillaceous and calcareous quartzite.



MINERALIZED 1300 LEVEL GEOLOGY, CHRISTMAS MINE, I.C.C. COMPANY



4, C ALIZED 1400 LEVEL GEOLOGY, CHRISTMAS M , I.C.C. COMPANY

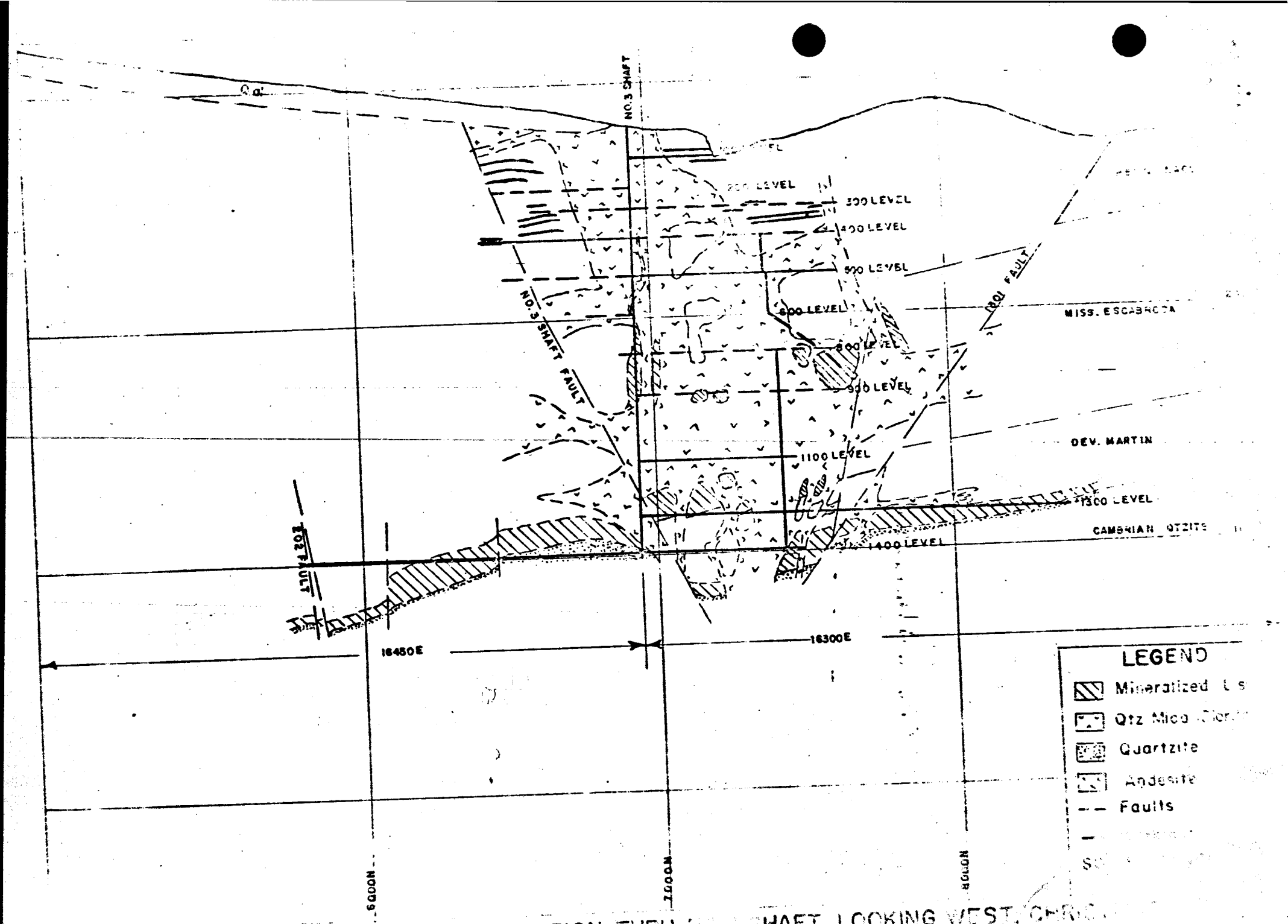


PLATE 5, GENERALIZED SECTION THRU SHAFT, LOOKING WEST

dEK Por Cu Descriptive
Copper Creek

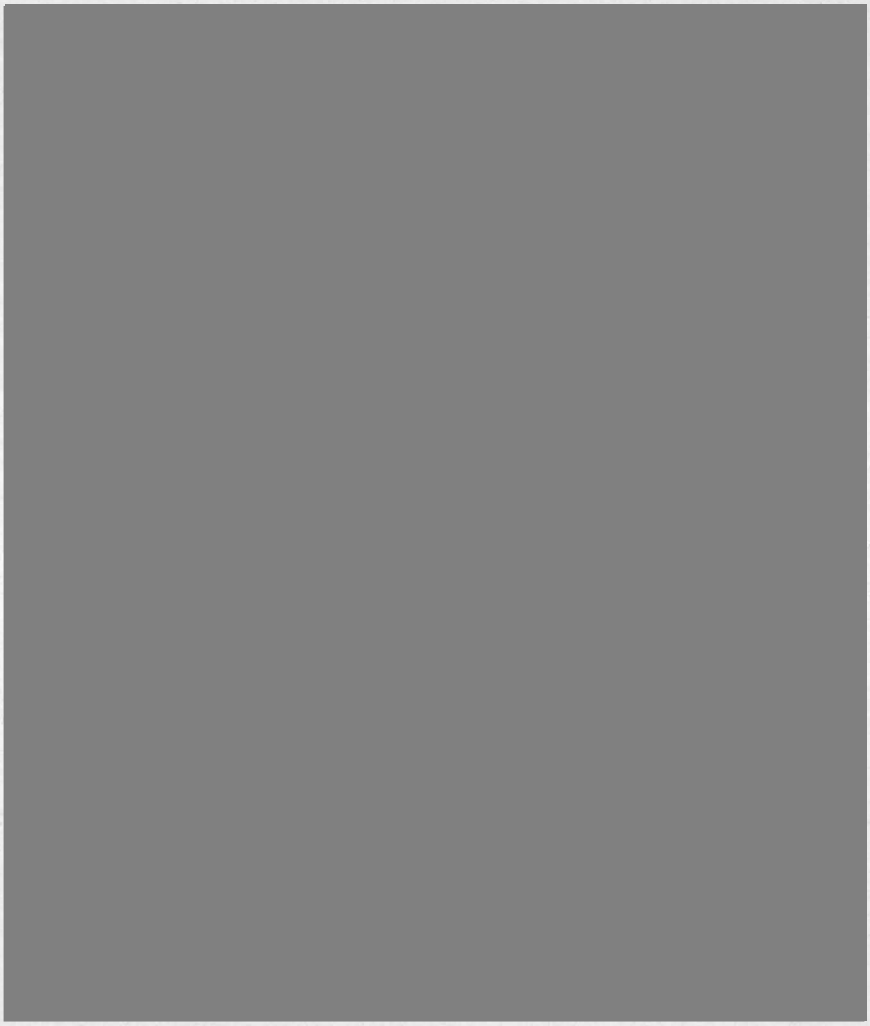
JOHN E. KINNISON

Reprinted from ECONOMIC GEOLOGY, Vol. XXXVI, No. 5, August, 1941
Printed in U. S. A.

JOHN F. KINNISON

PIPE DEPOSITS OF THE COPPER CREEK AREA, ARIZONA.

TRUMAN H. KUHN.



Ithica Peak
(Mineral Park)
(Grosse Ranch)

J. H. C.
MAY 24 1965

J. E. K.
MAY 25 1966

The

CRYSTALLIZATION, ALTERATION, and MINERALIZATION

of the

ITHACA PEAK INTRUSIVE

WALLAPAI MINING DISTRICT, MOHAVE COUNTY, ARIZONA

J. James Eidel

Protore .1% Cu
at Ithica Pk

TABLE of CONTENTS

INTRODUCTION	Page 1
ACKNOWLEDGEMENTS	1
GEOLOGY	
General	2
Igneous Petrology:	
Quartz diorite (?)	2
Quartz monzonite and quartz monzonite porphyry	3
Quartz porphyry	4
THEORY OF DIFFERENTIATION AND CRYSTALLIZATION	5
THEORY OF DEUTERIC CRYSTALLIZATION AND ALTERATION	6
HYDROTHERMAL MINERALIZATION AND ALTERATION	
First Type: (Pyrite, replacement quartz)	8
Second Type: (Pyrite, quartz)	9
Third Type: (Argentiferous galena, cupiferous sphalerite)	10
SUPERGENE ENRICHMENT	10
SYNOPSIS OF STRUCTURE	11

INTRODUCTION

Duval Corporation's Mineral Park property is located in the Wallapai Mining District approximately 16 miles north of Kingman, Arizona and 24 miles west of the Grand Wash Cliffs. The triumvirate of quartz monzonite intrusives, Ithaca Peak, Cross Peak, and Turquoise Mountain, form the core of the elliptical district whose axes trend 5 miles northeast and 20 miles northwest.

The earliest mining in what is now the Wallapai Mining District was for turquoise by Indians. Charcoal and stone hammers are still found in workings on Turquoise Mountain.

Gold was discovered in 1863 and concerted efforts to mine gold and silver began in the 1870's. The rich oxide zone silver chloride's were nearly depleted by the turn of the century and attention was diverted to argentiferous galena and sphalerite ores at depth.

Approximately $24,000,000 worth of gold, silver, lead, and zinc were produced through 1946. The Keystone Mine in Mineral Park was the last of over 225 mines and 1,000 prospects to close in 1948.

The porphyry copper-molybdenum mineralization at Mineral Park was first drilled in 1906; the first production, however, was in November 1964 by Duval.

The present mining operation is confined to Ithaca Peak, which was the highest at 5,200' and the easternmost of the above mentioned triumvirate of intrusives. This discussion will also be confined to Ithaca Peak and will be concerned with the petrology, theory of origin, mineralization, alteration, and structure of the Ithaca Peak intrusive.

ACKNOWLEDGEMENTS

The speaker wishes to emphasize the fact that the majority of the surface mapping was done by D. Clippinger and J. E. Frost. K. Martin, I. B. Gray, R. Sayers, and E. H. Lewis also contributed to the early mapping and logging. Dr. H. A. Schmitt

supervised the exploration phase. Discussions with J. E. Frost, D. Clippinger, H. A. Schmitt, and W. J. Roper have influenced the interpretation presented in this paper.

GEOLOGY

General

Quartz monzonitic magmas have intruded the Precambrian chlorite-biotite schists, amphibolite, and granite gneiss which comprise the Cerbat Complex. The copper-molybdenum mineralization is confined to the intrusives and their immediate environs.

The contacts of the Ithaca Peak stock with the Cerbat Complex are steeply dipping. The quartz monzonite magma was not chilled and is not foliated at the contact. The Cerbat Complex metasediments were deformed at the contact. These facts indicate that the quartz monzonites were forcibly intruded and then differentiated and crystallized in place.

The quartz monzonitic Ithaca Peak stock was extensively deuterically altered; it was then shattered and mineralized and altered by hypogene and supergene solutions. Finally, northwest trending vein-faults which are characteristic of the entire district were formed. These silver-lead-zinc veins also transect the Ithaca Peak stock.

The intensity of the deuteric, hypogene, and supergene alteration has made it impossible to obtain modal analyses to date.

GEOLOGY

Igneous Petrology:
Quartz diorite (?)

The quartz diorite (?) consists of small discordant injections into the Cerbat Complex and of a 5 to 10 foot rim containing inclusions of the Cerbat Complex. Weathered exposures of the quartz diorite (?) have been exposed at the north and northeast contacts of the Ithaca Peak stock and the Cerbat Complex. It should be emphasized that the volume of the quartz diorite (?) is very small when compared to the volume of the Ithaca Peak stock.

The quartz diorite (?) has a medium grained, subhedral granular texture. It is composed of red-brown biotite and/or hornblende, calcic plagioclase, and minor orthoclase and quartz.

The igneous texture, the presence of euhedral accessory minerals characteristic of igneous rocks, and the presence of inclusions of the Cerbat Complex attest to the igneous origin of the quartz diorite (?). The compositional differences between the quartz diorite (?) and the quartz monzonites suggest that the quartz diorite (?) is a facies of the quartz monzonite that was contaminated by reaction with the Cerbat Complex.

GABBRO

Igneous Petrology:
Quartz monzonite and quartz monzonite porphyry.

The quartz monzonite and quartz monzonite porphyry form a continuous intermediate zone, 250 - 1,000' thick, between the quartz diorite (?) rim and the quartz porphyry core.

There are no significant textural differences between the quartz diorite (?) and the quartz monzonite. The quartz monzonite and quartz monzonite porphyry are equivalent units but due to subtle variances in grain size, they have not been differentiated in the field.

The quartz monzonites and the quartz porphyry (described below) contain sericite pseudomorphs after euhedral micas and sericite and/or clay pseudomorphs after subhedral plagioclase in a matrix of fine grained, anhedral quartz and orthoclase. Pervasive sericitization and argillization has replaced all the primary plagioclase and mica in the quartz monzonites and in the quartz porphyry.

A biotite facies of the quartz monzonite occurs adjacent to a large xenolith or septa of Cerbat Complex metasediments near the north end of Ithaca Peak. This facies crops out for a distance of 2 to 200 feet normal to the contact with this xenolith. The biotite facies of the quartz monzonite is similar in all respects to the quartz

monzonite with the exception of the presence of red-brown biotite and somewhat stronger argillization. The biotite either is disseminated throughout the quartz monzonite or is restricted to the margins of veins leaving intravein areas that are void of biotite.

The restriction of the biotite to vein margins in some cases and its occurrence in the proximity of the Cerbat Complex suggest that the stability of the biotite may be due in part to contamination by the Cerbat Complex.

Accessory minerals in the quartz monzonites are rutile, apatite, and zircon.

GEOLOGY

Igneous Petrology:
Quartz porphyry

In contrast with the sometimes vaguely porphyritic quartz monzonite, the quartz porphyry forms the distinctly porphyritic core of the Ithaca Peak stock. The core is roughly elliptical with a northeast trending major axis of 2,000' and a northwest trending minor axis of 1,400'. Roughly in the center of the quartz porphyry is an elliptical area 700' by 500' which contains numerous quartz, aplite, and orthoclase pods and irregular veins as well as crenulate quartz veinlets in a matrix of quartz porphyry.

The quartz porphyry is characterized by quartz phenocrysts which range in size from 2 mm at the contact with the quartz monzonites to 15 mm, 20' to 100' from the contact. The sericitized and/or argillized plagioclase phenocrysts range from 5 to 10 mm and the sericitized mica phenocrysts are somewhat smaller. The grain size of these phenocrysts is greater than that of the quartz monzonites. The phenocrysts are contained in a matrix of fine grained, anhedral quartz and orthoclase.

Accessory minerals are rutile, apatite, and zircon.

Two small bodies of a biotite facies of the quartz porphyry are similar to the biotite facies of the quartz monzonite. The similarities suggest that these bodies may be almost completely digested xenoliths of the Cerbat Complex metasediments.

THEORY OF DIFFERENTIATION AND CRYSTALLIZATION

The consideration of the differentiation and crystallization of the Ithaca Peak stock is necessarily based upon evidence gathered from exposures in an essentially horizontal plane through what was the upper portion of a much larger igneous mass. This discussion is, therefore, restricted to a closed, planar system. No mobile components are assumed to have been introduced into this system until the late deuteric and hypogene stages. The successive igneous units are considered in the order in which they crystallized from the periphery toward the center of the stock.

The lack of significant disparity in grain size between the quartz diorite (?) and the quartz monzonites indicates that the quartz diorite (?) was not chilled at the contact with the Cerbat Complex metasediments. Significant reaction between the metasediments and the melt resulted in the disparity in the compositions of the quartz diorite (?) and the quartz monzonites.

Following this period of reaction with the Cerbat Complex, the melt was encased in a solid quartz diorite (?) rim and underwent normal differentiation following Bowen's reaction series. The composition of the quartz monzonites, disregarding the ferromagnesian components lay within the system Or-Ab-An-SiO_2. The micaceous texture of the fine grained sericite pseudomorphs after primary mica indicate that only hydrous ferromagnesian phases precipitated. As biotite and calcic plagioclase crystallized, the melt was gradually enriched in potash, silica, water and other low melting constituents. The vapor pressure within the melt gradually increased as the concentration of volatiles was increased in the remaining melt.

During the late stages of quartz monzonite crystallization, the composition of the melt approached the system Ab-Or-SiO_2-H_2O and the melt became supersaturated with respect to silica. Rounded quartz phenocrysts precipitated with alkali feldspars (composition inferred due to the intense alteration of the feldspars) and biotite. The quartz phenocrysts increased in size as the melt was enriched in silica. A cry-

and much developed within the nearly solid quartz monzonite shell. The composition of the remaining liquid approached the system $Or-SiO_2-H_2O$. No ferromagnesian components remained in the melt.

When the crystal-liquid ration in the mush contained within the solidified quartz monzonite shell was approximately 2:1, the vapor pressure exceeded the load pressure of the overlying and surrounding Cerbat Complex metasediments. The quartz monzonitic shell and the Cerbat Complex metasediments were ruptured. Potash and silica rich residual fluids were injected into the fractures and the groundmass of the quartz porphyry crystallized. Pressure equilibrium was rapidly attained; thermal equilibrium was not significantly disturbed.

The rapid decrease in pressure caused the remaining melt to quickly crystallize yielding a eutectic mixture of fine grained, anhedral quartz and orthoclase.

The extruded fluids, on the otherhand, crystallized as aplite and pegmatite veins in the quartz monzonite and the surrounding rocks. The lack of chilled margins at the contacts of these veins suggests that thermal equilibrium existed between the injected fluids and their wall rocks within the vicinity of Ithaca Peak. Movement of the semi-solid pegmatite masses created marginal leucocratic gneisses along the pegmatite contacts. The rhyolite dikes characteristic of the western portion of the Wallapai Mining District may represent chilled fluids of the same origin and composition as the aplites and pegmatites.

THEORY OF DEUTERIC CRYSTALLIZATION AND ALTERATION

Upon reviewing the use and definition of the term deuteric since its original definition by Sederholm in 1919, Robertson (1962, p. 1264) applied a more exacting definition to the term, one which was applicable to the silicic Boulder batholith and which is equally applicable to the Ithaca Peak stock. The high temperature limit of deuteric crystallization in intermediate and silicic igneous rocks is defined by "postgroundmass potassic feldspar crystallization".

Following the crystallization of the quartz-orthoclase groundmass of the quartz porphyry at Ithaca Peak, an aqueous intergranular phase existed in equilibrium with "pockets" of remaining, trapped liquid. These "pockets" of liquid crystallized as isolated masses of coarsely crystalline quartz and orthoclase with vague altered contacts with the wall rocks due to reaction with them.

The intergranular fluids deuterically altered the quartz porphyry groundmass forming oikocrysts or postgroundmass deuteric porphyroblasts of orthoclase which included groundmass quartz and orthoclase, and the mica and plagioclase phenocrysts. These oikocrysts have single dimensions as great as 6 inches.

Optically continuous quartz overgrowths on the primary quartz phenocrysts are also considered deuteric.

The large amounts of silica in the central portions of the quartz porphyry may represent the first mobile components introduced from below the system being considered or silicic fluids that were the final differentiate in place of the planar system described. The concentration of the gray-white quartz at the center of the quartz porphyry seems to favor the latter explanation. The pod-like and irregular configuration of the quartz masses suggests intrusion into what may have been semi-consolidated quartz porphyry. The dimensions of the quartz masses are tens of feet. The quartz contains trace amounts of pyrite and molybdenite.

Silica, in the vicinity of the quartz masses was also apparently injected into the quartz porphyry as sub-parallel, 1 - 3 mm thick, crenulate veinlets. These veinlets also suggest that the quartz porphyry may have been semi-consolidated at the time of their inception. Intergranular recrystallization within these veinlets, shearing of irregular protrusions from the veinlets, slightly biaxial quartz, and microfaults are all evidences of stress applied during and after the formation of the crenulate textures. The proximity of the crenulate quartz to the gray quartz masses suggests that they may have had a common origin by post differentiation injection.

HYDROTHERMAL MINERALIZATION AND ALTERATION

The lower temperature deuteric-hypogene boundary "is defined by the change from a stable-feldspar assemblage to an unstable-feldspar assemblage involving the alteration of feldspar to sericite and clay minerals" (Robertson, 1962, p. 1264). At Ithaca Peak the change from a stable to an unstable orthoclase assemblage is coincident with the first rupturing of the Ithaca Peak stock as a unit yielding a stockwork of throughgoing veinlets. The deuteric-hypogene boundary at Ithaca Peak is, therefore, both chemical and structural.

Three types of hypogene mineralization are recognized. Each succeeding type of mineralization occurs in fractures which transect the preceding type. Each succeeding type of mineralization was presumably precipitated at a lower temperature.

First Type: (Pyrite, replacement quartz)

Following the late-deuteric precipitation of minor amounts of pyrite and molybdenite in quartz pods and masses, vapor pressures again exceeded the load pressure and the now exposed portion of the Ithaca Peak stock ruptured, forming the first stockwork.

These earliest veinlets contain millimeter thick pyrite which filled the entire open space and is enclosed within bands of replacement quartz or soak silica and sericite. Orthoclase adjacent to the pyrite veinlets was replaced by sericite, probably yielding most of the replacement quartz. Some potash was introduced and lime and soda were removed from the quartz monzonite and the quartz porphyry. The primary micas were altered to white mica containing primary rutile and hydrothermal rutile, sphene, ilmenite and quartz.

The removal of iron from the primary micas provides a probable source for much of the iron in the pyrite veinlets. Part of the iron may, then, have been syngenetic and may have reacted with introduced sulfur.

Some molybdenite and probably some chalcopyrite were precipitated during this first period of mineralization.

HYDROTHERMAL MINERALIZATION AND ALTERATION

Second Type: (Pyrite, quartz)

The second type of mineralization followed a second period of rupturing which was, in general, areally coincident with the first period of rupture.

The second type of fractures contain quartz and pyrite. Quartz forms crude comb textures the center of which is filled with pyrite, coarse white mica, or supergene turquoise. The quartz in all cases preceded pyrite, chalcopyrite and molybdenite precipitation.

During the alteration associated with the second type of mineralization, iron, soda, and lime were leached from the stock and sulfur and potash were introduced.

The iron in solution may have reacted with introduced sulfur as suggested by the first type of mineralization. Pyrite which was less soluble than calcium sulfates in alkaline solutions, filled the vugs in the quartz veins.

Coarse white mica precipitated in some of the remaining open space.

Molybdenite was precipitated along the quartz vein selvages. Smaller amounts of molybdenite were precipitated in vugs in the quartz veins and within strongly altered vein margins. Chalcopyrite occurs as minute blebs and veinlets within the coarse grained pyrite.

The distinction between the first and second types of mineralization may be physical and not chemical. Pyrite, molybdenite, and probably chalcopyrite were deposited during both periods of mineralization. The extent and intensity of the associated alteration does differ between the two types of mineralization. The first type contains a small volume of fracture fillings with varied thicknesses of replacement quartz adjacent to the fractures in contrast to the much larger volume of fracture fillings with negible replacement quartz adjacent to the fractures of the second type.

It is suggested that the differences between the first two types of mineraliza-

tion may be a function of the reaction time of the hydrothermal solutions with the wall rocks. A lack of intensive replacement, therefore, may suggest throughgoing solutions, which did not have time to react with the wall rocks.

HYDROTHERMAL MINERALIZATION AND ALTERATION

[illegible] (Argentiferous galena, cupiferous sphalerite)

The third type of mineralization occurs within the Ithaca Peak stock as well as throughout the Wallapai Mining District. Within the Ithaca Peak stock several northeast trending veins contain sphalerite with exsolved chalcopyrite, argentiferous galena, minor covellite, and pyrite. The veins, in general, contain brecciated pyrite with post-brecciation sphalerite and galena; they represent the lowest temperature and latest hydrothermal mineralization within the Ithaca Peak stock.

The Wallapai Mining District is roughly a laterally zoned district with a peripheral zone of gold and silver mineralization, an intermediate zone of lead, zinc, silver, and minor gold mineralization and an intrusive core of copper-molybdenum mineralization with superimposed lead-zinc-copper-silver mineralization. This zonal distribution suggests that the mineralization of the northwest trending fissures was controlled by thermal gradients and that as temperatures decreased later, lower temperature lead-zinc mineralization were superimposed upon the earlier, higher temperature copper-molybdenum mineralization.

SUPERGENE ENRICHMENT

Late movement brecciated the pyrite in some of the veins and veinlets in the northern and southern portions of the Ithaca Peak stock, exposing a much greater surface area of pyrite to supergene solutions, than in the veins and veinlets which suffered no movement. The chalcocite which coated pyrite surfaces is, therefore, the richest in the areas of brecciated pyrite.

Nearly all chalcopyrite was totally replaced by chalcocite within the blanket enrichment.

The supergene enrichment has formed in irregular blankets, the top of which roughly conform to the topography of Ithaca Peak.

Roughly horizontal barren zones between thin blankets perched approximately 500 feet above the present water table have been explained by Schmitt (1962, p. 6) as [illegible] by the blanket to reach equilibrium during uplift. Schmitt (1962, p. 7) tentatively correlated the initial enrichment to a peridd of Late Miocene and Early Pliocene quiescence and the uplift to the Early Pliocene to Pleistocene uplift of the Colorado Plateau. Damon has suggested (1964, p. 1) that similar porphyry enrichment occurred during an Early Tertiary quiescent period preceding mid-Tertiary orogeny. The possibility remains that the ore body was exposed twice, which may explain some of the irregularities in the enriched zone. Erosion has dissected the initial blanket and the blanket migrated downward as evidenced by the thinner blankets now present. The fact that the blankets are now perched is evidence that equilibrium was never attained.

KINDS OF STRUCTURE

The Ithaca Peak, Gross Peak, and Turquoise Mountain intrusives may have been regionally controlled by the inferred Grand Wash fault 24 miles east of Mineral Park or by a parallel structure or structures. They may also have been influenced by other major Laramide lineaments.

At Mineral Park the intrusives may have been localized by the intersection of dominantly northwest trending foliation and northeast and northwest trending faults. Fold axes in the Cerbat Complex metasediments may also have localized the intrusives.

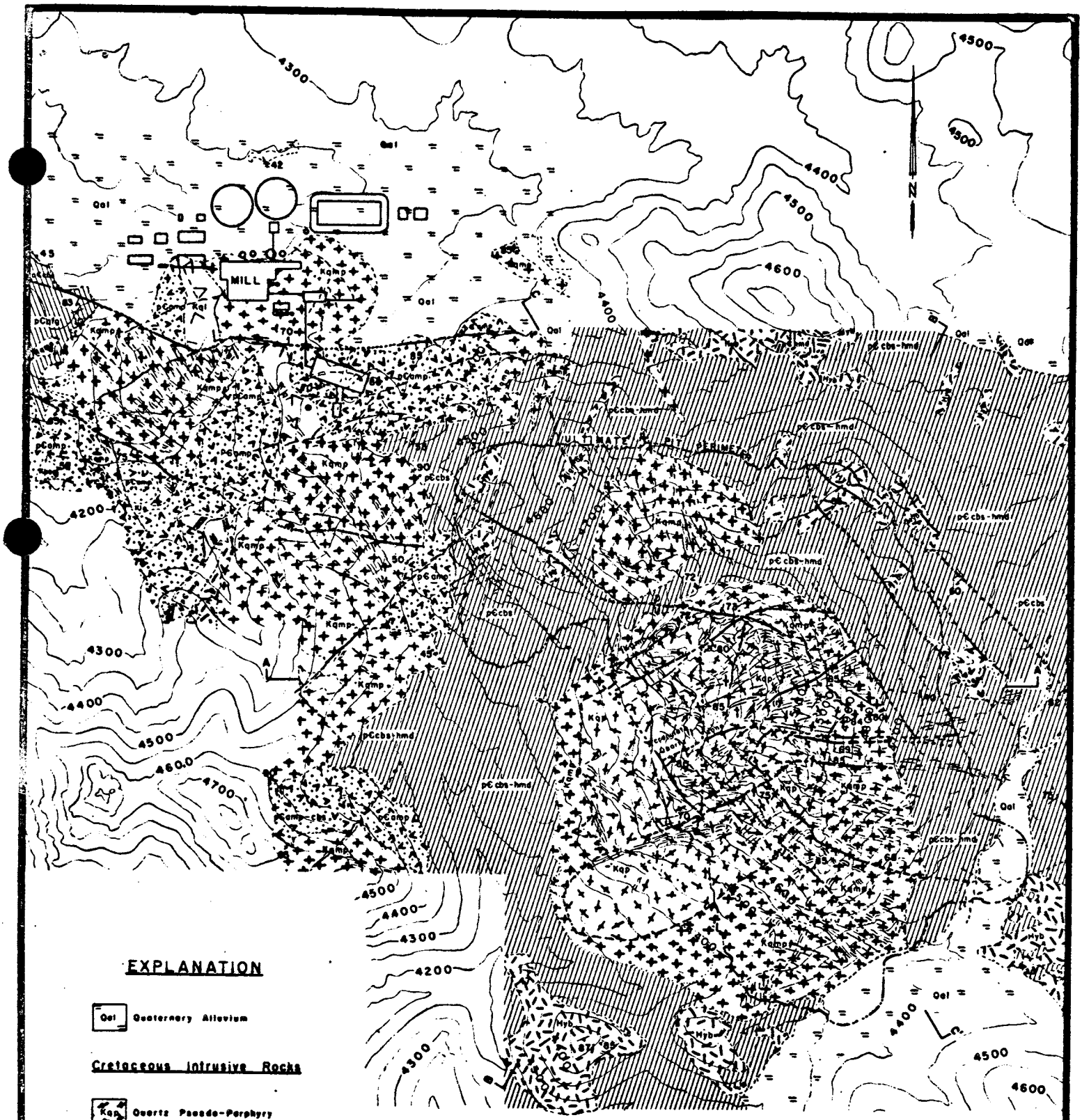
The intrusion and the crystallization of the monzonitic intrusives took place in a dynamic environment of regional stress. Local stress, however, developed during magmatic intrusion and later during crystallization due to increased vapor pressures.

Following the monzonitic intrusions, rhyolite intruded regional NNW-NNE trending [illegible] in the western part of the district. Aplites and pegmatites discordantly

and concordantly intruded the Cerbat Complex metasediments in the vicinity of Ithaca Peak.

The Ithaca Peak stock itself was probably ruptured by stress developed by the crystallizing magma. The resultant stockwork is comprised principally of steeply dipping NE, NW, and EW trending veins and veinlets. The movement on the veins and veinlets in the northern and southern parts of Ithaca Peak was predominantly vertical. The central part of the intrusive underwent little movement.

The northwest trending vein-faults which occur throughout the Wallapai Mining District continue through the monzonitic intrusives. The vein and veinlet patterns of the stockwork are displaced by these vein-faults. These facts indicate that following the hydrothermal "healing" of the stockwork, the monzonitic intrusives and the Cerbat Complex metasediments reacted as a unit to regional stress. The pre-existing northwest trending structures in the Cerbat Complex were reopened, extended through the monzonitic intrusives, and then mineralized.



EXPLANATION

Qal — Quaternary Alluvium

Cretaceous Intrusive Rocks

- Kap — Quartz Pseudo-Porphyry
- Kamp — Quartz Monzonite Porphyry
- Kq — Quartz Latite
- Kpeg — Pegmatite
- Klcm — Leucocratic Gneiss
- Kap — Aplite
- Hyb — Hybrid Rock (Kamp & pCcbs)

pC Cerbat Complex

- pCafg — Quartz-Feldspar Gneiss
- pCcbs — Chlorite-Biotite Schist
- pCamp — Amphibolite
- pChmd — Hornblende Metadiorite

Structural Symbols

- Fault, dashed where inferred
- Contact, dashed where inferred
- Shear Zone
- Schistosity

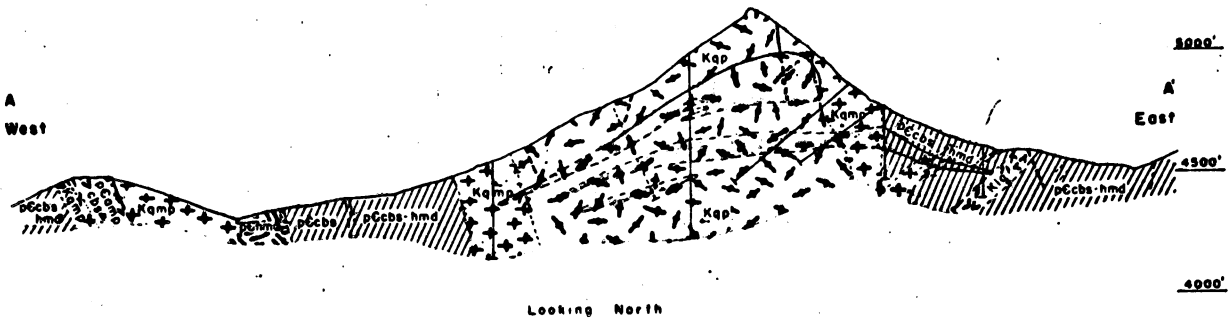
SCALE 1" = 800'

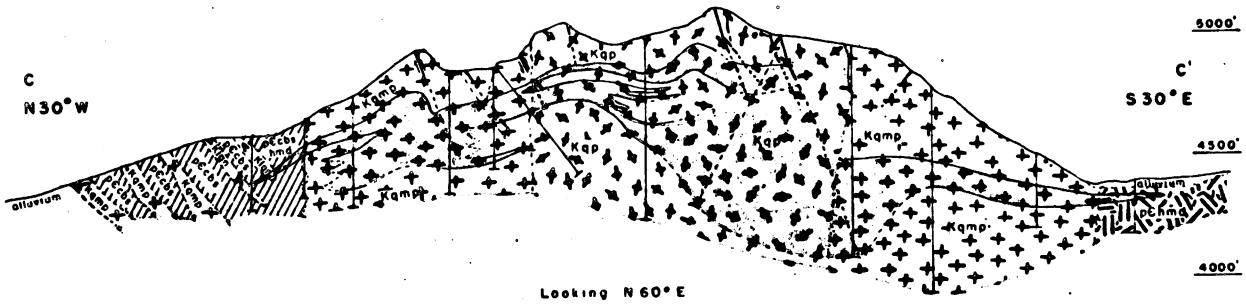
0 200 400 600 800 1200 1600

DUVAL CORPORATION
COPPER DIVISION
MINERAL PARK PROPERTY, KINGMAN, ARIZ.

SURFACE GEOLOGY

DRAWN BY	SCALE	DATE
W.G.L.	1" = 800'	Sept. 1, 1964
GEOLOGY BY J.E.F. D.M.C. J.J.E.	APPROVED BY J.E. FROST	





EXPLANATION

Cretaceous Intrusives

- Kqp — Quartz Psuedo-Porphyry
- Kqmp — Quartz Monzonite Porphyry
- Klgn — Leucocratic Gneiss
- Kap — Aplite
- Hyb — Hybrid Rock (Kqmp & pCcbs)

p€ Cerbat Complex

- pCcbs — Chlorite-Biotite Schist
- pCamp — Amphibolite
- pChmd — Hornblende Metadiorite

- Fault, dashed where inferred
- Contact, dashed where inferred
- Drill Hole
- Ore Body

SCALE 1" = 800'

0 200 400 600 800 1200 1600

DUVAL CORPORATION
COPPER DIVISION
MINERAL PARK PROPERTY, KINGMAN, ARIZ.

VERTICAL SECTIONS

DRAWN BY	SCALE	DATE
W.G.L.	1" = 800'	Sept. 1, 1964
GEOLOGY BY J.E.F. D.M.C. J.L.E.	APPROVED BY J.E. FROST	

minimal pump - mill - water from valley, lift 2000'
depth to valley water ≠ 700'

ABSTRACT

J. H. C. MAY 24 1965

WATER RESOURSES OF THE KINGMAN AREA, MOHAVE COUNTY, ARIZONA

A PROGRESS REPORT

Craig B. Bentley, U.S.G.S.

picking up water table as well as bed rk with seismic methods

A project by the Water Resources Division of the U. S. Geological Survey, financed on a matching fund basis by state and federal funds, is underway in the Hualapai and Sacramento Valleys, Mohave County, Arizona. The purpose of the project is to determine the quantity and quality of ground water in storage in the two valleys, depths to water, hydrologic characteristics of the aquifers, amount of water being added to and taken from the aquifers through natural recharge and outflow respectively, and the amount and characteristics of surface-water runoff in the drainage areas of the two valleys. To date, a ground-water inventory of all known springs and wells has been completed; water level recorders have been installed on four key wells; stream gages have been installed on several streams (washes) in the area; and a reconnaissance study of the geology, including some seismic work, is 50 per cent complete.

The geology of the area is typical of that of the Basin and Range Province, with tilted fault blocks of Precambrian granite and metamorphic rocks forming north-south trending mountains. The intermontaine Hualapai and Sacramento Valleys have been filled with Tertiary and Quaternary alluvium to depths in excess of 2,000 feet. Valcanics up to several hundred feet thick are present in the mountains and are interbedded with the alluvium in the valleys. Several hundred feet of saline deposits have been found in the Hualapai Valley. Ground water occurs in minor amounts in the volcanics and Precambrian rocks and at shallow depths in the alluvium on the pediments around the mountains, but most of the ground water lies in the alluvium in the valleys at depths of 200 to over 1,200 feet in the Sacramento Valley and from 250 to 600 feet in the Hualapai Valley. Of the 200 wells in the area, most are small stock and domestic wells in the

mountains and on the pediments. Few of these wells produce over 10 gpm, although some produce up to 100 gpm. Approximately 15 deep wells produce water from the valley alluvium. Yields from these wells vary from 200 to over 1,000 gpm. Little is known of the quality of the water except that it is quite hard, especially in the Sacramento Valley. Salt water has been found in one or two deep wells in the Hualapai Valley. Additional geologic, seismic, drill hole, and pump test data will supply information on the thickness, extent, and transmissibilities of the water-bearing alluvium in the valleys and on the amount of ground water flowing out of the valleys toward the Colorado River. Runoff and infiltration studies will indicate the amount of natural recharge to the aquifers.

A CASE HISTORY OF COPPER AND MOLYBDENUM GEOCHEMICAL PROSPECTING AT THE MINERAL PARK MINE OF DUVAL CORPORATION

J. H. C.

MAY 24 1965

By Donn M. Clippinger

Spectrophotometer

mo not appreciably leached –

ABSTRACT

At the outset of the exploration program at Mineral Park, Mohave County, Arizona a geochemical survey was planned. It was decided that this prospecting method might aid in delineating the areas of highest metal concentrations and reflect the ultimate potential area.

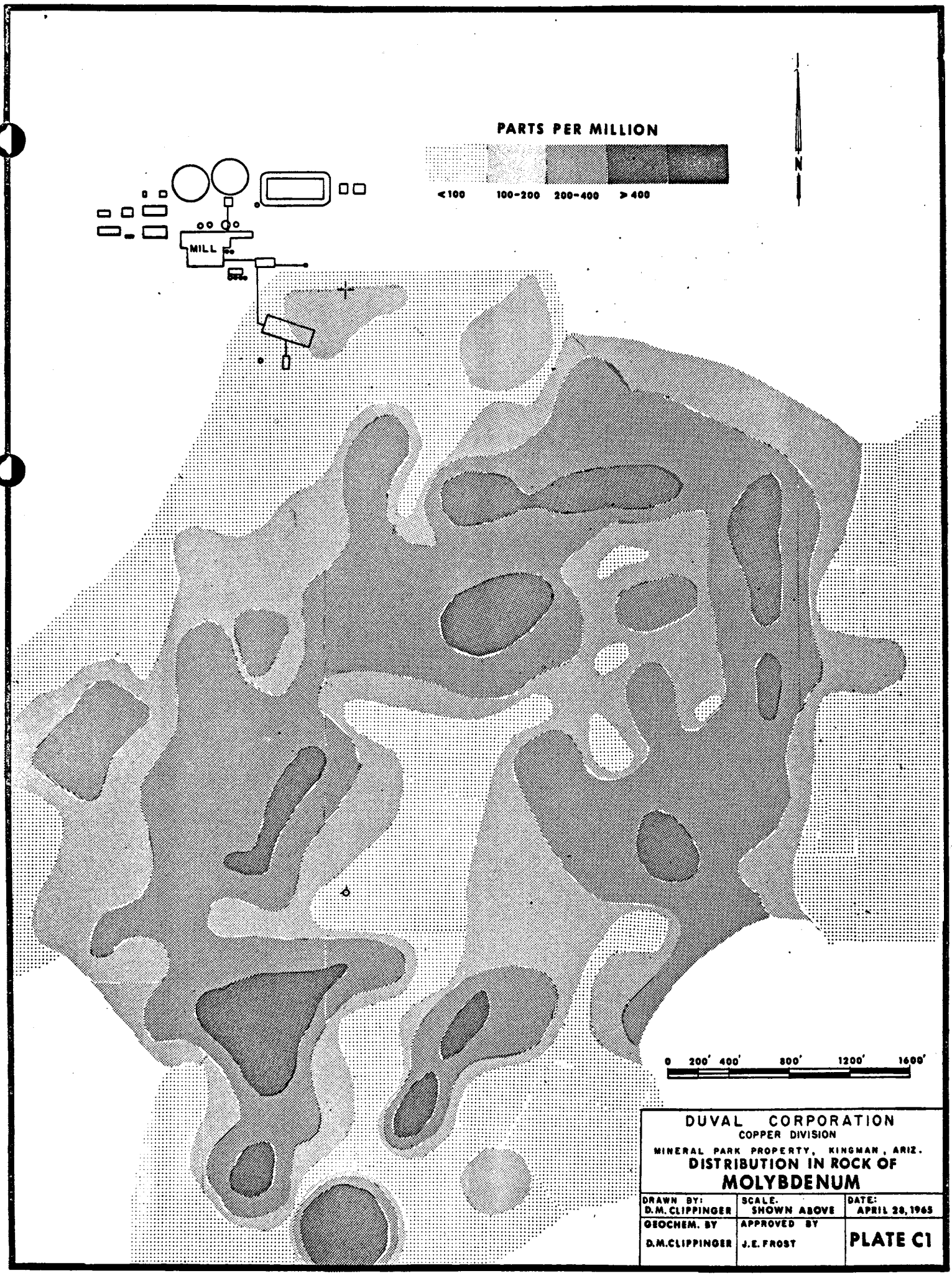
Methods chosen were sampling of rock outcrops, and of shallow soils. Geobotanical sampling, under similar conditions, had been found impractical so was not employed. Copper and Molybdenum, the economic metals concerned, were selected for analyses.

A 400-foot equilateral triangular grid pattern was sampled over an area of approximately one and three-quarter square miles. At each site the samples were taken as follows : (1) About one and one half pounds of soil was taken at depths not exceeding one foot. (2) Approximately twenty-five pounds of rock was obtained, by blasting, from the nearest outcrop within a radius of fifty feet. (3) A few ounces of rock chip specimens were selected for identification and reference. The minus 65-mesh screen fraction of the soil was used for soil analyses. All sample preparation and analytical work was done by laboratory methods. Analyses of both copper and molybdenum were determined colorimetrically by means of an electronic colorimeter.

At Mineral Park the distribution of molybdenum in either rock outcrops or soils serves as an excellent guide to exploration. Molybdenum does not migrate significantly. Rock samples are nearly as high in tenor as the underlying sulfide ores. The orebearing areas are found to be overlain by rock containing >300 p.p.m. and residual soil containing >150 p.p.m. of molybdenum.

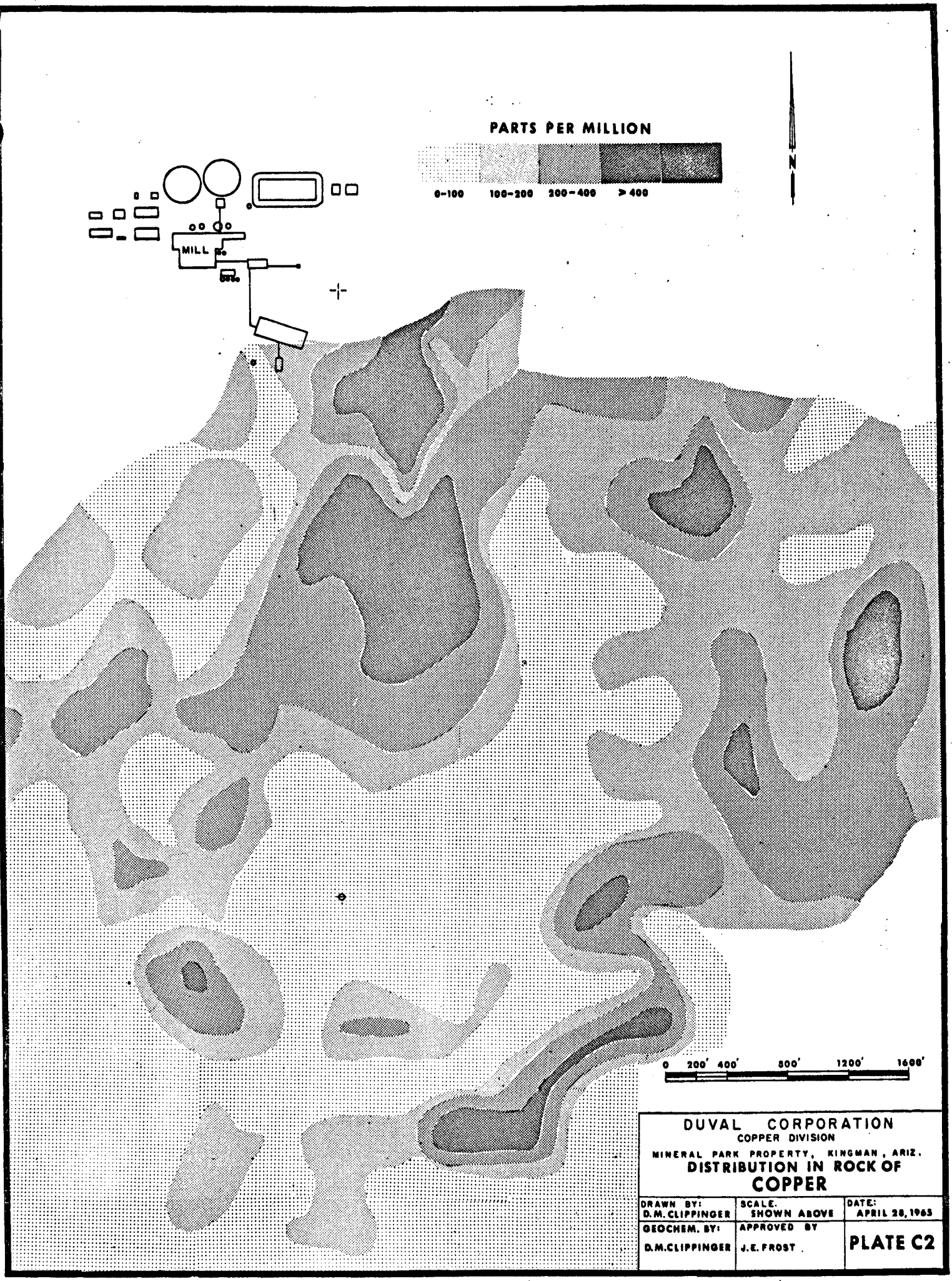
Copper distribution in rock outcrops and in the residual soils is misleading. Factors such as structure of contemporaneous minerals, permeability, pH, soil development, and petrology infulence the migration and localization of copper. More data are required concerning the behavior of copper in the form of oxidation and soil development.

The combined molybdenum and copper rock analyses show a pattern (>400 p.p.m.) that can be used as ore guides in the Mesozoic (?) intrusive rocks.



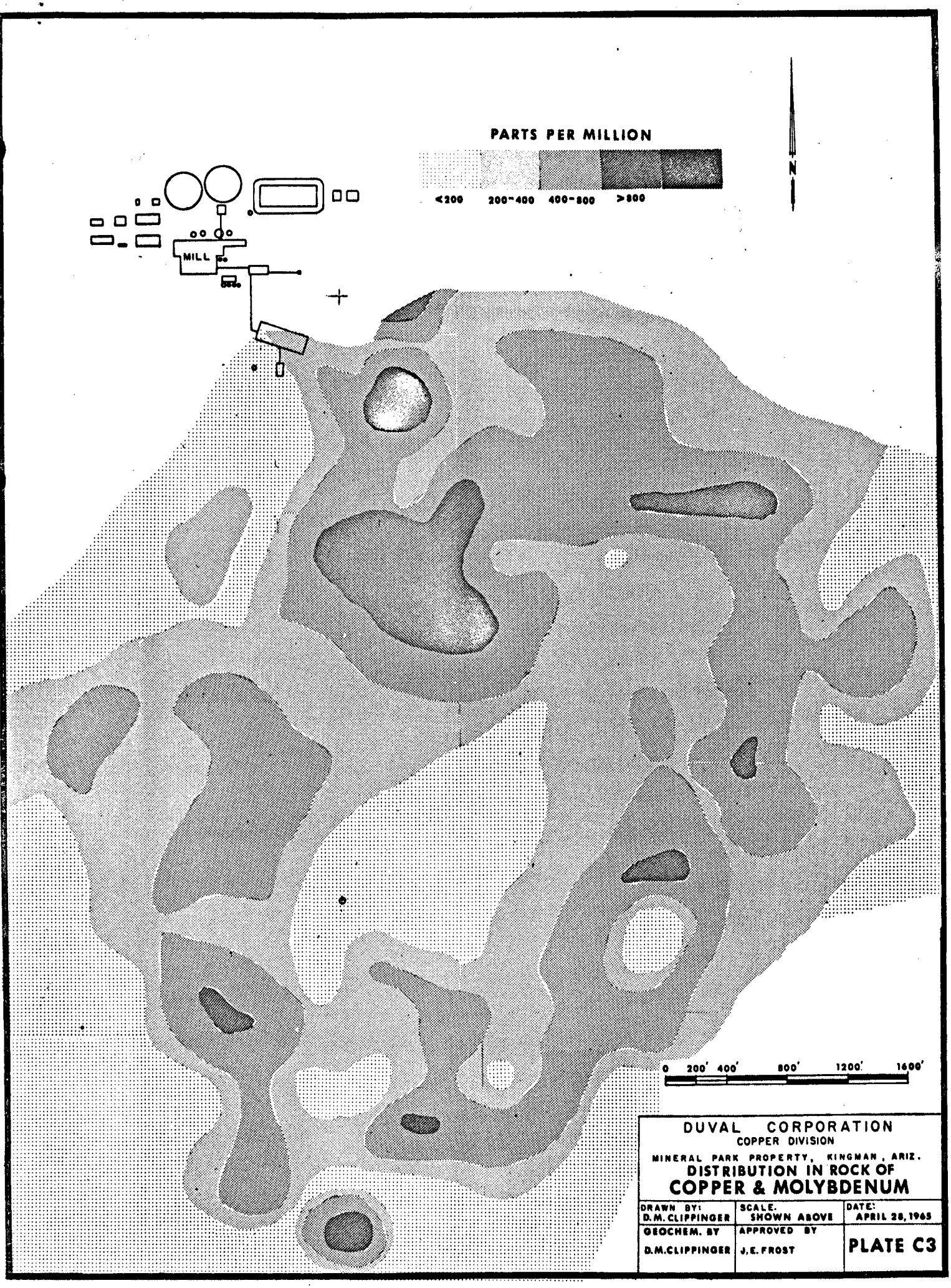
DUVAL CORPORATION
COPPER DIVISION
MINERAL PARK PROPERTY, KINGMAN, ARIZ.
DISTRIBUTION IN ROCK OF
MOLYBDENUM

DRAWN BY: D.M. CLIPPINGER	SCALE: SHOWN ABOVE	DATE: APRIL 28, 1965
GEOCHEM. BY D.M. CLIPPINGER	APPROVED BY J.E. FROST	PLATE C1



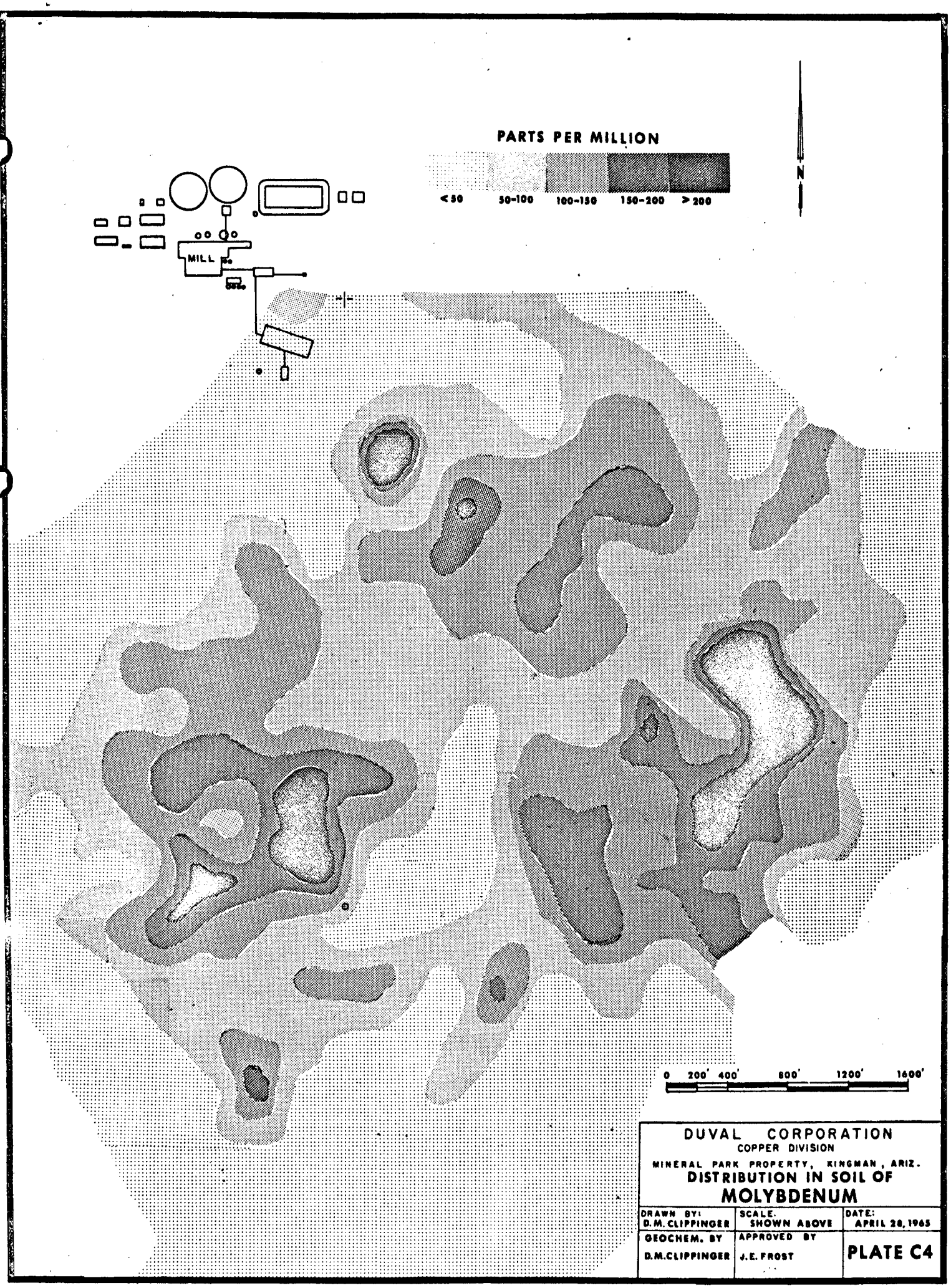
DUVAL CORPORATION
COPPER DIVISION
MINERAL PARK PROPERTY, KINGMAN, ARIZ.
DISTRIBUTION IN ROCK OF
COPPER

DRAWN BY: D.M. CLIPPINGER	SCALE. SHOWN ABOVE	DATE: APRIL 28, 1965
GEOCHEM. BY: D.M.CLIPPINGER	APPROVED BY J.E. FROST	PLATE C2



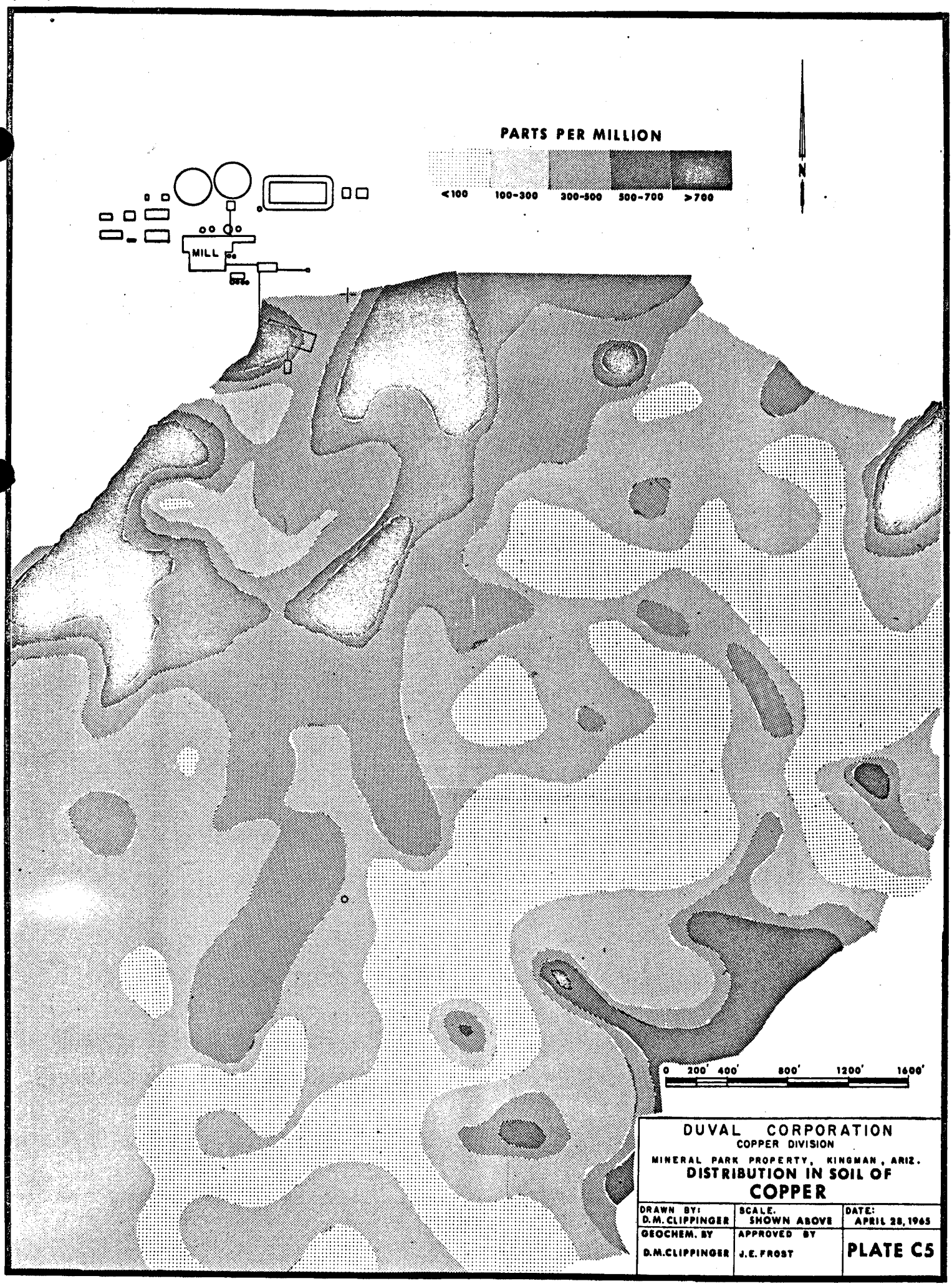
DUVAL CORPORATION
COPPER DIVISION
MINERAL PARK PROPERTY, KINGMAN, ARIZ.
DISTRIBUTION IN ROCK OF
COPPER & MOLYBDENUM

DRAWN BY: D.M. CLIPPINGER	SCALE. SHOWN ABOVE	DATE: APRIL 28, 1965
GEOCHEM. BY D.M.CLIPPINGER	APPROVED BY J.E. FROST	PLATE C3



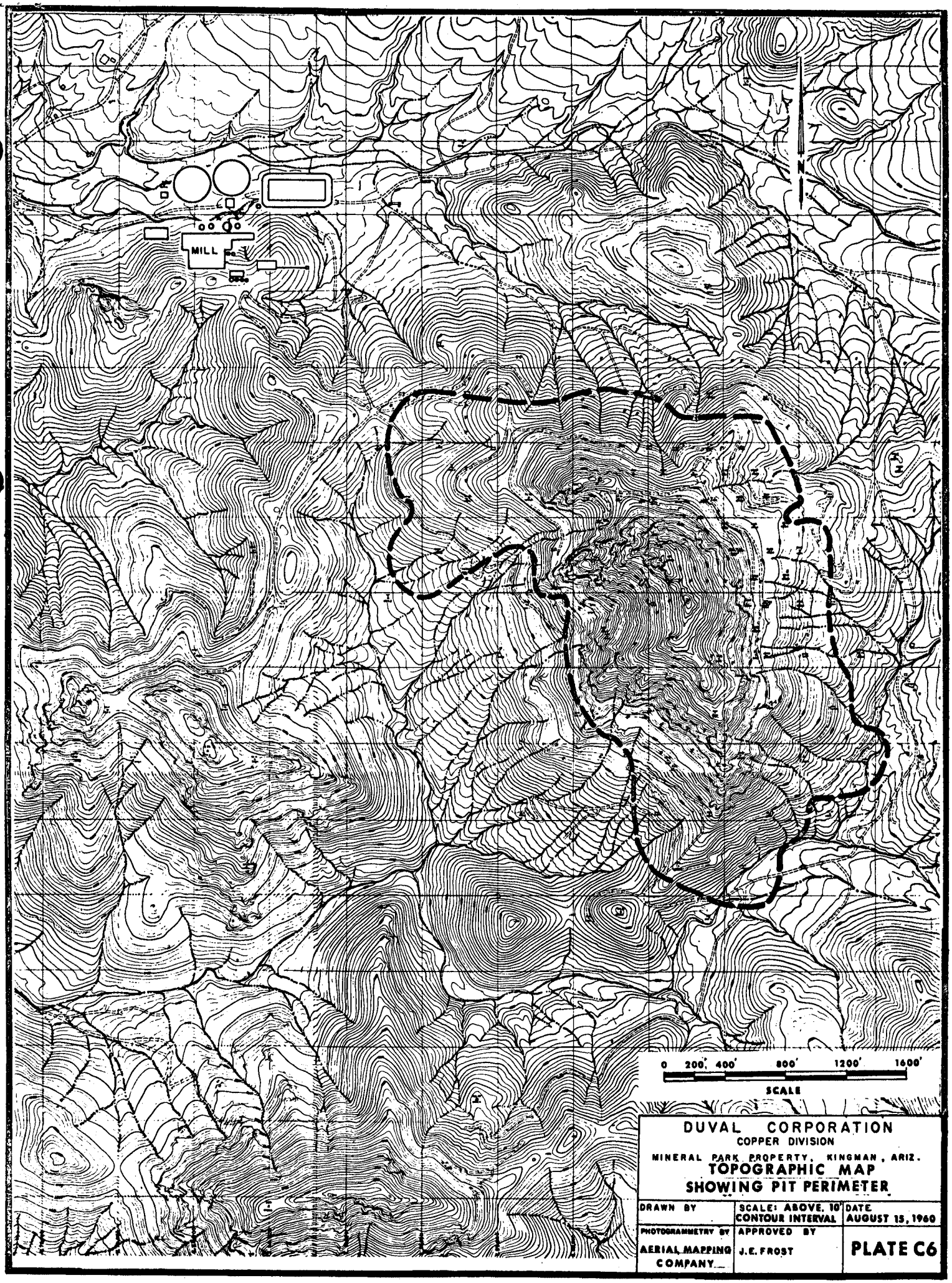
DUVAL CORPORATION
COPPER DIVISION
MINERAL PARK PROPERTY, KINGMAN, ARIZ.
DISTRIBUTION IN SOIL OF MOLYBDENUM

DRAWN BY: D.M. CLIPPINGER	SCALE: SHOWN ABOVE	DATE: APRIL 28, 1965
GEOCHEM. BY D.M.CLIPPINGER	APPROVED BY J.E. FROST	PLATE C4



DUVAL CORPORATION
COPPER DIVISION
MINERAL PARK PROPERTY, KINGMAN, ARIZ.
DISTRIBUTION IN SOIL OF
COPPER

DRAWN BY: D.M. CLIPPINGER	SCALE. SHOWN ABOVE	DATE: APRIL 28, 1965
GEOCHEM. BY D.M.CLIPPINGER	APPROVED BY J.E. FROST	PLATE C5



DUVAL CORPORATION
COPPER DIVISION
MINERAL PARK PROPERTY, KINGMAN, ARIZ.
TOPOGRAPHIC MAP
SHOWING PIT PERIMETER

DRAWN BY	SCALE: ABOVE, 10' CONTOUR INTERVAL	DATE AUGUST 15, 1960
PHOTOGRAMMETRY BY AERIAL MAPPING COMPANY	APPROVED BY J.E. FROST	PLATE C6

THE MINERAL PARK ORE DEPOSITS

by Harrison A. Schmitt

ABSTRACT

Like the Esperanza Mine and of course many others, Ithaca Peak and the Mineral Park area had a long if not very productive mining history. At Mineral Park four different attempts were made to develop porphyry copper ore, two of these were on and around Ithaca Peak.

The regional setting of Mineral Park and the Kingman mining area is of possible interest. I place the area on the extreme west side of the Wasatch-Jerome orogenic belt and just north of the north side of the Texas orogenic belt. Ajo, as I read it, is also on the west side of the meridianal belt but on the south border of the Texas belt.

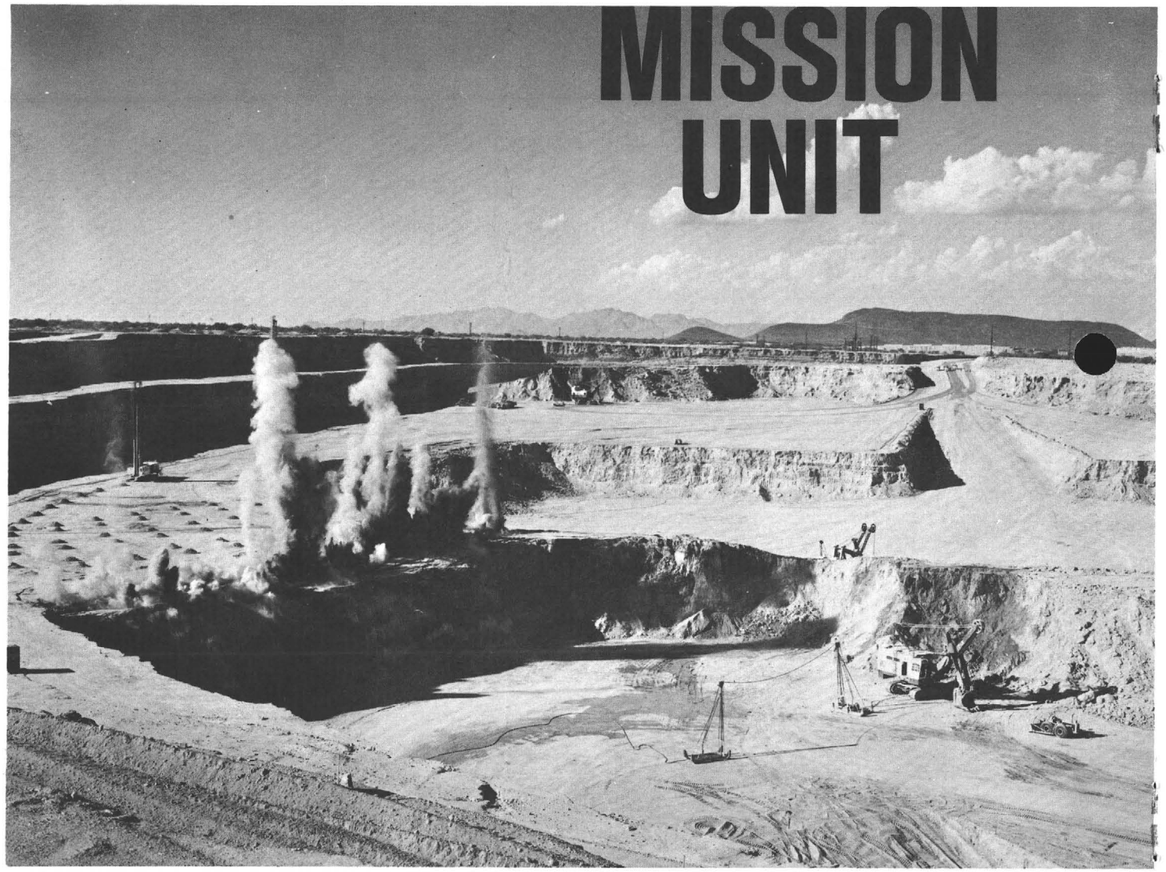
The extensive sampling work done tends to support the "rule" that the bigger the sample the more nearly the assay approaches the average assay.

Keith Martin (where now?)
Bert
Bill Roper
~~Bill~~
Don Clippinger

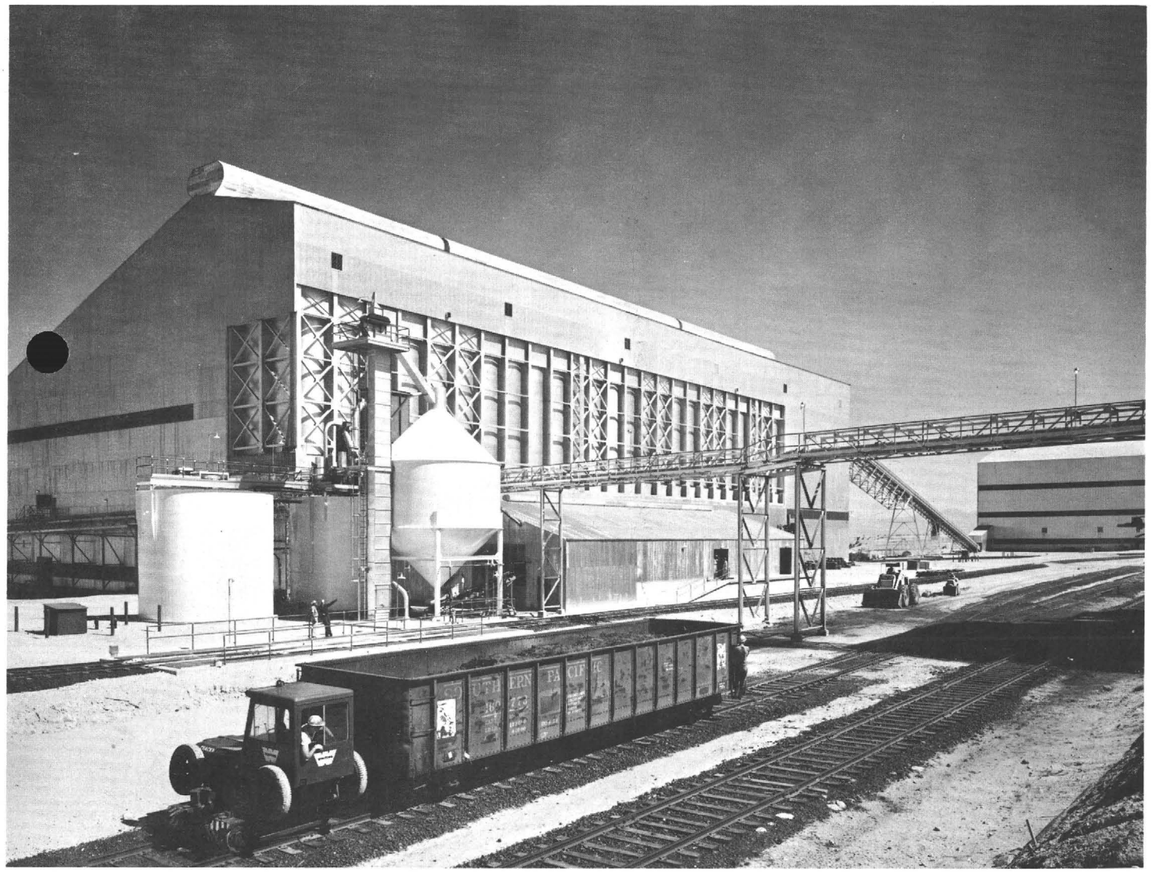
1907
1910 Cal + Ariz
1950 - Anderson several CD holes
1951 - drilled 6 holes - 2 in ore - ~~Fr~~
Thomas wrote thesis - stated por cop ore dep
Dings - stuck
1958 - Duval

— evidence for enrichment of molly - Jordesite (?) soot blaks
fine grained. no sulph - not visible in chalcocite.
— .01 % cu average, under, vs drill holes

CHRONOLOGY OF THE MISSION UNIT



Blasting in the Mission pit.



Mission mill, secondary crusher in background.

December, 1953: First property optioned.

September, 1954: Drilling was begun in part of the area.

September, 1957: Drilling was begun in the remainder of the area. In all, 346 holes were drilled; their total length being about 200,000 feet.

February, 1958: Work was started on a shaft, drifts, crosscuts and raises in the ore zone. Approximately 2300 feet of underground work was done to check interpretation of diamond drilling and obtain bulk samples for pilot mill tests. Pilot plant testing of samples was carried out at the University of Arizona to obtain metallurgical data for mill design. Plans were begun for the service area.

July, 1959: Appropriation approved providing funds for developing and equipping the property for operation.

August, 1959: The first brush was cleared in preparation for moving earth. During this month, three scrapers and two crawler tractors moved more than 37,000 tons of alluvial material, much of it to the site on which service buildings were to be erected. Western-Knapp Engineering Company was appointed to make detailed design of mill and crushing facilities under the general direction and supervision of Asarco personnel.

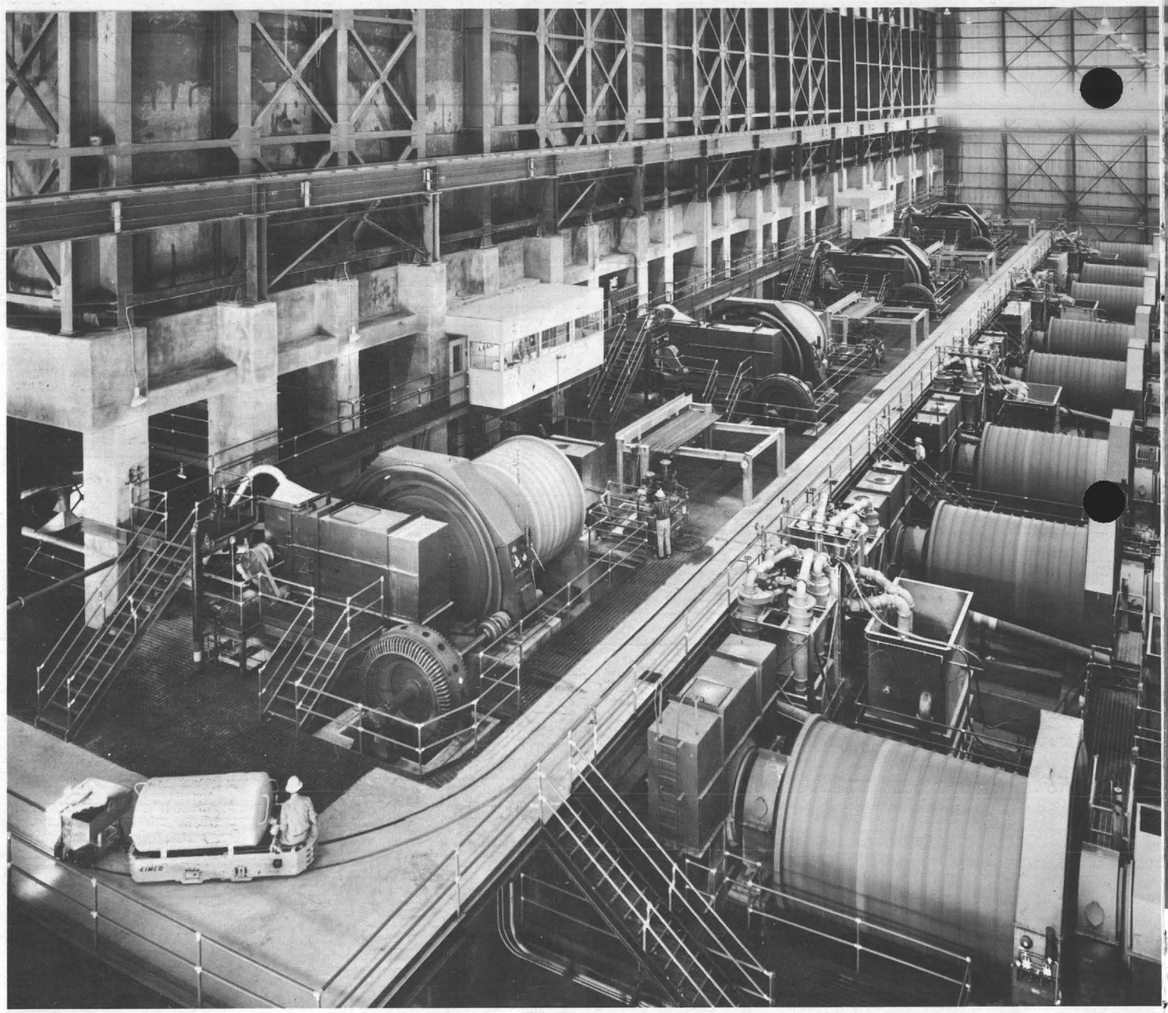
September, 1959: On the first of the month M. M. Sundt Construction Company of Tucson was awarded the contract for construction of the Mission Unit office building. Ground was broken September 28.

October, 1959: The first major mining equipment — a nine-yard electric shovel — reached Sahuarita. Parts of the shovel were too heavy for the Santa Cruz River bridges. Fording facilities and a special route were prepared for transport to the mine site.

December, 1959: The shovel was assembled and put in operation on December 3. Two days later the office building was completed and occupied.

January, 1960: The first of the Mission Unit's 29-truck fleet of 55-ton trucks arrived. Buildings for the truck lubrication center, tire shop, warehouse, maintenance shop and salvage building were under construction. Western-Knapp Engineering Company was awarded the contract — separate from the earlier engineering contract — for construction of the crushing and milling facilities. Negotiations for railroad facilities were concluded with the Southern Pacific Co. Asarco's mine-scraper fleet began work on the site for the mill building. January was also the first month during which 1,000,000 tons of material were removed from the mine area.

March and April, 1960: Construction of the mill and



The grinding bay of the mill.

related facilities began March 1. Water wells completed and put into service. Railroad spur completed and placed in service. This period also saw completion of the general office, change house, shop building, lubrication building, tire shop, warehouse and salvage building. The pit power system, fresh water and fire systems and sewage facilities were completed and the first concrete poured for the secondary crusher facility.

The one-month and two-month periods which have served to mark the progress of events at the Mission Unit in its early stages of development now encompass so many events that their enumeration would be tedious. With many areas and projects under construction simultaneously, a maximum work force was steadily employed. Peaks and valleys in the employment curve were minimized. Many projects progressed at once.

Spring and Summer 1960: The excavation for the primary crusher — 120 feet below grade at its deepest — was completed, and the first concrete poured. Pouring was also in progress for the coarse ore storage, secondary and fine crushing building and the mill building. The mine waste dump area was established. Roads were rearranged and an overpass built to eliminate traffic hazards. During August, 3,000,000 tons of material were stripped from the

Air view of Mission Unit, looking west.

is done in two stages with two 7-foot Symons standard cone crushers and two 7-foot shorthead Symons crushers. The final stage is in open circuit, but the plant is designed so that this can be closed merely by adding two screens.

The grinding circuit consists of four rod mills followed by eight ball mills. Because the ore varies greatly in hardness it was impossible to design grinding circuits to meet extremes at the rated tonnage so the over-all design was based on average hardness.

The rougher flotation time of ten minutes gives a good metallurgical recovery of the copper values of the ore, which are mostly in the form of chalcopyrite. Water is returned from the tailing pond and from two 275-foot tailing thickeners to keep the use of fresh water to a minimum.

WATER SUPPLY

Water is supplied from wells located near the Santa Cruz River about three miles east of the mill. The estimated consumption after return water from the tailings area is available, is 2,500 gallons per minute. Maximum requirements prior to that time are approximately 3,500 gallons per minute. Three wells 20 inches in diameter were drilled and each equipped with a 1600 gpm submersible pump.

POWER SUPPLY

Electric power for the operation is supplied by the Tucson Gas, Electric Light and Power Company over a 138,000 volt transmission line constructed from their Tucson facilities, stepped down to 4,160 volts at the mill substation.

TRANSPORTATION

A six mile branch of the Southern Pacific Railroad was constructed to the property from its Tucson-Nogales line to handle shipment of concentrates and incoming freight.

THE MISSION UNIT

GEOLOGY

The Mission Unit of American Smelting and Refining Company lies in Pima County, Arizona, about fifteen miles southwest of Tucson. The area to be mined by open pit methods will cover about 250 acres, the maximum pit dimensions being approximately 2500 x 5000 feet.

The deposit lies within an extensive zone of porphyry copper type alternation-mineralization in sedimentary rocks which have been folded, faulted and intruded by monzonite porphyry. Disseminated pyrite and chalcopyrite pervade all rocks within the zone, but ore-grade copper mineralization occurs principally along certain of the sedimentary horizons, forming gentle to moderately steep-dipping tabular bodies ranging from a few feet to over 200 feet in thickness.

In the mineralized area, bedrock is overlain by approximately 200 feet of gravel wash. All but the lower 20 to 30 feet of this gravel is loosely consolidated and amenable to low-cost mining methods. In contrast, the lower portion is tightly cemented forming a hard tough layer immediately over the mineralized bedrock.

From the standpoint of structure as well as mineralization, the ore body may be divided into three parts: east, central and west. On the east, where the grade is somewhat higher than the average, the ore-bearing beds are bounded in part by a series of northerly striking faults on which considerable movement has taken place, resulting in a horst-graben or vertically displaced structure. These faults are pre-mineral in age and have served to some extent to localize stronger copper mineralization. They also represent sharp ore-waste contacts, as, for example, the east fault which forms the near-vertical ore limit on the east. In the north central part of the deposit, barren limestone lies at relatively shallow depths and ore grade mineralization is confined for the most part to a thin, irregular layer just above the limestone. On the west, the structure is less complex and ore mineralization is much more continuous along the bedding, but the grade is generally lower than the average for the deposit.

Although there is little variation in the ore minerals (essentially chalcopyrite with minor bornite in the primary zone, and chalcocite with some oxide copper in a thin, discontinuous secondary zone), the gangue is variable in mineralogical composition, depending on where it is found in the several sedimentary formations. Tactite (composed mainly of garnet) and hornfels (composed of various lime-silicates) comprise two of the three major ore types. The third type, argillite or siltstone is generally lower in copper content than the first two.

MINING

It was necessary to remove about 200 feet of gravel. Several possible methods for removing this gravel overburden were studied. These included shovels and trucks, belt conveyors with drag lines, German-type excavating wheels and scrapers. The first was finally considered best because it offered maximum flexibility for placing waste in disposal areas and promised full life use of all major equipment.

The pit was designed with 50-foot benches in gravel and 40-foot benches in rock with main haulage road grades of 7%. The working slope of the pit averages 23 degrees. The ultimate slope will be 37 degrees or 1.33 to 1 in alluvial material and 45 degrees in rock, plus allowance for haul roads. Pit plans were laid out to keep at least 3000 lineal feet of ore exposed on working benches which makes the daily production rate five tons per foot of ore bench. Pre-mine stripping was planned in excess of 46,000,000 tons.

MILLING

The Company's engineers planned a mill for treatment of 15,000 net tons of ore of average hardness per day, after allowing for down-time. The annual rate of 5,400,000 tons is based on 360 days at normal capacity.

The primary crusher is a 54-inch gyratory with a grizzly for each of two truck dumping points. Further crushing

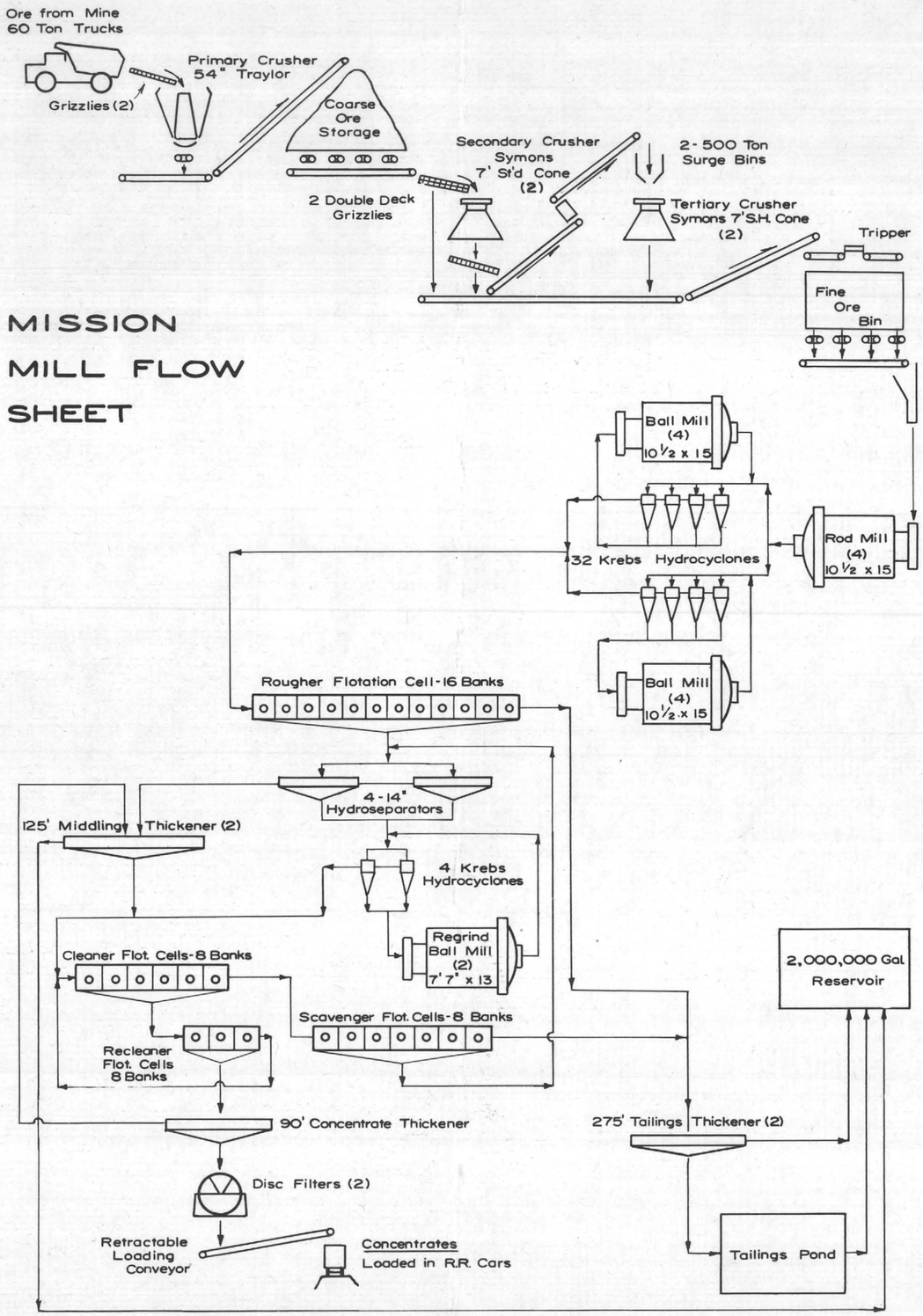
The flotation section of the concentrator.

mine area. Construction in the mill area, including tailing thickeners, continued. During this peak construction period there were more than 800 Asarco and Western-Knapp employees at work.

Fall and Winter 1960-61: Construction was begun on the assay and metallurgical laboratories. During January the first rock was uncovered in the pit, after the removal of 33,000,000 tons of alluvial material. Also in January, the Tucson Gas, Electric Light and Power Company started installation of the 138,000-volt power line to the Mission Unit. During March the Asarco scraper fleet started work on the tailing dam.

Spring and Summer, 1961: On April 17 the first electric power flowed from the Tucson power line. The tailings dam was completed during May. The first rock reached the primary crusher on June 15 . . . then passed through all phases of the fine crushing circuit. Ore was first test-milled in July. Formal operation began on August 1, at which time the estimated 46,000,000 tons of material had been removed from the pit and during August, milling exceeded 50% of rated capacity. Full capacity was reached during September.

From the first clearing of the desert's scrubby brush to the first flow of production required less than two years, bettering the estimated time by more than six months.



MISSION
MILL FLOW
SHEET

MISSION STATISTICAL DATA

GENERAL:

Location — Pima County, Arizona, 15 miles (23 miles by road) — southwest of Tucson.
First property optioned 1953.
Exploration drilling commenced September, 1954.
Construction commenced August, 1959.
Construction completed July, 1961.
Total approximate cost of pre-mine stripping and plant construction, $34,000,000.00.
Maximum number of employees (Company and contractors) during construction, 820.
Approximate number of employees — operating . . . 400.

MINE:

Ultimate pit dimensions approximately 2500 x 5000 ft.
Ultimate depth, approximately 700 feet.
Depth of gravel overburden, approximately 200 ft.

Bench height in gravel	50 ft.
Bench height in rock	40 ft.
Haul road grades	7%
Working slopes of pit	23°
Ultimate slope — in gravel	37° (1.33:1)
Ultimate slope — in rock	45° (1:1)
Pre-mine stripping waste	45,215,000 tons
Pre-mine stripping ore (stockpiled)	1,178,000 tons
Total	46,393,000 tons

PRINCIPAL MINE EQUIPMENT:

5 electric shovels — 9 yard
29 ore trucks — 55 ton
3 rotary drills — two 12¼ inch, one 9 inch
Main blasting agent, ammonium nitrate — estimated monthly consumption, 250 tons.

CRUSHING AND CONCENTRATING PLANTS:

Capacity — 15,000 tons net daily.
5,400,000 tons net per year.

Approximate annual production — concentrates	165,000 tons.
Approximate annual production — copper	45,000 tons.

PRINCIPAL EQUIPMENT:

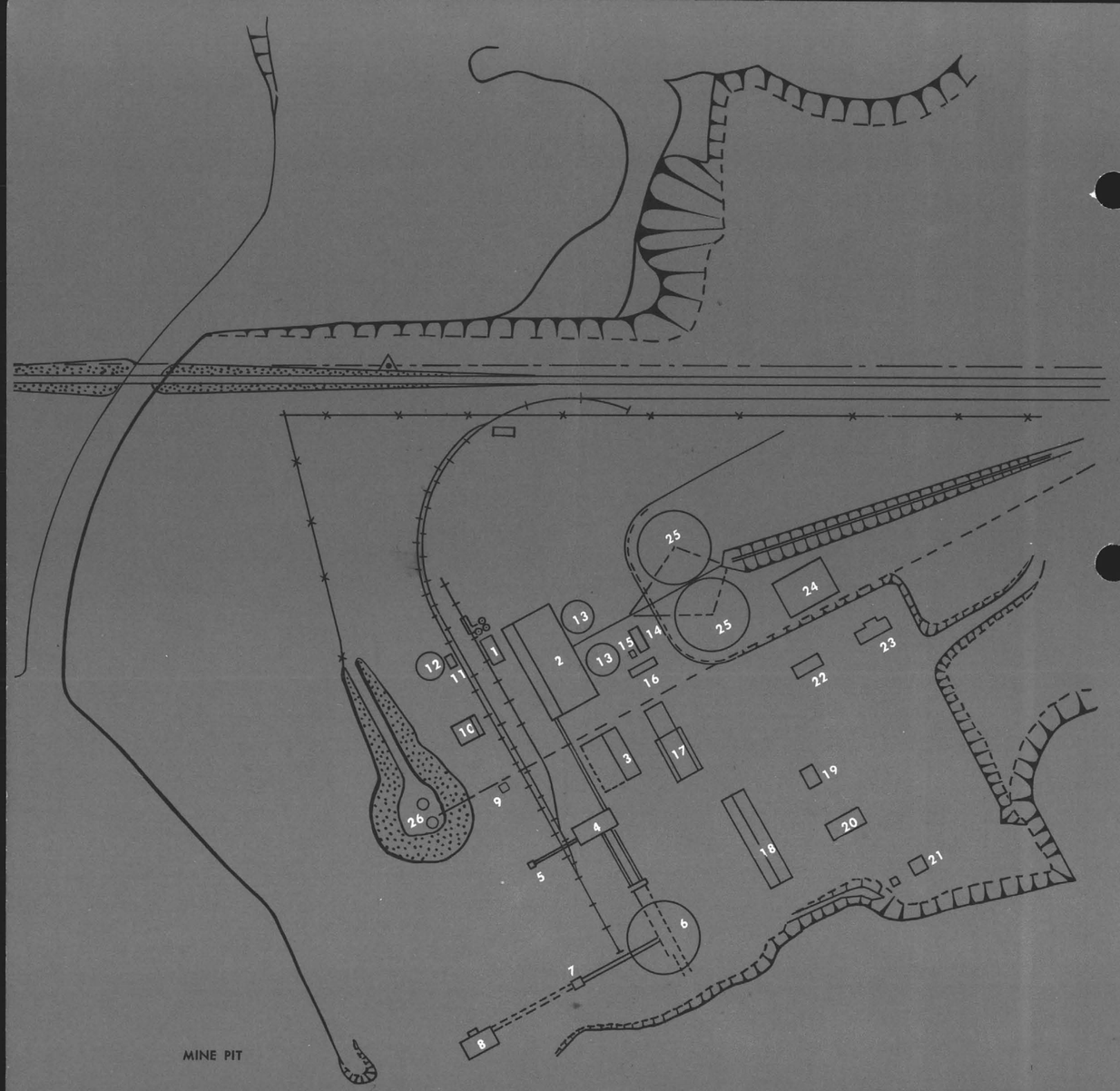
Primary crusher — 54" gyratory.
Intermediate ore storage pile — live capacity, 20,000 tons.
Secondary crushers — two — 7' standard Symons cone.
Tertiary crushers — two — 7' short head Symons cone.
Fine ore bins — live storage capacity, 15,700 tons.
Rod mills — four — 10½' x 15'.
Ball mills — eight — 10½' x 15'.
Flotation cells — 322.
Regrind ball mills — two — 7'7" x 13'.
Disc filters — two — 8' 10" diameter.
Tailings thickeners — two — 275' diameter.
Mill water tank — 600,000 gallons capacity.
Middlings thickeners — two — 125' diameter.
Concentrate thickener — one — 90' diameter.

WATER SUPPLY:

Three wells — 500' deep, capacity each, 1600 gallons per minute.
100,000 gal. gathering tank at wells.
Pipeline — 17,000 ft. 18 in. coated pipe.
Receiving tank at mill — 600,000 gal. capacity.
Estimated fresh water consumption, 2500 gal. per minute.

POWER:

Supplied by Tucson Gas, Electric Light and Power Co., over 138,000 volt transmission line from Tucson.
Stepped down to 4160 volts at mill substation.
Operating voltages — 4160, 480 and 120 volts.
Total estimated electrical load — 27,000, connected horsepower.
Estimated power consumption, 8,500,000 k.w.h./month.



1. REAGENT BUILDINGS
2. CONCENTRATOR
3. WAREHOUSE
4. FINE CRUSHING PLANT
5. TRANSFER HOUSE
6. INTERMEDIATE STOCK PILE
7. CONVEYOR DRIVE HOUSE
8. PRIMARY CRUSHER
9. FIRE LINE PUMP HOUSE
10. SUBSTATION
11. FILTER PLANT
12. CONCENTRATE THICKENER
13. MIDDLING THICKENERS
14. TEST LABORATORY
15. ACID SHED
16. ASSAY OFFICE
17. TRUCK AND MACHINE SHOPS
18. TRUCK PARKING
19. TIRE SHOP
20. LUB AND OIL STORAGE
21. WASH PAD
22. CHANGE HOUSE AND FIRST AID BUILDING
23. OFFICE
24. PUMP HOUSE AND WATER STORAGE
25. TAILINGS THICKENERS
26. WATER TANK

MISSION COPPER PROJECT

Total drilling incl SX.

2 Mil

ore 70 Mil = $.03/ton

Direct $7.03/ft

Indirect 3.59

Total 10.62/ft

@ .9 Cu –

18#/ton

.03/18# Cu = $.0016/# Cu

= .16 ¢/# Cu

ASARCO

AMERICAN SMELTING AND REFINING COMPANY

Litho U.S.A.

As submitted to Asarco publications Committee., 9/25/63.

THE MISSION COPPER DEPOSIT, ARIZONA

John E. Kinnison
Geologist
American Smelting and Refining Company
Southwestern Exploration Department

INTRODUCTION

The Mission mine, located in southern Arizona near Tucson (Figure 1), is a recently developed open pit which produces 15,000 tons per day of copper ore. The mine lies on a wide and gently sloping bajada sweeping northeasterly from the Sierrita mountains. It derives its name from the nearby Mission San Xavier del Bac, built circa 1700.

Before development the ore body was everywhere covered by about 200 feet of alluvium, as were the adjacent Pima and Palo Verde mines. The geology of the Mission deposit is known principally through the study of diamond drill holes spaced 150 to 300 feet apart. The open pit is in an infant stage and has not yet revealed much of the deposit, although information obtained there by the operating staff, and from a few thousand feet of exploratory underground workings, has added significantly to the general fund of knowledge.

I am indebted to Kenyon Richard and J. H. Courtright for criticism of this paper and for their direction during the several years in which I studied the Mission deposit, and acknowledge help given by Robert L. DuBois of the University of Arizona, consultant in petrography. Permission to publish was granted by the American Smelting and Refining Company.

Previous publications pertaining directly to the geology of the Mission deposit appeared in 1959 (Richard and Courtright) and 1963 (Kinnison). Cooper (1960) has published a short paper on the district in which he brought forth several significant and previously unpublished stratigraphic and structural hypotheses. The mining history of the district, which is an old one with many small underground mines which are now largely inactive, was summarized by Thurmond (et. al., 1954). Current activity was initiated with the geophysical discovery of the Pima mine, by the United Geophysical Company about 1951. The presence of a large zone of porphyry copper type alteration and mineralization was indicated by pervasive alteration and sulfide dissemination (exposed in the hanging wall) in the Pima mine exploration workings, and by strong sericitic alteration and limonite-filled cavities derived from sulphides in a small outcrop to the southeast of the Pima shaft. Exploration by Asarco in search of a covered disseminated copper deposit was begun in 1954.

GENERAL GEOLOGY

In brief summary, the geology of this region is diagrammed by the columnar-structure section shown on Figure 2. Paleozoic sediments totaling an estimated 5000 feet were deposited on pre-Cambrian granite. The formations are dominantly limestones or marls, with the exception of Cambrian and Permian quartzite layers. A thick sequence of clastic sediments -- arkose and siltstones -- of Cretaceous age

disconformably overlies the Paleozoic rocks. Following or during the earliest part of the Laramide revolution, thick sequences of unsorted and very poorly bedded silts and volcanic-pebble conglomerates were deposited on an eroded surface of Paleozoic and Cretaceous strata. A period of major deformation and erosion separates these rocks from an overlying formation composed of andesitic breccia and welded rhyolites. Volcanism was followed by the intrusion of a large plug of biotite-bearing rhyolite packed with foreign inclusions. Large granitoid plutons of "Laramide" age form the core of the nearby Sierrita mountains, and are separable into pre- and post-volcanic units. The youngest pre-ore intrusive is a quartz monzonite porphyry. Mineralization is believed to represent a single epoch following the porphyry intrusion. A thick sequence of middle to upper Tertiary sediments and volcanics were later deposited above a post-ore erosion surface.

Folding and thrust faulting are the dominant pre-ore structures. Major post-ore structural dislocations have produced the final chapter in an already complicated geologic history.

SUMMARY OF THE DEPOSIT

In the close vicinity of the Mission ore deposit, the principal rocks are sediments and small bodies of intrusive igneous porphyries, all of which are pre-ore in age. The bedrock surface is a buried pediment, and only a few small outcrops protrude from the alluvial plain. These small and isolated knobs, which are the tops of bedrock hills, lie within a large area of pervasive alteration and provided one of the principal exploration leads. The very simplified geologic sketch in Figure 3 shows these features.

Hypogene sulphides lie generally within 50 feet below the bedrock surface, and secondary enrichment by chalcocite is limited to a very thin veneer. The reasons for this lack of oxidation and enrichment may be manifold, but in part at least the process of pedimentation probably removed any original enriched blanket which might have existed below the older, middle Tertiary erosion surface; during the final stage of pedimentation a combination of a high water level and a geologically short time duration has inhibited deep oxidation and consequent enrichment.

Alteration --- the formation of new minerals or textures and the destruction of the original rock character --- is pervasive within the Mission ore deposit, and extends a considerable distance beyond the principal area of copper concentration. The limits of the Mission altered zone, although gradational and by no means sharply defined, are shown approximately in Figure 3. The altered zone is roughly 3 x 2 miles in areal dimension, whereas ore or possible ore appears to be limited to an area not much larger than $1\frac{1}{2}$ x 1 miles.

Copper and iron sulphides are disseminated throughout all rocks within the altered zone, and conversely, there are no epigenetic sulphides disseminated outside of the altered zone. This relationship is so singularly conspicuous and without exception, that one is of necessity obliged to regard rock alteration and sulphide impregnation as a process which was integrated in time as well as space. The Mission ore body represents only that portion in which the copper concentration is sufficiently great and which occurs in such position that it may be mined by an open pit operation. The average ore grade is typical of southwestern disseminated copper ore deposits.

Alteration of the feldspathic sediments and igneous rocks produced sericite, clay and metasomatic quartz and orthoclase, whereas the alteration of limestones has formed an assemblage of lime-silicates, such as garnet and diopside. Both types of alterations occur in a mutual environment, and all are veined and impregnated with sulphide minerals. The environment as a whole is so typical of porphyry copper deposits throughout the Cordilleran region that the occurrence of the commercial ore bodies within silicated sediments instead of within the porphyry itself should offer no detraction from the classification of the Mission ore deposit as a "porphyry copper".

ROCKS OF THE ALTERED ZONE

Not all of the sedimentary formations known to occur in the Mission vicinity are found within the altered zone. Those which are recognized (and this is with some uncertainty due to alteration effects) are as follows:

Paleozoic: Silicated limestones, marble, and altered marl, siltstone, and quartzite are the dominant host rocks for copper sulphide ore. These rocks most probably represent the Pennsylvanian and Permian section.

Cretaceous (?): Interbedded arkose and siltstone crop out in two isolated hills south of the Mission pit, and most likely are of Cretaceous age.

Tertiary: Two units which consist of unsorted siltstone and volcanic-pebble conglomerate are present within the Mission ore body. These rocks are hard and uniformly textured, and are referred to as argillite or conglomerate for purposes of mine mapping. The oldest, the Papago formation, consists dominantly of argillite, while the younger Kino formation, which consists dominantly of conglomerate, lies beneath a pre-ore thrust fault. Both are assigned tentatively to the early Tertiary on the basis of district and regional geologic mapping.

The youngest pre-ore igneous rock within the altered zone is a quartz monzonite porphyry of Stringham's (1960, p. 1623) "aphanitic porphyry" class --- a type almost universally present in porphyry copper districts.

The porphyry is seen to form sill-like bodies which have intruded an apparently unconformable contact between the Paleozoic rocks and the overlying Papago formation, and also have intruded in a horizontal fashion above and below this contact. The sills are thickest near the west margin of the porphyry mass, and widely spaced drill hole information suggests that they may merge into a thick dike or plug, which may be inferred to be the principal source, or magma channel.

A large mass of intrusive biotite rhyolite occupies the southern part of the altered zone. Regional mapping suggests this rock to be most closely allied to early Tertiary volcanism.

Narrow dikes of post-ore andesite are present.

A breccia dike crosses the pit in a northerly direction. The dike consists of various rock fragments set in a matrix of finely ground rock particles, the whole of which has been altered. It differs from the surrounding rock in that it contains less chalcopyrite and locally contains much galena, sphalerite, and argentiferous tetrahedrite.

ALTERATION

Pervasive alteration is here grouped broadly in two categories. The first, causing the most obvious changes in the rocks, involves the formation of new silicate minerals -- either lime or potassium types depending on the host. The second is the formation of copper and iron sulphides. A large area of marble in the central portion of the ore zone displays only slight evidence of alteration, such as the coarse grain size of the calcite crystals, representing recrystallization, and traces of sulphide impregnation. The general distribution of alteration in the pit vicinity is diagrammatically shown in Figure 4, which also shows the principal structural features.

Feldspathic Rocks:

Alteration products in the feldspathic rocks are sericite, orthoclase, quartz, biotite, and clay. The rocks so altered are quartz monzonite porphyry, argillite, and quartzite.

The quartz monzonite porphyry contains euhedral to subhedral phenocrysts of plagioclase and resorbed quartz phenocrysts, set in a recrystallized matrix of fine-grained quartz and feldspar. Ragged wisps of biotite are usually present. The rock is flooded by irregular blebs and replacement veinlets of pink orthoclase and quartz. The plagioclase phenocrysts are replaced by sericite in variable degrees, and to a lesser extent by clay minerals. The metasomatically introduced quartz and orthoclase replaces both the matrix and plagioclase phenocrysts. For comparative purposes, alteration of the porphyry may be said to resemble more closely the alteration at Ajo or Bagdad than that at Morenci or Ray --- to name a few typical and well known districts. Pyrite, chalcopyrite and, rarely, molybdenite occur as discrete grains scattered through the rock, and also in veinlets associated with borders of quartz and/or orthoclase. The tenor of copper is typical of chalcopyrite protore in many porphyry copper mines.

Argillite, both that of the Papago formation and the thin beds within the Paleozoic rocks, is almost totally altered to a very fine-grained aggregate of sericite and/or a recrystallized mosaic of quartz and feldspar. Sulphide veinlets bordered by a narrow zone of quartz and feldspar give way at the outer edges, first to sericite and then to fine-grained biotite. Pyrite and chalcopyrite occur both as disseminated grains and in veinlets. The conglomerate of the Kino formation, which consists of pebbles in a matrix of argillite, has been similarly altered, although chalcopyrite is virtually absent, and pyrite is the principal sulphide.

Quartzites in the Paleozoic section were generally derived from quite pure quartz sands. Their alteration is evidenced by nearly complete recrystallization of the quartz grains, together with the formation of sericite from a minor silt fraction. Sulphides are sparsely disseminated, and also occur as widely-spaced veinlets. In certain areas, however, chalcopyrite in disseminated form grades up to 0.6% Cu.

The arkose of Cretaceous (?) age has been altered so that the clastic quartz grains are set in a soft white matrix of sericite and clay, and the fabric is transected by sulphide veinlets bordered by white halos composed of quartz and sericite. Pyrite and chalcopyrite are disseminated, partly as discrete grains and partly in the little veins.

The biotite rhyolite in the southern part of the altered zone is altered to clay, sericite, and minor carbonate. The original biotite is altered to sericite. Feldspar phenocrysts are less altered than the matrix, which was originally glassy, and also less altered than most of the foreign inclusions. Pyrite is disseminated throughout, principally as discrete grains, and chalcopyrite occurs in minor amounts. Assays show that small amounts of lead, zinc and silver are there widespread.

Limy Rocks:

The Paleozoic sediments, which are principally cherty limestone, pure limestone, and marl, have been converted within the Mission altered zone to various lime-silicate minerals. Two general groups are dominant: these are (1) tactite, which consists chiefly of garnet, and (2) hornfels, which consists of diopside and calcite. In the western portion of the ore body a silicate zone separating two quartzites is composed almost entirely of the diopside hornfels type, suggesting the rock was originally a dolomite. Elsewhere both sharp contacts and broad gradational zones between the two types suggest a more complex history, possibly involving migration of Mg. A third variety, which I consider to represent weak alteration, is represented by white coarse-grained marble with merely traces of disseminated sulphide grains. This type possibly has formed from black thick-bedded Permian limestone, as suggested by residuals of black limestone of that type. The contact between marble and tactite/hornfels is commonly sharp; but in places it is marked by the presence of wollastonite.

The tactite type consists megascopically of massive structureless yellow-brown garnet, of yellow or brown euhedral friable masses, or of red-brown garnet. Primary hematite is present in some areas. Spectrographic analysis and refractive index place all the types of garnet so far tested in the andradite group. A few garnets show small amounts of alumina in the spectrograph. Soft white material commonly admixed with the garnet was in early stages of exploration mistaken for a clay alteration of what was, at that time, thought to be grossularite. The alumina content of the tactite appears too low to allow the presence of much clay as an alteration product, and the soft white mineral has been identified, in numerous samples in thin-section, as fine-grained diopside. Sulphides occur as small discrete grains, in thin irregular veinlets, in narrow replacement fissures, and as large pods of massive sulphides which locally assay 5 to 15% Cu.

The hornfels type is commonly composed of a variable hard to soft, white fine-grained aggregate, which in thin-section proves to be equigranular diopside with variable amounts of calcite (up to 20%). A variation is a hard greenish variety which in thin-section is seen to be composed of stubby prismatic crystals of diopside. The refractive indices of the white granular variety are slightly higher than those of pure diopside, and the prismatic crystals range about midway between the indices of hedenbergite and those of diopside. Thus iron metasomatism is obviously a major factor in the formation of both the hornfels and the andradite-tactite described previously.

In the western portion of the ore body a characteristic feature of the hornfels is the presence of small veinlets of blue-green actinolite, 1/16 to 1 inch in width,

most commonly, but not everywhere, having a medially disposed stringer of pyrite and chalcopyrite. The actinolite is commonly altered slightly to chlorite. Sulphides are distributed in the hornfels in the same manner as in tactite.

As a group, the limy rocks - tactite and hornfels - constitute the main source of copper and have a higher average grade than ore in argillite, which is the second principal copper host rock.

Sulphide Impregnation:

Hypogene sulphide mineralization is, from an economic viewpoint, the most important change, or alteration, of the host rocks. Figure 5 shows the distribution of copper grading plus 0.4%, as a diagrammatic illustration of copper-grade variation. When viewing the figure, bear in mind that the white areas (with the exception of marble units) may contain about as much total sulphide as do the shaded (plus 0.4% Cu) areas and only slightly less copper. The lower copper content, in some cases, represents a slight decrease in the total sulphide content, but more generally it reflects an increase in the pyrite, chalcopyrite ratio, or a combination of both.

Total sulphide content obtained by calculations based on chemical analysis of composite samples of drill core is shown in Figure 6. It will be noted that: (1) the total sulphide content is higher in the east part of the pit area; (2) in any one sample location, the total sulphide content is about the same in the argillite of the Papago formation, as in the tactite and hornfels zones below. The volumetric percentage is given (Figure 4) because the difference in specific gravity between tactite and argillite would otherwise introduce an error when comparing the degree of sulphide replacement.

There is a paucity of published analytical information on the total sulphide content of porphyry copper ore bodies as a group. Spencer (1917, p. 110) reports the sulphide content of three samples from the Ely District (a "typical" porphyry copper), based on chemical analysis, which appears to represent sulphides by weight. Some assumptions and calculations of mine yield the rough figures of 2.8, 4.0, and 4.9 per cent sulphides by volume for the three samples, which is comparable to the sulphide content at Mission (Figure 6).

ORE CONTROLS

All rocks within the Mission altered zone are recrystallized and/or metasomatized to various silicate minerals, and all are impregnated with sulphides. The ultimate source, or feeders, is not yet known. Within this altered mass, the Mission ore zone displays a few local ore concentrating structures, but for the bulk of copper and iron sulphides the method of implacement clearly did not depend on open channels of circulating hydrothermal solutions.

Referring again to Figures 5 and 6, the unconformable contact between the Papago formation and the underlying silicated sediments of the Paleozoic section has served as a localizing feature. Sulphides follow this contact in greater quantity and more uniformly grade in excess of 0.4% Cu than is the case at distances above or below the contact. Even the quartzite beds are well mineralized where they abut this surface. Similarly, the bottom sides of quartzite beds act as local controls. A high-angle fault is seen to cause even the unfavorable marble unit to become converted to tactite and hornfels and charged with sulphides.

In the eastern portion of the ore body certain low-angle faults of thrust aspect contain thick (10-40 feet) bands of 1 to 6% Cu above them. The vertical fault on the far east terminates the ore body (but not sulphide dissemination), and along this fault are concentrations of massive sulphides. Certain pods up to several feet in diameter seem to be related to mineralized fissures. And throughout the ore zones thin fissures of northeast strike contain sulphides, but there is no concentration of disseminated sulphides adjacent to these fissures.

That all of these structural features are local sulphide concentrators is undisputed; however, the great bulk of copper and iron sulphides occur at significantly large distances from these structures. From this, I draw the conclusion that the metasomatism which introduced great quantities of iron to form iron-lime-silicates and iron sulphides, along with sulphur, possibly magnesium, copper and other minor metals, involved ionic diffusion as a principal process. Conduits of open circulation are widely spaced and are regarded as features which were important only in their local environment, and not necessarily as principal ore feeders.

The porphyry, rather than being the direct source of mineralizing solutions, is itself most obviously a host rock, for it was altered and impregnated with sulphides after solidification. The porphyry may have a genetic relationship to mineralization to the extent that it may have been intruded from a deeper source of magma, which later furnished the elements which were introduced into the altered zone.

CONCLUSION

Pervasive alteration of the porphyry especially, and also of the altered clastic sediments (arkose and argillite) and of the rhyolite at the southern end of the altered zone, is of a type which few geologists would classify as other than hydrothermal. To go further, the minerals sericite, clay, carbonate, and pyrite-chalcopyrite, are commonly placed in Lindgren's mesothermal category. But at Mission the host for most of the copper mineralization is a complex of andradite garnet and diopside-hedenbergite, along with minor amounts of actinolite and wollastonite. These minerals, which are traditionally placed in a separate category such as "contact metamorphic", "contact metasomatic", or "pyrometasomatic", are generally thought of as forming at high temperatures and under special conditions, and of being related spatially to an igneous intrusive contact, from whence the mineralizing fluids came. A commonly stated assumption is that, since the sulphides in such deposits are seen to replace the silicates, the sulphides may be of some later phase, being formed at lower temperatures compatible with the Lindgren classification. The silicates, it then is held, formed early and at high temperatures.

At Mission, as stated under Summary of the Deposits in this paper, the intimate spatial relationship of silicated limestones with sericitized feldspathic rocks, and their associations with sulphide mineralization, admits of no other conclusion than that all rock alteration, including sulphide impregnation, was more or less contemporaneous. The temperatures existing in all rocks must have been similar. At Mission the sulphides, as might be expected, replace silicates -- both potassic and lime varieties. There is no evidence, such as pre-sulphide, post-silicate brecciation, to suggest that any appreciable time gap existed. As a comparison, the sulphides at Butte, although they clearly replace the altered rock, are the result of a continuous and contemporaneous process, as so excellently proven by Sales and Meyer (1948). The inescapable conclusion at Mission is that either the lime-silicates formed at lower temperatures than would commonly be thought or else the temperature range of sericite-pyrite-chalcopyrite must be considerably higher than generally admitted.

Similar conclusions were reached many years ago by Spencer (1917) in his study at Ely, Nevada, which is a porphyry copper deposit more similar to Mission than most others, in that extensive mineralization in sediments is there present.

In the Ely district an altered zone about 7 miles long and a mile wide contains numerous separate porphyry masses which have intruded a sedimentary series. The following quotes are representative of Spencer's conclusions:

> "The changes in the limestones comprise (1) loss of color and recrystallization to white fine-grained marble; (2) silicification with the formation of jasperoid usually carrying large amounts of pyrite; and (3) the development of silicate minerals, including garnet, tremolite, pyroxene, and scapolite."
>
> "The alterations of the porphyry ... comprise, in different stages, the progressive destruction of hornblende, of plagioclase, and of magnetite, and the formation in their stead of ... sericite and a brown variety (of mica) allied to biotite; the deposition of pyrite and chalcopyrite, and of calcite."
>
> "The distribution of the altered sedimentary rocks is so definitely limited to a zone comprising the medially disposed intrusive masses that no extended argument is required to support the conclusion that the metamorphism is causally related to these igneous rocks. However, ... the relation is not a direct one as regards the bodies of porphyry which appear at the present surface, for it is held that the alterations were effected by hot solutions expelled from deep-seated masses of igneous material, of which the observed intrusive bodies are off-shoots."
>
> "Though the different rocks have yielded to chemical reorganization and to metasomatic replacement, each in a manner depending primarily on its original composition, yet the resulting products are all heavily charged with pyrite, and in the main this mineral is accompanied by minor amounts of chalcopyrite."

Another comparison may be made with the Linchburg mine, New Mexico (Titley, 1961). Here a zoned sequence of lime-silicate minerals of classical "pyrometasomatic" or "contact" type, occurs along the Linchburg fault, well away from a known igneous mass.

Titley states, in part:

> "Neither of the alteration stages can be fixed in time. There is no direct evidence to indicate either continuity of deposition or a time break in the depositional process. Certain arguments, however, suggest that a time break, if one existed, was of such short duration as to be insignificant."
>
> "The alteration, therefore, is considered as a continuing process in which the ore-bearing fluids, although changing

slightly in their chemical properties, were more influenced by the nature of their environment of deposition than by any gross change in composition."

To recapitulate my major conclusions:

1. The Mission mine is a "porphyry copper" deposit.

2. The monzonite porphyry within the latered area has no specific spatial relationship to either ore or alteration, but probably has an indirect genetic relationship to the mineralization process.

3. Rock alteration and sulphide impregnation were more or less contemporaneous. The formation of lime-silicates was part of the hypogene alteration process.

4. Diffusion was an important alteration process. Major channels for open circulation of hydrothermal fluids were widely spaced.

REFERENCES

1. Cooper, John R., 1960, Some Geologic Features of the Pima Mining District, Pima County, Arizona: U. S. Geol. Survey Bull. 1112-C, 103 pp., map.

2. Kinnison, John E., 1963, Probable Origin of Mission Copper Deposit: AIME pre-print No. 631-33.

3. Richard, Kenyon and Courtright, James H., 1959, Some Geologic Features of the Mission Copper Deposit: Southern Arizona Guidebook II combined with 2nd Annual Digest, Arizona Geological Society, pp. 201-204.

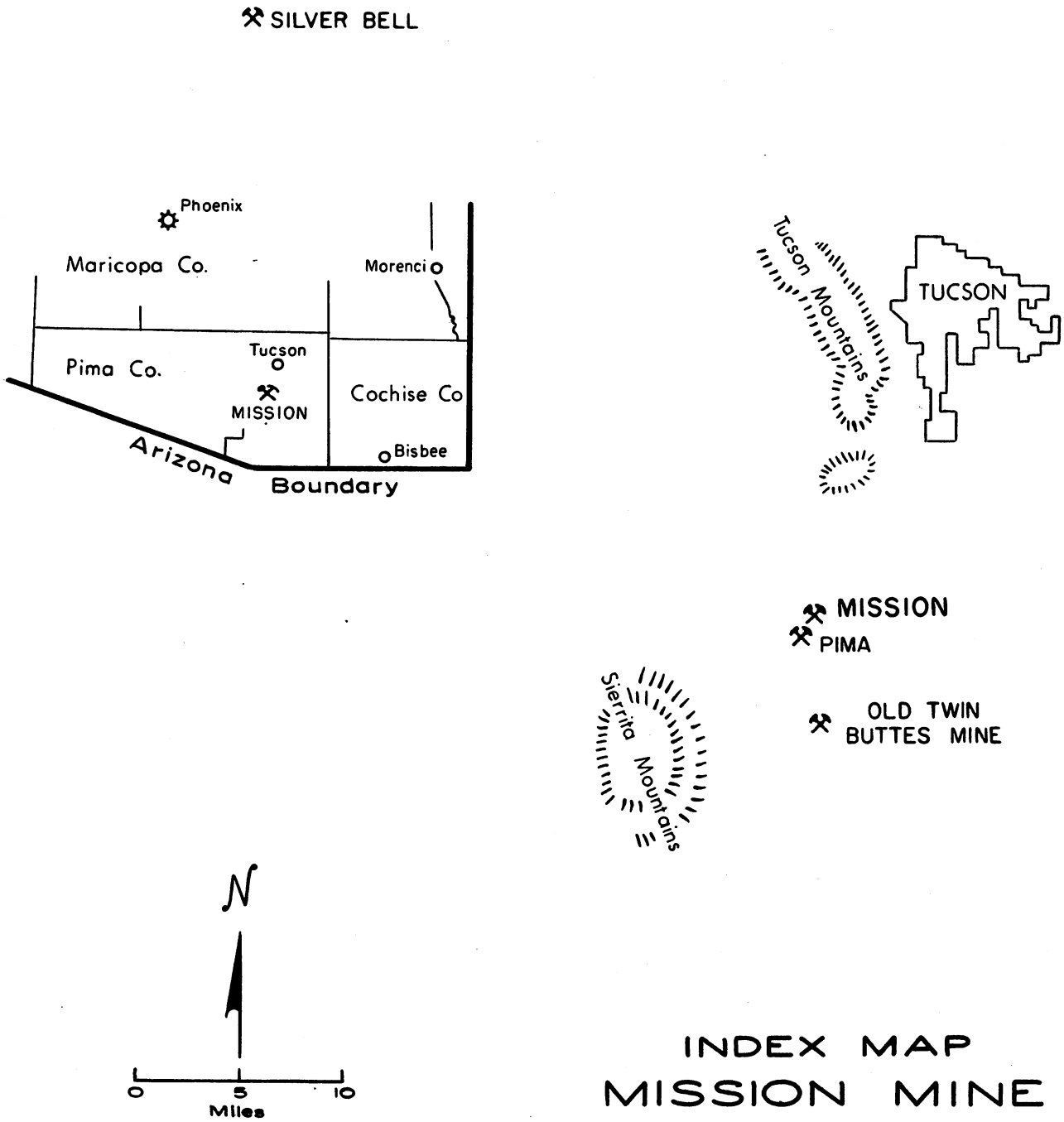
4. Sales, Reno H., and Meyer, Charles, 1948, Wall Rock Alteration at Butte, Montana: AIME Trans., Vol. 178, pp. 9-33.

5. Spencer, Arthur C., 1917, The Geology and Ore Deposits of Ely, Nevada: U. S. Geol. Survey Prof. Paper 96, 189 pp., maps.

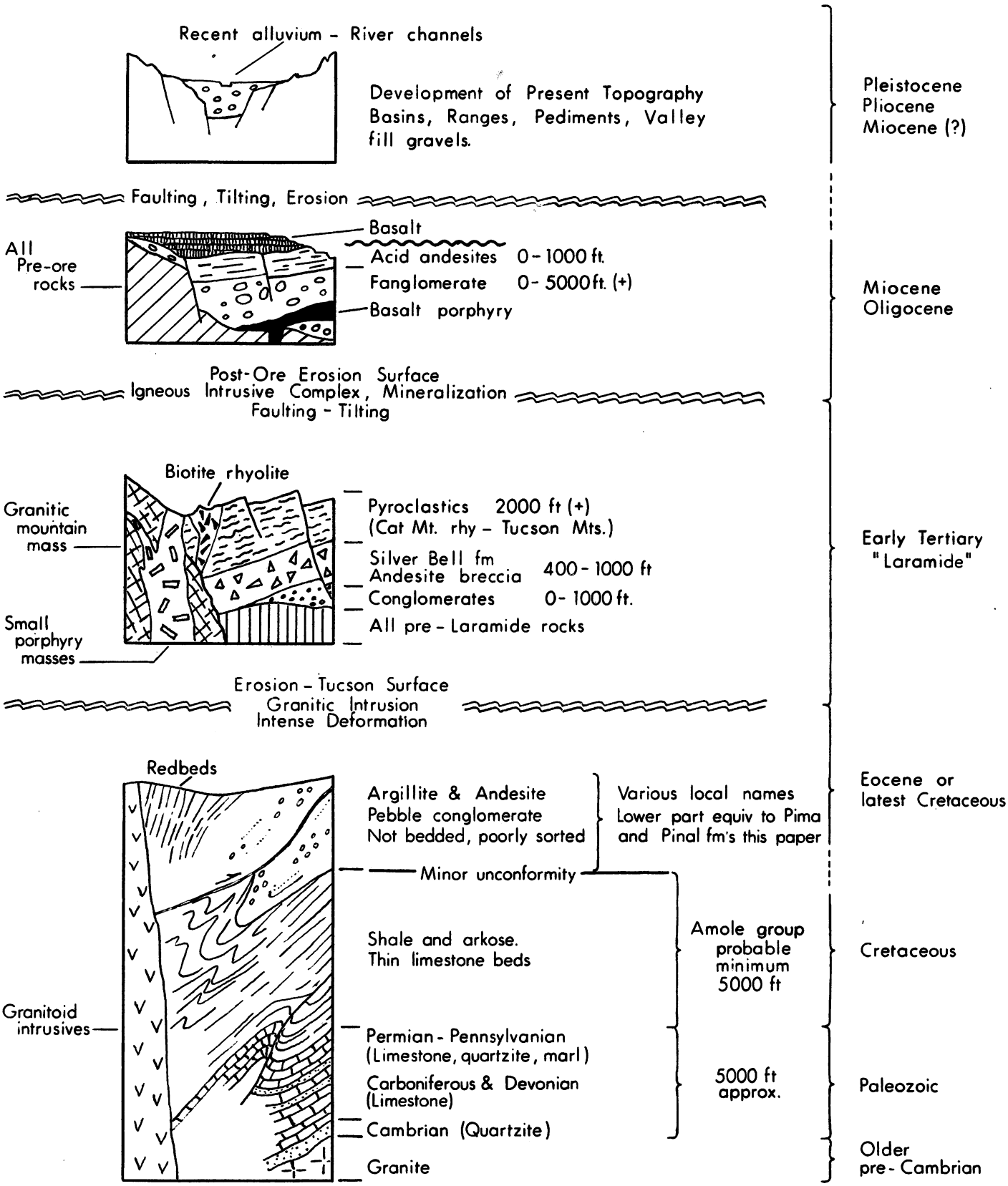
6. Stringham, Bronson, 1960, Differences between Barren and Productive Intrusive Porphyry: Econ. Geol., Bull., Vol. 55, pp. 1622-1630.

7. Thurmond, R. E., Heinrichs, W. E., and Spaulding, E. D., 1954, Geophysical Discovery and Development of the Pima Mine, Pima County, Arizona: AIME Trans., Vol. 199, pp. 197-202.

8. Titley, Spencer R., 1961, Genesis and Control of the Linchburg Orebody, Socorro County, New Mexico: Econ. Geol., Bull., Vol. 56, pp. 695-722.



INDEX MAP
MISSION MINE
Figure 1

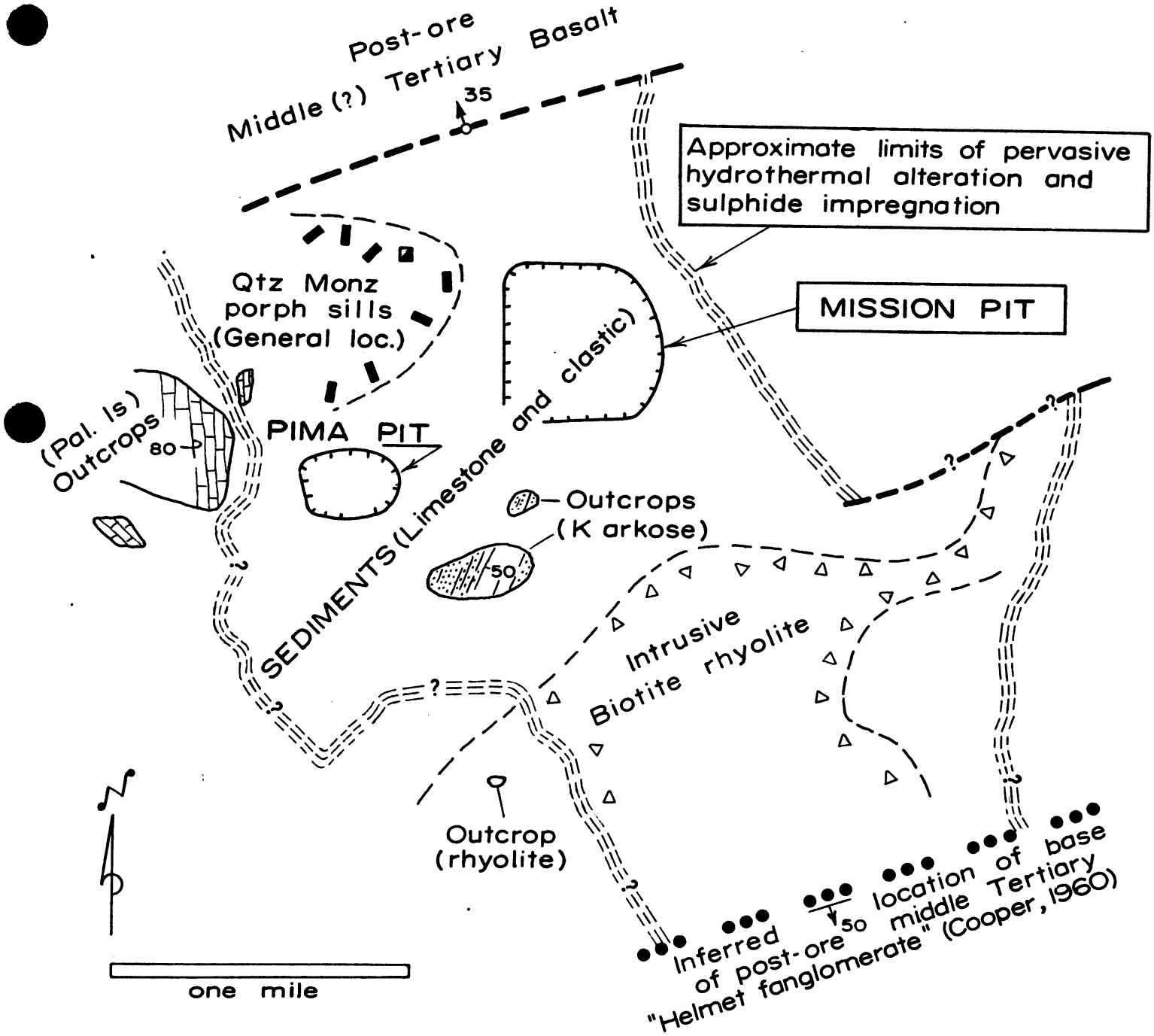


DIAGRAMMATIC COLUMNAR SECTION
GENERALIZED GEOLOGIC HISTORY OF SIERRITA-TUCSON MOUNTAIN REGION

Synthesized from published work
and personal field mapping

J. E. Kinnison

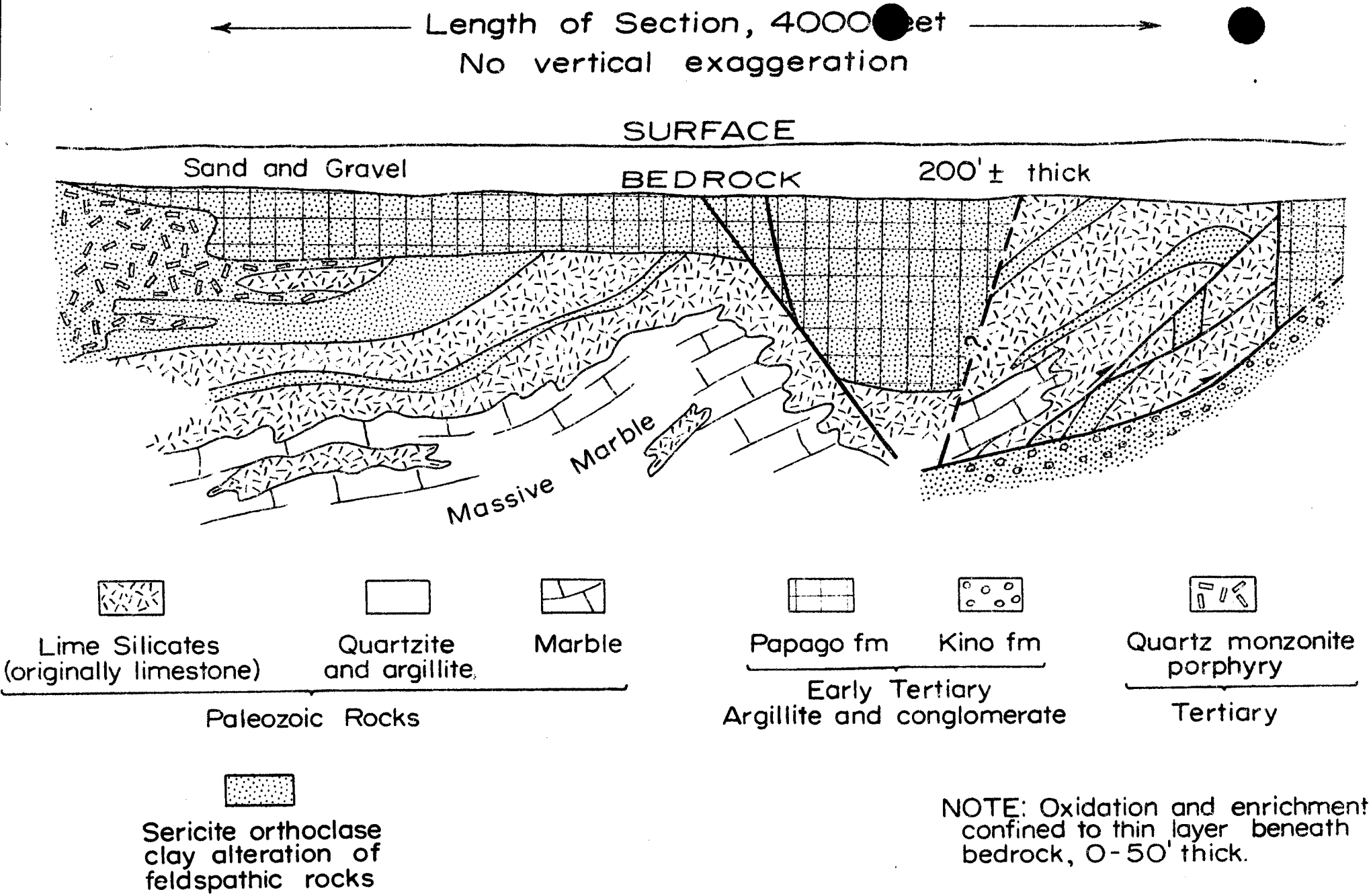
Figure 2



GENERALIZED MAP SHOWING DISTRIBUTION OF SEDIMENTS, IGNEOUS ROCKS AND ALTERATION BENEATH THE ALLUVIAL PLAIN AS KNOWN THROUGH DRILL DATA

Figure 3

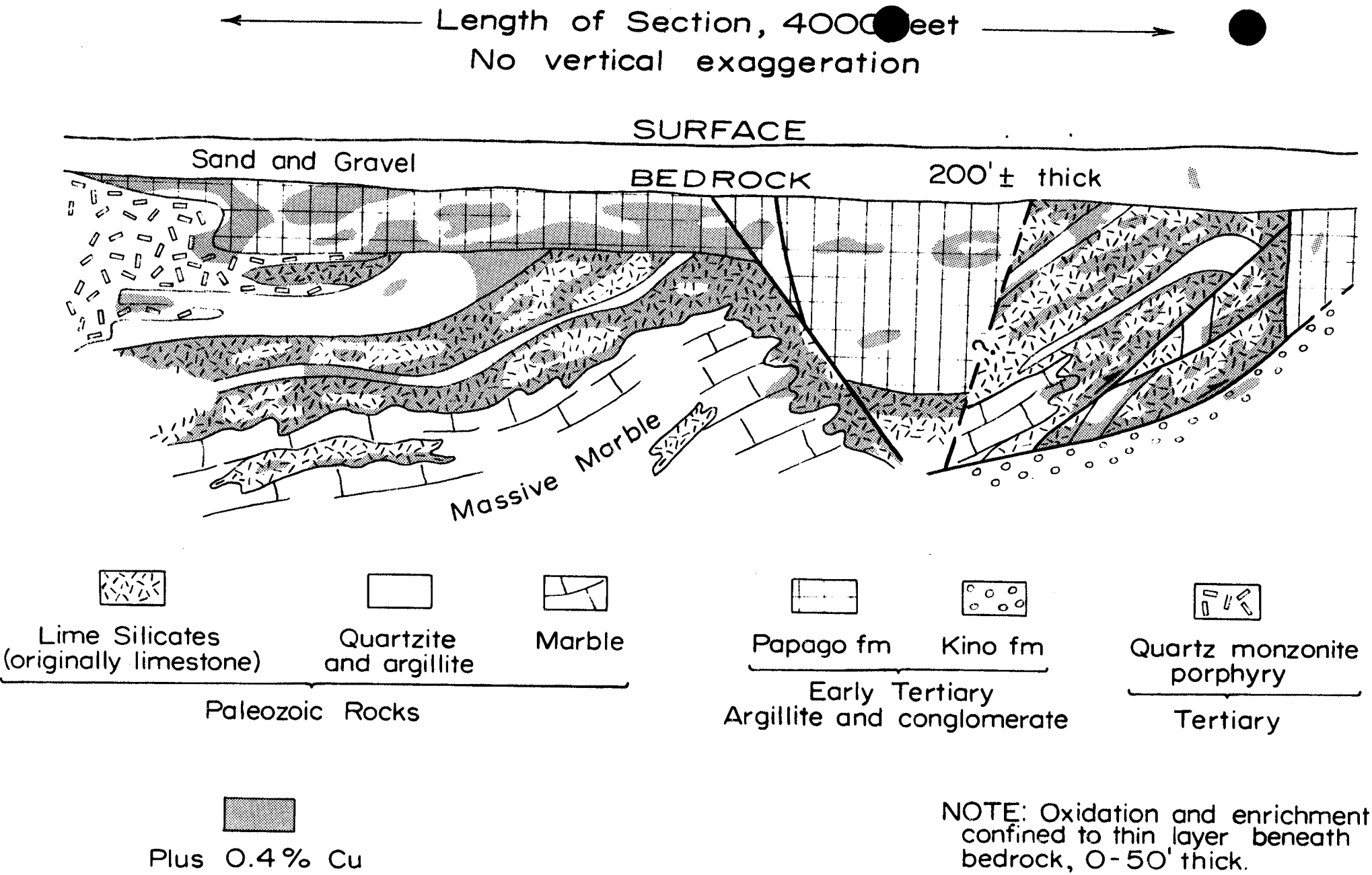
J.E. Kinnison



DIAGRAMMATIC CROSS SECTION THROUGH MISSION ORE BODY
LOOKING NORTH

Figure 4

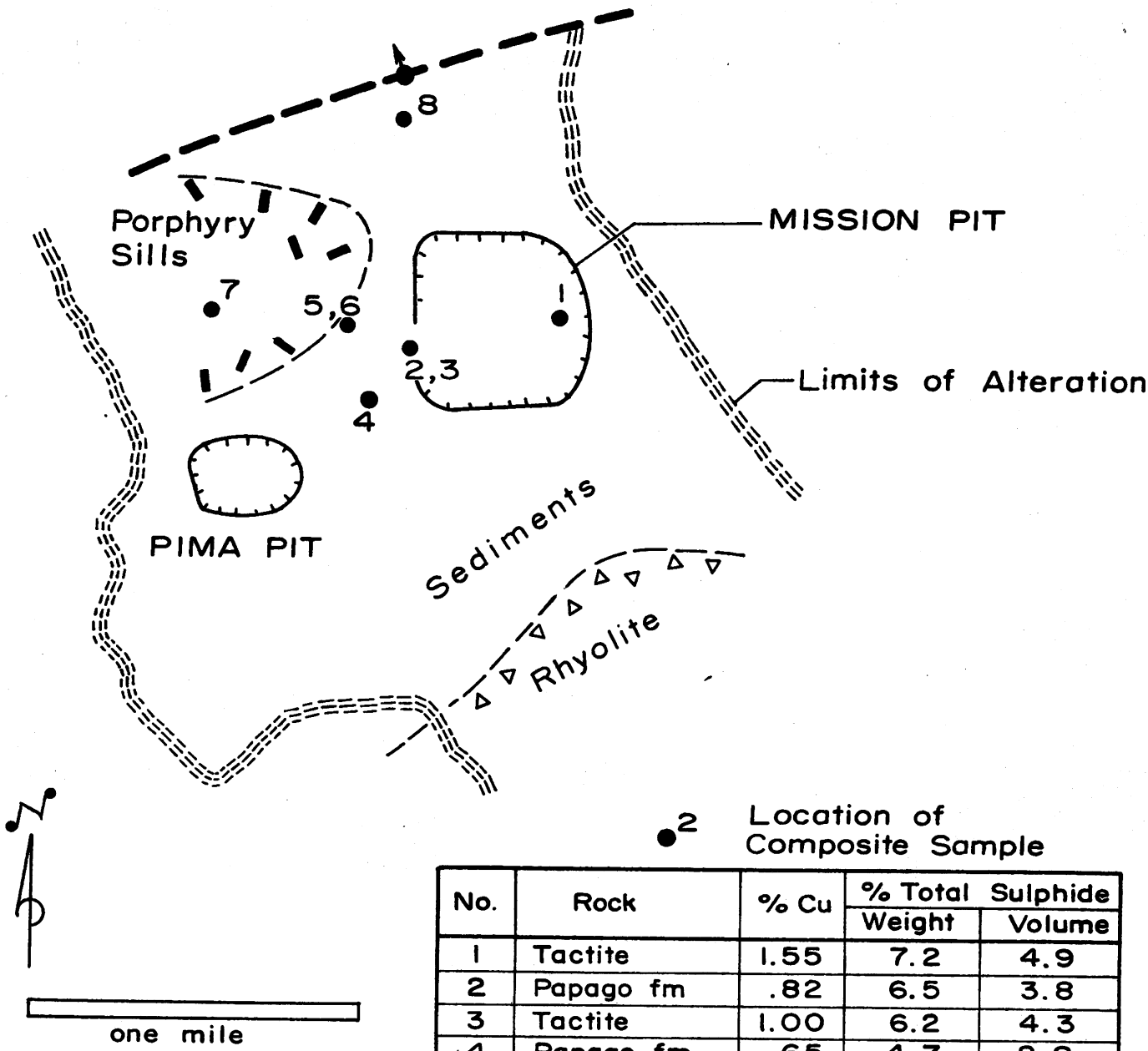
J.E. Kinnison



DIAGRAMMATIC CROSS SECTION THROUGH MISSION ORE BODY
LOOKING NORTH

Figure 5

J.E. Kinnison



2 Location of Composite Sample

No.	Rock	% Cu	% Total Sulphide	
			Weight	Volume
1	Tactite	1.55	7.2	4.9
2	Papago fm	.82	6.5	3.8
3	Tactite	1.00	6.2	4.3
4	Papago fm	.65	4.7	2.8
5	Papago fm	.94	4.5	2.7
6	Tactite	.87	4.5	3.0
7	Porphyry	.30	2.7	1.5
8	Papago fm	1.20	3.4	1.9

Note: All samples contain pyrite and chalcopyrite as the dominant sulphides, except No. 8 which is enriched by chalcocite.

TOTAL SULPHIDE CONTENT - MISSION MINE

Figure 6

J. E. Kinnison

THE MORENCI DISTRICT

BY R. T. MOOLICK AND J. J. DUREK

As submitted to Asarco publications committee., 9/25/63.

THE MISSION COPPER DEPOSIT, ARIZONA

John E. Kinnison
Geologist
American Smelting and Refining Company
Southwestern Exploration Department

INTRODUCTION

The Mission mine, located in southern Arizona near Tucson (Figure 1), is a recently developed open pit which produces 15,000 tons per day of copper ore. The mine lies on a wide and gently sloping bajada sweeping northeasterly from the Sierrita mountains. It derives its name from the nearby Mission San Xavier del Bac, built circa 1700.

Before development the ore body was everywhere covered by about 200 feet of alluvium, as were the adjacent Pima and Palo Verde mines. The geology of the Mission deposit is known principally through the study of diamond drill holes spaced 150 to 300 feet apart. The open pit is in an infant stage and has not yet revealed much of the deposit, although information obtained there by the operating staff, and from a few thousand feet of exploratory underground workings, has added significantly to the general fund of knowledge.

I am indebted to Kenyon Richard and J. H. Courtright for criticism of this paper and for their direction during the several years in which I studied the Mission deposit, and acknowledge help given by Robert L. DuBois of the University of Arizona, consultant in petrography. Permission to publish was granted by the American Smelting and Refining Company.

Previous publications pertaining directly to the geology of the Mission deposit appeared in 1959 (Richard and Courtright) and 1963 (Kinnison). Cooper (1960) has published a short paper on the district in which he brought forth several significant and previously unpublished stratigraphic and structural hypotheses. The mining history of the district, which is an old one with many small underground mines which are now largely inactive, was summarized by Thurmond (et. al., 1954). Current activity was initiated with the geophysical discovery of the Pima mine, by the United Geophysical Company about 1951. The presence of a large zone of porphyry copper type alteration and mineralization was indicated by pervasive alteration and sulfide dissemination (exposed in the hanging wall) in the Pima mine exploration workings, and by strong sericitic alteration and limonite-filled cavities derived from sulphides in a small outcrop to the southeast of the Pima shaft. Exploration by Asarco in search of a covered disseminated copper deposit was begun in 1954.

GENERAL GEOLOGY

In brief summary, the geology of this region is diagrammed by the columnar-structure section shown on Figure 2. Paleozoic sediments totaling an estimated 5000 feet were deposited on pre-Cambrian granite. The formations are dominantly limestones or marls, with the exception of Cambrian and Permian quartzite layers. A thick sequence of clastic sediments -- arkose and siltstones -- of Cretaceous age

disconformably overlies the Paleozoic rocks. Following or during the earliest part of the Laramide revolution, thick sequences of unsorted and very poorly bedded silts and volcanic-pebble conglomerates were deposited on an eroded surface of Paleozoic and Cretaceous strata. A period of major deformation and erosion separates these rocks from an overlying formation composed of andesitic breccia and welded rhyolites. Volcanism was followed by the intrusion of a large plug of biotite-bearing rhyolite packed with foreign inclusions. Large granitoid plutons of "Laramide" age form the core of the nearby Sierrita mountains, and are separable into pre- and post-volcanic units. The youngest pre-ore intrusive is a quartz monzonite porphyry. Mineralization is believed to represent a single epoch following the porphyry intrusion. A thick sequence of middle to upper Tertiary sediments and volcanics were later deposited above a post-ore erosion surface.

Folding and thrust faulting are the dominant pre-ore structures. Major post-ore structural dislocations have produced the final chapter in an already complicated geologic history.

SUMMARY OF THE DEPOSIT

In the close vicinity of the Mission ore deposit, the principal rocks are sediments and small bodies of intrusive igneous porphyries, all of which are pre-ore in age. The bedrock surface is a buried pediment, and only a few small outcrops protrude from the alluvial plain. These small and isolated knobs, which are the tops of bedrock hills, lie within a large area of pervasive alteration and provided one of the principal exploration leads. The very simplified geologic sketch in Figure 3 shows these features.

Hypogene sulphides lie generally within 50 feet below the bedrock surface, and secondary enrichment by chalcocite is limited to a very thin veneer. The reasons for this lack of oxidation and enrichment may be manifold, but in part at least the process of pedimentation probably removed any original enriched blanket which might have existed below the older, middle Tertiary erosion surface; during the final stage of pedimentation a combination of a high water level and a geologically short time duration has inhibited deep oxidation and consequent enrichment.

Alteration --- the formation of new minerals or textures and the destruction of the original rock character --- is pervasive within the Mission ore deposit, and extends a considerable distance beyond the principal area of copper concentration. The limits of the Mission altered zone, although gradational and by no means sharply defined, are shown approximately in Figure 3. The altered zone is roughly 3 x 2 miles in areal dimension, whereas ore or possible ore appears to be limited to an area not much larger than $1\frac{1}{2}$ x 1 miles.

Copper and iron sulphides are disseminated throughout all rocks within the altered zone, and conversely, there are no epigenetic sulphides disseminated outside of the altered zone. This relationship is so singularly conspicuous and without exception, that one is of necessity obliged to regard rock alteration and sulphide impregnation as a process which was integrated in time as well as space. The Mission ore body represents only that portion in which the copper concentration is sufficiently great and which occurs in such position that it may be mined by an open pit operation. The average ore grade is typical of southwestern disseminated copper ore deposits.

Alteration of the feldspathic sediments and igneous rocks produced sericite, clay and metasomatic quartz and orthoclase, whereas the alteration of limestones has formed an assemblage of lime-silicates, such as garnet and diopside. Both types of alterations occur in a mutual environment, and all are veined and impregnated with sulphide minerals. The environment as a whole is so typical of porphyry copper deposits throughout the Cordilleran region that the occurrence of the commercial ore bodies within silicated sediments instead of within the porphyry itself should offer no detraction from the classification of the Mission ore deposit as a "porphyry copper".

ROCKS OF THE ALTERED ZONE

Not all of the sedimentary formations known to occur in the Mission vicinity are found within the altered zone. Those which are recognized (and this is with some uncertainty due to alteration effects) are as follows:

Paleozoic: Silicated limestones, marble, and altered marl, siltstone, and quartzite are the dominant host rocks for copper sulphide ore. These rocks most probably represent the Pennsylvanian and Permian section.

Cretaceous (?): Interbedded arkose and siltstone crop out in two isolated hills south of the Mission pit, and most likely are of Cretaceous age.

Tertiary: Two units which consist of unsorted siltstone and volcanic-pebble conglomerate are present within the Mission ore body. These rocks are hard and uniformly textured, and are referred to as argillite or conglomerate for purposes of mine mapping. The oldest, the Papago formation, consists dominantly of argillite, while the younger Kino formation, which consists dominantly of conglomerate, lies beneath a pre-ore thrust fault. Both are assigned tentatively to the early Tertiary on the basis of district and regional geologic mapping.

The youngest pre-ore igneous rock within the altered zone is a quartz monzonite porphyry of Stringham's (1960, p. 1623) "aphanitic porphyry" class --- a type almost universally present in porphyry copper districts.

The porphyry is seen to form sill-like bodies which have intruded an apparently unconformable contact between the Paleozoic rocks and the overlying Papago formation, and also have intruded in a horizontal fashion above and below this contact. The sills are thickest near the west margin of the porphyry mass, and widely spaced drill hole information suggests that they may merge into a thick dike or plug, which may be inferred to be the principal source, or magma channel.

A large mass of intrusive biotite rhyolite occupies the southern part of the altered zone. Regional mapping suggests this rock to be most closely allied to early Tertiary volcanism.

Narrow dikes of post-ore andesite are present.

A breccia dike crosses the pit in a northerly direction. The dike consists of various rock fragments set in a matrix of finely ground rock particles, the whole of which has been altered. It differs from the surrounding rock in that it contains less chalcopyrite and locally contains much galena, sphalerite, and argentiferous tetrahedrite.

ALTERATION

Pervasive alteration is here grouped broadly in two categories. The first, causing the most obvious changes in the rocks, involves the formation of new silicate minerals -- either lime or potassium types depending on the host. The second is the formation of copper and iron sulphides. A large area of marble in the central portion of the ore zone displays only slight evidence of alteration, such as the coarse grain size of the calcite crystals, representing recrystallization, and traces of sulphide impregnation. The general distribution of alteration in the pit vicinity is diagrammatically shown in Figure 4, which also shows the principal structural features.

Feldspathic Rocks:

Alteration products in the feldspathic rocks are sericite, orthoclase, quartz, biotite, and clay. The rocks so altered are quartz monzonite porphyry, argillite, and quartzite.

The quartz monzonite porphyry contains euhedral to subhedral phenocrysts of plagioclase and resorbed quartz phenocrysts, set in a recrystallized matrix of fine-grained quartz and feldspar. Ragged wisps of biotite are usually present. The rock is flooded by irregular blebs and replacement veinlets of pink orthoclase and quartz. The plagioclase phenocrysts are replaced by sericite in variable degrees, and to a lesser extent by clay minerals. The metasomatically introduced quartz and orthoclase replaces both the matrix and plagioclase phenocrysts. For comparative purposes, alteration of the porphyry may be said to resemble more closely the alteration at Ajo or Bagdad than that at Morenci or Ray --- to name a few typical and well known districts. Pyrite, chalcopyrite and, rarely, molybdenite occur as discrete grains scattered through the rock, and also in veinlets associated with borders of quartz and/or orthoclase. The tenor of copper is typical of chalcopyrite protore in many porphyry copper mines.

Argillite, both that of the Papago formation and the thin beds within the Paleozoic rocks, is almost totally altered to a very fine-grained aggregate of sericite and/or a recrystallized mosaic of quartz and feldspar. Sulphide veinlets bordered by a narrow zone of quartz and feldspar give way at the outer edges, first to sericite and then to fine-grained biotite. Pyrite and chalcopyrite occur both as disseminated grains and in veinlets. The conglomerate of the Kino formation, which consists of pebbles in a matrix of argillite, has been similarly altered, although chalcopyrite is virtually absent, and pyrite is the principal sulphide.

Quartzites in the Paleozoic section were generally derived from quite pure quartz sands. Their alteration is evidenced by nearly complete recrystallization of the quartz grains, together with the formation of sericite from a minor silt fraction. Sulphides are sparsely disseminated, and also occur as widely-spaced veinlets. In certain areas, however, chalcopyrite in disseminated form grades up to 0.6% Cu.

The arkose of Cretaceous (?) age has been altered so that the clastic quartz grains are set in a soft white matrix of sericite and clay, and the fabric is transected by sulphide veinlets bordered by white halos composed of quartz and sericite. Pyrite and chalcopyrite are disseminated, partly as discrete grains and partly in the little veins.

The biotite rhyolite in the southern part of the altered zone is altered to clay, sericite, and minor carbonate. The original biotite is altered to sericite. Feldspar phenocrysts are less altered than the matrix, which was originally glassy, and also less altered than most of the foreign inclusions. Pyrite is disseminated throughout, principally as discrete grains, and chalcopyrite occurs in minor amounts. Assays show that small amounts of lead, zinc and silver are there widespread.

Limy Rocks:

The Paleozoic sediments, which are principally cherty limestone, pure limestone, and marl, have been converted within the Mission altered zone to various lime-silicate minerals. Two general groups are dominant: these are (1) tactite, which consists chiefly of garnet, and (2) hornfels, which consists of diopside and calcite. In the western portion of the ore body a silicate zone separating two quartzites is composed almost entirely of the diopside hornfels type, suggesting the rock was originally a dolomite. Elsewhere both sharp contacts and broad gradational zones between the two types suggest a more complex history, possibly involving migration of Mg. A third variety, which I consider to represent weak alteration, is represented by white coarse-grained marble with merely traces of disseminated sulphide grains. This type possibly has formed from black thick-bedded Permian limestone, as suggested by residuals of black limestone of that type. The contact between marble and tactite/hornfels is commonly sharp; but in places it is marked by the presence of wollastonite.

The tactite type consists megascopically of massive structureless yellow-brown garnet, of yellow or brown euhedral friable masses, or of red-brown garnet. Primary hematite is present in some areas. Spectrographic analysis and refractive index place all the types of garnet so far tested in the andradite group. A few garnets show small amounts of alumina in the spectrograph. Soft white material commonly admixed with the garnet was in early stages of exploration mistaken for a clay alteration of what was, at that time, thought to be grossularite. The alumina content of the tactite appears too low to allow the presence of much clay as an alteration product, and the soft white mineral has been identified, in numerous samples in thin-section, as fine-grained diopside. Sulphides occur as small discrete grains, in thin irregular veinlets, in narrow replacement fissures, and as large pods of massive sulphides which locally assay 5 to 15% Cu.

The hornfels type is commonly composed of a variable hard to soft, white fine-grained aggregate, which in thin-section proves to be equigranular diopside with variable amounts of calcite (up to 20%). A variation is a hard greenish variety which in thin-section is seen to be composed of stubby prismatic crystals of diopside. The refractive indices of the white granular variety are slightly higher than those of pure diopside, and the prismatic crystals range about midway between the indices of hedenbergite and those of diopside. Thus iron metasomatism is obviously a major factor in the formation of both the hornfels and the andradite-tactite described previously.

In the western portion of the ore body a characteristic feature of the hornfels is the presence of small veinlets of blue-green actinolite, 1/16 to 1 inch in width,

most commonly, but not everywhere, having a medially disposed stringer of pyrite and chalcopyrite. The actinolite is commonly altered slightly to chlorite. Sulphides are distributed in the hornfels in the same manner as in tactite.

As a group, the limy rocks - tactite and hornfels - constitute the main source of copper and have a higher average grade than ore in argillite, which is the second principal copper host rock.

Sulphide Impregnation:

Hypogene sulphide mineralization is, from an economic viewpoint, the most important change, or alteration, of the host rocks. Figure 5 shows the distribution of copper grading plus 0.4%, as a diagrammatic illustration of copper-grade variation. When viewing the figure, bear in mind that the white areas (with the exception of marble units) may contain about as much total sulphide as do the shaded (plus 0.4% Cu) areas and only slightly less copper. The lower copper content, in some cases, represents a slight decrease in the total sulphide content, but more generally it reflects an increase in the pyrite, chalcopyrite ratio, or a combination of both.

Total sulphide content obtained by calculations based on chemical analysis of composite samples of drill core is shown in Figure 6. It will be noted that: (1) the total sulphide content is higher in the east part of the pit area; (2) in any one sample location, the total sulphide content is about the same in the argillite of the Papago formation, as in the tactite and hornfels zones below. The volumetric percentage is given (Figure 4) because the difference in specific gravity between tactite and argillite would otherwise introduce an error when comparing the degree of sulphide replacement.

There is a paucity of published analytical information on the total sulphide content of porphyry copper ore bodies as a group. Spencer (1917, p. 110) reports the sulphide content of three samples from the Ely District (a "typical" porphyry copper), based on chemical analysis, which appears to represent sulphides by weight. Some assumptions and calculations of mine yield the rough figures of 2.8, 4.0, and 4.9 per cent sulphides by volume for the three samples, which is comparable to the sulphide content at Mission (Figure 6).

ORE CONTROLS

All rocks within the Mission altered zone are recrystallized and/or metasomatized to various silicate minerals, and all are impregnated with sulphides. The ultimate source, or feeders, is not yet known. Within this altered mass, the Mission ore zone displays a few local ore concentrating structures, but for the bulk of copper and iron sulphides the method of implacement clearly did not depend on open channels of circulating hydrothermal solutions.

Referring again to Figures 5 and 6, the unconformable contact between the Papago formation and the underlying silicated sediments of the Paleozoic section has served as a localizing feature. Sulphides follow this contact in greater quantity and more uniformly grade in excess of 0.4% Cu than is the case at distances above or below the contact. Even the quartzite beds are well mineralized where they abut this surface. Similarly, the bottom sides of quartzite beds act as local controls. A high-angle fault is seen to cause even the unfavorable marble unit to become converted to tactite and hornfels and charged with sulphides.

In the eastern portion of the ore body certain low-angle faults of thrust aspect contain thick (10-40 feet) bands of 1 to 6% Cu above them. The vertical fault on the far east terminates the ore body (but not sulphide dissemination), and along this fault are concentrations of massive sulphides. Certain pods up to several feet in diameter seem to be related to mineralized fissures. And throughout the ore zones thin fissures of northeast strike contain sulphides, but there is no concentration of disseminated sulphides adjacent to these fissures.

That all of these structural features are local sulphide concentrators is undisputed; however, the great bulk of copper and iron sulphides occur at significantly large distances from these structures. From this, I draw the conclusion that the metasomatism which introduced great quantities of iron to form iron-lime-silicates and iron sulphides, along with sulphur, possibly magnesium, copper and other minor metals, involved ionic diffusion as a principal process. Conduits of open circulation are widely spaced and are regarded as features which were important only in their local environment, and not necessarily as principal ore feeders.

The porphyry, rather than being the direct source of mineralizing solutions, is itself most obviously a host rock, for it was altered and impregnated with sulphides after solidification. The porphyry may have a genetic relationship to mineralization to the extent that it may have been intruded from a deeper source of magma, which later furnished the elements which were introduced into the altered zone.

CONCLUSION

Pervasive alteration of the porphyry especially, and also of the altered clastic sediments (arkose and argillite) and of the rhyolite at the southern end of the altered zone, is of a type which few geologists would classify as other than hydrothermal. To go further, the minerals sericite, clay, carbonate, and pyrite-chalcopyrite, are commonly placed in Lindgren's mesothermal category. But at Mission the host for most of the copper mineralization is a complex of andradite garnet and diopside-hedenbergite, along with minor amounts of actinolite and wollastonite. These minerals, which are traditionally placed in a separate category such as "contact metamorphic", "contact metasomatic", or "pyrometasomatic", are generally thought of as forming at high temperatures and under special conditions, and of being related spatially to an igneous intrusive contact, from whence the mineralizing fluids came. A commonly stated assumption is that, since the sulphides in such deposits are seen to replace the silicates, the sulphides may be of some later phase, being formed at lower temperatures compatible with the Lindgren classification. The silicates, it then is held, formed early and at high temperatures.

At Mission, as stated under Summary of the Deposits in this paper, the intimate spatial relationship of silicated limestones with sericitized feldspathic rocks, and their associations with sulphide mineralization, admits of no other conclusion than that all rock alteration, including sulphide impregnation, was more or less contemporaneous. The temperatures existing in all rocks must have been similar. At Mission the sulphides, as might be expected, replace silicates -- both potassic and lime varieties. There is no evidence, such as pre-sulphide, post-silicate brecciation, to suggest that any appreciable time gap existed. As a comparison, the sulphides at Butte, although they clearly replace the altered rock, are the result of a continuous and contemporaneous process, as so excellently proven by Sales and Meyer (1948). The inescapable conclusion at Mission is that either the lime-silicates formed at lower temperatures than would commonly be thought or else the temperature range of sericite-pyrite-chalcopyrite must be considerably higher than generally admitted.

Similar conclusions were reached many years ago by Spencer (1917) in his study at Ely, Nevada, which is a porphyry copper deposit more similar to Mission than most others, in that extensive mineralization in sediments is there present.

In the Ely district an altered zone about 7 miles long and a mile wide contains numerous separate porphyry masses which have intruded a sedimentary series. The following quotes are representative of Spencer's conclusions:

> "The changes in the limestones comprise (1) loss of color and recrystallization to white fine-grained marble; (2) silicification with the formation of jasperoid usually carrying large amounts of pyrite; and (3) the development of silicate minerals, including garnet, tremolite, pyroxene, and scapolite."
>
> "The alterations of the porphyry ... comprise, in different stages, the progressive destruction of hornblende, of plagioclase, and of magnetite, and the formation in their stead of ... sericite and a brown variety (of mica) allied to biotite; the deposition of pyrite and chalcopyrite, and of calcite."
>
> "The distribution of the altered sedimentary rocks is so definitely limited to a zone comprising the medially disposed intrusive masses that no extended argument is required to support the conclusion that the metamorphism is causally related to these igneous rocks. However, ... the relation is not a direct one as regards the bodies of porphyry which appear at the present surface, for it is held that the alterations were effected by hot solutions expelled from deep-seated masses of igneous material, of which the observed intrusive bodies are off-shoots."
>
> "Though the different rocks have yielded to chemical reorganization and to metasomatic replacement, each in a manner depending primarily on its original composition, yet the resulting products are all heavily charged with pyrite, and in the main this mineral is accompanied by minor amounts of chalcopyrite."

Another comparison may be made with the Linchburg mine, New Mexico (Titley, 1961). Here a zoned sequence of lime-silicate minerals of classical "pyrometasomatic" or "contact" type, occurs along the Linchburg fault, well away from a known igneous mass.

Titley states, in part:

> "Neither of the alteration stages can be fixed in time. There is no direct evidence to indicate either continuity of deposition or a time break in the depositional process. Certain arguments, however, suggest that a time break, if one existed, was of such short duration as to be insignificant."
>
> "The alteration, therefore, is considered as a continuing process in which the ore-bearing fluids, although changing

slightly in their chemical properties, were more influenced by the nature of their environment of deposition than by any gross change in composition."

To recapitulate my major conclusions:

1. The Mission mine is a "porphyry copper" deposit.

2. The monzonite porphyry within the latered area has no specific spatial relationship to either ore or alteration, but probably has an indirect genetic relationship to the mineralization process.

3. Rock alteration and sulphide impregnation were more or less contemporaneous. The formation of lime-silicates was part of the hypogene alteration process.

4. Diffusion was an important alteration process. Major channels for open circulation of hydrothermal fluids were widely spaced.

REFERENCES

1. Cooper, John R., 1960, Some Geologic Features of the Pima Mining District, Pima County, Arizona: U. S. Geol. Survey Bull. 1112-C, 103 pp., map.

2. Kinnison, John E., 1963, Probable Origin of Mission Copper Deposit: AIME pre-print No. 631-33.

3. Richard, Kenyon and Courtright, James H., 1959, Some Geologic Features of the Mission Copper Deposit: Southern Arizona Guidebook II combined with 2nd Annual Digest, Arizona Geological Society, pp. 201-204.

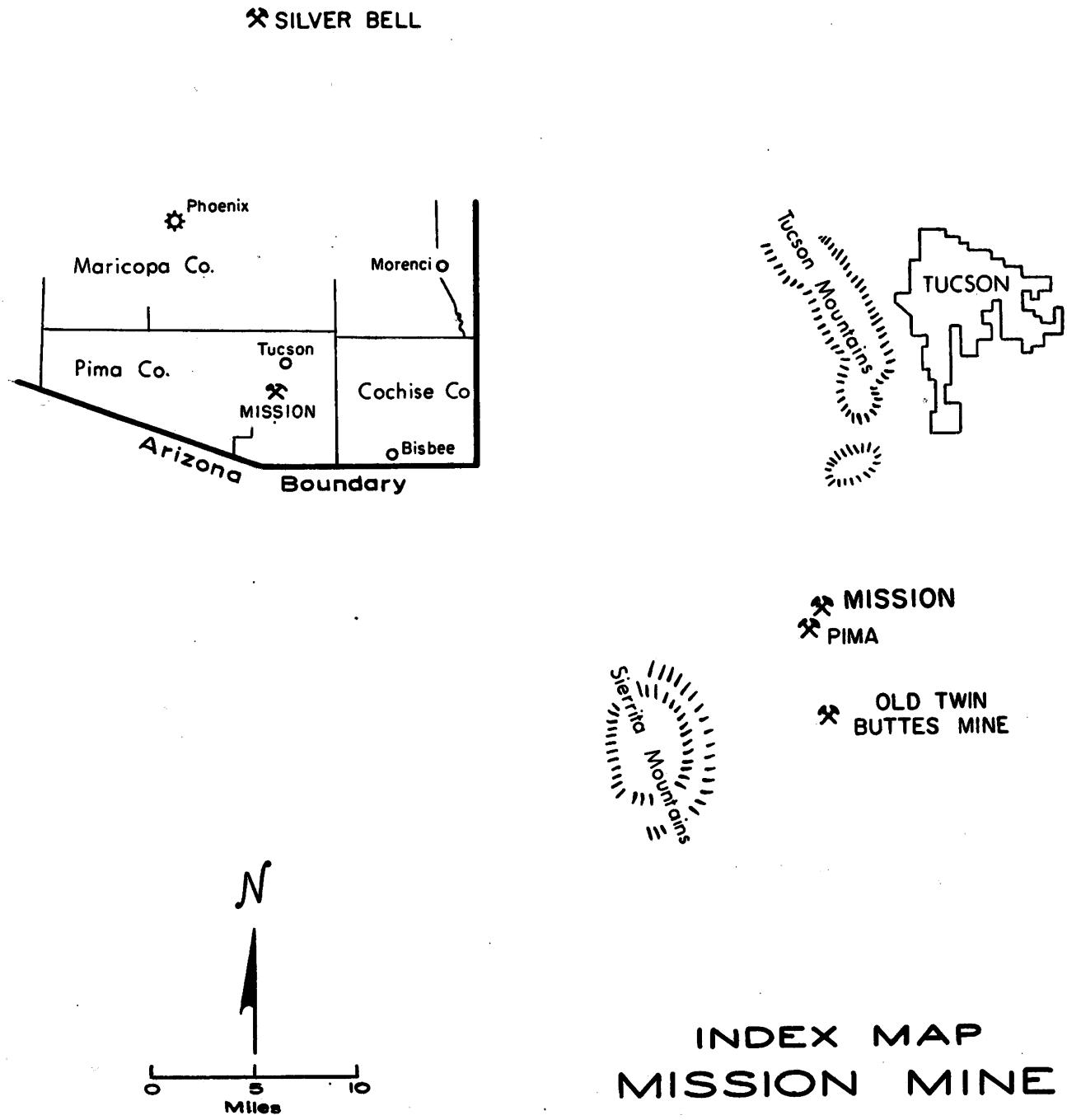
4. Sales, Reno H., and Meyer, Charles, 1948, Wall Rock Alteration at Butte, Montana: AIME Trans., Vol. 178, pp. 9-33.

5. Spencer, Arthur C., 1917, The Geology and Ore Deposits of Ely, Nevada: U. S. Geol. Survey Prof. Paper 96, 189 pp., maps.

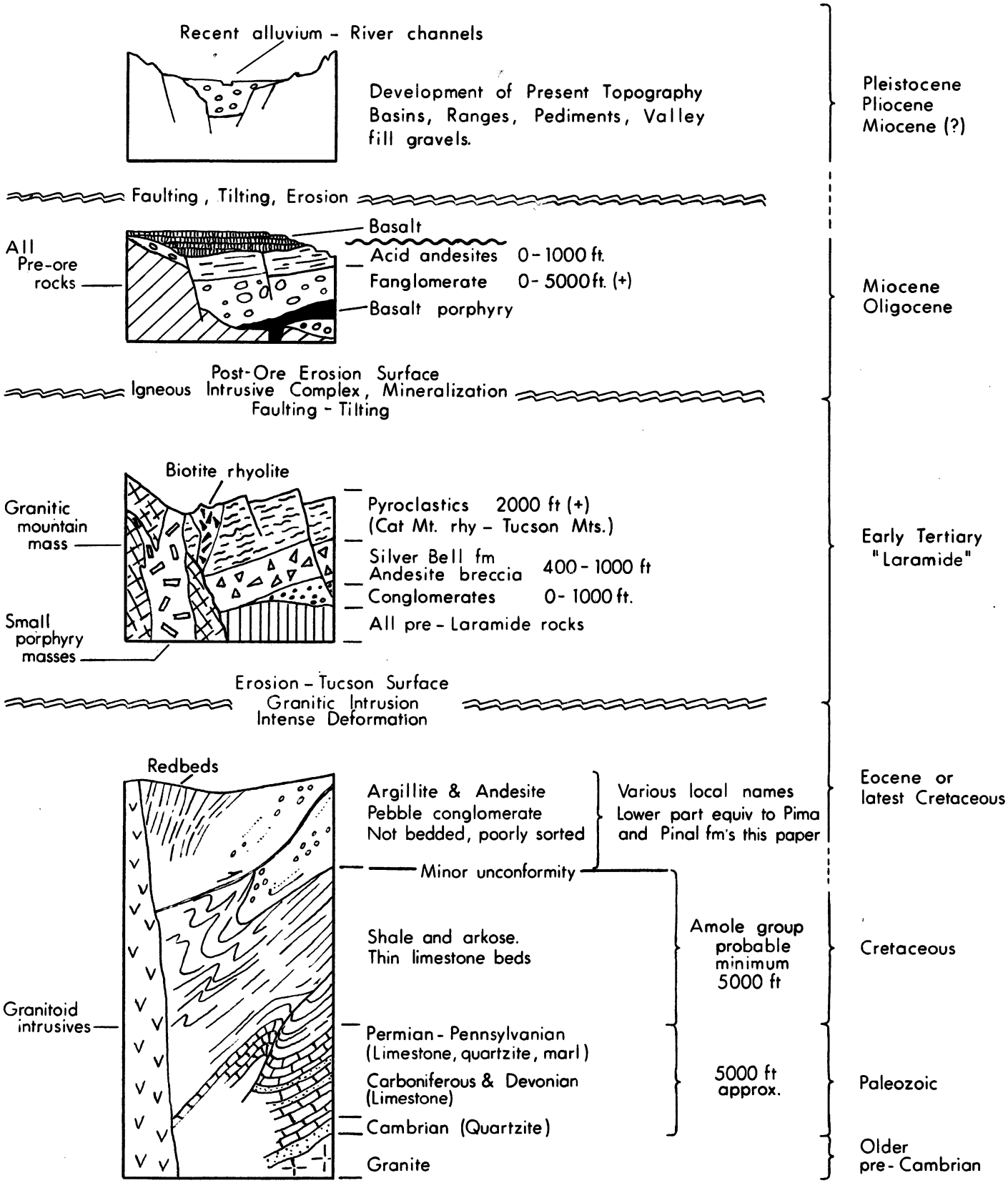
6. Stringham, Bronson, 1960, Differences between Barren and Productive Intrusive Porphyry: Econ. Geol., Bull., Vol. 55, pp. 1622-1630.

7. Thurmond, R. E., Heinrichs, W. E., and Spaulding, E. D., 1954, Geophysical Discovery and Development of the Pima Mine, Pima County, Arizona: AIME Trans., Vol. 199, pp. 197-202.

8. Titley, Spencer R., 1961, Genesis and Control of the Linchburg Orebody, Socorro County, New Mexico: Econ. Geol., Bull., Vol. 56, pp. 695-722.



INDEX MAP
MISSION MINE
Figure 1

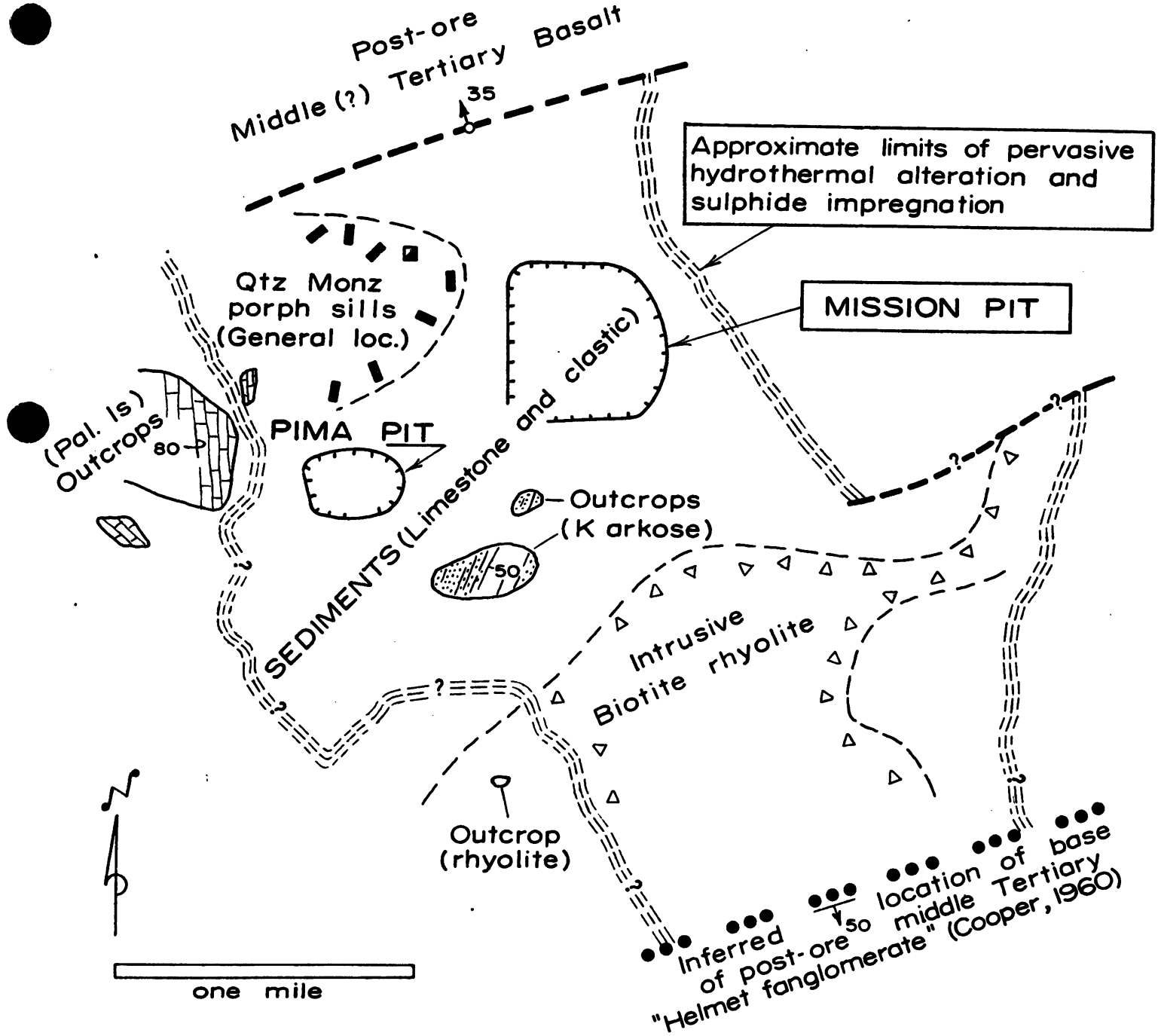


DIAGRAMMATIC COLUMNAR SECTION
GENERALIZED GEOLOGIC HISTORY OF SIERRITA-TUCSON MOUNTAIN REGION

Synthesized from published work
and personal field mapping

J. E. Kinnison

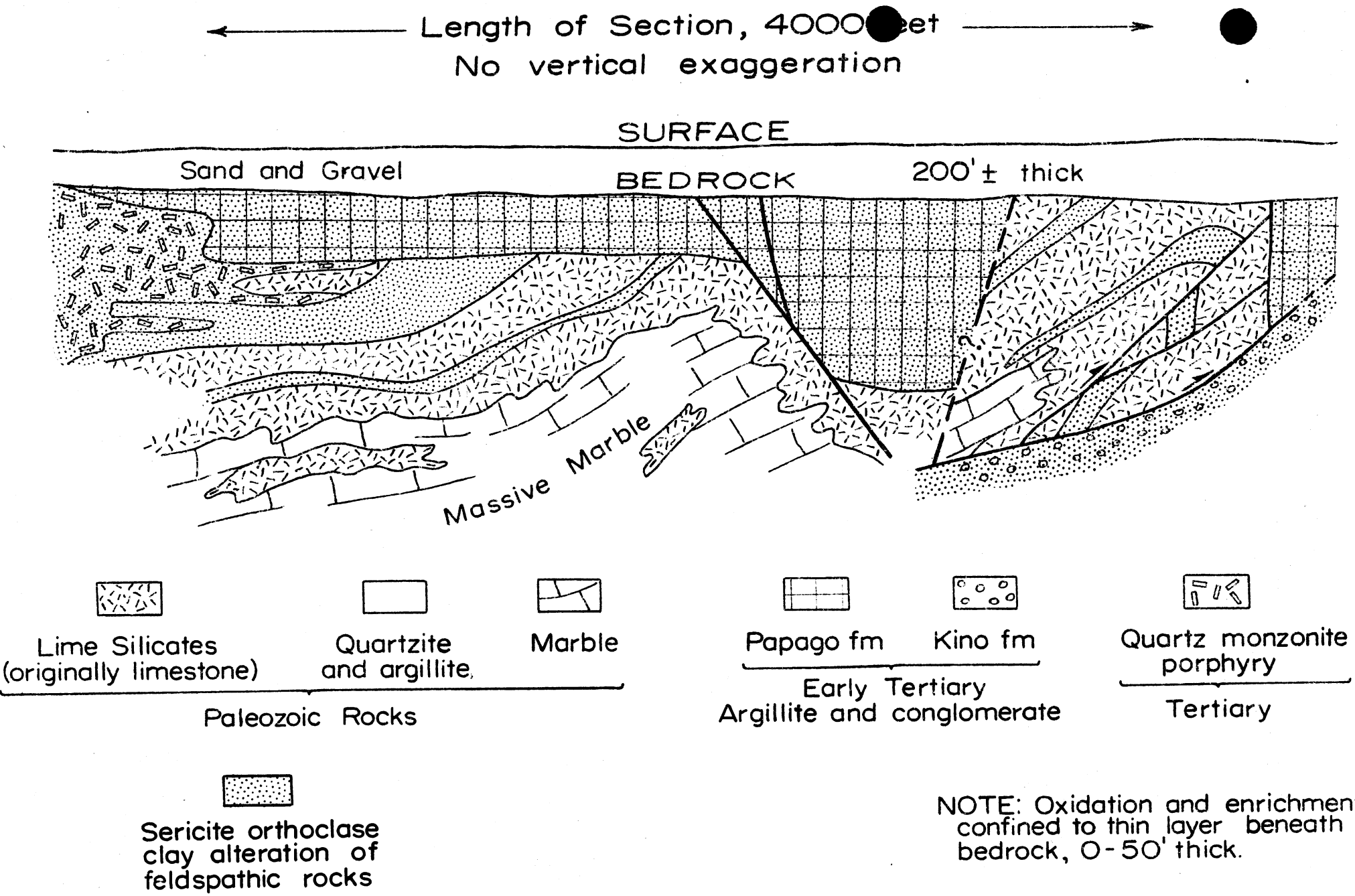
Figure 2



GENERALIZED MAP SHOWING DISTRIBUTION OF SEDIMENTS, IGNEOUS ROCKS AND ALTERATION BENEATH THE ALLUVIAL PLAIN AS KNOWN THROUGH DRILL DATA

Figure 3

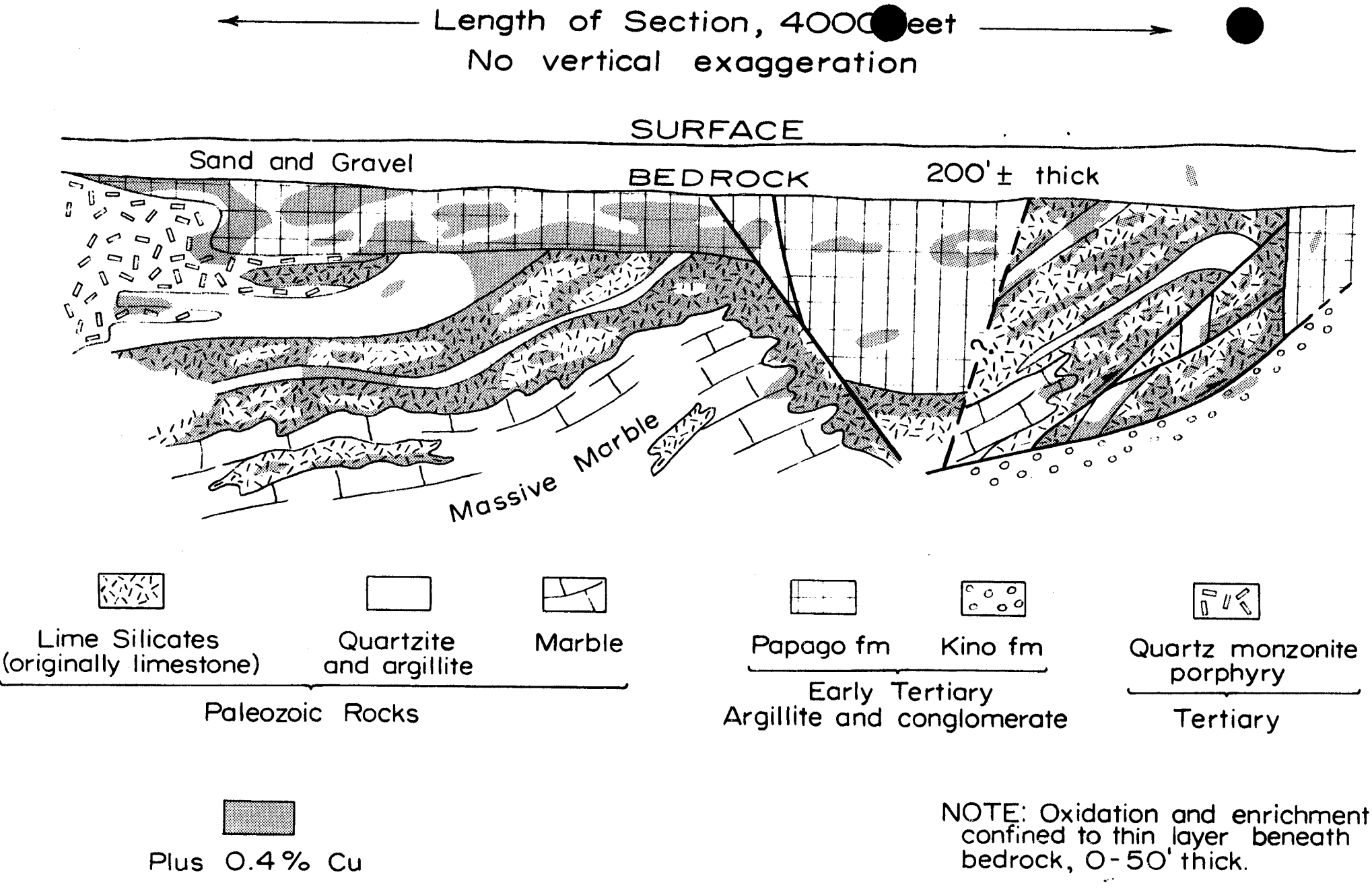
J. E. Kinnison



DIAGRAMMATIC CROSS SECTION THROUGH MISSION ORE BODY
LOOKING NORTH

Figure 4

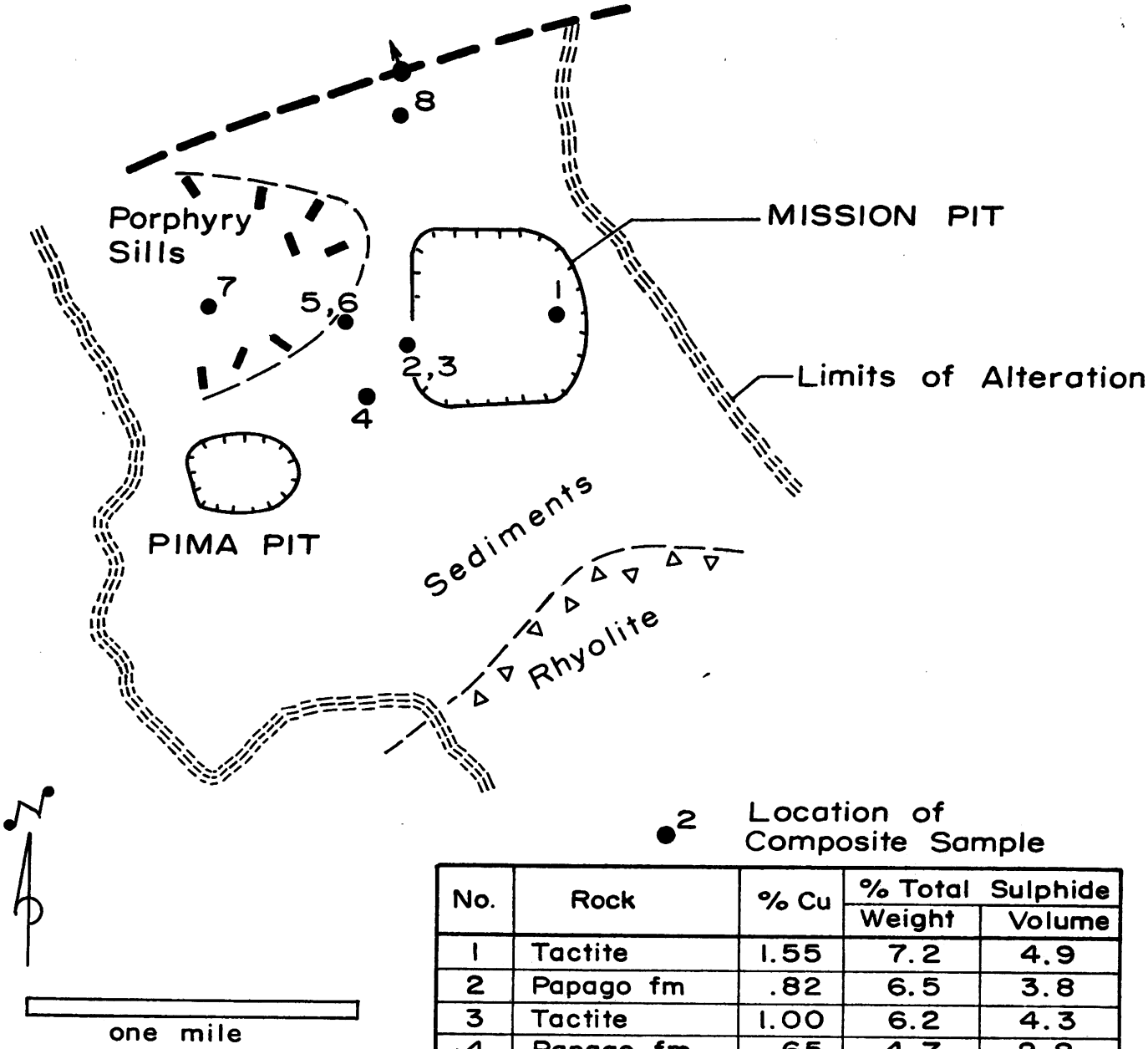
J.E. Kinnison



DIAGRAMMATIC CROSS SECTION THROUGH MISSION ORE BODY
LOOKING NORTH

Figure 5

J.E. Kinnison



2 Location of Composite Sample

No.	Rock	% Cu	% Total Sulphide	
			Weight	Volume
1	Tactite	1.55	7.2	4.9
2	Papago fm	.82	6.5	3.8
3	Tactite	1.00	6.2	4.3
4	Papago fm	.65	4.7	2.8
5	Papago fm	.94	4.5	2.7
6	Tactite	.87	4.5	3.0
7	Porphyry	.30	2.7	1.5
8	Papago fm	1.20	3.4	1.9

Note: All samples contain pyrite and chalcopyrite as the dominant sulphides, except No. 8 which is enriched by chalcocite.

TOTAL SULPHIDE CONTENT - MISSION MINE

Figure 6

J. E. Kinnison

EXPLANATION

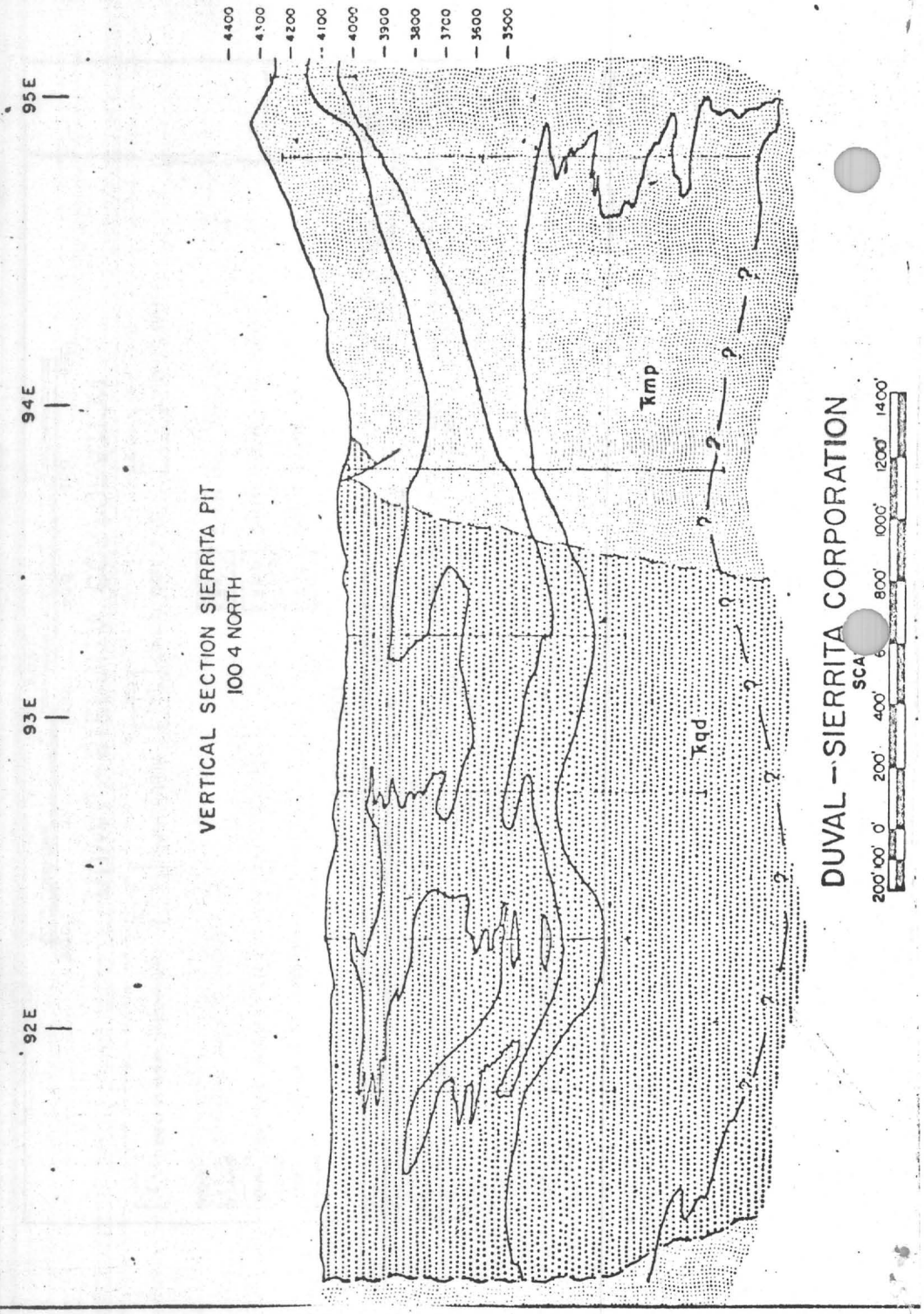
Qss — Quaternary stream sediments	Kqd — Quartz diorite
Krwt — Rhyolitic weldded tuffs (includes flows, breccias)	Kmp — Quartz monzonite porphyry
Ksbp — Silverbell andesite porphyry	Kqlp — Quartz latite porphyry

45 Fault or shear showing dip — Inferred fault — Contact showing dip — Inferred contact

DUVAL - SIERRITA CORPORATION

200' 0 200' 400' 600' 800'

SCALE



Gas requirements are expected to be some 50 million cubic feet per month with all but a fraction of the gas being utilized in roasting molybdenum sulphide concentrates into the oxide form.

Water requirements for the operation will be on the order of 15,000 gallons per minute with most of this amount being used in the milling operation. This water will be pumped from wells along the Santa Cruz River Basin belonging to the Sierrita property. To secure this advantageous use with its water rights, a 5900-acre ranch, which was part of an original Spanish Land Grant, was purchased.

facilities are estimated to cost $84 million. This capacity will be greater than any single copper-molybdenum concentrator in North America. The construction of plant facilities is expected to be completed in the third quarter of 1969.

PRODUCTION

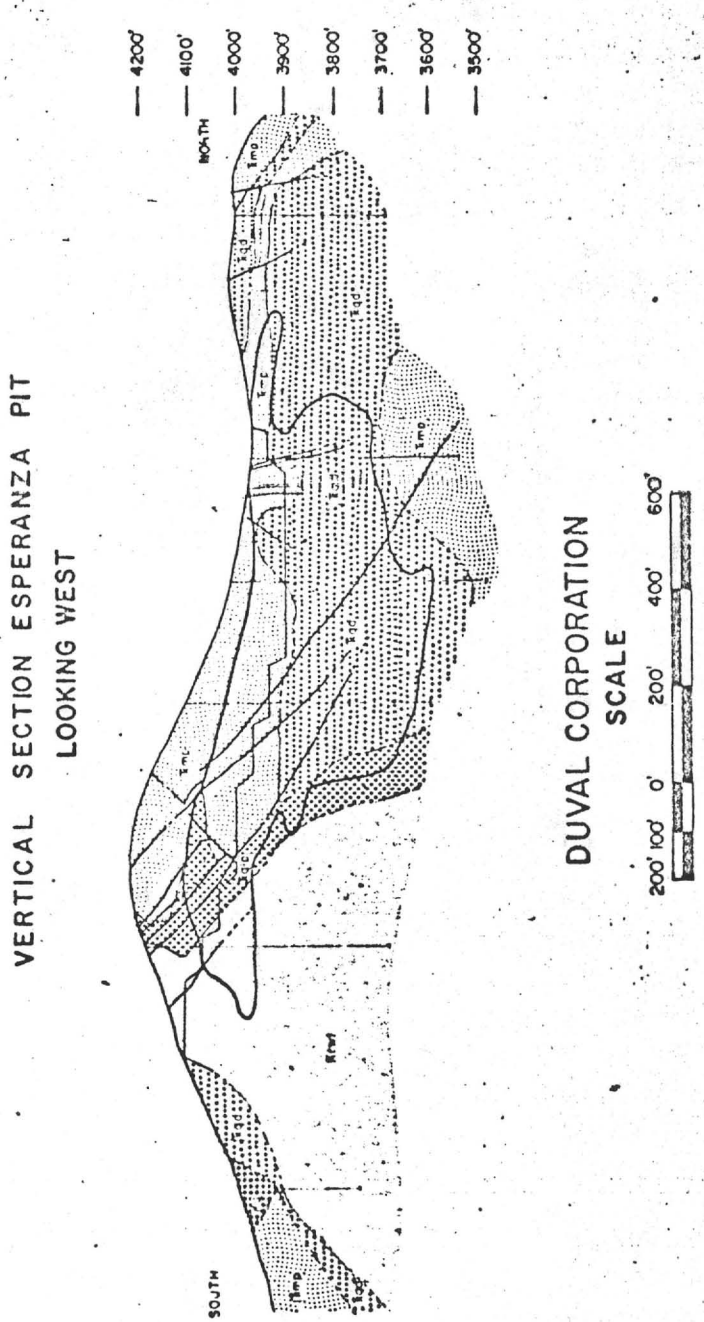
The Sierrita property will produce an annual minimum average of 114 million pounds of copper during the first five years of operations and 136 million pounds thereafter. In addition, the property will produce approximately 12 million pounds of molybdenum and 455,000 ounces of silver annually. When Sierrita reaches full production, Duval Corporation will rank fourth in U. S. copper mine production and supply approximately 14 percent of the free world's molybdenum.

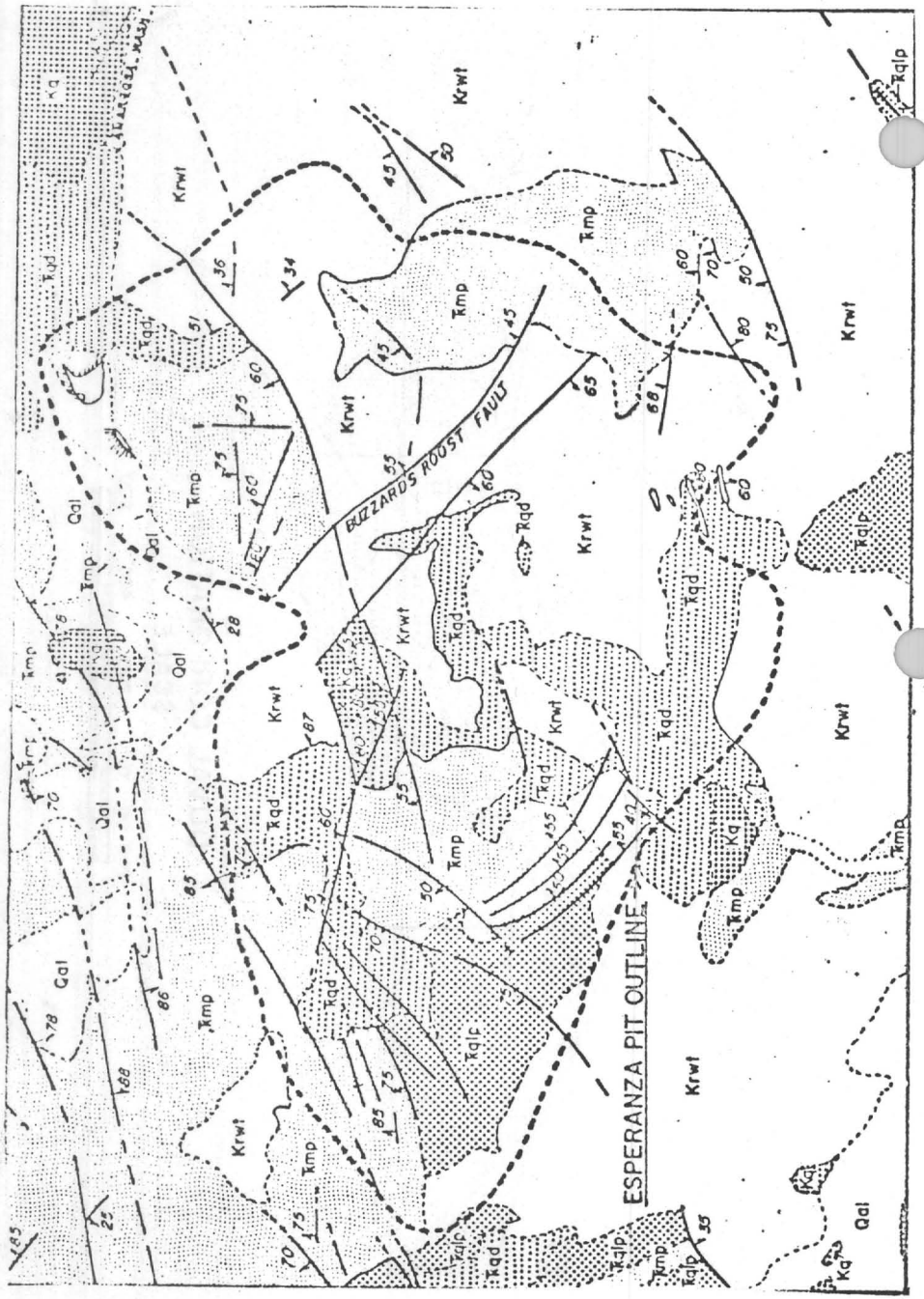
EMPLOYMENT

Peak employment during construction at the Sierrita property is expected to reach some 2,800. It is estimated, average permanent employment during production will be 1,100.

UTILITIES

Power and natural gas will be supplied by Tucson Gas and Electric Company. Power requirements are expected to be approximately 60,000 kilowatts or 40 million kilowatt hours per month. This amount of power would supply an average city of more than 100,000 population.





Because the power shovels and haul trucks represent the largest of these machines used in the industry, some pertinent facts concerning these units are of interest:

Power Shovels:

1. The weight of each shovel is approximately 450 tons.
2. Shovels are rated at 750 HP and are electrically powered by 4160 volt AC current.
3. When loaded, the 15 cubic yard bucket contains approximately 25 tons.

Haul Trucks:

1. The initial purchase of 28 electric wheel trucks was evenly divided between KW Dart Company and Westinghouse Air Brake Company.
2. The truck engines are 12 cylinder diesels rated at 1000 HP.
3. Engines drive DC electric generators, which supply power to electric motor assemblies in the rear wheels.
4. Trucks have a rated capacity of 120 tons and weigh approximately 75 tons empty.
5. Fuel tanks hold 450 gallons of diesel oil and the engines use one gallon per mile under full load conditions and level haul.
6. Truck tires are constructed of 48 ply, stand nine feet in height and weigh 3000 pounds.

PLANT FACILITIES

Stearns-Roger Corporation of Denver, Colorado has been awarded an engineering construction contract to build the Sierrita concentrator and associated facilities. The concentrator, which will have a designed capacity in excess of 60,000 tons of ore per day, and the associated

72.000 tpd - S.H.C. verbal
+ 15 000 tpd Esperanza mill
87 000 Tpd total - Largest in Ariz
- Second to Bingham in US

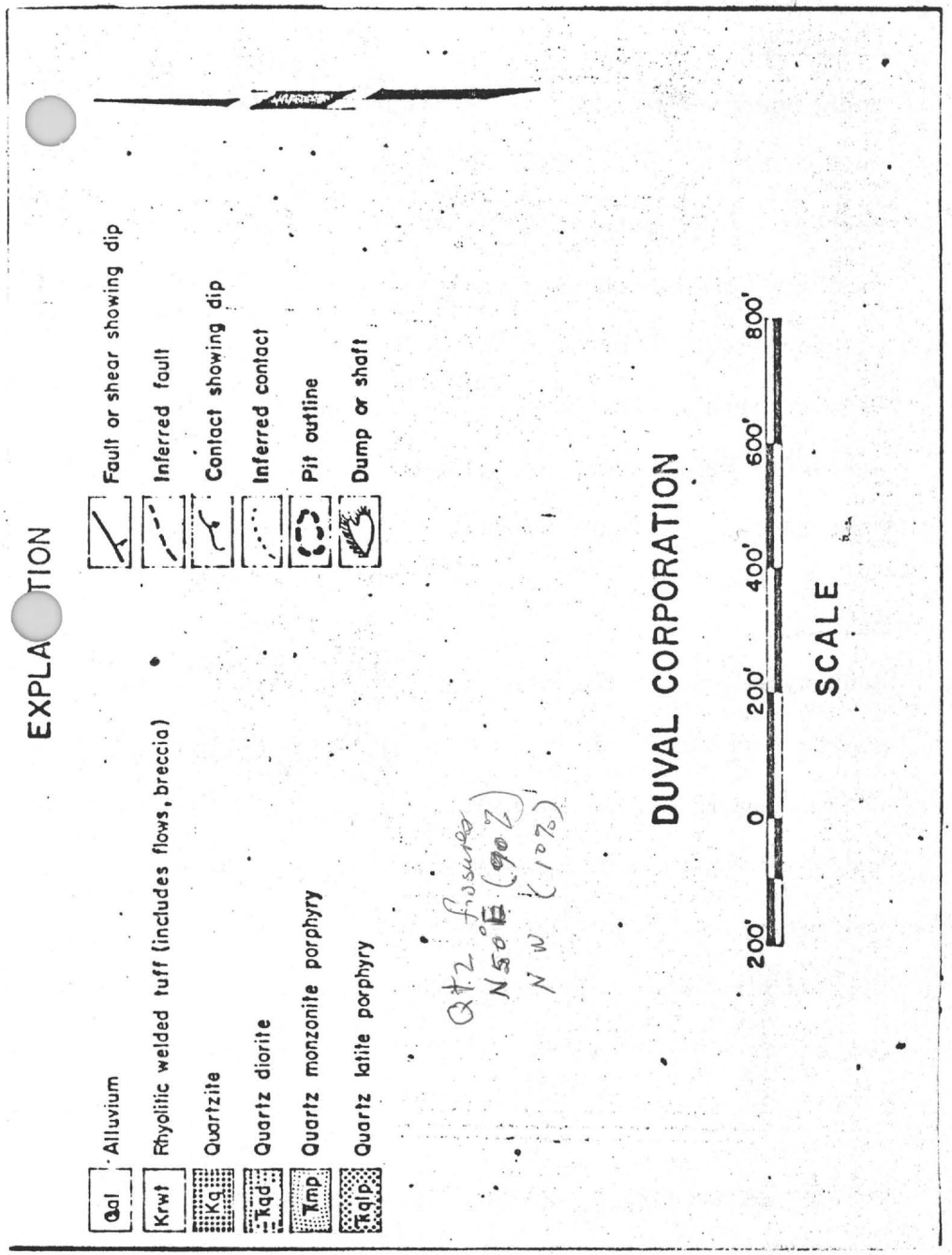
MINING

It is anticipated that the eventual perimeter of the Sierrita open pit will encompass an area of approximately 460 acres. As presently designed, the pit will ultimately reach a depth of 1850 feet below the highest elevation of the pit area prior to commencement of mining. By comparison, the Empire State Building is only two-thirds as tall as the pit will be deep.

The mining plans provide for the removal of 105 million tons of waste overburden before the commencement of ore mining operations. A daily average of 200,000 tons per day will be mined during the pre-mine stripping period. Thereafter, the mining of ore and waste will be conducted on a scale of approximately 235,000 tons per day for the initial six-year production period, after which the scale of mining operations will be somewhat reduced as less waste will be handled.

MINING EQUIPMENT AND FACILITIES

The mining equipment features six power shovels of P & H manufacture equipped with 15 cubic yard buckets and an initial order of 28 electric wheel haul trucks of 120-ton capacity which will be expanded to 40 by the completion of pre-mine stripping. These shovels and trucks are of the largest presently used in the copper mining industry. In addition, six rotary blast hole drills, 11 dozers and numerous other units such as motor patrols, fork lifts, cranes, water trucks, personnel buses and miscellaneous small trucks supplement the operation. Service facilities consist of two modern shops, steam cleaning pad, change room and offices.



Geology - Esperanza and Sierrita

ESPERANZA

Rock types within the ore zone consist of cretaceous welded tuffs, quartz diorite, latite, quartz monzonite porphyry. Hypogene metallization is syngenetic with rock type formation and consists of chalcopyrite, pyrite, molybdenite with minor sphalerite, galena and magnetite. Favored hypogene ore host is quartz monzonite porphyry. Supergene (chalcocite) metallization zone averaged 125 feet thick. Dominant structural trend is NE to ENE.

SIERRITA

Rock types within the ore zone consist of quartz diorite, quartz monzonite, and quartz monzonite porphyry. Metallization, again partly syngenetic, consists of chalcopyrite and molybdenite with minor amounts of sphalerite, galena and magnetite. There is no enriched blanket in the Sierrita ore body. Dominant structural trend is identical to that of Esperanza, which is NE to ENE.

THIS PAMPHLET EXCERPTED FROM "AIME" FIELD TRIP 3 PAPER.

SIERRITA PROPERTY

The Sierrita property consists of over 13,000 acres, which includes property rights for water field, tailing disposal and rights of way for pipe lines and a railroad spur. Included in this total acreage are 143 unpatented mining claims which were purchased by Duval Corporation. Approximately 58 percent of the Sierrita ore body was acquired in the purchase of these claims. The remaining 42 percent of the ore body was controlled by patented mining claims which were part of Duval's Esperanza Property. Duval has transferred these unpatented and patented mining claims to the Sierrita property.

EXPLORATION AND PRELIMINARY DEVELOPMENT

A total of 137 test holes have been drilled in order to delineate the Sierrita ore body and to test proposed waste dump areas. Some of the tests were drilled to check certain holes drilled by another mining company which had previously drilled 60 core tests in the area.

ORE RESERVES

The exploration and preliminary development program delineated an ore body of 414 million tons with an average copper content of 0.35% (Seven pounds) and an average molybdenum content of 0.036% (0.72 pounds). Engineering pit design indicates that a total of 634 million tons of waste must be handled prior to and during the mining of the 414 million tons ore reserve. This total of over a billion tons of ore and waste, which will be mined, represents more than twice the tonnage excavated in the construction of the Panama Canal.

NOTES

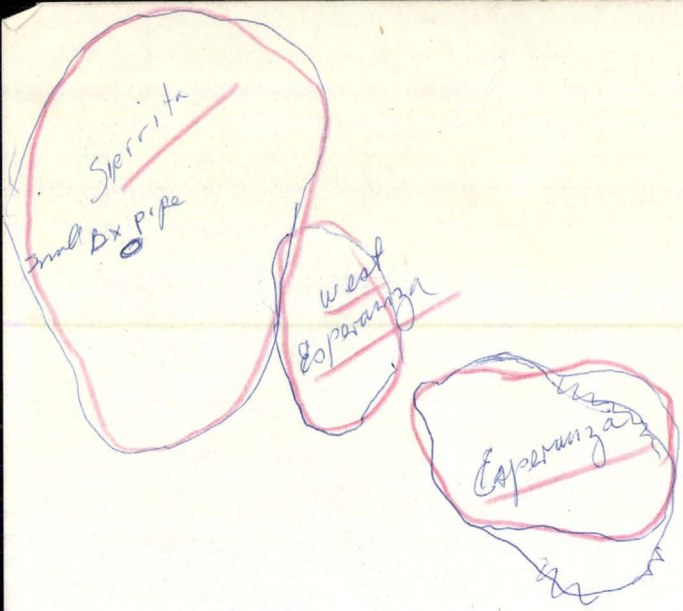
DUVAL SIERRITA CORPORATION

SIERRITA PROPERTY

ORGANIZATION

Resident Manager	S. H. Martin
Mine Superintendent	A. P. Holzworth
Chief Mine Engineer	F. H. Buchella, Jr.
Chief Mine Geologist	R. A. Metz
Safety Supervisor	D. L. Gidak
Chief Accountant	S. C. Polasek
Purchasing Agent	J. K. Peters
Personnel Relations Supervisor	S. L. Vaughn

Duval Sierrity Corp.



The three ore deposits are not connected by ore material.

Sierrita

in the south area Sierrita pit - little or no Mo. Mo increases to the North. Also, epidote, chl in north part of P.I.

John E Kinnison
AS & R Tucson

VISITOR'S INFORMATION PAMPHLET

Jan 1969
Field Trip
Penrose Conference

DUVAL SIERRITA CORPORATION

GEOLOGY DEPARTMENT

ROBERT A. METZ, CHIEF MINE GEOLOGIST

A. HARVEY JAMES, MINE GEOLOGIST

BOB GALYON, DRAFTSMAN

vides for the participation of the other mining companies should they decide to develop their properties in the future. In this case, Lornex would recover a pro-rata share of the capital cost of the tailings disposal system.

The area chosen for tailings disposal is some five miles to the north of the Lornex pit with a potential tailings capacity of about 1,000 million tons, and this capacity could be doubled by building a further dam to the west. For the initial impoundment area, two starter dams had to be constructed, as the disposal area is located near the junction of two watersheds. Canadian Bechtel were employed for the engineering and construction management of the main tailings starter dam. The choice of location of the tailings disposal area required the re-routing of both the Highland Valley road and the main power line.

It is estimated that for Lornex's own purposes the final main dam height will be just under 300ft. The dam walls are built round an impervious clay core and are built up with coarse classified tailings sand to the required height. The planned length of the tailings dam is about 2½ miles.

Mill tailings are developed to the dam in three stages. The first stage is by gravity flow through 4,800ft of 36in asbestos lined pipes down-grade from the tailings thickeners to the first pump station. The second stage is via two 20in steel pressure pipelines with two pump stations on each line. This section is about 17,000ft long. The pumps used are 16in × 16in slurry pumps driven by 700hp synchronous motors through single reduction gearing.

Water supply

In addition to make-up water pumped from the Thompson River, the company includes provision for the maximum recirculation of water at the plant. Water is re-cycled from the various thickener overflows, and also from the tailings sand. For the latter, three Peerless 350hp pumps mounted on a floating barge deliver the water to a booster pump station through a 20in pump column. The three Peerless booster station pumps are driven by 1,000hp motors and are capable of delivering 3,200 gal/min each to the mill. At the mill, water is stored in three steel tanks with a total capacity of 3 million gallons.

Make-up water for the mine has to be pumped the 17 miles from the Thompson River, since the Highland Valley is in a rain shadow area. (Annual precipitation is only 12–20in.) The Thompson River intake system has a capacity of 6,000 gal/min, and comprises three Peerless vertical turbine 125hp pumps (two operating – one standby). These elevate the water to a 90ft dia × 40ft high clear water storage tank, from which it is pumped to the main reservoir through 11 miles of 20in pipe. The pumps used are four Byron Jackson 9-stage 6in × 8in centrifugal pumps (three operating, one standby).

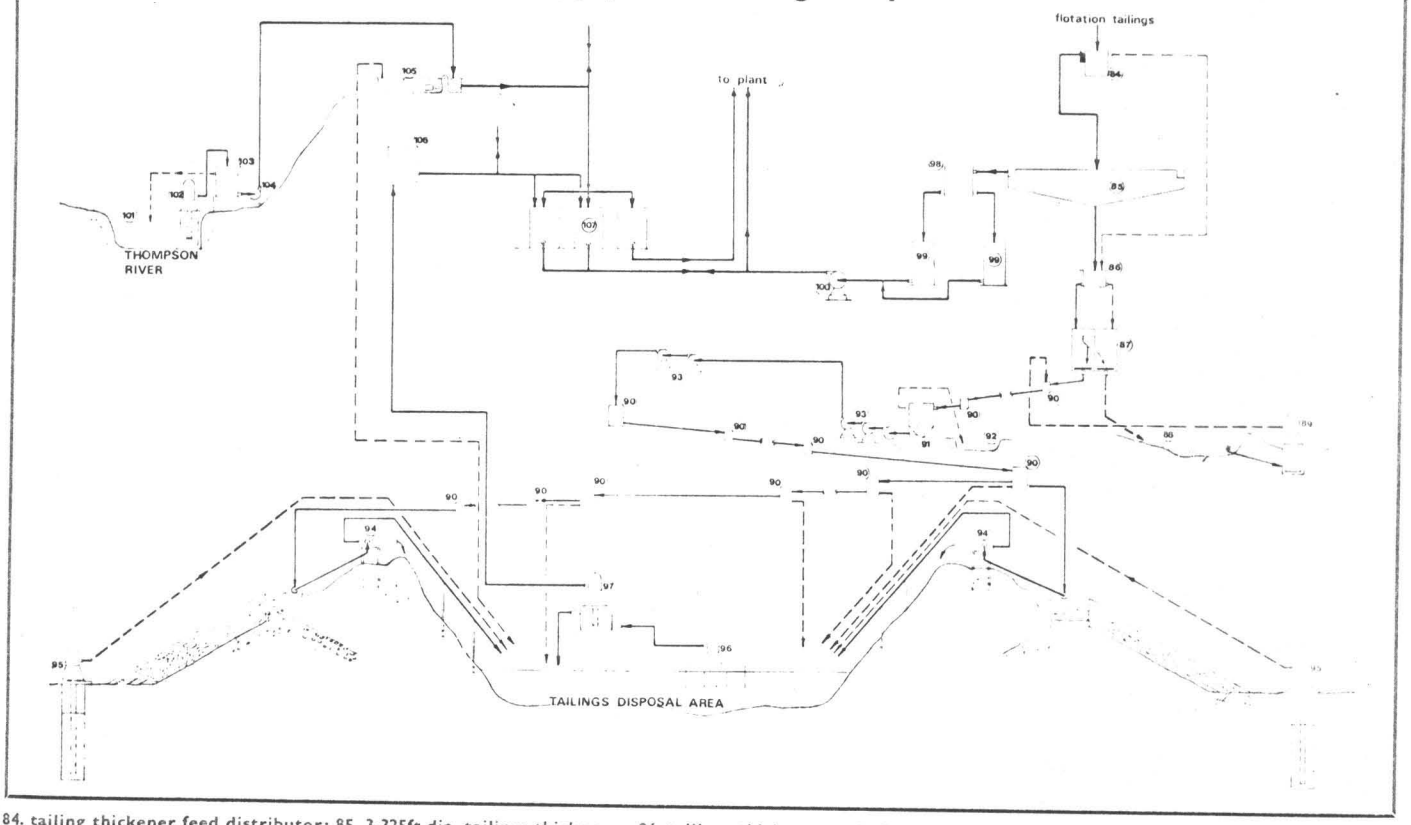
The whole Lornex operation is being carefully monitored to prevent pollution of either the atmosphere or the surrounding water systems. Parts of the waste dumps and tailings systems will have vegetation planted on them when they become inactive, and on completion of the mine the pit will be allowed to flood to form a natural lake.

The infrastructure of the project has included the construction of a mine township at Logan Lake, about eleven miles to the south-east. Housing for a little over 1,000 people has been constructed.

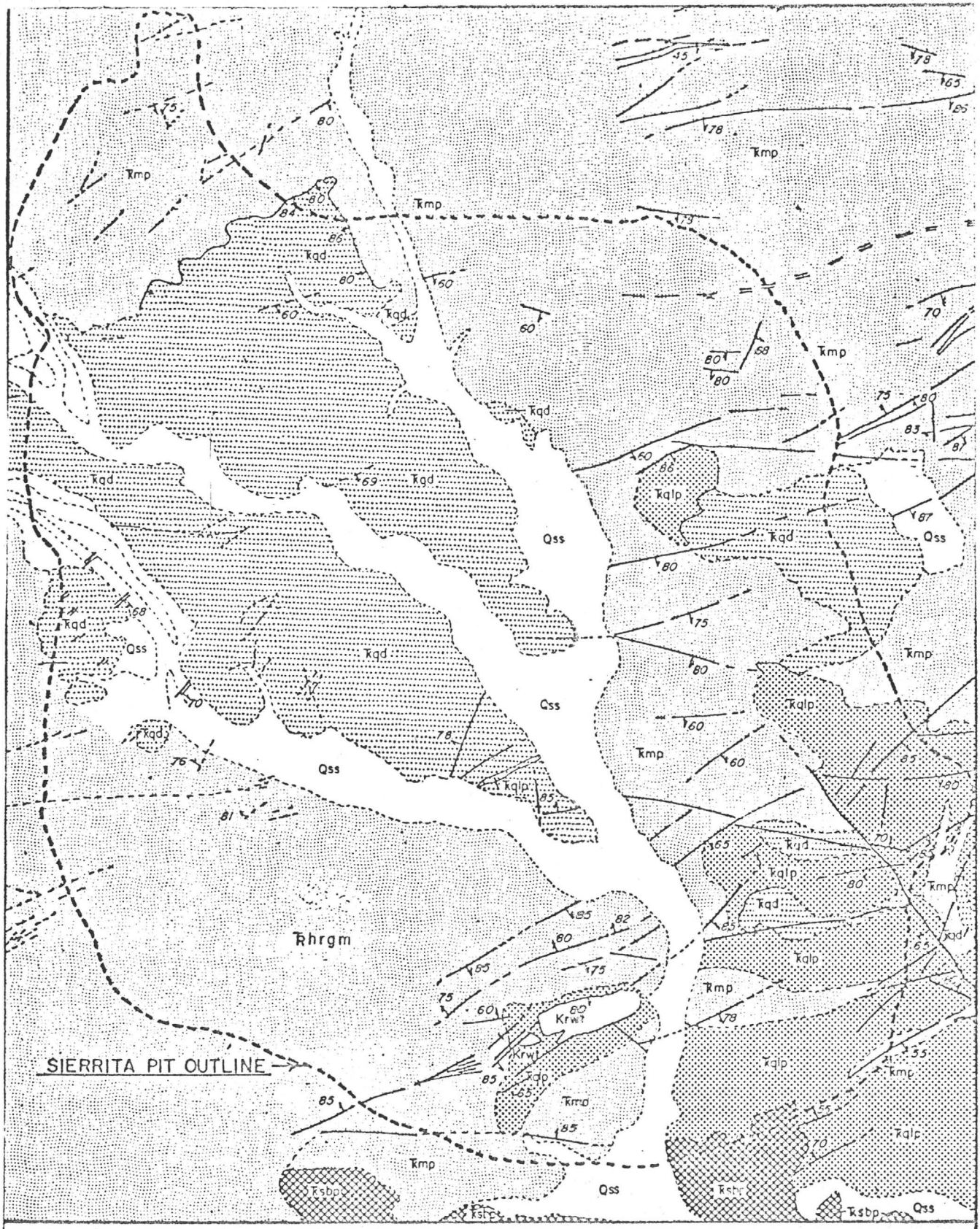
References

1. The Staff of Lornex Mining Corporation, *Western Miner*, August 1972.
2. British Columbia Department of Mines and Petroleum Resources, *Geology, Exploration and Mining in British Columbia*, 1969, 1970.
3. Lornex Mining Corporation Ltd. and Rio Algom Mines Ltd., *Annual Reports*, 1966–1971.

Water supply and tailings disposal



84. tailing thickener feed distributor; 85. 3-325ft dia. tailings thickeners; 86. tailings thickener underflow collection box; 87. tailings diversion box; 88. tailings emergency pond; 89. tailings emergency pond decant pump; 90. drop box; 91. tailings pump sump; 92. tailings emergency dump; 93. 10-tailings pumps; 94. 90-12in dia. tailings cyclones; 95. 6-interceptor well pumps; 96. 3-reclaim water barge pumps; 97. 3-reclaim water booster pumps; 98. tailings thickener o'flow collection box; 99. 2-100,000 gal mill water tanks; 100. 4-tailings thickener overflow pumps; 101. Thompson river-spatsum; 102. 3-vertical river intake pumps; 103. 1·5 million gal tank; 104. 4-9 stage river water booster pumps; 106. 1 million gal water surge tank; 107. 3-1 million gal water head tanks.



EXPLANATION

Qss	Quaternary stream sediments	Kqd	Quartz diorite
Krwt	Rhyolitic weldded tuffs (includes flows, breccias)	Kmp	Quartz monzonite porphyry
Ksbp	Silverbell andesite porphyry	Kqlp	Quartz latite porphyry

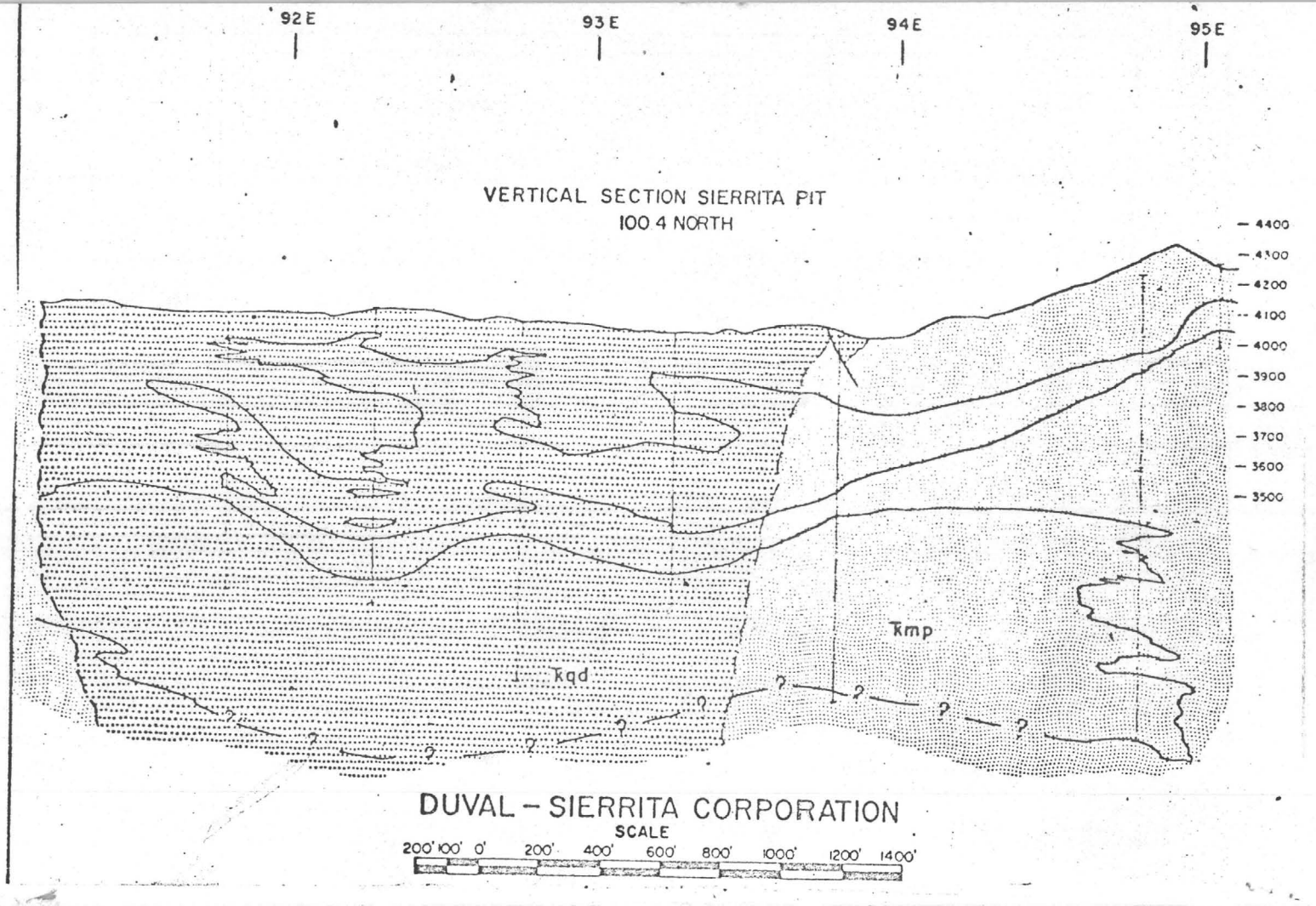
45 Fault or shear showing dip — Inferred fault — Contact showing dip — Inferred contact

DUVAL - SIERRITA CORPORATION

200' 0 200' 400' 600' 800'

SCALE

Esperanza - Sierrita



Gas requirements are expected to be some 50 million cubic feet per month with all but a fraction of the gas being utilized in roasting molybdenum sulphide concentrates into the oxide form.

Water requirements for the operation will be on the order of 15,000 gallons per minute with most of this amount being used in the milling operation. This water will be pumped from wells along the Santa Cruz River Basin belonging to the Sierrita property. To secure this advantageous site with its water rights, a 5900-acre ranch, which was part of an original Spanish Land Grant, was purchased.

facilities are estimated to cost $84 million. This capacity will be greater than any single copper-molybdenum concentrator in North America. The construction of plant facilities is expected to be completed in the third quarter of 1969.

PRODUCTION

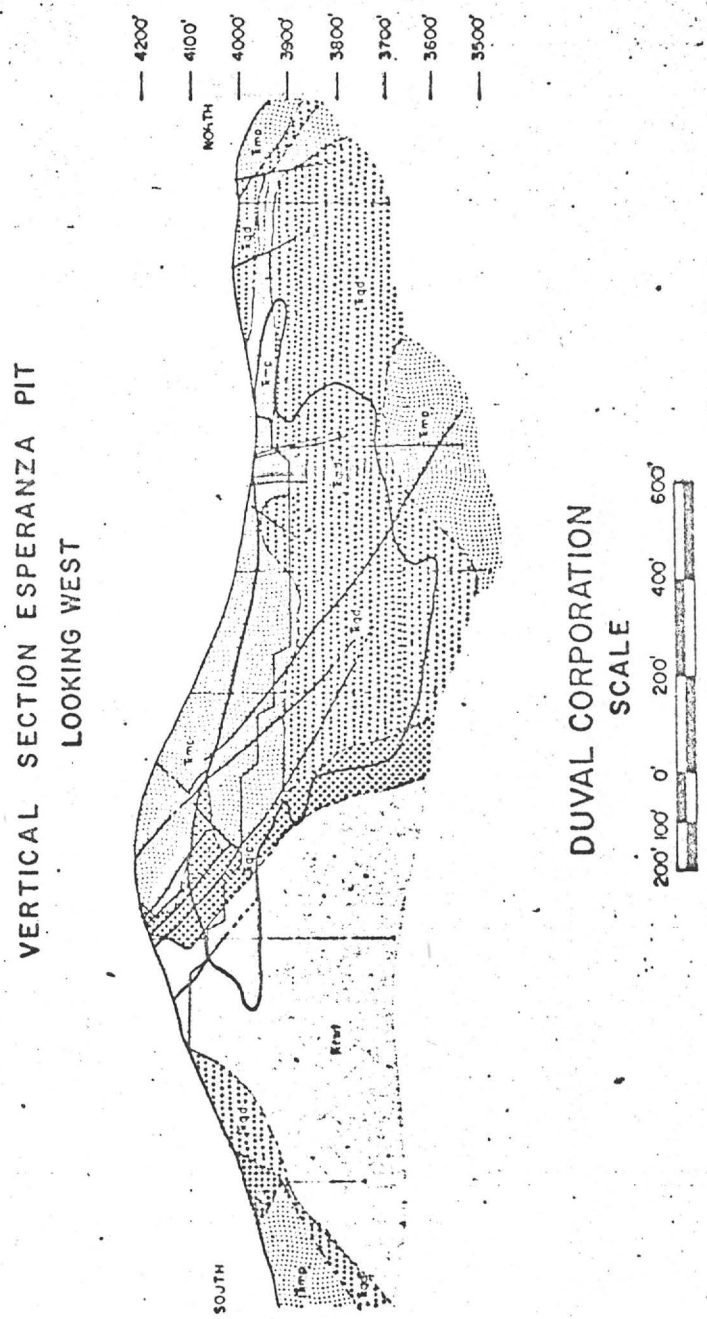
The Sierrita property will produce an annual minimum average of 114 million pounds of copper during the first five years of operations and 136 million pounds thereafter. In addition, the property will produce approximately 12 million pounds of molybdenum and 455,000 ounces of silver annually. When Sierrita reaches full production, Duval Corporation will rank fourth in U. S. copper mine production and supply approximately 14 percent of the free world's molybdenum.

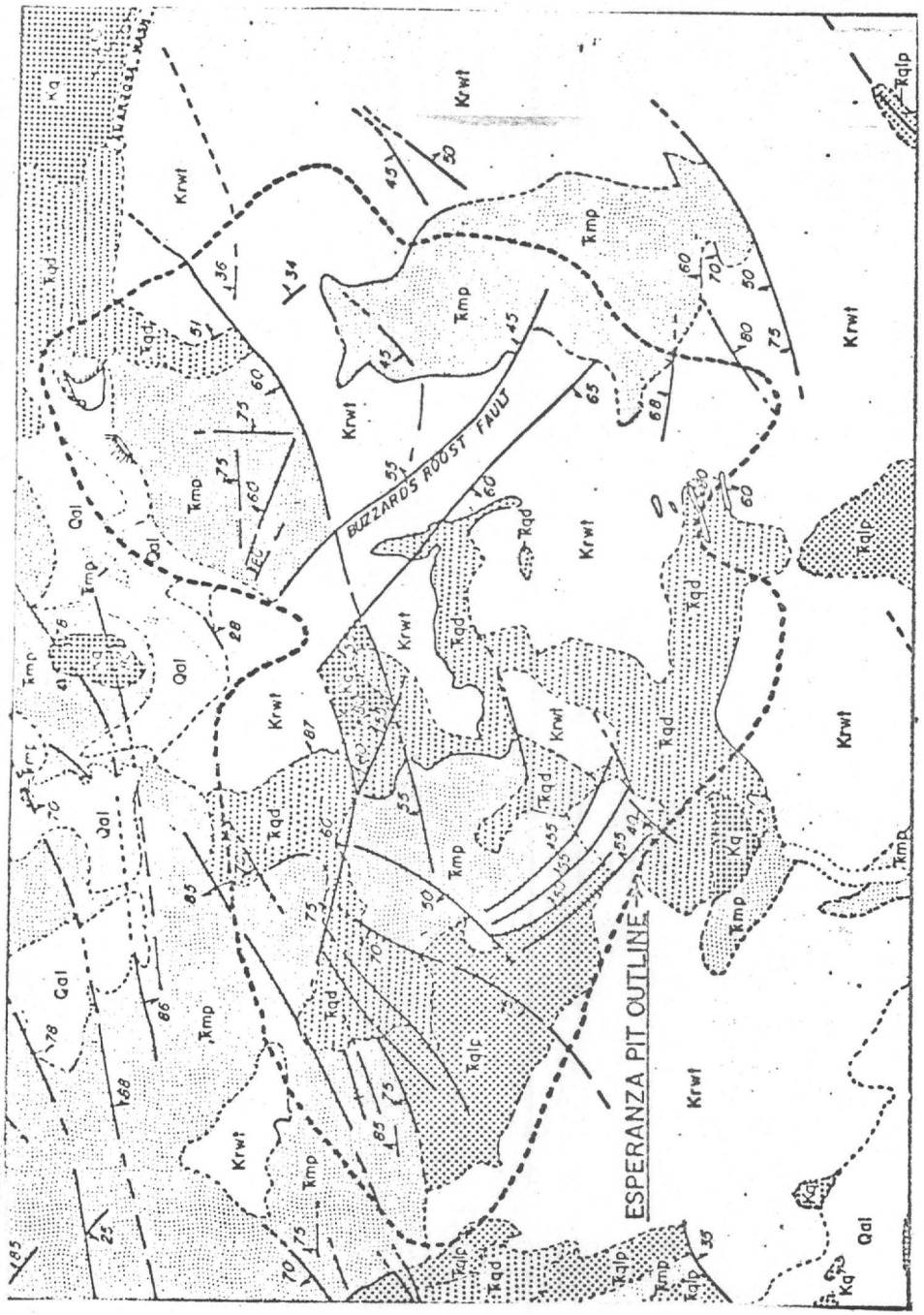
EMPLOYMENT

Peak employment during construction at the Sierrita property is expected to reach some 2,800. It is estimated, average permanent employment during production will be 1,100.

UTILITIES

Power and natural gas will be supplied by Tucson Gas and Electric Company. Power requirements are expected to be approximately 60,000 kilowatts or 40 million kilowatt hours per month. This amount of power would supply an average city of more than 100,000 population.





Because the power shovels and haul trucks represent the largest of these machines used in the industry, some pertinent facts concerning these units are of interest:

Power Shovels:

1. The weight of each shovel is approximately 450 tons.
2. Shovels are rated at 750 HP and are electrically powered by 4160 volt AC current.
3. When loaded, the 15 cubic yard bucket contains approximately 25 tons.

Haul Trucks:

1. The initial purchase of 28 electric wheel trucks was evenly divided between KW Dart Company and Westinghouse Air Brake Company.
2. The truck engines are 12 cylinder diesels rated at 1000 HP.
3. Engines drive DC electric generators, which supply power to electric motor assemblies in the rear wheels.
4. Trucks have a rated capacity of 120 tons and weigh approximately 75 tons empty.
5. Fuel tanks hold 450 gallons of diesel oil and the engines use one gallon per mile under full load conditions and level haul.
6. Truck tires are constructed of 48 ply, stand nine feet in height and weigh 3000 pounds.

PLANT FACILITIES

Stearns-Roger Corporation of Denver, Colorado has been awarded an engineering construction contract to build the Sierrita concentrator and associated facilities. The concentrator, which will have a designed capacity in excess of 60,000 tons of ore per day, and the associated

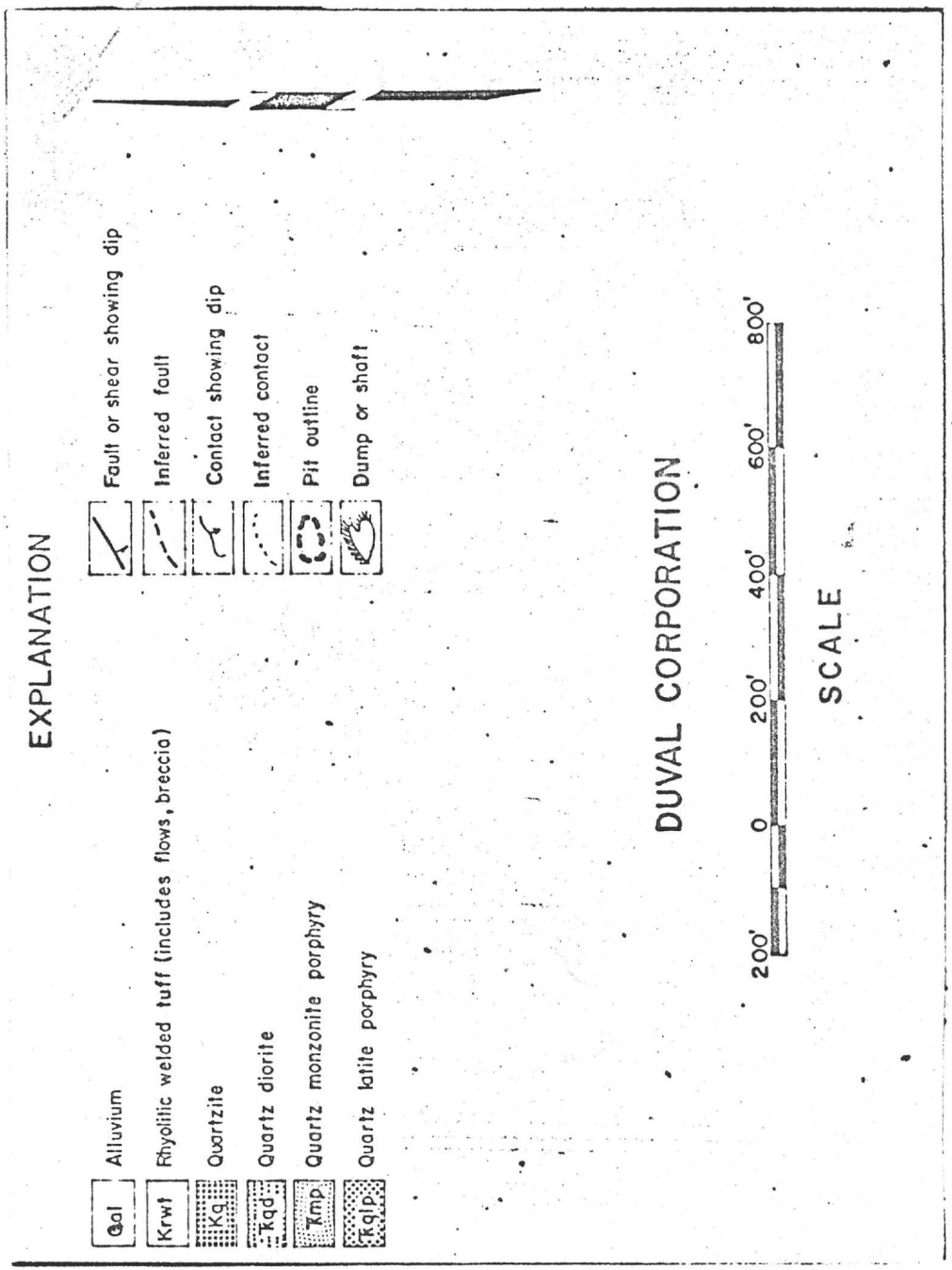
MINING

It is anticipated that the eventual perimeter of the Sierrita open pit will encompass an area of approximately 460 acres. As presently designed, the pit will ultimately reach a depth of 1850 feet below the highest elevation of the pit area prior to commencement of mining. By comparison, the Empire State Building is only two-thirds as tall as the pit will be deep.

The mining plans provide for the removal of 105 million tons of waste overburden before the commencement of ore mining operations. A daily average of 200,000 tons per day will be mined during the pre-mine stripping period. Thereafter, the mining of ore and waste will be conducted on a scale of approximately 235,000 tons per day for the initial six-year production period, after which the scale of mining operations will be somewhat reduced as less waste will be handled.

MINING EQUIPMENT AND FACILITIES

The mining equipment features six power shovels of P & H manufacture equipped with 15 cubic yard buckets and an initial order of 28 electric wheel haul trucks of 120-ton capacity which will be expanded to 40 by the completion of pre-mine stripping. These shovels and trucks are of the largest presently used in the copper mining industry. In addition, six rotary blast hole drills, 11 dozers and numerous other units such as motor patrols, fork lifts, cranes, water trucks, personnel buses and miscellaneous small trucks supplement the operation. Service facilities consist of two modern shops, steam cleaning pad, change room and offices.



Geology - Esperanza and Sierrita

ESPERANZA

Rock types within the ore zone consist of cretaceous welded tuffs, quartz diorite, latite, quartz monzonite porphyry. Hypogene metallization is syngenetic with rock type formation and consists of chalcopyrite, pyrite, molybdenite with minor sphalerite, galena and magnetite. Favored hypogene ore host is quartz monzonite porphyry. Supergene (chalcocite) metallization zone averaged 125 feet thick. Dominant structural trend is NE to ENE.

SIERRITA

Rock types within the ore zone consist of quartz diorite, quartz monzonite, and quartz monzonite porphyry. Metallization, again partly syngenetic, consists of chalcopyrite and molybdenite with minor amounts of sphalerite, galena and magnetite. There is no enriched blanket in the Sierrita ore body. Dominant structural trend is identical to that of Esperanza, which is NE to ENE.

THIS PAMPHLET EXCERPTED FROM "AIME" FIELD TRIP 3 PAPER.

SIERRITA PROPERTY

The Sierrita property consists of over 13,000 acres, which includes property rights for water field, tailing disposal and rights of way for pipe lines and a railroad spur. Included in this total acreage are 143 unpatented mining claims which were purchased by Duval Corporation. Approximately 58 percent of the Sierrita ore body was acquired in the purchase of these claims. The remaining 42 percent of the ore body was controlled by patented mining claims which were part of Duval's Esperanza Property. Duval has transferred these unpatented and patented mining claims to the Sierrita property.

EXPLORATION AND PRELIMINARY DEVELOPMENT

A total of 137 test holes have been drilled in order to delineate the Sierrita ore body and to test proposed waste dump areas. Some of the tests were drilled to check certain holes drilled by another mining company which had previously drilled 60 core tests in the area.

ORE RESERVES

The exploration and preliminary development program delineated an ore body of 414 million tons with an average copper content of 0.35% (Seven pounds) and an average molybdenum content of 0.036% (0.72 pounds). Engineering pit design indicates that a total of 634 million tons of waste must be handled prior to and during the mining of the 414 million tons ore reserve. This total of over a billion tons of ore and waste, which will be mined, represents more than twice the tonnage excavated in the construction of the Panama Canal.

NOTES

DUVAL SIERRITA CORPORATION

SIERRITA PROPERTY

ORGANIZATION

Resident Manager	S. H. Martin
Mine Superintendent	A. P. Holzworth
Chief Mine Engineer	F. H. Buchella, Jr.
Chief Mine Geologist	R. A. Metz
Safety Supervisor	D. L. Gidak
Chief Accountant	S. C. Polasek
Purchasing Agent	J. K. Peters
Personnel Relations Supervisor	J. W. Fortson

John E. Kinnison

– Esperanza Sierrita

VISITOR'S INFORMATION PAMPHLET

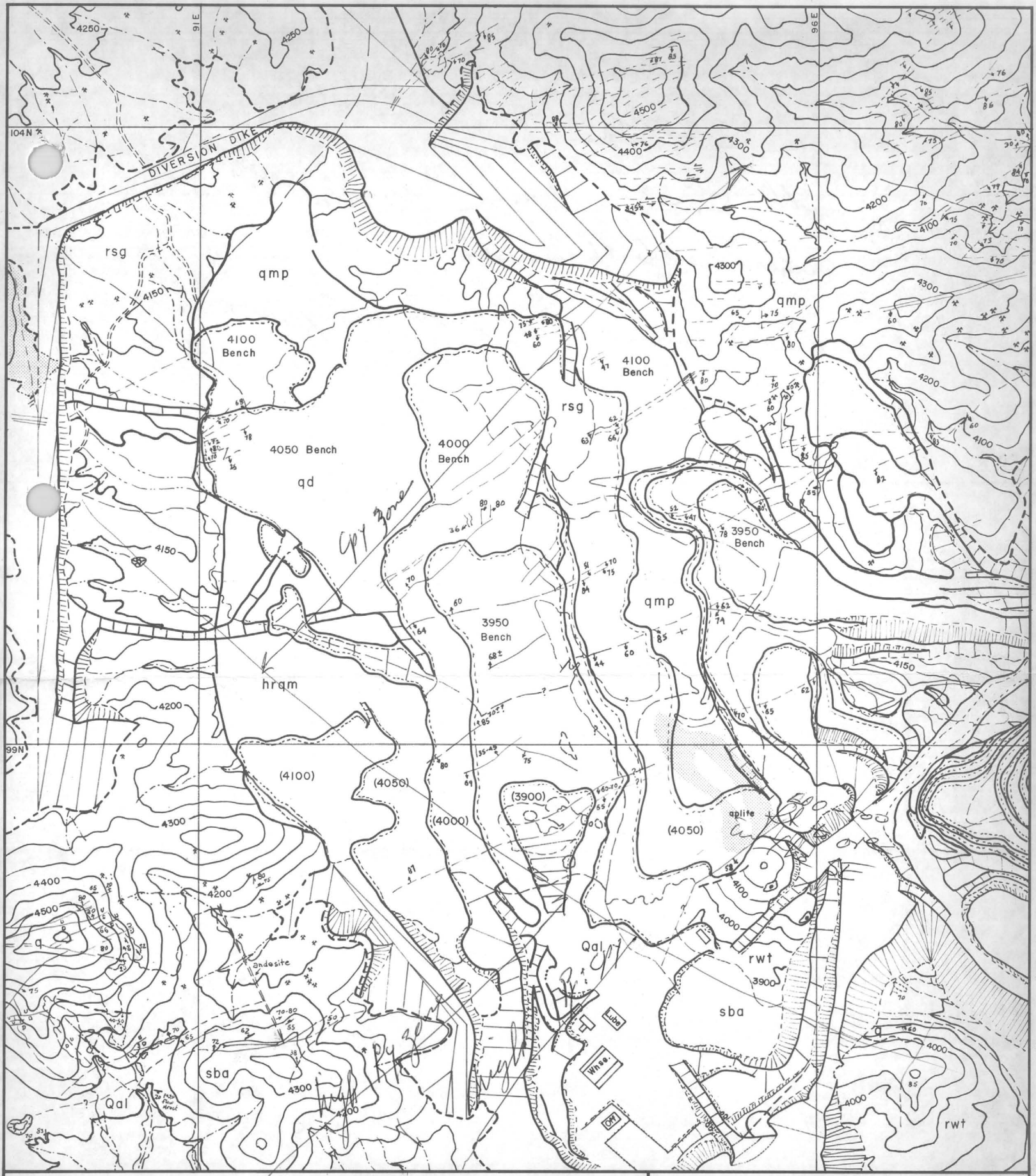
'AL SIERRITA CORPORATION

GEOLOGY DEPARTMENT

A. METZ, CHIEF MINE GEOLOGIST

HARVEY JAMES, MINE GEOLOGIST

BOB GALYON, DRAFTSMAN



EXPLANATION

Qal	— Alluvium, waste dumps,	sba	— Silver Bell (Demetrie) andesite
	— Aplite	qd	— Biotite quartz diorite
	— Massive quartz veins	hrqm	— Harris Ranch quartz monzonite
qlp	— Quartz latite porphyry	rwt	— Oxframe rhyolite welded tuff
qmp	— Quartz monzonite porphyry	q	— Quartzite
rsg	— Ruby Star granodiorite		

DUVAL SIERRITA CORPORATION

SIERRITA PIT GEOLOGY

SCALE: 1" = 1,000'

DATE: 2 / 28 / 69

GEOLOGY BY RAM, AHJ, BLW, DWL, FWM.

DRAWN BY R.B.G.

Sierrita

South Sierrita pit area No Mo
increase to the north

Epidote chlorite in north part of pit

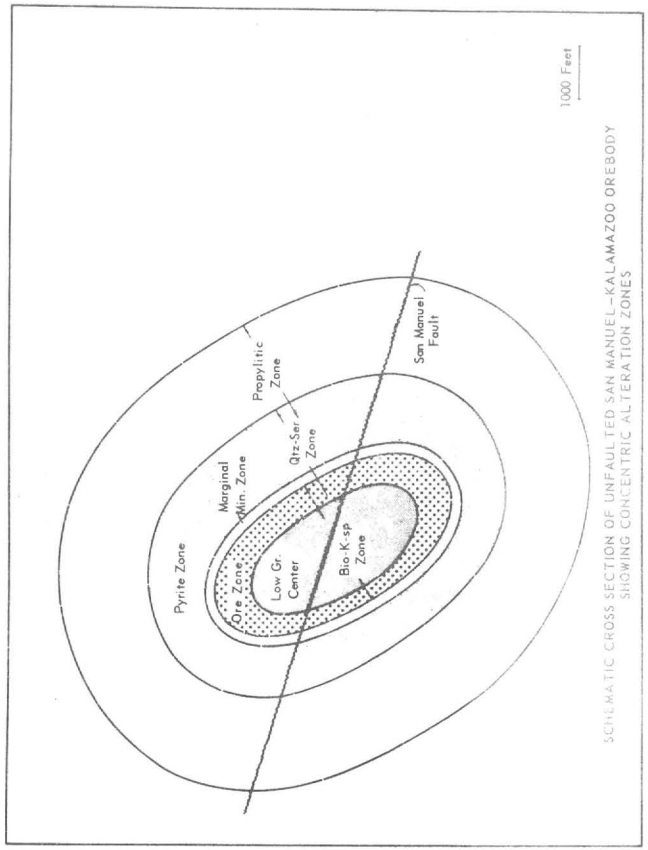


FIGURE 4

SCHEMATIC CROSS SECTION OF UNFAULTED SAN MANUEL–KALAMAZOO OREBODY SHOWING CONCENTRIC ALTERATION ZONES

KALAMAZOO

J. E. K.

MAR 21 1968

PREPRINT NO. 68-I-3

SOCIETY OF MINING ENGINEERS
of AIME
345 EAST 47TH STREET, NEW YORK 17, N. Y.

DISCOVERY AND EXPLORATION OF THE KALAMAZOO OREBODY

J. David Lowell
Consulting Geologist

Tucson, Arizona

This paper is to be presented at the Annual Meeting of the American Institute of Mining, Metallurgical and Petroleum Engineers, New York, New York, February 25-29, 1968

Permission is hereby given to publish with appropriate acknowledgments, excerpts or summaries not to exceed one-fourth of the entire text of the paper. Permission to print in more extended form subsequent to publication by the Institute must be obtained from the Secretary of the Society of Mining Engineers of A.I.M.E.

If and when this paper is published by the Institute, it may embody certain changes made by agreement between the Technical Publications Committee and the author, so that the form in which it appears here is not necessarily that in which it may be published later.

These preprints are available only on a coupon basis. The coupon books may be obtained from SME headquarters for $5.00 a book (10 coupons) for members or $10.00 a book for nonmembers. Each coupon entitles the purchaser to one preprint. Mail completed coupons to PREPRINTS, Society of Mining Engineers, 345 East 47th Street, New York, N. Y. 10017.

PREPRINT AVAILABILITY LIST IS PUBLISHED PERIODICALLY IN MINING ENGINEERING.

DISCOVERY AND EXPLORATION OF THE KALAMAZOO OREBODY

San Manuel District, Arizona

J. David Lowell
Consulting Geologist
Tucson, Arizona

INTRODUCTION

This paper describes the geology of the Kalamazoo copper orebody discovered in the course of an exploration project carried out by Quintana Minerals Corporation under the author's direction in an area immediately southwest of the San Manuel mine, Pinal County, Arizona.

In the period 1943–1947, exploration projects were carried out in the San Manuel area by the U.S. Bureau of Mines and Magma Copper Company which resulted in the development of the San Manuel underground block-cave mine which is now in production at a rate of 41,000 tons per day.

Mining claims covering the area immediately west of the San Manuel orebody were staked in 1946 by Frank F. Salas, R. A. Buzan, H. G. Buzan, and W. C. Buzan of Mammoth, Arizona. These claims were optioned to Martha Purcell in 1946, and in the period of 1947–1958 seven churn drill holes ranging in depth from 1,400 to 2,950 feet were drilled by Mrs. Purcell. These holes did not intersect ore and no further deep exploration was attempted prior to the Quintana Minerals project which began in August, 1965, and which is described in this report.

The Kalamazoo deposit is in Sections 3, 4, 9, and 10, T 9 S, R 16 E, Pinal County, Arizona, and it is reached by driving seven miles east from Oracle, Arizona (Figure 1).

The writer is indebted to Corbin J. Robertson and Ronald B. Thompson who participated in the exploration planning of this project and to a number of other individuals who contributed to its execution and management. Petrographic work by J. M. Guilbert was used as a basis for rock and alteration classifications.

SUMMARY

Twenty-five exploration drill holes have been completed in the Kalamazoo project to an average depth of about 4,000 feet. These holes

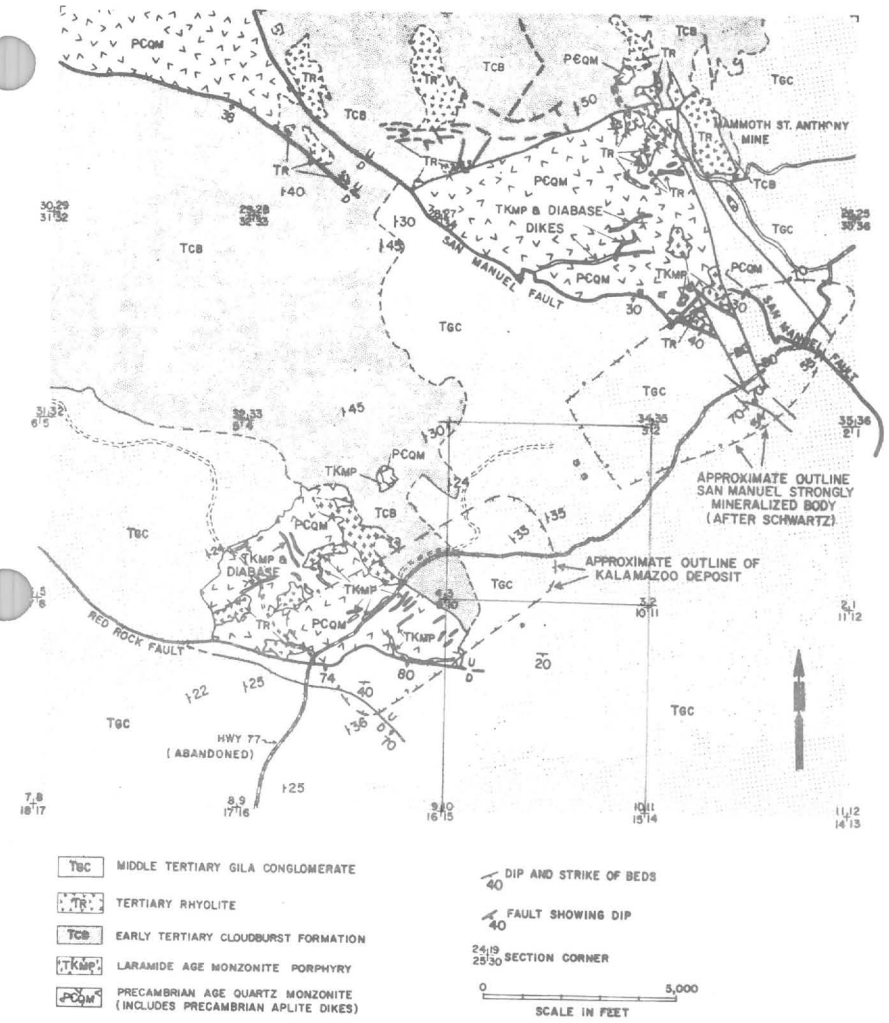
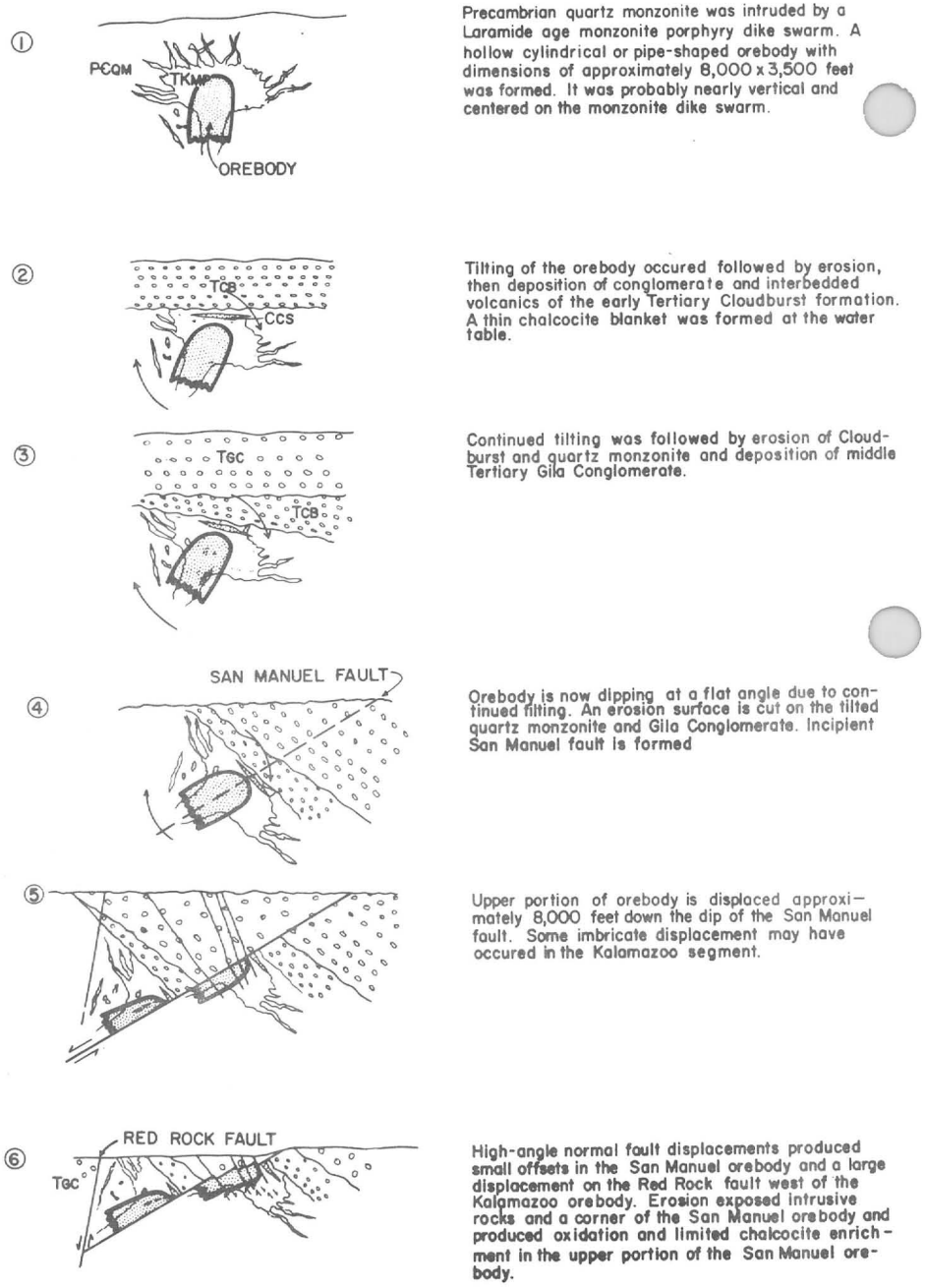


FIGURE 3



Precambrian quartz monzonite was intruded by a Laramide age monzonite porphyry dike swarm. A hollow cylindrical or pipe-shaped orebody with dimensions of approximately 8,000 x 3,500 feet was formed. It was probably nearly vertical and centered on the monzonite dike swarm.

Tilting of the orebody occured followed by erosion, then deposition of conglomerate and interbedded volcanics of the early Tertiary Cloudburst formation. A thin chalcocite blanket was formed at the water table.

Continued tilting was followed by erosion of Cloudburst and quartz monzonite and deposition of middle Tertiary Gila Conglomerate.

Orebody is now dipping at a flat angle due to continued tilting. An erosion surface is cut on the tilted quartz monzonite and Gila Conglomerate. Incipient San Manuel fault is formed

Upper portion of orebody is displaced approximately 8,000 feet down the dip of the San Manuel fault. Some imbricate displacement may have occured in the Kalamazoo segment.

High-angle normal fault displacements produced small offsets in the San Manuel orebody and a large displacement on the Red Rock fault west of the Kalamazoo orebody. Erosion exposed intrusive rocks and a corner of the San Manuel orebody and produced oxidation and limited chalcocite enrichment in the upper portion of the San Manuel orebody.

Schematic Drawing Showing Possible Origin of Kalamazoo Orebody

FIGURE 2

have delineated a disseminated copper orebody which, on the basis of indicated tonnage figures, will rank as one of the large copper orebodies of North America. The project was based on a new interpretation of the origin and geology of the San Manuel orebody which assumed that the original cylindrical orebody had been first tilted approximately 70° to the east, then bisected by the flat San Manuel fault into the lower plate San Manuel orebody and the upper plate Kalamazoo orebody.

GEOLOGY OF THE SAN MANUEL DISTRICT

The geology of the San Manuel area has been described by Steele and Rubly (1947), Schwartz (1953), Pelletier (1957), Creasey (1965), and Thomas (1966).

Precambrian quartz monzonite of the Oracle granite batholith in the San Manuel area was intruded in Laramide time by swarms of monzonite porphyry dikes and irregular monzonite porphyry masses. The rock classified as monzonite porphyry can be subdivided into a range of rock types including quartz latite porphyry, quartz monzonite porphyry, monzonite porphyry, biotite dacite porphyry, and probably other rock types. Some of these rocks appear to be slightly later than others, but all are closely related in time and all are apparently pre-ore in age. A few diabase dikes are also present in the Laramide-age dike swarms. Closely related in time with this Laramide intrusive activity was a pulse of porphyry copper-type mineralization which produced the San Manuel-Kalamazoo orebody and its associated hydrothermal alteration zones. The axis of the hydrothermal system seems to have been centered in the middle of one of the monzonite porphyry dike swarms. Following emplacement of hydrothermal mineralization and alteration, district-wide structural displacements occurred which produced northeasterly tilting and probably resulted in elevation of the block which included the San Manuel-Kalamazoo orebody. Erosion cut into this block forming the Cloudburst erosion surface and exposing a small corner of the orebody. Supergene activity produced a thin chalcocite enrichment blanket. At this time the long axis of the orebody may have dipped at an angle of about 65° (see Fig. 2). Some postore andesite porphyry dikes may be of immediate postore, pre-Cloudburst age, and extrusive andesitic flow rocks were also interbedded with detrital sediments and pyroclastics of the Early Tertiary Cloudburst formation which was deposited on this surface. Further igneous activity following the Cloudburst sedimentation resulted in the emplacement of andesite and rhyolite dikes.

Further tilting, averaging perhaps 15°, followed deposition of the Cloudburst formation. It seems likely that tilting was accompanied by renewed elevation of the fault block since the block was again beveled by the erosion surface on which the Gila Conglomerate was later deposited. A third stage of about 30° of tilting moved the Gila Conglomerate into its present inclination and brought the long axis of the San Manuel-Kalamazoo orebody into a 20° west-dipping attitude. As seen on Fig. 2, the San Manuel fault then diagonally bisected and offset the total orebody into two pieces: the San Manuel and the Kalamazoo. It is uncertain whether the San Manuel fault displacement occurred before or after the last stage of tilting, but the fault has several characteristics

Kalamazoo orebody which represents pre-San Manuel fault tilt of the San Manuel-Kalamazoo orebody. Some plunge may also result from overriding related to flat fault displacements. In spite of this plunge, a very large tonnage of ore is accessible in the projected first block-cave lift. The general configuration of the San Manuel orebody is that of an upright canoe, and the ore taken in the first San Manuel block-cave lift consisted of the upper portions of the two canoe walls. The Kalamazoo orebody, on the other hand, has the shape of an overturned canoe, and the first lift ore will consist of the relatively wide, relatively flat canoe bottom. This ore block will be overlain by the marginal mineralization zone so that block-cave dilution material will average about 0.35% Cu which will increase the average grade of the mill heads. The Kalamazoo ore lacks any chalcocite enrichment, but the ore is also free of oxide copper content which will tend to increase flotation recovery. The molybdenum content of the ore falls in the same range as in the San Manuel orebody, and the ore contains a small recoverable gold and silver content.

The rock in the Kalamazoo orebody appears to be well suited to block-caving mining under conditions similar to those found in the nearby San Manuel mine. The geothermal gradient of the Kalamazoo area averages about 0.9°F per 100 feet of depth, and the rock temperatures in the first mining lift will probably be in the range of 100°–105°F.

REFERENCES CITED

Creasey, S. C., 1965, Geology of the San Manuel area, Pinal County, Arizona: U.S.G.S. Prof. Paper 471, 64 pp.

Heindl, L. A., 1963, Cenozoic geology in the Mammoth area, Pinal County, Arizona: U.S.G.S. Bulletin 1141-E, 41 pp.

Pelletier, J. D., 1957, Geology of the San Manuel mine: Mining Eng., July, p. 760.

Schwartz, G. M., 1953, Geology of the San Manuel copper deposit, Arizona: U.S.G.S. Prof. Paper 256, 63 pp.

Steele, H. J., and Rubly, G. R., 1947, San Manuel prospect: Am. Inst. Min. Met. Eng., Tech. Pub. 2255, Mining Technology, vol. 11, no. 5, 12 pp.

Thomas, L. A., 1966, Geology of the San Manuel Ore Body, In Titley, S. R., and Hicks, C. L. (eds.), Geology of the Porphyry Copper Deposits, Southwestern North America, the University of Arizona Press, Tucson, Arizona, pp. 133-142.

Wilson, E. D., 1957, Geologic factors related to block caving at San Manuel copper mine, Pinal County, Arizona: U.S. Bur. Mines Rept. Inv. 5336, 78 pp.

Zones of Mineralization

1. The low-grade center zone averages about 2,600 feet in diameter and about 0.3% Cu in grade. Total sulfide content is low with a pyrite-to-chalcopyrite ratio of about 1:2.

2. The ore shell averages about 600 feet in thickness and ranges in grade from 0.5%–1.0% Cu. The pyrite-to-chalcopyrite ratio is about 1:1.

3. The marginal mineralization zone which surrounds the ore shell averages about 200 feet in thickness and ranges in grade from 0.1%–0.5% Cu. The pyrite-to-chalcopyrite ratio is about 10:1.

4. The pyritic zone which surrounds the marginal mineralization zone ranges in thickness from about 1,000–1,500 feet and ranges in grade from 0.01%–0.10% Cu, averaging about 0.03% Cu. It contains from 6%–25% pyrite by weight, averaging about 10% pyrite.

Zones of Alteration

1. The inner alteration zone of the San Manuel-Kalamazoo orebody consists of biotite K-feldspar alteration (Fig. 4).

This intense potassic alteration produced fresh-looking secondary minerals which led to the incorrect conclusion on the part of previous workers that this alteration zone represented alteration weaker than that of the surrounding zones. The intense phase of biotite K-feldspar alteration tends to produce an alteration product which somewhat resembles in texture the fresh Precambrian quartz monzonite. This alteration is not nearly as obvious as alteration effects in the surrounding quartz-sericite zone which represents weaker hydrothermal conditions but more obvious destruction of rock textures.

2. A zone of quartz-sericite alteration generally includes all of the marginal mineralization and pyritic zones and overlaps the biotite K-feldspar alteration in the outer part of the ore shell. The zone contains sections of spectacular, pervasive pyrite mineralization where pyrite sometimes constitutes more than 20% by weight of the rock.

3. Surrounding and overlapping the quartz-sericite zone is a zone of propylitic alteration in which chlorite, epidote, and minor carbonates are developed. Pyrite content by weight averages 4%.

This zone fades out gradually away from the orebody and may have a total thickness of 2,000 feet or more. The configuration of the alteration zone is apparently not related in detail to the distribution of monzonite porphyry bodies.

Alteration zones in this deposit, as in most porphyry copper deposits, are rather poorly defined and overlapping. Various host rocks respond in different ways to alteration solutions to produce somewhat different alteration products within the same volume and apparent alteration facies. Alteration zones are more clearly defined here than in most

porphyry deposits, however, because the original San Manuel-Kalamazoo orebody had unusually uniform boundaries and a symmetrical configuration. This probably resulted from the fact that alteration and mineralization affected intrusive host rocks which were of generally similar chemical composition and of essentially isotropic fabric.

The San Manuel-Kalamazoo orebody has unique genetic significance in the study of porphyry copper deposits because of the great length (or original height) of the original vertical column of mineralization. If the orebody has been tilted approximately 70° as postulated, then the west end represents ore mineralization which was originally about 8,000 feet deeper than the east end. Including the pyritic halo exposed east of the San Manuel orebody together with mineralization in drill intercepts in the lower plate of the San Manuel fault below the Kalamazoo orebody, it is possible to partly reconstruct vertical mineral zoning changes over an original vertical column of perhaps 13,000 feet.

GEOLOGICAL PREMISES FOR KALAMAZOO PROJECT

Prior to the initiation of the Kalamazoo project, it had been assumed by the writer (1) that the San Manuel low-grade center and its potassic alteration represented the most, rather than the least, intense alteration zone present and, therefore, perhaps the core of an original cylindrical-shaped orebody, and that this original orebody would have had coaxial alteration and mineralization zones which would complete the cylindrical symmetry found truncated at San Manuel; (2) that evidence existed for at least 45° of tilting of this cylindrical-shaped orebody and that it was reasonable to postulate additional tilting in pre-Cloudburst time so that the cylinder could have been originally in a near-vertical position typical of pipe-like porphyry copper deposits; and (3) that the direction of displacement in the San Manuel fault could more logically have been in a down-dip direction rather than having had 10,000 feet of strike-slip displacement as postulated by Creasey (1965), or having had reverse fault displacement as postulated by Wilson (1957) and Heindl (1963).

Initial investigation involved reviewing the geologic and assay logs and drill cuttings samples from the old Purcell drill holes. It was found that four of these holes apparently penetrated from weakly pyritic propylitic alteration into a strongly pyritic, quartz-sericite zone at depth, and one hole apparently bottomed in mineralization typical of the San Manuel marginal mineralization zone. The geometry of these intersections together with the projection of the San Manuel fault plane approximately determined the position of the cylindrical-shaped Kalamazoo pyritic zone.

A geochemical soil survey was carried out in the pre-ore outcrop area of the Purcell claims. This survey produced a moderately well-defined copper and molybdenum anomaly which was later found to overlie the Kalamazoo orebody. The anomaly probably represents

the outcrop of a cylindrical shell of comparatively copper-rich (± 0.04% Cu) propylitic alteration. Assaying the soil samples for total Fe produced a less well-defined anomaly approximately centered on the orebody which is thought to represent the outcrop of a shell of pyrite mineralization within the propylitic zone but outside the strong pyritic zone. The geochemical survey was not diagnostic in itself but did serve as additional evidence for the location of the faulted segment.

Elevations of intersections of San Manuel drill holes with the San Manuel fault were compiled from U.S.G.S. Professional Paper 256 and were contoured in a structure contour map of the San Manuel fault. This map showed large ridges and valleys in the fault surface which formed a large-scale mullion structure consistent with either up-dip reverse faulting toward the northeast or down-dip normal faulting to the southwest. Reverse faulting would imply erosional destruction of the segment faulted away from San Manuel, while normal faulting was consistent with stratigraphic relationships, geochemical results, and observed alteration patterns. The Kalamazoo orebody was located by the first deep drill hole spotted according to the normal faulting interpretation and the other evidence cited.

KALAMAZOO EXPLORATION PROJECT

The first Quintana Minerals Corporation drill hole penetrated through Gila Conglomerate and Cloudburst formation into monzonite porphyry in which it passed from propylitic into quartz-sericite alteration. The hole passed from the pyritic and marginal mineralized zones into ore-grade mineralization at about 2,500 feet. From structural considerations it appeared that the axis of the Kalamazoo orebody might have an orientation of N 57° E. A 600-foot rectangular drill grid on a N 33° W and N 57° E orientation was laid out centered on the first drill hole. It was planned first to bracket the width of the orebody with a N 33° W fence of holes, then bracket the length with a N 57° E fence of holes. The 600-foot intersections would then be drilled followed by center holes in each 600-foot square in the area to be initially developed for mining. This pattern would result in a final hole spacing equivalent to a 425-foot rectangular grid. The unique opportunity for extrapolating geology and symmetry of mineral zones from the San Manuel deposit has made it possible to intersect the Kalamazoo orebody with every hole completed to date.

Typical holes in the project were drilled to a depth of about 3,000 feet by the relatively cheap rotary drilling method. Core point of 0.2% Cu was determined by assaying rotary cuttings using a field analytical method. The final intercept of approximately 1,000 feet which contains the marginal and ore zones was completed with NX wireline core drilling by the same drill rig. No casing was used. Holes were drilled with oil field type rotary drill rigs equipped with 125-foot masts, automatic bit pressure controls, and geolograph recorders.

Exploration has indicated some southwesterly plunge to the