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STRUCTURAL GEOLOGY OF THE RAY MINE

RECENT DEVELOPMENTS

by

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INTRODUCTION

The Ray Mine stands apart from most porphyry copper deposits for the complexity of its structural geology. The complexity is exemplified in the professional literature by the history of the Diabase Fault over the life of the mine, as shown on the attached table. The dip of the fault was thought to be easterly from the 1916 publication by Spurr until the 1966 publication by Metz and Rose, when the dip became westerly. Movement on the fault was considered in the literature to be east side down until the 1971 publication of the Sonora Quadrangle by Cornwall, Banks and Phillips, when this sense of movement was reversed. The interpretation of displacement along the Diabase Fault ranges from a few hundred feet in the 1919 publication by Ransome to a "proven minimum" of 2,000 feet in Metz and Rose's 1966 publication.

In 1974 John Witner and the writer redefined the location of the Emperor Fault in the West Pit area and proposed a model to explain the nature and age of the fault's main movement. As part of an in-company slope stability investigation of the West Pit south wall, we concluded, in agreement with work by Wray in 1971, that the trace of the Emperor Fault does not form a complete circle in the Pearl Handle Pit; rather, it

crosses the south side of Emperor Hill. The 1974 report finds that the Emperor Fault separates the oxidized West Pit north wall from the unoxidized West Pit south wall. A large fault interpreted as the Emperor was mapped up the West Pit west wall and projects over Granite Mountain to the southwest.

On Emperor Hill the geology has been redefined by careful pit mapping in conjunction with prospect hole logging. An east-west trending horst block exposes the diabase/Apache Group sequence on the surface of the Emperor Hill area. North and south of the horst, the diabase/Apache Group sequence is structurally covered by schist in the upper plate of the Emperor Fault. The western portion of the horst block is lower plate schist down-section from the diabase/Apache Group sequence.

An apparent breccia pipe occurs at, and just south of, the extreme western end of the horst block. This structure involves clasts of Pioneer Formation, Scanlan Conglomerate, Pinal Schist and diabase.

DIABASE FAULT

The most obvious fault systems at the Ray Mine are the Diabase and Emperor Faults. Several other significant faults are documented in the mine area, including the Bishop, Empress, North End, Sun, West End, Consuelo and School Faults. In the silicate orebody there is at least one additional unnamed fault with several hundred feet of displacement.

The Diabase Fault is a moderately to steeply westerly dipping normal fault, characterized by several tens of feet of gougy, broken and brecciated rock and up to a few feet of strong gouge. In the Pearl Handle Pit, the hanging wall of the Diabase Fault contains the downthrown diabase/Apache Group sequence, which is overlain by schist in the upper plate of the Emperor Fault. The diabase/Apache Group sequence is underlain by basement Pinal Schist. The pre-Tertiary footwall rocks in the same area consist of the diabase/Apache Group sequence.

In the northern corner of the Pearl Handle Pit the normal displacement is about 800 feet, west side down. Southeastward in the mine area the displacement increases to more than 2,000 feet. The Diabase Fault in the Pearl Handle Pit terminates the Emperor Fault to the east; east of the

Diabase Fault, the Emperor Fault is upthrown and eroded away. The hypogene orebody occurs mostly in diabase within the lower Apache Group rocks, which are offset along the Diabase Fault.

EMPEROR FAULT

The Emperor Fault is commonly characterized by several feet of dense, dark gouge and up to tens of feet of gougy, broken and brecciated rock. On the whole, the fault dips about 10 to 30 degrees easterly in the Pearl Handle Pit and northerly in the West Pit. The upper plate, consisting of schist, some porphyry and minor diabase, overlies schist, some porphyry and the diabase/Apache Group sequence in the mine area.

In the Pearl Handle Pit, the Emperor Fault is downthrown in the hanging wall of the Diabase Fault and eroded away in the footwall. A minimum displacement of about 3,000 feet along the Emperor Fault is indicated where schist overlies the diabase/Apache Group sequence. The large amount of schist in the upper plate of the Emperor Fault dictates a westerly source area for that plate.

Geologic pit maps prior to 1975 show the trace of the Emperor Fault as a circle in the Pearl Handle Pit with a ridge of upper plate rocks between Sonora-Barcelona and the two pits. The first step toward the present interpretation of the Emperor Fault was taken by Wray in a 1971 in-company report. Wray mapped the fault correctly in the south Emperor Hill and Sonora-Barcelona areas. In the Barcelona area, the Emporor Fault plane is exposed on original ground forming the dip slope. This is the western termination of the ridge

of upper plate rocks in the Sonora area. In the area between south Emperor Hill and the West Pit floor, Wray shows a sharp southwestward bend in the Emperor Fault trace. The southwestward trace is currently believed to be an unrelated fault.

The Emperor Fault in the northern Pearl Handle Pit is very near the contact between hematitic leached cap and unoxidized, enriched sulfide-bearing rocks. In this area the Emperor Fault is near the "red-to-gray" contact. The 1967 Ray series 1,000-scale color aerial photography shows the red-to-gray contact crossing south Emperor Hill and tracing across the floor of the West Pit to the west wall. There a large fault fitting the description and general attitude of the Emperor was mapped continuously down the recently mined upper half of the west wall, and was visible down the lower half of the west wall to the lake at the floor of the West Pit. This is believed to be the westernmost expression of the Emperor Fault in the mine area.

The red-to-gray rule-of-thumb for locating the Emperor Fault is not applicable west of the West Pit floor nor south of the Pearl Handle Pit extension. In these areas the hematitic oxidation decreases in the upper plate of the Emperor Fault to an irregular oxidation contact. In the Pearl Handle Pit extension there is ore grade (+0.4% Cu) primary as well as secondary sulfide mineralization in both plates of the Emperor Fault.

On Emperor Hill the proximity of the Emperor Fault to the oxidation, or red-to-gray, contact is somewhat variable. In drill core from one recent Emperor Hill hole, the main gouge zone precisely separates leached cap from high-grade (+1.0% Cu) secondary sulfide enrichment. In a second recent hole 250 feet from the first hole, there is 400 feet of high-grade secondary sulfide enrichment with mostly weak oxidation above the fault and more than 100 feet of high-grade secondary sulfide enrichment below the fault, as one continuous ore intercept. On south Emperor Hill, where the 2020 level intersects the Emperor Fault, the main gouge zone is 25 feet below the oxidation contact.

Two older diamond drill holes on south Emperor Hill intersect the Emperor Fault at the depths predicted using the new trace of the fault across Emperor Hill and the mapped 30-degree dip. Hole 881 intersects seven feet of greenish-gray gouge 44 feet below the first sulfides and eight feet above the oxidation contact. Hole 882 encounters a 33-foot gouge zone starting 103 feet below the first sulfides and very near the oxidation contact. A 1977 hole was drilled 450 feet south of hole 881 and south of the new trace of the northward dipping Emperor Fault. The new hole drilled through rocks believed to be upper plate according to the old Emperor Fault interpretation and lower plate according to the new interpretation. This hole proved the new interpretation to be correct. No substantial fault was inter-

sected, and the schist facies encountered from the surface is a more mafic, sometimes mottled facies characteristic of the lower plate in the Emperor Hill area. The same mottled lower plate facies was intersected below the Emperor Fault in hole 881, and a more mafic schist was logged in the lower plate portion of hole 882. It is recognized that the observed schist facies changes may, at least partly, be produced by supergene leaching effects.

This writer agrees with Wray's 1971 in-company report description of the Emperor Fault as a gravity slide rather than a thrust fault. A causative mechanism was proposed in Witner and the writer's 1974 in-company report that would date the main movement of the Emperor Fault. The Granite Mountain Porphyry, with age dates of 60 and 63 million years (Banks and others, 1972), is commonly described in the literature as mushrooming out above the Emperor Fault. In some areas of the mine, the mushrooming concept yields to the likelihood of Granite Mountain Porphyry offset along the Emperor Fault.

The largest stock of Granite Mountain Porphyry in the Ray area centers at Granite Mountain, three miles southwest of the Pearl Handle Pit. The intrusion of this stock would have uplifted the area, causing a gravity slide that moved to the northeast over the Ray Mine area with a shallow northeasterly dip. Further uplift on Granite Mountain to the west

and downfaulting along the Diabase Fault to the east steepened the dip on the Emperor Fault. This mechanism would set the age of the main movement along the Emperor Fault at 60 to 63 million years ago. Since the slide movement would have occurred during the time of Granite Mountain Porphyry intrusion, porphyry masses may have intruded the upper plate both slightly before and after the main movement. Consequently, some porphyry masses would be offset while others would not.

The drilling data, consisting of more than 1,000 diamond drill holes and several hundred churn drill holes, gives no indication of major post mineral displacement along the Emperor Fault. There is hypogene mineralization, some of which is ore-grade (+0.4% Cu), in both plates of the Emperor Fault in the same area. The flat secondary sulfide enrichment blanket clearly crosses the gently dipping Emperor Fault in the Pearl Handle Pit-Emperor Hill area. At the intersection of the enrichment blanket with the Emperor Fault, secondary sulfide ore is commonly found in both plates of the fault within a single drill hole.

It is likely that the Emperor Fault has experienced recurrent minor movements since the episode of major movement. Sulfides in the fault are sheared and thin sheets of native copper are found that exhibit obvious shearing effects. On the other hand, an undisrupted one-half inch thick chalcocite vein occurs in hole 1075 six inches below the Emperor Fault main gouge zone. Between the 1740 and 1780 levels of the

northern Pearl Handle Pit, substantial amounts of Emperor Fault gouge-mylonite with obvious fluxion structure were collected for the native copper content. Unsheared seams of native copper invade the gouge-mylonite along seams of fluxion structure, demonstrating an absence of post native copper movement.

In plan view, central to the horseshoe-shaped hypogene ore zone (Phillips and others, 1974), there are three apophyses of Granite Mountain Porphyry outcropping at about 2500 feet elevation. A review of the diamond drilling data and correlation of the geologic sections and cross-sections adds significance to the central Granite Mountain Porphyry apophyses. The data are permissive if not indicative of a coalescence at depth of the apophyses into the largest stock of Granite Mountain Porphyry in the mine. The main body of this stock appears to be about 2,000 feet wide at sea level. The central relationship of this stock to the geometric hypogene copper zoning suggests strongly that this central Granite Mountain Porphyry stock is the parent intrusive for the Ray orebody. Since only apophyses of porphyry occur at the present surface, it seems likely that the level of erosion at Ray is high in the sulfide system and relatively little hypogene ore has been lost.

EMPEROR HILL

Pre-1976 geologic pit maps show an island of Dripping Spring Quartzite in a sea of schist on north Emperor Hill. The Dripping Spring Quartzite block is about 1,000 feet long and 500 feet wide. It is commonly depicted with faulted boundaries and speculation existed that this was an allochthanous megabreccia slide block from the Dripping Spring Mountains. The area was known to be complexly faulted, but was poorly understood due to the presence of schist on both sides of most faults.

An intensive pit mapping program was undertaken by the writer in late 1975 in order to unravel the structural complexity of the Emperor Hill area. Detailed pit mapping was conducted on a daily to semi-weekly basis in conjunction with prospect hole logging. The following geologic picture emerged.

Six major faults were traced across Emperor Hill in order to clarify the geologic setting. According to the previous interpretation, the surface on Emperor Hill was in the upper plate of the Emperor Fault. The present study reveals a horst block of lower plate rocks in the area of the previously mapped Dripping Spring Quartzite block. The quartzite is part of the diabase/lower Apache Group sequence exposed beneath the Emperor Fault in the Pearl Handle

Pit. The Emperor Fault was uplifted and eroded away in the horst block area.

From east to west, in plan view, the Emperor Hill portion of the horst block consists of Quaternary alluvium, 400 feet of Dripping Spring Quartzite, 450 feet of diabase, 100 feet of Pioneer Formation, 10 feet of steeply to moderately eastward dipping Scanlan Conglomerate, 900 feet of Pinal Schist, 200 feet of an apparent breccia pipe, and mine dump. The east-west trending horst block is adjoined to the south by schist in the upper plate of the Emperor Fault, where drilling information shows the Emperor Fault to be a few hundred feet deep. The area north of the horst block is geologically complex and poorly understood. Immediately north of the horst block diabase/Apache Group sequence, the same diabase/Apache Group sequence is overlain by several hundred feet of schist. This schist blanket was eroded away in the Tertiary basin northeast of the exposed horst block.

The northern horst block bounding fault dips 90 to 70 degrees southward. Although it is locally referred to as the north branch of the North End Fault, it is interpreted to be the same fault as the North End Fault in the West Pit. In the horst block area, the expression of the fault ranges from one foot of breccia with a hematitic silty matrix to several feet of gouge and gougy rock.

The southern horst block bounding fault dips steeply to moderately southward, with steeper dips to the east and more moderate dips to the west. Although this fault is

called the south branch of the North End Fault in the horst block area, it is interpreted to be the western portion of the Diabase Fault. The horst block, therefore, resulted from the union of two steep faults with opposite senses of movement.

The expression of the south branch of the North End Fault normally consists of one or more feet of gouge and up to tens of feet of gougy rock; however, in the southwestern horst block area, the fault becomes quite tight. There is little doubt that the tight fault mapped in this area is the same fault, since it separates a sericitic schist facies to the south from an arkosic/mafic schist facies to the north, as does the larger fault.

Stratigraphic relationships put some time constraints on the ages of movement of the horst bounding faults. The south branch of the North End Fault, or western Diabase Fault, was covered on the original surface by a small patch of Whitetail Conglomerate and Apache Leap Tuff. The concealed fault trace bisected the Tertiary cover. Movement along this fault was therefore pre-mid Tertiary. It is interesting for comparison to note that in the Pearl Handle Pit extension, a small block of Apache Leap Tuff on Pinal Schist was mined in the hanging wall of the Diabase Fault.

The minimum displacement along the western Diabase Fault, based on the depth of the Emperor Fault and the current topography, is around 300 feet. However, the original topography

on Emperor Hill contributes an additional 600 feet to the likely minimum displacement along the western Diabase Fault.

The eastern North End Fault shows a minimum displacement on the order of a few hundred feet where Apache Leap Tuff is faulted against Big Dome Formation northeast of Hagen's Dam. However, there may have been additional movement prior to the development of the Tertiary basin.

The upper plate of the Emperor Fault south of the horst block contains an important fault associated with a thin diabase sill. This is the Empress Fault, which was first mapped in earlier mine exposures. The Empress Fault and its associated diabase sill were folded into a syncline on the northeastern side of the Bishop Fault. The Empress Syncline is probably the result of drag folding along the western Diabase Fault. Southwest of the Bishop Fault, at a farther distance from the western Diabase Fault, only the "south limb" of the Empress Fault has been found. The offset of the Empress Fault along the moderately westerly dipping Bishop Fault is the same as that of the underlying Emperor Fault--30 feet, west side down. In addition, the attitude of the Empress Fault is exactly conformable to that of the Emperor Fault on the southwest side of the Bishop Fault. Genetically, the Empress Fault is probably an imbricate structure relating to movement along the Emperor Fault. The lack of any indication from earlier mapping that the Empress Fault folds also tends to confirm the drag folding hypothesis.

The Empress Fault is generally characterized by up to a few feet of dense limonitic gouge and many feet of strongly sheared diabase. The thickness of the diabase sill associated with the Empress Fault averages around 10 to 20 feet. Like the Emperor Fault, the Empress Fault dips about 30 degrees to the northwest in the hanging wall of the Bishop Fault. A peculiar feature of the Empress Fault is that the gouge zone sometimes occurs at the upper diabase contact, sometimes at the lower diabase contact, and sometimes bisects the diabase or occurs anywhere within the diabase sill. The 1977 geologic pit map shows that a small patch of apparent Whitetail Conglomerate covers the Empress Fault, indicating a pre-mid Tertiary age of movement.

On Emperor Hill, the Bishop Fault is a comparatively small fault, expressed by only a few inches or less of hematitic gouge. This westerly dipping normal fault shows 30 feet of post Emperor/Empress Faults movement. A generally moderate west-northwesterly schistosity dip is retained across the Bishop Fault.

The last significant feature to be recognized as a result of the Emperor Hill pit mapping program is an apparent new breccia pipe near the western end of the horst block. Like the Calumet Breccia Pipe, this pipe is probably related to the post ore (60 million year old) Teapot Mountain Porphyry. An old diamond drill hole in the pipe intersects several Teapot Mountain Porphyry dikes.

The breccia pipe is located within and just south of the westernmost end of the horst block. Surface mapping indicates fragments of Pinal Schist, Scanlan Conglomerate, Pioneer Formation, and diabase are involved in the brecciation. The surface of the pipe is commonly intensely limonitic. The lateral distance to the nearest Apache Group rocks within the horst block is 750 feet. It is not clear at this time what the nature of movement was within the pipe in order to accomplish the substantial apparent lateral offset of Apache Group rocks. Little drilling information is available since this is a poorly mineralized area.

DIABASE FAULT

Date	Author(s)	Paper	Structure	Dip	Movement	Displacement
1916	J. E. Spurr	The relation of ore deposition to faulting: Econ. Geol., v.11.	"Ray Fault"	Easterly	East side down	1000-2000 ft.
1919	F. L. Ransome	The copper deposits of Ray and Miami, Arizona: USGS PP 115.	"Mineral Creek-Ray Fault"	Easterly	East side down	100-600 ft.
1952	O. M. Clarke	Structural control of ore deposition at Ray, Arizona: AGS Guide for Field Trip Excursions in Southern Arizona	"Ray Fault"	Easterly	East side down	1000-2000 ft.
1966	R. A. Metz, A. W. Rose	Geology of the Ray copper deposit, Ray, Arizona: Geology of the Porphyry Copper Deposits, Southwestern North America	"Diabase Fault"	Westerly	East side down	"Proven minimum" 2000 ft.
1968	R. A. Metz, C. H. Phillips C. R. Caviness	Recent developments in the geology of the Ray area: AGS Southern Arizona Guidebook III	"School-Ray-Diabase Fault"	Westerly	East side down?	More than 1500 ft.
1971	H. R. Cornwall, N G. Banks, C. H. Phillips	Geologic Map of the Sonora Quadrangle, Pinal and Gila Counties, Arizona	"Diabase Fault"	Westerly	West side down	1200 ft.
1974	C. H. Phillips, N. A. Gambell, D. S. Fountain	Hydrothermal alteration, mineralization, and zoning in the Ray deposit: Econ. Geol., v.69, no. 8	"Diabase Fault"	Westerly	Either east or west side down	More than 1500 ft.
1977	S. A. Hoelscher	Structural geology of the Ray mine - recent developments: Spring Meeting AIME Mining Geology Division	"Diabase-North End (South Branch)Fault"	Westerly	West side down	Less than 800 ft, to more than 2000 ft.

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Banks, N. G., Cornwall, H. R., Silberman, M. L., Creasey, S. C., and Marvin, R. F., 1972, Chronology of intrusion and ore deposition at Ray, Arizona--Part I, K-Ar ages: Econ. Geol., v. 67, p. 864-878.

Phillips, C. H., Gambell, N. A., and Fountain, D. S., 1974, Hydrothermal alteration, mineralization and zoning in the Ray deposit: Econ. Geol., v. 69, p. 1239-1246.

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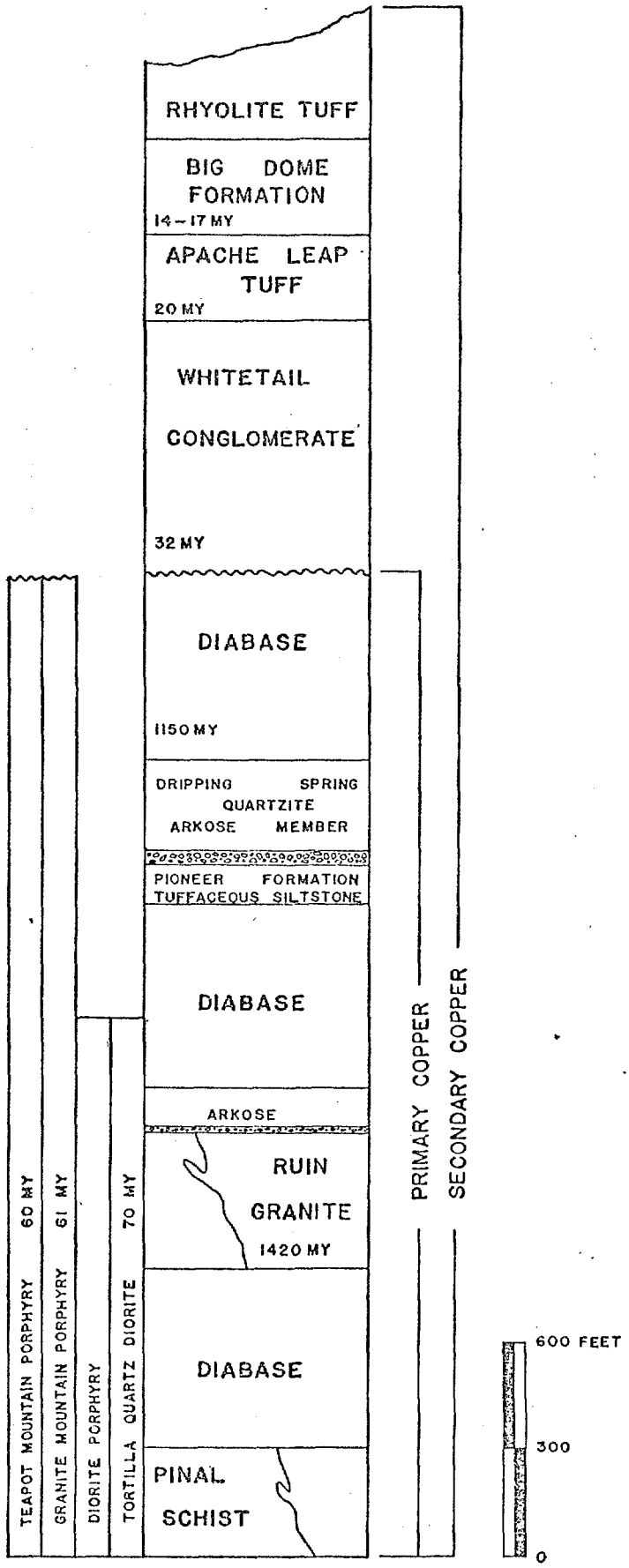
Econ Geol. vol. 69, No. 8, p. 1237-1250. (1974)


RHYOLITE TUFF
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DRIPPING SPRING QUARTZITE
ARKOSE MEMBER
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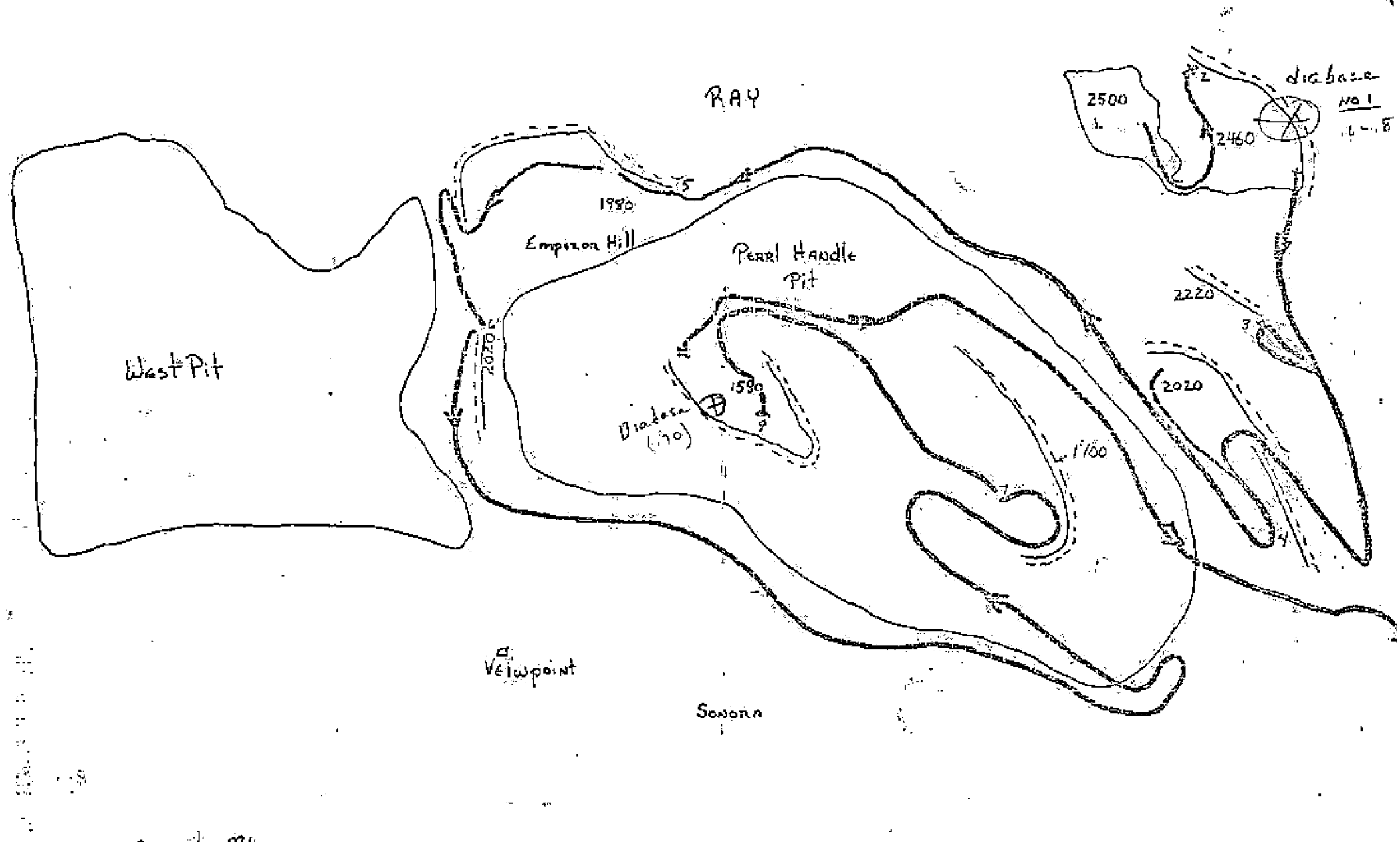

Symbol	Intensity	Explanation	Approximate Percent of Rock
1		Single or questionable occurrence	
2	Trace	Minute portion of rock but found by checking several samples with care	Much less than 1%
3	Weak	Minute portion of rock but common	−1%
4	Moderate	Very common, easily found in any sample	Less than 5%
5	Strong	Obvious, a major constituent	5% or more
6	Intense	All available parts gone to this mineral (pyrox-biotite)	Generally more than 20%
7	Total	Rock consists mainly of this	More than 50%

FIG. 1. Alteration-mineralization notation method at Ray. The advantages of this system over percentage estimates are that it is more rapid, provides three distinct categories of less than or near 1 percent, and does not imply the precision of a percentage.

have been adjusted to approximate agreement with the copper assays.

In the quartzose Precambrian rocks, assay averages for MoS_2 were also contoured, but these data were so incomplete that only a very general pattern was evident.

The scope of the study was limited to outlining the vertical and horizontal distribution of those alteration minerals which could be readily identified with a hand lens or petrographic microscope with a minimum of X-ray or microprobe assistance. Because of the time involved, no attempt was made to count or estimate percentages of specific minerals; the frequency of occurrence was noted by utilizing the same system used in core logging at Ray as outlined in Figure 1. It is important to stress that the conclusions derived in this paper are the result of a detailed study of a small portion of a large, complex porphyry copper orebody. Optimistically, the data are a good approximation of the truth and will be of interest to those engaged in mining geology or related fields.

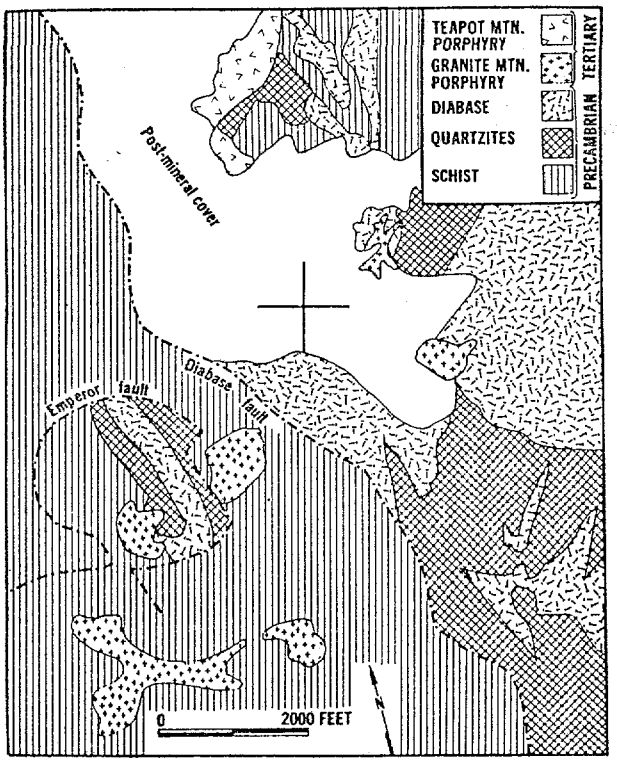

FIG. 2. Generalized geologic map of the Ray copper deposit. The cross on the figure is a reference point enabling the reader to correlate Figures 2, 3, 4, and 6A.

District Geology

Because the geology and ore deposits of the district have been discussed in detail by Ransome (1919), Metz and Rose (1966), and by Cornwall et al. (1971), only a brief resumé of the Ray geologic setting follows.

The Ray sulfide system is developed in a variety of Precambrian rocks and in Laramide intrusives (Fig. 2). The oldest of the Precambrian rocks is the Pinal Schist. This is a sequence of metamorphosed shale, siltstone, sandstone, and conglomerate with flows or plutons of a rhyolitic(?) porphyry. Rarely, some biotite-rich zones which appear to have been a porphyry of dioritic composition are encountered.

The Precambrian Ruin Granite, a coarsely crystalline quartz monzonite, intrudes the schist but postdates the metamorphism. Although the Ruin does not crop out in the mine area, it is consistently encountered in the subcrop along the eastern side of the sulfide system.

Overlying the Pinal Schist and Ruin Granite are the Pioneer Formation and Dripping Spring Quartzite of the upper Precambrian Apache Group. These are quartzitic clastic rocks ranging from tuffaceous mudstone to arkosic conglomerate. They are not differentiated in Figure 2.

The youngest Precambrian rock, diabase, occurs as dikes and sills in all the older rocks. The diabase is the most receptive rock to copper mineralization at Ray. The sills in the Pioneer Formation, the Pinal Schist, and the Ruin Granite are the most important hosts of mineralization. Some of the diabase in the Dripping Spring Quartzite contains ore-grade mineralization, but most of this sill is restricted by erosion and geologic structure to the pyrite halo.

A series of Laramide intermediate to acidic dikes and stocks intrude all the older rocks. These in-

trusives are discussed in detail by Cornwall et al. (1971). The Ray sulfide system affects most of the Laramide intrusions including the Tortilla Quartz Diorite (Sonora Diorite of Ransome), the Teapot Mountain Porphyry quartz monzonite, the Granite Mountain Porphyry, and many of the dikes.

The sulfides were introduced after crystallization of the Granite Mountain Porphyry, and this rock is assumed to be genetically related to the ore deposit. The unaltered rock is granodiorite and commonly porphyritic; locally, however, it grades into subporphyritic and equigranular textures. The two breccia pipes in the mine area appear to be associated with the Teapot Mountain Porphyry. The age of the mineralization is not unequivocally established, but we believe, on the basis of limited crosscutting relationships, that the breccia pipes and the Teapot Mountain Porphyry are younger than much, but not all, of the mineralization.

Stratified Oligocene, Miocene, and later volcanic and clastic rocks overlie parts of the sulfide body. These postmineral rocks tend to thin and/or pinch out over the Ray deposit, indicating arching along the northeasterly trend of the Granite Mountain Porphyry intrusions.

The relation of geologic structure to placement of the sulfide system is obscure. Cornwall et al. (1971) showed that the entire region is complexly faulted. The results of the authors' work indicates that premineral fault and fracture zones have no major effect on the shape of the sulfide or alteration zones beyond very local and minor disruption of the pattern. The foliation of the schist, which parallels the trend of the porphyry stocks as well as the mid-Tertiary arching, may represent some sort of deep structure that controlled the location of the porphyry stocks, but this is a problematical relationship. At least one igneous contact does modify the zoning. This is the north-trending contact between Precambrian granite and schist on the eastern side of the deposit (in the subcrop).

Two large faults cross the orebody, the Diabase-Ray-School Fault (hereafter referred to as the Diabase Fault) and the Emperor Fault. The Diabase Fault dips to the west and trends northerly across the orebody and at the surface separates older rocks on the west from younger rocks on the east resulting in apparent reverse movement. The Emperor Fault has shallow north or easterly dips and is considered to be a thrust. It is cut by the Diabase Fault and is known only on the west or hanging wall side of the Diabase Fault. The thrust places older schist above younger quartzites and diabase so that at depth there are younger rocks in the hanging wall than in the footwall of the Diabase Fault (Fig. 6b), the opposite of the surface indications. Therefore, movement on the Diabase Fault can be either reverse or normal. The direction and total displacement on either fault has never been determined satisfactorily. The displacement on the Diabase Fault exceeds 1,500 feet, while the minimum movement on the Emperor Fault is about 3,000 feet with some very late movement indicated on both faults. Obviously, large postmineral displacement of the sulfide system (and orebody) had to be considered as a possibility on both of these faults until evidence to the contrary such as that presented here was developed.

The hypogene sulfide minerals identified in or near the Ray deposit are pyrite, chalcopyrite, molybdenite, galena, and sphalerite. Occasionally, small amounts of tennantite, tetrahedrite, and bornite have been seen.

Hypogene Copper, Sulfide and Alteration Zoning

Systematic changes of sulfide content and copper grade related to rock type changes in the Ray orebody have long been recognized (Metz and Rose, 1966; Metz and Caviness, 1968). Consequently, the

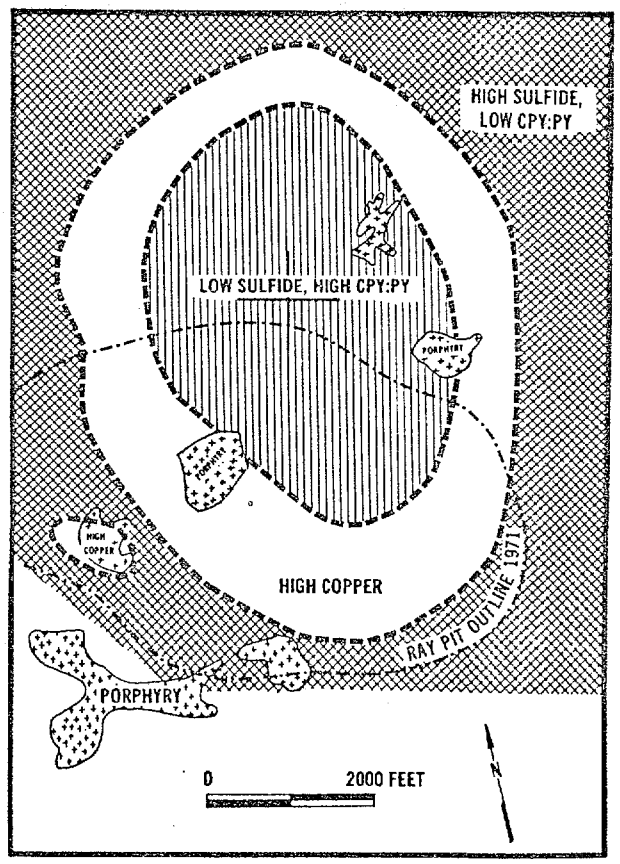

FIG. 3. Generalized zoning of hypogene sulfides in the Ray deposit. The porphyry shown is the Granite Mountain Porphyry.

TABLE 1. Preore Composition of the Diabase in the Ray Area (after Rose, 1960, unpublished private report)

Plagioclase, An_{45-55}	40–70%
Hornblende or pyroxine	25–50%
Quartz	5%
Biotite	(?) 5%
Orthoclase	0–5%
Magnetite	3%
Apatite	1%

The following description of alteration and mineralization in the diabase is derived primarily from work on the lower sill on the eastern side of the Ray orebody. This sill extends from the core of the sulfide system eastward into the pyritic halo and is the most extensive diabase sill within the zone of hypogene mineralization. In the low sulfide, high chalcopyrite core, much of the lower sill has been oxidized and now forms a large part of the Ray silicate copper orebody.

Sulfide mineralogy

The bulk of the sulfide mineralization in the diabase is controlled by stockwork fracturing. The sulfides are concentrated in both the veins and the adjacent alteration envelopes, decreasing outward into the wall rock to occasional disseminated grains.

Chalcopyrite and pyrite are the major hypogene sulfide minerals in the diabase. Bornite is present in minor quantities and is always found as incipient to partial replacements of chalcopyrite. Bornite in the diabase, schist, and porphyry is generally restricted to that portion of the sulfide system in which the abundance of chalcopyrite exceeds that of pyrite. Molybdenite in the diabase occurs most frequently along the outer edges of quartz-chalcopyrite-pyrite veins and is less abundant than in the more siliceous rocks. Limited assay data indicate that the highest concentration of molybdenite in the diabase occurs inside the +0.40% copper ore zone.

Sphalerite with minor galena is present in veins with chalcopyrite, pyrite, quartz, and calcite. These veins are late and occur in the zone of highest copper concentration and outward through the high pyrite zone.

Tennantite is found in veins with quartz, calcite, chalcopyrite, and pyrite. The veins are usually pinkish in color and have a banded texture.

Copper, sulfide, and magnetite distribution

The horizontal distribution of copper in the lower sill has been contoured from drill hole data (Fig. 6A). The figure was generated by averaging copper assays from over 100 diamond drill holes that penetrated the sill. The copper distribution exhibits a horseshoe shape with the shoe opening to the north. The north-south elongation of the horseshoe is perpendicular to the northeasterly trend of the porphyry intrusions. If, however, a plot of total sulfides including those in the pyrite halo is considered,

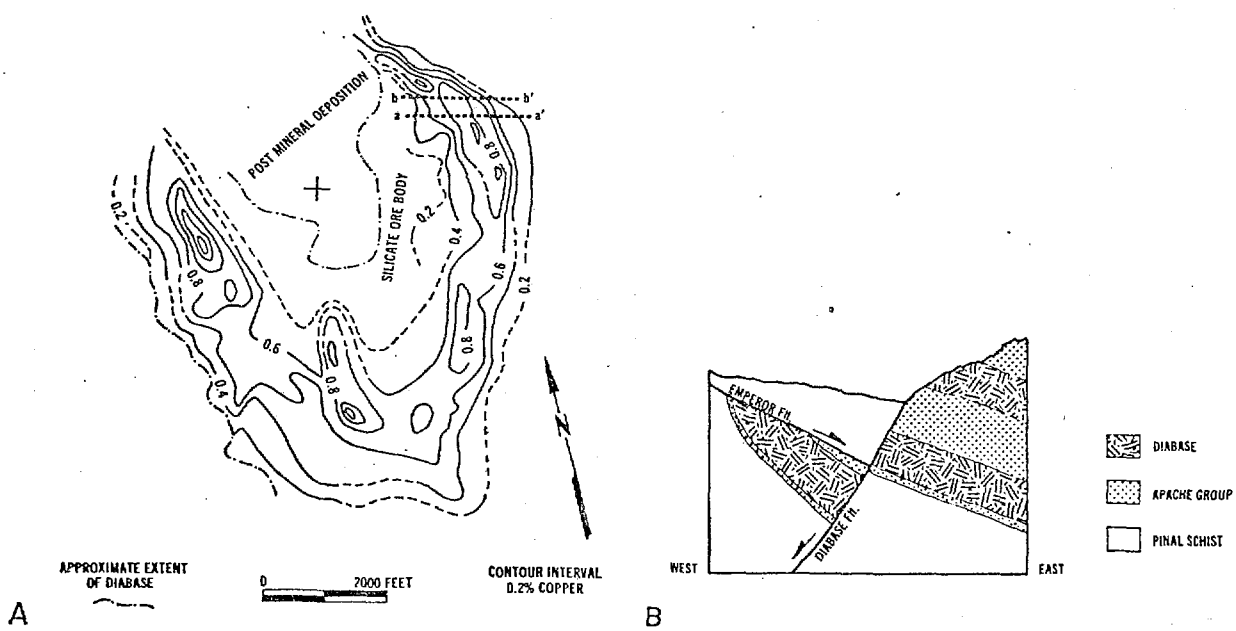

FIG. 6A. Plan view of the hypogene copper distribution in the lower diabase sill at Ray, Arizona. The contours indicate the average grade for the entire thickness of the lower sill at a given point without reference and elevation.
FIG. 6B. Generalized cross section (not to scale) illustrating the extent of the lower diabase sill beneath the Emperor Fault.

GEOLOGY AND MINERALIZATION

OF THE

RAY SILICATE OREBODY

by

Neil A. Gambell

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Ray Mines Division

Kennecott Copper Corporation

Presented at the

Arizona Geological Society and the University of Arizona

Porphyry Copper Symposium

Tucson, Arizona

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and after revision at the

Arizona Conference - AIME

Mining Geology Division Meeting

Ray Mine, Arizona

April 16, 1977

Geology and Mineralization of the Ray Silicate Orebody

Associated with the sulfide deposit is a complex body of silicate copper mineralization. The use of the term silicate, when referring to the orebody, is due to the abundance of chrysocolla; however, the deposit also contains major quantities of copper bearing manganese wad, copper montmorillonite and halloysite, copper-iron oxide complexes, cuprite, malachite, native copper, with lesser amounts of cupriferous allophane, dioptase, azurite, libethenite, torbernite, and chalcocite. and CP

By the early 1960's, drilling had delineated some 93 million tons of potential ore and a program of research and pilot plant studies was initiated with the objective of developing a viable extraction process. Success was realized in 1969 when a vat leaching system, utilizing sulfuric acid from the smelter acid plant, went into production. The most recent estimate of the silicate ore reserve is 156 million tons which averages 0.9 percent copper (total). The portion of this that is readily soluble is not known with certainty but a reasonable estimate would be 55 percent (.50 percent copper). The uncertainty arises from what technique is used to determine readily soluble copper. Ray Mines Division defines readily soluble copper as that portion of the total copper that is dissolved from a minus 100 mesh sample by boiling the sample for one minute in a 10 percent by weight sulfuric acid solution.

Currently we subdivide our mineralization into seven categories. These are primary sulfide, secondary sulfide, native, silicate, mixed native-sulfide, mixed native-silicate and oxide.

Slide 1 - Ore Type Distribution

The slide you see shows, in plan view, the distribution of the primary sulfide ore zone in the diabase, the secondary sulfide ore zone and the silicate ore zone.

The primary ore zone in the diabase is horseshoe shaped. The open end of the horseshoe results from a combination of the following: orebody uplift and tilting 15 to 20° to the southeast, the elimination of the diabase by deep pre-Whitetail (Oligocene) erosion, and the intrusion of a postmineral Teapot Mountain Porphyry stock.

The secondary ore zone (chalcocite) occurs largely in the Pinal Schist. The zone is extended to the west along the Last Turn shear zone. For the most part, it occupies the West Pit, Emperor Hill, and Pearl Handle Pit areas. In the later case, it is largely restricted to the area west of the Diabase Fault which bisects and down-drops the orebody. An interesting thing to note is that approximately half of the chalcocite blanket is located in the pyrite halo west of the underlying primary sulfide orebody. The enrichment blanket here represents at least a ten-fold increase in the hypogene copper grade.

The silicate orebody is subdivided into that which occurs in premineral rocks (horizontal pattern) and that which occurs in postmineral rocks (square pattern). Note that the bulk of the silicate orebody is located in the low-sulfide core area of the system. The Diabase Fault approximates the western boundary of the orebody. With illustration in hand, one can immediately recognize some potention metallurgical nightmares. Specifically, we can see areas where we could penetrate silicate ore, secondary sulfide ore, and primary sulfide ore, encountering several

transition zones characterized by complex mineral assemblages. This picture would be considerably complicated and undoubtedly impossible to illustrate if the oxide, native, mixed native-silicate, and mixed native-sulfide types were included.

Slide 2 - Aerial Oblique (Looking Southeast) of Silicate Orebody

Silicate copper mineralization is found in the Precambrian Pinal Schist, Pioneer Formation, Dripping Spring Quartzite, diabase and to a lesser extent, in the Granite Mountain Porphyry. In postmineral rocks, significant amounts of silicate copper is present in the Whitetail Conglomerate and the Apache Leap Tuff. This slide was taken from above Emperor Hill (foreground) and is directed toward the southeast.

Pronounced silicate ore in the diabase is represented by the blue area (top center) of the pit wall. The light colored areas are lenses of Apache Group quartzite and siltstones. The red area above the diabase is a channel fill deposit of Whitetail Conglomerate. The onlap of the younger Tertiary rocks is illustrated by the white zone which is the basal ash unit of the Apache Leap Tuff. Moving back down below the diabase, the red zone is the trace of the Diabase Fault. The pink zone on the adjacent bench is leached Pinal Schist and the white zone below is the Emperor Fault, which separates the schist from the Apache Group and diabase in the bottom of the Pearl Handle Pit. The offset on the Diabase Fault here is 1600 feet, west side down.

Slide 3 - Aerial Oblique (Looking East) of Silicate Orebody

This slide was taken from above the old town of Sonora (foreground) and shows a closer view of the features discussed in the last slide. Note how the diabase fault essentially terminates the silicate copper mineralization.

Slide 4 - Thickness of Silicate Ore - Premineral Rocks

The contour maps that are presented in the following slides were generated by manipulating the assay data from 137 diamond drill holes. I feel these types of illustrations are basic to understanding where the ore is, why it is there and where some problem areas may be located from a metallurgical standpoint.

This slide shows the thickness of silicate ore in all premineral rocks. The contour interval is 100 feet. A feature that really stands out is the linear zone where the silicate ore is plus 300 feet thick. The protrusion of thin ore corresponds exactly with a Granite Mountain Porphyry intrusive.

Slide 5 - Feet Percent Copper in Premineral Rocks

Here we have a feet percent copper map for premineral rocks. The linear zone observed in the previous slide is enhanced, and we can see that not only is the silicate orebody thick here, but it also contains a lot of copper.

Slide 6 - Feet Percent Copper in Diabase

This feet percent copper map shows the effect of isolating the diabase from the other premineral rocks. Again we see the linear feature observed previously and we now know the orebody is thick in this area, it contains large amounts of copper and a lot of the copper is in the diabase. The dead area between the two high zones is due to intense leaching of the diabase on a pre-Whitetail erosion surface, leaving hematite and minor native copper mineralization.

oxidation essentially in place - reactive rock

Slide 7 - Percent RSCu of TCu in Premineral Rocks

This is a plot of percentage of readily soluble copper of the total copper in premineral rocks. The contour interval is 10 percent. This map is the most important

from an operation standpoint because it identifies the potential areas of good and bad recoveries. If we use the 60 percent contour as the minimum for good recovery ore, we see that most of the thick zone of high copper content is included, but we also see some good recovery zones where the orebody is thin and low grade. The embayment of less than 40 percent readily soluble copper are partly due to the location of two Granite Mountain Porphyry masses and the influence of old drilling data. In the year since this paper was originally presented, we have generated a formula which allows upgrading of the old assay data resulting in the expansion of the 60 percent contour.

Slide 8 - Percent RSCu of TCu in Diabase

Again, isolating the diabase, this time relative to the readily soluble copper we see that most of the linear feature is enclosed by the 60 percent contour. Outlining the extent of mineralized diabase, a lot of it can be predicted to yield recovery problems.

Slide 9 - Feet Percent Copper in the Apache Leap Tuff

Moving on to silicate copper in postmineral rocks, this slide illustrates the feet percent copper in the 20 m.y. old Apache Leap Tuff. In the middle portion, we see a sizable zone of the equivalent of a 110 feet of one percent copper. The bow shape is important to note because the axis of a synclinal fold passes through this area (point out). Perhaps this structure played a role in localizing copper concentrations.

Slide 10 - Percent RSCu of TCu in the Apache Leap Tuff

Once again, using 60 percent as the cutoff for acceptable copper recovery in the leaching process, we can recognize a fair sized area of potential. An additional point about this map is that it is the best one to suggest that oxide copper deposits are

zoned because we have precluded the possibility of residual sulfide interference producing the difference between the readily soluble and total copper assays. Not only are they zoned horizontally, as the map shows, they are also zoned vertically.

Slide 11 - Feet Percent Copper in the Whitetail Conglomerate

The final contour map shows the feet percent copper in the 32 m.y. old Whitetail Conglomerate. The slide shows the scattered nature of the mineralization with the smaller areas being isolated to the contact zones with the underlying premineral rocks. The largest area of copper is associated with a paleochannel cut into the basement schist.

The Ray silicate orebody was developed largely in association with a major zone of normal faulting. The Diabase Fault forms the western boundary of the zone. East of the Diabase Fault, there are numerous small, parallel and sympathetic faults. The total displacement across the entire zone is on the order of 1500 to 2000 feet. The northwest trending linear characterized by a great thickness of ore and large amounts of copper in premineral rocks correlates well with this fault system.

The formation of the silicate orebody was an enrichment process. From what we can infer from the hypogene sulfide zoning pattern, it is probable that if the silicate orebody had not formed, we would be looking at 0.2 percent hypogene copper grades or less; therefore, the average grade of the silicate orebody (0.9 percent copper) represents an enrichment factor of at least 4.5.

except in diabase ?

except diabase?

Copper silicate mineralization formed as replacements of the original sulfide veins, as replacement (or copper soaking) of the wall rock clays, as (in the case of the Whitetail Conglomerate) replacement of reactive rock fragments and matrix, and most importantly as a filling in open fractures and joints.

Slide 12 - Southwest-Northeast Cross Section (Looking Northwest Through the Silicate Orebody

This geologic section, which looks to the northwest, is fairly typical of the silicate orebody and illustrates most of the features I have discussed. All the major pre- and postmineral rocks are represented (explain rock type symbols). The Diabase Fault is located just off the left side of the illustration. The fault shown is seen to be pre-Whitetail in age. The solid black lines on the drill holes represent intercepts of silicate ore. The sawtooth pattern is primary sulfide ore and the open blocks are secondary sulfide ore. Note the thickness of silicate ore in the schist below the pre-Whitetail channel and in the footwall of the fault. On the other sections, the bulk of the ore is in the hanging wall of the fault. The schist is the oldest rock in the area and hence it has been subjected to every ground preparation event since the Precambrian.

Slide 13 - Ore Type Overlay of Geologic Cross Section

This slide is intended to be an overlay to the last slide. It shows just the ore zones and their relationships. In this case, the solid black area is primary sulfide ore with the sulfide content of the rock increasing both to the left and right sides of the illustration. The vertical bar pattern shows the extent of secondary sulfide ore and the unshaded areas are silicate ore. The bulk of the silicate ore located below the channel was formed in a low total sulfide environment by the direct conversion of chalcopyrite to copper pitch ~~limonite~~, the conversion of weak chalcocite mineralization to malachite and chrysocolla, and the introduction of copper bearing solutions along zones of high permeability.

At Ray, we have initiated a detailed investigation of the silicate orebody which will probably take years to complete. The goals of the project are: 1) to document the mineralization as it is mined, and 2) to assist in the efficient mining and benefaction of the ore by recognition and characterization of both distinct mineral zones and transition mineral zones.

Drill core observations are being supplemented by detailed pit mapping at a scale of 1" = 200', with representative samples being taken at least every 50 feet or less if a change in lithology occurs.

Some preliminary observations on supergene mineral zoning and paragenesis are as follows:

1. In the area west of the Diabase Fault, formerly characterized by a moderate to high, probably slightly pyritic, sulfide content, the following zones occur: a) hematitic leached capping, b) cuprite, c) chalcotrichite-native copper, d) native copper, e) native copper—chalcocite, f) chalcocite, and g) hypogene pyrite-chalcopyrite.

2. On the fringe of the silicate orebody, formerly moderate to low sulfide content in diabase adjacent to hypogene sulfides, there is extensive development of cupriferous wad on fractures with copper bearing clays in the rock matrix. Quartzitic rocks in this zone show strong iron oxide mineralization on fractures, some of which is copper bearing.

3. Below this zone, chrysocolla and some malachite begins to appear with the cupriferous wad and copper clays.

4. Adjacent to this zone, chrysocolla becomes more abundant, with cupriferous wad and copper bearing clays still present.

5. In diabase, the above zone begins to pick up cuprite with depth and finally cuprite and native copper prevail. In the siliceous rocks, the chrysocolla zone yields to a malachite-chalcocite zone.

6. In the larger vein structures, the following assemblages can be seen from the inside out: chacocite, cuprite, malachite, black and blue chrysocolla. If the vein was largely chalcopyrite, you see pitch linonite which is being replaced by chrysocolla.

7. In some cases, malachite and azurite seem to be the direct result of sulfide destruction and the common occurrence of malachite being replaced by chrysocolla in some of the larger veins suggests that the bulk of our copper silicate orebody may have once been a copper carbonate orebody. ?

Slide 14 - Pit Wall in Silicate Orebody (Looking East)

The following slide series will illustrate some of the above points.

This is a view of the silicate orebody as it is currently exposed in the pit wall. Immediately below the natural topography at the top, we can see three or four dark gray bench faces. This area represents the upper and outer zone of cupriferous wad and copper clay mineralization in the diabase. The blue-gray zone below is the strong chrysocolla zone.

Slide 15 - Clope-Up of Cupriferous Wad Zone

This is a close-up of the cupriferous wad-copper clay zone. The upper benches are recent gravelly deposits with a manganese rich layer at the bedrock contact.

Slide 16 - 2460 Level Close-Up

Going deeper or inward, we can see chrysocolla and malachite beginning to show up.

Slide 17 - Chrysocolla Zone in Diabase

Here we see a contact between a diabase sill and the Pioneer Formation. Strong chrysocolla has been developed in the diabase. The reasons for this are the fact that the hypogene copper mineralization preferred the mafic diabase, the reactive nature of the rock undoubtedly affected the pH of the supergene copper solutions, and the diabase contains abundant clay which soaked up the copper. Lastly, note the closely spaced sheeting at the top of the diabase. Many of these low angle fractures show evidence of movement. In any period of post diabase structural readjustment, movement occurred in the weaker diabase which is conducive to the all important ground preparation phenomena.

Slide 18 - Close-Up of Diabase Silicate Ore

This close-up illustrates the nature of the good chrysocolla zone in the diabase. Note the abundant veins and fractures. A close-up of the adjacent gray wall rock areas would show copper soaked clays after the feldspars.

Slide 19 - 1980 Bench

This view of the pit wall shows the influence of the diabase on the mineralization. In this particular area, we see a reddish tint along the top of the sill below the strong chrysocolla at the contact. The red color is the result of cuprite, chalcotrichite, and native copper. I will use the bench face in front of the haulage truck to illustrate the complex mineralization that can be encountered during mining operations. Although the contacts aren't clearly visible in the slide, the following rock types are present from right to left; Dripping Springs Quartzite with its basal Barnes Conglomerate member,

the Pioneer Formation and the diabase. The Dripping Springs contains disseminated chalcocite with malachite, minor cupriferous wad, and chrysocolla on the fractures. The sulfide gradually disappears, resulting in a dioptase, chrysocolla, malachite assemblage just above the Barnes. The Barnes contains malachite with some cupriferous wad and chrysocolla. The upper Pioneer contains malachite and cupriferous wad which yields to a cuprite, chrysocolla, malachite, and native copper zone near the diabase contact. The diabase contains cuprite, copper clay, native copper, and chrysocolla. This boils down to a sulfide-silicate zone, a silicate zone, and a native-silicate zone occurring along this 1000 feet of bench face.

Slide 20 - Close-Up of Cuprite Zone

This slide is a close-up of the cuprite-native copper zone along the upper portion of the diabase sill.

Slide 21 - Whitetail Conglomerate - Granite Mountain Porphyry Contact

The next series of slides will show the nature of copper silicate mineralization in the postmineral rocks. The first slide shows the spotty nature of some of the ore along the contact zone. Here, the Whitetail Conglomerate onlaps the Granite Mountain Porphyry.

Slide 22 - Silicate Copper Mineralization in the Whitetail Conglomerate

Here we see more extensive silicate copper mineralization along selected beds near the base of the Whitetail Conglomerate.

Slide 23 - Close-Up of Silicate Ore in the Whitetail Conglomerate

This close-up view of a boulder of Whitetail ore shows the preferential replacement of limestone cobbles.

Slide 24 - Apache Leap Tuff with Copper Silicate Copper Mineralization

This slide shows the contact between the diabase and the Apache Leap Tuff on the 2020 level. The dark zone in the tuff above the basal ash unit is the result of cupriferous wad with some chrysocolla coating the fracture surfaces. The clay minerals in the tuff matrix also contain copper. The intense fracturing in the tuff here is the result of its proximity to a postmineral reverse fault which produced the syn linal fold noted earlier. Minor amounts of silicate copper mineralization also occur in the 17 million year old Big Dome Formation and as noted by Phillips, Cornwall, and Rubin (1971); a small deposit of exotic copper mineralization was found in recent stream gravels which contained a fossil log dated at 7.35 thousand years.

The non-copper bearing minerals in the deposit that may give some clues to its origin are: 1) calcite in the Whitetail Conglomerate, especially near its base and in the diabase where it is apparently of hypogene origin and was stable during the development surrounding and intergrowing cuprite and native copper mineralization, and 2) minor megascopic opal with chrysocolla in the Whitetail Conglomerate. On the microscopic level, opal may be abundant in the orebody. 3) Both early and late occurrences of selenite. Some specimens of malachite appear to be pseudomorphs after selenite as do some specimens of chrysocolla. 4) Extensive development of clinoptilolite and huelandite mineralization, most of which postdates the formation of chrysocolla but predates most, if not all, libethenite. 5) Small rosettes of barite have been found growing on some native copper and malachite specimens.

Metz and Rose, 1964, suggest that hot springs activity may have aided in the formation of the silicate orebody.

In the Inspiration Mine area, Throop and Buseck, 1971, suggest that silica may have been released during the alteration of the volcanic glass to heulandite. At Ray, zeolites coat fractures and much of the chrysocolla in all the rock types.

At this state of the research, I offer no speculations on the silica source. However, I will re-emphasize a point made earlier - I feel that in its initial stages, the Ray silicate deposit was characterized by strong copper carbonate mineralization.

Slide 25 - View (Looking East) of the Silicate Ore Leaching Plant

Some vital statistics on the silicate ore processing plant you see here are as follows:

? 1. 10,000 tons of $-\frac{1}{2}$ inch ore per day to leach vats.

2. Sulfuric acid concentration in vats is maintained at 35 grams per liter.

3. Plant life acid consumption has averaged 100 pounds per ton of ore.

4. Currently, plant recoveries are 60 to 65 percent of the total copper. Plant recoveries have varied from 45 to 75 percent of the total copper.

5. The solution to electrowinning contains 20 to 35 grams per liter copper.

6. 4,000 tons of -10 mesh silicate ore per day to new agitation leaching plant with production being achieved by the precipitation method.

7. At current operating rates, the combined output of both sections will be 28,000 tons of copper per year.

Rock related factors that affect copper recovery in the leaching process are: 1) the mineralogy of the ore minerals. Malachite, chrysocolla, cuprite, azurite, cupriferous wad and copper bearing halloysite leach well. Copper bearing montmorillonite,

as noted by Metz and Stephens, 1967, and some copper iron-oxide complexes leach poorly. The copper bearing phosphates, libethenite, and torbernite don't leach at all. 2) The mineralogy of the gangue minerals. Calcite and biotite are two abundant types that can consume or neutralize sulfuric acid. 3) Rock type. The Apache Leap Tuff slimes rapidly in the acid environment as does the diabase only to a lesser extent. The siliceous rocks retain their competency, allowing better solution circulation and access. 4) How the mineralization occurs in the rock. In the quartzites, most of the mineralization occurs on fractures and in veins which become well exposed in the crushing process. In the diabase and the Apache Leap Tuff, a lot of the copper is disseminated throughout the rock in the clay sites requiring diffusion of the leach solution.

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ARIZONA CONFERENCE - AIME

1977 SPRING MEETING

MINING GEOLOGY DIVISION

Hosted by Kennecott Copper Corporation, Ray Mines Division, Hayden, AZ

Date: Saturday, April 16, 1977

Registration: 0800 to 0830 Ray High School Auditorium, Kearny, AZ

Welcome: 8:30 0830 - 0845 K. H. Matheson, Jr., General Manager

Technical Session: 0845 to 1200

1. A review of the Ray Orebody - N. A. Gambell, RMD Geology Department
2. Igneous Rocks and Copper Mineralization at Ray, Arizona by H. R. Cornwall, USGS, Menlo Park, California
3. Magmatic Behavior of Cu, S, Cl, F, and H_2O in Igneous Rock Associated with the Ray Porphyry Copper Deposit, Arizona by N. G. Banks, USGS, Menlo Park, California
4. Structural Geology of the Ray Mine - Recent Developments by S. A. Hoelscher, RMD Geology Department
5. The Ray Copper Silicate Orebody by N. A. Gambell, RMD Geology Department

Lunch: 1200-1400 Indian Gardens

Pit Tour: 1400-1700 J. Witner, RMD Geology Department

Cocktail Hour: 1800-1900 General Kearny Inn, Kearny, AZ

Dinner: 1900-2000 General Kearny Inn, Kearny, AZ

For those interested in staying overnight, a block of rooms at the General Kearny Inn has been reserved. Interested parties are requested to make their own arrangements with the Inn (602-363-5505) prior to April 8. Specify "AIME Meeting" when reserving rooms. The lunch at Indian Gardens and the pit tour will be via charter bus only. If you plan to attend the meeting, please so evidence by signing on the dotted line and returning the lower portion of the announcement by April 8, 1977 to:

. . . . . .

Detach here and return to:

Neil Gambell, Division Geologist
Kennecott Copper Corporation
Ray Mines Division
Hayden, Arizona 85237

I plan to attend _____
NAME

_____
AFFILIATION

A REVIEW OF THE RAY OREBODY

by

Neil A. Gambell

Division Geologist

Ray Mines Division

Kennecott Copper Corporation

Presented at the

Arizona Conference - AIME

Mining Geology Division Meeting

Ray Mine, Arizona

April 16, 1977

85% ore
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A REVIEW OF THE RAY OREBODY

INTRODUCTION

The Ray Mine is owned and operated by Kennecott Copper Corporation and is located in eastern Pinal County, Arizona, seventy miles southeast of Phoenix. The deposit has been a major copper source since 1911, producing an estimated 2.7 million tons of copper. The bulk of the production has been derived from sulfide ores. Mining was accomplished by underground techniques until 1955 when full conversion to open pit methods was achieved.

Currently we are mining 30,000 tons of sulfide ore and 14,000 tons of silicate ore on a five-day per week basis. The sulfide ore is crushed to minus 10 inches at the mine and shipped by rail some 18 miles to the concentrator and smelter works at Hayden. The silicate ore is processed entirely at the mine via a percolation/agitation leaching system with the final product being electrowon cathode copper.

LITHOLOGIES

The first slide shows the lithologic units which are important in the Ray deposit. The oldest rock is the Pinal Schist which is composed of quartz-sericite and quartz-chlorite-epidote metasediments, as well as some metavolcanic units. A metarhyolite unit in the schist has been dated at 1660 m.y. (Livingston and Damon, 1968). The Ruin or Oracle Granite, which is compositionally a quartz monzonite, intrudes the schist and has been dated in the Winkelman area at 1420 m.y. (Livingston and Damon, 1968). Following a long period of erosion, the younger Precambrian

quartzose sediments of the Apache Group were deposited.

The Pioneer Formation is approximately 230 feet thick and consists of interbedded arkose and tuffaceous siltstones with a basal conglomerate (Scanlan Conglomerate member). Above the Pioneer Formation, there is typically 40 feet of basal Dripping Spring (Barnes Conglomerate). Above this we have approximately 250 feet of the lower arkose-quartzite member of the Dripping Spring. Although the upper Dripping Spring, the Mescal Limestone and the Troy Quartzite are present east of the mine, they are not important from the standpoint of copper mineralization.

Extensive diabase intrusions, mostly as sills, occurred 1150 m.y. ago (Livingstone and Damon, 1968). The preore mineralogy of the diabase is variable; however, the bulk of it appears to have been a hornblende-pyroxene labradorite diabase with minor quartz, biotite orthoclase, magnetite, and apatite. At Ray, this diabase is an important host rock. In the mine area there are two sills which average about 500 feet in thickness. The sills prefer certain stratigraphic horizons which are: (1) the Pinal Schist-Ruin Granite about 300 feet below the Apache Group, (2) the middle of the Pioneer Formation, and (3) between the lower arkose and upper siltstone members of the Dripping Spring Quartzite. Going north through the mine, the sill in the Pioneer migrates downward into the schist and granite. Likewise, the upper sill in the Dripping Spring Quartzite migrates downward into the Pioneer Formation. Economic hypogene copper mineralization is not found in Precambrian rocks above the upper diabase sill in the Dripping Spring Quartzite.

Referring to the left side of the first slide, we have four Laramide intrusives which warrant description. The Tortilla Quartz Diorite (Sonora Diorite) dated at approximately 70 m.y. (Banks and others, 1973) is largely restricted to the south and

and west sides of the deposit, while the main mass of diorite porphyry is found on the east side of the deposit. Depending upon their location within the sulfide system, both of the rocks can contain significant amounts of ore grade (at least 0.40% copper) hypogene copper mineralization. Within the Ray deposit, neither the Tortilla Quartz Diorite nor the diorite porphyry has been found intruding any lithologies above the diabase sill in the Pioneer Formation.

The Granite Mountain Porphyry has been dated at 60 m.y. (see Banks and others, 1972-1973, Livingston and others, 1968, and McDowell, 1971) and has been long thought to be the causative intrusive at Ray. The rock is in reality a porphyritic granodiorite composed of oligoclase, quartz, biotite-magnetite, and orthoclase phenocrysts with an orthoclase matrix (Cornwall and others, 1971). At the present surface, the main mass of Granite Mountain Porphyry is west of Ray in the Granite Mountain area where it is at least two miles in diameter and appears to have intruded near a northeast trending Pinal Schist/Ruin Granite contact. In the mine, there are several small masses of Granite Mountain Porphyry which are aligned in a N70^{o}E direction along a zone of weakness referred to as the "porphyry break" (Metz and Rose, 1966). Diamond drilling indicates that some of these masses may coalesce at depth to form a stock central to the hypogene ore mineralization.

The Teapot Mountain Porphyry is slightly younger than the Granite Mountain Porphyry and intrudes as stocks and dikes along a northeast trend north of Ray. The Teapot is characterized by large euhedral orthoclase and quartz phenocrysts. The Calumet Breccia Pipe may be associated with one of the Teapot

Mountain Porphyry stocks. The upper portion of the pipe contains secondary copper mineralization and supergene effects have largely masked relationships between mineralization and fragmentation. Recent drilling shows two periods of hypogene mineralization. The first period is associated with the main stage of mineralization at Ray and is characterized by pyrite-chalcopyrite-quartz veins which are terminated at fragment boundaries. The second period fills the breccia interstices, cuts the fragments and is characteristically galena-sphalerite-dolomite and/or rhodochrosite.

In summary, the major Laramide intrusive masses in the Ray district are all mineralized, all intrude along a northeast trend and they vary compositionally (south to north) from quartz diorite, to granodiorite, to quartz monzonite.

The Tertiary began with the deposition of the Whitetail Conglomerate 32-plus million years ago (Cornwall and others, 1971). The Whitetail at Ray is divided into two facies. One is reddish brown and is composed primarily of schist fragments. The other is light brown and contains abundant Paleozoic Limestone and Apache Group/diabase fragments, with minor schist. Both Whitetail facies exhibit poor sorting and bedding.

The Apache Leap Tuff (Superior Dacite) sheet was deposited 20 m.y. ago (Creasey and Kistler, 1962). The Apache Leap Tuff is about 230 feet thick and is a rhyodacite (Cornwall and others, 1971), with a light pink to white basal ash unit overlain by a red to black welded vitrophyre which grades upward into a light reddish brown tuff. Supergene solutions have rendered the vitrophyre unit unrecognizable over the deposit.

The Big Dome Formation was named for exposures south of the mine (Krieger and others, 1974). A biotite tuff within the Big Dome has been dated discordantly at 14 and 17 m.y. (Cornwall and others, 1971). In the deposit area, the Big Dome can be subdivided into a schist-porphyry facies and a coarser grained, gray mixed limestone-Apache Group facies.

The youngest rock unit at Ray is a water lain rhyolite tuff. This light pink to brown tuff appears to interfinger with the Big Dome in places and may closely resemble it in age.

Secondary copper mineralization can be found in any of the lithologies shown on the first figure with the exception of the Ruin Granite.

The second slide gives a general feeling for the distribution of the major rock units. The western part of the figure is predominately Pinal Schist, while the eastern portion is mixed diabase and undifferentiated Apache Group. Note the masses of Granite Mountain Porphyry and the onlap of the postmineral volcanics and sediments.

Hypogene Sulfide Zoning

The next slide illustrates the hypogene sulfide zoning. A high sulfide-low copper pyrite halo surrounds an ore zone of moderate sulfides with approximately equal amounts of pyrite and chalcopyrite. Inside the ore zone, there is a low sulfide-high chalcopyrite zone. The pyrite halo is elongate in an east-west direction and measures approximately 14,000 by 10,000 feet. The hypogene ore shell trends northwest and is about 6,000 feet wide and 8,000 feet long. Chalcopyrite is the dominant copper mineral.

Ore Type Distribution and Reserves

The fourth slide shows the distribution of the various ore types at Ray. Of interest is the location of the secondary chalcocite zone to the west of and above the western branch of the hypogene ore zone. Most of the chalcocite occurs in the Pinal Schist which, if you recall the second slide, is the dominant rock type in this area. The location of the chalcocite orebody if affected by structure. The hypogene orebody is horseshoe shaped with the open end being the result of the combined effects of postmineral faulting, intrusion, and erosion. The diabase fault bisects the hypogene ore zone.

The silicate/oxide orebody was developed in the low total sulfide-high chalcopyrite core zone.

The total reserve of all ore types is greater than 650-million tons, with an average grade of about 0.80 percent copper.

Hypogene Mineralization and Alteration

To discuss the hypogene alteration and copper-molybdenum distribution, it is convenient to divide the lithologies into quartzose Precambrian rocks/Granite Mountain Porphyry and diabase. Because of today's time constraints, I will give only the highlight features of the first group.

This slide shows a detailed copper distribution map for the quartzose Precambrian rocks. Only small areas of plus 0.4 percent copper are present with the best one being located on the east side and associated with Pinal Schist/Ruin Granite contact which may have acted as a barrier to the mineralizing solutions (Metz and Rose, 1966). Similarly, there is little ore grade copper mineralization in the Granite Mountain Porphyry. Unfortunately, molybdenite favors these rocks.

In the siliceous Precambrian rocks and the porphyry, the hypogene alteration pattern from the inside out is biotite-K-feldspar, quartz-sericite, and epidote-chlorite.

The remainder of this talk will be devoted to the most important host rock, the diabase (Metz and others, 1968, Metz and Rose, 1966, Phillips and others, 1974).

Looking at the hypogene copper distribution in the diabase, we note large areas of plus 0.4% copper as well as five distinct areas of plus 0.8% copper. Comparing this figure with the previous slide demonstrates the affinity of copper for the diabase. Approximately 85 percent of the Ray ore reserve is in the diabase.

In the next two slides we will look at the copper distribution in diamond drill holes along a-a' and b-b'. The diabase in this area intrudes the Pinal Schist and splits into two branches on the west side of the section. Along section a-a', the higher copper grade follows the top of the sill and plunges abruptly between holes 4 and 5. Note the lower copper grades in the schist. Along b-b', the zone of maximum copper concentration migrates uniformily down the sill from hole 8 through holes 9 and 10. The presence of the reactive diabase sill tends to broaden and flatten the top of the ore shell.

Using the six drill holes along section a-a', we can look at the variation in four significant parameters across the ore zone. The first graph is a plot of the percent copper encountered in the diabase in each drill hole (dotted line). You will recall that in holes 1 and 2 there is a small lens of schist in the diabase. The solid lines "a" and "b" represent the copper grades of the upper and lower sections of diabase while the "c" line shows the copper grade of the schist. Note the total copper

in the schist is lower than that in the diabase.

The second graph shows how the sulfide content varies. Here again the slashed line is the average for the diabase. Points "a" and "b" represent the upper and lower diabase sections respectively and "c" represents the schist lens and the average of the two diabases. Unfortunately, hole 2 is an old hole and samples couldn't be located for analysis, hence the question mark. Observe (1) the sulfide content of the schist and diabase are the same, and (2) the appearance of the high sulfide (7 wt. percent) pyrite zone in holes 5 and 6.

The third graph demonstrates the change in the chalcopyrite/pyrite ratio across section a-a'. Points "a" and "b" are the diabase and point "c" is the schist. From the previous slide, we know that hole one is close to the low sulfide core zone, yet this slide shows the schist lens to be pyritic, illustrating once again the affinity of the diabase for copper. The pyrite halo is also illustrated by the chalcopyrite content of holes 5 and 6.

The final graph shows the magnetite distribution in the drill holes. Points "a" and "b" are diabase and "c" is schist. The general shape of the graphs is similar to the copper distribution graph. The most magnetite is accompanied by the best copper mineralization.

Biotite is one of the most common alteration products in the diabase. It occurs as a fine-grained mesh in vein envelopes and as thin rims surrounding disseminated magnetite and sulfide grains in the wall rock. Biotite envelopes are easily distinguished from the less altered wall rock. The width of the vein envelopes is directly related to the size and frequency of occurrence of the quartz-sulfide veins.

In a well-mineralized area with strong stockwork veining, the wall rock may be totally altered for tens of feet. Coarse-grained (2.5 mm) secondary biotite is encountered in some quartz-sulfide veins and is most common in the low sulfide-high chalcopyrite core of the deposit.

Two distinct color varieties of secondary biotite are present - brown and olive-green. A small number of observations have shown that the olive-green variety becomes more abundant outward from the high copper zone. The difference in color may be due to variation of the titanium content of the biotite.

Within the vein envelopes, most of the secondary biotite is an alteration product of pyroxene and hornblende. The biotitization in vein envelopes is accompanied by alteration of the plagioclase to an orange-brown clay. Secondary biotite may be present along the twin planes in the plagioclase.

Secondary biotite in vein envelopes has a widespread lateral distribution in the lower diabase sill. It is present in the low sulfide-high chalcopyrite core outward through the high copper zone, where strong biotite alteration correlates with high copper values.

Secondary magnetite is found in the wall rock and vein envelopes as disseminated anhedral blebs and subhedral, needle-like crystals. Both forms commonly are enclosed by an inner envelope of sphene and an outer envelope of biotite or chlorite. Secondary magnetite also occurs in veins with quartz and sulfides. Chalcopyrite and pyrite veins appear to cut most magnetite veins.

Secondary sphene and rutile are present in the altered diabase, and they exhibit a zonal relationship with rutile closer to the veins than sphene. Light gray to white sphene envelops some anhedral magnetite grains in the wall rock. In most

cases the sphene is itself enveloped in secondary biotite or chlorite and may show some alteration to calcite. Bright orange, crystalline aggregates of alteration rutile are usually restricted to the vein envelopes associated with strong biotite alteration.

Both early and late barren quartz veins are present in the diabase. Mineralized quartz veins are abundant in the low sulfide-high chalcopyrite core outward through the high copper zone. In the pyrite halo, vein quartz decreases markedly. Fine anhedral quartz is present in many vein envelopes with biotite and clay.

The chief alteration product of the plogioclase in the diabase is a light orange-brown clay mineral. This alteration is most intense in vein envelopes and accompanies strong biotite alteration of the mafic minerals.

Secondary K-feldspar is a rare alteration product in the Ray diabase. Also, hypogene sericite in the diabase is not abundant. In the high sulfide-high pyrite zone, sericite and clay minerals are present as partial replacements of plagioclase in the vein envelopes. Late stage sphalerite-galena veins frequently have sericitic envelopes. Where these veins cut earlier quartz-sulfide veins with biotite envelopes, the biotite is altered to sericite.

Like biotite, chlorite may envelop disseminated sulfide and magnetite grains in the wall rock. Primary hornblende is partially to completely altered to chlorite-biotite. Chlorite in vein envelopes seems to be related to the introduction of late calcite in the vein. Such veins frequently exhibit an inner chlorite and an outer

biotite envelope. The frequency of chlorite occurrence in the diabase increases outward from the center of the sulfide system.

Though occasional epidote occurs in quartz-sulfide veins throughout the high copper zone, epidote is most abundant in the pyrite halo where it occurs in pyrite veins and more extensively in the vein envelope as an alteration product of plagioclase. Epidote rimming and veining a clay product in a plagioclase site suggests that the epidote is a late alteration.

Milky-white calcite occurs near the center of veins as a filling with microveinlets cutting the sulfide grains. In some cases calcite floods the vein envelopes and replaces earlier formed clay minerals. Although it appears to be largely a late mineral, calcite is most abundant in veins in the high copper zone and shows a tendency to decrease, both inward and outward, from this zone. Calcite crystallization or deposition may have been favorably influenced by the calcic nature of the plagioclase (labradorite) in the unaltered diabase.

Coarsely crystalline, light purple anyhydrite is present as a major constituent of some quartz-sulfide veins. The abundance of anhydrite increases with depth, and, for some unknown reason, the greatest concentration of purple anhydrite occurs in the high copper zone on the southwestern side of the orebody west of the Diabase Fault.

Minor quantities of orange to white crystalline chabazite occur in some quartz-sulfide veins in the ore zone and outward through the pyrite halo. Chabazite appears to be a late vein filling.

Much of the pyroxene in the diabase shows partial to complete alteration to fine-grained amphibole. The author believes that at least part of the uralitization in the diabase is the result of hydrothermal alteration. This is compatible with the tendency to form hydrous silicate alteration products, and petrographic studies indicate decreasing uralitization and increasing pyroxene with increasing distance outward from the orebody.

SUMMARY

The Ray orebody was developed in older and younger Precambrian rocks. Stratigraphically, the highest unit of the Apache Group affected by the hypogene ore solutions appears to be the arkose member of the Dripping Spring Quartzite. The deposit is thought to be genetically related to the 60 to 61 million year old Granite Mountain Porphyry. Secondary copper mineralization is found in the Precambrian rocks (excluding the Ruin Granite), the Laramide intrusives, and the Tertiary conglomerate and volcanic units.

Supergene chalcocite mineralization formed above and lateral to the hypogene copper orebody, largely in the pyrite halo. The bulk of the silicate/oxide orebody formed in a low total sulfide-high chalcopyrite environment.

The deposit exhibits a typical hypogene sulfide zoning pattern with an outer high sulfide-low copper pyrite halo, an ore zone of moderate sulfide content characterized by approximately equal amounts of chalcopyrite and pyrite, and an inner low sulfide-high copper zone which is chalcopyritic in the diabase and, in places, pyritic in the quartzose rocks.

The bulk of the ore grade (at least 0.40% copper) mineralization occurs in the semi-reactive, mafic, Precambrian diabase host rock. Molybdenite mineralization favored the quartzose lithologies.

In the siliceous Precambrian rocks and the Granite Mountain Porphyry, the hypogene alteration zones from the inside out are (1) biotote-K-feldspar, (2) quartz-sericite, and (3) epidote-clorite.

In the diabase, biotite-clay alternation predominates in both the core and ore zones. Chlorite and epidote increase outward into the pyrite halo. There is no extensive development of hypogene sericite or K-feldspar in the diabase.

In all rock types, the frequency of quartz veins decreases outward from the center of the deposit.

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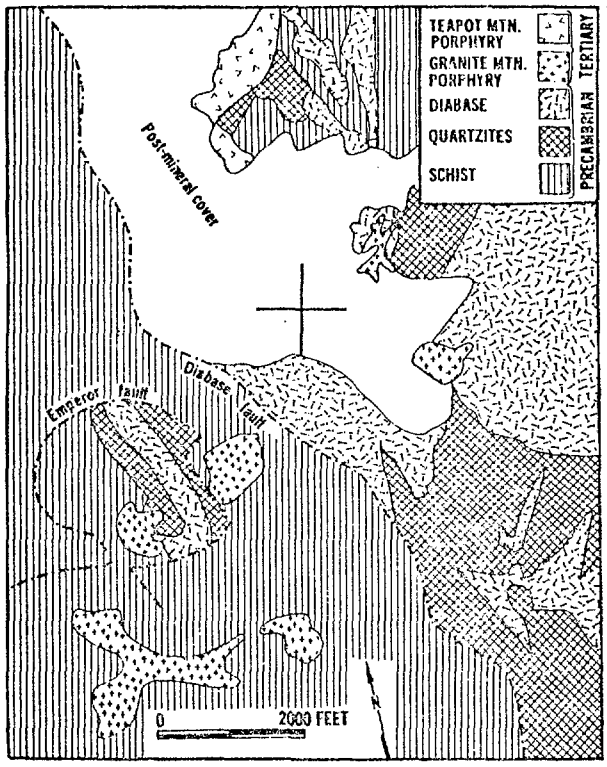


FIG. 2. Generalized geologic map of the Ray copper deposit. The cross on the figure is a reference point enabling the reader to correlate Figures 2, 3, 4, and 6A.

Slide 2

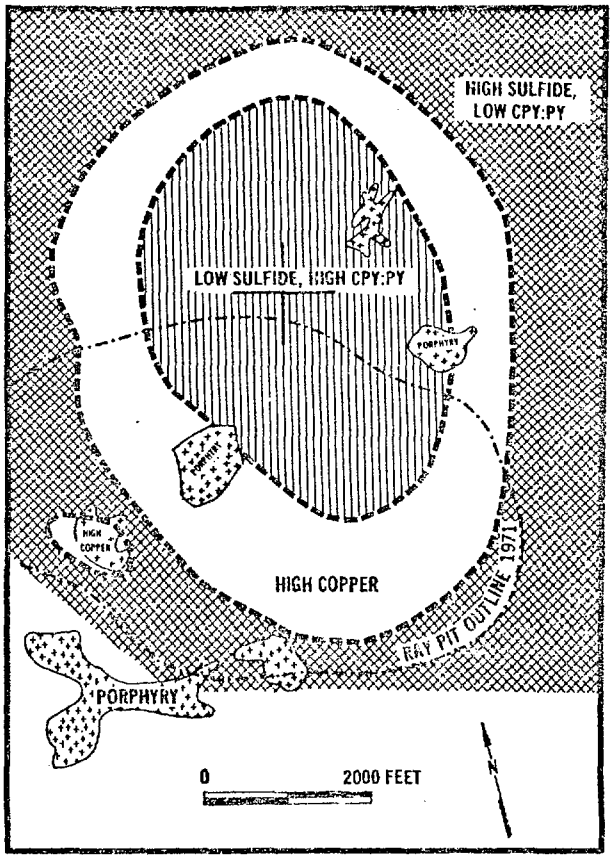


FIG. 3. Generalized zoning of hypogene sulfides in the Ray deposit. The porphyry shown is the Granite Mountain Porphyry.

Slide 3

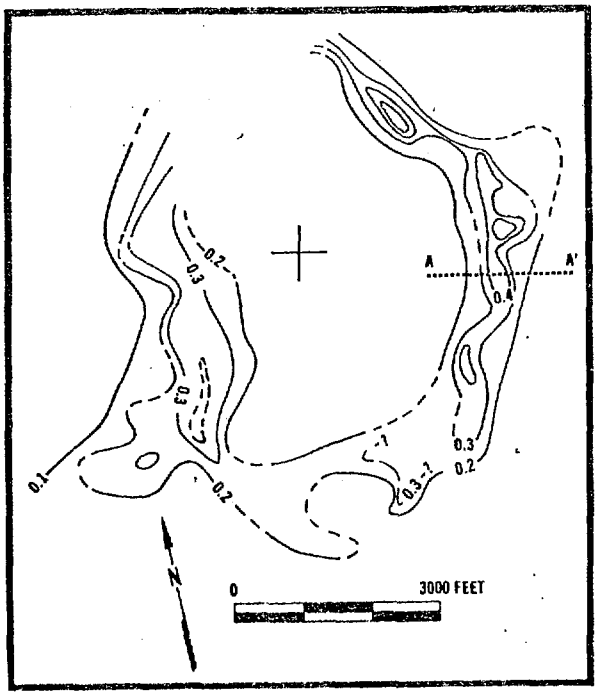
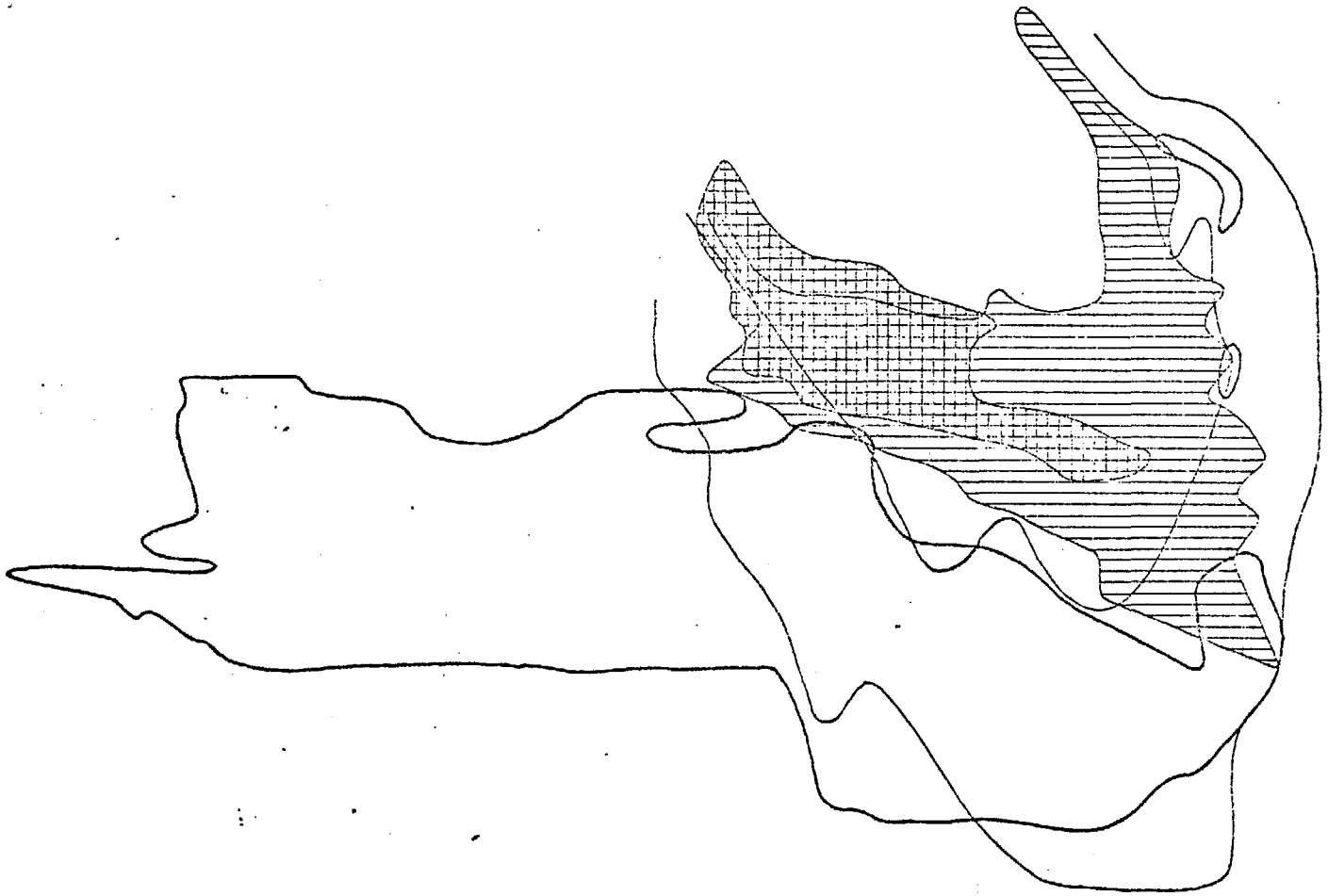
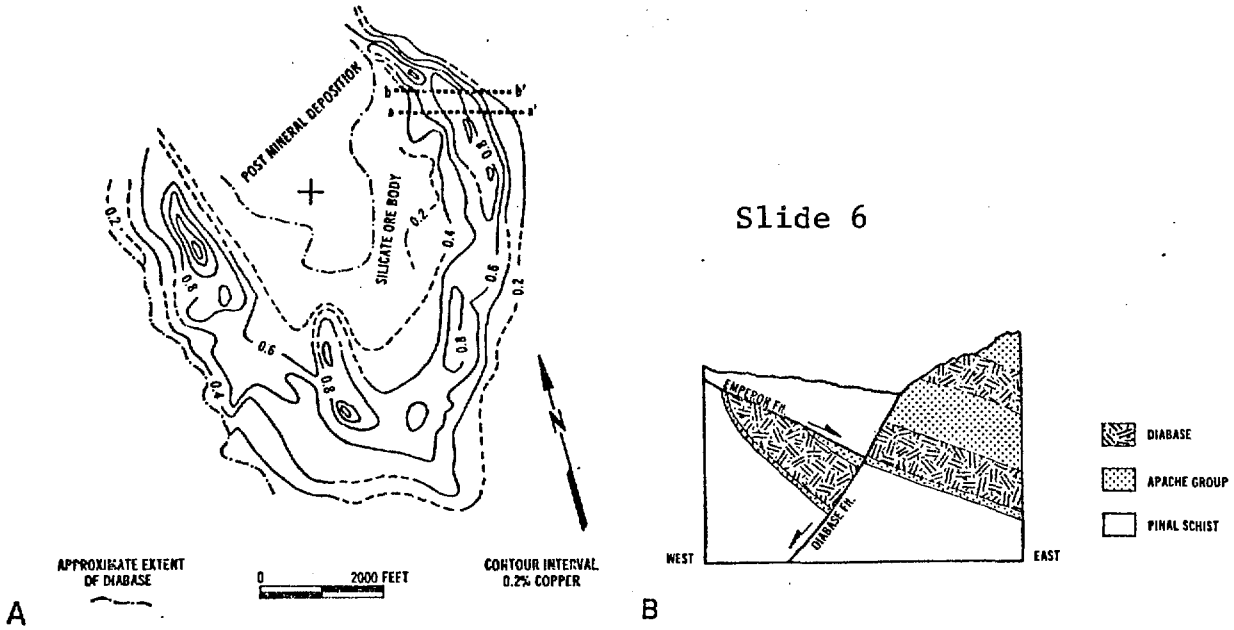


FIG. 4. Contoured copper distribution in the quartzose Precambrian rocks at Ray. Contour interval is 0.1 percent copper.

Slide 5

Slide 4

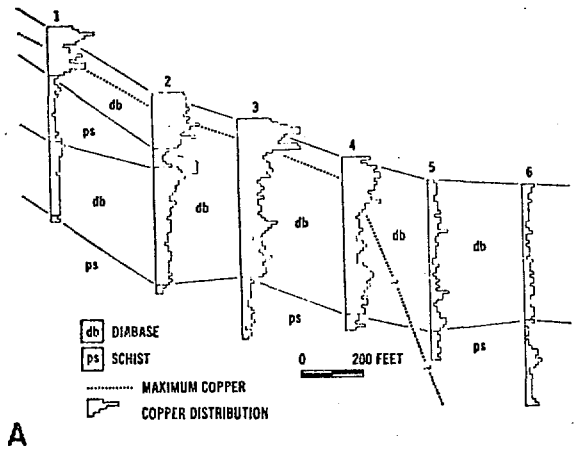




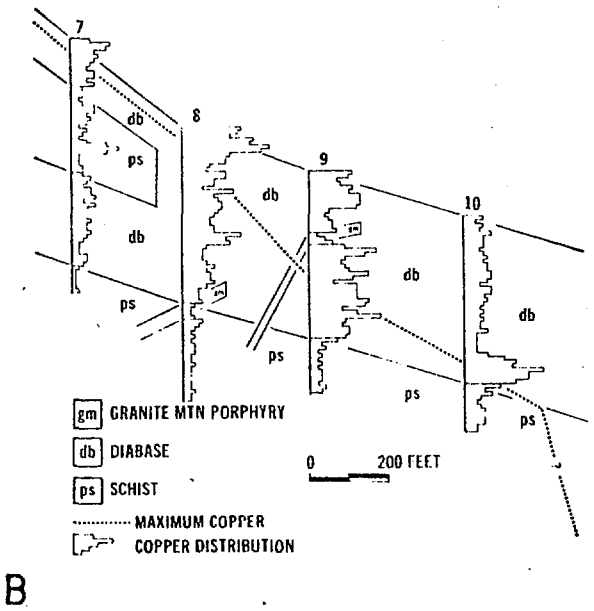
Slide 6

FIG. 6A. Plan view of the hypogene copper distribution in the lower diabase sill at Ray, Arizona. The contours indicate the average grade for the entire thickness of the lower sill at a given point without reference and elevation.

FIG. 6B. Generalized cross section (not to scale) illustrating the extent of the lower diabase sill beneath the Emperor Fault.



Slide 7

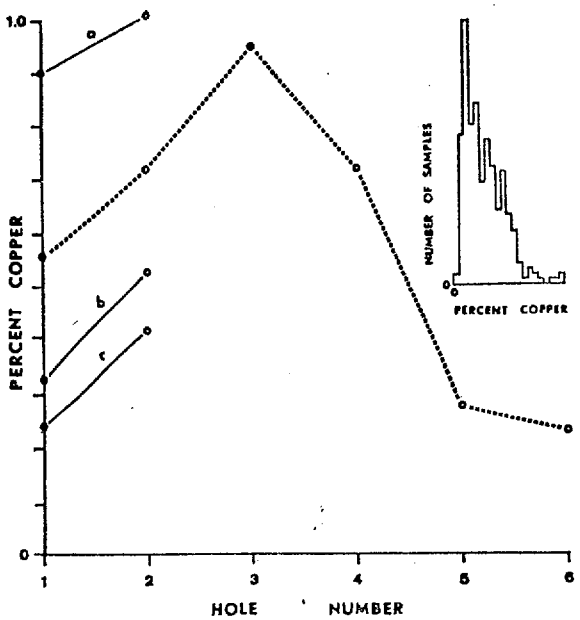


Slide 8

FIG. 7A. Hypogene copper distribution in drill holes along section a-a′ (Fig. 6A). Note the high copper concentration at the top of the sill.

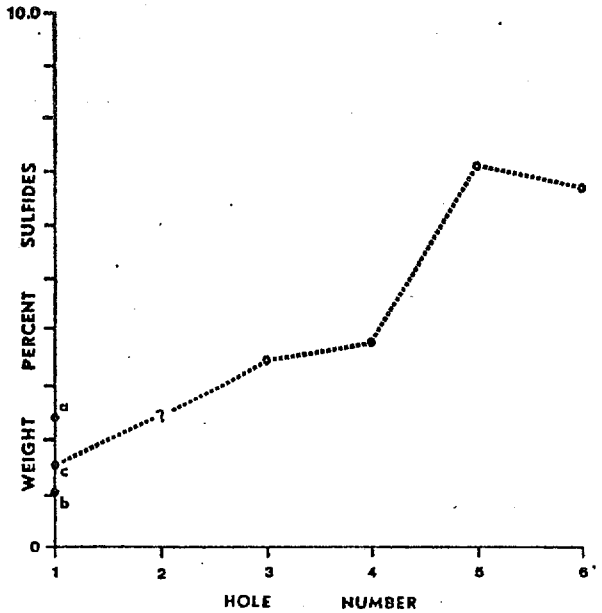
FIG. 7B. Hypogene copper distribution in drill holes along section b-b′ (Fig. 6A). Note the high copper concentration in the lower part of the sill in holes 9 and 10.

Slide 9



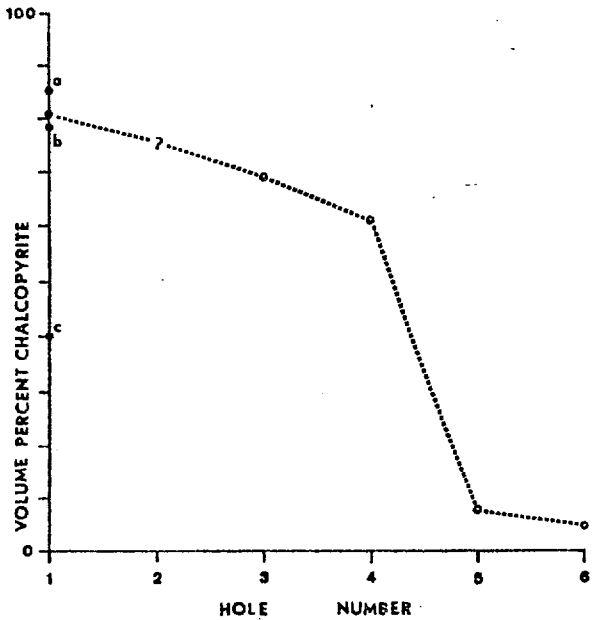
A

Slide 10



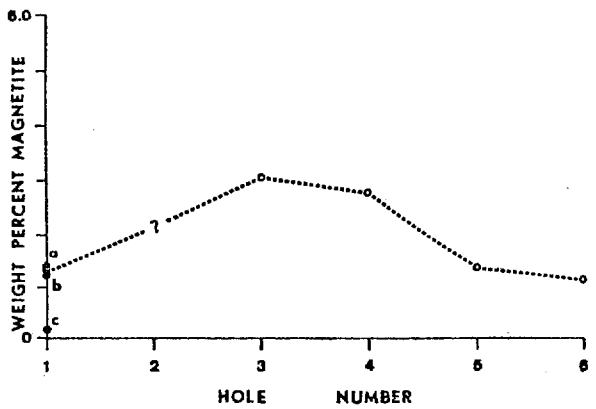
B

Slide 11



C

Slide 12



D

FIG. 8A. Total copper distribution along section a-a′. Lines a and b represent upper and lower diabase, while c is a schist lens. Classes in histogram are in units of 0.10 percent copper.

FIG. 8B. Weight percent sulfides in the rock along section a-a′. Points a and b are diabase, while point c is a schist lens and the average of a and b. Dashed line connects data points for the diabase.

FIG. 8C. Volume percent chalcopyrite in the sulfides. Point a and b are diabase and point c is schist. Note the drop in chalcopyrite in the schist.

FIG. 8D. Weight percent magnetite in the rock. Points a and b are diabase and point c is schist. Compare this curve to Figure 8A.

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

IGNEOUS ROCKS AND COPPER MINERALIZATION IN THE RAY PORPHYRY COPPER DISTRICT, ARIZONA

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1977

This report is preliminary and
has not been edited or reviewed
for conformity with Geological
Survey standards and nomenclature.

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INTRODUCTION

The Ray porphyry copper district is approximately 110 km north of Tucson and 120 km east-southeast of Phoenix in southeastern Arizona. The major disseminated copper deposit at Ray has reserves estimated at 650 million tons[1] of both primary and secondary ore, and occurs mostly in Precambrian Pinal Schist and diabase, but partly in the Granite Mountain Porphyry of Laramide age. The Granite Mountain Porphyry is part of a suite of Laramide igneous plutons and dikes in the Ray area that range in age from 70 to 60 m.y. and in composition from diorite to quartz monzonite. Hydrothermal biotite from the copper deposit at Ray has been dated at 65 m.y. (K-Ar age), and apatite in mineralized diabase has been reset at 60 m.y. (fission-track age). These ages indicate a close temporal and possibly genetic relationship with these Laramide igneous rocks.

LARAMIDE PLUTONS

The Laramide plutons, roughly in order from mafic to silicic and from older to younger are: (1) Tortilla Quartz Diorite, (2) Rattler Granodiorite, (3) Tea Cup Granodiorite, (4) Granite Mountain Porphyry, and (5) Teapot Mountain Porphyry. In addition, there are swarms of east-west-trending dikes, mostly rhyodacite, but ranging from andesite to quartz latite.

Tortilla Quartz Diorite

The Tortilla Quartz Diorite forms a large stock, 5 km long and 3 km wide, 5 km south of the Ray mine. It also crops out as small stocks in the same area, in the southern part of the Kearny quadrangle, the eastern Sonora quadrangle, and in the central El Capitan Mountain quadrangle. It intrudes Precambrian Ruin Granite, Madera Diorite and diabase, and late Paleozoic Escabrosa and Naco Limestones. Where it intrudes these limestones at Elder Gulch in the southern Sonora quadrangle, it is partly surrounded by breccia masses containing fragments of Naco and older rocks. The Tortilla Quartz Diorite is variable in composition and appearance from stock to stock, ranging from pyroxene-hornblende

[1]N. A. Gambell (oral commun., 1976).

diorite to biotite-hornblende quartz diorite, but quartz diorite predominates. It is fine to medium grained, typically with hypidiomorphic-intersertal texture, partly porphyritic, with andesine, hornblende, pyroxene (mostly augite), biotite, and magnetite-ilmenite in an interstitial matrix of quartz and potash feldspar.

Rattler Granodiorite

The Rattler Granodiorite crops out as a pear-shaped body in the southeastern Sonora quadrangle. It is 2.7 km long, east to west, and 0.3 to 1.8 km wide with two offshoots up to 0.9 km long, extending westward from the main body. A second pluton of Rattler Granodiorite crops out 0.8 km to the east in the El Capitan Mountain quadrangle. It is 0.6 km wide and 0.9 km long and is overlapped on the east and north by Tertiary and Quaternary gravels. The granodiorite intrudes Precambrian diabase, siltstone, quartzite, limestone, and dolomite, Cambrian sandstone and siltstone, and Devonian dolomite. It is a composite intrusion ranging from quartz diorite to quartz monzonite with small marginal bodies of melanocratic quartz diorite and late-formed leucocratic aplitic dikes of quartz monzonite.

Texturally the Rattler Granodiorite is fine- to medium-grained hypidiomorphic-seriate to porphyritic. The phenocrysts are most commonly plagioclase (predominantly andesine), but also include quartz, biotite, and hornblende, 1-4 mm long. The groundmass and smaller grains in the seriate rocks consist of the same minerals plus magnetite-ilmenite, interstitial K-feldspar and quartz, and accessory minerals. The accessory minerals in this and the other intrusives of the Ray area are apatite, sphene, zircon, sulfides, and locally primary epidote, allanite, and garnet. The sulfides are pyrite and chalcopyrite plus rare bornite.

Tea Cup Granodiorite

The Tea Cup Granodiorite occupies the western half of the Grayback quadrangle about 10 km southwest of the Ray copper deposit and extends south and west for possibly 35 and 8 km, respectively. It is overlapped on the west and partly on the south by Tertiary and Quaternary gravels. It cuts Precambrian Ruin Granite, diabase, and Pinal Schist. Locally apophyses of the granodiorite and its aplitic facies project out into the host rock for as much as 1,200 m. The Tea Cup Granodiorite ranges from granodiorite to quartz monzonite in composition. It is medium grained and locally contains aplitic dikes and pegmatitic segregations. In some areas these latter rocks and associated granodiorite or quartz monzonite contain two micas, phengite and biotite, and traces to 0.6 percent almandine garnet. Elsewhere the granodiorite and aplite contain only biotite. The texture is hypidiomorphic-seriate, porphyritic, and granitic. Phenocrysts, where present, are plagioclase (oligoclase-andesine), quartz, and locally hornblende up to 12 mm long. The groundmass and smaller grains in the granitic and seriate-textured

rocks are these same minerals plus K-feldspar, biotite, magnetite, and accessory minerals.

Granite Mountain Porphyry

The Granite Mountain Porphyry crops out in eight separate plutons plus half-a-dozen smaller bodies mostly intruded into Precambrian Pinal Schist in the southeastern Teapot Mountain quadrangle and southwestern Sonora quadrangle. The intrusions occupy a zone elongated in an east-northeast direction for 8 km. At the west end the zone is 4 km wide, at the east end 0.6 km wide. The Ray porphyry copper deposit occurs in the eastern part of this zone.

The Granite Mountain Porphyry is mostly granodiorite, but partly quartz monzonite. Textures range from granitic to porphyritic. Phenocrysts are plagioclase (oligoclase and andesine), quartz, and K-feldspar. In addition, the rock contains biotite, magnetite, and accessory minerals.

Laramide dikes and small plugs, ranging in composition from andesite to quartz latite, are closely related temporally and spatially to the larger plutons just described. The oldest are andesitic with a K-Ar age of 90-75 m.y. (unpublished K-Ar and fission-track ages in Hayden and Christmas quads.); the youngest are rhyodacitic and quartz latitic with a probable age of about 60 m.y. They thus range from older to somewhat younger than the larger intrusives. The dikes are steep to vertical, mostly trending east-west to N. 70° E., but locally northwest or northeast and are mostly less than 30 m thick.

The andesites contain phenocrysts of hornblende and labradorite in a groundmass of these minerals plus a little quartz, K-feldspar, ilmenite-magnetite, and accessory minerals.

The rhyodacite porphyries are the most abundant of the dikes, and crosscutting relationships indicate that they were intruded at several periods between 70 and 60 m.y. The rhyodacites have phenocrysts up to 15 mm long of andesine, hornblende, quartz, biotite, and magnetite-ilmenite in a groundmass of the same minerals plus K-feldspar and accessories. The melanocratic rhyodacite is similar but contains more hornblende in the groundmass.

Teapot Mountain Porphyry

The Teapot Mountain Porphyry is one of the youngest Laramide intrusive rocks in the area and forms small plugs and dikes in the Teapot Mountain quadrangle and northeastward in the Sonora quadrangle just north of the zone of Granite Mountain Porphyry plugs. The Teapot Mountain Porphyry is a silicic rock, quartz monzonitic in composition and similar in appearance to the rhyodacite porphyries but distinguished

from them by the presence of large pink K-feldspar phenocrysts.

The quartz latite porphyry, also one of the youngest intrusives in the area, is quite similar to the Teapot Mountain Porphyry but contains more K-feldspar in the groundmass.

CHEMICAL AND MODAL DATA

The triangular diagram pc-qtz-Kspar of the modes for the larger plutons shows that they range from diorite, quartz diorite, and syenodiorite to granodiorite, quartz monzonite, and granite. The sequence is from Tortilla Quartz Diorite to Rattler Granodiorite to Granite Mountain Porphyry to Tea Cup Granodiorite. The most silicic rocks in the quartz monzonite and granite fields are aplitic facies of the plutons.

The triangular diagram pc-qtz-Kspar for the dikes shows a trend similar to the larger plutons with the andesite most mafic, rhyodacites intermediate, and quartz latites most silicic. The dikes are lower in quartz than the plutons. This may be due to a greater abundance of unresolved or not easily discernible aphanitic groundmass in the dikes that contains quartz not seen.

The triangular diagram of normative pc-qtz-Kspar shows a trend similar to the one shown for the modes but more orderly. Nockold's average for quartz monzonite and quartz latite (qtz monzonite field), granodiorite (near qtz monzonite field), and dacite and quartz diorite (near qtz diorite field) are shown for comparison.

The triangular plot of normative Ab-An-Or shows a trend of decreasing An as we go from mafic Rattler Granodiorite to Tortilla Quartz Diorite to main Rattler Granodiorite to Granite Mountain Porphyry and Tea Cup Granodiorite. The lowest in An and richest in Ab+Or are the Teapot Mountain Porphyry and aplitic facies of the other plutons.

Chemical compositional trends of the igneous rocks show an orderly progression from mafic to silicic as is well shown in this slide where individual oxides of the major cations are plotted against the differentiation index (D.I.) modified from Thornton and Tuttle (1960). We determined the D.I. by adding quartz+albite+K-feldspar from molecular catanorms rather than from the CIPW norms, but the two are quite similar.

The andesites, Tortilla Quartz Diorite, and mafic facies of the Rattler Granodiorite, are the most mafic, ranging in D.I. from 48 to 58. The main body to the Rattler Granodiorite is intermediate in composition, ranging in D.I. from 65 to 78. The Granite Mountain Porphyry and Tea Cup Granodiorite are the most silicic of the plutons, ranging in D.I. from 79 to 87. Dikes and small stocks of rhyodacite and Teapot Mountain Porphyry overlap the Rattler Granodiorite and

Granite Mountain Porphyry in D.I. Aplites of the Rattler Granodiorite, Granite Mountain Porphyry, and Tea Cup Granodiorite range in D.I. from 93 to 96 except for one from the Rattler Granodiorite which is 87.

SiO_2 and K_2O show an orderly increase with increasing D.I. the SiO_2 from 55 to 76 percent, and the K_2O from 1.5 to 6 percent. Al_2O_3, total Fe as FeO, MgO, and CaO decrease with increasing D.I. as follows: Al_2O_3, 19 to 13 percent; ΣFe, 9 to 0.5 percent; MgO, 4 to 0 percent; CaO, 8 to 0.3 percent. For all of these constituents, the trends are reasonably orderly except for MgO in an andesite with a D.I. of 55 which has a high MgO content of 5.3 percent. Na_2O ranges from 2.7 to 4.2 percent in these rocks but does not show a trend up or down with increasing D.I.

In considering the trends of the oxides, it should be kept in mind that because the sum of the oxides in an analysis is constant, a large increase in one oxide (commonly SiO_2) causes a proportionate decrease in the sum of the remaining oxides. The true trends of individual oxides are modified by this effect but still convey a general impression of relative increases and decreases, especially where pronounced. This problem has been discussed by Chayes (1967) Krauskopf (1967, p. 398-399), and others.

The Ray igneous rocks are a calc-alkaline suite. Using the criterion of Peacock (1931), the trend line of Na_2O+K_2O crosses the trend line of CaO at about D.I. 60 where the SiO_2 line is at 60 percent. This is in the calc-alkalic (calc-alkaline) range. These rocks also fall in the calc-alkaline field using the criteria of Irvine and Barager (1971).

The Laramide igneous rocks at Ray were intruded in five surges during a 10-m.y. period, 70-60 m.y. ago (see Banks and others, 1972; Banks and Stuckless, 1973; Banks, 1976). One or more major plutons were intruded in each of the first four periods as follows: I, Tortilla Quartz Diorite and Rattler Granodiorite; II, Tea Cup Granodiorite; III, Granite Mountain Porphyry; IV, Teapot Mountain Porphyry. Rhyodacite to quartz latite dikes were intruded during periods II, IV, and V. As is shown by the D.I. trends and the above discussion, the oldest plutons are the most mafic and the progressively younger plutons are successively more silicic. The entire differentiation trend is also seen in successive facies of the Rattler Granodiorite, the pluton that we have been able to study in greatest detail.

The dike rocks follow the D.I. trends of the larger plutons and in general range from more mafic to more silicic with decreasing age; namely, andesite to mafic rhyodacite to rhyodacite to quartz latite, but there are reversals within the rhyodacite group, and andesite dikes cut the granodiorites of periods I and II.

As with the major constituents, the trace elements show similar trends in each pluton during successive stages of differentiation.

This suggests a common source for the magmas probably at considerable depth either in the upper mantle or lower crust.

Using all of our analytical data, we have calculated Spearman Rank correlation coefficients. Part of the matrix is shown in this slide where minor elements are correlated with major elements and with each other. Only positive and negative correlation coefficients greater than 0.6 are shown here. (Number of data pairs: major vs. minor elements 35; minor vs. minor elements 75; coefficients shown significant at 99 percent confidence level.) Minor elements with positive correlations toward each other are: Mn, Co, Sc, Sr, V. These elements also show positive correlations with Al, Ti, Fe, Mg, Ca, and P, and negative correlations with D.I., Si, K, and Pb.

Copper at a lower level correlates positively with Co, Ga, Ni, Ti, Fe, Mg, and P. Copper is erratically distributed in the igneous rocks ranging from less than 2 to 365 ppm. The mean for all the rocks (77 samples) is 74 ppm; for the Granite Mountain Porphyry (21 samples) 80 ppm; for the Rattler Granodiorite (40 samples) 81 ppm. Our studies indicate that less than half of the copper was a primary constituent of the rock.

DEPTH OF INTRUSION

Stratigraphic reconstructions indicate that the depth of cover in the Ray district at the time of the Laramide pluton intrusions was between 1 and 3 km. It is interesting to note that a similar depth range has been estimated for the Bingham stock in the Bingham mining district, Utah, by Gilluly (1932; 1946) and Moore (1973, p. B38). The maximum depths of the upper parts of the Rattler Granodiorite and some of the Tortilla Quartz Diorite intrusives are estimated to have been 1.5 km , and of the Granite Mountain Porphyry and Teapot Mountain intrusives 2.5 km. Concordance of apatite fission-track ages with other mineral ages indicates a maximum depth for these plutons and for the Ray copper deposit of 5 km during and since Laramide time (Banks and Stuckless, 1973). No stratigraphic reconstruction can be estimated for the depth of intrusion of the Tea Cup Granodiorite as it was intruded into older Precambrian rocks of unknown thickness.

VOLATILE CONTENTS OF THE MAGMAS

As has been pointed out by Banks (1976, p. 94), several petrochemical features of the Laramide plutons in the Ray area suggest that they did not saturate early during their crystallization nor evolve much water. The MgO content of the biotite decreases slightly with increasing differentiation index, but markedly with decreasing age of the intrusives. Wones and Eugster (1965) have suggested that such a trend indicates undersaturation of water in the melt. Low volatile contents of the magmas are also indicated by: scarcity of aplites and

pegmatites in the plutons, minor metamorphic aureoles around all of the intrusive bodies, absence of miarolitic cavities, sparsity of fluid inclusions in quartz and the fact that they are dilute, two phase, and homogenize at below 450°C (J. T. Nash, written commun., 1971, 1972; M. J. Logsdon, oral commun., 1973).

The water content of the magmas at their emplacement is also indicated by the point during crystallization at which hydrous minerals first formed. In the rhyodacite dikes, Teapot Mountain Porphyry and a restricted porphyritic variant of the Rattler Granodiorite phenocrysts of biotite and hornblende occur in a fine-grained groundmass that makes up 30-50 percent of the rock, which indicates that the hydrous minerals started to form before the midpoint of crystallization. However, in the Granite Mountain Porphyry, Tea Cup Granodiorite, Tortilla Quartz Diorite, and the main facies of the Rattler Granodiorite, the hydrous minerals are interstitial to plagioclase, which makes up about 50 percent of the rocks, and intergrown with quartz and K-feldspar. Thus in these rocks, which comprise the bulk of the intrusive bodies at Ray, biotite and hornblende probably did not start to form before the midpoint of solidification.

At their depths of emplacement the intrusives at Ray should have contained 2.5-3.0 wt. percent H_2O before biotite started to form (D. R. Wones, oral commun., 1973; Wones and Dodge, 1966). Thus if, as indicated above, biotite first formed after the plutons were 50 percent crystallized, the initial water content of the magma must have been less than 1.5 percent.

Our textural studies also show that hydrous minerals show cross-cutting, interstitial, and coeval relations with the late-forming anhydrous minerals (mainly quartz, K-feldspar, and plagioclase). These relations and the presence of biotite, apatite, and sphene in late-stage aplitic differentiates of all the plutons indicate that hydrous phases continued to form until only a small amount, if any, liquid remained.

Banks (1976) has also studied the halogen contents of igneous minerals in the Laramide intrusives at Ray. He has summarized the results of this study as follows:

> "Apatite and biotite in younger, more silicic rocks contain more F but less Cl and H_2O+ than apatite and biotite in older, more mafic rock; the same relations hold for F and H_2O+ in sphene. * * * The contents of Cl, F, and H_2O+ in whole-rock samples decrease with increasing differentiation index and decreasing age. * * * The data are satisfactorily although not exclusively explained by postulating that the melts each contained progressively less Cl, F, and H_2O and that the hydrous minerals consumed most of the Cl, F, and H_2O in the magmas."

SOURCE OF COPPER IN THE RAY DEPOSIT

The Ray deposit is a major disseminated copper deposit. Since 1911 production has amounted to 1-3/4 million tons of copper, 45,000 oz of gold, and 4.5 million oz of silver. Total reserves are estimated at 650 million tons of ore of which three-fourths is primary, the remainder secondary (N. A. Gambell, oral commun., 1976). The deposit covers an area 3.2 km long in an east-west direction and 2.4 km north-south and is at the intersection of major northwest- and northeast-trending fault zones. It is also in an area of small plugs of Granite Mountain Porphyry, which occupy a zone elongated in an east-northeast direction for 5 km from the main exposed pluton of Granite Mountain Porphyry.

The primary hypogene minerals are pyrite, chalcopyrite, minor bornite and molybdenite, with traces of galena, sphalerite, and tennantite. Primary copper, occurring mainly in chalcopyrite, averages 0.1-0.2 percent in the Pinal Schist (Precambrian) and Granite Mountain Porphyry and forms large bodies of ore grade (more than 0.4 percent Cu) in the Precambrian diabase.

In considering the source of the copper and mineralizing solutions that formed the Ray deposit, several factors should be considered. First, the age of mineralization has been determined by K-Ar dating of hydrothermal biotite intergrown with ore minerals at 65 m.y. (Banks and others, 1972, p. 872, 875), and at 60 m.y. by fission-track determination of reset apatite in the deposit (Banks and Stuckless, 1973). The Granite Mountain Porphyry, which was mineralized by the ore solutions at the deposit, has a K-Ar age of 61 m.y. The Teapot Mountain Porphyry, which crops out as northeast-trending zone of small stocks and dikes 0.8 km north of the Ray deposit, has been dated at 63 m.y. The Tortilla Quartz Diorite dated at 70 m.y. (Banks and others, 1972, p. 871, 874) crops out in a small stock 0.8 km south of the deposit and also in a large pluton 3 km to the southwest.

These stocks and the east-trending rhyodacite dikes in the area are the intrusive rocks most closely related spatially and possibly genetically with the Ray copper deposit. It is possible that ore solutions emanated directly from one of these igneous bodies, or from a common source beneath the area at shallow or great depth. The ore deposit and two of the intrusives (Granite Mountain Porphyry and Teapot Mountain Porphyry) occur near the intersection of major northwest- and northeast-trending fault zones. It is quite likely that these throughgoing intersecting shear zones provided access to the surface from great depth for both magmas and hydrothermal solutions. The hydrothermal solutions could have carried copper from a deep source or have leached it from basement rocks as they migrated upward.

We prefer a model of magmas and copper-bearing hydrothermal solutions ascending from considerable depth--probably from the upper mantle. Derivation of the copper-bearing solutions directly from one

of the nearby plutons does not appear too likely in view of the probable small amounts of volatiles that could have been evolved from most of these as discussed above. If a local source directly from a pluton is postulated, the Granite Mountain Porphyry is probably the most likely one. The small stocks in the area of the copper deposit could be underlain at shallow depth by a larger body from whence the solutions could have emanated.

As discussed above, the distribution of trace copper in the igneous bodies in the Ray area does not give any clues that one or another is a likely source of copper for the deposit, either because it is enriched or depleted in copper. The range of copper content is similar in all the bodies including those far removed from the Ray deposit and goes from several to several hundred ppm, but commonly less than 90 ppm. Our studies indicate that more than half of this copper is secondary, introduced after solidification of the bodies.

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W/O — 2.2/1

600 m at .78 Cu
"underground" ore to E | .4 cutoff

MINE PLANNING AT THE RAY MINE

27000/tpd 1979 — .77 Sul
13 tpd 1.03 Silicat | .4 cut off

Haul Road, now 10% grade (old roads 8?
Roads 80" wide

pit — 28°/36° slopes

Some slides — upward bulge in floor of pit

by

W. J. Belobraidich

Senior Mining Engineer

Ray Mines Division

Kennecott Copper Corporation

Presented at

Arizona Conference - AIME

Open Pit Mining Division Meeting

Ray Mine, Arizona

April 21, 1979

HISTORY

This area was originally known for its silver mines in the late 1800's but as prospecting continued, copper became the most prominent metal.

At the turn of the century, an English company began developing the first copper mine. This company was not destined for success, for the orebody that was claimed to contain 4-5% copper, turned out to be less than 2%. It is said that the company spent more money on polo grounds, tennis courts and staff housing than they did on mining equipment. With this type of condition prevailing, it is easy to see why the company did not succeed.

In 1907, D. C. Jackling and Associates organized the Ray Consolidated Copper Company and gained control of the English holdings. By 1911, a 5,000-ton mill was constructed at Hayden and that mill, with numerous expansion, revisions, and alterations, has operated almost continuously from that time until the present. During the early days, several acquisitons and ownership changes took place, some of the companies involved in these transactions were the Ray Copper Company, Mineral Creek Copper Company, Arizona Hercules Copper Company, Gila Copper Company, and the Nevada Consolidated Copper Company, finally in 1933, Kennecott Copper Corporation assumed the controlling interest in the property.

All of the early mining was done by the underground method and in 1948, after an extensive exploration program, it was decided that the Ray orebody could better be mined by open pit method. The transition from underground to open pit mining was completed in 1955. This step was followed by an expansion program resulting in the construction of the Kennecott smelter at Hayden and an increase in mine production from 15,000 tons per day to 24,000 tons per day. As the exploration drilling program continued, large amounts of silicate ore were discovered and in 1968 the silicate ore leaching plant was constructed for processing silicate ore.

GEOLOGY

The Ray area geologically is composed of early Pre-Cambrian sediments, the Pinal Schist, and intrusives, the Ruin Granite and Madera Diorite, which are overlain unconformably by later Pre-Cambrian sediments, the Apache Group

Quartzites. This sequence was intruded toward the end of the Pre-cambrian by diabase sills.

The range bounding fault for the Dripping Springs Mountains down dropped Apache Group and diabase at about 70 million years and formed the Mineral Creek drainage basin. This fault in the Ray area is called the Diabase Fault. From the west, Pinal Schist moving along a low angle gravity fault, slid into the basin and overrode the down dropped diabase and Apache Group rocks. This low angle fault was important in the development of supergene ore at Ray and is called Emperor Fault. At about 60 million years, intrusion by a granodiorite, the Granite Mountain Porphyry, into this system began the formation of the Ray orebody. Hypogene mineralization in the form of Chalcopyrite, Molybdenite, Pyrite, and minor Bornite developed in a stockworks and vein system in the porphyry, quartzites, and especially the diabase. The hypogene system conformed with typical porphyry zoning models by forming a poorly mineralized core, a rich copper zone, and a large pyrite halo. However, the diabase's affinity for copper deposition created the singularly most distinct feature at Ray. The diabase with grades ranging from 0.40% to +1.00% copper contain 85% of the orebody's reserves. Porphyry and quartzose rocks contain copper in grades below 0.30% copper.

Continued faulting caused further down drop and rotation, which can be seen by the increased angle, up to 35° dip, on the Emperor Fault.

Weathering and erosion for the next 20 million years developed Ray's supergene deposits. On the east side of Mineral Creek in the low grade core area, less than 0.20% copper was leached and enriched to 0.80% copper. In the low acid environment, total sulfides present were under .01%, oxide and carbonate copper minerals were formed. Cuprite, goethite, and manganese copper oxides, Malachite and Azurite, were the dominant copper minerals.

In the pyrite halo areas, quartzose Pinal Schist high in total sulfides, 8% by weight, and protore grades of less than 0.10% were leached and enriched to about 2% copper. The enrichment of about twenty-to-one was made possible, in part, because the schist's permeability had been increased

during movement along Emperor Fault. In addition the Emperor floored the downward percolation of the leach solutions. Coupled with containment by near vertical faulting along the west and north end faults, Ray's Chalcocite blanket was localized and enriched beyond normal expections.

At 20 million years, the last major events occurred at Ray. The deposit was covered with the Apache Leap Tuff and the last movements along the Diabase Fault occurred. The Tuff covering the deposit was significant because it supplied the necessary silica to change the oxide and carbonate deposit to primarily silicate minerals, Chrysocolla, Neotocite and the zeolites.

The last movement along the Diabase Fault allowed extremely deep leaching of enriched portions of the secondary ore zones. This deep leaching, which is specially related to Mineral Creek, formed the bulk of Ray's native copper ores. The native copper comprises about 5% of the reserves.

OREBODY

The one word that most clearly describes the Ray orebody is "complexities". With three different ore types, several different rock types and many minor and major structural features, the ability to consolidate and project information is far from ideal. It is not uncommon for a group of blast holes to contain an intermittent scattering of both ore and waste. With inconsistencies such as this over a small area, the planning and also the actual removal of the ore becomes a real challange.

The sulfide ore, which is the largest ore type, is predominately calcocite in the upper layers and because this area has been secondarily enriched, it contains the highest grades of the sulfide ores. The deeper primary ore is chalcopyrite and some of this material is presently being mined in the bottom of the Pearl Handle pit. The sulfide ore is trucked to the primary crusher where it is reduced to -6 inch. It is then loaded in railroad cars and hauled to Hayden where it goes through the concentrator and smelter. The anodes are then shipped by rail to Baltimore, Maryland where the copper is refined and sold.

The silicate ore is principally chrysocolla. It is the green color that shows up on the banks mostly on the east side of the mine. The silicate ore is treated at the plant located at the mine site. The ore is trucked to the dump pocket where it passes through the primary and secondary crushing. A coarse and fine split is made and the coarse is leached in vats while the fines go to the agitation leach section. The pregnant leach solutions from vat leaching end up at the electrowinning building where the copper is plated out as cathodes. A small amount of cathodes are sold, but the majority are sent to our Chino Division in New Mexico for fire refining. The pregnant solutions from agitation leaching report to the precip plant and end up as cement copper, which is then sent to the Hayden smelter and is blended with the sulfide copper to form anodes.

The native ore is usually the disseminated variety although some of the more massive type have been located in our deeper drilling. Most of the native ore is mixed with either silicate or sulfide ore and will probably require a dual process plant to recover the majority of the copper. The native ore occurs in small pockets scattered throughout the orebody, because of the inconsistency in mining, the ore is now being stockpiled and will continued to be stockpiled until a sufficient amount has been accumulated to assure the continuous operation of a plant. When the plant is built, the erratic pockets of native ore in the pit will be treated as they are mined and the remaining amount of plant feed will be drawn from the stockpile.

There is a minor amount of moly in our orebody, and it is usually associated with the sulfide ore. A small plant in our Hayden concentrator recovers the moly whenever a sufficient amount of ore warrants the operation of the plant.

RESERVES

The open pit ore reserves are calculated on a 0.40% cutoff grade for all ores, and it is estimated that over 600 million tons are available at an average grade of 0.78% copper. The overall stripping ratio of our present pit design is 2.22:1. Some of the deeper drill holes have penetrated ore zones below the pit design indicating an

underground reserve. Preliminary estimates have been made of this material but additional drilling is required to verify and consolidate the information before reliable reserve figures can be calculated.

Kennecott is also exploring three satellite properties ranging in distance from 4 miles to 18 miles away from our present pit. These properties could be mined in conjunction with the Ray pit or be used to extend the life of the operation when the present pit is exhausted.

OPERATIONS

This mine operates on a 3-shift per day, 7-day per week basis. The present production rates are 27,000 TPD sulfide ore, 14,000 TPD silicate ore, and 160,000 TPD total material mined. The head grades for 1979 are 0.77% copper for the sulfide ore and 1.03% copper for the silicate ore. The stripping ratio for the year will be a 2.90:1. With the above mining rates, the life of the Ray pit is in excess of 50 years.

The haulage roads inside the pit limits are planned at a 10% grade, while outside the pit limits 8% maximum grades are used. The total designed road width is 100 feet, which includes a berm and drainage ditch leaving an actual road width of approximately 80 feet.

The pit slopes in the ultimate pit design range from 1-3/8:1 (36°) to 2:1 (27°) depending on the fault patterns, hardness of the rock, and other structural features.

Kennecott has contracts with two special groups for removing material from the mine. The Southwest Mineral Associates removes hand specimens of rocks and minerals and two nurseries have been engaged to remove the cacti plants from the proposed dumping and mining areas.

MINE PLANNING

The first job of the mine planner is the designing of the ultimate pit limits. Without going into a lot of detail, we use the computer cone method and determine the

economic breakeven point of each block of ore on the outer shell of the pit design. When this is done, the pit is usually divided into various mining areas and a road system set up to servicing each of the areas. A systematic order for mining the orebody must be determined which will satisfy the company's major objectives and which will incorporate good mining practices.

In dealing with any of the elements of mine planning, we have found the computer to be an almost indispensable tool. Ray Mines has been engaged in computer programming for over 13 years. Practically all of the long range mine and dump plans have been computerized. A few of the short range plans that are still done by hand utilize the computer printout sheets for all of the basic planning information.

Our computer (IBM 3031) is located in Salt Lake City, and it is activated by a remote terminal located in the Ray engineering department. Other equipment in the engineering department is an IBM 1058 cardpunch machine and a Numonic 224 digitizer.

Ray Mines Division maintains two computer mine models. One has 100' x 100' x 40' blocks and is used for long range planning. The other model has 50' x 50' x variable height blocks and is used for short range planning. The variable height aspect of the second model gives us the capability of updating the model with the current bench elevations taken from a pit topo map. The computer can then use the actual height of each block for computing tonnages. This is a necessary requirement for short range planning when the blocks on the existing benches being mined are not 40 feet in height.

The Ray engineering department provides mining plans on an one month, one year, 10 year and life of the mine basis. The monthly and the first year mining plans are the ones that are still done by hand. Much of the day-by-day blast hole information and current changes in the mining conditions are not reflected in the computer model. Until changes are made in our present programs to handle this type of information, it is easier and more reliable to do the short range planning by hand. I strongly feel, however, that our future plans of this type will computerized.

Each year our management requires a mining plan for the following year to establish operating goals, also a year-by-year 10 year plan to determine operating trends for the future. The computer does an excellent job updating this type of program each year. The volume of information that must be examined, in a review of this type, makes it almost impossible to do by hand, especially when the time element is considered.

Several mining plans extending for the life of the mine have been prepared. These plans, using our present mining rates, expanded mining rates, and a variety of other economic conditions have been conducted as needed. This type of long range planning is necessary to provide the management with the basic information for making prudent long range plans. The ability of the mine planner to accurately determine the amount of recoverable copper in an orebody and to develop the various mining rates at which the ore can be extracted becomes very important. This fundamental information is usually the ground work upon which most of the major company decisions are made.

The mining engineers use of a computer can range from very little, to almost total dependence. Ray engineering is leaning towards the upper end of the dependence scale. The computer has the ability to store vast amounts of information and the number and types of programs that can be developed are only limited by the engineers' imagination.

The program that we use the most is a program that mines out various areas from the computer model and prints out a level-by-level summary sheet giving much of the information that is required for making a mining plan. Each of the areas being considered for the mining plan is digitized, this gives the computer all of the coordinate points outlining the area and the computer can remove that bench from the model and assimilate the information. The type of data that is printed out is as follows:

Tons of sulfide ore, schist rock type, head assay.
Tons of sulfide ore, diabase rock type, head assay.
Tons of silicate ore, total copper assay, readily soluble assay.

Tons of native ore, head assay.
Tons of waste.
Stripping ratio.
Mill test for sulfide ore, recovery and concentrate grade.
Leach test for silicate ore, recovery, pounds of acid.

This printout gives the data for one bench, but it includes the information for the entire area. Many times only part of an areas is needed for a particular plan. In this case a row and column program is run on the 100' model. The computer is given the direction in which the bench is to be mined (N, E, S or W). The computer will accumulate the information in 100' increments as it progresses down the bench. For example, if the bench is to be mined in a northerly direction, the first row of east-west block for the width of the area will be added together. The computer will then advance 100' north and add all of the east-west blocks in that row, and then add that row to the first row. The third row will be added to the first and second rows, etc, for the length of the area. With this program, the engineer can determine the partial bench information. If 500,000 tons of sulfide ore is needed from this area, the engineer can run down the sheet until he finds the row where the necessary tons have been accumulated. The computer will also give the grade of the sulfide ore, the tons and grades of the silicate and native ores, and also the amount of waste that must be removed to mine the above ores. With this type of data available for each area, the engineer can determine where the various ores and waste must come from to meet the criteria of a particular mining program. In addition to the number of tons of ore that must be mined to produce a continuous supply of ore to both plants, the following other conditions must be considered:

Maintain consistent head grades (above division goals).
Provide proper blending of ores for hardness and wetness.
Mine ores which will produce acceptable concentrate grades, recoveries, acid consumption.
Plan for pre-stripping which will uncover ore in time for mining and usually several other current conditions, which for various reasons, restrict the mine from operating under its normal practices.

The combining of all these variables to make a concise, accurate mining plan becomes a real challenge. It is usually easy to see where a change in one condition will help the plan, but that change usually affects several other conditions so it becomes a matter of the degree of change that must be considered.

The "complexities" of the Ray orebody, as described in this paper, will give you some idea of the problems involved in mine planning at this operation. An attempt was made to give some background information and also a general discussion of the various activities performed at the mine along with our mine planning programs. Because of the variety of topics covered in this paper, only a general discussion was presented of the computer mine planning programs and the other techniques used by the Ray engineering department. If anyone is interested in more details concerning the mine planning programs, I will be happy to discuss them with you during the tour this afternoon or at dinner tonight.

LARGE MINING EQUIPMENT AT THE RAY MINE

By

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PIT OPERATIONS SUPERINTENDENT

RAY MINES DIVISION

KENNECOTT COPPER CORPORATION

Presented at the

ARIZONA CONFERENCE - AIME

OPEN PIT MINING DIVISION MEETING

Ray Mine, Arizona

April 21, 1979

LARGE MINING EQUIPMENT

AT THE RAY MINE

GENERAL

Current ore production rates at Ray are 27,000 tons per day of sulfide ore and 14,000 tons per day of silicate ore, seven days per week, at a stripping ratio of approximately three to one, for a total daily rate of 160,000 tons. Sulfide ore is crushed to approximately eight inches in one 54-inch by 74-inch gyratory crusher and hauled about five miles by Kennecott in 60 car trains to Ray Junction, from where the Southern Pacific Railroad delivers the ore to the secondary crusher at Hayden. Silicate ore is hauled to the silicate leach plant about one mile south of the mine. Two copper precipitation plants are operated with solutions from the sulfide waste dumps, and solutions from the slimes circuit of the silicate leach plant.

Operating manpower at the mine consists of 340 hourly employees and 30 supervisors. Mine maintenance employees number approximately 330.

Seven shovels and thirty-two haulage trucks are scheduled to operate on each of the 21 shifts during the week. Conventional type drilling, loading and hauling equipment is utilized, and includes the largest mining shovel in Arizona, and the largest fleet of over 200-ton haulage trucks in the United States; a detailed listing of this equipment is attached (Exhibit A). Nearly all material mined must be drilled and blasted, and bulk ammonium nitrate prills are currently handled by a contractor.

Rotary drills are Bucyrus-Erie 40R (9-inch holes) and 60R (10-inch holes). Mill tooth bits are used in soft and medium hard ground, and silicon carbide "button" bits are used in hard ground. Shovels are Marion and P&H, and consist of five older six and seven-yard shovels, five fifteen-yard shovels and one 27-yard, P&H, 2800 shovel. Other loading equipment includes three 600B, KW Dart, front end loaders with twelve-yard dippers, which are used chiefly for ore blending and construction work. Haulage trucks include thirty-four 120 WABCO trucks,

and eight 250-ton, 3200B WABCO trucks. The latest two trucks are being put into service, and are the unit at the American Mining Congress exhibition last October, and the unit that was on trial at the Pima Mine, which has been rebuilt to current 3200B specifications.

P&H 2800 SHOVEL

Kennecott's six and seven-yard mining shovels at Ray were purchased starting in 1950 and as noted, five of these smaller machines are still in service. In 1968, two fifteen-yard, Marion 191M shovels were placed in service, and a third one was purchased in 1970. In early 1975, a fifteen-yard P&H, 2100 BL shovel was placed in service. These larger shovels performed well from the outset, and 1975 loading costs for the fifteen-yard machines were approximately thirty-four percent lower than the costs for the smaller shovels. Cost reductions were chiefly in the labor, power, and maintenance areas. Haulage savings accrued also because of the shorter loading times with the larger shovels.

Ray Mines Division was scheduled to replace two small shovels in 1977 with one larger shovel, and considered 15, 20, and 25-yard shovels. Kennecott's Utah Copper Division had two P&H 2800 shovels which had been put in operation in 1975. Two more were being purchased in 1977 and the Utah Division was generally satisfied with the shovels. Ray's estimated operating cost analysis of this model shovel in the Ray operation was attractive, and the shovel would still match fairly well with the 120-ton trucks. The 27-yard, P&H 2800 shovel was purchased in 1976 and placed in service in April, 1977. Exhibit B shows a Model 2800 ownership listing.

The shovel measures 55 feet to the top of the point sheaves, compared to 47 feet for the P&H 2100 shovel. Working weight is approximately 925 tons, including about 160 tons of counterweight. The shovel uses two 2-1/4-inch hoist cables, two 700 hp hoist motors, and four 170 hp swing motors.

The P&H 2800 has the Electrotorque Control System, which was first introduced by Harnischfeger on operating machines in 1967. This all solid state system for total AC power conversion requires no motor-generator units, and has no moving parts between the introduction of power to the shovel and delivery of controlled power to the motors. The shovel also has the joystick-type control for the hoist, swing, crowd, dipper trip, and horn.

After three weeks' erection time, the shovel was put into

extremely difficult waste stripping service in the east side of the mine. Rock types include the extremely tough and hard breaking conglomerate, dacite, and quartzite, which usually provided only fair digging. The conglomerate usually broke with many pieces too large to load with the shovel, and usually caused hard digging face-up conditions, even with reduced blast hole spacings. The dacite was also sometimes coarse breaking, and usually was extremely dusty, which reduced operator effectiveness because of impaired vision. Also, during the first several months of operation, all 52 shovel operators and helpers were trained in the operation of the joystick-type control.

The shovel was slightly slower than the 15-yard shovels, with an average cycle time of about 35 seconds to about 28 to 31 seconds for the 15-yard shovel. Adversely affecting cycle time were the swing acceleration, and the hoist lowering speed. In 1978, Harnischfeger installed electrical modifications which increased stall swing armature current, to provide about 13 percent greater motor torque for faster acceleration to peak swing speed. A control change also improved the hoist lowering speed, and these improvements reduced the cycle time to about 29 seconds. In addition, a field current adjustment increased the propel speed in the low torque range, and a propel brake improvement providing about 50 percent more torque was installed.

Availability of the shovel has been 82 percent, which is about average for the other shovels in the mine. Most shovel interruptions have been because of minor electrical problems, but oftentimes difficult to locate, and usually involving dust or dirt on relays or contactors in control circuits. These problems are greatly reduced during damp weather conditions. A premature propel gear failure did occur at about 4,000 hours, evidently because of a bad bearing. Some problems have occurred with the crowd motor, including three broken shafts.

Hoist cable life has been approximately 2,000,000 tons, compared with 900,000 to 1,000,000 tons for the other shovels. The original dipper on the shovel was a P&H fabricated steel dipper with a cast lip-front. Except for some minor trip problems, this dipper performed well and handled 17,000,000 tons before being taken from service for rebuild. The present dipper, a 27-yard cast AMSCO dipper, has been on the shovel about three months, and indications are that it also will give good service.

Shovel tonnage rates improved last year with operator proficiency, shovel motion modifications, and in some cases, improved bank conditions. Use of the 250-ton haulage trucks also helps loading efficiency; five good passes with the 2800 shovel will adequately load one of the 3200 trucks. Average tons

loaded per shift is still under 20,000 tons, but shifts in good bank conditions exceed 25,000 tons. Fifty or sixty-foot benches in place of present forty-foot benches may be used in the shovel's next location, and this would further improve operating efficiency. During 1978, 2800 shovel costs were about 30 percent lower than costs with the 15-yard shovels.

WABCO 3200B HAULAGE TRUCKS

The first trucks used by Kennecott at Ray were Euclid FFD, 34-ton units, which were put into service in 1951 and retired in 1960. These were the first of several different kinds of trucks used in the 28-year history of the mine; these trucks and years in service are shown on Exhibit C. Four of the 50-ton KW Dart trucks are still active in specialized service in mine and leaching operations, and two of the 65-ton, KW Dart units are in service as water trucks.

During the period from 1960 to 1968, as tonnage requirements increased and more types of trucks became available, Ray purchased several of these, and as shown, at one time in 1968, the fleet consisted of seven different truck types. This naturally caused problems with operator and mechanic training and spare parts, and fortunately the mine is not in that position now.

The first electric drive trucks used were the Unit Rig, Lectra Haul, M-85 Models, which utilized VT-600 hp Cummins engines. Following the Lectra Hauls, two fleets of mechanical drive trucks were purchased, the six 100-ton, RX Euclids, and the fifteen 85 and 100-ton, KW Darts.

In 1971, the first three 120 WABCO trucks were purchased, and subsequent additions of these models through 1977 increased that fleet to the present thirty-four trucks. These trucks have either GMC 12V-149 or Cummins 12V KT-2300 engines. Average operating life on this fleet is 23,000 hours, with the three original trucks having about 32,000 hours.

Ray's haulage truck replacement program had scheduled the 85 and 100-ton Dart trucks to be replaced in 1977. At this time, the fleet included thirty-three 120 WABCO trucks which were, and still are, giving excellent service. There were larger trucks on the market, and because the mine could easily accommodate larger trucks, several models of 120 to over 200-ton trucks were considered.

One of the 3200 WABCO 200-ton prototype trucks had been

on trial at Ray for a few months in 1973, before it was retired following an accident. This truck had the same model engine as the present 3200B trucks, although it was derated to 2200 horsepower. The truck also had a lighter frame, suspension units, and spindles than the present trucks, and could not use the larger 3600x51 tires. In 1977 there were only two 3200 trucks operating in the United States, those at the Pima and the Duval Sierrita Mines. There were eight of the trucks (and three more on order) at a Canadian mine and twenty-two operating at two properties in Australia. In mid-1977, six of the 3200 trucks were ordered for Ray, and the trucks were put into service in late 1977 and early 1978. As mentioned, Ray just recently activated two more of these trucks for a total of eight. Exhibit D shows a current 3200B ownership listing.

The present 3200B trucks have the EMD 12-645, E-4 locomotive diesel engines. The two-cycle, 12-cylinder, turbocharged engines are rated at 2475 horsepower at 900 RPM. An EMD, AR-5B alternator is a three-phase, AC synchronous generator directly connected to the engine crankshaft through a flexible flywheel coupling. The generator's AC power is rectified to DC power by a silicon rectifier assembly. Two EMD Type D79 traction motors, rated at 1125 horsepower each, are used, each driving one of the rear tandem axles. Reduction gears, differentials, and planetaries are shown in Exhibit E.

The dynamic retarding system has continuously rated blown grids for a broad range of speed control, and includes extended range for retarding at slower speeds. Service brakes on all six wheels are air-over-hydraulic drum and shoe type, and are designed to stop a loaded truck traveling at twenty miles per hour on a minus ten percent grade in about 130 feet, without any dynamic brake assistance.

The 3200B frames are much heavier than the earlier ones, and include a modified box section of 60,000 PSI alloy steel, which is 40 inches deep with 3/4-inch side plates and 1-1/2 - inch top and bottom plates. The six Hydrair suspension units are larger than the ones used on the earlier trucks; the two rear Hydrair suspension cylinders on each side of the truck are hydraulically interconnected and provide a "hydraulic walking beam" for equalizing tire loads in uneven ground conditions.

Empty weight of the Ray truck, with fuel, oil, and water, is about 400,000 pounds. Loaded weight with a 250-ton payload is about 900,000 pounds, equally distributed to all ten tires. Tires are 3600x51, 50-ply, and are inflated to 70 PSI.

Dump bodies have 3/4 or 1-inch T-1 steel floor plates

and 3/8-inch side plates. The bodies were specified to haul 250-ton average payloads and were 186 cubic yards capacity at a 3:1 slope. After a careful check of payload weights with various rock types, the bodies were sideboarded seven inches to provide for an average 250-ton load.

Exhibit F shows the relationship in section between a 3200B and a 120 WABCO. The top of the dump body was 16 feet, 7 inches from the ground, only eleven inches higher than the 120 truck; the sideboards increased this difference to 18 inches. Width is 24 feet compared to about 18 feet for the 120 trucks. Because of the tandem rear drive, the relatively long, flat bottom dump body conforms better than the V-type body with the two-axle trucks; the truck is 54 feet, 3 inches long, compared to the 120 truck length of 36 feet, 1 inch, and has a turning circle of about 155 feet, about twice that of a 120-ton truck.

3200B Performance

The first six 3200B trucks at Ray have been in service for from thirteen to sixteen months, having accrued an average of 8,000 operating hours. This has been enough service to adequately evaluate certain aspects of the truck's performance, such as field operation, fuel consumption, and the like, and to obtain a fair idea of the expected maintenance, repair, and replacement of most of the truck's components.

General Operating Performance

The general performance of the truck on mine roads, dumps, and around other equipment is about as expected for a very large three-axle haulage truck, proportioned very much like the three-axle, 50-ton LLD Euclids that were used earlier at Ray. The trucks are very stable, easier riding, and less prone to skidding than the two-axle trucks, and the tandem drive units are safer to back into a dump berm. The large turning radius does require more room, but this requirement presents no problem with the normally wide working benches at Ray.

Occasionally, when starting a new level, smaller trucks are used on the narrow ramps or roads, but only for a day or so; if another shovel is working nearby, it can be used to open up the new level.

Ray Mine haul roads have been 100 feet wide (occasionally 80 feet) for several years, and provide ample widths for the larger trucks. The only road change was construction of larger protective berms at road edge.

3200B truck availability has averaged 78 percent, the entire fleet average for 1978, and material hauled per truck shift has averaged about 3500 tons. At Ray, available truck hours do not include those times that the trucks are in for fuel and lube service, tire work, or preventive maintenance inspection.

The speed of the truck on grade is slightly better than expected. Actual performance curves based on time cycles over measured grades are developed for Ray Mine trucks; Exhibit G compares performances of the 3200B and 120 WABCO trucks. Exhibit H shows the average ore and waste haulage profiles for the Ray Mine during 1978.

The truck cab and controls are very similar to those of the 120 truck, and driver acceptance is good. All drivers back using mirrors, so the inset cab posed no problem. Because of its size, there is a much larger blind area on the right front of the truck than with the smaller trucks, and the drivers and other persons driving in the area must take this into account. There seems to be no problem with drivers moving from one size truck to the other. To date, the large trucks have had no collisions.

Operating Costs

The 3200 trucks are using somewhat less fuel than was expected, and are averaging 29.5 gallons per hour. The 120 WABCO trucks use about 17 gallons per hour. The 3200 trucks were on slightly easier hauls, but with fuel consumption factored for this difference, the fuel used per ton material hauled has been about ten percent less than the 120 truck fuel use.

Tire life on these trucks was extremely questionable, especially regarding the front end, which is subject to severe scuffing action when the truck is turning. Tires are taken from the front wheels for safety purposes after a period of use and transferred to the rear axles, where they are run to destruction. Tires were originally moved from the front wheels at about 1500 hours, but now are generally left there for 2,000 hours. Tire wear has improved in general over the past several months, with all tires now averaging approximately 4,000 hours.

Tire costs to date per ton material hauled are slightly less than those of the smaller trucks, and it appears at this time that tire costs for the 3200 trucks will be no more than those for the 120 trucks.

Operating labor costs per ton material hauled to date for the 3200 trucks have been considerably less than half of the costs for the 120 trucks, even when factored for the difference in haulage profiles. The 240-ton factor for the 3200 truck com-

pared to the 110-ton factor for the 120 truck accounts for some of this variance. Another contributing factor is the usual matching of the large trucks with the 27-yard shovel, and also the fact that only the 120-ton trucks are used with the six and seven-yard shovels.

All things considered, indications are that direct operating labor costs per ton material hauled for the large trucks will be less than fifty percent of the labor costs for the 120 truck. The additional fringe labor costs would also be comparably less for the larger trucks.

Maintenance and Repair Costs

The 3200B trucks in the Ray fleet averaged 8200 operating hours on April 1, not nearly enough on which to accurately predict fine ranges of component life and detailed maintenance costs in all areas. In addition, some modifications are under way, and the maintenance cost effect of some of these may not be known for a long time. Some limited amount of information has been obtained in the Ray operation, and data is also available from 3200B experience in other operations, and from 3200B component use in other applications. This information indicates that certain component life, and some M&R costs can be fairly well defined, and that others can be estimated within reasonable limits.

The truck engine, generator and traction motor have been successfully used for over 20 years in the railroad industry, and the engine has also been extensively used in marine and stationary power applications. Unfortunately, two premature engine failures occurred at Ray. One occurred at about 800 hours when a rod came through the cylinder wall and the crankshaft counterweight was bent. The cause was not definitely determined, but it may have been because of a problem with the piston snap ring. The other failure happened at about 2,500 hours, when broken turbocharger blades knocked holes in the turbocharger aftercooler, allowing water to enter the air box. Because some drain hole plugs had not been removed, the water entered a cylinder causing a hydrostatic lock, which bent the rod and caused other damage.

Three power pack units, which consist of the cylinder head, liner, piston and connecting rod, have been installed in one engine, and two more in another, because of scored liners.

There have been four turbocharger failures, all resulting in broken turbo blades. It is planned to pull the turbos at about 5,000 hour intervals for bearing replacement and PM inspection.

Engines in these trucks at other properties are doing well. Some of the engines at one mine have almost 20,000 hours, and to date, none of the engines at this mine have had to be replaced. Another mine using 3200B trucks report comparable engine performance. Two of these engines have been in locomotive service at Ray for almost nine years, average over 32,000 hours, and have never been out of the locomotives.

The EMD 12-645 engines can easily be inspected by the removal of covers and checking of pistons, rings, liners, and bearings and these items are relatively easy to replace. Indications are that with proper operating procedures, and adequate preventive maintenance inspection and parts replacement, the engines will provide 20,000 to 25,000 hours of service between major overhauls, at unit production costs lower than those for the higher speed diesel engines in the 120 WABCO trucks.

There have been no problems with the alternators, and based on experience with these at other mines and in other applications, alternator life should greatly exceed generator life in the 120 trucks, and the units should last as long as the engines between major overhaul or rebuild. There have been six traction motor failures, mostly because of flashover or blown armature coils, but this is not excessive for the service life of the trucks.

There have been four drive gear failures. One of these occurred when the bolts that hold the idler gear shaft in place broke and the shaft slipped out. Twice a single tooth broke off of idler gears, and two planetary units were replaced because of a sun gear failure, and one differential unit failed because of a broken weld.

Truck frames are holding up well, and there are only minor cracks about two inches long on two trucks in the weld where the horsecollar engine mount is welded to the frame. WABCO is now welding heavy reinforcement plates to the horsecollar and frame in this area. Indications are that frames will not be a large problem in the Ray operation, and will require only a minimum of maintenance.

Ten hoist cylinders have been replaced. Most of them failed because the piston heads, which were welded to the rods, were pulled apart from the rods. WABCO is providing new style units with the piston head integral with the rod. It is expected that cylinder life will equal the 10,000 hour life of the hoist cylinders on the 120 trucks.

The suspension units are working out well, with only one replaced to date, and a life of about 15,000 hours is expected from these Hydrair units.

Because of its configuration, the dump body will probably cost more per ton to maintain than the 120 WABCO bodies. The kick sheet at the rear end of the body receives considerable wear as the material is turned at this point. Also, the dump body holds more than twice the tonnage, but is only about 30 percent wider than the 120 truck bodies, consequently, more material passes over each unit of width. Kick sheets are being lined with one-inch thick abrasion resistant type bolt-in liners at about 7,000 hours. Three-eighth-inch bolt-in side plates are also being installed in this area.

Minor problems have occurred with the PTO gear box, engine fan drive shaft and coupling, steering ball studs, and the hoist control valve seals, but improved parts are being installed which should correct these problems.

One maintenance cost advantage of the 3200B trucks is that generally for most jobs, the same mechanic man hours are required for both the 3200B WABCO and the 120 WABCO trucks, which contributes to lower unit hauled maintenance labor.

E X H I B I T S

A. Ray Mine Equipment List

B. P&H 2800 Ownership List

C. Ray Truck History

D. 3200B WABCO Ownership List

E. 3200 Propel Gearing

F. 3200 - 120 Truck Size

G. 3200 - 120 Performance

H. Ray Mine Haulage Profiles

EQUIPMENT LIST

RAY MINE - 1979

ROTARY DRILLS

	Type	Year
1	Bucyrus-Erie, 40-R	1956
1	Bucyrus-Erie, 40-R	1957
1	Bucyrus-Erie, 40-R	1960
2	Bucyrus-Erie, 40-R	1968
2	Bucyrus-Erie, 60-R	1976

SECONDARY DRILLS

2	Joy Econodrill	1974

SHOVELS

1	4161 Marion, 6-Yard	1951
1	4161 Marion, 6-Yard	1964
1	1600 P&H, 7-Yard	1954
1	1600 P&H, 7-Yard	1956
1	1600 P&H, 7-Yard	1957
2	191-M Marion, 15-Yard	1968
1	191-M Marion, 15-Yard	1970
1	2100 BL P&H, 15-Yard	1975
1	2100 BL P&H 15-Yard	1978
1	2800 P&H, 27-Yard	1977

FRONT-END LOADERS

1	600B KW Dart, 12-Yard	1973
1	600B KW Dart, 12-Yard	1974
1	600B KW Dart, 12-Yard	1974

HAULAGE TRUCKS

3	120 WABCO, 120-Ton	1971
5	120 WABCO, 120-Ton	1973
16	120 WABCO, 120-Ton	1974
6	120 WABCO, 120-Ton	1975
3	120 WABCO, 120-Ton	1976
1	120 WABCO, 120-Ton	1977
3	3200-B WABCO, 250-Ton	1977
3	3200-B WABCO, 250-Ton	1978
2	3200-B WABCO, 250-Ton	1979

EXHIBIT A

CRAWLER DOZERS

	Type	Year
3	Caterpillar D8H	1973
4	Caterpillar D8H	1974
2	International TD25C	1974
2	Caterpillar D9G	1975
1	Caterpillar D8K	1975
1	International TD25C	1978

RUBBER-TIRED DOZERS

1	Caterpillar 966C	1968
1	Caterpillar 814	1973
2	Caterpillar 814	1974
2	Caterpillar 814	1975
2	Caterpillar 814	1977

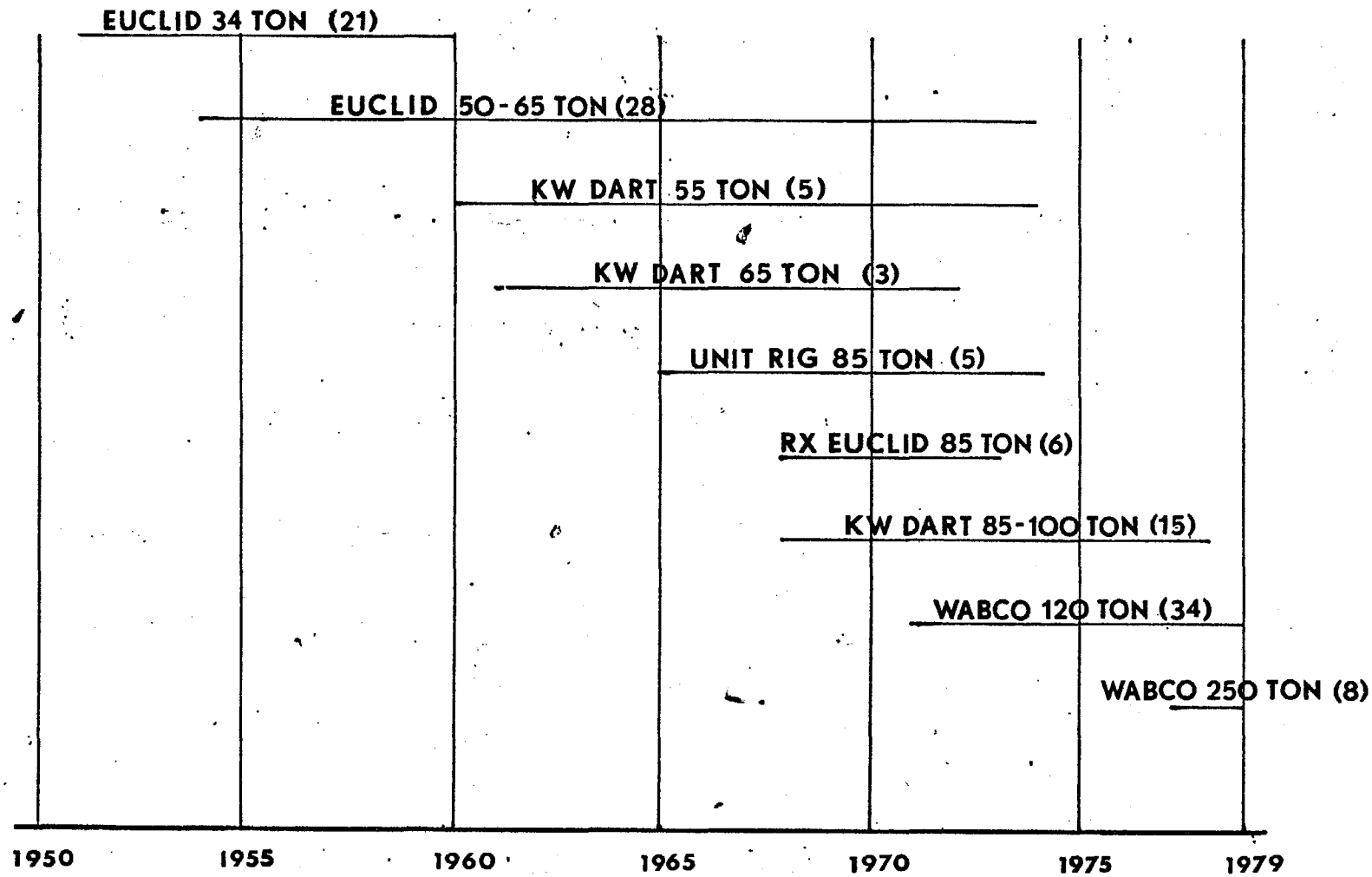
P & H MODEL 2800 SHOVEL

OWNERSHIP LIST

April, 1979

MINE AND LOCATION	YEAR	QUANTITY
UNITED STATES		
Anaconda Company Butte Operations, Butte, Montana	1978	1
Atlantic Richfield Black Thunder Coal Co., Gillette, Wyo.	1976 1977 1978 1979	1 1 2 1
Kennecott Copper Corporation Utah Copper Division, Utah	1975 1977 1978	2 2 1
Ray Mines Division, Arizona	1977	1
AUSTRALIA		
Bloomfield Collieries Pty. Ltd. East Maitland Mine, South Wales	1978	1
Mt. Newman Mining Co. Pty., Limited Mt. Newman, WA	1974 1975 1976 1977	1 1 1 1
CANADA		
Kaiser Resources, Ltd. Fernie, B.C.	1969	4
CHILE		
Corporation Del Cobre (CODELCO) Compania de Cobre Chuquicamata Chuquicamata	1977	2
MEXICO		
Compania Minera de Cananea, S.A. Cananea Operations, Cananea, Sonora	1973	1
	Total	24

EXHIBIT B



PIT HAULAGE TRUCK HISTORY

RAY MINES DIVISION KENNECOTT COPPER CORP.

EXHIBIT C

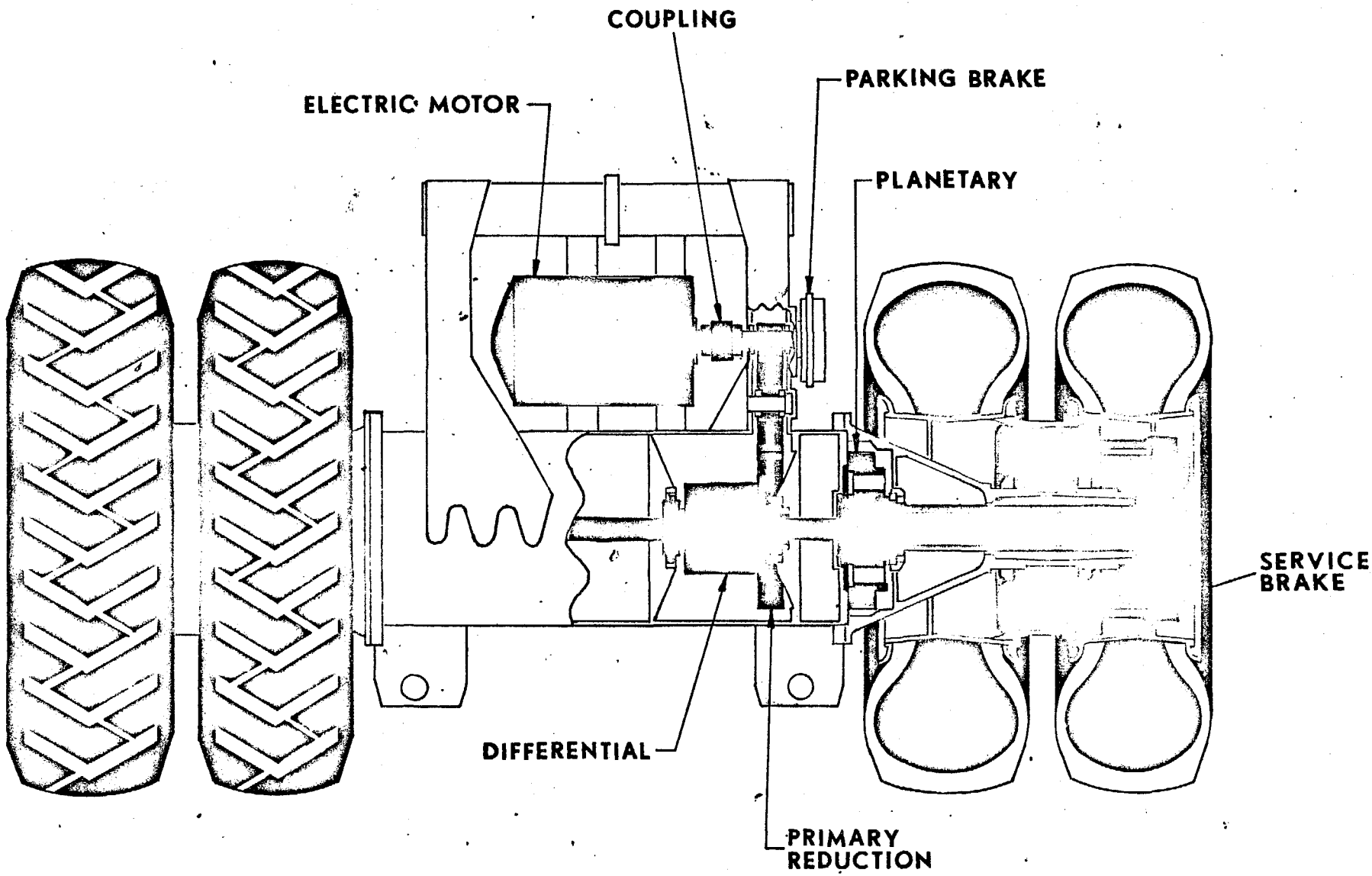
MODEL 3200B WABCO TRUCK

OWNERSHIP LIST

April, 1979

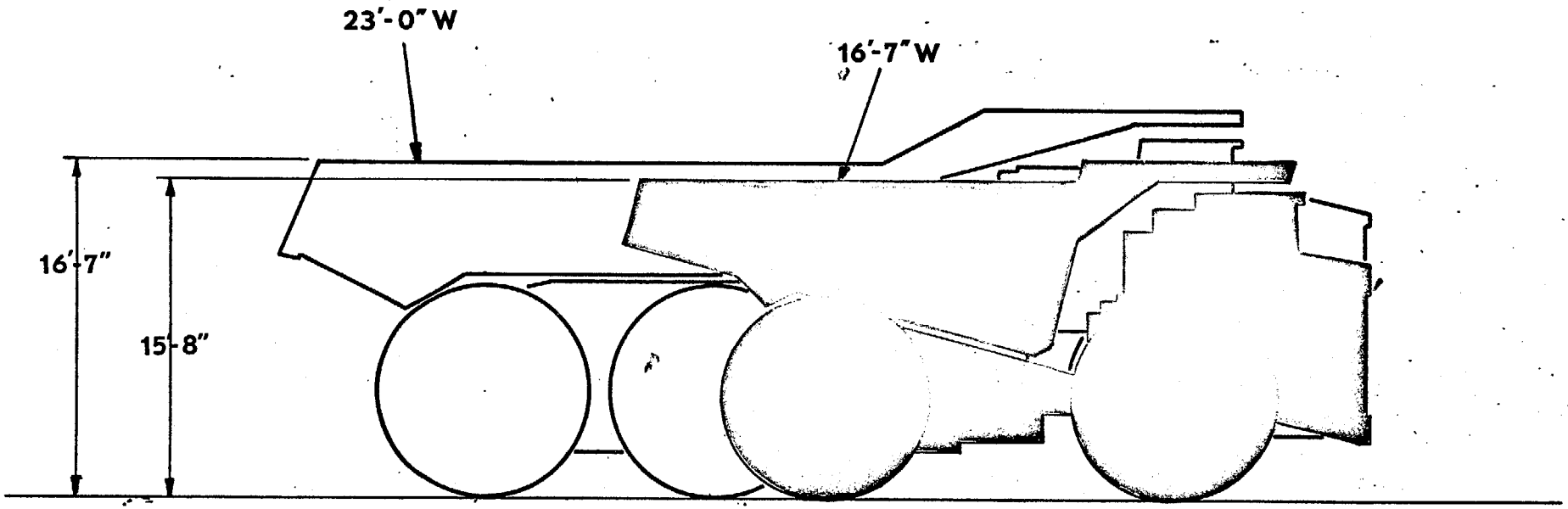
MINE AND LOCATION	YEAR	QUANTITY
UNITED STATES		
Duval Copper Corporation Sierrita Mine - Tucson, Arizona	1973	1
Kennecott Copper Corporation Ray Mine - Arizona	1977 1979	6 2
CANADA		
Lornex Mining Company, Ltd. Highland Valley, British Columbia	1973 1974 1975 1976 1977	1 1 1 3 5
AUSTRALIA		
Hammersly Iron Pty. Ltd. Mt. Tom Price, West Australia	1976	5
Mt. Newman Mining Company, Ltd. Mt. Newman, West Australia	1972 1975 1976	1 11 5
CHILE		
La Corp. Nac. del Cobre de Chile (CODELCO) Chuquicamata Mine	1979	4
	Total	46

EXHIBIT D



3200B PROPEL GEARING

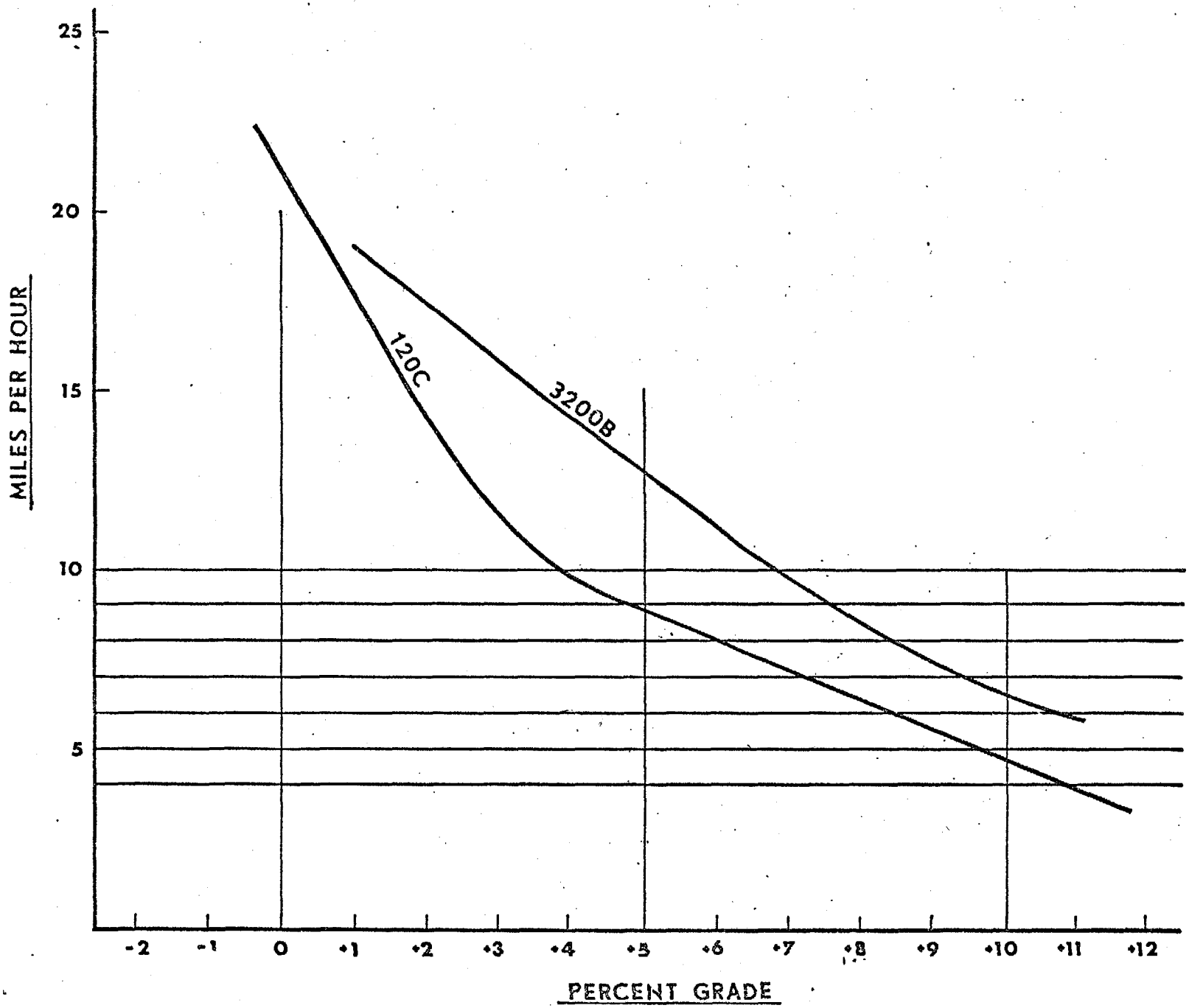
EXHIBIT E



DUMP BODY COMPARISON

WABCO 3200B — WABCO 120C

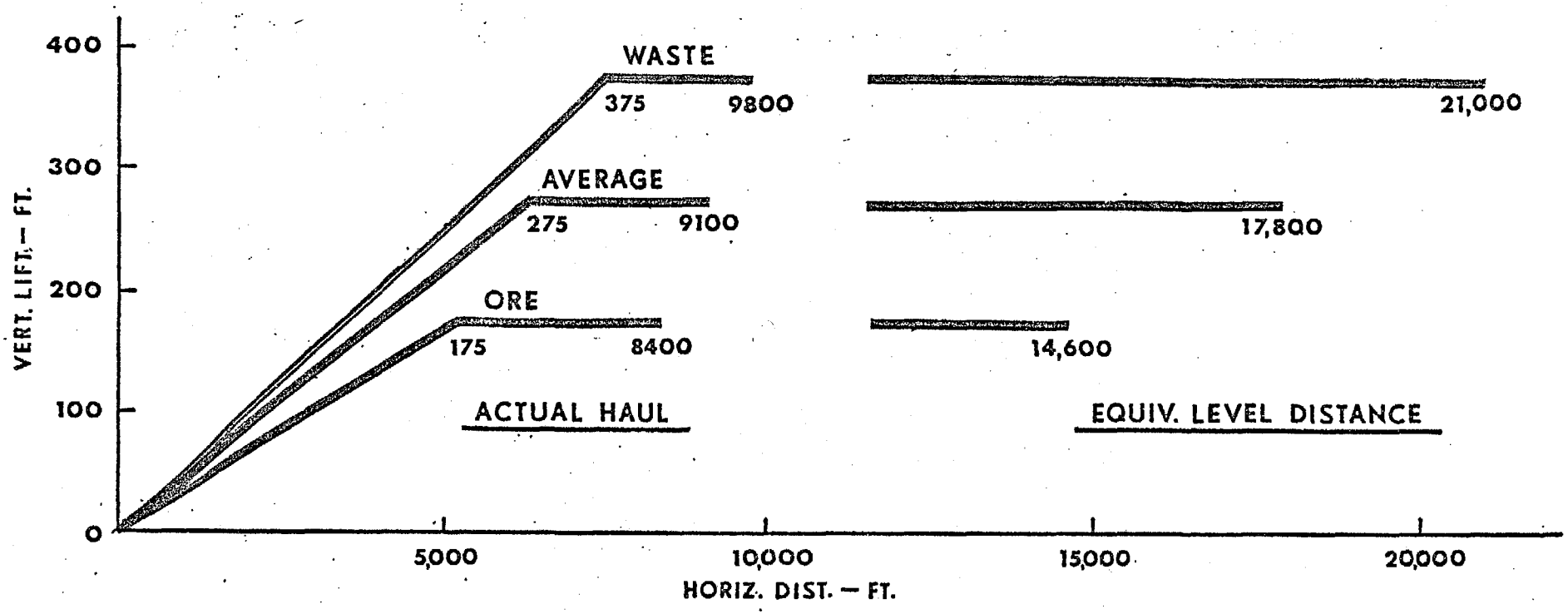
EXHIBIT F



PERFORMANCE CURVES (RAY)

3200B WABCO - 120C WABCO

EXHIBIT G



HAULAGE PROFILE

RAY MINES — 1978

EXHIBIT H

WATER POLLUTION CONTROL AT THE RAY MINE

By

NEIL A. GAMBELL

DIVISION GEOLOGIST
RAY MINES DIVISION
KENNECOTT COPPER CORPORATION

Presented at the

ARIZONA CONFERENCE - AIME
OPEN PIT MINING DIVISION MEETING
RAY MINE, ARIZONA

APRIL 21, 1979

WATER POLLUTION CONTROL AT THE RAY MINE

Introduction

The operations at Ray are a complex, integrated facility whose purpose is to produce copper. The facility consists of an open pit mining operation, five active sulfide leach dumps serving two precipitation plants, and two types of containerized silicate leaching facilities that utilize sulfuric acid. In addition, construction of the largest Liquid Ion Exchange Plant in Arizona has begun. Needless to say, an operation like this requires a great deal of process water circulating through pipes, ponds, and tanks. By design, most of this water has a high metal content and a low pH, making it a pollutant if it were to enter the waters of the United States. This paper deals with how we attempt to keep the waters of Kennecott separate from the waters of the United States.

The Waters of the United States

The Ray operation is located 3-1/2 miles north of the Gila River on an intermittant tributary known as Mineral Creek.

The 7,800 square miles of Gila River watershed above Kelvin consists of the mainstream of the Gila River as well as the San Francisco, Blue, San Simon, San Carlos, and San Pedro rivers. With the exception of the San Pedro contribution, the flow in the Gila River is regulated by San Carlos Reservoir. Normally, the entire flow of the Gila River is utilized by the agricultural and Indian interests below Hayden Ashurst Dam which is located twelve miles down river from Kelvin.

The Mineral Creek-Devils Canyon drainage system originates on the south slopes of the Pinal Mountains and encompasses some 98 square miles above the mine. Mineral Creek was so named by Lt. W. H. Emory in 1846 because of its mineral content. A major portion of the creek channel was cut into mineralized bedrock from a point just north of the mine to its confluence with the Gila River at Kelvin. Replacement deposits of oxide copper minerals in the creek gravels are evidence of the historical quality of Mineral Creek water. Mineral Creek and ultimately the Gila River would be the receiving waters for pollutants from the Ray Mine.

The water quality standards for all surface waters in the state are established and revised every three years by the Arizona Water Quality Control Council. The numerical standards are based upon the designated protected uses. The proposed protected uses for the Gila River segment between Mineral Creek and Ashurst Hayden Dam are (1) aquatic and wildlife, (2) agriculture irrigation, and (3) agriculture livestock water. As a result of these designations, the copper standards for this segment will be .05 mg/l dissolved and 0.5 mg/l total.

The Mining Operation

Mining is entirely by the open pit method and presently involves some 800 acres. Currently we are mining 27,000 tons of sulfide ore and 14,000 tons of silicate on a seven-day basis. To supply a constant supply of ore at these rates requires that we remove 119,000 tons of waste each day.

The Waters of Kennecott

Dump Leaching - A substantial portion of the waste rock contains low-grade copper mineralization which is recoverable by leaching. This rock is placed in one of five dumps ranging in height from 20 to 250 feet and occupying 1,100 acres. The dumps are located on original bedrock topography. The dump surface is prepared by constructing ponds and furrows. Leach water totaling 14,000 gpm is applied by both flooding and spray techniques. At any given time, only thirteen percent of the total dump surface is undergoing leaching. Rather than add acid to the dumps, we depend upon the oxidation of sulfide minerals in the dump to produce enough acid to do the leaching. At all natural drainage points along the toe of the leach dumps, a series of thirteen concrete dams keyed to bedrock collect the leach water. This water typically has a pH of 2.4 and contains about 3.7 lbs. of copper per thousand gallons. From each dam, the leach solution is either pumped or flows by gravity to one of two headwater reservoirs which, in turn, feed the precipitation plants. Excess solutions can be transferred between both plant headwater reservoirs.

Containerized Leaching - The silicate ore is processed entirely at the mine via a percolation/agitation leaching system, with the final products being electrowon cathode and precipitate copper respectively.

The ore is crushed to minus one-half inch in three stages. From a fine ore storage bin the material is classified by wet screening, which results daily in a 10,000-ton coarse fraction and a 4,000-ton slimes fraction. The coarse ore is placed in one of fourteen leach vats each measuring 110' x 100' x 25'. By-product sulfuric acid from our smelter is added and the ore is leached for ten days. The process water from the leach vats is transferred to one of two holding tanks which service the electrowinning plant at the rate of 600 gpm. The fine ore goes to a Pachuca agitation leach plant. Sulfuric acid is also added here. Clarification is accomplished in a series of counter current decantation thickeners which underflow to a slimes tailings pond. Process solutions which are generated by the agitation leaching method are transferred to one of the precipitation plants at the rate of 6,000 gpm.

The Waters of Kennecott (cont'd)

Process Water Treatment Plant - A portion of the precipitation plant tailwater (pH 3.0) goes to a process water treatment plant. This plant utilizes raw, fine limestone rock and a mechanical/air agitation system to raise the pH to 5.6 and precipitate a portion of the dissolved iron and alumina. This water is suitable for reuse in ball mills, screens, and plant cleanup.

Wastewater - The mine offices, shop facilities, and the silicate plant are serviced by two activated sludge sewage treatment plants. Effluent from both of these plants enters the process tailwater stream for either recycling or treatment.

Pollution Control

In the early 1970's, a 155-foot tall arch dam was constructed on Mineral Creek just below its confluence with Devils Canyon. This dam, known as the Big Box Canyon Dam is a flood control structure which has a capacity of 9,800 acre feet. In conjunction with Big Box Canyon Dam, a diversion dam and tunnel were completed in 1973. The tunnel is 3.4 miles long, 16 feet in diameter, and fully concrete lined. Both the dam and the tunnel were designed to handle a 100-year flood resulting from six inches of rain in twenty four hours. In this event, there would be 33,000 cfs of water going into the dam, with the tunnel being fed at a rate in excess of 4,000 cfs.

Looking at our operation, this $15,000,000 project was necessary for two reasons. First, if Mineral Creek were removed from the mine area, it would be possible to prepare an orderly mining plan that wouldn't require that a creek channel be maintained through each stage of development. Secondly, the threat of flooding in the active mining areas which would result in reduced operating rates as well as large volumes of polluted water would be reduced.

From the standpoint of pollution control, Mineral Creek would be diverted around a major portion of the outcropping mineralized rock associated with the orebody. In the future, if we are allowed to maintain a reservoir at Big Box Canyon Dam, there would be a positive effect on sediment loading in the creek.

The constant circulation of more than 20,000 gpm of process water through the copper leaching cycle and recovery plants requires a complex control system.

Pollution Control (cont'd)

All process water dams that don't drain by gravity to other facilities have standby pumping capabilities and overflow provisions. The water levels in each dam are monitored constantly enabling transfers to be accomplished. In the event of power failures or excess water, the dams can overflow to other dams, the pits, or a holding pond.

The Big Dome Holding Pond is located south of the mine and is fed primarily by gravity from a 30-inch line that begins at one of our precipitation plants. Three process water dams overflow directly into this pond. The Big Dome pond is plastic lined and has an 18.5 million gallon capacity. The 30-inch line can receive process and tailwater overflows, effluent from the sewage treatment plants, wash rack water, and low-flow storm water runoff. The Big Dome pond also has a pump-back facility which allows us to recycle the water to the leach dumps.

Because only thirteen percent of the dump surface is normally utilized in the leaching process, and because of the long delay in water return, these dumps have a large surge capability. Additional surge capacity for excess process and tailwater, as well as stormwater runoff which has comingled with process water, is available in inactive portions of the pit and the slimes decant pond.

In an attempt to keep stormwater runoff out of the process water system, we have constructed diversion ditches around our leach dumps. Because of topographic constraints, there is a limit to this practice.

Normal rainfall in the Ray area based on fifty years of records is 17.65 inches. In 1977 we received 9.85 inches of rain which appears to have ended a ten-year drought. In 1978 our rainfall totalled 31.47 inches, the second wettest year in our history. Thus far in 1979, we have recorded 10.62 inches of rain. Our ability to absorb the resulting excess water is being strained. Currently we have 700,000,000 gallons of water in one of our pits.

When our capability to recycle water is exceeded, we have one additional means to deal with contaminated water. At the south end of the property, we built a lime neutralization/precipitation water treatment plant in 1973. This plant is a NPDES facility capable of treating 1,200 gpm. The plant consists of a ball mill lime slaking system, two 87,000-gallon lime storage tanks, one of which can be used as a reactor vessel, and a 52,500-gallon reactor tank.

Pollution Control (cont'd)

Plant influent comes from the Big Dome pond with the exception of one process water dam, which can overflow directly to the water treatment plant. The wastewater is treated with a lime slurry which is fed through air actuated pinch valves. High volume air provides mixing and agitation. The effluent goes to one of five settling ponds with a combined holding capacity of 47 million gallons. Discharge has been totally by percolation. Some important operating parameters for this plant are shown in Table I.

There are some problems associated with the operation of the water treatment plant. The first deals with the discharge of the treated water. The plant effluent is a slurry containing three percent solids which eliminates surface discharge because the effluent stream rapidly short circuits to any point of open flow. To circumvent this problem, we use diffuse percolation through the sandy pond bottoms. During continuous operation, a pond will retain only one of six gallons of water which allows us to fill the pond with sludge. The second problem is sludge drying and removal. The sludge consists of the precipitated metal hydroxides with some gypsum and, even in Arizona, it takes months for this material to dry enough so it can be removed by loaders and trucks. To deal with this limitation, we are currently in the process of installing a system to pump the effluent to a new series of permanent holding ponds.

At Ray Mine, we have spent a great deal of time and money to comply with the Water Pollution Control Act, especially as it applies to point source discharges. The Ray Mine is located in an area characterized by thin soil zones overlying bedrock and, therefore, the potential for water pollution is essentially that of surface flow resulting in point sources. A problem that is common to the entire mining industry deals with the uncertainty of government regulations. Our NPDES permit expired on June 1, 1978, and we have applied for a new one. In the interim, we were hit by the ore mining and dressing point source category effluent regulations. These regulations clouded the whole issue with such things as net evaporation areas and ten-year 24-hour precipitation events. Was the water treatment plant even necessary? Would we be required to build evaporation ponds capable of holding the 24-hour precipitation event? Could we discharge raw water that was in excess of this event? And finally, what about the downstream users of the water that we would be evaporating? Until these issues are resolved, we will abide by the guidelines set forth in our old NPDES permit.

Pollution Control (cont'd)

What does the future hold? Water quality management plans have been completed by the local 208 agencies. Many of these plans call for the formation of mining task force groups to address the non-point source aspects of mining pollution.

All that has been said here today concerns surface waters. Regulations dealing with groundwater pollution from mining operations are forthcoming and they will undoubtedly call for costly monitoring programs, especially for mines located in or near drinking water aquifers.

On another front, our mining waste and leach dumps as well as tailings piles are being looked at as a result of the Resource Conservation and Recovery Act. Will mining wastes be designated as hazardous wastes?

TABLE I

WATER TREATMENT PLANT PARAMETERS

NPDES Permit - renewal pending

Effluent Limitations:

pH	-	6.0 - 9.0
Cu	-	.15 mg/l
Zn	-	.75 mg/l
TSS	-	20 mg/l

Plant Operating Personnel Per Shift

1	Loader Operator
1	Technician

Influent (Average) 1,200 gpm

pH	-	3.5
Cu	-	52 mg/l
Zn	-	80 mg/l

Lime Consumption - .09 pounds/gallon