Field Guide to the San Manuel Porphyry Copper Open Pit Mine, *In Situ* Leach Field, and Solvent Extraction-Electrowinning Plant

by

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with a section on

The Geology of the Tiger-Mammoth Area

by M. J. Rex

Guidebook for the
Arizona Geological Society
Fall Field Trip
November 2, 1996

Compiled by S.M. Richard

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Dear Field Trip Participant,

Welcome to the 1996 Fall field trip of the Arizona Geological Society. This trip will visit the San Manuel porphyry copper deposit to examine the lithology, mineralization, alteration, and structure within the open pit copper oxide mine and *in situ* leach field. We will also briefly visit the Tiger-Mammoth mine area north of the San Manuel open pit to collect samples of gold-vanadium-molybdenum ore in quartz veins in silicified rhyolite breccia. We will end the day with a tour of the solvent-extraction, electrowinning plant.

I wish to acknowledge the management of BHP Copper for permission to visit the mine and processing facilities, and to thank the BHP geologic staff for leading the tour.

Stephen Richard
VP Field Trips

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Arizona Geological Society Fall Field Trip
November 2, 1996

San Manuel Open Pit, In Situ Leach Field, and Solvent Extraction-Electrowinning Plant, BHP Copper, N.A.

Introduction

This tour is based on the recent mapping of the San Manuel Oxide pit that was done to provide a geological framework to on-going hydrological, geological, and geochemical studies of the San Manuel in situ operations. Although geological mapping had been conducted throughout the life of the open pit operations, the mapping had not been compiled to show the distribution of geological features over the pit surface. Lithology, structure, hydrothermal alteration, and distribution of oxide mineralization all affect solution flow within the leach field; thus, the locations and character of these features need to be documented in order to interpret hydrological and geochemical data collected from the in situ well fields.

Numerous publications describe the general geology of the district, as well as the geology of the San Manuel and Kalamazoo porphyry copper ore bodies. Selected articles are listed in the bibliography at the end of the following brief geology synopsis and mine tour notes.

Mapping was conducted in June and July 3, 1996 by F. Bain, C. Hoag, R. Moulton, R. Parker, and R. Preece. This field guide was written by: C. Hoag, R. Preece, and R. Moulton

Mine History and Production

On a large scale, the San Manuel open pit and *in situ* leach field are part of the integrated Kalamazoo-San Manuel porphyry system (Figure 1). Underground block cave mining began in 1956 by the San Manuel Copper Company (Subsidiary of Magma Copper Company) based on development work by Magma and the U.S. Bureau of Mines; the San Manuel ore body is currently producing 41,000 tons per day. In 1965, an exploration project initiated by J. D. Lowell and Quintana Minerals resulted in the discovery of the Kalamazoo ore body, a downthrown upper plate segment of the San Manuel ore body. Currently, BHP is mining 15,000 tons per day from the Kalamazoo operation; development is proceeding on the 3440 level. As of June 1996, more than 646 million tons of ore averaging 0.71 percent total copper have been hoisted from the San Manuel-Kalamazoo underground operations.

During the operation of the San Manuel open pit from August 1985 through January 1995, Magma Copper Company mined 222 million total tons of material at an overall stripping ratio of 1.35:1 and an average unit operating cost of $0.47 per pound of cathode. The material included 93 million tons of oxide ore at an average acid soluble copper grade of 0.47 percent and 1.5 million tons of sulfide ore at a total copper grade of 1.02 percent. Currently, BHP is leaching oxide ore from the San Manuel open pit on large heaps north of the pit. Since 1986, these heaps have produced more than 654 million lbs cathode and will continue until the year 2000. Development of the *in situ* oxide leach well field within the open pit began in 1986; well-to-well leaching was initiated in 1988. Dilute sulfuric acid (raffinate) is injected into oxide ore via screened PVC pipe. The copper-bearing, pregnant leach solution is retrieved from the recovery wells on the benches and in the underground workings below the open pit. The PLS is then pumped to the SX-EW plant where more than 149 million lbs of copper cathode have been produced to date

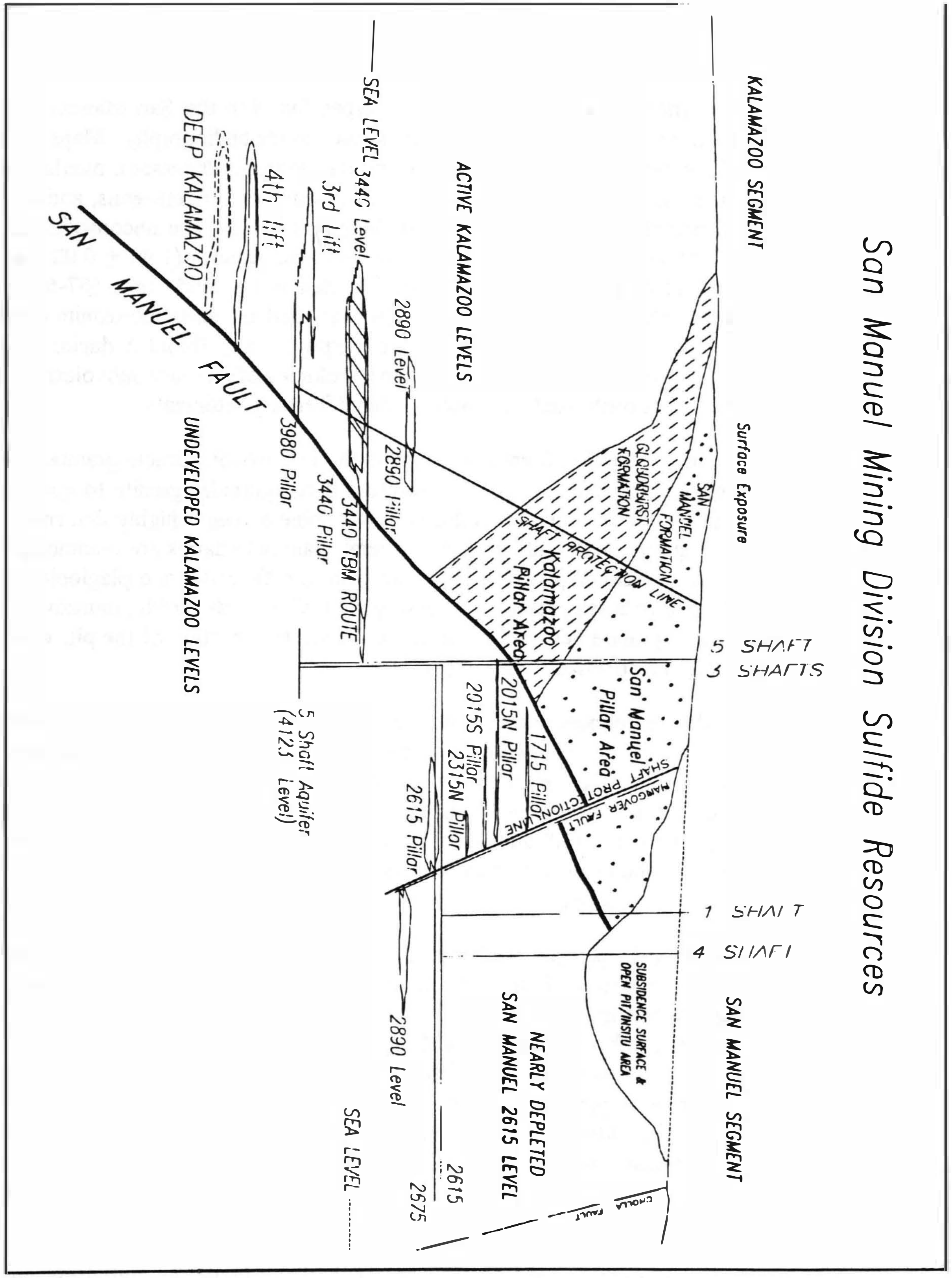

Figure 1. Diagram of the San Manuel-Kalamazoo underground and open pit operation.

Lithology

Numerous authors have described the rock types found in the San Manuel area so only a brief overview will be given, with selected articles listed in the bibliography. Maps are included as Figures 1 and 2, representing the base geology and mineralization/alteration overlay, respectively. The rock types at San Manuel essentially consist of Precambrian, Cretaceous, and minor Tertiary intrusive rocks overlain by a thin sequence of Oligocene to Pliocene unconsolidated sediments. The coarse-grained Precambrian quartz monzonite (Oracle granite) (1.44 $\pm$ 0.02 Ga) and minor Precambrian diabase dikes (1.04-1.1 Ga) were intruded in Laramide time (67-69 Ma) by dike swarms and irregular masses of porphyry variously described as quartz monzonite porphyry, monzonite porphyry, granite porphyry, granodiorite porphyry, and (biotite) dacite porphyry (e.g. Hausen, 1975). These units are intruded by minor volumes of Tertiary subvolcanics and unconformably overlain by consolidated and unconsolidated Tertiary sediments.

The oldest unit in the San Manuel open pit is the Proterozoic Oracle granite, known locally as the quartz monzonite. The unit is a coarse-grained equigranular granite to quartz monzonite. Eastoe (1996) described the samples collected in the mine as being highly deformed, as undulatory extinction in quartz and highly irregular mineral grain boundaries are commonly observed in thin section. The rock is composed of 8-10 mm quartz, orthoclase, and plagioclase grains, with porphyritic and aplitic phases present. Accessory minerals include biotite, muscovite, zircon, and apatite. The Oracle granite lies predominantly in the western portion of the pit, with only minor amounts present in the northwest portion (Fig. 1).

The Laramide San Manuel porphyry was divided into two mapping units on the basis of hand specimens descriptions. These varieties were characterized by grain size differences of the groundmass, and were labeled granodiorite and dacite porphyry for phaneritic and aphanitic textures, respectively. Similar differences had been noted by previous workers, with between two (e.g. Lowell and Guilbert, 1970) and five (Hausen, 1975) textural and/or compositional varieties noted. In addition to the mapped textural variations, differences in phenocryst size and abundance were also noted, but unmapped.

In the San Manuel open pit, unaltered granodiorite porphyry is medium to light gray, and contains zoned oligoclase to andesine plagioclase and biotite phenocrysts as the prominent mineral phases in a fine-grained granular to mosaic matrix of quartz and orthoclase. Only rare quartz phenocrysts are noted in hand specimens, although quartz can be relatively abundant in the matrix. Phenocrysts make up 15 to 50 percent of the rock, and are generally less than 4 mm in diameter, although feldspar phenocrysts up to 8 mm may occur. Two textural varieties of the granodiorite porphyry were noted in hand specimen. One of the varieties contains 40 to 50 percent 3-4 mm phenocrysts that generally are in contact with each other in a crowded texture. The other variety is characterized by lesser amounts of up to 5-8 mm phenocrysts that are typically supported by a fine-grained granular matrix.

Dacite porphyry was mapped in the bottom of the San Manuel pit and elsewhere as isolated dikes. Except for a phenocryst population that has a slightly greater abundance of biotite and only rare quartz, the dacite porphyry has almost identical mineral composition as the granodiorite porphyry. In general, dacite porphyry has an aphanitic dark gray to black matrix with zoned plagioclase and biotite phenocrysts. The dacite porphyry also was observed in two textural varieties.

Both types are comprised of matrix-supported plagioclase and biotite phenocrysts, with one variety characterized by 2-4 mm phenocrysts, and the other containing 4-6 mm phenocrysts, with occasional phenocrysts up to 10 mm long. The dacite porphyry is thought to be very close in age to the granodiorite porphyry, although it is usually unmineralized and weakly altered.

Both the dacite and granodiorite porphyries were mapped in the lower portions of the pit, although in a relatively simplified manner. The porphyries were often observed to alternate, and were generally lumped as to the dominant porphyry over a particular bench face exposure. The ability to distinguish between the granodiorite and dacite porphyries was very difficult above the 2100 to 2160 levels as textures are partially obliterated by the intensity of argillic alteration that increases toward the base of Tertiary sediments. In addition, thin section analyses (Eastoe, 1996; Hausen, 1975) indicate that groundmass texture is not a significant criteria for subdividing the San Manuel porphyry. Both workers believed that groundmass grain size and mineralogy are modified by hypogene alteration. The mapped distinctions, therefore, may not be due to different intrusions, but instead be only a reflection of supergene and hypogene alteration. The eastern portion of the mine area consists predominantly of the two porphyries, with northeastern-trending dikes present in the western half of the pit. Only one intrusive contact was measured; it was found to dip at a low angle to the south.

Mid-Tertiary andesite dikes visible in the upper benches of the San Manuel pit crosscut Laramide granodiorite porphyry and Precambrian quartz monzonite. The olive gray to dark greenish gray intrusive rocks are aphanitic to fine-grained with minute interlocking plagioclase and pyroxene grains; these dikes may correlate to Late Cretaceous/Tertiary diabase dikes reported by Thomas (1966). Occasional phenocrysts and calcite-filled vesicles were noted, especially at higher elevations. Thin section analysis by Eastoe (1996) reported compositions and ferromagnesian contents that bordered andesite and basalt. On the 2580, 2520, and 2460 benches, especially within the failure zones on the north wall, high-grade exotic chrysocolla and copper wad mineralization is hosted by an andesite dike sub-parallel to the bench wall (compare Figs. 1 and 2). Above the 2520 bench in the northeast corner of the pit, the same andesite dike was intruded along the Mafic fault, but it is not mineralized in the upper benches. On the 2880 bench, the dike is present on the hanging wall of the fault, pinching out just above the Cloudburst/San Manuel contact. One bench higher, the andesite appears to be capped with a layer of caliche and overlain by Recent (?) stream sediments. A dike of apparently the same composition is present in the northwestern portion of the pit.

Tertiary rhyolite and rhyolite breccia crosscuts all of the older igneous host rocks and the Tertiary Cloudburst Formation, but not the Tertiary San Manuel Formation; thus the rhyolite has an approximate date of 22 Ma. White, pinkish gray and light brownish gray rhyolite occurs as 10-50 foot-wide dikes, brecciated often along both borders. The rhyolite is a microcrystalline mixture of quartz and feldspar, with minor 1 to 2 mm quartz, plagioclase, and biotite phenocrysts. Devitrification textures and lithic fragments were observed in thin section, and contained foliation textures resembling a felsic lava or ash-flow tuff. In the oxide zone, rhyolite fracture surfaces are commonly coated with copper wad and chrysocolla, and are coated with iron oxides in the leached cap. A white, 15-meter wide dike with distinctive tabular and columnar jointing patterns is visible on the 2160 and 2220 benches in the west bottom corner of the pit. On the south wall of the pit on the 2280 and 2340 benches, fragments of granodiorite porphyry were noted within the rhyolite breccia dike; the breccia matrix and rims around the fragments are stained an intense brick red or moderate reddish brown by hematite and goethite.

The Tertiary (upper Oligocene to lower Miocene) Cloudburst Formation is the oldest of the tilted conglomerate units in the mine area. Basaltic lava near the base of the type section of the Cloudburst Formation in Cloudburst wash has a whole rock date of 28.3 $\pm$0.6 Ma (Dickinson and Shafiqullah, 1989). A rhyolite clast from rhyolitic breccia and tuff-breccia from the uppermost Cloudburst Formation has a K-Ar date of 22.5 $\pm$ 0.5 Ma. Regionally, this formation is reported to be more than 10,000 feet thick, but within the open pit the Cloudburst Formation is less than 30 meters thick due to erosion before deposition of the San Manuel Formation. Regionally, the lower member consists of interbedded intermediate-composition volcanic rocks and volcaniclastic conglomerates up to 1,500 meters thick. The upper member comprises conglomeratic units containing clasts of all the older units in the area, as well as muddy, arkosic and volcaniclastic redbeds. Within the open pit, the Cloudburst Formation consists of pyroclastic flows and maroon-colored conglomerate beds that dip 40 degrees to the east. The present mean strike and dip of the Cloudburst Formation in the structural blocks containing the San Manuel porphyry system is N20°W, 30°NE (Force and Dickinson, 1994).

The Tertiary (lower Miocene) San Manuel Formation is in depositional contact with the Cloudburst Formation and San Manuel porphyry along the northeast and eastern edges of the San Manuel pit, and in fault contact with the underlying igneous rocks on the north, northwest, west and south sides of the pit. The unit consists of loosely to moderately consolidated conglomerate cemented by a red to gray, calcareous arkosic and silty matrix. The poorly sorted, subangular to subrounded conglomerate clasts include all of the older rock types including Oracle granite, diabase, granodiorite porphyry, andesite, and rhyolite. In the Mammoth area, the lower Kanally member of the formation is nearly 1,200 m thick. The upper Tucson Wash member consists of fragments of the Cloudburst Formation and older rocks and is approximately 300 m thick (Sandbak and Alexander, 1995). The present mean strike and dip of the San Manuel Formation in the structural blocks containing the San Manuel porphyry system is N35°W, 30°NE (Force and Dickinson, 1994). Within the open pit, the San Manuel Formation dips 25 to 35 degrees to the southeast and northeast, although dips as low as 11 degrees to the northeast were recorded. Bedding trends in all of the overburden units have been affected by ground subsidence related to the underground block caving. Thin rhyolitic ash-fall (?) tuffs are present locally, generally less than 1 m in thickness, and rarely exposed for more than 10 m in strike.

The youngest unit, visible around the periphery of the San Manuel pit, is the mid-Miocene to Pliocene (Dickinson, 1993) Quiburis Formation. The Quiburis consists of relatively flat-lying fluvial deposits of pale yellowish brown, well-sorted silt, sand, and gravel lenses in nonconformable contact with the tilted San Manuel Formation. Within the open pit, the Quiburis dips 11-25 degrees to the southeast. The Quiburis Formation is one of the most extensively exposed valley fill units within the San Pedro River trough (Agenbroad, 1967).

Alteration and Mineralization

This report includes a color copy of the 1:2400 scale alteration and mineralization map completed in July 1996. Alteration assemblages mapped in the San Manuel pit followed the nomenclature of Lowell and Guilbert (1968), although the presence of supergene argillization often masks the nature of hydrothermal alteration.

Hydrothermal alteration and vein assemblages observed during mapping included:

- Potassic; consisting largely of quartz + K-feldspar veinlets, occasionally accompanied with biotite veinlets.
- Phyllic; characterized by quartz + sericite veinlets and 5-7 vol. % sulfides.
- Propylitic; chlorite + minor epidote, mostly as pervasive alteration.

In general, quartz + K-feldspar veins were observed in rocks with relatively low intensity of supergene argillic alteration, so that hypogene assemblages were not obliterated. Although not always observed in hand specimen, it is assumed that potassic alteration occurs throughout the remainder of the mineralized zones. The alteration overlay map shows that phyllic alteration occurs in the northern portion of the pit. San Manuel porphyry that is essentially unmineralized and weakly altered (containing only minor chlorite after biotite and sericite after plagioclase) is present in a NNE-trending zone in the southern portion of the mine. Although not large enough to map, local areas of propylitic alteration were observed on the southern margin of the pit.

Supergene silicate alteration consists largely of clay minerals that pervasively alter mineralized rocks. Where oxide mineralization occurs, the supergene alteration tends to be moderately developed as pervasive replacements of plagioclase and biotite. Near the eastern edge of the deposit, intense argillic alteration underlies the Cloudburst and San Manuel formations, resulting in a very low-strength rock. It is believed on the basis of map patterns that this intense argillization is related to the Cloudburst-aged topographic surface, and may be a 30- to 45-meter thick leached capping zone that is underlain by typical oxide mineralization.

The hypogene sulfide mineralization consists of chalcopyrite, pyrite, and molybdenite in veinlets, disseminated blebs, and fracture coatings. Larger veins of pyrite $\pm$ chalcopyrite $\pm$ magnetite are occasionally visible, and tend to be northeast trending and moderate to low dips. In the sulfide ore body, total sulfide contents are approximately 2 to 4 percent and pyrite to chalcopyrite ratios are approximately 1:1 to 1:3 (Lowell and Guilbert, 1970, Sandbak and Alexander, 1995). Molybdenite is associated with the higher grade chalcopyrite ore and occurs as fracture coatings and in quartz-molybdenite $\pm$ chalcopyrite veinlets. Within the San Manuel Oxide pit, the only exposed sulfides are located within the phyllic alteration boundary (Fig. 2). Here, the Oracle granite contains 3 to 15 percent total sulfides on fractures and veinlets, with pyrite to chalcopyrite ratios of 10:1 to 30:1. Molybdenite within quartz veinlets is common, but nowhere abundant. Chalcocite coats pyrite and chalcopyrite and is especially visible on the 2520 to 2220 benches on the northwest walls of the pit.

The dominant supergene oxide minerals include chrysocolla and copper wad with minor cuprite, malachite, and traces of native copper. Goethite dominates the limonite mineralogy in the oxide and leached capping areas, and jarosite in the areas where sulfides still remain. Transported limonites are generally more abundant than indigenous, and sulfide boxworks are completely filled. Most of the leached capping appears to be poorly developed, and does not indicate that significant enrichment was developed. A small area of well developed leach cap was noted in the uppermost northern pit wall on the hanging wall of the West fault that is within the phyllic alteration zone.

Alteration and mineral precipitation related to the in situ leaching operations were also noted, as mining and in situ leaching had been conducted simultaneously since 1985, and the current mining levels are now within volumes that had been previously leached. The major affects observed in the field include:

- partial dissolution of chrysocolla, varying from a greenish yellow discoloration of the chrysocolla to visible reaction fronts that have removed portions of chrysocolla from individual fracture plane leaving a core of residual chrysocolla; and
- mineral precipitation products that certainly include gypsum and may include other phases such as goethite, clays, and aluminum sulfates.

Gypsum was observed to be in two major forms, thin coats that tended to form on chrysocolla, and acicular sprays of crystals that generally formed on barren portions of fractures and open spaces. Both types of gypsum could often be observed on a single fracture. Both the goethite content of the iron oxides and the clay alteration intensity appeared to be higher in the in situ leach fields, compared to oxide mineralization that have not been leached in situ. These differences may be due to slightly different geological histories, as these areas occur on opposite sides of the West fault, or may be due to the effects of in situ leaching.

Figure 2 is a schematic representation of the shape of the ore zone using a 0.5 percent TCu cutoff grade. At this cutoff, the San Manuel ore body has a strike length of 2,350 m and a depth to 825 m below the surface (Thomas, 1966); the ore body is within a larger zone of mineralized and altered rock measuring 2,400 to 2,740 m in width and 2,835 m in length. Thomas (1966) described the San Manuel ore body as consisting of two limbs which converge to the northeast. The northern limb is approximately 120 m wide and has an overall strike and dip of N60°E, 55°SE; the southern limb is as much as 300 m wide and trends N60°E to N45°E. The dip of the southern limb flattens as the two limbs coalesce at depth. With the exception of a small triangular area of surface outcrop in the footwall of the West fault, the San Manuel ore body is completely buried by the Tertiary Cloudburst Formation, San Manuel Formation, and Quiburis Formation.

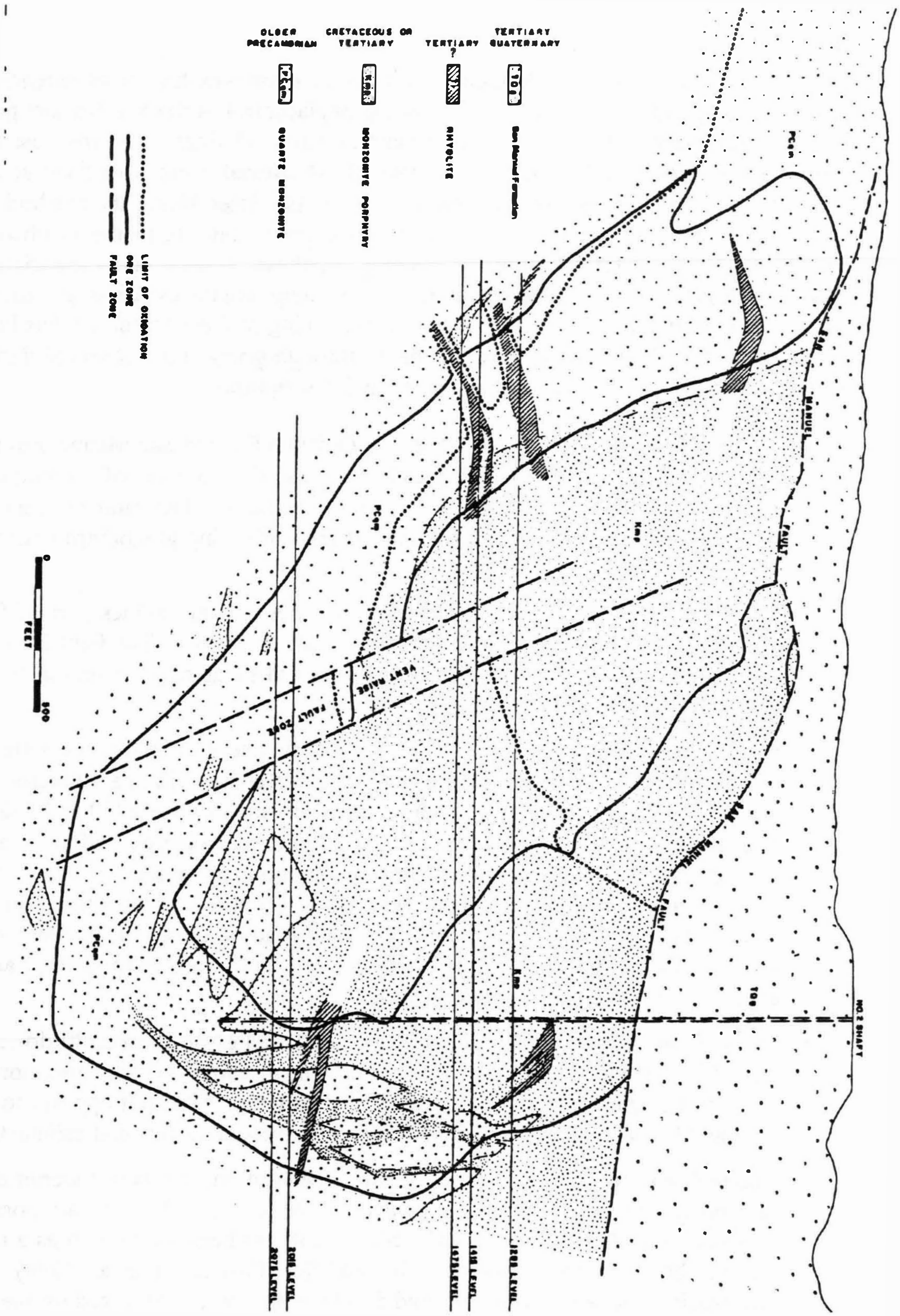

Figure 2. Idealized cross section looking northeast of San Manuel ore body. Ore zone based on a 0.5 percent copper grade. Modified from Thomas, 1966.

Structure

The structure of the San Manuel area involves a complex history of extension evidenced by post-ore tilting and normal faulting. Following emplacement of the San Manuel porphyry, the San Manuel/Kalamazoo ore body was tilted approximately 35 degrees to the east during the mid-Tertiary (Force et al, 1995) through a series of extensional events that followed, or was coeval with, the deposition of each of the conglomerate units. After tilting, the ore body was cut by the San Manuel fault that displaced the Kalamazoo segment 2400 m to the southwest. The deposit was then cut by a series of northwest trending, northeast dipping faults associated with regional Basin and Range extension. Several northeast trending, southwest dipping structures have been mapped within the San Manuel ore body, but the timing of these structures has had various interpretations. The following is a list of the major, through-going faults observed during the mapping project with their corresponding orientations and descriptions:

- **Cholla fault**: N30°W, 70°NE; separates Quiburis Fm and San Manuel Fm in the northeastern side of the pit. The fault typically consists of 1 to 2 cm of brecciation and shearing, with calcite present in the most northern exposures. The fault appears to shallow and horsetail as it encountered the Cloudburst and underlying granodiorite porphyry, and could not be traced below the 2640 level.
- **Cactus fault**: N25°W, 63°NE; cuts San Manuel Fm and defines part of San Manuel Fm/ Cloudburst contact along the northeastern side of the pit. The fault is very similar in appearance to the Cholla fault, being a breccia and shear zone several inches to as much as one foot wide. Calcite is locally present.
- **East (Mammoth) fault**: N20°W, 58-80°NE; cuts several lithologies within northeast central portion of pit, and consists of multiple faults planes within a 30 meter zone; characterized by failure zones where it is cut by the Mafic fault on the 2460 and 2520 benches. The individual fault strands are generally 0.3- to 1-meter wide argillized breccia zones that vary in width along strike. The most dramatic variation can be seen from a 2-meter wide breccia located on the 2280 that pinches down to 1 cm 100 meters along strike on the 2460 bench. The fault zone was traced to the haul road on the 2280, at which point bench face exposures are subparallel to the fault. Several faults were mapped that are similar in orientation, but none that were along strike.
- **Mafic fault**: N20-50°E, 70°SE; cuts northeast wall of pit from 2880 down to 2520(?); intruded in part by andesite dike. The fault is an argillized breccia zone normally a 0.5 to 1 meter in thickness, but can be up to 2.5 meters wide. The fault appears to be truncated by the San Manuel Formation, with an apparent erosional surface and caliche layer
- **Marty fault**: N65°E, 65°SE; cuts northeast side of pit; it was not identified during the recent mapping project, but fault segments on the following benches are possible candidates: 2100-2160, 2220, 2400-2460. The Marty fault has been interpreted as a major control on the distribution of oxide mineralization and fluid flow (Burt, et al, 1994), and needs to be systematically located from projected drill hole intercepts and traced on the surface.
- **San Manuel fault**: pre-mining orientation was N66°W, 26°SW (Creasey, 1965), block caving has rotated the fault from N5°W,35°SW to N45°E,35°SE from north to south (Fig. 1); the fault defines contact between conglomerates and crystalline rocks in western half of

pit; within the pit, the structure is defined by a 15 to 30 cm red clay gouge zone; locally with 1.5 to 5 m of gouge and shearing in the crystalline footwall. In contrast, the San Manuel fault consists of 20- to 30-meter wide shear and breccia zone where both the hanging wall and footwall are crystalline (Thomas, 1966)

- **Vent Raise fault**: N59°E, 80-90°SE; cuts granodiorite in southeastern portion of the pit; located between north and south ore body in the upper portions of the underground workings. Because the fault is parallel to the bench faces, projections from drill hole intercepts and underground workings are required to extend the fault trace east along strike.
- **West fault**: N34°W, 61°NE; cuts north wall from surface to bottom of pit; fault zone dimensions vary from <1 to 10 meters; usually contains several centimeters to a meter of clay gouge zones that occur in *en echelon* fashion within a larger brecciated and fractured zone. Although the West fault is easily traced along the northern pit wall, it appears to have undergone right-lateral displacement along a north-dipping fault traversing the bottom of the pit. It is believed that the high-angle fault that places San Manuel Formation against granodiorite porphyry in the south pit wall is the southern extension of the West fault.

Previous interpretations of the timing of the Vent Raise and Marty faults have been varied. Both of these structures have been interpreted as "post-ore, pre-conglomerate faults" (Sandbak and Alexander, 1995). The Marty fault has been mapped previously within the open pit as cutting the San Manuel Formation (M. Rex, pers. comm.). The Vent Raise fault may cut the San Manuel Formation along the east wall of the pit, however relationships are unclear due to failures and runoff material covering the bench faces. These timing relationships are further complicated by subsidence due to block caving within the underground operations. Where not intruded by andesite, the Mafic fault has a similar orientation to the Marty fault and is mapped as cutting the East fault on the 2340-2400 benches. The intrusion of an andesite dike within part of the Mafic fault suggests a pre- or syn-Cloudburst structure. The Mafic fault places Cloudburst and unconsolidated gravels against Oracle granite on the 2820 and 2880 benches, and was not traced into San Manuel Formation on the 2940 which also indicates pre-San Manuel Formation movement. However, the East fault cuts the San Manuel Formation (Creasey, 1965), which should make it younger than the Mafic fault. Clearly any interpretation of timing of particular structures must incorporate the various phases of the complex structural history of the area together with any recent subsidence due to block caving

Fault breccia and gouge zones observed during the geological mapping are generally less than 1 meter in width, and are frequently cross cut by small-scale fractures. Only the West fault appeared to be significant in width and strike length to have a large scale influence on fluid flow. Although small-scale heterogeneties are certainly related to the mapped faults, there are numerous short-strike length faults that were unmapped that may also provide equally important small-scale discontinuities to fluid flow. These can be easily observed by the numerous seeps present in the in situ well field that occurred along small fractures equally as often as along major faults.

Open Pit and In Situ Wellfield Tour Notes

Stop 1: Overview near Red Hill, looking east.

Introduction to San Manuel geology.

Tertiary sediments are exposed in the eastern wall of the San Manuel Oxide pit. The upper reddish to gray waste dumps are underlain by the beige-colored Quiburis Formation. The San Manuel Formation (gray) is in fault and nonconformable contact with both the overlying Quiburis and the underlying maroon-colored Cloudburst Formation. The Cloudburst in the San Manuel pit consists only of conglomerates and nonconformably overlies the pale red crystalline rocks. The San Manuel Formation under our feet is separated by the underlying rocks (mostly Oracle granite) by the San Manuel fault.

Stop 2: San Manuel fault and leached capping in Oracle granite beneath Red Hill.

The San Manuel fault is clearly visible at this stop, marked by a 5-8 cm maroon to reddish-orange gouge zone with 1-1.5 m shearing and brecciation, mostly in the footwall rocks. The San Manuel Formation is present on the hanging wall (west side) of the fault, with bedding planes dipping into the fault. Several 1-1.5 m thick rhyolitic tuff unit can be seen in the San Manuel Fm. as we make our way from Stop 1. Oracle granite and aplite are in the footwall, both of which exhibit fairly typical leached capping. Limonites are dominated by goethite, with minor hematite and local jarosite. Former sulfide sites are filled with limonites, and transported limonites are more abundant than indigenous. Pearly sericite/illite pervasively alters feldspars, and kaolinite(?) is locally present on fractures. Hydrothermal alteration was probably weakly developed quartz and sericite, although the total sulfide content was less than 2-3 vol. %.

Stop 3: Mafic and Cactus faults, San Manuel and Cloudburst Fm., and intensely argillized leached capping.

This stop on the 2820 bench consists of a traverse that starts in intensely argillized Oracle granite, moves through the Mafic and Cactus faults, ending in Tertiary sediments. Both fault and sedimentary contacts can be observed.

Starting on the west end of the traverse, we are in Oracle granite that has been intensely argillized during the development of the leached capping. The limonites are goethitic in composition, as indicated by the orange-red color, and the abundance of transported limonites are about the same as indigenous. This style of supergene alteration is common along the east side of the pit, immediately underlying the Tertiary sediments, and possibly related to pre-San Manuel Fm. leaching.

Move to the east, where the Mafic fault can be seen as a 1.5 m thick breccia and gouge zone that places a small sliver of granodiorite porphyry against Tertiary conglomerates. A small andesite(?) dike is present on the hanging wall of the fault, pinching out just above the Cloudburst/San Manuel contact. On the bench above this stop, the andesite appears to be capped with a layer of caliche and overlain by stream sediments. San Manuel and Cloudburst conglomerates are exposed on the hanging wall of the Mafic fault, in nonconformable contact that continues eastward along the bench. A small window through the bench talus about 15-20 m east of the fault exposes the Cloudburst/granodiorite porphyry contact at the toe of the bench. The Cloudburst Formation thus has a total thickness of about 10 m at this location. Flagging marks a location that provides a good look at the Cloudburst.

Moving further to the east, the Cloudburst abruptly thickens immediately east of the Basin and Range Cactus fault that places San Manuel Formation against Cloudburst. The Cactus fault is similar in age and orientation to other Basin and Range faults in the area, including the Cholla, East (Mammoth), and West faults.

Stop 4: Leached capping, phyllic alteration, Laramide granodiorite porphyry, and West fault

This stop on the 2580 bench consists of a traverse across the Basin and Range-aged West fault that shows both the Laramide granodiorite porphyry, Precambrian Oracle granite, leached capping, and sulfide mineralization associated with quartz + sericite alteration. The traverse starts on the east (hanging wall) side of the West fault in the granodiorite porphyry. The unit hosts goethitic leached capping, characterized by abundant transported limonites, both on fractures and pervasive flooding. Boxworks are completely filled by orange to reddish-orange compact limonites. Remnant quartz + Kspar and weak quartz + sericite veinlets are visible in the granodiorite porphyry.

The West fault is marked by a 2-5 m fault breccia and gouge zone. While the hanging wall of the fault zone is relatively planar, the footwall dip shows abrupt changes as the fault courses up the bench face. The West fault marks the western boundary of the in situ leach field, and probably acts as a hydrological barrier to leach solutions. Exposures in lower bench faces, however, contain zones of highly brecciated material that probably act as transmissive zones.

CAUTION - Hard Rocks. Be very careful when hammering.

Oracle granite occurs on the footwall of the West fault, characterized by 3-5 vol. % sulfides (pyrite much greater than chalcopyrite) associated with quartz + sericite veins. Sulfides are largely oxidized to goethite + minor malachite immediately adjacent to the fault, with oxidation gradually decreasing to the west. This indicates that some oxidation occurred after (or during) movement on the West fault. Effloresces of chalcanthite and the heady aroma show that sulfides are currently oxidizing.

Stop 5: Oxide mineralization in granodiorite porphyry, in situ leaching, East fault.

The East fault at this location on the 2280 bench is a fault gouge and breccia zone approximately 2 m thick, striking N45°W; normally the fault is 80-100 cm (and is as thin as 5 cm) and strikes N15-20°W.

The granodiorite porphyry contains abundant chrysocolla + goethite mineralization, with much of the chrysocolla fracture-controlled. Original sulfide content was relatively low, less than

2 vol. %, with sulfide sites filled with goethitic limonites. Note that chrysocolla is rarely in previous sulfide site, indicating some (probably on the cm scale) transport of copper. Remnant quartz + Kspar and rare biotite veinlets can be observed.

The white 6- and 3-inch diameter PVC pipes seen in the bench face are previous in situ production and injection wells that were producing during open pit mining, and subsequently mined out. The results of in situ leaching can be seen by the abundant gypsum crystals and greenish yellow discoloration of partially leached chrysocolla. It is probable that some of the goethite was precipitated by in situ fluids, as well as yellowish to white Fe^{+3}-Al-SO_4 precipitates.

Stop 6: Oxide mineralization, Tertiary rhyolite dike, dacite porphyry.

The bench face north of the parking area is composed of granodiorite porphyry hosting potassic alteration and oxide mineralization that is similar to the previous stop. In situ operations, however, have never been conducted in this area. The white dike exposed in the western corner of the pit (2160 and 2220 benches) is Tertiary rhyolite that hosts minor Cu-wad and chrysocolla mineralization on fracture surfaces.

Walk along the south bench face, where the talus slopes are composed of weakly mineralized granodiorite porphyry. Two rhyolite dikes can be seen, as well as rubblized material that may be related to the uppermost San Manuel block cave drawpoints, located a few hundred feet below the pit. Near the end of the level, where the road enters the haul ramp, a fault places weakly mineralized granodiorite porphyry against unaltered and trace to nil mineralized dacite porphyry. The dacite porphyry can be recognized by the aphanitic matrix and biotite books with a large c:a axis ratio.

Stop 7: Tiger Quarry

The Tiger Quarry was operated by the Magma Copper Co. until 1987, supplying precious metal-bearing silica flux to the San Manuel smelter. The material belongs to the Mammoth-Tiger vein system, and averaged about 0.08 oz/T gold, with highest gold values confined to a silicified rhyolite breccia. The system also produced Pb-Zn-Cu-Mo-Ag ores, and is renowned for vanadinite and wulfenite. The Tiger vein and rhyolite breccia can be observed in the south wall of the quarry, cutting the Cloudburst Formation, thus documenting the mid-Tertiary of the gold system. The vein system is offset by the Mammoth fault, which has been traced into the San Manuel pit along strike of the East fault.

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Geology of the Tiger-Mammoth Area

Martin J. Rex
BHP San Manuel

Arizona Geological Society
Fall Field Trip
November 2, 1996

GEOLOGY

Regional Geology

The geologic units that comprise the Santa Catalina Mountains, the dominant physiographic feature in the area, represent a suite of rocks typical of a metamorphic core complex (Dickenson, 1988). Precambrian intrusive rock, occurring in the central portion of the range, is over lain by a sequence of upper Precambrian metamorphic and sedimentary rocks that in turn are over lain by a series of Paleozoic sedimentary units. Cretaceous age, felsic igneous bodies locally intrude all of the older units.

North of the Santa Catalina Range Precambrian intrusive rock is still common in outcrop whereas the Precambrian and Paleozoic sedimentary units are only locally exposed. Thick sections of Tertiary intermediate volcanic and sedimentary units along with small Tertiary age, Felsic intrusive bodies increase in occurrence both north and east of the range.

Extensive northwest trending and northeast trending normal faults are present in the region. Thrust faults and detachment faults associated with the formation of the Catalina metamorphic core complex are also present.

Geology of the Project Area

Pervious geologic work in the Tiger area includes studies by Creasy (1950, 1967) and Peterson (1938).

Lithologies

The oldest rock unit found in the project area is the Precambrian Oracle Granite. This intrusive body consists mainly of gray to green, medium- to coarse-grained, prophyritic biotite quartz monxontie. Aplite dikes are locally common. Widespread exposures of this intrusive unit occur west of the project area (Map 1) where it acts as host for the San Manuel and Kalamazoo porphyry copper ore bodies. Occurrences of granite rock around Tiger are mainly found in the area of the Collins ridge and in the Mammoth flux pit. Underground maps indicate the exposures to this unit increase with depth in both the Collins and Mammoth areas. At the Mohawk mine exposures of this unit are rare.

Late Cretaceous early Tertiary, gray grandiorite to quartz monzonite porphyry dikes infrequently occur in the project area. The only exposures found to date are in Collins ridge and north of the Mammoth mine near Tucson Wash. These intrusives are similar to those associated with porphyry copper minealization found to the west.

Rocks of the mid-Tertiary Cloud Burst formation outcrop throughout the project area with the most extensive exposures occurring in the north. The formation consists mainly of interbedded adesite flows and volcanic agglomerate/breccia. The agglomerate/breccia is composed of angular to subrounded intermediate volcanic clasts with lesser subrounded granite and rhyolite clasts in an intermediate volcanic matrix. This unit is typically gray-green to dark-green in color. Other units mapped in the Cloud Burst include 1) an orange-brown fanglomerate member consisting of subangular to subrounded fragments of various Lithologies in a sandy matrix and 2) blue-gray rhyolite to rhyodaciate flows.

Tertiary rhyolite dikes are abundant in the area and can be found at all the major mines. The rock is light colored and typically fine grained. Local prophyritic zones of brecciation are also present. In general, the intruvises tend to be elongate in a northwest direction.

In many areas rhyolite intrusive breccia occurs associated with the rhyolite dikes. This breccia is similar in color to the rhyolite dike rock as it is composed of altered rhyolite fragments in a fine grained rhyolitic ground mass. This unit was probably formed as a result of autobrecciation of the rhyolite dike as the margins cooled and intrusion of magma continued.

An adesitic intrusive breccia was also mapped in the project area. This unit typically contains abundant rhyolite fragments with minor granitic and intermediate volcanic fragments. The matrix ranges in color from green to maroon and appears to be andestic in composition. This unit is commonly silicified. In many respect this unit is similar to breccia units found in the Cloudburst Formation yet due to the large volume of rhyolite fragments this unit was mapped as an intrusive.

The youngest rocks mapped in the area belong to the upper Tertiary Gila Formation. This unit consists of poorly to moderately consolidated, tan conglomerate and sandstone.

Structure

Faulting in the areas is extremely complex with at least four episodes represented. An early northeast episode associated with emplacement of the San Manuel porphyry copper system is present just west of the project area. This was followed by a northwest-trending system that appears to have controlled the mineralization at Tiger. These structures include the Dream fault and the main structural zone as seen in the Mannoth flux pit (Plate 1). A series of northeast to east trending post mineral faults was observed in the Mammoth flux pit as well as in the northern part of the project area. The fourth and youngest episode of faulting consists of an extensive series on northwest-trending faults of post-Gila formation age. These include the Mammoth fault.

ORE DEPOSITS

Structure

A main northwest trending zone of veining and mineralization encompasses both the Mammoth and Mohawk mines. The shear zone has been traced by drilling, at least 1,500 feet southeast of the Mohawk shaft.

Northwest of the Mohawk mine the main structure apparently splits to the southeast forming tow separate faults as indicated by Peterson (1938). Due to limited access to the underground workings, this was difficult to confirm. In the area of the Mohawk mine the structural zone tends to dip to the Northeast. The zone continues along a northwest strike until just past the Mammoth flux pit. The structure now tends to dip to the southwest. Past the pit the zone bends to the west and is eventually truncated by the post mineral Mammoth Fault. This northwest trending major fault dips to the northeast at an average of 60°. Data from underground level maps indicate that the dip on this structure tends to flatten with depth thereby appearing listric in nature. The Collins vein and Collins east vein located west of the Mammoth Fault, occur along the up thrown portion of the mineralized structure. The structure cuts all the major rock units except for the post mineral Gila Formation.

Mineralogy

Due to extensive oxidation in the region the mineralization of the deposit is extremely complex. Several episodes of silica deposition ranging from crystalline, amethystine quartz to white coloform microcrystalline quartz are present. Other gangue minerals include minor fluorite, adularia, barite and calcite. . Primary sulfide minerals, including galena, chalcophrite, tetrahedrite, pyrite and sphalerite are present only in the deeper unoxidized levels of the Collins mine. Numerous secondary oxide minerals occur throughout all levels of Mammoth Mohawk mines and in the upper 700 feet of the Collins mine. The mines are known for producing museum quality samples of wulfenite, vandadinite, and desclorixite among other rare oxide minerals (Bideaux, 1980) . Strong hematite and limonite along with local chrysocolla are commonly found associated with the vein zones.

Alteration

Hydrothermal alteration is confined to the main structural zone. Silicification is laminated to those areas just adjacent to the veins whereas secondary clay, sericite, epidote and chlorite are more extensive. Other than silification the remaining alteration products tend to be more developed in the quartz monxonite than the rhyolite, the two main host units. Tourmaline is also locally present as an alteration product.

Gold Mineralization

Gold mineralization is confined to several distinct areas along the main structure. In the area of the Mohawk mine an ore zone occurs at depth just southeast of the Mohawk shaft and continues northwest for approximately 700 feet. A low grade to barren zone, approximately 200 feet along strike, separates the Mohawk and Mammoth ore bodies. At the mammoth, ore grade gold mineralization occurs along strike for approximately 1,000 feet in northwest direction. At this point the structure turns to the west with gold mineralization occurring for and additional 500 feet until the intersection with the Mammoth fault. Gold mineralization associated with the Collins system begins where the structure intersects the Mammoth fault and can be traced for approximately 600 feet northwest along strike. At this point gold mineralization appears to become more sporadic.

Gold values also tend to decrease somewhat with depth as indicated by production records. Grades are still relatively high as evidence by recorded assays in excess of 0.2 opt gold in oxidized ore as deep as 800 foot level at the Mammoth mine. It does appear that oxidation may have been important in gold concentration. Production from the Collins mine indicates a significant decrease in gold values associated with reduced ore. It has been reported that some select samples of galena have assayed as high as 0.375 opt gold (Bideaux, 1980).

In general, gold values tend to increase with increasing quartz veining and silicification but this is not always the case. There is some indication that near-surface, secondary enrichment of gold had taken place. North of the Mammoth Flux pit drill hole MM-66 intersected an ore zone containing gold values as high as 0.375 opt. Drill cuttings of this zone show weakly altered quartz monzonite containing very little veining. Some silicification was noted and the mafic minerals were typically altered to chlorite. Bideaux (1980) also reports native gold associated with chlorite-rich zones in the upper portion of the Mammoth vein.

Additional Metals

Of the metals analyzed, gold tends to occur in economic grades mere consistently than the rest. Through silver values as high as 4 opt over 5 feet were obtained it is very uncommon to get assays in excess of 1 opt. Average silver content in the mineralized zones is less than 0.15 ounces per ton. Values in molybdenum, vanadium, lead and copper, through present in anomalous concentrations, are typically sporadic and low grade. Of the base metals, zinc tends to occur in higher concentrations. Drilling in the area of the Mammoth flux pit indicates an average zinc grade of approximately 0.7% for this area.

Width of Mineralized Zones

The with of mineralization within the main structural zone varies throughout the property. Though individual veins as wide as 15 feet are present, a typical ore zone contains numerous subparallel veins ranging in thickness from less than ½ inch to about 2 feet. Local stockwork quartz vein zones and quartz breccia zones are also present. At the Mammoth the area of mineralization is up to 150 feet wide. The width of the ore zones is dependent on the density of veining and/or post mineral faulting which can juxtapose ore zones thereby increasing width.

In some areas post mineral faulting has affected the geometry of the ore zones. Several faulted segments of high-grade vein ore were encountered during drilling. An ore zone north of the Mammoth flux pit appears to be offset from the main trend by a possible splay of the Mammoth fault.

Other Mineralized Zones

Several additional mineralized structures occur throughout the property. These include the Dream vein (Map1). Portions of this vein/fault are still accessible from the underground workings at the Mohawk mine. The mineralized structure strikes northwest and dips 45° - 60° northeast and typically has granite in the footwall and rhyolite in the hanging wall. Ore grade gold values were obtained along this structure both underground samples (up to 3,000 opt on the 400 foot level) and in drill cuttings (up to 0.572 opt in MM-4). Underground sampling has shown that the distribution of this ore is erratic. However, the grades obtained do indicate some potential for the development of thigh grade ore. The projected near surface expression of this structure occurs under Magma's SX-EW plant and copper leach pads thereby limiting any potential mining to underground. Other mineralized veins can be found north of the Collins area. Erratic gold values also occur along these structures which are typically narrow.

EXPLANATION

TERTIARY

Tg	Gila Formation–Light gray to tan, unconsolidated conglomerate to sandstone.
Tib	Intrusive Breccia – Primarily Rhyolite fragments, commonly silicified, in a gray to green siliceous matrix.
Tr	Orange-brown to white Rhyolite to Rhyodacite dikes.
Tcb	Cloudburst Formation – Dark gray to gray-green mafic agglomerate with interbedded gray-green Andesite to Basalt flows.
	Arkose fragments of Oracle Granite in a mafic volcanic matrix. Local mafic agglomerate interbeds. Unit grades into Cloudburst Formation and Oracle Granite.

pЄ

pЄg	Oracle Granite

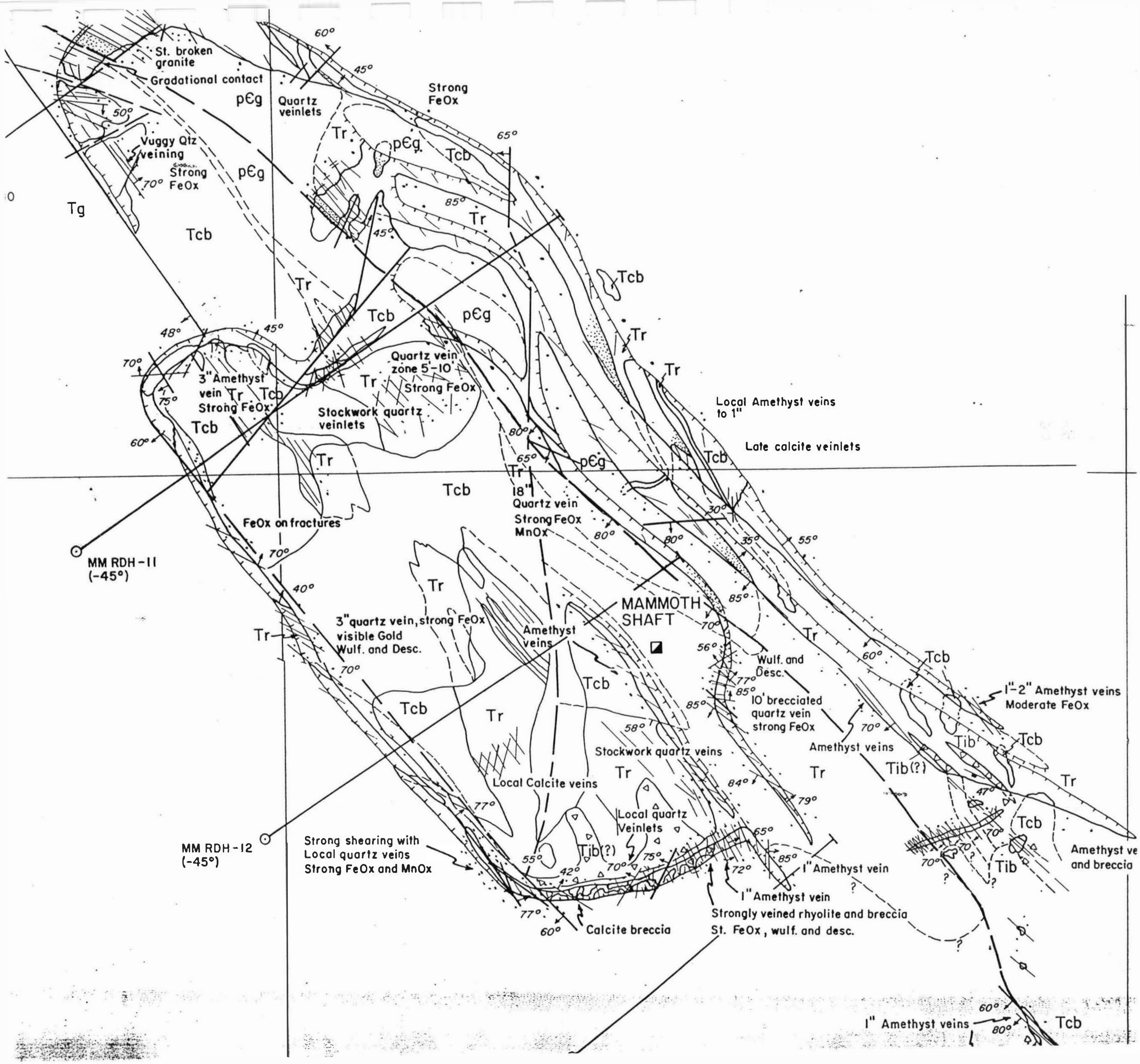
Silicification, quartz veining

FeOx, sulfides

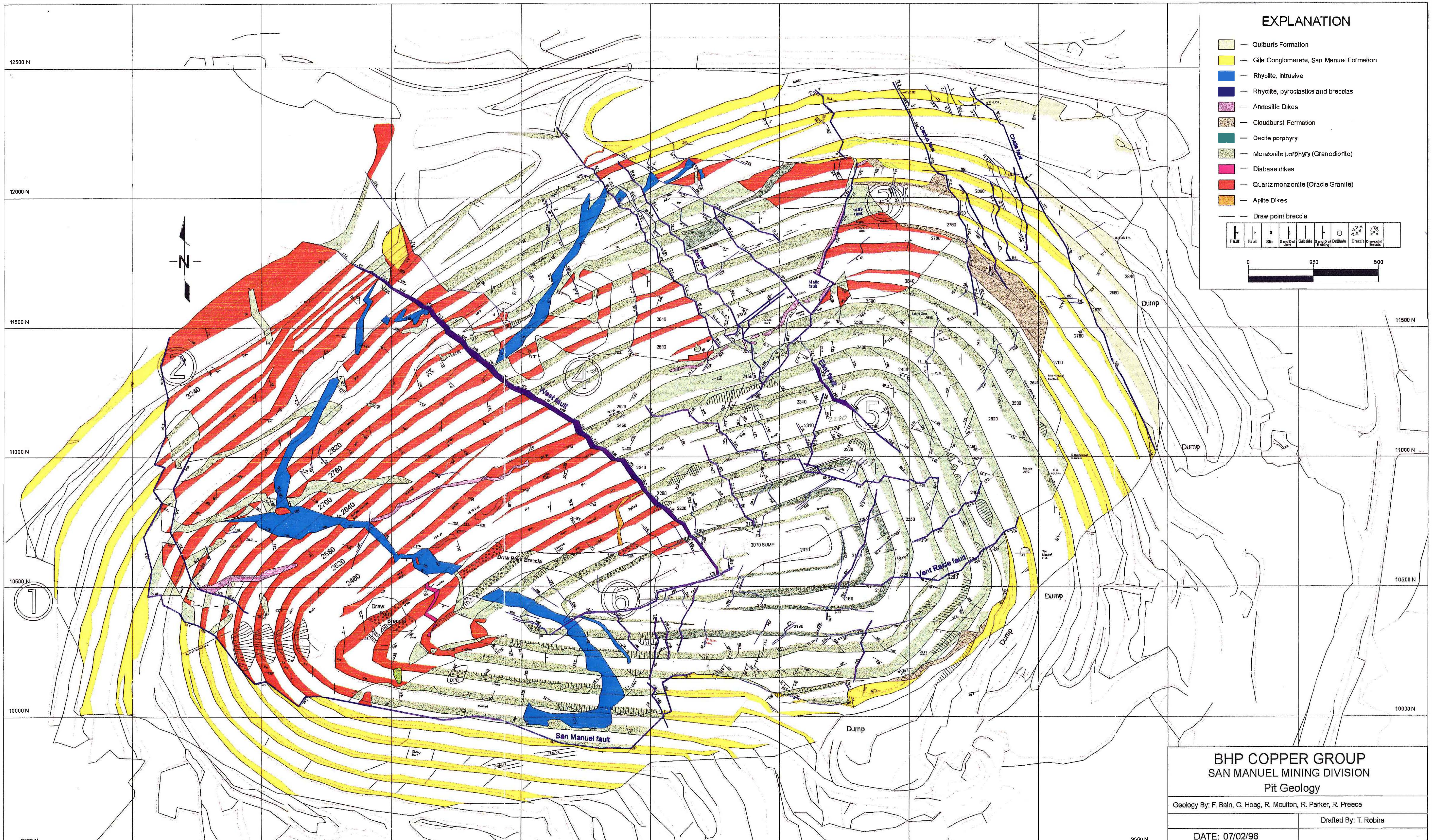
80° Fault, dashed where inferred

Contact, dashed where inferred

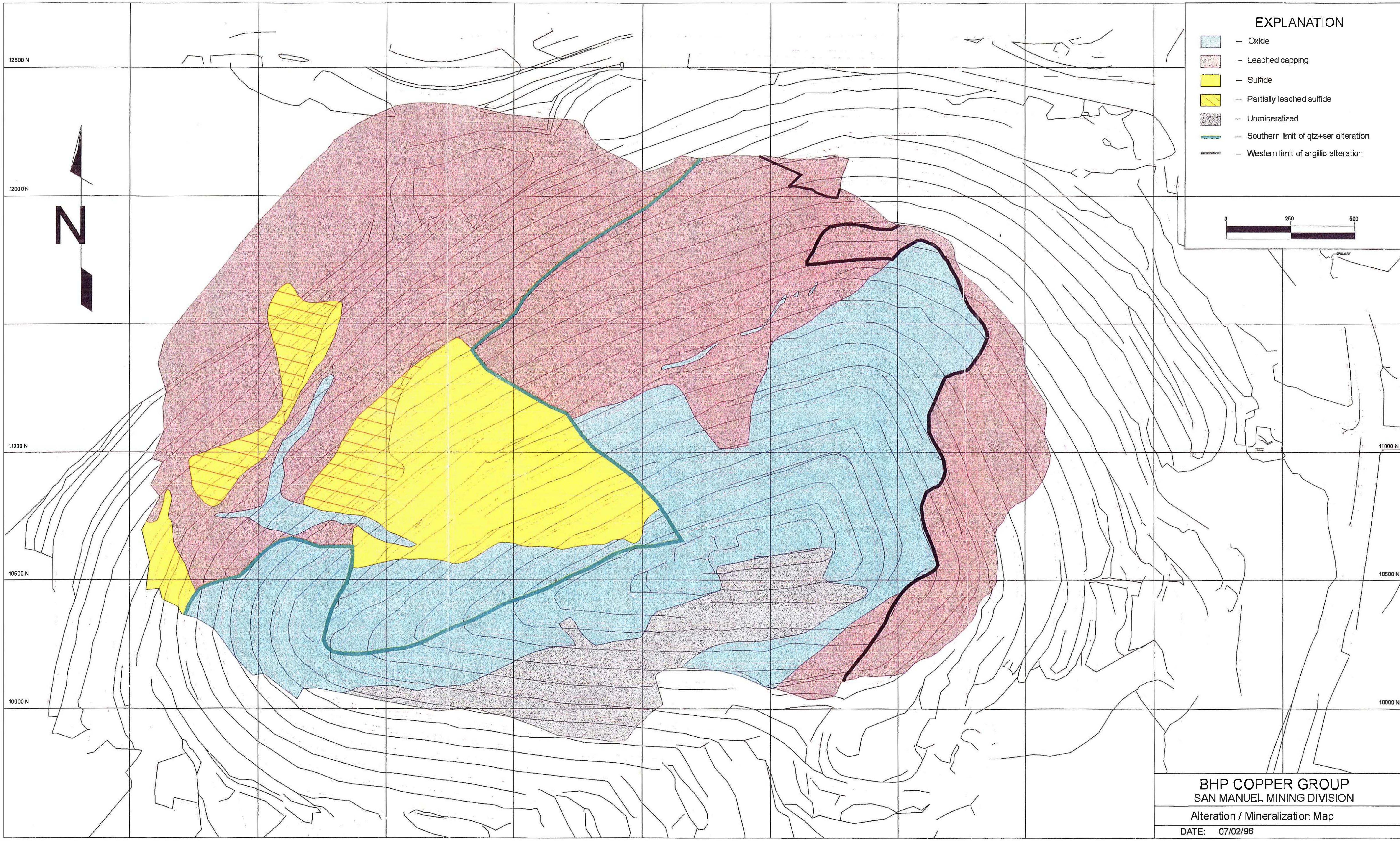
15,500 N



St. broken granite
Gradational contact
pЄg
Quartz veinlets
Strong FeOx
Vuggy Qtz veining
Strong FeOx
Tg
Tcb
Tr
65°
85°
45°
Tcb
pЄg
Quartz vein zone 5-10'
Strong FeOx
3" Amethyst vein
Strong FeOx
Stockwork quartz veinlets
FeOx on fractures
MM RDH-11 (-45°)
Local Amethyst veins to 1"
Late calcite veinlets
18" Quartz vein
Strong FeOx
MnOx
MAMMOTH SHAFT
3" quartz vein, strong FeOx
visible Gold
Wulf. and Desc.
Amethyst veins
Wulf. and Desc.
10' brecciated quartz vein
strong FeOx
Amethyst veins
Tib(?)
1"-2" Amethyst veins
Moderate FeOx
Tib
Stockwork quartz veins
Local Calcite veins
Local quartz Veinlets
MM RDH-12 (-45°)
Strong shearing with
Local quartz veins
Strong FeOx and MnOx
Calcite breccia
1" Amethyst vein
1" Amethyst vein
Strongly veined rhyolite and breccia
St. FeOx, wulf. and desc.
Amethyst ve
and breccia
1" Amethyst veins

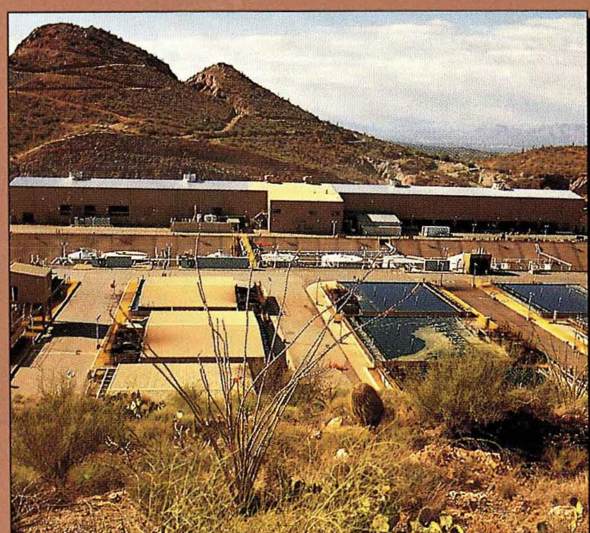


EXPLANATION
Quiburis Formation
Gila Conglomerate, San Manuel Formation
Rhyolite, intrusive
Rhyolite, pyroclastics and breccias
Andesitic Dikes
Cloudburst Formation
Dacite porphyry
Monzonite porphyry (Granodiorite)
Diabase dikes
Quartz monzonite (Oracle Granite)
Aplite Dikes
Draw point breccia
Fault
Fault
Slip
S and D of Joint
Subside
S and D of Bedding
Drillhole
Breccia
Drawpoint Breccia
0
250
500
N
12500 N
12000 N
11500 N
11000 N
10500 N
10000 N
9500 N
West fault
East fault
Mafic fault
Vent Raise fault
San Manuel fault
Draw Point Breccia
2070 SUMP
Dump
Dump
Dump
Dump
Dump
3240
2820
2760
2700
2640
2580
2520
2460
BHP COPPER GROUP
SAN MANUEL MINING DIVISION
Pit Geology
Geology By: F. Bain, C. Hoag, R. Moulton, R. Parker, R. Preece
Drafted By: T. Robira
DATE: 07/02/96


EXPLANATION
– Oxide
– Leached capping
– Sulfide
– Partially leached sulfide
– Unmineralized
– Southern limit of qtz+ser alteration
– Western limit of argillic alteration
0
250
500
12500 N
12000 N
11000 N
10500 N
10000 N
11000 N
10500 N
10000 N
N
BHP COPPER GROUP
SAN MANUEL MINING DIVISION
Alteration / Mineralization Map
DATE: 07/02/96

FIELD TRIP
HANDOUTS

MAGMA



Magma Copper Company
P.O. Box M
San Manuel, AZ 85631
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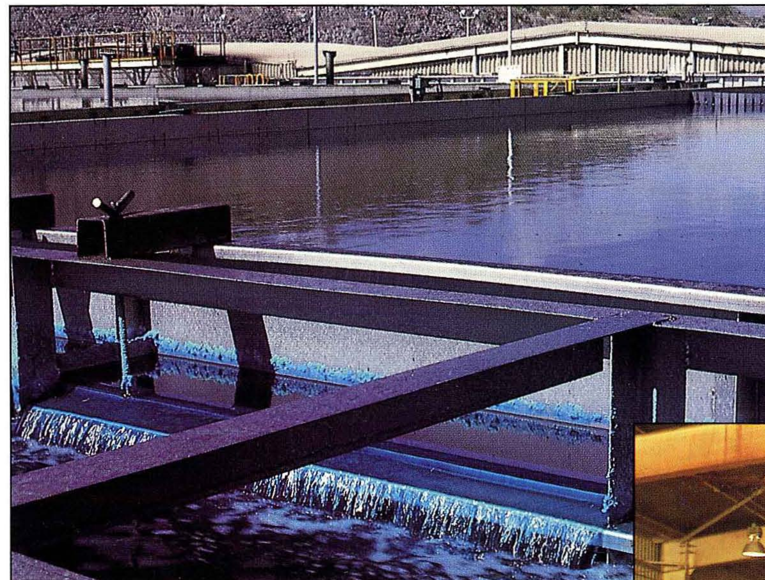
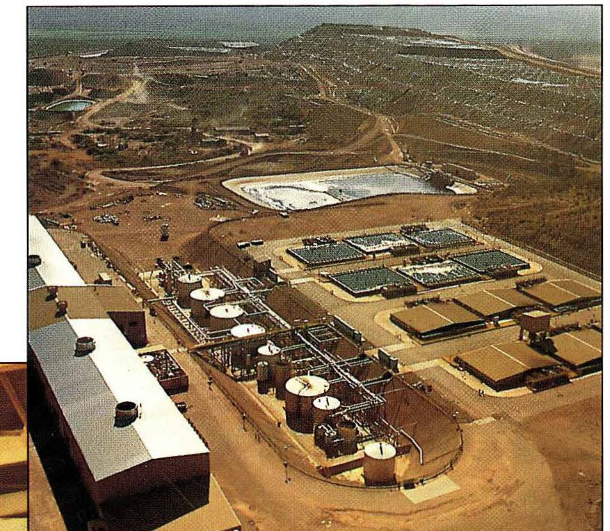
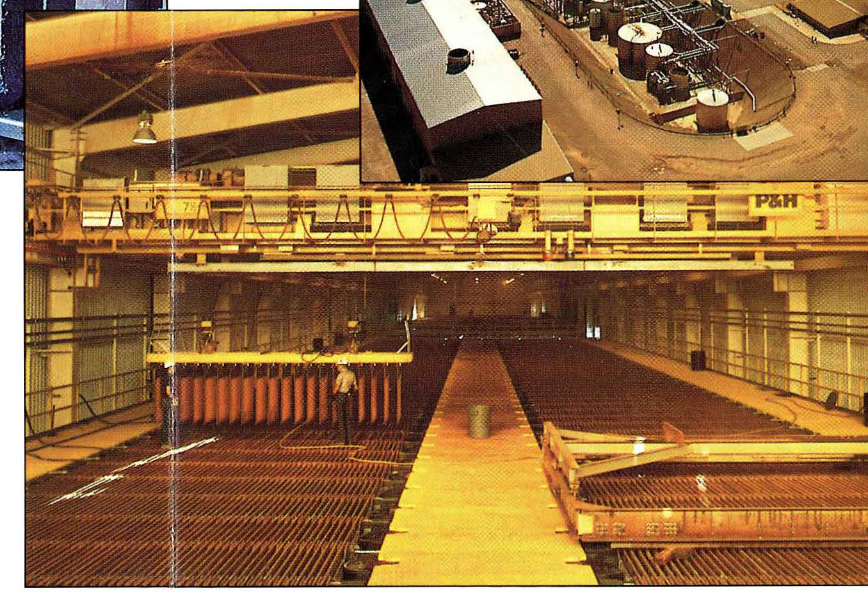
SX-EW/SOLVENT EXTRACTION-ELECTROWINNING







Solvent Extraction

While the process of electrowinning copper from a rich electrolytic solution is as old as industrial electrical applications, the technology of solvent extraction is newer and with the development of special reagents can now be applied efficiently to large scale operations.

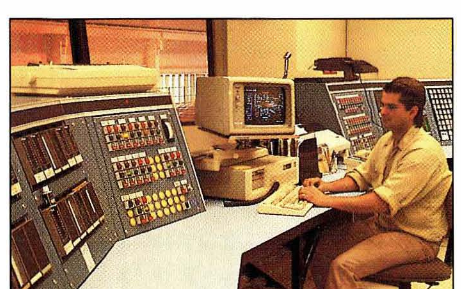
The purpose of solvent extraction is to remove copper from the pregnant leach solution (PLS) by mixing it with an organic extractant and then removing the copper from the organic into a rich solution of sulfuric acid and copper sulfate.

The solvent extraction process takes place in four stainless steel tank trains at the rate of 4,000 gallons per minute each.

The resulting electrolyte solution is pumped to the electrowinning tankhouse, the organic and reagents are recycled, and the now barren PLS called raffinate is discharged to the raffinate pond for recycling to the leach dumps.

Electrowinning

Electrowinning is an electrochemical process in which copper from an electrolyte is plated onto a cathode. The primary difference from electro-refining is that refining uses a copper anode while a lead alloy anode is utilized in electrowinning.



The electrowinning tank house has 188 concrete cells each containing 61 lead anodes and 60 stainless steel cathode mother blanks.

The plating cycle is seven days to obtain a 100 pound cathode from each side of the mother blanks.

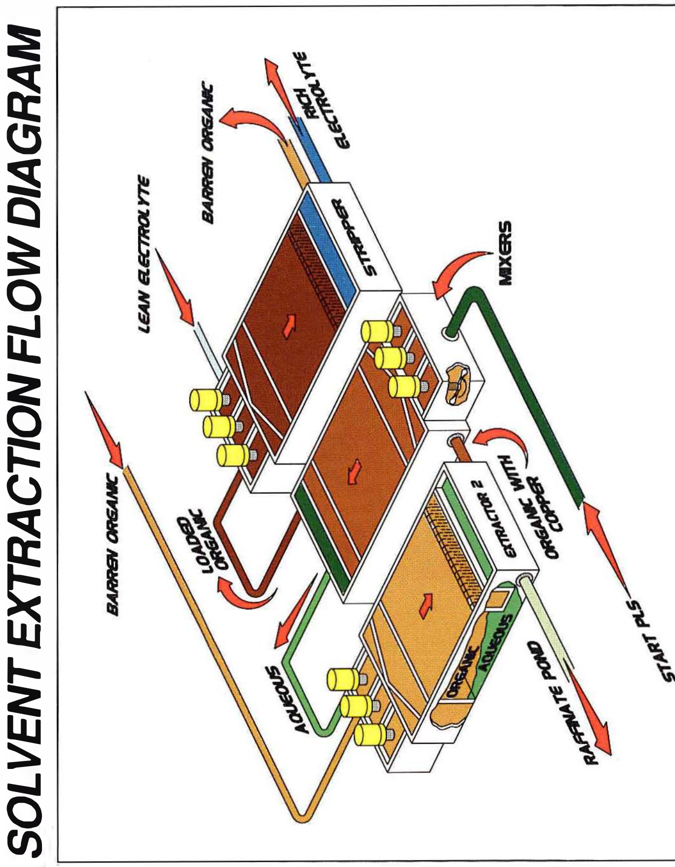
The cathodes are stripped mechanically from the mother blanks and are transported directly to the rod plant for continuous casting.

The extractant used in the solvent extraction process is very selective to only transfer copper from the leach solutions. This results in especially high purity copper metal production during electrowinning.

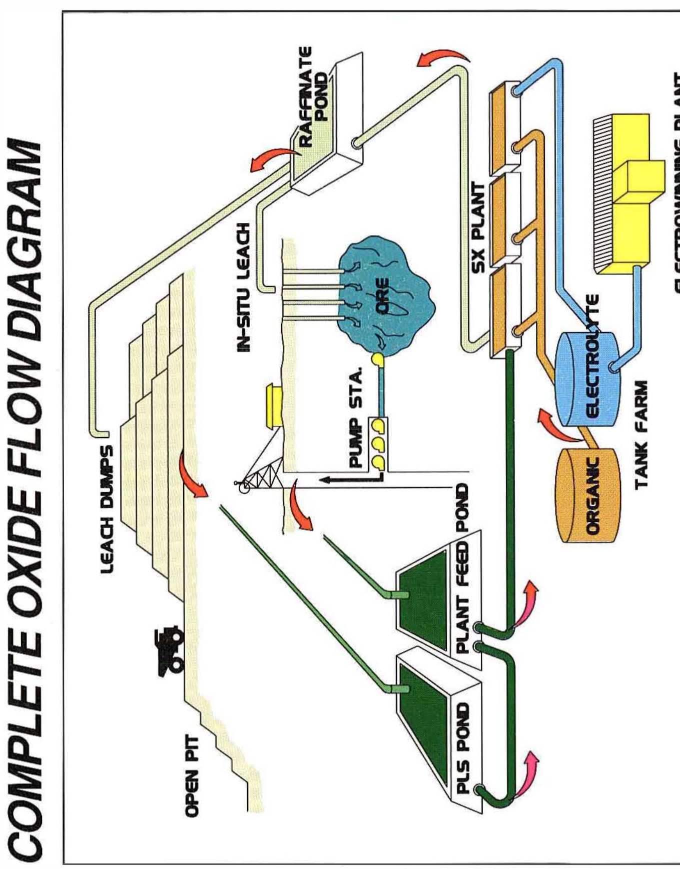
All SX-EW functions are fully instrumented for automatic operations and direction from a comprehensive distributive control system.

Altogether Magma operates three SX-EW plants:

Location	Production
San Manuel	100,000,000 lbs./yr.
Pinto Valley mine unit	15,000,000 lbs./yr
Miami in-situ unit	10,000,000 lbs./yr.



SOLVENT EXTRACTION FLOW DIAGRAM

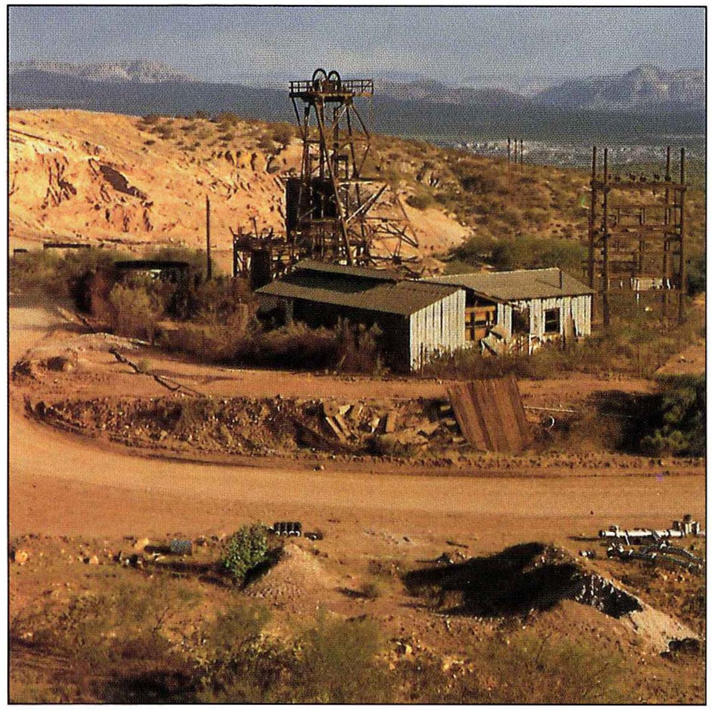


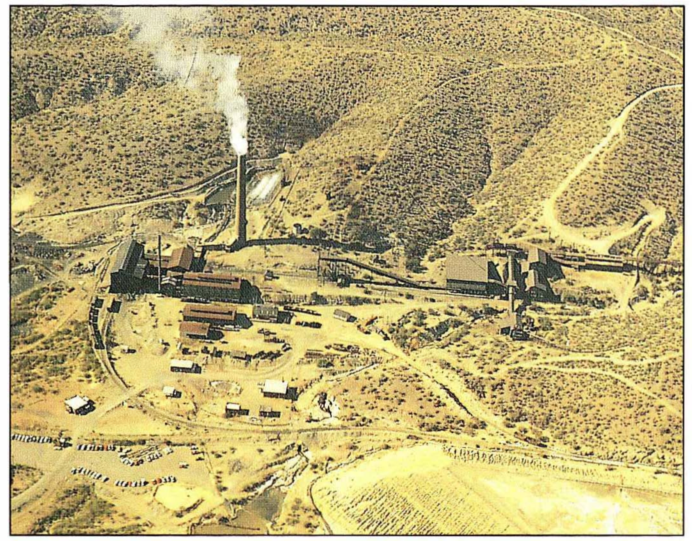
COMPLETE OXIDE FLOW DIAGRAM

MAGMA

OUTLINE HISTORY OF MAGMA COPPER COMPANY

Last Remaining Headframe at Tiger, Arizona





Superior Smelter in the 1950's

1877 Silver Queen Mine in production at Hastings (Superior) Pioneer Mining district, Arizona Territory.

1879 Mines started in Old Hat District around Mammoth (gold and silver mines).

1896 Post Office opens for Schultz, Arizona, later renamed Tiger (located adjacent to San Manuel's SX EW plant).

1910 Magma Copper Company organized, Superior, Arizona Territory, holding the old Silver Queen mining property.

1915-19 Molybdenum and vanadium campaigns at Tiger.

1921 Newmont Mining Corporation founded.

1924 Smelter erected at Superior, Arizona.

1934 St Anthony Mining Company buys Tiger mines

1935-43 Renewal of activity; lead and zinc campaigns at Tiger.

1942 War Production Board investigates Mammoth area for copper.

1943-45 Exploration Drilling by U.S. Bureau of Mines at Red Hill (San Manuel).

1944 Magma consolidates and purchases San Manuel claims, and begins additional exploration and drilling.

1948 Underground exploration and development begins.

1952 Federal loan of $94,000,000 made to Magma to build the San Manuel mine, plant, railroads and community.

1953 Construction begins on surface plant.

1956 First stopes undercut and first smelting begins.

1965 Expansion from 30,000 tons of ore per day to 40,000 TPD.

1968 Purchase of nearby Kalamazoo orebody doubles size of reserves.

1969 Merger with Newmont Mining Corporation .

1971 Superior smelter shut down.

1972 Expansion from 40,000 to 60,000 TPD ore processing. Operation of electrolytic refinery and continuous rod casting begins. Smelter expansion underway.

1973 New Superior mine-plant in operation; expanded to 3,300 TPD.

1974 Start-up of air quality control systems and sulfuric acid plant at San Manuel.

1982 Superior Division is shut down.

1985 Development of open pit at San Manuel begins.

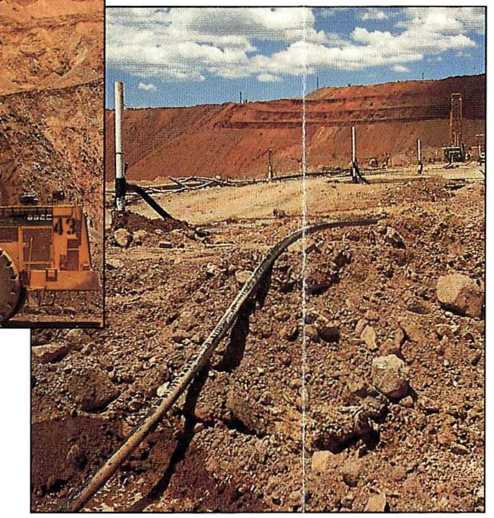
1986 Oxide open pit, leaching and SX-EW plant begin production. Newmont recapitalizes Magma and contributes Pinto Valley as an operating division.

1987 Magma is reorganized and spun-off to stockholders of Newmont. In-situ leaching production starts. Sale of Magma owned San Manuel townsite begins. Development of Kalamazoo orebody begins. Modernization programs begin.

1988 Flash furnace at smelter started, old reverbs shut down. Mill and refinery expansion and modernization programs are completed. Expansion of San Manuel's SX-EW Plant from 25,000 TPY–50,000 TPY.

1989 Recapitalization and repurchase of Newmont interests result in new era of independence for Magma.

1990 Superior operations resume.



THE OPEN PIT OXIDE MINE

Located in the subsidence zone of the San Manuel underground mine, the oxide open pit was established to recover a large reserve of copper oxide ore. The principal oxide mineral leached is chrysocolla.

Waste material is dumped into the adjacent cave area created by the underground mine and ore material is hauled a short distance to the heap leaching dumps.

The pit is a medium-size operation which will produce approximately 28,000 tons of ore and 68,000 tons of waste per day over a nine-year period .

Blasted ore is loaded by front-end loaders and hydraulic excavators into 100-ton-diesel electric haul trucks which operate on roads 80 feet wide with a maximum grade of 10%.

The leach dumps are built on an area of 152 acres underlain with a thick high density polyethylene liner to prevent any loss of leaching fluids into the surrounding watershed.

A typical leach dump has a surface area of 125,000 sq ft. and contains approximately 110,000 tons of oxide ore. As leaching progresses and new dumps are built on top of the old dumps, they become increasingly higher and will eventually reach approximately 250 ft. in height.

For leaching, a network of pipes and wobbler sprinklers is laid on the surface of a newly completed dump and a weak solution of sulfuric acid is continuously sprayed at the rate of 0.8 gallons per minute per 100 sq. feet of surface area.

The leach solution percolates down through the dump, dissolving copper in the ore, and flows from the dump's base as pregnant leach solution (PLS), drains into a collection pond, and is then pumped to the 10,000,000 gallon feed pond for the solvent extraction plant.

IN-SITU LEACHING

Additional reserves of acid-soluble oxide ore lie beneath the open pit area and above the depleted portion of the underground mine.

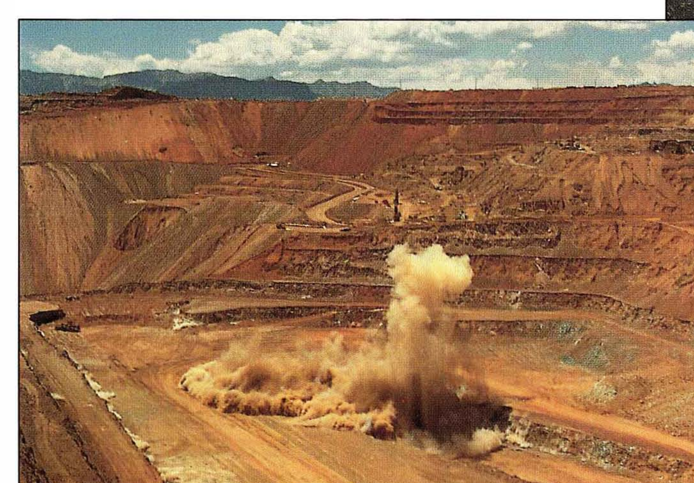
An ore reserve of approximately 272,402,000 tons has been rubblized by the underground mining activity and is available for the in-place method of in-situ leaching.

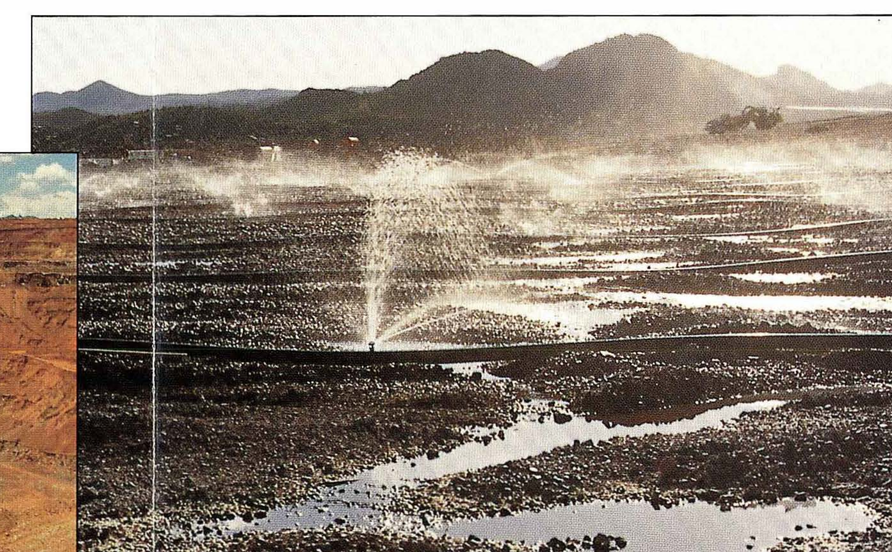
Injection wells are drilled into this zone to a depth of 1,000 ft. The wells are cased with PVC pipe, the bottom portion of which is slotted to allow solution into the ore.

A leach solution of weak sulfuric acid is injected into each well at a rate dependent upon the permeability of the zone into which it was drilled.

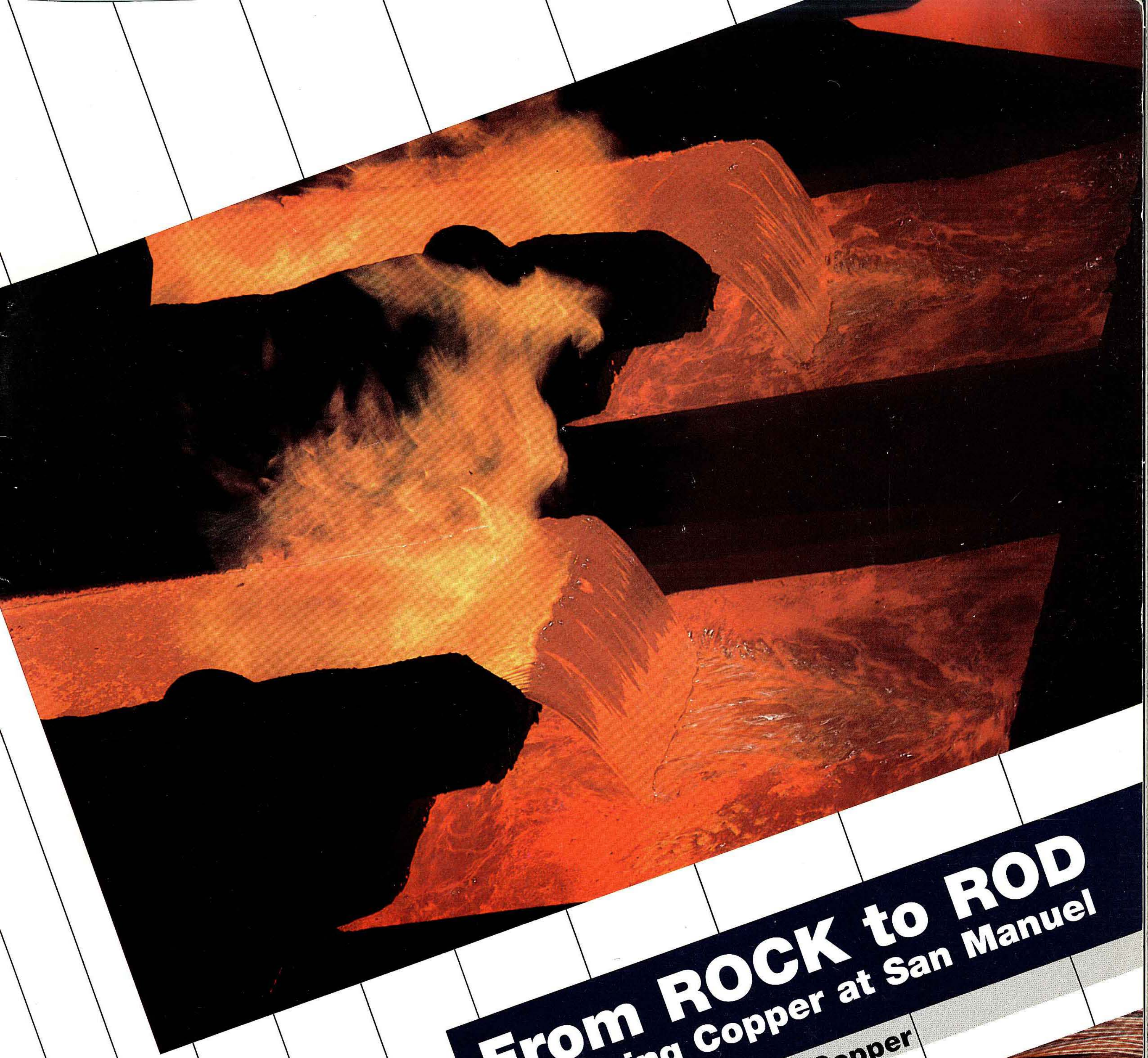
The solutions percolate down through the ore zone, dissolve the copper minerals, and drain into a prepared collection area. The collection area had previously been haulage drifts of the underground mine.

This PLS (copper-bearing solution) is pumped to the surface by means of a corrosion-resistant pumping system, where it joins PLS from the leach dump, for processing in the SX-EW plant.





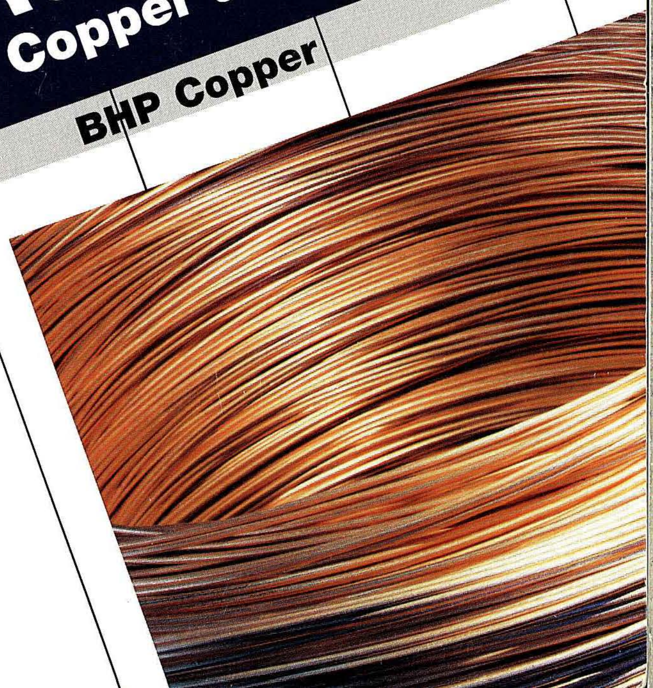
MAGMA



From ROCK to ROD

Producing Copper at San Manuel

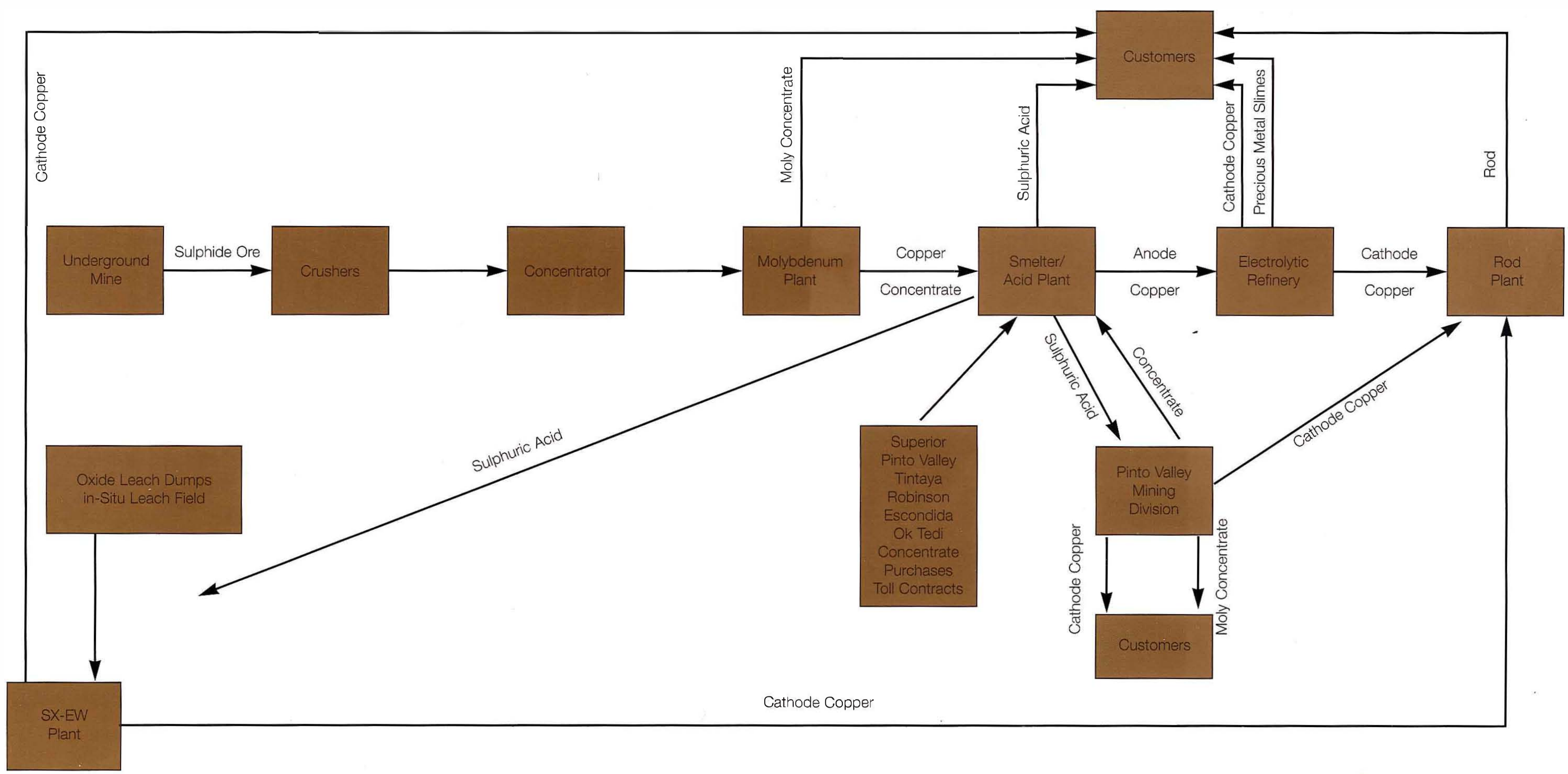
BHP Copper

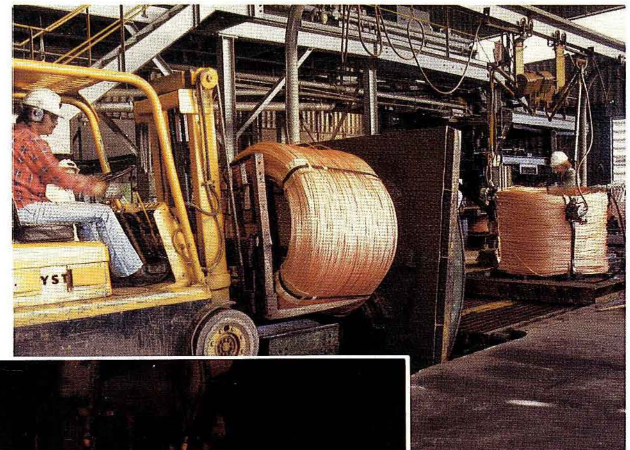


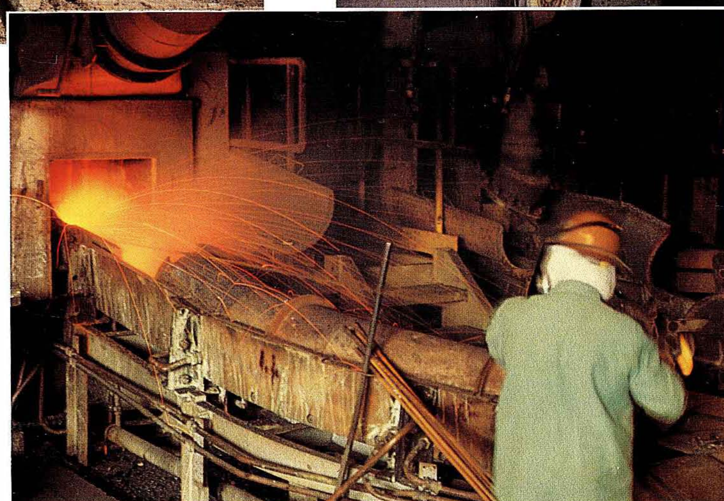
BHP

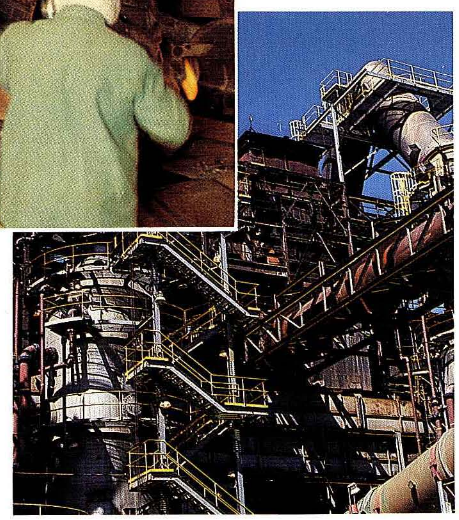
BHP Copper

MAJOR OPERATIONS at SAN MANUEL









BHP Copper

San Manuel, Arizona copper production operations have a unique degree of vertical integration of underground mining, in situ leaching, solvent extraction-electrowinning, concentrating, smelting, electrolytic refining, continuous rod casting, sulphuric acid production, transportation and shipping.

These interconnected operations result in a synergy which provides efficient, economical operations and quality products.

Mining

The San Manuel and Kalamazoo underground sulphide mines are the largest underground mining operations in North America and since start-up in 1956 have produced over 583 million tonnes of ore.

Concentrating

Sulphide ore from the underground mine is crushed, milled and concentrated in a modern bulk flotation plant. In addition smelter slag is recycled through the concentrator and special circuits recover by-product molybdenum.

In Situ Leaching

Acidic leaching solutions are injected directly into a copper oxide reserve where they dissolve copper minerals and are pumped to the surface for processing.

The in situ well field occupies a former open pit oxide mine. Ore from the pit, previously placed on leach pads, continues to be leached for optimum recovery of copper.

SX-EW/Solvent Extraction - Electrowinning

Copper-rich leaching solutions are concentrated in the solvent extraction process and the copper is electroplated out in the form of high purity cathode copper for utilisation at the San Manuel rod plant or for direct sale to customers.

Smelting

The flash smelter at San Manuel handles approximately 25% of the U.S. copper smelting capacity and processes BHP Copper concentrates, purchased custom concentrates and toll concentrates.

Refining

The electrolytic refinery produces premium grade cathode copper for market.

Rod Plant

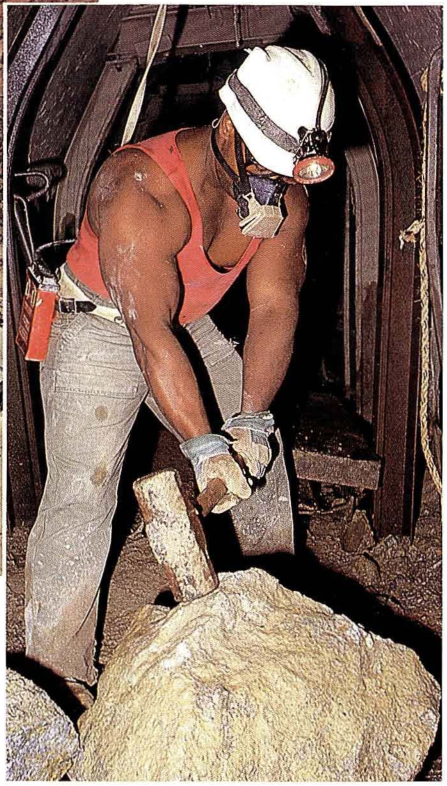
Located at the electrolytic refinery, the rod plant produces continuous cast 7.9 mm copper rod for the wire and cable industry.

Products

Full plate electrolytic copper cathode
7.9mm copper rod
Molybdenite concentrate
Sulphuric acid
Gold and silver residue

Railroads

The San Manuel Arizona Railroad Company interconnects with the Southern Pacific rail system to provide North American freight service.



THE UNDERGROUND MINE

In production since 1956, the San Manuel mine has hoisted over 583 million tonnes of ore from a mineral deposit of approximately 900 million tonnes of ore.

In terms of production capacity, ore-body size and installed facilities the San Manuel mine is currently the largest underground copper mine in North America.

The economic minerals are mined from an elliptical-shaped porphyry cylinder some 2,400 metres long and 760 metres wide across, lying between 210 metres to 915 metres below the surface.

A faulted segment called the Kalamazoo, or "K" orebody, similar in size and composition, lies 1.6 km to the west and between 760 and 1,220 metres below the surface.

In 1990 this orebody was brought into production and is currently producing 14,500 tonnes of ore per day.

Production from the San Manuel and Kalamazoo orebodies is from zones of disseminated copper mineralisation at an average grade of 0.61% copper or approximately 6 kilograms of copper contained in each tonne of ore.

Too deep for open pit mining, the ore-body is recovered by the underground block caving method. Total underground production is currently 54,430 tonnes of ore per day.

Block caving entails removal of a horizontal slice of ore so that the ore above will not support itself and will collapse by gravity into and through a gathering system funneling into an underlying haulage level.

Ore is loaded by gravity into trains hauling up to 270 tonnes per trip to the dumps at vertical hoisting shafts where it is hoisted to the surface.

There are four production shafts and three service shafts. The service shafts provide intake ventilation and supplies to the underground operation. The production shafts serve as exhaust ways. The forced-air ventilation system provides in excess of 34,000 cubic metres per minute of fresh air circulating through the mine.

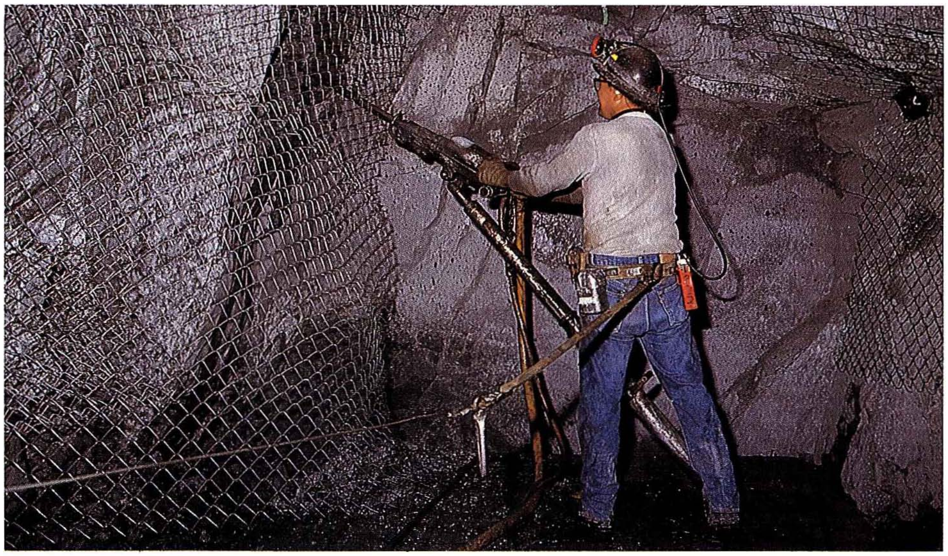
Primary development is performed with rail-mounted, pneumatic equipment, or rubber-tired LHD's (load-haul-dump) and hydraulic, rubber-tired drill jumbos. In the Lower Kalamazoo 10,000 metres of drift were excavated by means of a tunnel boring machine (TBM). Secondary development including undercutting uses jackleg drills.

All openings are supported by either timber, concrete, or steel mesh and rockbolts.

Ore production requires a pair of levels separated from each other by 18 vertical metres. The upper draw level funnels ore through a system of transfer raises to the underlying haulage level.

Filling the transfer raises are employees on the draw level who pull the ore from draw raises which reach up into the undercut zone of broken ore.

Thus the ore flows by gravity from the undercut 7 metres downward to the draw level and thence 18 metres down to the haulage. The caving system achieves its



production by drawing small tonnages of ore each day from an average of 900 draw points. The amount of ore and the specific draw points to be operated are determined by assays and according to the variables of production requirements.

As the ore is drawn, the surface subsides and produces a caved area which was utilised as a waste dump while the open pit mine was in operation.

Ore is hoisted to the surface in either 19 or 28 tonne capacity bottom dump skips through the four production shafts at 850 metres per minute. The hoists are either automatic or manual operation with 5.7cm rope winding on 4.6 metre double drums, powered by two 3000 hp DC motors. Surface ore bins have a total capacity of 36,000 tonnes for loading the trains which transport the ore to the mill.

Vital mine systems are monitored in a central surface control room where computers display the continuing status of all major switchgear, rectifiers, pumps and ventilation fans. Underground airflows and gas level monitoring provides information for fire prevention. Data on compressed air pressures and water flows help in the efficient use of these systems.

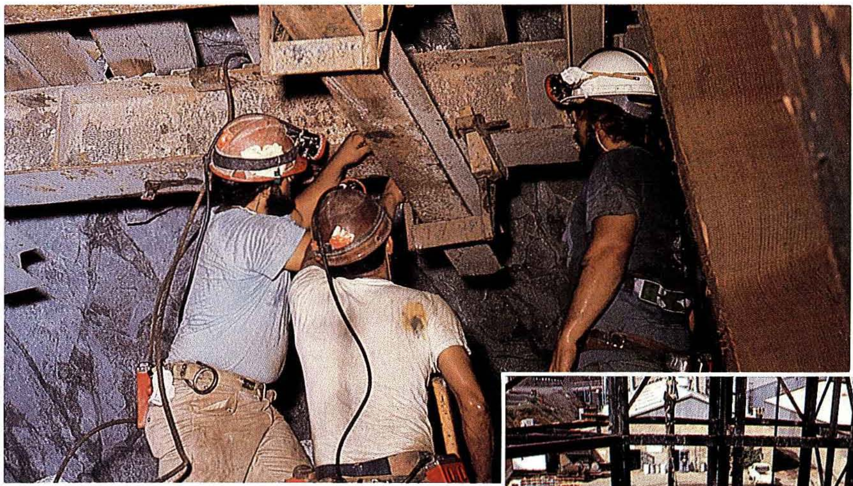
Lower K-Orebody Project

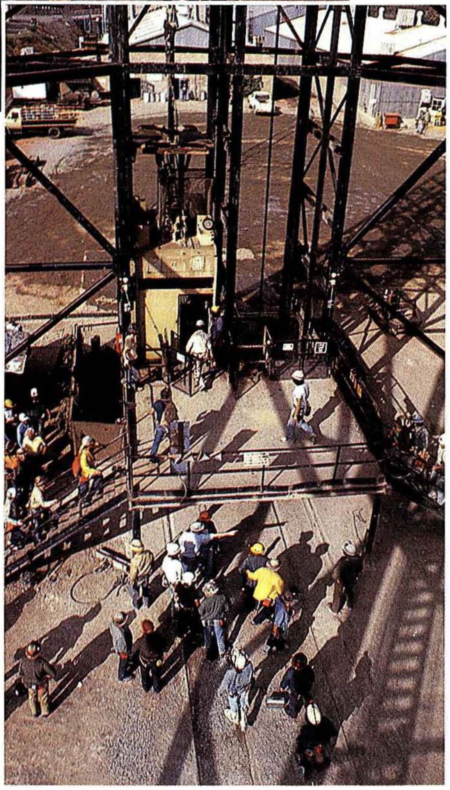
After completion of the latest exploration drilling program in 1992, additional ore reserves were confirmed below the 2950 haulage level of the Kalamazoo orebody. The first lift (2890/2950) of the Kalamazoo orebody was named the Upper K, while the deeper second lift (3440/3570) is known as the Lower K.

Following a detailed feasibility study completed in late 1992, the decision was made to invest $167.1 million to develop the Lower K in preparation for production. Due to critical time constraints during the development phase, it was decided that tunnel boring technology would be utilised for rapidly excavating access to the orebody. A 4.6 metre diameter tunnel boring machine (TBM) was assembled underground in 1993. The TBM completed 10,000 metres of drift during its two-year campaign.

In addition to the TBM, the Lower K also utilises raise boring technology. Raise boring machines capable of driving a 1.5 metre circular raise at an average rate of 2.1 metres/hr. will be utilised. Ore transportation along panel and main haulage drifts uses 1.4 metre and 1.8 metre wide conveyors respectively.

Production is scheduled to start in late 1996. Production from the Lower K will increase steadily over the years until it reaches a 50,000 tonne per day rate by the year 2000.





Mine Shafts at San Manuel

	#1	#4	#3A	#3B	#3C	#3D	#5
Current Depth (metres)	862	832	900	900	881	1,140	1,257
Ultimate Depth (metres)			1,140	1,140	1,140		
Headframe Height (metres)	31	33	55	55	61	61	48
Dimensions (metres)	7.8x1.8	8.1x4.3	8.8x2.1	8.8x2.1	6.7dia	6.7dia	7.6dia

#1 For supplying pump discharge, power lines and employee access.

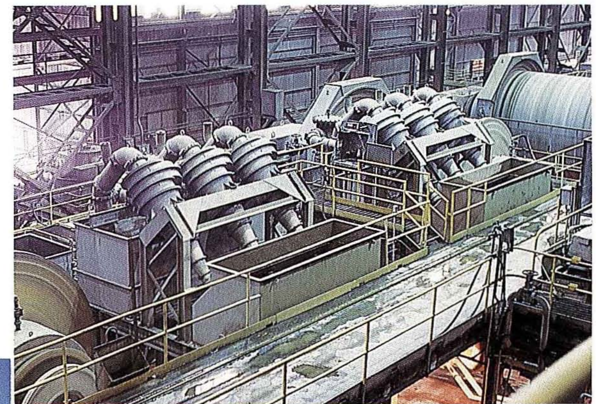
#4 Main service shaft with two double-deck cages for employees and supplies. Shaft contains main compressed air lines and in situ pump lines.

#3A & #3B Twin ore-hoisting shafts each contain two skips in counterbalance, an employee cage and a compartment for pipes and cables.

#3C & #3D Twin ore-hoisting shafts each contain two skips in counterbalance, an employee cage, and a compartment for pipes and cables.

#5 Multipurpose shaft provides service to the "K" orebody. contains two supply and employee cages, two waste rock hoists and a compartment for pipe, cables and concrete lines.

All shafts are of reinforced concrete construction containing structural steel sets. Each contain ladderways.



CONCENTRATING AT SAN MANUEL

Two crushing plants size the ore from the underground mine, first at the mine site with four 1,100 tonne per hour gyratory crushers and then at the mill in two stages with 11 cone crushers.

Ore is transported from the primary crusher at the mine to the mill in a 40-unit ore train of 91 tonne bottom dump cars pulled by a 1,600 hp diesel electric locomotive.

The concentrator at San Manuel processes the ore production from the underground mine as well as slag from the smelter's flash furnace and converters.

The concentrator utilises 13 wet grinding sections, each with one rod mill and two ball mills, operated by digitally-based programmable controllers.

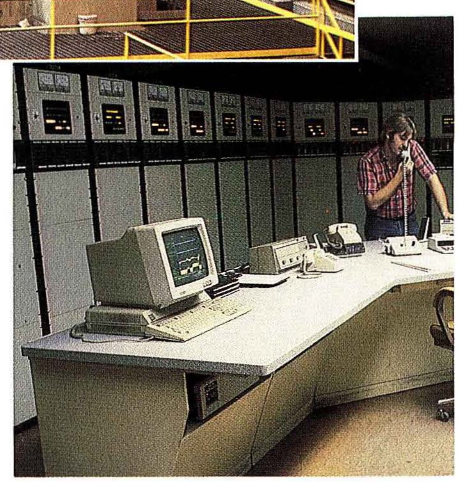
There are eight independent froth flotation sections. Rougher flotation occurs in ten 57 cubic metre and in one hundred forty three 8.5 cubic metre flotation machines.

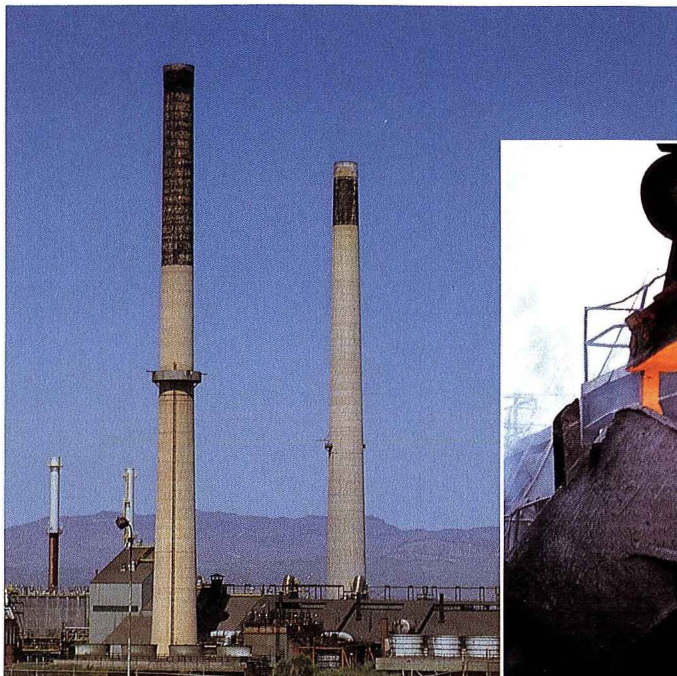
Cleaner flotation is performed in 16 state-of-the-art column cells which are 12 metres high.

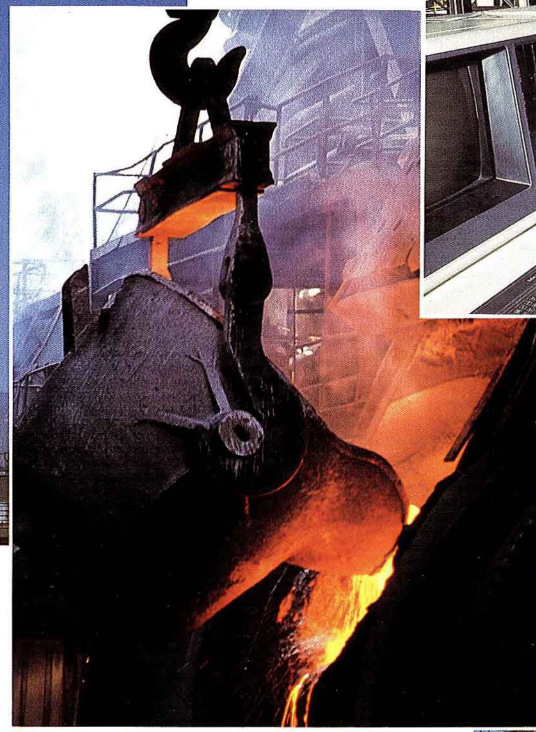
The product from froth flotation is thickened and pumped to the molybdenite plant where a flotation process recovers a molybdenum disulphide concentrate, a major by-product of San Manuel.

Tailings from the moly plant are the final copper concentrates which, after filtering and drying, are transported by conveyor to the smelter.

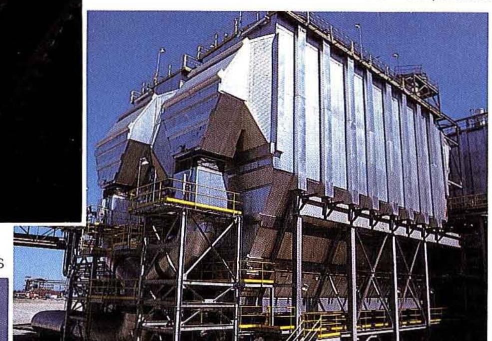
Tailings from the copper plant are thickened and flow by gravity to the large tailings impoundments. All water from tailing dams and the thickeners is continuously recycled back into the milling process.

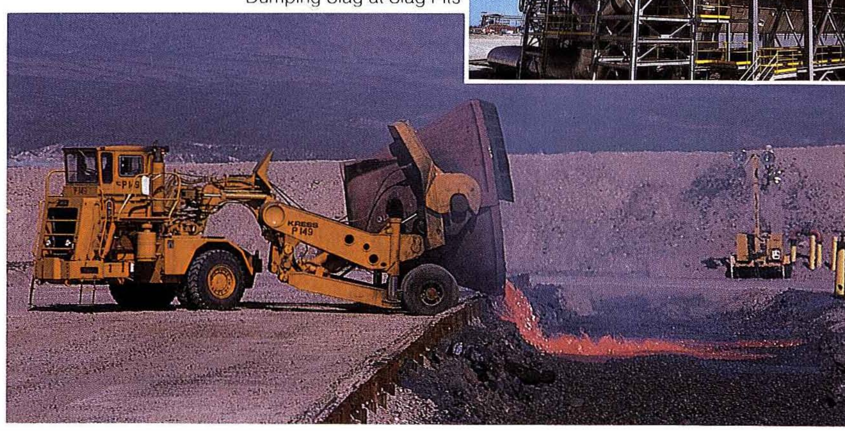



The San Manuel Smelter


Charging a Converter

Flash Furnace Controls


Electrostatic Precipitators


Dumping Slag at Slag Pits


THE SMELTER

World's Largest Flash Furnace

Commissioned in 1988 the San Manuel flash furnace is an Outokumpu design and has a processing capacity of over 1.8 million tonnes per year of copper concentrate, more than 25% of the U.S. smelting capacity.

This state-of-the-art smelter is operated through a sophisticated, distributed-control computer system, recovers 99% of the input sulphur and is environmentally the best in the U.S.

The smelter processes BHP Copper concentrate, purchases custom concentrates and provides toll smelting services for domestic and foreign producers.

Copper concentrate contains about 30% copper, 27% iron and 33% sulphur and this mineral combination oxidizes readily. Flash smelting takes advantage of this by providing an oxygen-rich (50%) atmosphere into which fine, dry concentrates and fluxes are injected through a single concentrate burner.

The minerals are rapidly oxidized and emit sufficient heat to melt all the ingredients of the charge as the particles fall down the 4.51 metre high reaction shaft into the settler.

The resulting hot gas loaded with dust particles and containing nearly 26% sulphur dioxide, is drawn through the uptake shaft into the waste heat boiler where the heat is removed for the production of steam by the San Manuel power plant.

The cooled gas is ducted to two high-efficiency electrostatic precipitators. Dust from the waste heat boiler and precipitators is contained within flues, collected and recycled.

Molten copper matte containing about 61% copper is tapped through covered launders into ladles positioned in tunnels beneath the furnace. Full ladles are taken by overhead crane and the matte is poured into one of three hot converters.

In the converters further oxidation of sulphur, and slagging of iron and other metals, takes place over a ten-hour period until the copper reaches a purity of 99%.

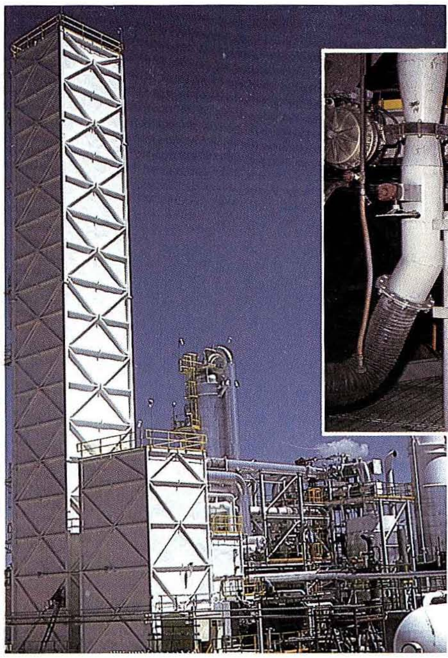
This molten copper, called blister, is transferred by overhead crane to the casting department where it is fire refined for the removal of oxygen and cast into 380 kg pound anodes for transport to the electrolytic refinery.

Molten slag, containing approximately 2% copper from the furnace and/or 6% from the converters, is skimmed into pots which are transported by rubber-tired diesel haulers to shallow slag pits. Here the slag is air cooled, then water cooled, broken, crushed and loaded into rail cars for copper content recovery by wet grinding and froth flotation. The resulting slag concentrate rejoins the other furnace feed.

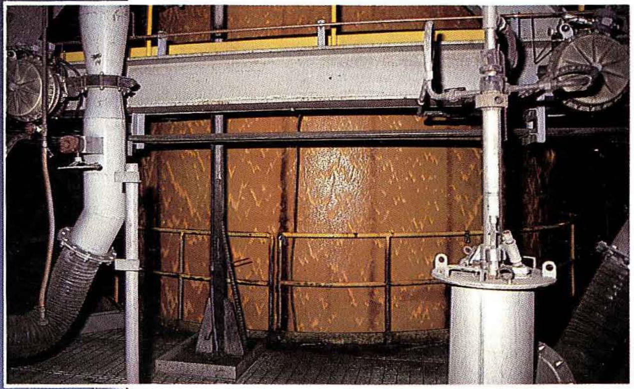
Each of the four converters utilises primary and secondary hoods for maximum capture of SO_2. Behind each converter is a gas scrubbing system which prepares the gas stream for processing in the double-absorption sulphuric acid plant.

In the acid plant the SO_2 is cleaned, dried and converted by catalyst to sulphur trioxide (SO_3). The SO_3 is readily absorbed in circulating sulphuric acid to become salable grade acid.

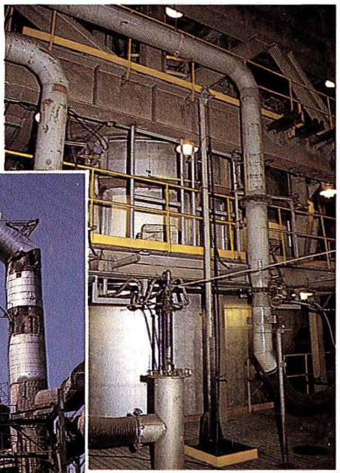
Oxygen for the flash reaction is produced by fractional distillation at -190ºC at the oxygen plant. Oxygen is provided at the rate of 780 tonnes per day. Nitrogen is also produced and used as a non-combustable atmosphere in the concentrate drying system to reduce the fire hazard.



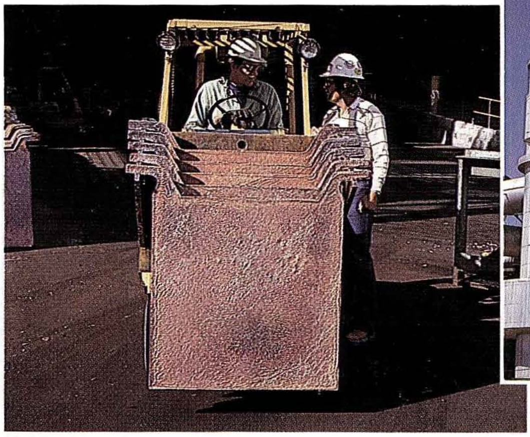
Air Separation Plant



Reaction Shaft



Gas Uptake Shaft



Finished Anodes

Sulfuric Acid Plant

Converter Gas Scrubbers

Flash Furnace Data (tonnes)

Furnace Feed Rate	
Concentrate	181 TPH
Flue Dust	6-7 TPH
Flux	16 TPH
Total	204 TPH
Furnace Matte Produced	77 TPH
Furnace Slag Produced	75 TPH
Off Gas to Acid Plant	
Volume	107,000 Nm^3/Hr
SO_2 Content	26%
Temperature	315ºC
Oxygen Consumed	25,500 Nm^3/Hr
Natural Gas Consumed	510 Nm^3/Hr
Steam Production	
Volume	54.5 TPH
Pressure	60 Bar

Converter Data

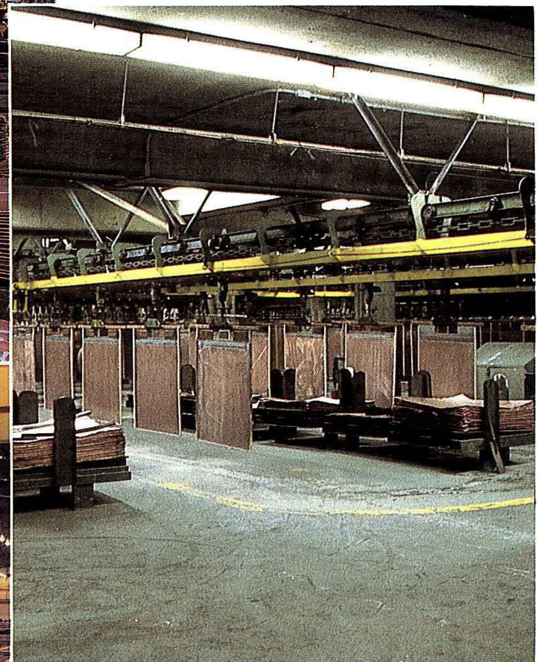
Converter Feed	
Matte	1,850 TPD
Flux	144 TPD
Scrap Copper	190 TPD
Gas Flow to Acid Plant	
Volume	160,000 Nm^3/Hr
SO_2 Content	Avg. 4.8%
Temperature	63ºC

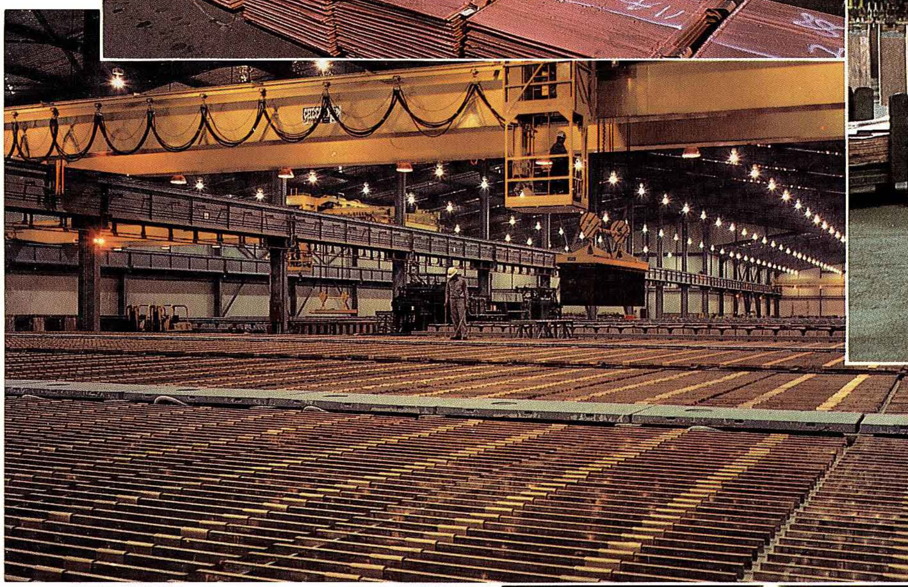
Sulphuric Acid Plant

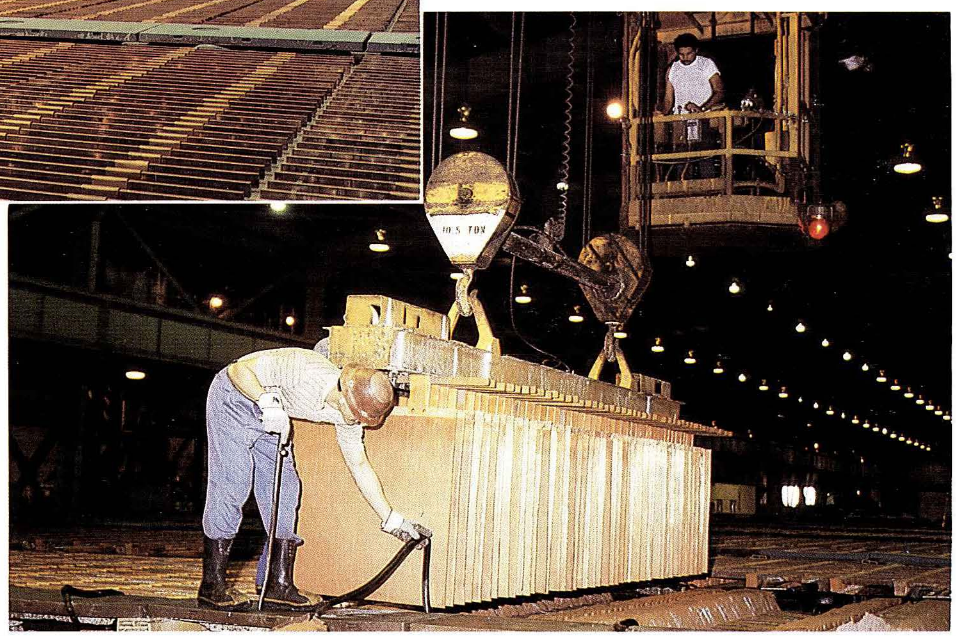
Total Gas Feed	
Volume	460,000 Nm^3/Hr
SO_2 Content	10%
Temperature	315ºC FSF 63ºC Conv.
Production	3,200 TPD

Copper Production

New Copper	1,075 TPD
Anodes Cast	1,140 TPD







ELECTROLYTIC REFINING

In an electrolyte composed of sulphuric acid, copper sulphate and plating reagents, copper is transferred from an anode at the positive pole of an electric circuit to the cathode at the negative pole. The copper is plated at the cathode and impurities settle to the bottom of the refining cell.

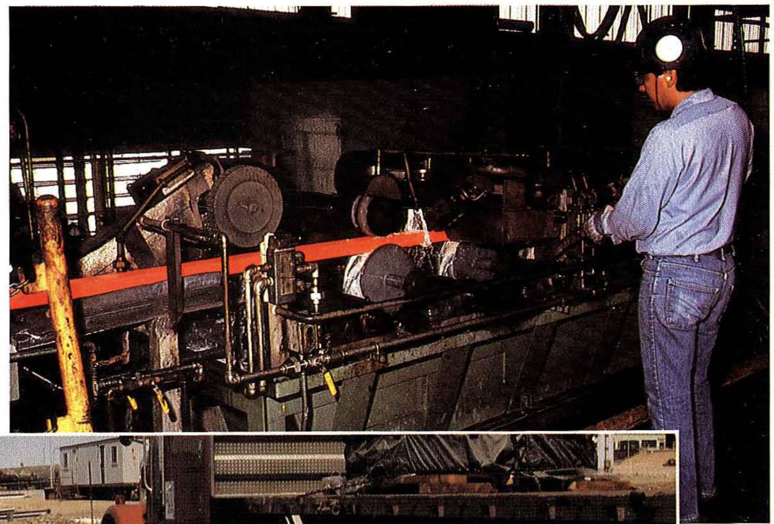
At the San Manuel electrolytic refinery tankhouse there are 28 refining sections each with 42 cells into each of which are suspended 46 anodes and 45 copper starting sheets.

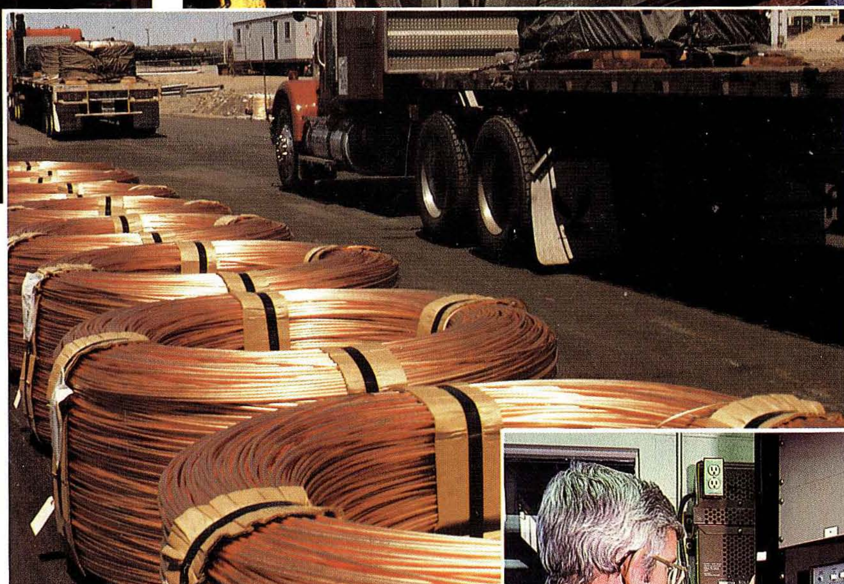
Direct current at .275 volts and 28,000 amperes is applied to the electrodes. Two, 10-day cycles of plating at a current density of 336 amps per square meter produce 170 kg cathodes from each anode charge.

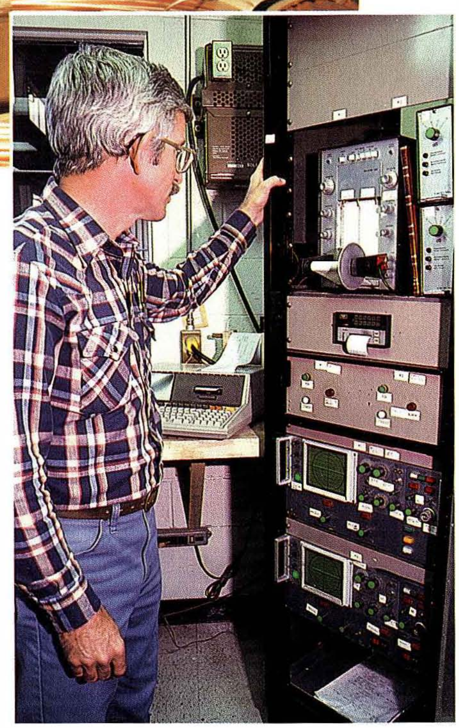
Starting sheets are produced in a 24-hour cycle and are plated on rolled copper mother blanks. The 6.4 kg starting sheets are finished and assembled mechanically at the rate of 5,300 sheets per day.

Settled residue from the refining process is collected and leached to recover copper. The remaining residues containing precious metals are filtered, dried and packaged for shipment.

The San Manuel cathode is certified grade 1 by the London Metal Exchange and the New York Commodity Exchange and meets all quality standards for rod casting or direct sale to copper fabricators.







CONTINUOUS CAST COPPER ROD

About 35-40% of San Manuel's copper production is converted into premium quality continuous cast 5/16 inch (7.9 mm) wire rod for customers in the wire and cable industry. It is shipped in three standard, plastic-wrapped packages of either three, four or five tonne coils, with other sizes available on request.

The San Manuel rod plant utilises the Southwire casting system and the 12-stand Morgan non-twist rolling mill.

Cathodes from the electrolytic refinery and the San Manuel and Pinto Valley SX-EW plants are fed to a natural gas fired shaft furnace for melting and the stream discharges to a holding furnace.

The molten copper is fed to a 2,440 mm diameter rotating, vertical casting wheel at the rate of 33 tph which produces a bar casting having 45.20 mm^2 of cross-sectional area.

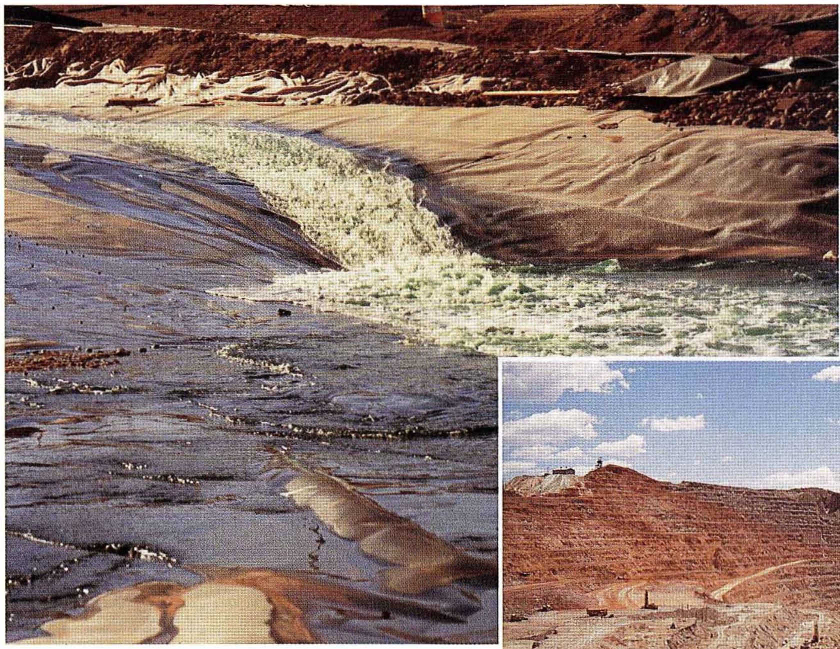
The bar continuously moves through the 12-stand rolling mill where it is sequentially reduced to the 7.9 mm diameter and then pickled, rinsed, waxed and coiled.

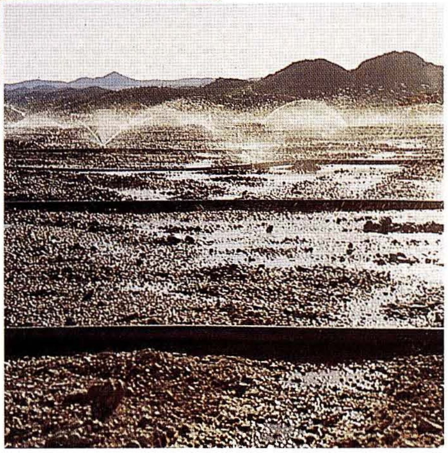
The bar casting moves from the wheel at 13.5 m/minute, then through the roughing and finishing mills and exits the coiler at 1,170 meters per minute.

The coils are banded, wrapped, weighed and loaded on trucks or rail cars for shipment.

A sample of each coil is subjected to rigid quality-control tests before loading and shipment is permitted.

The rod plant has a production capacity of 190,000 tonnes per year.





THE IN SITU MINE AND HEAP LEACHING

Located in the subsidence zone of the San Manuel underground mine, the now-completed oxide open pit was established to recover a large reserve of copper oxide ore. The principal oxide mineral leached is chrysocolla.

Waste material was dumped into the adjacent cave area created by the underground mine and ore was hauled a short distance to the leaching pads.

The leach pads are built on an area of 104 hectares underlain with a thick, high-density polyethylene liner to prevent any loss of leaching fluids into the surrounding watershed.

Approximately 84 million tonnes of oxide ore mined over the open pit's nine and one-half year life span now rests on the lined area. The height of the heaped ore is over 104 metres.

For leaching, a network of pipes and wobbler sprinklers is laid on the surface of the completed dump and a weak solution of sulphuric acid is continuously sprayed at the rate of 0.32 litres per square metre of surface area.

The leach solution percolates down through the dump, dissolving copper in the ore, flows from the dump's base as pregnant leach solution (PLS), drains into a collection pond and is then pumped to the 37.8 million litre feed pond for the solvent extraction plant.

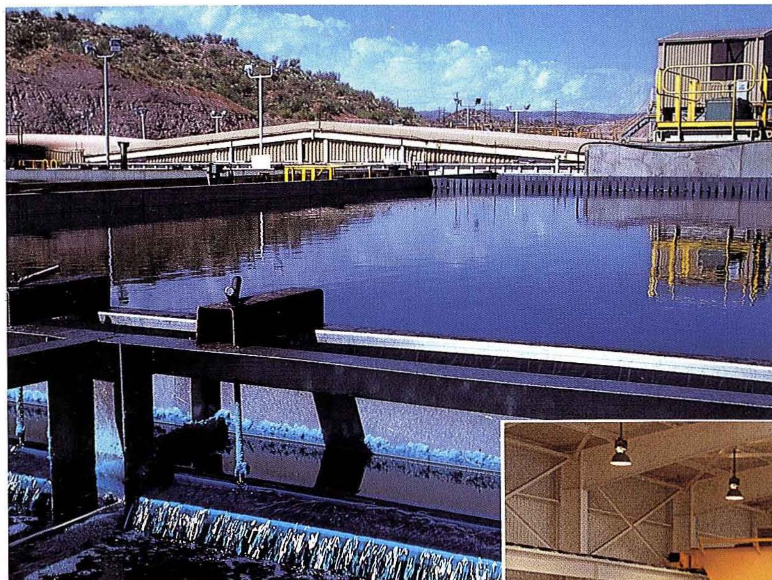
IN SITU LEACHING

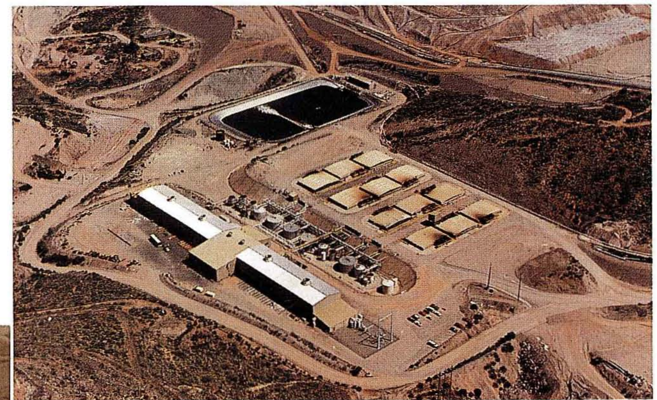
Additional reserves of acid-soluble oxide ore lie beneath the open pit area and above the depleted portion of the underground mine and are available to the in-place method of in situ leaching.

Injection and production wells are drilled into this zone to an average depth of 152 metres. The wells are cased with perforated PVC pipe strategically placed to allow a weak sulphuric acid solution to interact directly with the orebody.

The resultant copper-bearing solution (PLS) is recovered primarily by adjacent production wells. These wells are either 15 or 20 cm in diameter and contain stainless steel submersible pumping units which lift the PLS to surface processing systems.

Solutions targeted for the lower portion of the oxide orebody are allowed to drain into an underground collection area. The area consists of unused haulage drifts in the depleted section of the underground mine. This PLS is pumped to the surface and joins copper-bearing solution from both the leach dump and the in situ surface production wells for processing in the SX-EW plant.





SX-EW/SOLVENT EXTRACTION-ELECTROWINNING

Solvent Extraction

While the process of electrowinning copper from a rich electrolytic solution is as old as industrial electrical applications, the technology of solvent extraction is newer and with the development of special reagents can now be applied efficiently to large-scale operations.

The purpose of solvent extraction is to remove copper from the pregnant leach solution (PLS) by mixing it with an organic extractant and then removing the copper from the organic into a rich solution of sulphuric acid and copper sulphate.

The solvent extraction process takes place in each of four stainless steel tank trains at the rate of 15,140 litres per minute each.

The resulting electrolyte solution is pumped to the electrowinning tankhouse, the organic and reagents are recycled and the now barren PLS called raffinate is discharged to the raffinate pond for recycling to heap leaching.

ELECTROWINNING

Electrowinning is an electro-chemical process in which copper from an electrolyte is plated onto a cathode. The primary difference from electro-refining is that refining uses a copper anode while a lead alloy anode is utilised in electrowinning.

The electrowinning tankhouse has 188 concrete cells each containing 61 lead anodes and 60 stainless steel cathode mother blanks.

The plating cycle is seven days to obtain a 45 kilogram cathode from each side of a mother blank.

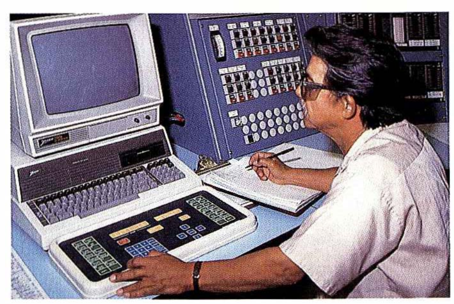
The cathodes are stripped mechanically from the mother blanks and are either sold as is or transported directly to the San Manuel rod plant for continuous casting. The electrowon copper is guaranteed 99.999% pure. It is certified for sale against COMEX grade 1 and LME grade A cathode standards.

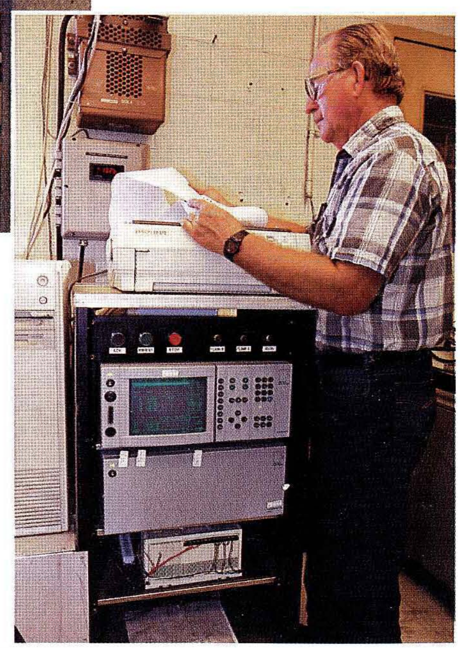
The extractant used in the solvent extraction process is very selective to only transfer copper from the leach solutions. This results in especially high-purity copper metal production during electrowinning.

All SX-EW functions are fully instrumented for automatic operations and direction from a comprehensive distributive control system.

Altogether BHP Copper operates three SX-EW plants in Arizona:

Location	Production Capacity
San Manuel	68,000 tonnes/yr.
Pinto Valley Unit	7,250 tonnes/yr.
Miami In Situ Unit	5,500 tonnes/yr.





METALLURGY AND QUALITY ASSURANCE

BHP Copper is dedicated to producing and delivering the highest quality copper rod and cathode to our customers.

In addition BHP Copper believes strongly in the responsibility for prompt and aggressive customer service to insure the integrity of the quality assurance program and to maintain complete customer satisfaction.

Each operating department from the mines through the rod plant has goals for quality of workmanship and for delivery of the process materials to the next operating level.

At the refinery and rod plant a program of statistical process control is used for maintaining product quality.

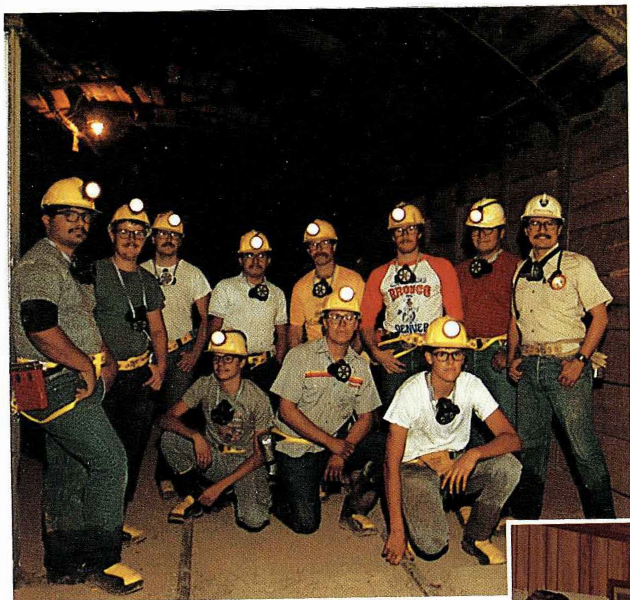
Metallurgical testing occurs at each process level and rigid quality control testing of cathode and rod determine if final shipment will be made to a customer.

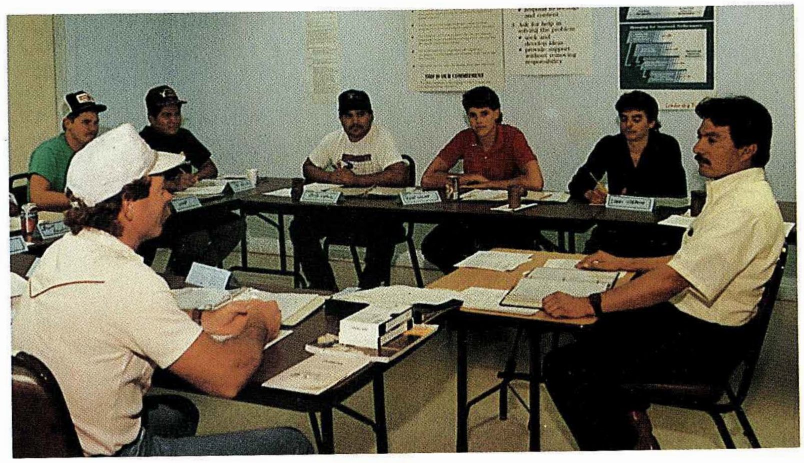
Laboratory methods include x-ray fluorescence spectography, atomic absorption analysis, emission spectography, gas chromatography, electron microscopy, wet chemistry, and both physical and process metallurgical testing.

Six fully-equipped, modern laboratories serve the San Manuel production operations, one of which is the quality assurance unit located adjacent to the coiler in the rod plant for testing of each production coil of rod.

Metallurgical department operations include ore assay, process materials assay, product quality determination, furnace gas analysis, process efficiency analysis, equipment wear and failure analysis, lubricant controls, research on new processes and products and flow chart development.

The department also has a team of metallurgists who provide technical service to rod customers, including feedback for product improvement as well as assisting customers in use of the products.





EMPLOYEE INVOLVEMENT, EDUCATION AND SAFETY

Approximately 3,300 individuals each contribute their own special skills and knowledge to their jobs at San Manuel.

In reaching the goals and objectives of the organization, BHP Copper values and seeks the ideas and contributions of employees. By actively involving those employees who do the work, more cost-effective ways to meet company goals are often found. Active participation in the jobs has the benefit of making those jobs more challenging, satisfying and productive.

Another key to high employee productivity is the high level of union-management cooperation with those unions representing San Manuel employees.

To better utilise employees' experience to solve work problems and to analyze production methods, tools, and procedures, employees join together in work teams which are increasingly self directed and participate in breakthrough project teams. Focusing their combined experience on problems brings about sensible solutions and results in cost-effective and efficient processes and procedures.

All employees participate in safety programs aimed at accident prevention by awareness of the work environment and respect for proper work procedures. At San Manuel, safety is more important than production.

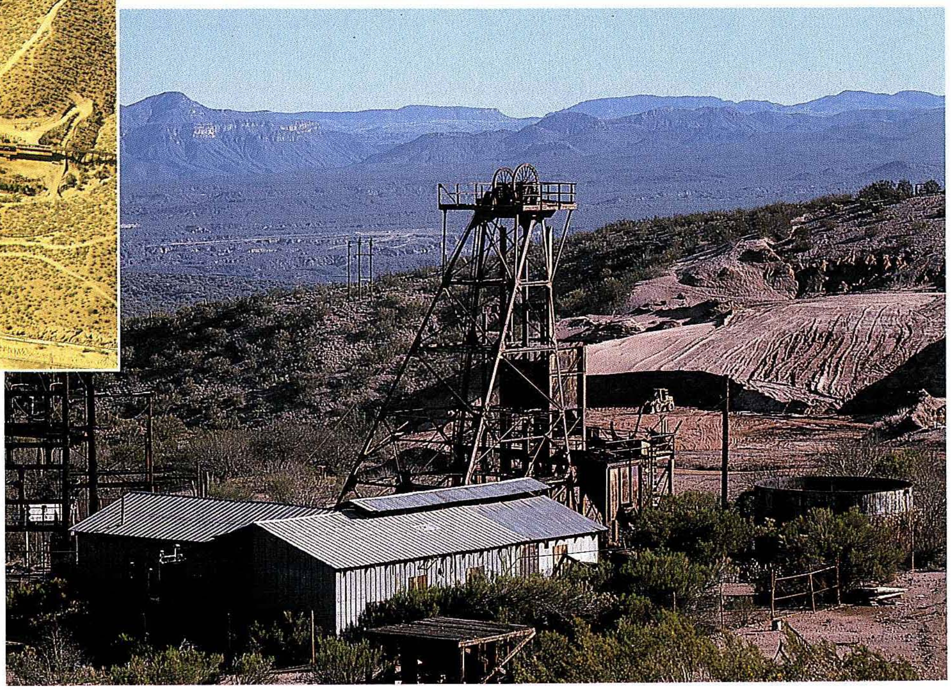
Employees exposed to possible hazardous materials or environments are carefully trained in the handling of these hazards and are provided with personal protective clothing and equipment.

Supervisors' training is conducted at all levels to ensure common understanding and fair implementation of company policies and to learn techniques in human resource skills.

San Manuel employees and their unions are, in every sense, partners in the company's efforts to achieve and maintain an accident-free workplace, outstanding product quality, technical leadership and business success.

Superior Smelter in the 1950's

Historic Tiger Mine at Mammoth, Arizona.



OUTLINE HISTORY OF SAN MANUEL

1877 Silver Queen Mine in production at Hastings (Superior) Pioneer Mining district, Arizona Territory.

1879 Mines started in Old Hat District around Mammoth (gold and silver mines).

1896 Post Office opens for Schultz, Arizona, later renamed Tiger (located adjacent to San Manuel's SX-EW plant).

1910 Magma Copper Company organized, Superior, Arizona Territory, holding the old Silver Queen mining property.

1915-19 Molybdenum and vanadium campaigns at Tiger.

1921 Newmont Mining Corporation founded.

1924 Smelter erected at Superior, Arizona.

1934 St. Anthony Mining Company buys Tiger mines.

1935-43 Renewal of activity; lead and zinc campaigns at Tiger.

1942 War Production Board investigates Mammoth area for copper.

1943-45 Exploration Drilling by U.S. Bureau of Mines at Red Hill (San Manuel).

1944 Magma consolidates and purchases San Manuel claims and begins additional exploration and drilling.

1948 Underground exploration and development begins.

1952 Federal loan of $94,000,000 made to Magma to build the San Manuel mine, plant, rail roads and community.

1953 Construction begins on surface plant.

1956 First stopes undercut and first smelting begins.

1965 Expansion from 27,200 tonnes of ore per day to 36,300 TPD.

1968 Purchase of nearby Kalamazoo orebody doubles size of reserves.

1969 Merger with Newmont Mining Corporation.

1971 Superior smelter is shut down.

1972 Expansion from 36,300 to 54,430 TPD ore processing. Operation of electrolytic refinery and continuous rod casting begins. Smelter expansion underway.

1973 New Superior mine-plant in operation; expanded to 3,000 TPD.

1974 Start up of air quality control systems and sulphuric acid plant at San Manuel.

1982 Superior Division is shut down.

1985 Development of open pit at San Manuel begins.

1986 Oxide open pit, leaching and SX-EW plant begin production. Newmont recapitalises Magma and contributes Pinto Valley as an operating division.

1987 Magma is reorganised and spun-off to stockholders of Newmont. In situ leaching production starts. Development of Kalamazoo orebody begins. Modernisation programs begin.

1988 Flash furnace at smelter started, old reverbs shut down. Mill and refinery expansion and modernisation programs are completed.

1989 Recapitalisation and repurchase of Newmont interests result in new era of indepen dence for Magma.

1990 Superior Division operations resume. Kalamazoo mine start up.

1991 Historic 15-year labor agreement ratified.

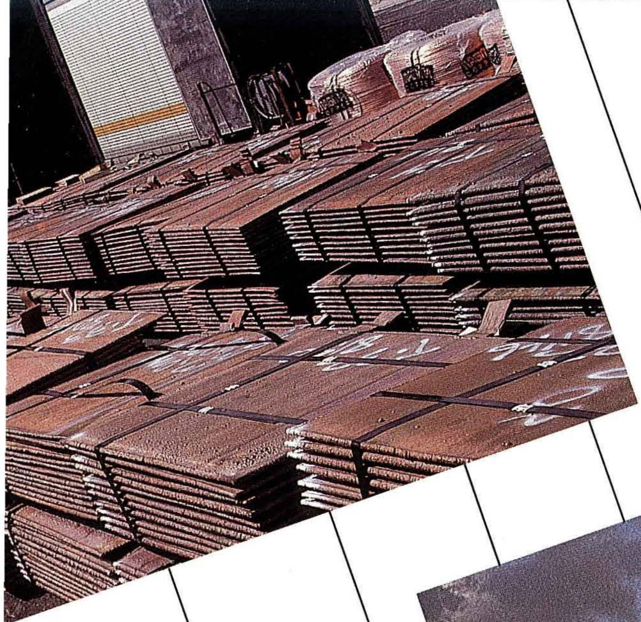
1992 Magma Metals Company and Magma Nevada Mining Company organised.

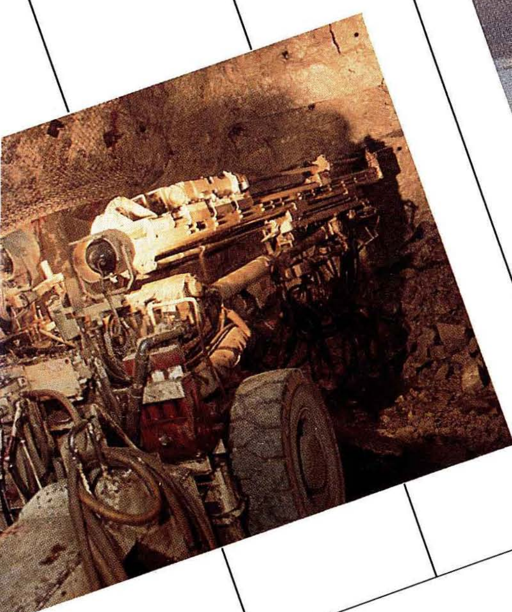
1993 Expansion projects begin at smelter. Lower K orebody development begins.

1994 Smelter completes 20% expansion with addition of 3rd acid plant. Robinson begins construction and Tintaya, Peru acquired.

1995 Robinson Mine at Ely, Nevada begins production. San Manuel open pit completed.

1996 Merger to form BHP Copper.





At San Manuel mineral ores are processed through a series of extractive operations to produce premium quality copper which is sold throughout the world for the production of basic industrial and consumer products.

One of the first metals discovered and utilised by man, copper is so much a part of civilisation it is difficult to conceive of progress without its contributions.

Reaching from the past and extending into the future BHP Copper is proud to be a part of the tradition of copper.

BHP

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