REMARKS OF

CHARLES F. BARBER, CHAIRMAN
AMERICAN SMELTING AND REFINING COMPANY

AT THE DEDICATION OF

THE HAYDEN ACID PLANT

JANUARY 25, 1972

Greetings to Governor Jack Williams of Arizona

Recognition of Others Present

We have just completed a short dedication ceremony at the new acid plant up on the hill. At the ceremony Governor Williams unveiled the plaque that is pictured in your invitations. You will all see it when you visit the plant this afternoon. It records that the new acid plant is "Dedicated to Better Air Quality." That is the theme that brings us together today.

Before he unveiled the plaque, I told the Governor that this was a gratifying day for Asarco. Detailed planning for this sulfuric acid plant began five years ago, and funds for its construction were appropriated by our Board of Directors in June 1968 - thus, this plant was conceived before concern for the environment had burgeoned into a national issue. It is tangible evidence, therefore, that we at Asarco are, and have been, well aware of our environmental responsibilities and intend to fulfill them.

The sulfuric acid plant we are dedicating today will significantly improve air quality here at Hayden. The plant will capture substantially all the dust, particulates, and sulfur dioxide from the converter gases. These account for more than 50% of the sulfur contained in the ores and concentrates received at the plant.

We have comparable programs underway at our El Paso and Tacoma copper smelters. It is appropriate to refer to these other copper smelters for, like the Hayden smelter, they process ores and concentrates

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from Arizona mines. Last year, for example, 112,000 tons of concentrates from Arizona were smelted at Tacoma and 185,000 tons were treated at El Paso. These three Asarco smelters, which account for about 25% of the domestic smelter capacity, differ from those operated by other companies in that they operate as custom smelters, treating primarily ores and concentrates produced by others. For example, the Hayden smelter has treated concentrates from Duval's Esperanza, Mineral Park and Sierrita mines, from Anaconda's Twin Buttes mine, from the mines of Bagdad Copper Corporation, and others as well as from Asarco's own Mission and Silver Bell mines.

The sulfur recovery facilities at these three copper smelters will cost more than $50 million. That is a measure of our immediate investment in Better Air Quality. In each case we will achieve good ambient air quality in the vicinity of the smelter and nearly eliminate visible emissions. Ambient air standards are the ultimate criteria of air quality; it is that goal, air quality, to which we are committed. You have all read about the controversy here in Arizona over the so-called 90% sulfur emission standard as applied to copper smelters. The controversy has not been over whether the recovery and preservation of pristine air quality is good or an ultimate ideal goal. All of us are for clean air; most of us are conscious that in seeking the ultimate we must also proceed with due regard for insuring the continuity of our economic welfare.

As a people we must seek an enduring balance among our several goals. The determination of applicable standards based on the available evidence as to need and impact is an important part of that process. Meanwhile, there has been a head-on conflict in Arizona and elsewhere over such immediate, practical questions as those relating to available technology, tolerable costs, likely side effects, and time schedules.

Last Thursday the Arizona State Board of Health issued an important position statement. It is eloquent in that it identifies as an objective the ultimate ideal of the recovery and preservation of "the pristine air qualities that are inherent in Arizona."

It was disappointing in that the Board did not at this time recognize that there is no evidence that 90% control of sulfur at the existing copper smelters is required to meet ambient air standards adequate to protect health and welfare. But it did assure those of us responsible for maintaining the flow of commerce that "appropriate consideration is going to be given to the many technical, social and economic problems that will arise in developing an effective plan of implementation." Thus, the Board of Health deferred for the time being formulation of its implementation plan for sulfur oxides, acknowledging "a need and requirement for further studies and research before the definitive development of an equitable implementation plan."

The actions in recent weeks of other Western States with copper smelters - Texas, Utah, New Mexico, Nevada, and Washington - indicate a similar willingness to distinguish between what may be feasible ultimately from what reasonably can be done now.

We of Asarco are proud to be corporate citizens of Arizona, and a part of its copper industry. Construction of the Hayden smelter began in Territorial days, and the first blister copper was produced here in 1912, the year Arizona became a state. We have been here a long time, and we are going to continue to be good citizens carrying on our essential industrial activities in a constructive manner and with full regard for their environmental impact.

The presence here with me of Asarco's President, Ralph Hennebach, and of the members of our Board of Directors signals our commitment to better air quality. That is the testimony of the new acid plant we dedicate today.

I hope that all of you will take the time to see the plant after lunch. It is a splendid plant, the largest single plant in the United States producing sulfuric acid from smelter gases. It embodies a number of technical innovations, including a unique water recirculation system that minimizes the potential for pollution of the area ground water by acid wastes and an extremely efficient heat exchange system. It is described in the brochure which you will receive. And, if you have any questions, your guides will do their best to answer them. I hope you will enjoy your visit with us.

Once again on behalf of Asarco, its Officers and Board of Directors, I bid you welcome and thank you for joining with us here today.

ASARCO NEWS

AMERICAN SMELTING AND REFINING COMPANY

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ASARCO DEDICATES ACID PLANT TO BETTER AIR QUALITY

HAYDEN, Arizona, January 25, 1972--American Smelting and Refining Company (Asarco) formally dedicated its new $17 million sulfuric acid plant here today.

Governor Jack Williams joined Asarco Chairman Charles F. Barber and President Ralph L. Hennebach in dedicating the new plant to "better air quality".

Mr. Barber told several hundred guests at the ceremonies that the new sulfuric acid plant will improve air quality significantly in the vicinity of the Asarco smelter. It "is tangible evidence of Asarco's dedication to improved air quality," he said.

The invited guests included Arizona legislative, regulatory, business and community leaders. Besides its two top Asarco officers, the Company was represented by the Board of Directors and a number of other key executives.

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Most of the acid is sold to other companies for leaching copper ores with the remainder being used in the manufacture of fertilizers and other chemical applications. Some of the acid will be used by Asarco itself at a new plant to be built to treat oxide ore from its San Xavier mine on the Papago Indian Reservation near Tucson.

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The new acid plant, Mr. Barber said, sharply reduces sulfur dioxide emissions from the smelter - cutting them in half - and also removes all of the dust and particulate matter from the converter smoke stream. The plant is now in full operation.

Mr. Barber noted that planning of the new acid plant was started by Asarco in 1966 "before concern for the environment burgeoned into a national issue".

The Hayden acid plant is part of an intensive program, involving an investment over a five-year period of more than $50 million, to improve air quality in the areas of Asarco's three copper smelters at Hayden, El Paso, Texas, and Tacoma, Washington. These three smelters, of which the Hayden plant is the largest, produce about 20 percent of the domestic supply of blister copper.

The sulfuric acid plant produces between 1,000 and 1,200 tons of acid per day. It consumes and cleans all of the gases produced by the smelter converters in the last stage of the production of blister copper. This is more than 50 percent of the sulfur dioxide byproduct of the smelting process.

The plant employs one of the world's most advanced gas cleaning systems. Among the technical innovations is a specially designed water recirculation and recovery system that avoids pollution of the area ground water by acid wastes.

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ASARCO NEWS AMERICAN SMELTING AND REFINING COMPANY

HAYDEN SMELTER

HISTORY

Located in the rolling hills of the San Pedro Valley in Arizona approximately 70 miles from Tucson and 90 miles from Phoenix, the state's two major cities, the Asarco Hayden smelter dates back to the year 1911.

Excavation and construction began in September of that year and was completed in the spring of 1912. On May 18, 1912, the first blister cakes were cast.

Since then, the Hayden plant has continued to grow and increase in production, with the addition of increasingly advanced air quality devices throughout the years.

The plant was expanded in 1916, adding two reverberatory furnaces to the two original furnaces. Other ancillary equipment was also added.

In 1940, the advances in metallurgy and operating techniques almost tripled furnace capacity. This increased production did away with the need for all four furnaces, so three were dismantled leaving a single furnace to smelt the entire plant intake.

Then in 1949, further construction was begun to handle additional concentrates pouring into the smelter from new Southwest copper producers. In August of 1958, the smelter commenced operating as a custom smelter sharing available tonnage with the Asarco smelters in El Paso, Texas, and Tacoma, Washington.

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When the decision was made to develop the Asarco Mission Mine Unit south of Tucson, it became necessary to expand the capacity of the smelter to handle 21,000 tons of concentrates per month. This construction program started in the spring of 1961 and was completed by the end of that year.

By February 1, 1961, the blister copper casting system had been changed. Huge overhead cranes were now used to cast 6,000 pound blocks. Previously, only 350 pound bars could be cast on a casting wheel.

Asarco cooperated with the plant service car manufacturers in the design of a new type of concentrate railroad car. This project permitted concentrates to be dumped directly into the bedding system, thus making a more efficient receiving method for incoming concentrates.

Asarco's Mission and Silver Bell units supply the Hayden smelter with copper ore of 26% to 30% concentration, supplemented by custom smelting under contract with various other Arizona mining companies.

Hayden processes approximately one third of all Asarco's custom contract tonnage of copper concentrates, with the balance going to the El Paso or Tacoma plants.

At present, Hayden smelts 40,000 to 50,000 tons of concentrates per month.

THE PROCESS OF SMELTING

The smelter contains 12 roasters, two reverberatory furnaces and five converters. In addition, the plant contains maintenance and repair shops, waste heat steam power plant, ten miles of rail trackage and raw material storage facilities.

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The plant is served by the Southern Pacific Railroad. All inbound materials are weighed and sampled for moisture and metal values.

The cars are delivered to the receiving hopper where they are discharged and conveyed to one of four bedding areas. A prepared bed consists of concentrates and plant by-product material in addition to silica sand and limerock which are added for metallurgical control.

A front end loader reclaims the bedded material, delivering it to a belt conveying system that distributes the material to the feed hoppers which service each of the twelve roasters. In the roasting process the charge is subjected to heat for drying and elimination of a calculated amount of sulfur for production of a 1100 degree calcine product.

The calcines are then taken from the bottom of the roasters into ten ton larry cars and transported to each of the reverberatory furnaces.

Calcines are melted to a liquid state in the reverberatory furnaces to produce a liquid copper-iron sulfide matte. The 40% to 45% copper matte is tapped periodically and charged to convertors where removal of iron and sulfur results in the production of blister copper which is about 99% pure. Three overhead 60-ton cranes service this department and the finished charges are transferred by 20-ton capacity ladles for pouring into open molds.

The blister copper is cast into 6000 pound cakes which are then loaded into railroad gondolas and weighed for shipment to Eastern seaboard refineries where the cakes are remelted, cast into anodes, electrolytically refined and subsequently cast into wire bars and other marketable shapes.

A new anode casting plant, estimated to cost over $4,000,000, is presently being constructed to replace the blister casting system. The final product from the smelter will then be in the form of anodes that can be charged directly into electrolytic refining tanks without further processing at the receiving Eastern seaboard refineries.

All of the roaster and reverberatory gases pass through settling chambers, cooled and conditioned with water sprays and cottrelled for the removal of over 97% of the contained particulate matter. New equipment currently being installed will increase the percentage of particulate matter recovered. The evolved gases pass through a flue system prior to discharge from the 250 foot stack. These collected flue dusts, along with roaster and cottrell dusts as well as miscellaneous reverts are returned to the bedding system.

ENVIRONMENTAL QUALITY CONTROL MEASURES

American Smelting and Refining Company has long been concerned with problems of environmental quality control and beautification. The Company was the first in the world to install the Cottrell electrostatic precipitator (in 1907) to remove particulates from smelter gas streams. Frank J. Cottrell, inventor of the process, worked for Asarco's predecessor company in California when he discovered the dust collection process that bears his name.

In 1928 another Asarco scientist, Dr. M.D. Thomas developed a chemical-mechanical device that could continuously detect, measure and record minute quanities of sulfur dioxide (SO_2) in the atmosphere. This instrument, the Thomas autometer, made it possible to conduct round-the-clock measurements of SO_2 at particular locations. Since 1958 the Company has managed a monitoring program of the air in the San Pedro Valley.

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Asarco has also established and operated SO_2 and particulate monitoring stations at Coolidge and Florence, approximately mid-way between Hayden and Phoenix, to determine the extent of diffusion of SO_2. It is conduting measurements of SO_2 in smoke plumes and has done atmospheric inversion studies by airplane.

At the Hayden plant there are many devices to control particulate emissions, including cyclones, settling chambers and electrostatic precipitators. Additional control equipment now being installed will further reduce the emissions.

As concrete evidence of the Company's concern, a new sulfuric acid manufacturing plant has been installed at the Hayden smelter at a cost of $17 million. The new plant includes a converter flue system, electrostatic precipitators gas cleaning facilities and a sulfuric acid plant which is now in operation. The five converters have been changed over for the delivery of process gases to the new cyclone and electrostatic precipitators with these gases available for acid production.

After approximately two years of preliminary design and process evaluation, construction on the new acid plant complex started in 1969. The acid plant reached full production in November, 1971, and the process guarantee acceptance tests were finalized in December, 1971.

The new electrostatic precipitator, together with existing equipment is designed to recover 97% of the particulate matter from the smelter gases. Full production from the acid plant will capture 100% of the sulfur dioxide gas produced in the converter department. This represents 50% of the sulfur dioxide produced in the smelter.

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HOW THE NEW ACID PLANT WORKS

Each of the five converters discharges flue gas into a water-cooled dust settling chamber. The gas flows through seven-foot diameter high-velocity steel radiation flues to a bank of three cyclones and into the Cottrell precipitators.

The cyclones take out the coarse particulate matter, while the precipitators remove 97% of the remaining particulate matter. Dust collected by these precipitators goes to a pug mill where it is mixed with water to reduce dust loss prior to off plant shipment for recovery of metal values.

The clean SO_2 gas stream from the hot Cottrell is cooled and washed in five scrubbing towers. The washed gas passes through a bank of four parallel wet mist electrostatic precipitators which remove the final traces of dust and SO_3 mist.

The gas cleaning facility employs a unique gas scrubbing and cooling system that recovers the traces of sulfur trioxide in the gas stream and concentrates the weak acid solution to a marketable product. In standard practice, the recirculated scrubber effluent would be wasted; however, at Hayden such a procedure would pollute the groundwater and therefore a new technique was developed to recover the water, the acid content, and the solid sludge.

The wet, clean SO_2 gas stream is now prepared to enter the 750/1000 ton per day sulfuric acid plant. In the first step the gas stream is dried in a packed tower flushed with 93% sulfuric acid. The purpose of this unit is to remove water vapor from the gas stream before it passes into the steel heat exchanger and converter system.

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The gas is pulled from the drying tower and pushed through the remainder of the acid plant system by two large centrifugal blowers, each driven by a 2500 horsepower electric motor.

By this time the gas has been cooled down to about 120 degrees F. and must be heated to 825 degrees F. for the catalytic reaction to take place. This is accomplished in the heat exchanger system and the heated gas goes to the acid plant converter. The converter contains several layers of pelletized vanadium pentoxide catalyst. The heated SO_2 gas stream in the presence of the catalyst and excess oxygen is converted to sulfur trioxide, SO_3.

The chemical reaction in the catalyst mass generates heat, which is used by the tubular heat exchangers to preheat the cool gas stream from the blower. Several stages of catalytic reaction are employed to gain maximum conversion and gas passes through two cold heat exchangers which cool it to the proper temperature for admission to the absorption system.

In the absorbing tower -- identical to the drying tower -- the gas is scrubbed with 98-99% acid and the sulfur trioxide is absorbed in the solution making sulfuric acid. The acid is then pumped to four 6000 ton storage tanks where it is held for shipment by railroad tank car and tank truck to consumers in Arizona.

FUTURE EFFORTS FOR REMOVAL OF SULFUR DIOXIDE

Much work is yet to be done before total or near total elimination of SO_2 from smelter gases can be realized. The remaining 50% of the SO_2 from the Hayden plant is present in dilute form in gases from the hearth-roasting and reverberatory furnace operations and cannot readily be used for sulfuric acid production. Asarco, together with governmental and industrial research groups, is continuing to study new systems for dealing with SO_2 in dilute streams, but presently no feasible method is at hand.

Another problem of removing SO_2 from smelter gases is the safe disposal of the sulfuric acid. It is not economically or technically feasible to store the large amounts of sulfuric acid which will be produced by this plant. Nor is it feasible to ship the acid over long distances. The acid must be consumer as produced or a more severe pollution problem will result. One use is the treatment of oxide copper ores from Arizona by means of sulfuric acid leaching.

The problem of disposal of sulfur by-products can be greatly assisted if a feasible system can be devised to produce elemental sulfur from smelter gas. Asarco has directed extensive research efforts toward developing a method for reducing SO_2 stack gases to elemental sulfur. The next major step is a pilot plant evaluation in which Asarco and Phelps Dodge have joined forces to build and test such a plant.

ECONOMIC IMPORTANCE OF HAYDEN SMELTER

Ever since its introduction to Arizona, the Hayden smelter has meant jobs, money for products and equipment as well as taxes contributed to the state.

The smelter employs a total of approximately 500, with annual payroll and fringe benefits of approximately $5,300,000. (1971)

Other expenditures in 1971 included:

1 - Purchasing - State of Arizona - approximately $2,000,000.00

2 - Electicity - approximately $150,000.00

3 - Fuel - approximately $1,100,000.00

4 - Total taxes approximately $680,000.00

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A Background Report

SULFUR DIOXIDE AND ITS CONTROL

At the hearings before the Arizona State Board of Health on December 30, 1971, Kenneth W. Nelson, Director of Environmental Sciences of American Smelting and Refining Company (Asarco), presented to the Board testimony with particular reference to the 90% sulfur removal requirement which was before the Board on a petition filed by Asarco and others seeking review of the standard. The following statement is from that testimony.

Because sulfur dioxide is a product of the burning of coal and oil, it is one of the air contaminants that has created a condition of air pollution in certain cities of the world for hundreds of years. Literally dozens of other air contaminants, including soot, coal tar droplets, carbon monoxide, nitrogen oxides, phenols, cresols, etc., contributed also to such pollution.

The sulfur dioxide content of air is easy to measure, even in concentrations of fractions of one part per million. So it was, when air pollution and its relationship to health began to be studied, that sulfur dioxide was one of the air contaminants, even the only contaminant in many instances, that was measured.

There have been hundreds of studies of health and air pollution relationships, yet none has proved that sulfur dioxide caused or contributed to any health effects found. Particularly, there is no published evidence of adverse health effects from SO_2 in western smelter communities. Nevertheless, in our efforts to improve air quality in all inhabited areas we cannot omit sulfur dioxide as one contaminant to be limited in the ambient atmosphere.

During 1969 and 1970 - before the setting of national ambient

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standards by the Environmental Protection Agency - a number of states and regions set extraordinarily strict standards for sulfur dioxide in ambient air. Even though these standards were often adopted at the urging of NAPCA, EPA's predecessor in the air control field, they were not based on any sound evidence - but simply upon a desire for cleaner air. Many of these standards are not being met and may never be met, simply because sufficient low sulfur fuels may not be available and technology may not be perfected to remove low concentrations of SO_2 from power plant and industrial effluents.

As a result, at least in part, of the confusion over standard-setting, Congress directed that national ambient air standards be adopted for certain pollutants. Sulfur dioxide standards have been duly promulgated after consideration of all available scientific evidence. Because these standards are less severe, they have been met with hostility by some who earlier promoted adoption of the more extreme standards. Nevertheless, the newer evidence supports the adequacy of these new standards to protect the health of even the most sensitive members of our population.

The matter of sulfur dioxide in Arizona air has been an especially sensitive issue because copper smelters emit large quantities of sulfur dioxide as an inevitable by-product of the smelting process. Smelters also emit particulate matter which is highly visible and which remains suspended in the atmosphere for a considerable time and can be transported for long distances. Asarco believes these visible emissions are largely responsible for the adverse opinion many of the public have with regard to the smelters. Sulfur dioxide is actually invisible and, according to extensive studies we have made over the past several years, it contributes little or not at all

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to the atmospheric haze which people associate with smelters. Yet, strong public opinion and, we believe, misunderstanding have contributed to the adoption in Arizona of highly restrictive SO_2 emission standards for copper smelters and restrictive ambient air standards.

The requirement that sulfur emissions from smelters be limited to 10% of the input sulfur is not believed by Asarco to be a fair or necessary standard for several reasons:

1. There is no evidence that such a continuing percentage of control is required to meet ambient air standards adequate to protect health and welfare.

2. The 90% abatement requirement for all copper smelters does not consider the differing topographical and meteorological situations of the various units.

3. No practicable technology has been developed to handle the problem of gas streams, common to all existing U. S. smelters, containing low sulfur dioxide concentrations.

4. No workable alternatives are permitted which would allow smelters to meet ambient air standards by intermittent curtailment of operations in accordance with atmospheric conditions or by other means.

Ambient air standards are the ultimate criteria of air quality; it is that goal, air quality, to which Asarco is committed. The Company is convinced it can achieve good ambient air quality at all of its copper smelters, including Hayden, and at the same time nearly eliminate visible emissions, so that the esthetic desires of Arizona residents can also be accommodated. With the new Hayden acid plant in operation and with other means available to us we are confident we can meet primary air quality standards for sulfur dioxide well within the time limit imposed by the Clean Air Act of 1970.

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Technical Background

HOW THE HAYDEN SULFURIC ACID PLANT WORKS

Asarco's new 1,000-ton-per-day sulfuric acid plant at Hayden, Arizona uses one of the world's most advanced process technologies for continuous conversion of smelter sulfur dioxide gases into sulfuric acid. It embodies a number of technical innovations, including a water recirculation system that minimizes the potential of pollution of the area ground water by acid wasts and an extremely efficient heat exchange system.

Asarco personnel visited smelters and acid plants in the United States, Europe, Japan and elsewhere to evaluate the latest technology. Design of the plant was awarded to Chemiebau-Dr. A. Zieren, GMBH & Company of Cologne, West Germany; The Rust Engineering Company was named prime contractor. (Rust, a division of Litton Industries, is the Chemiebau-Zieren licensee in the United States.)

The Asarco plant is the first in the United States to employ the Chemiebau-Zieren process. A major factor in the choice of this process was that it has proven itself trouble-

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free under continuous operation in several similar large European non-ferrous smelter installations.

Designed for conversion of low concentration gases (the design is based on gas with only 4.12-6.5% sulfur dioxide content), it handles a far greater gas through-put than a conventional sulfuric acid plant, which usually requires a high concentration gas produced by the direct burning of sulfur.

Other features of the plant:

- o It is equipped with one of the most advanced water recirculation and recovery systems ever put into a metallurgical sulfuric acid plant in the U. S. so that it contributes virtually no acid wastes to the area's ground water.
- o It is one of the largest single installations using the Du Pont Teflon tube heat exchanger (83 Model 3100 units) for cooling circulating acid.
- o It employs two of the largest-volume blowers yet put into an acid plant. These 2,500-hp units are used to convey scrubbed and dried converter gases to acid-making areas of the plant.

The process starts at the Hayden smelter's five converters. This is the final stage of production of blister copper, where sulfur and other impurities are removed from the molten, semi-refined ore (copper matte). The sulfur is converted into SO_2 through oxidation.

Leaving each converter, the gas is cooled in a water-cooled hood section which dissipates approximately 13 million BTU per hour. The gas then passes into a cast steel dust hopper of waffle construction and drops out a copper-rich dust that is collected by chain conveyor for return to the smelter.

Flues five feet in diameter lead out of the converters to the acid plant; the flues vary in length from 340 to 470 feet. The gas flows from these flues into cyclone banks, centrifugal collectors that 'scalp' the remaining coarse copper dust from the gas stream. This dust also is returned to the smelter circuit.

From the cyclone banks, the gases from the converters discharge into a common header for four three-stage Chemiebau hot-gas electrostatic precipitators. These precipitators, which remove particulate matter, are designed to recover 97% of the particulates remaining. This dust is collected and shipped to the Asarco plant in El Paso, Texas for further processing.

The clean gas, still relatively hot, then passes through a 'weak acid' tower where the minor amounts of SO_3 that are formed in the converters are made into a weak sulfuric acid (up to 50% acid). The remaining gas, mostly SO_2, is then cooled and washed in another series of towers. A final purification step (four parallel two-stage Chemiebau wet-gas electrostatic mist precipitators) takes out the remaining dust and particulates. The acidic scrubber water, plus the weak acid, is not wasted or permitted to contaminate ground water; it is used later to make a saleable 75% acid.

The moisture-laden SO_2 gas is dried in a tower, irrigated with 94% sulfuric acid, and sent by two 2,500-hp single-stage centrifugal blowers into the contact plant.

The gas must then go through a series of heat exchangers to raise the temperature to at least 450^{o} centigrade (842^{o}F). At this temperature, the SO_2 reacts with oxygen in the presence of vanadium pentoxide catalyst (V_2O_5) to form SO_3.

The SO_3 is then sent back through the same series of heat exchangers to cool the gas to an absorbing temperature of approximately 190^{o} centigrade (380^{o}F). The cooled, converted SO_3 is recovered in the circulating 98% sulfuric acid in the absorbing tower. A cross flow of weakened acid from the drying tower and enriched acid from the absorbing tower are interchanged to produce the final 94% and 98% sulfuric acid. A portion of the 94% acid is mixed with the 50% acid formed in the earlier stages of the operation (in the scrubbers) to produce 75% acid.

The Hayden sulfuric acid plant presently is charged with 126,000 liters of catalyst for the operating rate of 1,000 tons of acid per day at 5.5% SO_2 inlet gas. With a catalyst loading of 249,000 liters, the capacity can be increased to 1,200 tons per day at 6.5% SO_2 inlet gas.

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A Background Report

SOME ECONOMIC ASPECTS OF SO_2 CONTROL

(At hearings before the Arizona State Board of Health on December 30, 1971, Lee C. Travis, General Manager-Western Department of American Smelting and Refining Company (Asarco), presented testimony with particular reference to the 90% sulfur removal requirement which was before the Board on a petition filed by Asarco and others seeking review of the standard. The following statement is from that testimony.)

Asarco recognizes that substantial resources must be committed to improve the ambient air in the area surrounding our smelters. It also recognizes that the Company's future depends on responding to the public concern over the environment in a responsible way.

At the same time, there are technical and economic limitations within which we must operate and which we must assess accurately. Therefore, we are vitally concerned with the degree of control that may be imposed on the copper smelters, the establishment of a reasonable time frame in which to achieve this control, an honest appraisal of the technology needed to accomplish the desired goal and a recognition of the economic consequences involved.

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In Arizona, Asarco operates a copper smelter at Hayden and two copper mines in the Tucson area. In addition to these existing mines, Asarco is now seeking to develop other mining properties in the Tucson area and elsewhere in the State. The Company employes 1,537 Arizonans and contributes directly some $40 million yearly to Arizona's economy.

Briefly stated, Asarco's position, as detailed to the Arizona Board of Health, is as follows:

The ambient air standards for sulfur dioxide adopted by the Board in January 1970 are unnecessarily severe. These standards are not supported by scientific evidence and would impose enormous costs on Arizona industry without any commensurate benefit to anyone. We have urged the Board to modify these standards to conform with the recently promulgated national ambient standards.

The 90% sulfur removal requirement applicable to copper smelters adopted by the Board on May 25, 1970 also was an arbitrary requirement unrelated to the type or degree of emission control needed to provide desired air quality in Arizona. This standard was adopted at the urging of representatives of NAPCA (EPA's predecessor in the air pollution control field) whose position was simply that all of American industry should be required to employ maximum control measures without regard for costs or the socio-economic impact of doing so.

For Asarco even to attempt compliance with the 90% emission standard at Hayden would appear to require not only the complete replacement of a large part of the present production facilities of the plant, but also the development of a viable process for converting the SO_2 gases into a product other than sulfuric acid -- a product which would be disposable and which itself would not create new environmental problems.

In an effort to develop a control system that will produce such a disposable product, Asarco and Phelps Dodge Corporation are now operating an experimental plant at El Paso, Texas to produce elemental sulfur from smelter gas. Assuming this pilot plant, now in its initial stages of operation, proves technically and economically successful and becomes available for use at Hayden, the capital investment required to attempt compliance with the present 90% standard would be between $52 and $65 million. This is in addition to the $17.3 million already spent to build the sulfuric acid plant that has just gone into production to treat the Hayden converter gases.

The cost estimates developed by Asarco for sulfur emission control at its various plants were reviewed by the Bureau of Mines at the time the Bureau was preparing its Information Circular No. 8527, "Control of Sulphur Dioxide Emissions in Copper, Lead and Zinc Smelting". We believe

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these estimates to be conservative. Our experience with the just-completed sulfuric acid plan at Hayden demonstrates that actual costs are likely to exceed by a substantial margin even the most careful estimates prepared in the last few years.

On the basis of its review of the data provided by Asarco and by others in the industry, the Bureau of Mines circular indicates a cost increase in the neighborhood of four cents per pound of copper would be involved in the industry now attempting to meet the 90% emission standard.

What does such a cost increase mean to a company like Asarco, primarily a custom smelter processing a basic metal the price of which is largely determined in world markets? A pound of copper can be transported half way around the world for about two cents. This means that substantially increased smelting costs cannot simply be passed on to the consumer in the form of arbitrarily increased prices. Costs can only be passed back to the mine and this means that Asarco can tolerate increasing costs only to the point that the independent mines that it serves are willing and able to bear those costs.

Such costs ultimately would have to be borne not only by Asarco's Mission and Silver Bell mines but other mines shipping to the Asarco smelters, such as Anaconda's Twin Buttes mine; Duval's Esperanza, Mineral Park, and

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Sierrita mines; the mines of Bagdad Copper Corporation; Cyprus Mines Corporation (Bruce Mine Division); El Paso Natural Gas Company; and others in the Southwest.

Because the price of copper is determined by worldwide supply and demand, as the cost of producing Arizona copper increases, the reserves of Arizona ore that can be economically recovered diminish. This is of great concern to Asarco which depends primarily on custom ore to keep its smelters operating and whose shippers include those mines that are least able to tolerate substantial increases in smelting and refining charges.

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MINE ENGINEERING METHODS AT ASARCO'S MISSION MINE

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MINE ENGINEERING METHODS AT ASARCO'S MISSION MINE

INTRODUCTION

This paper describes the nature of engineering and geologic services for the production stage and a review of pit design factors peculiar to the development period. The Mission pit has passed into the mining phase where development is of secondary importance; however, until the pit reaches its final size, development will be a continuing function occurring simultaneously with mining operations.

PRELIMINARY DEVELOPMENT

Exploration of the Mission tract began in September 1954 with property acquisition, geophysical prospecting, and randon scout-drilling on a gravel covered pediment north and east of the Pima pit and Daisy mine. A mineralized zone was found to lie under 200 feet of loosely consolidated gravels and wash.

Scout drilling by coring samples from bedrock proved to be a rapid and successful method for obtaining geologic information of the underlying rock. Forty-two holes aggregating 10,900 feet were drilled during this initial phase.

A systematic program of development followed in which the drilling sites were laid out on a rectangular grid with hole spacings on 300-foot north-south intervals and 250-foot east-west intervals. Along a few of the north-south grid lines, additional holes were drilled in the eastern and central areas of the deposit by interspacing holes at 150-foot intervals.

All drilling totaled 138,000 feet in 239 holes of which 85,600 feet were core drilled, 46,900 feet were rotary drilled, and 5,500 feet were churn drilled.

In early 1958 underground development was started from a 375-foot vertical shaft sunk in the eastern area of the deposit to provide material representative of the early mining period. From 1895-feet of level development, bulk metallurgical samples were obtained for pilot plant testing. This work provided more information on copper distribution and, to a minor extent, for studying the occurrence of ore in place.

GEOLOGY

At the base of the alluvial cover, a tightly cemented caliche conglomerate forms a thin layer up to 40-feet in thickness immediately over bedrock.

The deposit occurs in an extensive zone of altered sedimentary rocks which have been fractured by three fault systems, flexed or folded, and intruded by monzonite porphyry. The deposit is a low-grade copper sulfide ore body within a broad zone of pervasive hydrothermal alteration in sedimentary rocks converted to tactite, hornfels, and argillite. Ore minerals essentially are calcopyrite with a minor amount of bornite and small amounts of molybdenite and sphalerite. Pyrite and galena are associated metallic minerals.

Lithology and structure provide a basis for dividing the deposit into three areas: The east area which offers a softer grinding ore of higher than average grade in complex and displaced structures forming sharp ore waste contacts; a central area which is a comparatively thin layer of ore lying at relatively shallow depths above limestone; and a west area where the structure is less complex, copper mineralization is more continuous and lower than average in grade.

PLANNING THE OPERATION

Geological, mining, and metallurgical teams developed criteria for a long-term plan for mining the deposit. Plan-view maps to a scale of 1-inch to 100-feet were made showing the drilling grid, property boundaries, mineral rights, and the location of drill holes. Bench maps were drawn for each 40-foot difference in elevation, and details were plotted on the median line. One set of maps showed a geological compilation of lithologic characteristics and geologic structures. A second set consisted of ore-reserve maps showing an evaluation of the deposit by a geologic-block method where the configurations were delimited by interpretation of the geologic setting. Characteristics compiled included mineral grade, ore type, rock type, alteration, and specific gravity. In addition, both sets showed the geometric shape for the end of each annual planning period over the projected life of the pit.

Also two sets of vertical sections were made to show similar characteristics as compiled for the plans. These sections were made to correspond to the drilling grid.

Topographic maps of the general project area were obtained by photogrammetric methods to a scale of 200-feet to one-inch, with contours at 5-foot intervals.

Dilution, due to the relatively large total area of contacts between ore and waste, was handled by the following system:

A strip 10-feet in thickness on each side of an ore-waste contact was assumed to become mixed during mining which would reduce the recovered grade to the average of the blocks adjacent to the contact. Because the average attitude of the ore-waste contacts is 30 degrees, the 10-foot strips were plotted as 20-foot strips on the bench plans. Both grade and specific gravity of each pair of strips were determined by averaging the opposite ore and waste polygons.

The material in these strips was classified by the following rule: When the average grade was less than 0.4 per cent copper, the strip on the ore polygon side of the contact was classified as dilution ore. The strip on the waste polygon side remained waste. When the average grade was 0.4 per cent and above, the ore polygon remained unchanged and the 20-foot strip was transferred from waste to dilution ore at the grade and specific-gravity values of the waste polygon.

The tonnage requirement to the mill was fixed at 5,400,000 tons a year or 15,000 tons per 24 hours. Other interrelated parameters pertaining to the mine were as follows:

Topography over the pit slopes from 3,300 feet on the west to 3,160 feet on the east perimeter.

Benches in the alluvium were initially 50-feet in height; but soon after stripping was begun, the design was changed to 40-foot heights so the shovels could load more effectively. The height of ore benches remained unchanged at 40-feet. The final slopes of the pit are designed for 37 degrees (1.33 to 1) in gravels and 45-degrees in rock with 30-foot and 25-foot berms, respectively, between benches.

Mission is a good example of a large pit operating on a flat working slope. That this is necessary, is due in part to the elongate dimensions of the pit. Today, the pit is 5,000 feet long, 2,900 feet wide, and 500 feet deep with a planned ultimate depth of over 600 feet. The working faces are advancing westward.

The pit is designed with two permanent roadways, the main haul road is along the south side rising from the lowest bench in a counterclockwise direction on a seven per cent grade. The road crests on the east wall and leads to the crusher and east dump where submarginal-grade rock is piled. The other exit along the north side leads to the north dump or gravel disposal pile. These roadways are 50-feet wide. Temporary ramps are laid out on 10 per cent maximum grade.

During a 24-month period ending July 31, 1961, preliminary to the operating stage, 45,214,900 tons of waste and 1,177,900 tons of ore were handled. Development aimed at two targets: (1) Establish benches of sufficient length to expose one foot of ore face for each 5 tons of daily production. (2) Expose one year's supply of ore in advance of mining.

By the end of 1961, ore was mined at a daily rate of 16,600 tons and 66,400 tons were stripped. Since then ore production has been maintained at rates over 20,000 tons per day and the stripping rate has been increased to 86,000 tons per day. Through December 31, 1964, 24,043,000 tons of ore and 135,729,000 tons of waste were mined and stripped.

ENGINEERING CONTROL

The engineering department, comprising six engineers, two geologists, one draftsman, and six helpers, is responsible for the usual functions. The department maintains a library of original and outsiders' drawings for the superintendent. More than 35 routine miscellaneous reports of technical data and map sets are required by operations. For example, the department is prepared to perform the following engineering and geologic services to mine operations:

1. Pit planning and production scheduling

2. Reserve computations

3. Pit surveying and mapping

4. Geologic mapping

5. Core-drilling

6. Ore-grade control

7. Drafting

8. Tonnage and grade statistical records

No young engineer is expected to perform all of the functions listed, but after a reasonable amount of informal on-the-job training a man is expected to handle any of the engineering duties required.

PIT PLANNING AND PRODUCTION SCHEDULING

The engineering and geology sections are responsible for revising, updating, and predicting forecasts and schedules. Forecasts are made on a monthly, quarterly, annual and long-term basis.

Short-term planning includes grade and tonnage forecasting of pit operations for time intervals up to and including quarterly periods, and are as consistent as possible with longer-term plans except grade is updated from assays received from blast-hole drilling and the geology is better defined as more exposures develop. Short-term forecasts are planned to suit production quotas.

Long-term pit planning is utilized to lay out orderly pit development from the remaining minable reserves and for predicting probably future grinding rates.

The staff maintains the following schedules of ore production and removal of waste materials:

1. Bench maps and plans detailing mining operations one month ahead.

2. Bench maps and plans detailing mining operations one year ahead by quarters which is updated at the end of each quarter.

3. Bench maps and plans predicting operations five years in advance and showing the projected pit boundaries at completion of mining.

4. Bench maps and plans showing actual accomplishment and projecting to the exhaustion of the ore reserves.

All maps and plans undergo constant revision.

ESTIMATION OF ORE RESERVES

The geologic block method of ore evaluation was found to be unwieldy for scheduling purposes because of numerous small blocks subdividing the ore zone and dilution material along ore-waste contacts. Work effort is indicated to some degree by the total number of blocks which must be handled. The geologic-block reserve consisted of more than 3,600 ore and dilution ore blocks and almost 2,000 blocks of material submarginal in grade.

Two more reserves were calculated for the deposit. One calculated by the triangular method was replaced by the polygonal method. The final reserve consisted of 1,000 ore and waste polygons. This decreased the calculation effort to manageable proportions.

TRIANGULATION

Coast and geodetic survey monuments, covering a large area encircling Mission's mineral and surface holdings, form control for a major triangulation network. Markers located near the village of Sahuarita and on Helmet Peak, a prominent hill on the eastern foot of the Sierrita Mountains, were ideally situated to serve as ends for a base line 39,000 feet in length. A network was then expanded over the general project area for mapping by photogrammetric methods.

From the major net, minor nets were established around the proposed perimeter of the pit and within the various plant and dump areas. All subsequent surveys for pit and plant operations originate from these networks which establish coordinates in the Arizona plane coordinate system, Central zone, which is a Transverse Mercator map projection. Surveys of an isolated area usually can be started from a convenient triangulation station.

PIT CONTROL SURVEYING

Engineering control of mining activities necessary to develop the pit according to plan and to maintain ore production near the desired grade and tonnage levels is handled through close cooperation with the pit superintendent.

Bench elevations, development of drop cuts, and ramp grades are watched closely. Trim lines and bench expansion limits especially near the final slopes are carefully controlled with the plane table.

Operating benches are maintained for grade by providing a shop-built level and tripod near each working shovel and placing it so the shovel oiler or Pit Supervisor can, by sighting the cross wire on the shovel tracks, advise the shovel operator about grade.

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PIT MEASUREMENTS

Shot or blast maps made by plane-table surveying provide a means for the engineering department to maintain daily progress maps and to calculate tonnages mined and stripped from the pit. Shop maps also assist the mine operating crews for controlling the grade of production.

The daily routine for mapping the progress on the working benches is done by a field party of two men using a Kern type RK plane table outfit. This outfit consists of a self-reducing alidade and parallel plotter with tripod and 24-by 31-inch plane table board.

The plane table is setup in front of the shot on the elevation of the toe. The plane table is located and the position is plotted by resection methods using the three-point problem. Details are located and plotted by the radiation method on a map scale of 1-inch to 100-feet. Features mapped include the location of the collars of all blast holes drilled in waste rock or ore, and the outline of the crest and toe lines of the bank to be blasted. The elevation of the crest and toe-line points are recorded on the plane table sheet wherever the elevation is typical for obtaining the height of the bench.

After the bank has been blasted and the broken material loaded, the same surveying procedure is repeated for measuring the next blast behind the one previously measured. Two successive measurements of a bank determine the crest and approximate toe lines of a shot before and after blasting. When both surveys are plotted on the plane table sheet an enclosed area is outlined.

Once the shot has been outlined, the surface area is planimetered directly from the plane-table sheet using the crest line. This area multiplied by the average height of the bank produces a volume which is converted to tonnage by a conversion factor appropriate for the class of material.

The factors for computing tons are 17.0-cubic feet per ton for gravels and 11.5-cubic feet for waste rock and ore.

Shots containing ore and rock waste are split from the truck tallies in truck-count tons. The tonnage of waste is found by subtracting the tonnage of ore which has been adjusted by a factor obtained by dividing the actual mined (weighed) tons by the truck-count tons (estimated) for a monthly period.

Uncompleted shots or holdbacks from benches are credited monthly to mined tonnage according to the truck count, and when removed from the pit are measured and a tonnage adjustment made.

GEOLOGIC MAPPING

Maps which present a complete record of geologic features are compiled for each bench. These maps are drawn to a scale of 1-inch to 100-feet on drafting film. Details are mapped at the bench median.

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A daily geologic survey is made in conjunction with the blast-hole sampling program as the contacts of the main rock types are posted on the shot maps to aid the shovel crews for sorting ore.

The geologists periodically scrutinize the pit slopes for potential zones of weakness and to maintain inspections on any sloughing from the walls.

CORE DRILLING

The geology section is in charge of the drilling program started in February, 1962 and continued ever since with two rigs equipped with wire line. Diamond drilling is done on contract, under supervision of the resident geologist and his assistant.

Recent core recovery averaged 92.4 per cent from NX and BX wire line core sizes. The rate of advance per shift worked was 62.4 feet for rotary drilling and 21.2 feet for coring.

The hole spacing in the western half of the ore body was relatively wide and interspaced holes were needed for short-term pit planning. Also, some of this drilling was needed to help in placing permanent haul roads. Areas showing spotty mineralization were drilled to improve the chance for developing ore.

A trained sampler is assigned to collect and care for samples on each of the two shifts worked daily. A detailed report is made on the procedures and techniques practiced by the drillers along with the usual drilling and sampling data.

The core is logged, split, and a specific-gravity determination made on each run. Portions from each run are sent for assay and to storage, or for making sludge boards. All mine samples are assayed for copper by the short iodide method.

ORE-GRADE CONTROL

Although data from the exploratory drilling are sufficient for long-term planning and ore-reserve estimation, assay values from blast-hole samples provide data that enables the operating crew to separate ore from waste during shovel loading. Values from blast-hole samples are also used for short-range forecasts.

A sample is taken with a wedge-shaped pan which is designed to catch a representative section through the conical pile of ejected cuttings. The helper on each rotary drill places the narrow end of the pan near the drill stem so the long axis is parallel to the radius of the drill hole. When the hole is drilled to grade the sample is removed and split in a Jones-type cutter.

The daily mine grade is arrived by applying the average of the blast-hole values of ore to the tonnage loaded from each separate shot comprising a day's shipment. A blast-hole value in 1964 represented about 1,430 tons of rock material. The daily tonnage is ascertained from a haulage report compiled by the mining department by multiplying the number of truckloads by a predetermined normal capacity.

The department provides operations with prints to a scale of 1-inch to 100-feet for each shot or group of holes to be blasted simultaneously. The prints show a small portion of the pit and designate the shot to be blasted. The location and number of each blast hole with its corresponding copper value are given. Other features added after printing are: (1) the blast area is outlined in red. (2) rock type and major structural information contributed by the pit geologist are shown in blue. (3) blast holes are color coded to show grade classifications, and (4) the sample numbers of the holes are tabulated for each shot.

CONCLUSION

Thus, we believe that the application of engineering and geologic techniques is keeping pace with the daily open-pit operations to assist management in controlling operating problems.

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"DRILLING AND BLASTING AT THE MISSION MINE"

by: S. C. FALL
DRILLING AND BLASTING FOREMAN

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May 17, 1965

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DRILLING AND BLASTING AT THE MISSION MINE

The basic aims of the Drilling and Blasting program at the Mission Mine are fourfold:

1. To provide 100,000+ tons per day of broken alluvium and rock material for shovel excavation,

2. To obtain fragmentation that will permit the most efficient digging of the broken material and provide an acceptable crusher feed,

3. To conduct the drilling and blasting program in accordance with approved safety procedures, and

4. To obtain these objectives at the lowest possible cost.

This paper will discuss the practices that have been developed to realize these aims.

The material that is mined from the pit is divided into four different rock types and the overlying alluvium. Each of these materials is broken by using procedures tailored to its individual characteristics.

Although the alluvium overburden can be handled successfully without blasting, it was found that shovel output could be increased by as much as 40 per cent when the gravel and caliche were well broken. The drilling and blasting methods call for drilling 9-inch diameter holes in the alluvium to a depth of 45 feet (5 feet of sub-grade drilling) for a 40-foot bench height. Hole spacing is 30 feet with 24 feet between rows when multiple row shots are drilled. A seven-tenth powder factor (7/10 lb. of explosive per yard of burden) gives good fragmentation.

Underlying the alluvium is a tough, hard-to-break conglomerate formation. This rock has caused the greatest fragmentation problem. The conglomerate is a concrete-like material, overlying the bedrock in this area, with a thickness varying from 20 to 50 feet. It dips gently to the northeast, and this causes it to occur at different elevations throughout the mine. This changing of positions in the mining face requires the changing of techniques. Sometimes the bench grades are raised or lowered to provide an advantageous positioning of the formation. Best fragmentation can be obtained when the conglomerate position occurs in the central portion of the bench face.

Breakage of this formation is almost entirely dependent upon powder distribution. Earlier work had shown that 9-inch holes, closely spaced, with three or four deck loads per hole could adequately fracture a full face of conglomerate. This led to drilling 6-3/4 inch holes on the same spacing (15 feet between holes, 10 feet between rows) with a solid powder column loaded throughout the conglomerate layer.

All holes drilled in this formation are drilled 10 degrees off vertical and the shots consist of only two rows. These techniques minimize backbreak and resulting excessive toe burden.

The other rock formations, ore and waste, are composed of argillite, tactite, and hornfels.

All blast holes in rock formations are 9-inch diameter and 55-feet deep to provide 12 to 14 feet of subgrade breakage for a 40-foot bench. The spacing of the holes is dependent upon rock type and characteristics.

Argillite is a hard, abrasive, highly fractured rock. It is moderate to difficult to drill, but usually breaks easily. This formation is drilled on a 24-foot by 18-foot pattern. In the more highly fractured areas, a powder factor of five-tenths will usually give excellent fragmentation; however, some of the tougher, less fractured argillite requires a much higher powder factor and a reduction in blast hole spacing.

The tactite is of moderate to extreme hardness, usually drills slowly, and has few fractures. Drill hole spacing is reduced to 21 feet between holes and the rows 15 feet apart. A powder factor of 0.9 to 1.0 is used to obtain proper fragmentation. Multiple rows with high deck charges improves breakage in more difficult areas.

Hornfels is a soft, friable, easy to drill rock. It breaks quite easily and is drilled using the 24' x 18' pattern. A powder factor of 0.7 or 0.8 will give proper breakage.

DRILLING - GENERAL

Earliest blast hole drilling at the Mission Mine was with 12-inch diameter bits. As stripping progressed to ore production, it was found that proper fragmentation for crusher feed (-54") was dependent upon a reduction in hole spacing. By changing to 9-inch diameter holes, we obtained better powder distribution and the desired breakage with an increased drilling rate.

Primary blast hole drilling is done by two model 60-R Bucyrus Erie drills and by two model C-850 Reich drills. These drills use rotary, roller cone, hard formation rock bits for the major portion of the drilling. Carbide button bits are used in extremely hard ground. Each machine drills with two joints of integral drill stem 27'6" long with a 5-foot long bar-stabilizer running behind the bit. Seventy-five foot masts allow the drills to drill 55-foot holes in one continuous pass.

One of the Reich drills, currently equipped to drill 6-3/4 inch holes, is used only on the conglomerate benches.

DRILLING STATISTICS

During the year 1964, blast hole drilling at the Mission Mine totaled 1,237,433 feet. The drills were operated a total of 2,404 shifts with an average of 515 feet of hole drilled per shift. The drilling rate was somewhat faster for the 6-3/4 inch holes, averaging 625 feet drilled per shift, and a total of 78,065 feet drilled.

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Approximate penetration rates for the different rock types, using the 60-R drill and 9-inch bits is tabulated:

Alluvium	3.0 to 5.0 feet per minute
Conglomerate	2.5 to 3.5 " " "
Argillite	1.0 to 2.0 " " "
Hornfels	2.5 to 3.0 " " "
Tactite	0.5 to 2.0 " " "

DRILLING PROCEDURES

For average drilling conditions, the 60-R drills and the Reich drills drill 9-inch diameter, vertical holes. The 60-R's use approximately 50,000 to 60,000 pounds of weight on the bit and rotate at 60 to 70 RPM. The Reich drills operate with 45,000 to 50,000 pounds on the bit and 80 RPM. When drilling 6-3/4 inch holes the Reich drills are operated with a pull down of 20,000 to 25,000 pounds and a rotation speed of 80 RPM.

When the penetration rate falls below 1.0 foot per minute, a carbide button bit is used. Down pressure is then reduced to 40,000 pounds on the 9-inch bit and the rotation reduced to 40 RPM.

All of the drills are capable of drilling angle holes, and are, on occasion, used in this manner to correct an excessive toe or to back up the conglomerate drill.

Detergent is added to the drilling water to give better penetration and longer bit life.

Bit life averages 788 feet for the 9-inch steel bits, 1,221 feet for the 9-inch carbide bits and 1,225 feet for the 6-3/4 inch bits. The alluvium is drilled by using worn-out 9-inch bits with one cone removed. This footage is not tabulated for bit life records.

DRILL HOLE SAMPLING

All blast holes drilled in rock benches are sampled to provide mining grade control. As the drill begins a hole, a wedge-shaped sample cutter, or "pie-can", is placed at the collar with the point toward the drill stem. The "pie-can" is oriented along the drill hole radial axis, with the point approximately 6 inches from the drill stem.

When the drill hole reaches a depth of 40 feet, or bench grade, the sampler is pulled from under the drill, and the sample is reduced to 10 pounds in a Jones splitter. It is then placed in a sample sack and left at the drill hole for the field engineers.

This method of sampling has proved to be adequate, giving a 95% accuracy for mine grade control.

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BLASTING - GENERAL

The loading and blasting of primary and secondary holes is done by a crew of 10 men on day shift. Insofar as is possible, all shots are detonated at the 4:00 p.m. shift change. Holes are loaded and shot the same day, thereby avoiding the leaving of explosives in the pit overnight.

EXPLOSIVES USED

The blasting agent, used for all dry primary holes, is prilled fertilizer grade ammonium nitrate mixed with fuel oil. The ammonium nitrate prills are stored in bulk storage bins of 300,000 pound capacity and delivered to the drill holes in a 20,000 pound capacity prill mixing truck. The prills are mixed with the fuel oil as they are dispensed into the drill hole.

The wet holes are blasted by the use of nitro carbo nitrate slurry. This is delivered in 50-pound plastic bags from the explosives company.

Sixty per cent amogel cartridges are used for special applications in primary blasting such as trim-out shots and difficult to fracture rock, and for all secondary work; however, for safety and economy, the use of this more sensitive explosive is kept to a minimum.

The holes loaded with AN/FO are detonated by primacord and 3/4 pound boosters. Three boosters are used in 9-inch holes and four are used in 20-foot or longer powder columns in 6-3/4 inch holes. Slurry-loaded holes are detonated by 3-pound boosters. One booster is used for each two or three bags of slurry. All holes are tied into the shots by using primacord and millisecond delay connectors. The shots are then initiated by the use of a cap and fuse.

Three different millisecond delay connectors are used: 17 millisecond delay between widely spaced holes in the alluvium, 9 millisecond delay between holes in normal rock shots, and 5 millisecond delay between closely spaced holes in the conglomerate.

LOADING PROCEDURES

Dry holes are primed by placing two 3/4-pound boosters on a single line of primacord suspended in the hole. As the prill truck dispenses the AN/FO mixture into the hole, the boosters are suspended about 2 feet off the bottom. When approximately 1/2 of the powder load has been placed in the hole, the third booster is dropped down the prime line. When the proper "cut-off" on stemming depth is reached, a man with a measuring tape, known as "the dunker" gives a signal to the powderman operating the prill truck. The prill flow is stopped and the truck moves to the next hole. Two or three hand shovelers then fill the hole with stemming consisting of drill cuttings from the "ant hill" surrounding the hole. One hundred or more holes can be loaded in a shift quite easily using this method.

When loading wet holes, the slurry is delivered to the drill hole (in bags) by a flat-bed powder truck. To prevent the bags from hanging up in the drill holes, the slurry is removed from the bag and cut up into five or six-pound pieces. One bag of cut up slurry is placed in the drill hole, then a three-pound booster on a single primacord line is placed in the hole. Then two

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more bags of cut slurry are loaded, another booster, etc. until the proper amount of powder is in the hole. The hole is stemmed, tied in, and detonated the same as a prill-loaded hole.

The cartridges of 60 per cent amogel, when used, are detonated by the use of a single 3/4-pound booster on a primacord line.

SECONDARY DRILLING AND BLASTING

All secondary blasting is done by drilling and loading small diameter holes in the boulders and hard toes. A rubber-tired travel drill is used to drill 1-1/2 inch holes in boulders and a crawler-mounted tracdril is used for drilling 3-1/2 inch holes in areas of hard toe and humps in the bench floor. The 1-1/2 inch holes are loaded with 1" x 8" 60 per cent amogel sticks and the larger holes with 2" x 8" sticks. The secondary holes are tied together with primacord and detonated in groups or with the primary shots.

Since secondary blasting is potentially hazardous and very expensive, every effort is made to reduce or eliminate this part of the operation by increased effectiveness in the primary blasting.

The drilling and blasting program conducts an ever-changing search for ways to do its job more effectively, safer and more economically.

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EVIDENCE INDICATING THE HYDROTHERMAL ORIGIN OF A "CONTACT METASOMATIC" MINERAL SUITE, MISSION COPPER DEPOSIT, ARIZONA

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INTRODUCTION

20,000 +

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

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

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

The only previous publication pertaining directly to the geology of the Mission deposit appeared in 1959 (Richard and Courtright), and may not be everywhere readily available. Cooper (1960) has published a short paper on the district.

SUMMARY

In the close vicinity of the Mission ore deposit, the principal rocks are sediments and small bodies of intrusive igneous porphyries, all of which are pre-ore in age. The bedrock surface is a buried pediment, and only a few small outcrops protrude from the alluvial plain. These small and isolated knobs, which are the tops of bedrock hills, lie within a large area of pervasive alteration and constituted one of the principal exploration leads. The very simplified geologic sketch in Figure 1 shows these features.

Alteration --- the formation of new minerals or textures and the destruction of the original rock character --- is pervasive within the Mission ore deposit, and extends a considerable distance beyond the principal area of copper concentration. The limits of the Mission altered zone, although

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gradational and by no means sharply defined, are shown approximately in Figure 1. The altered zone is roughly 3 x 2 miles in areal dimension, whereas ore or possible ore appears to be limited to an area not much larger than 1½ by 1 mile.

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

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

GENERAL GEOLOGY

In brief summary, the geologic history has been as follows. Paleozoic sediments totaling an estimated 5000 feet were deposited on pre-Cambrian granite. These formations are dominantly limestones or marls, with the exception of Cambrian and Permian quartzite layers. A thick sequence (5000' plus) of clastic sediments -- arkose and siltstones -- of Cretaceous (?) age disconformably overlies the Paleozoic rocks. Following or during Laramide folding, thick sequences of unsorted and very poorly bedded silts and volcanic-pebble conglomerates were deposited on an eroded surface of Paleozoic and Cretaceous (?) strata. A second period of major erosion separated these rocks from an overlying formation composed of andesitic breccia and welded rhyolites. Volcanism was followed by the intrusion of a large plug of biotite-bearing rhyolite packed with foreign inclusions. Large granitoid plutons of "Laramide" age form the core of the nearby Sierrita mountains, and are separable into pre- and post- volcanic units. The youngest pre-ore intrusive is a quartz monzonite porphyry which is emplaced, generally, as sills along bedding and structurally weak zones.

Folding and thrust faulting are the dominant pre-ore structures. Major post-ore structural dislocations are also evident.

ROCKS OF THE ALTERED ZONE

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

> <u>Paleozoic</u>: Silicated limestones, marble, and altered marl, silt, and quartzite are the dominant host rocks for copper sulphide ore. These rocks most probably represent the Pennsylvanian and Permian section.
>
> <u>Cretaceous</u> (?): Interbedded arkose and siltstone crop out in two isolated hills south of the Mission pit, and most likely are of Cretaceous age.
>
> <u>Tertiary</u>: Two units which consist of unsorted silt and volcanic-pebble conglomerate are present within the Mission ore body. These rocks are dense and flint-like in character, and are referred to as argillite or conglomerate for purposes of mine mapping. The oldest, the Papago formation, consists dominantly of argillite, while the younger Kino formation, which consists dominantly of conglomerate, lies beneath a pre-ore thrust fault. Both are assigned tentatively to the early Tertiary on the basis of district and regional geologic mapping.

The youngest pre-ore igneous rock within the altered zone is a quartz monzonite porphyry of Stringham's (1960, p. 1623) "aphanitic porphyry" class -- a type almost universally present in prophyry copper districts. This rock may originally have more closely approximated a dacite porphyry, for its present mineral composition includes much introduced orthoclase.

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

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

Narrow dikes of post-ore andesite are present.

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

<u>ALTERATION</u>

Pervasive alteration may be here grouped broadly in two categories. The first, causing the most obvious changes in the rock bulk, involves the formation

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of new silicate minerals -- either lime or potassium types depending on the host. The second is the formation of copper and iron sulphides. An exception is the large area of marble in the Mission pit area, in which the only evidence of alteration is the coarse grain size of the calcite crystals, representing recrystallization with traces of sulphide impregnation. The general distribution of alteration in the pit vicinity is diagrammatically shown in Figure 2, which also shows the principal structural features.

Feldspathic Rocks;

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

The monzonite porphyry consists of euhedral to subhedral phenocrysts of plagioclase and resorbed quartz phenocrysts, set in a recrystallized matrix of fine-grained quartz-feldspar. Ragged wisps of biotite are usually present. The rock is flooded by irregular blebs and replacement veinlets of pink orthoclase and quartz. The plagioclase phenocrysts are replaced by sericite in' variable degrees, and to a lesser extent by clay minerals. The metasomatic intergrowths of quartz and orthoclase replace both the matrix and plagioclase phenocrysts. Pyrite, chalcopyrite, and rarely molybdenite occur as discrete grains scattered through the rock, and also in veinlets associated with borders of quartz and/or orthoclase. The tenor of copper is typical of chalcopyrite protore in many porphyry copper mines. There is only a few feet of chalcocite enrichment beneath a thin-leached zone.

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

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

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

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

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and silver are there widespread.

Limy Rocks:

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

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

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

In the western portion of the ore body a characteristic feature of the hornfels is the presence of small veinlets of blue-green actinolite, 1/16 to 1 inch in width, most commonly, but not everywhere, having a medially disposed stringer of pyrite and chalcopyrite. The actinolite is commonly altered slightly to chlorite. Sulphides are distributed in the hornfels in the same manner as in tactite.

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

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Sulphide Impregnation:

A discussion of hypogene sulphide mineralization is included here under the general heading of alteration, because it is from an economic viewpoint the most important change, or alteration, of the host rocks.

Figure 3 shows the distribution of copper grading plus 0.4%, as a diagrammatic illustration of copper-grade variation. When viewing the figure, bear in mind that the white areas (with the exception of marble units) may contain about as much total sulphide as do the shaded (plus 0.4% Cu) areas and only slightly less copper. The reduction in copper content, in some cases, represents a slight decrease in the total sulphide content, but more generally it reflects an increase in the pyrite:chalcopyrite ratio, or a combination of both.

Total sulphide content obtained by calculations based on chemical analysis of composite samples of drill core is shown in Figure 4. It will be noted that: (1) the total sulphide content is higher in the east part of the pit area. (2) In any one sample location, the total sulphide content is about the same in the argillite of the Papago formation, as in the tactite and hornfels zones below. The volumetric percentage is given (Figure 4) because the difference in specific gravity between tactite and argillite introduces an error when comparing weight percentage to the degree of sulphide replacement. (3) There is no pattern of total sulphide content with respect to the area of porphyry sills.

There is a paucity of published analytical information on the total sulphide content of porphyry copper ore bodies as a group. Spencer (1917, p. 110) reports the sulphide content of three samples from the Ely district, based on chemical analysis, which appears to represent sulphides by weight. Some assumptions and calculations of mine yield the rough figures of 2.8, 4.0, and 4.9 per cent sulphides by volume for the three samples, which is comparable to the sulphide content at Mission (Figure 4).

ORE CONTROLS

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

Referring again to Figures 2 and 3, the unconformable contact between the Papago formation and the underlying silicated sediments of the Paleozoic section has served as a localizing feature. Sulphides follow this contact in greater quantity and more uniformly grade in excess of 0.4% Cu than is the case at distances above or below the contact. Even the quartzite beds are well mineralized where they abut this surface. Similarly, the bottom sides of quartzite beds act as local controls. A high-angle fault is seen to cause even the unfavorable marble unit to become converted to tactite and hornfels and charged with sulphides.

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

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

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

CONCLUSION

The Mission altered zone is a zone of porphyry copper-type pervasive alteration and sulphide dissemination. The proposals presented in preceeding sections of this paper are that sulphide mineralization and alteration were all, broadly speaking, a contemporaneous process. The mineralized monzonite porphyry does not show a spatial relationship to the altered zone as a whole or to the copper ore deposits.

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

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

I suggest that the criteria of geologic temperature indicators involving lime silicate minerals requires reappraisal. The inescapable conclusion at Mission is that either lime silicates form at lower temperatures than commonly believed, or else the temperature range of sericite-pyrite-chalcopyrite must be considerable higher than generally admitted.

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

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

> "The changes in the limestones comprise (1) loss of color and recrystallization to white fine-grained marble; (2) silicification with the formation of jasperoid usually carrying large amounts of pyrite; and (3) the development of silicate minerals, including garnet, tremolite, pyroxene, and scapolite."

> "The alterations of the porphyry . . . comprise, in different stages, the progressive destruction of hornblend, of plagioclase, and of magnetite, and the formation in their stead of .... sericite and a brown variety (of mica) allied to biotite; the deposition of pyrite and chalcopyrite, and of calcite."

> "The distribution of the altered sedimentary rocks is so definitely limited to a zone comprising the medially disposed intrusive masses that no extended argument is required to support the conclusion that the metamorphism is causally related to these igneous rocks. However, ... the relation is not a direct one as regards the bodies of porphyry which appear at the present surface, for it is held that the alterations were effected by hot solutions expelled from deep-seated masses of igneous material, of which the observed intrusive bodies are off-shoots."

> "Though the different rocks have yielded to chemical reorganization and to metasomatic replacement, each in a manner depending primarily on its original composition, yet the resulting products are all heavily charged with pyrite, and in the main this mineral is accompanied by minor amounts of chalcopyrite."

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

He states, in part:

> "Neither of the alteration stages can be fixed in time. There is no direct evidence to indicate either continuity of deposition or a time break in the depositional process. Certain arguments, however, suggest that a time break, if one existed, was of such short duration as to be insignificant."
>
> "The alteration, therefore, is considered as a continuing process in which the ore-bearing fluids, although changing slightly in their chemical properties, were more influenced by the nature of their environment of deposition than by any gross change in composition."

Titley attributes zoning halos of alteration and sulphides in the Linchburg mine to continuing growth of each alteration halo, away from feeder-veins, with the inner halos expanding and replacing the halo adjacent. Note the similarity to the Sales-Meyer proposals for the formation of sericite-clay "envelopes" at Butte. Titley's careful work indicates another lime-silicate assemblage in which, contrary to common assumptions of early silication followed by fracturing and sulphide replacement, the silication and sulphide formation are contemporaneous, and are all the result of a normal hydrothermal process.

To recapitulate my major conclusions:

1. The monzonite porphyry within the altered area has no specific spatial relationship to either ore or alteration.

2. Alteration and sulphide impregnation were more or less contemporaneous. Alteration, as used here, includes the silication of large masses of limy host rocks.

3. Diffusion was a process of major importance. Major channels for open circulation of hydrothermal fluids were widely spaced.

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

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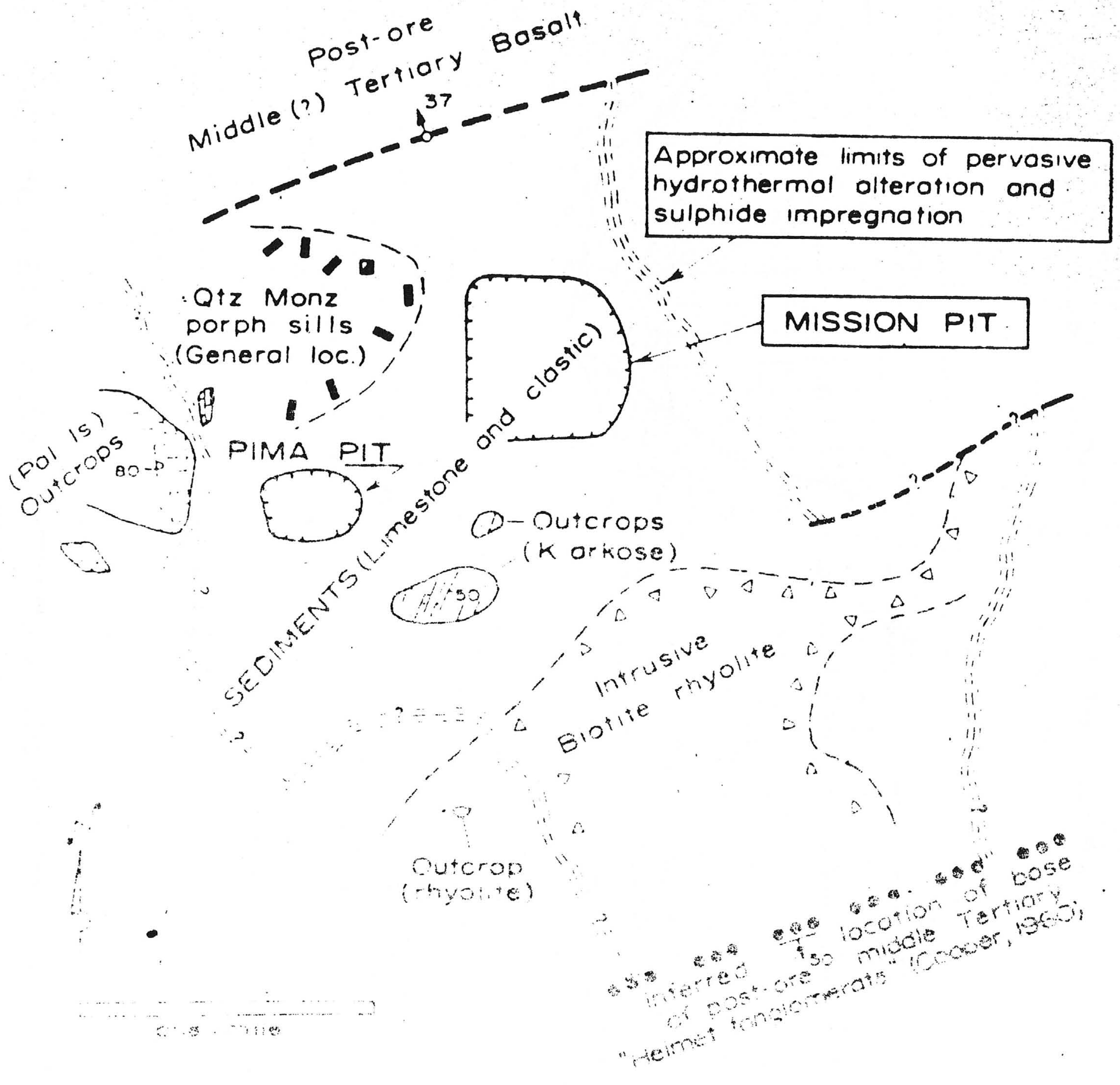

GENERALIZED MAP SHOWING DISTRIBUTION OF SEDIMENTS, IGNEOUS ROCKS AND ALTERATION BENEATH THE ALLUVIAL PLAIN AS KNOWN THROUGH DRILL DATA

Figure 1

J. E. Kinnison

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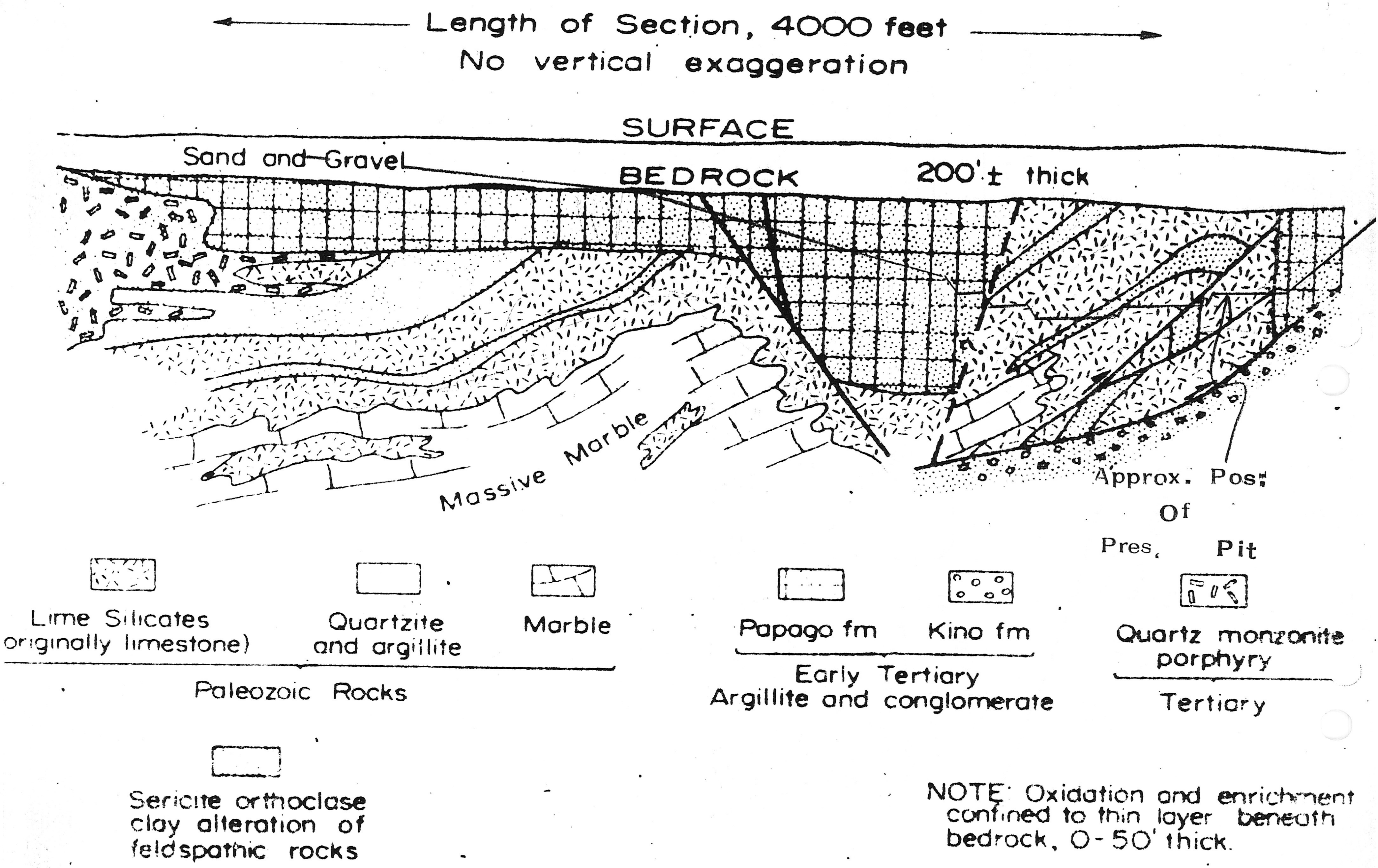
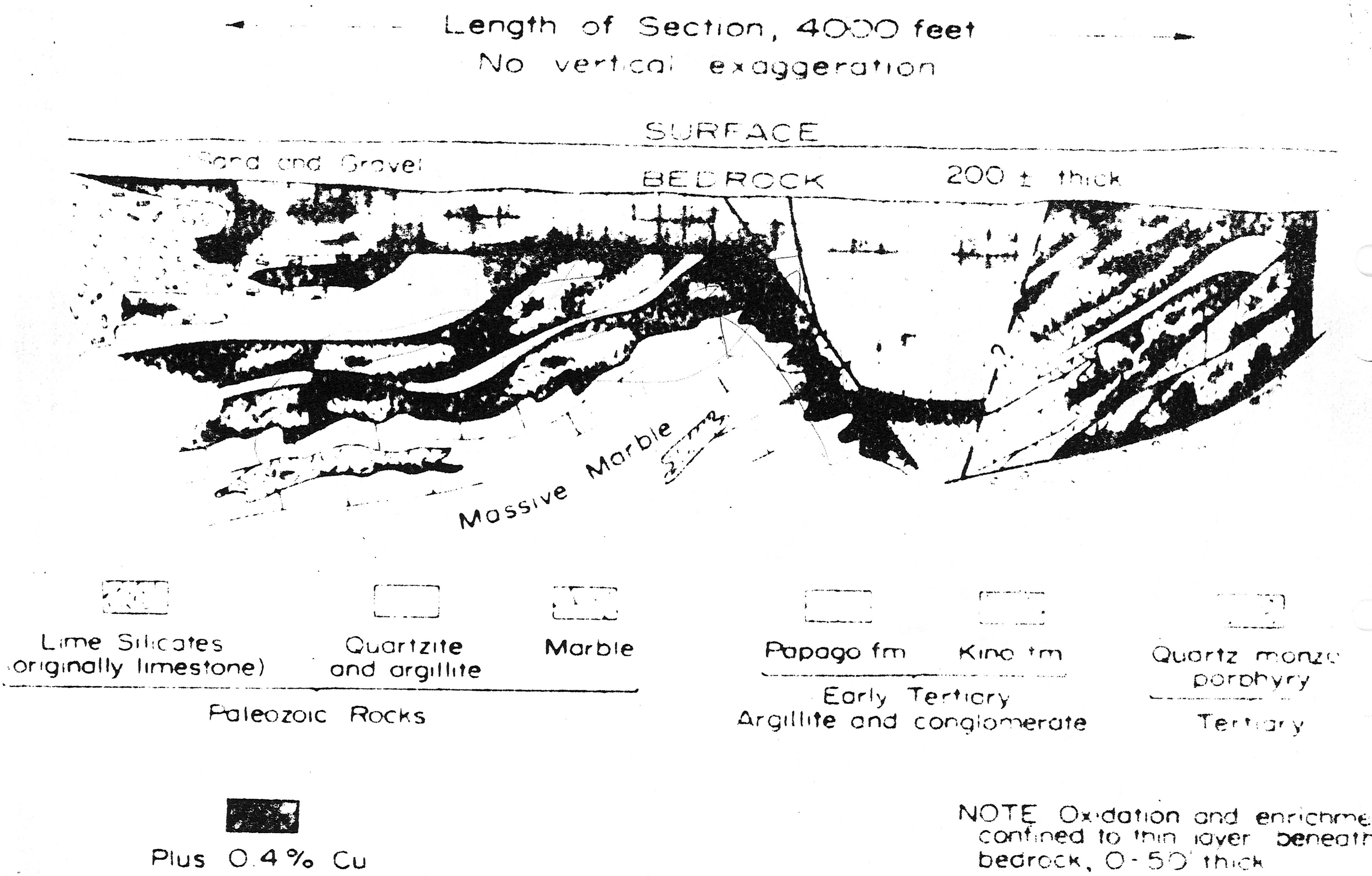


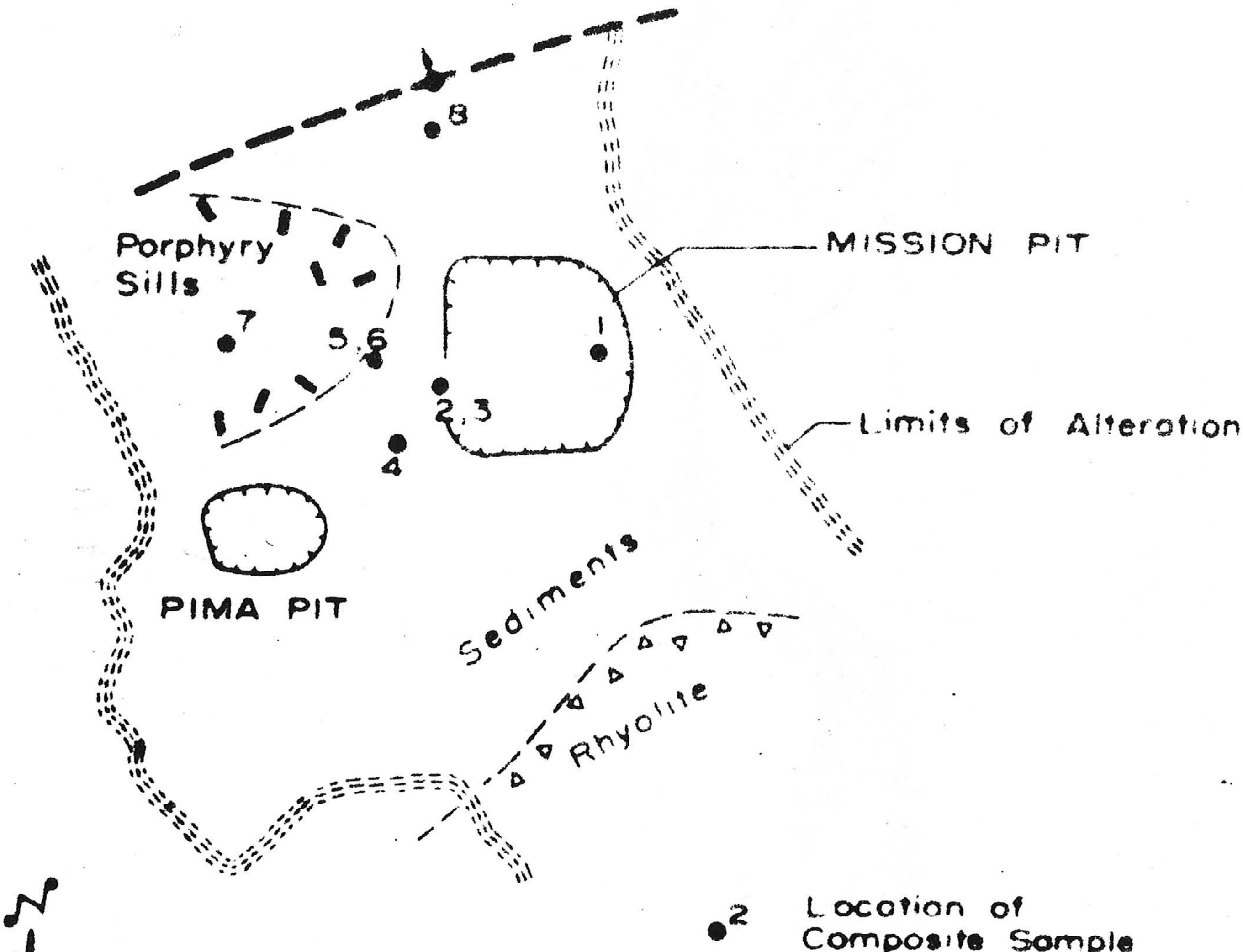
DIAGRAMMATIC CROSS SECTION THROUGH MISSION ORE BODY
LOOKING NORTH

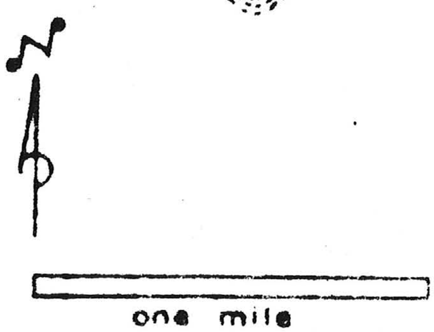


DIAGRAMMATIC CROSS SECTION THROUGH MISSION ORE BODY
LOOKING NORTH

Figure 3

J E Kinnison





No	Rock	% Cu	% Total Sulphide Weight	Volume
1	Tactite	1 55	7 2	4 9
2	Papago fm	82	6 5	3 8
3	Tactite	1 00	6 2	4 5
4	Papago fm	65	4 7	2 8
5	Papago fm	94	4 5	2 7
6	Tactite	87	4 5	3 0
7	Porphyry	30	2 7	5
8	Papago fm	1 20	3 4	1 9

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

TOTAL SULPHIDE CONTENT - MISSION MINE

Figure 4

J. E. K[illegible]son

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