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

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J E Lennon
236-A

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

March 14, 1963

CONFIDENTIAL

Mr. C. P. Pollock, Exploration Manager
American Smelting and Refining Company
120 Broadway
New York 5, New York

PORPHYRY COPPER DEPOSITS - ARIZONA & NEW MEXICO

Dear Sir:

Attached is a memorandum with map by Mr. Courtright in which he lists and comments briefly on the known porphyry deposits in the Southwest and arrives at the gambling odds involved in porphyry copper exploration.

He limited his tabulation to the Southwest because there are enough deposits and ore bodies here to provide a sound statistical base.

He concludes that, given a porphyry copper deposit at least one-half mile in diameter, the odds are about even that the deposit will contain a commercial ore body. These odds are far better than any statistics which could be put together for any of the other base and precious metals, wherein the ratio of known deposits to ore bodies might be derived.

This 50-50 chance, of course, does not include the gambling odds for finding a porphyry prospect. In the Southwest these odds are long because the area has received, and is being given, so much exploration attention. These "prospecting" odds are much more favorable in other countries, particularly Latin America, if political and economical conditions are, for the purpose of these comments, disregarded.

The basic gambling odds of 50-50 can be applied in a general way to these other countries, and to other areas in this country, once a porphyry deposit is found.

Yours very truly,

Kenyon Richard

KENYON RICHARD

KR/kw
Attachment
cc: CPPollock(2 extra)
DJPope
KWhiting
RBSprague
AGBlucher

ALL CONFIDENTIAL, W/ATT.

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona
February 18, 1963

FILE MEMORANDUM

PORPHYRY COPPER DEPOSITS - ARIZONA & NEW MEXICO

A general review of porphyry copper exploration in the Southwest was contained in my memorandum of October 4, 1950. Since that time considerable exploratory work has been carried out by various companies, and several new mines have been put into production. The purpose here is to bring the picture up to date and to re-examine the gambling odds involved in porphyry copper exploration.

In the following tabulation porphyry copper occurrences are divided into 5 different categories: (1) Productive Deposits, (2) Marginal Deposits (undeveloped), (3) Deposits Currently Under Exploration, (4) Prospects which have been Tested and Proven Sub-Marginal, and (5) Untested Prospects.

1) Productive Deposits

Over 100 Million Tons*	Under 100 Million Tons*
Morenci	Bagdad
Santa Rita	Copper Cities
San Manuel	Silver Bell
Miami-Inspiration	Esperanza
Ray	Christmas
Ajo	Mineral Park (under development)
Cananea (Sonora, Mex.)	Castle Dome (mined out)
Bisbee	
Mission-Pima	

* Production plus potential

2) Marginal Deposits (Undeveloped)

Tyrone..... Reportedly plus 400 million tons @ .70% Cu, chiefly chalcocite. Owned by Phelps Dodge.

Lone Star..... Reportedly 800 million tons @ .55% Cu, mixed sulphides and oxides. Kennecott.

San Juan..... "Large ore body too deep for open pit mining." Owned by Phelps Dodge.

Helvetia..... 14 million tons .80% Cu. Mixed sulphides and oxides. Controlled by Banner.

3) Deposits Currently under Exploration

Sacaton	Asarco
McGee (NW of Esperanza)	Bear Creek
Saginaw Hill (So. Tucson Mtns.)	Anaconda
Red Mt. (Patagonia)	Kerr-McGee
Twin Buttes	Banner
Four Metals	Noranda
Johnson Camp	Cyprus
Chilito	Bear Creek

4) Sub-Marginal Deposits
Proven either too small or too low grade

	Drilled By
Kelvin	Con Coppermines
Copper Creek	Bear Creek & others
Sunnyside	ASARCO
Turquoise	ASARCO, Bear Creek
Red Hills (Texas)	ASARCO, Bear Creek(?)
Poston Butte	ASARCO
Lake Shore	USBM, Shattuck-Denn & Trans Arizona
Pioneer Group	Duval Sulphur & others
Blackwater	Magma Copper
Cerrillos	Bear Creek
Hiltscher	Bear Creek
Steeple Rock	Bear Creek
Madera	Miami Copper
Cactus	Miami Copper
Three R	Con Coppermines (property recently acquired by Anaconda)
Copper Basin	Phelps Dodge

5) Porphyry Copper Prospects - Untested

Rock House (No. of Superior)	Outcrops indicate minor chalcocite enrichment below, but zone too small in size.
Border Pipe (So. of Patagonia)	Mineralized breccia pipe ± 500' in diameter. Outcrops indicate original disseminated pyrite with minor enrichment. Deposit too small to warrant drilling.
Tyndall District (So. Santa Rita Mts.)	Zone of strong quartz-sericite-pyrite alteration several square miles in extent. General character of leached outcrops, plus occasional exposure of sulphides in old adits, indicate little more than traces of either primary or secondary copper.

5) Con't

Tombstone	Zone of alteration one mile or more in diameter lies southwest of this old silver mining district. Outcrops do not appear too promising, but total extent of zone has not been determined. Further reconnaissance planned.
Organ District (Organ Mts.,NM)	Zone of alteration ½ mile wide extends about one mile northwesterly where it passes beneath valley alluvium. Mineralization in exposed portion of zone not sufficiently attractive to warrant exploration. Possibilities under cover highly speculative. A possible application of geophysics was considered at one time; however, the area is now partly within the White Sands Testing Range.

The Productive Deposits listed above (see attached map for location) range in size from 18 million tons (Castle Dome) to a plus one billion tons (Morenci), if future potential is added to past production. With the exception of Castle Dome, which is mined out, nearly all of the mines listed here have a future life of at least 10 years, and at least 50% of them a future life of over 20 years.

Tyrone is included in the group of marginal deposits; however, under different ownership this deposit would likely be in production. Phelps Dodge spent several years in drilling and evaluating and then placed it on the shelf --- presumably because they possess ample resources of lower cost copper elsewhere. Tyrone, with a relatively large tonnage and a grade of .70% copper, would be at least equally profitable, if not more so, than either of Duval Sulphur's two deposits, Esperanza and Mineral Park.

Among the Deposits Currently under Exploration, Saginaw Hill and the Four Metals are noteworthy simply because both are relatively small deposits which have undergone repeated unsuccessful exploration attempts by various companies in the past. Anaconda is now drilling a 3000' hole on Saginaw Hill and Noranda is preparing to drill the Four Metals.

Reportedly Bear Creek ("McGee" Prospect) has been finding .4 to .5% primary copper in diorite and andesite in ground adjacent to the Experanza.

Red Mt., Patagonia, lies within a large alteration zone which includes the Sunnyside breccia pipe (drilled by Asarco in 1950). Kerr-McGee recently completed driving an incline on the east side, encountering low grade (± .05% Cu) primary mineralization. Reportedly, they plan drilling higher on the mountain.

Chilito produced 91,000 tons of 1.4% Cu. This ore, which consisted of disseminated copper in quartzite, was shipped to Hayden as siliceous flux. Kennecott acquired the property last year.

Banner recently drilled several holes in a gravel covered area southeast of

Twin Buttes. This is the area generally considered to be the probable location of the "roots" of the Mission-Pima zone of mineralization. According to a local contractor, Banner recently cancelled plans for an additional 90,000 feet of diamond drilling at Twin Buttes. The area may still hold exploration possibilities.

Most of the copper ore mined at Johnson Camp came from more or less massive sulphide lenses in the Cambrian Abrigo formation. Disseminated copper occurs, however, in the Cambrian quartzite and in the lowermost part of the overlying limy shale of the Abrigo. During the past few years, 150,000 tons or more of oxidized copper-bearing rock has been mined open pit and shipped to the Douglas, El Paso and Hayden smelters for siliceous flux; and recently, Cyprus completed a series of drill holes in this disseminated copper horizon, reportedly indicating a zone 150' thick and 2000' long of .75% Cu. No intrusive rocks of the porphyry copper type have been found in the area; however, the deposit resembles a porphyry type occurrence in other respects, and an intrusive center of relatively strong alteration-mineralization could exist under the alluvial covered valley east of the mine.

Brief comments on the Untested Porphyry Copper Prospects are included in the foregoing list.

Referring to the attached map, it is to be noted that with the exception of Christmas, mines developed within the past 12 years --- Mineral Park, Mission, Pima, and Esperanza --- all fall within a northwest-trending belt which includes Bagdad, Sacaton, Silver Bell and Cananea. In his report on the discovery of the Sacaton Prospect (Feb. 13, 1961), Mr. Kinnison referred to the aforementioned belt as the Silver Bell zone, and pointed out that the Sacaton area was situated at the intersection of this zone and two cross-trending zones which he labeled "Miami" and "Poston Butte". Since that time, drilling at Sacaton has demonstrated the existence of a major-sized porphyry copper deposit, the full extent of which has yet to be determined. This, and other new discoveries, tend to emphasize certain trends along which the exploration chances may be better; but we must still depend on finding a lead, such as an altered outcrop with evidence of leached sulphide mineralization, or altered boulders derived from a now-buried outcrop, wherever it be located --- on trend, or off.

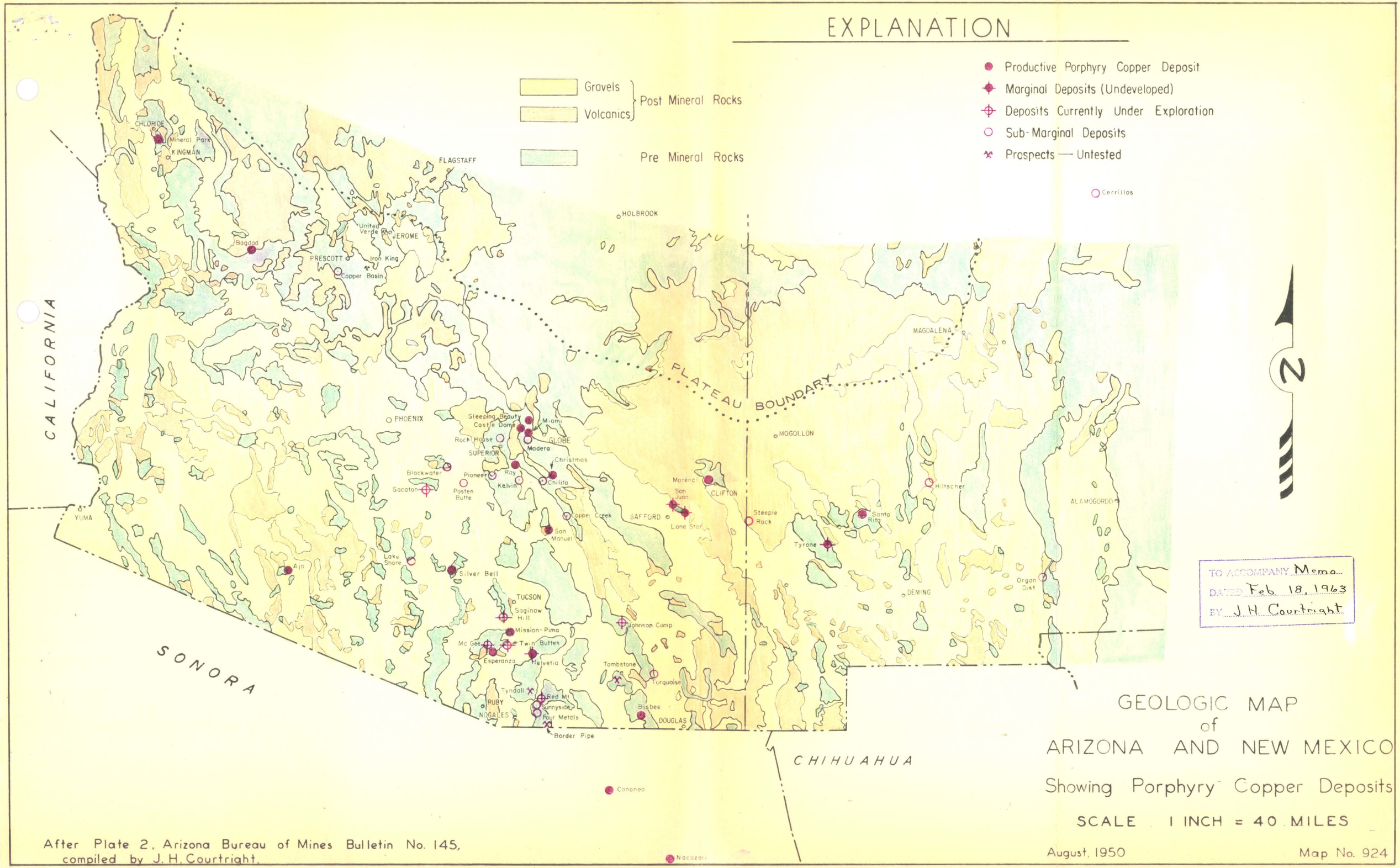
In 1950 (above mentioned memo of Oct. 4, 1950) there were 12 "commercial" deposits (excluding Tyrone and Pilares) and 10 deposits regarded as either "non-commercial" or as "prospects" with unknown potential. The ratio has changed some in the past 12 years, but the odds still appear very favorable. Today there are 17 "commercial" deposits (including Tyrone), 3 marginal, 16 sub-marginal, 8 currently under exploration and 5 untested. Four of those currently under exploration, Saginaw Hill, Chilito, Red Mt., and Four Metals, should be regarded as sub-marginal on the basis of prior exploration results. Thus, we have a 20-25, or 4-to-5 ratio if the 3 marginal deposits are included with the 17 "commercial" deposits, and all 5 untested deposits are included with the sub-marginal deposits. This ratio has no bearing on the chances of finding a new porphyry copper prospect --- due to the great concentration of exploration personnel in the Southwest for many years, this chance must be regarded as very slim --- but it does suggest that if a new prospect

is found, and the zone of alteration-mineralization demonstrated to be of adequate size (say, a half mile or more in diameter), the odds should be roughly even that the zone will contain a "commercial" ore body.

J. H. Courtright

J. H. COURTRIGHT

JHC/kw
Attachment - Map


EXPLANATION
Gravels
Volcanics
Post Mineral Rocks
Pre Mineral Rocks
Productive Porphyry Copper Deposit
Marginal Deposits (Undeveloped)
Deposits Currently Under Exploration
Sub-Marginal Deposits
Prospects — Untested
Cerrillos
CALIFORNIA
SONORA
CHIHUAHUA
PLATEAU BOUNDARY
CHLORIDE
Mineral Park
KINGMAN
FLAGSTAFF
HOLBROOK
Bagdad
United Verde
JEROME
PRESCOTT
Iron King
Copper Basin
MAGDALENA
PHOENIX
Sleeping Beauty
Castle Dome
Miami
GLOBE
Rock House
SUPERIOR
Madera
MOGOLLON
Christmas
Blackwater
Pioneer
Ray
Kelvin
Chilito
Sacaton
Posten Butte
Morenci
San Juan
CLIFTON
Hiltscher
YUMA
Copper Creek
SAFFORD
Lone Star
Steeple Rock
Santa Rita
ALAMOGORDO
San Manuel
Tyrone
Lake Shore
Ajo
Silver Bell
Organ Dist
DEMING
TUCSON
Saginaw Hill
Johnson Camp
Mission-Pima
Mc Gee
Twin Buttes
Esperanza
Helvetia
Tombstone
Turquoise
Tyndall
Red Mt
RUBY
Sunnyside
NOGALES
Four Metals
Bisbee
DOUGLAS
Border Pipe
Cananea
Nacozari
TO ACCOMPANY Memo
DATED Feb. 18, 1963
BY J. H. Courtright
GEOLOGIC MAP
of
ARIZONA AND NEW MEXICO
Showing Porphyry Copper Deposits
SCALE 1 INCH = 40 MILES
August, 1950
Map No. 924
Revised February, 1963
After Plate 2, Arizona Bureau of Mines Bulletin No. 145,
compiled by J. H. Courtright.

236-D

February 6, 1951

Mr. R. F. Goodwin, Vice-President
American Smelting and Refining Company
120 Broadway, New York 5, New York

PORPHYRY COPPER EXPLORATION

Dear Sir:

Following is the report on porphyry exploration which you asked me to write, when I was recently in New York.

INTRODUCTION

This report does not deal comprehensively with the subject of porphyry copper geology, but it does go into detail in regard to those features which have a bearing on exploration for new porphyry deposits. Although some of the data herein may be useful in current exploration programs, recommendations do not affect any of these programs insofar as I am aware. Rather, an additional type of research is suggested.

The suggestions set forth herein have evolved partly as a result of certain unique characteristics of porphyry mineralization which have shown up in the Southern Peru deposits, and also as a result of discussions of porphyry geology in recent years with many members of the company's exploration staff. More particularly, I have had the opportunity to discuss specific phases of porphyry exploration in recent months with Messrs. Courtright, F. V. Richard, Landwehr, James Pollock, Kitch and Kursell. Though these men may not susbscribe to all my conclusions, their ideas have conditioned mine. This is presented, then, as the field observations and opinions of others in combination with my own.

SUMMARY

My principal contentions are:

1. Though they should be important in prospecting, some characteristics of porphyry geology are obscure and their significance is not widely appreciated. In certain geologic (and economic) environments, porphyry deposits could exist unrecognized in known mining districts even though their leached cap rocks are exposed. This statement applied more particularly to less well-known districts in parts of Latin America. Its application to the better-known areas of Southwestern United States is problematical, but worth consideration in certain respects.

2. A major porphyry deposit is a commercial resource in almost any environment. Therefore, search for such does not need to be geographically limited, or controlled by the locations of existing smelting and other industrial facilities.

A program is recommended involving research of geological literature specifically for any descriptions of mines or districts which fit certain criteria of porphyry geology. Field reconnaissance of any indicated favorable localities would follow.

CRITERIA

Even though they are generally well-understood by exploration men, under the following subheadings there are listed those geological features which are characteristic in a broad sense of all porphyry deposits. What is possibly more important, there are also included descriptions of some less obvious features which may not be very widely understood and which support the central idea of this report, that porphyry deposits could have been overlooked in productive mining districts and can be found if searched for specifically.

Mineralization

Metallization: Though copper is the principal introduced metal, molybdenite, galena, sphalerite, gold and silver commonly are disseminated with the copper. The gold and silver economically are very important in most North American deposits; the molybdenite in some; none of these subsidiary metals is important commercially in the South American deposits.

Alteration: Sulphur is the principal nonmetallic substance introduced, along with some potash. Original rock minerals are hydrothermally altered, and new minerals formed. The list of these hypogene-formed minerals is long but most commonly comprises quartz, sericite, alunite. kaolin, feldspar, hydromuscovite, pyrite and chalcopyrite. The combinations of these vary from district to district. (The iron of the pyrite and chalcopyrite and the silicon of the quartz are not introduced, except possibly in minor amounts, as is usually considered to be the case; however, there frequently is considerable movement and concentration or depletion of various elements within the mass of the deposit.) The rocks within and around the ore bodies usually consist of varying proportions of these and related minerals. Zones of quartz, sericite, and alunite usually represent the most intense hypogene alteration. In some cases hypogene-formed feldspar is prominent, as at Ajo; it is common in small amounts in many deposits, as at Lingham and Ely; but it is by no means universal. Away from the stronger zones, but usually comprising much of the ore, the proportion of various clay minerals (particularly in the supergene zone) and hydromuscovite is higher. This is the so-called argillic zone. Marginal zones are characterized by progressively less alteration of orthotectic minerals and clearer original textures. These zones are unimpressive and very easily overlooked during ground reconnaissance.

The amount of sulphides is variable, but ranges within 2% and 10%. Customarily, a higher proportion of chalcopyrite accompanies the quartz-sericite-alunite, or more intense hypogene alteration, but in some deposits other combinations of minerals represent hypogene ore. The marginal zones referred to above carry minor pyrite and sometimes chalcopyrite.

In the Toquepala and Cimarrona areas there are breccia pipes which are mineralized with specularite. Some of them (Cerro Azul) may carry some pyrite

and a very minor amount of copper. The alteration accompanying this oxide-and-weak-sulphide mineralization resembles the fringe or the argillic porphyry types, and the specularite breaks down to a dark brown to wine-colored limonite resembling chalcocite-limonite. Exploration should be wary of this kind of mineralization.

The entire mineralized (altered and pyritized) zones of all the major and some of the minor porphyry deposits are large, from 3 to possibly 30 square miles in extent. The ore bodies proper occupy relatively small portions of these zones. Also, the typical porphyry district is not represented by a single zone of mineralization. There usually are one or two larger zones of strongest hypogene mineralization, and these are surrounded by outlying, separate, smaller zones which may or may not contain commercial ore bodies. From this, the conclusion is obvious that a small zone of porphyry mineralization may not itself be of commercial interest, but there may be nearby ore bodies.

Alteration phenomena have received much scientific attention in recent years--a disproportionate amount, perhaps. Study of alteration zones is useful, but it is just one of several field techniques (others: structure, live limonite, etc.) which appropriately help to guide a drilling campaign <u>after</u> the presence of porphyry ore is known and the question has become "how big is it" instead of "where is it." The classification of alteration types in a newly-discovered outcropping mineralized area will not alone indicate the amount of copper in the sulphide zone, or for that matter even whether or not copper is present. In the search for new porphyry deposits, the exploration man needs only to be acquainted with the appearance of all types of porphyry alteration. The question of which alteration type contains the best ore is one to be answered subsequently in conjunction with a number of other geological questions.

Texturally, porphyry ore most often is an even, fine-grained mosaic. On the margins, and frequently in large interior zones, the texture of the original rock (most often porphyritic) is discernible. The sulphides occur either or both as discrete, small grains, or as veinlets. Quartz and sericite also may occur along veinlets.

<u>Oxidation</u>: The reactions of sulphides being dissolved by downward-percolating, oxygen-charged meteoric water proceed very slowly. Surface erosion may progress more rapidly and cut into the sulphide zone, removing ore as sulphide debris. Though direct evidence is not recognized, this may have been operative at Quellaveco; and, likewise, at Yerington. It should be kept in mind as a factor which could influence evaluation of a raw porphyry prospect.

Feldspar and the clay minerals are the common reactive constituents of porphyry deposits (i.e., those constituents which react chemically with copper-bearing supergene solutions). Of course, fresh limestone and calcite are the most reactive, but these are found only on the fringes of porphyry districts. Quartz, sericite, and alunite are non-reactive. Thus, if supergene solutions carrying copper percolate down through quartz-sericite-alunite rock toward the water table, no copper is precipitated until a reducing environment below the water table is reached. But if feldspar, carbonates and/or kaolin are present,

some copper is "fixed" as silicates and carbonates in the oxide zone. Subsequently exposed by erosion, this green-stained material has been the guide by which all known porphyry districts originally were recognized and prospected. In many cases, these green-stained zones were on the fringes of the main ore bodies. They were drilled first; then, exploration progressed step by step into the quartz-sericite zones (no copper-staining in the outcrops) where the major portions of most of the ore bodies eventually were developed.

Cananea is a rather special example of this. Here, hypogene alteration was so intense in the entire area (12 square miles) in which porphyry-type ore bodies occur that the rocks were converted completely to nonreactive minerals, principally quartz, sericite, and alunite. There are no oxide copper minerals in the cap rocks overlying porphyry ore. However, in fringe portions of the district there are important replacement copper ore bodies on limestone contacts. Copper carbonates in the outcrops of these chalcocite ore bodies attracted the early prospecting, and considerable production from them followed. But the district's principal production has come in recent decades, and it has come from porphyry ore bodies (the phenomenally rich Colorado ore body is in the porphyry class, genetically) which have been discovered more or less gradually and not because they were connected with copper-stained outcrops.

In the first exploration at Toquepala and Quellaveco, Cerro wasted several thousand feet of tunneling in widely scattered copper-stained zones on the margins of mineralization where the rocks contain reactive minerals. Their first six holes were drilled alternately in two copper-stained areas. These holes all found average-grade ore but not the high-grade that Cerro was searching for. Their seventh hole was spotted more or less symmetrically (and desperately ?) between these two areas in a zone where there is no copper-staining; here they fortuitously penetrated the high-grade ore which encouraged them to continue drilling.

Cerro's Toquepala experience is a typical, not a unique, example of past porphyry exploration. Thus, the copper-staining may be the prospector's lead to the porphyry district, but it is not a guide to the principal ore bodies (except under special conditions, as at Ajo and Chuquicamata).

With or without visible copper, the leached capping contains important clues for ore discovery. Depending on color, texture, distribution, and amount of limonite, and the abundance and distribution of relict sulphide cavities, the leached capping provides information in most cases on whether or not copper is present in the sulphide zone at depth, and whether the copper minerals are secondary or primary. Under certain conditions, the grade can be approximated. The estimation of copper occurrence in the sulphide zone by study of the leached outcrops should never be based alone on the character of the limonite. The relative intensity of hypogene and supergene alteration, and the character of limonite and sulphide cavities are conjunctive phenomena.

Careful descriptions of the variations in color, texture, etc., and the significance of each type of limonite and relict structure would be lengthy and inappropriate here. But the following points are significant:

1. Limonite is a very minor percentage of the average porphyry capping.

2. It is by no means prominent in appearance.

3. Material of somewhat similar appearance is produced also by weathering of many kinds of rocks carrying no sulphides.

Thus, limonite derived from disseminated sulphides would be easily missed by the exploration man (prospector, engineer or geologist) who is not specifically looking for it in combination with porphyry alteration

Mr. Courtright has proposed that the dark seal-brown color of the so-called "live limonite" after chalcocite is imparted by a small quantity of cuprite (unrecognizable megascopically as such). This has become of interest in regard to the Cimarrona area which lies northwest of Toquepala. Here, there are large zones of alteration more or less of the porphyry type. Disseminated pyrite-limonite unquestionably is present but it is mixed with zones of specularite-limonite (almost identical in appearance to chalcocite-limonite). Complete absence of copper-stain, even on the margins of altered areas, introduces doubt as to whether an appreciable amount of copper could be present in the sulphide zone. However, Messrs. Kitch and Pollock, following up Mr. Courtright's theory, assayed a few outcrop specimens from these doubtful-live-limonite zones and these ranged within .010% and .035% copper, as I recall. This is quite significant because it establishes the presence of copper in the area. When last I talked with him in December, Mr. Pollock was mapping this area and he planned to sample more of the leached outcrops for assaying. His final results will be of interest. The foregoing has been included here, possibly prematurely, only because it may prove to be a useful technique in studying areas of suspected porphyry mineralization where there is no visible copper-staining.

In the Southern Peru deposits, there are some unusual conditions of oxidation and enrichment. At Toquepala, typical chalcocite-limonite is found only on the high ridges, and it is not found in the leached outcrops at lower elevations where it should be abundant overlying the rich supergene ore. Also, there is a large internal zone which, though altered, carries only pyrite-limonite in the leached outcrops. Ore of good grade and thickness now is being penetrated by drill holes in this weak-looking area. In some of the areas of outcrops overlying the Quellaveco ore body we are unable to reconcile the character of the leached outcrops with the grade and thickness of supergene ore vertically beneath.

These anomalous conditions are explained by two processes which theoretically could have functioned during enrichment:

1. If, following the formation of the first, thin chalcocite zone, the water table became suddenly depressed (about 300 meters at Toquepala), and then stayed there for a long period of time, the sulphides above this deep water table would have been placed in an environment of permanent oxidation. There would not have been the customary, slow downward progression of copper by repeated solution and deposition of chalcocite as the water table was lowered in unison with degradation of the ground surface. Instead, once in solution, copper would not have been deposited until it was carried below the more or less permanent, deep water table. Without the repeated solution and deposition of chalcocite there would be no relict chalcocite-limonite in the leached capping,

except in those outcrops representing the original, thin chalcocite blanket.

2. In the past, it has been assumed that the movement of copper is vertical during enrichment. This may not always be the case; there may be considerable lateral migration. In other geological environments, there is considerable circulation of ground water, both in the vadose and phreatic zones. There seems to be no reason why this could not have occurred in the porphyry district also, particularly if the water table was deep, as theorized above. Consequently, the possibility of lateral migration of copper during enrichment should always be considered, particularly in Southern Peru or Northern Chile.

The above descriptions of certain unusual features of the Southern Peru deposits have been included here because they could be useful in appraisal of other zones of porphyry mineralization. Even though copper-staining and definite chalcocite-limonite do not seem to be present, any zone of porphyry alteration should be studied critically because it might carry enriched ore at depth. The two wildest prospects, Cimarrona and Patillani, are precisely in this category.

Associated Ore Deposits: In many porphyry districts in North America commercial deposits of lead, zinc, gold and silver are found. These are outside the porphyry zone proper, and represent concentrated rather than disseminated mineralization--that is, they are replacement and vein deposits, frequently in different rocks than the porphyry deposits. They probably are more or less contemporaneous with porphyry mineralization, and they have rude zonal distribution. Examples are the lead-zinc ore bodies around Bingham, Santa Rita and Bisbee, and the gold around Ely (it was a productive gold camp for 35 years before porphyry possibilities were recognized).

Both supergene and hypogene vein and replacement deposits of copper commonly occur in limestone within and around most of the porphyry deposits of North America. These may be tactites in which the chalcocite and/or chalcopyrite are in somewhat erratic distribution but still disseminated. At Ely, these deposits interfinger the porphyry ore and are aimed in conjunction with it. They seldom are of ore grade for more than 200' or 300' away from the intrusive contact. They are of pyrometasomatic origin, partially pre-dating the mesothermal porphyry mineralization. Bisbee is a porphyry district; but the bulk of its production has been from irregular, comparatively high-grade deposits in zones of contact metamorphism in limestone extending long distances away from the intrusive contact.

The significant point is that tactite zones commonly carry reactive calcite and other carbonates which precipitate oxide copper minerals and prevent enrichment. Also, if pyrite is present, many of the iron-bearing silicates of the tactite break down to limonite. Thus, there is produced a heavy, prominent gossan which is the prospector's favorite target. It requires no great stretch of the imagination to picture a set of conditions in which copper-stained tactite gossan has been actively prospected, but adjacent quartz-sericite porphyry mineralization has gone unnoticed.

INTRUSIVE ROCKS

All porphyry deposits are connected, usually spatially as well as genetically, with one or more intrusive rocks having the following general characteristics:

Texture: Porphyritic, granitoid.

Composition: Monzonitic to dioritic; sometimes dacitic.

Structure: These intrusives usually have small surface exposures (seldom more than a few square miles); their shapes are irregular, sometimes intricate; their contacts dip outwardly, with both high-angle and low-angle attitudes; dikes and irregular apophyses are common. It is generally considered that these small exposures are acrobatholithic, or the high points or cupolas of intrusive masses of batholithic proportions. These intrusives may not actually be exposed in the zones of porphyry mineralization, but they can be assumed to lie at depth. For example, the dacite porphyry of Toquepala and Cuajones is not recognized at Quellaveco, but possibly it occupies the central breccia pipe somewhere at depth.

Age: Pre-mineral or inter-mineral; Cretaceous and Tertiary.

Metamorphism: These intrusives never are themselves metamorphosed. They do not produce regional metamorphism. Contact, or thermal metamorphism is common. The metamorphic effects on the bordering rocks sometimes are weak or entirely absent locally, but most often they are prominent, particularly in limestone. Characteristically, they are very erratic, in some cases being most intense away from the contact; and their distance range normal to the contact is within a few inches to several hundred feet.

BRECCIA PIPES

Singly or in clusters, breccia pipes are associated with practically all porphyry deposits, as has been pointed out by Messrs. Hart, Courtright, and F. V. Richard. Only at San Manuel and Ajo are breccia pipe phenomena unrecognized. In some cases they are the principal loci of hypogene mineralization (Toquepala, Braden, Quellaveco, Cananea, Pilares). In others, they are pre-mineral but do not contain ore (tourmaline and specularite pipes at Toquepala; magnetite at Santa Rita). In others, they are post-mineral (Ely, Toquepala). But, their mere presence increases the chances of porphyry ore occurrence in the vicinity.

Breccia pipes are more prevalent than is generally recognized. In the first place, they are not always symmetrical, vertical, oval cylinders as commonly pictured. They may have very ragged, highly irregular shapes, both in section and plan, or they may even be dike-like in form. In the second place, due to lithologic similarity they often are wrongly interpreted as being, (1) conglomerates (many breccia pipes have rounded fragments in all size ranges up to several feet in diameter), (2) volcanic flow breccias and agglomerates, and (3) fault breccias.

In a very few cases, the positions of breccia pipes can be shown to have been structurally controlled--that is, spaced along, or at intersections of, pre-existing major fault zones. However, their habit apparently is a completely random spatial occurrence, a pattern of diffusion, either on a small scale--several pipes within an area of a few square miles--or on a regional scale involving several dozen pipes in several hundred square miles. Though the problem is somewhat academic, without direct application to exploration, I would hazard an explanation that they reflect the cupolas of deeply buried intrusives. If so, the regional pattern of breccia pipes assumes significance and warrants analysis in connection with Mr. Landwehr's theories of regional trends. A characteristic which

bears directly on regional exploration is that within a field of breccia pipes there usually is a center of strongest brecciation--a center of repeated volcanic activity--and this is apt to be the locus of best porphyry mineralization, Toquepala being an excellent example. Therefore, if cover rocks are present in a breccia pipe field, the possibility that a major center of mineralization is buried should be considered, as Mr. F. V. Richard has proposed.

COVER-ROCKS

As distinguished from leached cap-rocks, cover-rocks are those formations, extrusive volcanic and sedimentary, of post-hypogene and either pre- or post-supergene age. They are widespread in all regions of known or potential porphyry mineralization. Since these rocks may conceal, or partially conceal, major undiscovered porphyry districts, they have received and are receiving much attention by our Southwestern exploration staff. In the course of their work, some good investigative techniques have been developed, or proposed, and the following descriptions of them are included here because they may be useful in exploration elsewhere.

Small windows in large areas of cover-rocks might disclose portions of porphyry zones which have not heretofore been recognized by pospectors because the exposed portion carries no copper-staining. It is considered that these can be recognized by aerial reconnaissance, in areas of awkward ground access.

In another situation, cover-rocks can hide all but a few fringe patches of a major porphyry deposit. These fringe zones, too, could be best recognized from the air. Assuming such has been found, the problem of where to explore for the possible buried center of mineralization involves surface and aerial mapping to determine the patterns of intrusives, faults, and breccia pipes in connection with alteration, and live limonite, as has been described in letters by Wilson, Landwehr, Hart, Courtright, and F. V. Richard.

There are two conditions under which the cover-rocks themselves provide guides to ore.

(1) The U.S.G.S. has experimented with detection of trace amounts of copper in the various types and ages of alluvium within the San Manuel deposit and in the drainage below it. A very sensitive field test (a few parts per million) involving use of dithizone has indicated that copper may be disclosed in alluvium several miles from its source. It would seem that this would be useful in case porphyry mineralization has been found and (1) either the limonite and alteration are not diagnostic, or (2) the mineralization is of the fringe type and projects beneath cover-rocks.

Mr. Pollock was planning to use this technique in the Cimarrona area.

(2) Mr. Courtright has described an occurrence of boulders carrying live limonite in the post-mineral Gila conglomerate. This phenomena would be helpful after porphyry mineralization has been found and under the conditions described for the dithizone test.

GENERAL ENVIRONMENT

The ages of mineralization in porphyry districts are estimated variously as Cretaceous and Tertiary. In a very broad sense, this is significant because the genetically-related intrusive rocks probably are components of the Laramide revolution of Cretaceous and early Tertiary age, and therefore are confined to regions affected by these and contemporary ore-genies--The Basin and Range province of the United States, and extending southward through Mexico and western South America.

Providing the above criteria of mineralization, intrusive rocks, and (possibly) breccia pipes are satisfied, the lithologic environment or type of host rock of porphyry mineralization is not consequential from the regional exploration standpoint. Though mostly in the intrusives themselves, porphyry mineralization is known in many rock types berdering the intrusives. Diorite is common; schist has been very productive at Miami; limestone (tactite), at Ely; lava flows and tuffs, at Cananea. Diabase contains ore at Ray; quartzite, at Andes; and shale, at Ely. Maybe ore will be found in quartzite conglomerate at Patillani (?). Excepting the tactite, the altered equivalents of all of these rocks are remarkably similar in texture and composition. These rocks which border the intrusives customarily are less favorable to hypogene mineralization than the intrusives; however, at Ely the primary ore in tactite is richer than in adjacent monzonite.

All porphyry districts are structurally complex, usually having had long records of pre-, inter-, and post-mineral disturbance. But also, almost the entire Basin and Range province is structurally complex in detail. For the most part it is only within and immediately adjacent to the mining district that the details of these complexities are more or less understood. Therefore, though structural complexity might be considered as a required characteristic, it alone is by no means a guide to porphyry districts.

The distribution of porphyry deposits within the large-scale structural framework of the Cordilleran region is an important but very, very long-range problem. In the first place, those structures (dikes, pre-mineral fissures, pre-intrusive fissures, aligned intrusives) which can be genetically related to porphyry mineralization must be reconstructed, or separated, from the abundant structures of post-mineral origin. For an area the size of Arizona, say, the field work involved in thorough investigation of this problem would be tremendous--quite beyond the scope of a single company's staff. However, where regional trends are known, or suspected, or can be compiled from available literature, they should be given first exploratory attention. Mr. Landwehr has statistically demonstrated that the important structures of mineral districts in the West most often trend northeast or east. Consequently, these trends should receive emphasis, particularly in exploration adjacent to known porphyry mineralization.

HISTORY OF PORPHYRY EXPLORATION

Following the earliest porphyry developments, exploration engineers rapidly examined all known large green-stained zones in Western United States, and prospectors searched for others. This effort became concentrated in the Southwest due to exploration success there. By 1910, the major porphyry districts were known; and in addition, considering the inaccessibility of the region, a surprising number of prospects had been drilled by 1917.

The effectiveness of this early drilling may have been slowed down somewhat because the first holes always were put down in the zones of strongest copper-staining; but sheer exploration aggressiveness overcame this, and the adjacent large ore bodies beneath cap rocks with little or no copper-staining soon were penetrated by drill holes. Yerington was the only porphyry district which apparently went unrecognized as such, in those early days; and San Manuel was the only major ore body missed, though its copper-stained outcrop was drilled, in the first decade and a half of this century. Of course subsequent drilling has continued to increase ore reserves in most districts; and additional lower grade ore bodies have been developed as economic conditions improved and the geology became better-understood in various districts, such as Ely and Globe-Miami.

There are two very significant features of the early history:

(1) A very small group of men accomplished all of these porphyry discoveries, and they were about the only men who can be considered as having been qualified at that time to search for other porphyry deposits. (2) Although these men certainly were aware that brown-stained cap-rocks were a necessary accompanying characteristic (at Silver Bell they apparently recognized live limonite), their original targets were the copper-stained zones. If drilling of these zones found no ore (San Manuel), the prospect was abandoned.

From these two points above, questions arise: (1) Did these men investigate all reported zones of brown, limonitic rocks even if they contained no copper either as stain or exposed sulphides? (2) Would they have recognized in all cases the significance of typical leached porphyry outcrops, which they may have traversed accidentally, if there were no copper-stained rocks in the vicinity? (3) How far and how thoroughly did these men carry their exploration outside of Western United States and the northern fringe of Mexico?

It seems to me the first two questions well might be answered negatively. The third question cannot be answered with assurance; but there is likelihood they may not have penetrated far afield, and it seems particularly unlikely that they thoroughly investigated very many of the small mining districts in Mexico and South America specifically in search of porphyry mineralization.

The three Chilean deposits (Braden, Chuquicamata, and Andes) were developed early because men experienced in Arizona recognized in hand specimens the typical prophyry ore and were attracted by descriptions of the large areas of spectacularly copper-stained outcrops associated with each of these deposits. Toquepala, Quellavaco, and Cuajone have only minor zones of weak copper-staining, which probably accounts for the lack of attention to them until comparatively recently.

Following the early exploration men in the West came the scientists, Ransome, Lindgren, etc., and by their careful studies the geology of porphyry deposits became much better understood. Particularly in the last decade, a succession of men on the staffs of government agencies and private companies have continued the expansion of this knowledge. These men would be qualified to recognize porphyry mineralization, but it is doubtful if any of them have carried on serious exploration, specifically for porphyry mineralization outside the United States. Due to the pressure of domestic industrial need for porphyry deposits, the exploratory attention of these men have been confined to the States.

Anaconda may be an exception. They have had men experienced in porphyry geology doing regional exploration work in Mexico and Chile. (As a matter of fact, it is rumored they have two likely prospects, El Tesoro and Mejillones, respectively about 100 km. south and 150 km. southwest of Chuquicamata.) However, it should not be assumed that their work has approached any degree of thoroughness because (1) they may not have been searching specifically for porphyry deposits, and (2) they may not have been acquainted with all the porphyry criteria described above.

As an example in support of point (2) above, it can be stated that Cerro engineers and geologists must have traversed the Cimarrona mineralized area many times. It is almost certain that they did not recognize it as porphyry mineralization; and in any event, there is no evidence that they ever studied it as a possible prophyry deposit. This is not necessarily to their discredit; it merely is illustrative of the fact that porphyry mineralization can indeed be obscure.

GENERAL ECONOMIC ASPECTS

Certainly, no careful economic analysis is attempted here. However, certain economic factors are repeated here for emphasis because they have a bearing on the problem of how extensive or intensive porphyry exploration should be.

It is a fairly widely held opinion that within two to four decades several of the operating porphyry ore bodies in the States will be seriously depleted; others will at best have low production rates; and some of them likely will be finished. Naturally, operational momentum will be lost slowly as ores of lower and lower grade are handled, but this cannot go on indefinitely. Of course, the major exploration effort should be in the States as long as worthwhile avenues of investigation remain, and many do remain; but it seems very unlikely that discovery will keep pace with depletion, regardless of the magnitude of the domestic exploration effort. Therefore, foreign exploration assumes importance because foreign sources will have to fill the gap as domestic production rates decline.

Roughly half of the known porphyry ore bodies have been of sufficient magnitude alone to have supported individual milling, smelting, transportation, and power developments. They did not need to be found near an existing smelter or railroad. Therefore, a new porphyry ore body theoretically would have a 50-50 chance of being commercial even in an industrially isolated environment. This greatly reduces the necessity of considering remoteness as a deterrent to exploration.

Mr. Courtright has pointed out that known porphyry prospects (most of these have been tested to a certain extent, and are considered non-commercial) are about equal in number to known ore bodies (both major and minor). Therefore, disregarding possible very small, isolated patches of porphyry mineralization, about one out of every four or five new porphyry prospects should be a major ore body. As compared to all other types of non-ferrous metal deposits, this ratio is much more favorable to exploration.

Profitwise, the major porphyries are at the top of the list of non-ferrous-metal ore bodies.

In these respects, then, porphyry exploration philosophy should be comparable in a limited way to that of petroleum exploration in which (1) geographical boundaries are of little concern, (2) geological favorability is of first importance,

and (3) success in a few ventures underwrites tremendous numbers of "dusters."

The foregoing is meant to infer that areas tributary to company smelters should continue to receive the thorough exploratory situation they now have; but at the same time, other areas should not be neglected.

LITERATURE RESEARCH

Men doing exploration work for private companies frequently do not take full advantage of the published work of the scientific geologist or explorer. The valid reason for this is that usually it is quite impractical to spend days or weeks gathering obscure facts from the published literature in connection with any single mine examination. However, when the investigation is regional and involves a single problem or objective rather than a single mine, the research of literature can be systematized and it then becomes feasible.

Though in obscure publications, Toquepala and Quellaveco were described as early as the 1880's. If a detailed search of the literature had been made, say, 20 years ago, it should have indicated that these deposits were worth attention. They escaped discovery for many years because no one studied these publications with the sole purpose of finding descriptions suggestive of porphyry mineralization in a favorable geological environment. The change that this condition could exist elsewhere is inviting, and a thorough search of the literature is warranted.

The objective of this research would be to find descriptions which fall within the porphyry criteria. It is not to be expected that all criteria by any means would be satisfied from the literature.

In a broad way, the first investigative limitation would be to mining districts in those regions tectonically active during Cretaceous and Tertiary times. Next, there should be indication of porphyry-type mineralization. Next in importance would be information on the other porphyry criteria such as intrusives, breccia pipes, etc. Depending on the amount of detail and the nature of this secondary information, the mine, district, or area would be classified as "definitely attractive," "possible," "doubtful, but not impossible," or on some such basis pertaining to the advisability of its being inspected in the field.

Fundamentally, this literature review would be a search for new porphyry districts and not extensions of those already known, except in the sense that known porphyry regions, such as parts of Northern Mexico, Southern Peru, and North and Central Chile should be given early attention.

The chance is remote that in the geological literature of Western United States there exist descriptions of unrecognized porphyry mineralization. However, in light of some of the less-well-known prophyry criteria, it is not impossible that review would provide some leads. This would apply to obscure lead-zinc districts, say, or to tactite copper deposits of minor production, long inactivity, or remote location.

In Latin American countries the less-well-known or long inactive districts offer the best chance for unrecognized porphyry mineralization, and descriptions of these may go back into very old publications some of which, possibly, are more

geographical than geological in character. There is Peruvian literature of this kind accessible in libraries in Lima, and this should be the starting point in the case of Peru. It would seem likely that a parallel condition exists in the other Latin American countries.

Of course, research of the literature should be correlated with review of old company files. Actually, the files probably would be much more productive in many areas than the published material.

In total, this research would take a lot of time; but it need not be done in one step. A few weeks' or months' work should turn up enough interesting leads to warrant field reconnaissance in several localities. Thereafter, the field and office research could be carried on either alternately or in parallel as circumstances warranted.

FIELD WORK

Assuming that some mines or districts with porphyry possibilities have been picked out of the literature or files, the preliminary field reconnaissance would have the very specific objective of trying to find typical porphyry mineralization. If such was not found in the field, the district should be quit promptly without the time being taken to map or evaluate existent mineral deposits of any other kind. If porphyry mineralization is found, then subsequent work would be conducted along one or more of the following lines.

(a) Further regional reconnaissance of a "prospecting" character.

(b) Aerial reconnaissance.

(c) Property acquisition.

(d) Detailed geological mapping of structures, alteration, leached outcrops, etc.

(e) Preliminary drilling or tunneling.

Being more or less standard, these procedures need no enlargement here, excepting the case of aerial reconnaissance which warrants special emphasis. It is particularly well adapted to porphyry exploration because the yellow-brown limonite against the white or cream-colored alteration usually is in contrast to surrounding rocks. Also, from the air it should be possible to correlate a number of small alteration patches and outline an area worthy of ground reconnaissance, which might be entirely missed by the ground reconnaissance alone. It is only useful in regions such as Southern Peru and parts of Arizona where the general geology is known, and where there are known prophyry alteration zones by which the observer can calibrate from the air the appearance of typical alteration types as compared with known formations of the region.

In this same category, color aerial photography should be mentioned. Two lines of color photographs were taken between, and including, the Toquepala and Quellaveco deposits. The chalcocite-limonite areas (and also specularite-limonite) can actually be differentiated from the areas or pyrite-limonite and certain other

rocks where they are side-by-side. But this is a matter of "post-mortem" observation. Only under very special conditions could colored photographs be used, for example, to classify an area as having no porphyry mineralization. In some cases they might disclose some zones worth field reconnaissance; however, this application is only of secondary importance. Their principal use should be in connection with ordinary areal mapping. The inter-formational contrasts are very much clearer on colored than on black-and-white aerial photographs. For example, if it became necessary to map geologically the area covered by the colored photographs between Quellaveco and Toquepala, the time required to do the job would be 80% or 90% less than if no photographs were available, and something like 50% less than if only black-and-white photographs were at hand.

CONCLUSIONS AND RECOMMENDATIONS

(1) Much of the cap-rock overlying porphyry ore is not copper-stained and this material is inconspicuous.

(2) Without copper-staining the leached outcrops do not necessarily attract the attention of the casual prospector, or even probably the engineer or geologist who is not specifically on the lookout for them.

(3) Whether copper-staining is present or not, there is evidence in the leached outcrops as to whether or not copper exists in the sulphide zone.

(4) The total zones of associated alteration in prophyry districts are much larger than the porphyry ore bodies proper.

(5) Porphyry districts commonly encompass ore bodies of other metals and also types of copper deposits other than prophyry.

(6) Porphyry deposits are genetically connected with acrobatholithic intrusives related to crogenies of the Laramide revolution. Contact but not regional metamorphism accompanies these intrusives.

(7) Breccia pipes of pre-, inter-, and post-mineral age are almost always present in porphyry districts and in some cases they are the primary ore control.

(8) It so happens that post-mineral cover-rocks abound in those regions which could contain porphyry deposits.

(9) Many districts which theoretically could contain porphyry deposits may not have been prospected by exploration men qualified to recognize typical porphyry mineralization without abundant copper staining.

By various combinations of the above points, it is theorized that porphyry deposits could have been overlooked, particularly in Latin America. It is recommended that they should be searched for systematically. The first step should be research of published geological and geographical data in connection with a certain amount of review of company files. This work should indicate specific mines, districts, or localities with porphyry potentialities. These then should be examined by field reconnaissance.

The first objective of porphyry exploration, in literature research as well as in the field, should be the discovery of possible porphyry-type mineralization. Very briefly, this comprises zones of quartz-sericite-clay-type alteration with disseminated limonites or sulphides, the size of the zone does not necessarily limit its significance and the absence of visible copper is not necessarily a deterrent. Once such a discovery is made, the program becomes specific. The other criteria of porphyry districts (typical intrusives and/or breccia pipes, live limonites, local structural trends, etc.) then become of significance and are searched for and studied, first in the literature, and then in the field.

This research (again, both in the literature and in the field) should not be restricted either to regions of known porphyry districts or to regions of convenient industrial environment. Logically, though, it should be carried on more thoroughly in areas tributary to company smelters.

Yours very truly,

Kenyon Richard

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PORPHYRY SYMPOSIUM ASSOCIATES

[redacted]

5115 NORTH ORACLE ROAD TUCSON AZ 85704 U.S.A.

Porphyry Copper Seminars • Research • Publications

Paul I. Eimon
415-894-3401

John M. Guilbert
602-884-2509

J. David Lowell
602-887-5341

Thomas W. Mitcham
602-623-6316

Kenyon Richard
602-297-5733

Lecture Notes --- Kenyon Richard 10/30/75

Sampling and Evaluating Porphyry Copper Deposits

The word "evaluating" does not mean "complete feasibility study."

This talk will be concerned mostly with vertical coredrill sampling because the use of that method currently is almost universal. The cases for angled drillholes, underground bulk sampling and channel sampling and for rotary and down-the-hole hammer methods will be discussed a bit as we go along.

Also, I'll be talking about ore reserve estimation, because I've found most geologists and all engineers have handled that problem very carelessly in recent years. Maybe that's because there have not been so many newly-found ore bodies lately. I worked back in the days when it was easy to find ore, and I had a lot of practice, first, in how to make erroneous ore estimates, and then having to repeat the whole tedious procedure correctly.

Before a deposit or orebody with drillholes itself can be evaluated, the accuracy of the drillhole samples themselves must be evaluated. The best way to obviate this latter problem, which is a very difficult and uncertain exercise at best if the samples are suspect, is to take accurate samples to begin with. That may seem easy, but it is not.

First, accurate samples are expensive. This is a matter of real constraint, but not if you are dealing with a wildcat situation in which little if anything really is known about the geology of pre-mineral rocks. In that context I am assuming that all you have is a geochem., or a geophysical, or a geological anomaly, or all three, in which essentially all information is projected, or otherwise exists only theoretically, beneath gravel, soil, talus or dense vegetation such as jungle. In these circumstances when pre-mineral rock is encountered and assays are less than, say, .05% Cu (or equivalent additive values in other metals), the accuracy, or representativeness of samples is not of consequence, and imprecise samples are acceptable. As soon, however, as values get into the range of .1 to .2% Cu, good drilling and sampling techniques with high core recovery should be undertaken.

Some of the statements herein may seem elementary or self-evident. Yet, even with the modern drilling equipment that is available, the carelessness of many current sampling procedures is remarkable. This is true even in the U.S. where good equipment and sampling techniques for porphyry copper deposits were developed, but carelessness here is prevalent, I suspect. I recently saw what I presume is a currently standard drilling contract. I was appalled. It was written by a contractor for himself. If the contractee eventually gets accurate samples it will only be because the drillers actually are conscientious. The contractee has no real control over whether the core samples are good or poor. The drilling cost in that particular contract was high. But that didn't bother me. I personally don't care, really, whether a core sample costs $5 or $50/ft.-----if it is representative. (I have participated----usually in a nervewracking way-----in projects where large expenditures in checking drill-ore sample accuracy were necessary before total financing could be finalized. That is why I'm very particlar about sample accuracy.)

This sloppiness in drillcore sampling prevails, I think, because so many prospects are drilled and abandoned without finding ore, or else the material found is so marginal in

grade that things are put on the shelf. In these cases it may take years or decades to discover that all samples were systematically low, or high, due to low core recovery or some other careless procedure.

The net result is that there are many projects which never reach the stage of ore reserve calculation or financing at which time a glaring spotlight can be focused on sample accuracy. Thus, a great amount of drilling is done in which not much thought is given to sample accuracy. Geologists, contractors, foremen, drillers-----everyone-----has grown careless in recent years.

Sampling of any kind of course means that one or many small samples are taken in a manner that they are supposed to represent the whole mass. For our purposes perfection depends (1) on grain size and/or the textures of the valuable minerals, the hardness or softness of the rock, and the frequency of changes in these physical characteristics, and (2) on the number of samples. This degree of perfection could be derived by the mathematical theory of sampling----you can, and should, look that up in the older handbooks of metallurgists. You'll be surprised as to how high a proportion of the sample is required for an accurate sample of the mass as the grain and fragment sizes become larger----but in exploration work we cannot expect to come up with an ore body which is "mathematically perfectly measured", to the same high degree that a metallurgist may require in his milling control sampling.

For our exploration sampling purposes we should attempt to approach mathematical precision. But the matter of how close we get to precision is, unfortunately, conditioned by costs and the availability of money.

The people who put up or control the money supply for exploration usually are tightfisted because exploration is a lottery, whether we, as explorationists, admit it publicly or not, and they are more-or-less aware of the gambling risks of finding an ore body. They usually are not aware, however, of the really serious risks of ending up with an ore body for which the core samples are under suspicion, by the financiers and their advisors, of being inaccurate.

The geologist in charge of any part, or the whole, of an exploration program must continually push for money. If he really believes in his program he often must badger the money people, to the point of almost risking his own job. This is all a matter of personal judgment tempered by experience and just plain hunch of the geologist.

I think the first porphyry copper ore bodies were "blocked out", or whatever you want to call it, by driving adits, crosscuts and raises on 200' to 400' centers then milling the bulk material and/or channel sampling the walls of the workings. This was done at Ely and Bingham Canyon about the turn of the century. Around 1906 churn drilling at Ray was tried, successfully, because some really smart engineers happened to be doing the work, and because the drillholes were not very deep. On that first job, underground workings and raises were driven on some of the drillholes. The comparison was an almost perfect check. Shortly thereafter diamond drilling was attempted in many districts with questionable degrees of success. Both were used during the 20s, 30s and 40s. Most individuals favored the churn drill because the 'bulk' of each sample had a sort of magic connotation of automatic accuracy. The diamond drill however was cheaper and more mobile. Arguments over which equipment was best were heated during those years. Actually, the arguments should have revolved around which method was least worse, particularly as drillholes became deeper and got into the ground water. Both were subject to serious systematic errors. Principally, the churn drill sample was subject to salting by caving from the wall of the drillhole above the sample interval. This became worse below the water table. With only the rigid core barrel and screw-feed machines available, diamond core recovery usually averaged only 10 to 30%, and the accuracy of recovered diamond drill sludge samples was always dubious. The application of formulae for combining diamond core and sludge samples, such as the famous but erroneous "Longyear Formula", was another cause of many arguments. During the 40s improvements in diamond drilling equipment such as hydraulic feed, wireline, mud circulation, truck mounting and swivel barrels improved the core recovery and lowered costs to the extent that churn drills were phased out in the 40s and 50s. Incidentally, the swivel, or non-rotating or double tube barrel, not wireline, was the single most

important piece of new equipment ever developed for sampling porphyry copper deposits because it alone improved core recovery from, say 20 to 90%.

The foregoing brief comments have been made because in former decades the reliability of drillhole samples, individually and collectively, and of various types, often was subject to serious doubts and had major influence on the dealing and financing of ore bodies. Occasionally now-a-days, one is confronted with old drillhole samples acquired with questionable equipment and techniques, and, as mentioned before, even today questionable samples of ore bodies are being taken with poor equipment and poor sample handling methods.

If a person is confronted with a number of drillholes and their assays representing thousands or even only hundreds of samples, the matter of sample accuracy should be examined critically whether the samples are new ones or very old. The problems usually get worse with age. In any case the matter can never be ignored----and you cannot just throw everything away and say "Redrill every hole!" If you have a bunch of assays you should be stuck with demonstrating they are accurate, or, if inaccurate, how inaccurate.

Engineers have 4 irritating methods of getting around this problem.

(1) They begin a report with the statement "If it is assumed that the samples are correct . . . ."-----then they go through a 100-page report about everything else including discounted cash flow to the year 2000. This gets the engineer off the hook because by the time the reader has tried to digest the details of the report he has forgotten that opening sentence.

(2) Another engineering stunt is when an ore reserve estimate is made in which a number of safety factors, sometimes hidden, are introduced. This results in the so-called "conservative" report in which the word "conservative" is supposed to be synonymous with "virtue." Actually, when I hear or read the word "conservative" I automatically assume that something is wrong. Most likely the ore body is bigger and better than the bottom line numbers would indicate. But sometimes, of course, the word "conservative" means that something is faked.

On the other hand, I know of several cases where actual ore bodies were "safety factored" out of existence. These situations mostly were due to "misguided conservatism" not dishonesty, although some of them may have been motivated by fear of loss of job or promotion.

(3) Another approach is to decide to "check" the questionable samples either with new drillholes or with underground workings which provide magical "bulk" samples. Sometimes either or both of these methods really is advisable, as will be described later on. However, sometimes it is done because the fallaceous idea seems to have been accepted by many that all drillhole samples always are a bit low, and that a bunch of bulk samples automatically will raise a potential ore body from the "marginal" into the "profitable" category. This alone is not really a valid concept, but I know of several instances where large sums of money were wasted with this idea in the back of peoples' minds.

(4) Another ploy is that underground sampling sometimes is undertaken only as a delaying tactic in which a relatively small amount of money is spent while say, one financial group is trying to raise money for a bigger part of the total deal. In other words, this work and expense may be justifiable in a financial sense, but not really necessary in a technical sense.

Before any program of "checking" old drillhole samples by new drilling or underground work is undertaken, a detective-like search should be made (1) for all old correspondence and periodic daily or monthly reports such as those by drillers, by supervisors, by geologists, by metallurgists, etc., and (2) for all possible stored material such as core, crushed rejects, or assay pulps. By analysing the old written material and by re-assaying and re-studying the stored material in light of modern appreciations of mineralogy and other geological features, it often can be determined that certain systematic errors can be quantified to the extent that "check drilling" or whatever is either unnecessary or at least needs to be done only to a limited degree. For example, a statistical study of samples taken above and below all points where casing was set in all drillholes, both ore and waste, may provide factors by which all assays within certain areas, or drillhole

sequences, or depths can be validly corrected up or down. Or, a study of the texture and mineralogy of the core or underground workings may lead to the valid conclusion that core recovery of only 40 or 50% really does give assays representative of the rock mass. By texture, I'm referring to hard and soft minerals which occur selectively on seams or in matrix.

You may feel that the foregoing remarks only apply to drilling done decades ago when techniques really were bad. But I know of several instances, and I suspect others, where recent and on-going drilling programs are of such a nature that detective work like that mentioned above will have to be done by someone in 1, 5, 10 or 20 years.

Equipment other than modern diamond drills can be used for sampling under certain conditions. For example, if there is reason to suspect the presence of an alteration zone beneath generally flat-lying and, hopefully, thin post-mineral rocks, a number of types of low-cost air or mud rotary equipment can produce a few feet of chips of bedrock for geological study and assay. These samples can be likened to geochem. samples, and accuracy is not a requirement. In fact, this technique is quite valuable in determining the best locations later to drill deep holes with correct coring procedures.

I understand that some consider that the cuttings collected from low-cost, air rotary, or reverse circulation systems, or particularly, down-the-hole hammer drills provide representative samples. I have had but little experience with the more modern types of these rigs, but I wonder if the same problems of salting by caving as with the old churn drills would occur, particularly in deeper drillholes or below the water table.

For momentary analysis of a drilling program let's assume that the following 11 optimum conditions obtain:

(1) The first half-dozen or so drillholes indicate that you might be dealing with an ore body.

(2) Road building is not a serious cost.

(3) The drills are truck-mounted, and only vertical holes will be drilled.

(4) The diamond drills have hydraulic feed with sensitive controls.

(5) The drills will chuck NX or larger core sizes. (The larger the core diameter the better the core recovery.)

(6) Good drilling mud with conditioners and additives is available.

(7) Mud circulation is used continually and mud pumps are adequate for mixing and circulating.

(8) Individuals, whether drillers or foreman, experienced in handling mud are always around to check and change the character of the mud according to rock conditions.

(9) A core-run is always stopped whenever the core barrel is blocked, even if only a few inches of hole progress has been made. There should never be an attempt to core to an even interval such as five feet or two meters for every run. That practice will lead to "grinding" and low core recovery.

(10) Never permit a contractor, foreman or driller to get bonuses for footage of hole drilled. Ideally, they should get a bonus for high core recovery (Say, over 90%) and a penalty for low recovery (Say, less than 70%).

(11) Have your own sampler on each rig each shift. His job is to check the removal of the core from the barrel, and place it properly in order in the core carrying boxes, and to measure and mark each run. He should also check the driller's measurement of rods and "stick-up", keeping precise record of drillhole progress. And he should keep written records of the driller's general activities, problems of drilling, mud control, etc. Do not let the driller or contractor handle these matters for you.

If the foregoing 11 procedures all are used, you will have highly representative samples of almost any kind of rock penetrated. Beyond that point, however, there are opportunities for errors to be introduced in sample handling after the core is removed from the core barrel.

Core splitting with a spring wedge and hammer with half being saved and half sent for crushing and assaying is a common but somewhat controversial procedure. Core is an excellent sample because it is round----that is, symmetrical, in contrast, for example, to a rough-walled channel sample which is unsymmetrical and therefore never really accurate. Wedge-splitting spoils the symmetry of the core, but usually the core half needs to be saved and re-logged by various geologists, and for bench tests by metallurgists. I have check assayed both halves of split-core for many core runs in ordinary ore and have found the assays of the two halves of short runs diverge as much as 25 to 50% from their average. The error tends to be compensating over long footages, however; and for that reason it is fairly acceptable. Still, the hammer blow tends to send fragments flying, and the sampler unconsciously will put the shiny sulphide pieces in the sack for assay, thus producing a systematic error. The best way to split core is to cut it with a diamond saw. This preserves the sample's symmetry, and it also permits much better geological core-logging. But it is slow and somewhat costly, so it is rarely done, though I advise it.

Sometimes, a small piece of core is saved out of each core run for inspection by future geologists, and the entire remainder is crushed for assay. In effect this reduces core recovery by some 5% and so introduces a potential, small systematic error. Generally, though, it is a good practice.

Another method is to crush the entire core for assay. This is good because it retains the integrity of the core sample. Sometimes it is poor, however, because it eliminates re-inspection of the core. In this, as in all cases, a Jones-splitter portion of the crushed (-1/4") material is retained. A small portion of this crushed "reject" always should be glued in strips on a narrow board. The assay and depth is plotted beside each sample. (See example). These are variously termed "core boards", "sludge boards", or "sand boards." Actually, this kind of record of the samples of a hole drilled by any method is of great advantage in geological interpretation because it permits fast recognition of subtle mineralogical changes in one drillhole or among several drillholes. These differences or similarities in alteration, rock types, etc. can otherwise be lost or unrecognized in the detailed written descriptions of core. Also, it is a hell of a job to haul out 200 or 300 boxes of core for geological review of some uncertainties----or, to show a visiting consultant. Also, the retained crushed core fragments can be briquetted and polished for detailed, later geologic study. That sometimes becomes desirable in metallurgical as well as geological study.

All split core, crushed rejects and ground pulps should be carefully labelled and permanently stored. Often in the financing of ore bodies these stored materials become highly important for check work. Even if no ore body is found, remember that over the past 75 years marginal waste has become ore with regularity about every 10 years.

If oxidized Cu minerals or chalcocite with pyrite are present, materials should be stored in tight containers because additional oxidation can take place within a matter of days.

Until now I have been talking about the accuracy of individual samples of drillholes. To summarize that aspect, careless collection of individual samples is permissible if you don't penetrate any ore or near-ore-grade material on any single project. If, however, results indicate you might be dealing with an ore body, accurate individual samples should be obtained pretty much regardless of cost. If you cannot get enough money to insure accurate samples, you should at least get yourself on record that the samples might be systematically inaccurate. Regardless of your own position in the order of responsibility at that time, if it later develops that the samples within and around an ore body actually were systematically inaccurate or even suspect, trouble will be explosive and the fall-out can hit anyone-----but most often the geologist.

When results indicate there might be an ore body around somewhere----the spacing of drillholes assumes more and more importance.

In considering the sampling of an ore body in its entirety, accuracy is a function of "measurement" or, in other words, hole-spacing. In turn, this is another function of money-availability. The depth of drillholes also is involved here as a function just like hole-spacing. I don't have the time to go into all the variables in that equation, except, to advise you to take what comfort you can in the fact that, when everything is finished, all drillholes will turn out to have been either too deep or too shallow.

Any new drilling project whether it is in a new, untested region or in an untested or incompletely tested part of an old district has, of course, some kind of target area defined. This area may be either vague or sharp. And it is to be presumed, hopefully, that it has been defined as well as practicable by regional and detailed geologic mapping, by geochem, or geophysical surveys, by photogeology, or by whatever combinations. Actually, if the prospect is an obviously good one, some of those surveys may not be finished or even begun when the drills arrive. You then have to spot drill locations sooner than you might like.

Anyway, in the more normal beginning situation, anywhere from 2 to a dozen or more drillholes may be planned. Whatever the number, it is assumed that money is authorized for that number of drillholes. Never ask for money for only a single drillhole, because the results from it may be a fluke.

Although the locations of the first few drillholes can be planned, there should be flexibility. Particularly if he is isolated, the geologist running the project in the field should be allowed to change drillhole locations according to his interpretations of the significance of the core as he sees it from day to day. This means that the geologist in the field should have had sufficient experience that the various supervisors on up the line of authority do have confidence in the field man's ability to recognize something important as soon as it shows up in the core, and adjust drillhole locations accordingly.

This all implies that early drillholes are usually located in a random pattern, and that it should be expected that each successive drillhole should be spotted with a "take-your-best-shot" attitude. Don't be averse to the abandonment of some access roads and building new ones.

When the money for the original project of drilling is gone it is to be expected that the program will be suspended or terminated----unless, of course, a few of the drillholes are in ore-grade material. In that happy event, among a variety of speculative considerations, one topic which usually crops up and is given unnecessary importance is, "What drill grid and drillhole spacing should we use and how should it be oriented?" There is a tendency for some individuals in authority to impose at that time in the drilling program a rigid, square pattern of 200', or of 100 meters, or 400', or 75', or rectangles or triangles. Actually, the matter is rather unimportant once it is realized that no single pattern and spacing is best for all porphyry ore bodies, and different parts of the same ore body should have differing drillhole spacings. Many ore bodies have been adequately "measured" by completely random drillhole positioning. I rather favor that technique. But my friend Courtright says something like this, "Use some kind of grid as long as there is no reason not to, but be prepared easily to depart from the grid when special circumstances are recognized." My only argument with him is that once you start with a grid it seems difficult to let go.

Remember, if it begins to seem that you may have an ore body you immediately have two somewhat divergent but simultaneous objectives: They are Exploration and Ore Body Measurement. In the exploration sense you step drillholes outward in wide jumps, or drill some holes extra deep to get some idea of ore body limits. At the same time you should be drilling closer-spaced measurement drillholes. The latter are needed to demonstrate that the first few ore-grade holes are not flukes and to keep up the availability of money. If the ore-grade material is low in tenor or deep, you should not monkey around with very many wide-spaced or deep exploration-type drillholes looking for the limits because you might get too many waste holes too fast. In that case the money supply might get stopped.

Let's assume that we are both exploring and measuring a low-grade deposit. We should be trying to do two things: First, to get some idea of the total tonnage and overall average grade and, second, to determine more precisely the average grade of those small ore production units which will be mined first.

In the first consideration remember there is no such thing as "average" ore because an ore body varies mineralogically and, therefore, probably metallurgically, from place to place. Next, keep in mind that for any ore outside of about 200 million tons, knowledge of the precise grade and tonnage is not really necessary. Further, in a fairly large open pit ore body, production grade and operating waste/ore ratios can be closely controlled

day-by-day and planned ahead for, say 2 or 3 months by blast hole sampling. This cannot be done for a cave-mine ore body; or for a relatively small open pit ore body; so, for these you theoretically need more measurement drillhole assays per unit per volume of ore -----that is, closer-spaced drillholes. The difficulty here lies in the fact that it sometimes requires a good deal of drillhole data before you have an idea how deep your open pit mine will reach, or how shallow your cave-mine can reach. So, as drilling progresses one often does not know exactly what spacing is best in which parts of the ore body.

Toquepala was "measured" for the 1st 10 yrs. and almost measured for the next 10 or 20 yrs. I believe that was the first time that much pre-production drilling had ever been done. As I recall, about 15 yrs. after production started, a program of 100 or more drillholes within the pit were planned. That information was not needed before the first production. I understand La Caridad in Sonora is almost entirely measured; and, considering its huge pre-production investment, $620 mil., Cuajone surely must be measured for 30 or 40 yrs. of production.

In most large mines interior drilling has been undertaken within a year or two after first ore production-----Pima, Sierrita, Mission. At most mines both measurement and exploration programs have been conducted off and on over many years. That has been proper.

At a few mines, however, exploration drilling was begun promptly after production start-up and continued for years, along with substantial increases in mill capacity, and a daily scramble for ore in the mine. Those cases were poor original management. At a few large old mines, essentially no drilling was done for decades after production started. Then, massive programs of exploration were begun and continued for years. Shafts, plants and townsites were moved. Some of those cases were due to faulty original managements, although partly valid excuses existed.

Above 200 million tons of the first and best grade ore to be mined, the average grade and total tonnage figures have usefulness only in determining the size of the plant which should be built. It is almost axiomatic, however, that the bigger the plant the bigger the profit per ton of ore. So, the availability of capital really is the factor which ultimately puts a top limit on plant size. It's nice to brag about having 800 million tons of ore, but what really is important is how carefully has that highest grade, 200-million-ton-best-portion of the ore body been measured by drillholes?

This brings us to the matter of measuring the smaller production units of an ore body. As a crude rule of thumb, about the smallest tonnage for which exploration drillhole samples alone should be used to provide grade predictions is a 3-month's ore supply. Within this parameter there are about 8 considerations.

(1) The grade of the first 3 to 6 months of ore production should be particularly well-sampled----that is, close-spaced drillholes.

(2) Predictions of average ore grade should be quite accurate in yearly ore-production units for the first 5 years----or, until cash flow returns the invested capital. That is important.

(3) Beyond that time the estimate of average grade should be reasonably accurate for each 5-year production unit.

(4) The edges of an ore body should be better-defined as to position, tenor and shape than the rest of the ore body. For example, in open pit mines the waste/ore ratios for thin, low-grade edges of the ore body can become very high. For cave mines the costs of extraction workings are so high that the positions of ore body edges, whether gradational or sharp, should be known pretty closely.

(5) The uniformity or spottyness of the distribution of values in an ore body, or within portions of it, has a direct bearing on drillhole spacing. I cannot give you any good guidelines for drillhole spacing in this regard. It is mostly a matter of geological hunch or experience. I know of one small open pit ore body that was drilled on 75' centers and even that spacing proved to be too wide. There is one large ore body that was drilled on 50' centers. That was ridiculous. Many years ago I saw a map of Bingham Canyon and it seemed to me that tenor was so uniform that 600' spacing would have been close enough. And then there is Chuquicamata which doesn't need any drillholes. At least, when I visited

there in '61 they had mined out about 80% of their drillholes and they were not even taking control samples in the pit. However, many holes have been drilled there since '61.

As a rough guide in working with hole-spacing and spottyness of ore distribution, consider that each 5' drillhole assay-interval has mathematical influence on 500 tons at 100' spacing; at 500' spacing, 25,000 tons are influenced by each assay.

(6) Usually different rock units within an ore body contain differing average values. Thus, structures are important, such as the positions and displacements of post-mineral faults, the shapes of early- and late, pre-mineral intrusives, the shapes of post mineral intrusives, the degree of mineralization control by layered volcanics and sedimentary rocks, and the positions and sizes of breccia pipes. Each of these units may require its own drillhole spacing----if that can be arranged.

(7) Exploration samples should contribute some information (not measurement) on the character of mineralization beneath or outside any easily foreseeable open pit or underground mining.

(8) Often the locations of drillholes is conditioned by unusually high costs of road building where there is steep topography, cliffs, and/or dense jungle. These conditions can sometimes be obviated by drilling angled holes, even nearly flat ones. I still like the vertical drillholes if the extra money can be arranged.

This matter of angled drillholes requires a little special attention. Actually, it is possible to "measure" with fair accuracy an ore body which has been perforated with drillholes angled like jackstraws. But the calculations and geometry are awkward to handle, whether it is done by sections, plan maps and planimeter, or by computer. Drillholes in erratic directions result in too many assays in some blocks of ore and too few in other blocks. In my opinion a good deal of extra money oftentimes can be well-spent in extra drill roads so that vertical drillholes can be used.

There are situations in which a few angled drillholes actually are necessary. These usually involve steep, sharp structural contacts representing distinctive interfaces in values, such as thick pre- or intra-mineral dikes, breccia pipe margins, irregular intra-mineral intrusives, or steep, layered volcanics or sedimentary units, post-mineral faults or steep, thick, close-spaced veins.

Structural conditions which do <u>not</u> require angled drillholes (but where many misguided individuals automatically believe they <u>are</u> necessary) are: (1) very close-spaced, parallel veinlets whether high- or low-angled; (2) low-angle beds or thick ore lenses. The common idea is that through-going structural blocks or zones should be penetrated by drillholes normal to the structure. I do not know why this idea is prevalent----but it certainly is. Possibly it is because the geometry on a section view looks good to amateurs, engineers and even to many geologists who should know better. This is fallacious, except as noted above where sharp contacts and interfaces need to be located precisely, and with another exception where thick lenses of ore or waste have dips of, say, 70° to vertical and are separated by thick lenses of waste.

The real reason for drilling vertical drillholes if at all possible is that core recovery is appreciably higher, as an average. That is important.

In the following I will be concerned only with some of those procedures of ore reserve. calculation which either I approve of or dislike.

The basic principal of ore reserve estimation is that the assay for, say, each 5' of drillcore is applied to a volume extending about halfway to surrounding drillholes. This we can call "an area of influence" or "a unit volume" for each assay. This is only a mathematical assumption. We know this is, in a sense, incorrect because the rock really does not maintain precisely the same Cu content in a thin layer extending horizontally for any distance at all. The assumption approaches reality, however when we compare by averaging the assays of many unit volumes, or when we decrease the size of each unit volume by spacing drillholes, with their columns of assays, closer together.

These unit volumes are usually handled geometrically on a stack of plan maps with each map showing the various unit assay-areas of a single mining bench.

If only the total tonnage and its average grade is sought, the data can be compiled on a single map. In a foregoing section I gave some reasons why the results of such a calculation are often not really important. Further, it is pointed out that this geometrical exercise can be classed as "simple" for another reason. Namely, it usually is unrelated to a mining method. Ore reserve estimates are really meaningless if they are not geometrically tied to mining systems. Unfortunately this kind of an estimate; that is, one unrelated to a mining system, provides a mass of rock floating around without anyone specifying what parts of it can be mined. What really irritates me is that it is commonly termed "geological ore." In reality it is usually the work of some mining engineer who doesn't want to stick his neck out by outlining exactly where, how and when each part of the ore body is going to be mined.

The shapes of each area of assay-influence, or polygon, on each predicted mining bench, can be adjusted in shape to fit the projections of geologic structures where these have a sharp difference in average assay from one side of the structural plane to the other. For example: A column of assays in a drillhole in a breccia pipe may average, say 1.5% Cu whereas surrounding rock averages .5% Cu. If the edge of the pipe can be properly projected to a position on a bench plan that is 50' from a low-grade drillhole and 150' from the high-grade drillhole in the breccia pipe, the polygons are adjusted in shape to match the contact so that the volume influence of higher assays extends, in a mathematical sense, 150' to the contact, and the assay-influence of the low-grade material only extends 50'. This construction of adjusted polygons is accomplished by compiling detailed sets of geologic structure sections through the ore body and plotting all important contacts on each polygon bench plan.

Often pits can be designed (1) for various pit slopes, (2) approximately for different grade cutoffs and (3) for different production intervals such as the shape of the pit at the end of pre-production stripping, the end of the 1st yrs'. production, the 5th year, etc. All of these theoretical pit shapes can be plotted on the bench plans and the grade-polygons adjusted accordingly. If the old fashioned system is used, each adjusted polygon on each bench plan is measured by planimeter and the various assay-polygons are subtotaled and totaled by weighted averaging. This can give assay averages and waste/ore ratios for production time-tonnage units ranging from 3 months to 10 yrs. or whatever. All it takes is many thousands of man hours of work.

All of this work can be handled much more rapidly and with the solving of more variables by computers. All <u>that</u> requires is hundreds of man hours while the engineers, geologists and programmers are trying to understand each other and get the bugs out of the programs.

In fairly recent years I've heard of computer programs called something like trend surface analyses. I think they involve a mathematical theory whereby every assay in an ore body has some influence on all assays. As you can realize, I do not really understand it and am therefore leary. I was told recently, however, that programming is back to the basic principles, which I term the adjusted polygon system. The modern computer programmers no doubt have much more elegant terms.

A few years ago some papers about computer programming appeared which demonstrated that in the case of a number of large porphyry ore bodies it could be proved that average grade could have been derived by drilling only a <u>small</u> fraction of the number of holes that were actually drilled. If you have understood me this far, you will appreciate that that idea is ridiculous, but it cheered me up greatly. I could envision the day when, with some further program refinements, we could just plug into a computer some data about a theoretical ore body somewhere and then start mining without putting down any drillholes anywhere.

Kenyon Richard