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AGS NEWSLETTER

Arizona Geological Society, Inc. April 2001

CALENDAR OF EVENTS

Tue. April 3 AGS Dinner Meeting. Location - Innsuites Hotel. Social 6:00, Dinner 7:00, Talk 8:00

DINNER MEETING

DINNER MEETING SPEAKER:

M. Stephen Enders, PhD.

Vice President, Mine-Site Exploration

Phelps Dodge Exploration Corporation

SUBJECT: The Evolution of Supergene Enrichment in the Morenci Porphyry Copper Deposit, Greenlee County, Arizona

Date: Tuesday April 3, 2001

➡ ***Location: InnSuites Hotel*, 475 N. Granada Ave. in Tucson**

SCHEDULE: CASH BAR @ 6:00 PM DINNER @ 7:00 PM TALK @ 8:00 PM

WITH RESERVATION: MEMBER = $18.00, GUEST = $20.00, STUDENT = $7.00

Without reservations you may not get dinner. If you do, an extra $2.00 will be charged.

To make dinner reservations please call the **AGS answering machine** at **(520) 663-5295** by 5:00 P.M. on the Friday before the meeting. Leave name, number of attendees, and whether a vegetarian or low-salt meal is required. This number can be used for field-trip reservations and leaving messages for Society officers. Please cancel your reservation via the answering machine if you find that you will be unable to attend.

Abstract

Supergene enrichment in the Morenci porphyry copper deposit was formed as a result of the coupled processes of erosion and chemical weathering that accompanied five stages of landscape evolution in the Cenozoic Era. During Stage 1 (64 to 53 Ma), low-grade primary chalcopyrite and pyrite mineralization was deposited as a result of Laramide magmatic and hydrothermal processes at about 55 Ma. During Stage 2 (53 to 30 Ma), initial unroofing and erosion removed approximately 1.8 km of rocks overlying the deposit and shed detritus to the north in the Eocene and to the south in the early Oligocene. During Stage 3 (30 to 18 Ma), the deposit was preserved under 640 to 950 meters of volcanic rocks as a result of mid-Tertiary extension and volcanism. During Stage 4 (18 to 2 Ma), most of the supergene copper enrichment at Morenci appears to have been formed as a result of Basin and Range deformation between ~13 and ~4 Ma. Sixteen new $^{40}Ar/^{39}Ar$ ages from alunite, jarosite, and potassium-bearing manganese oxides in the district recorded three cycles of enrichment and leaching that peaked at about 7.3 Ma. Microbiological and geological studies revealed that acidophilic iron oxidizing bacteria and dissimilatory sulfate reducing bacteria contributed to leaching and

enrichment of copper in the supergene environment, at least since the late Miocene. During Stage 5 (2 Ma to present), destruction of the current enriched blanket accompanied base-level drop and stream incision as a result of progressive drainage integration in southern Arizona in the late Pliocene and Pleistocene.

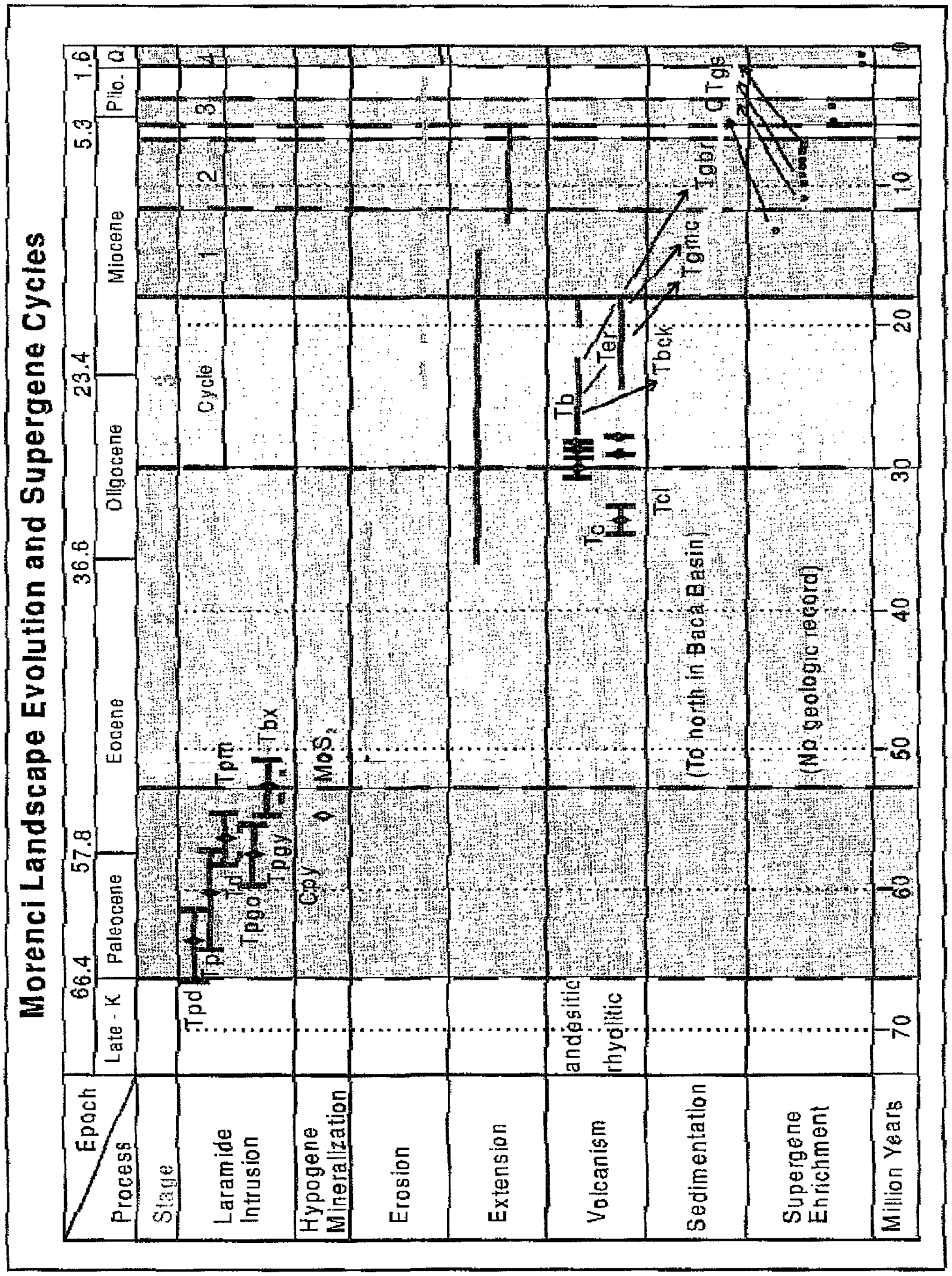


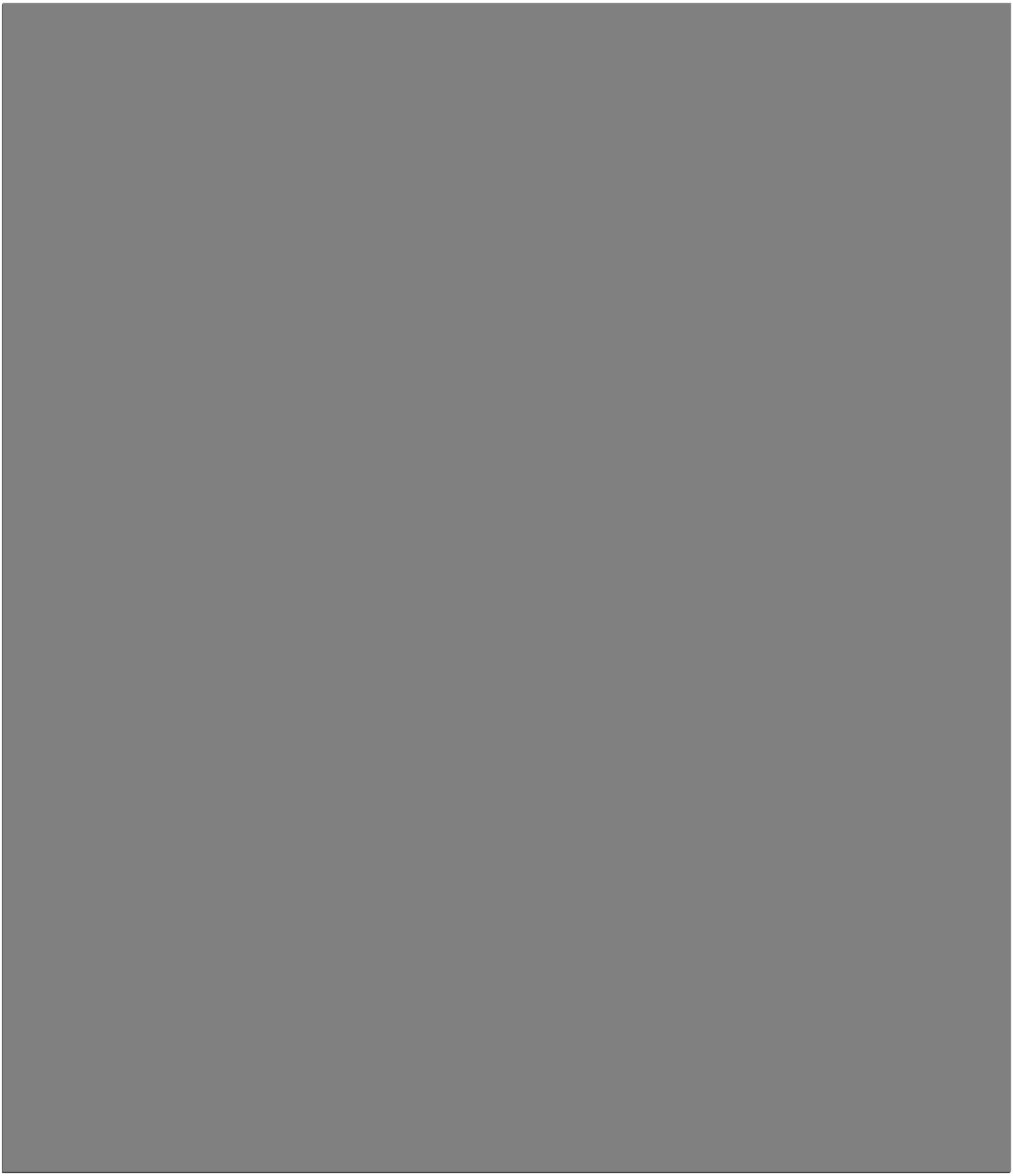
FIGURE 69. Morenci landscape evolution and supergene cycles. Diamonds indicate age date and show error bars. Dots are $^{40}Ar/^{39}Ar$ age dates for supergene minerals: red = alunite, blue = jarosite, black = Mn-oxides.

MEMBER NEWS

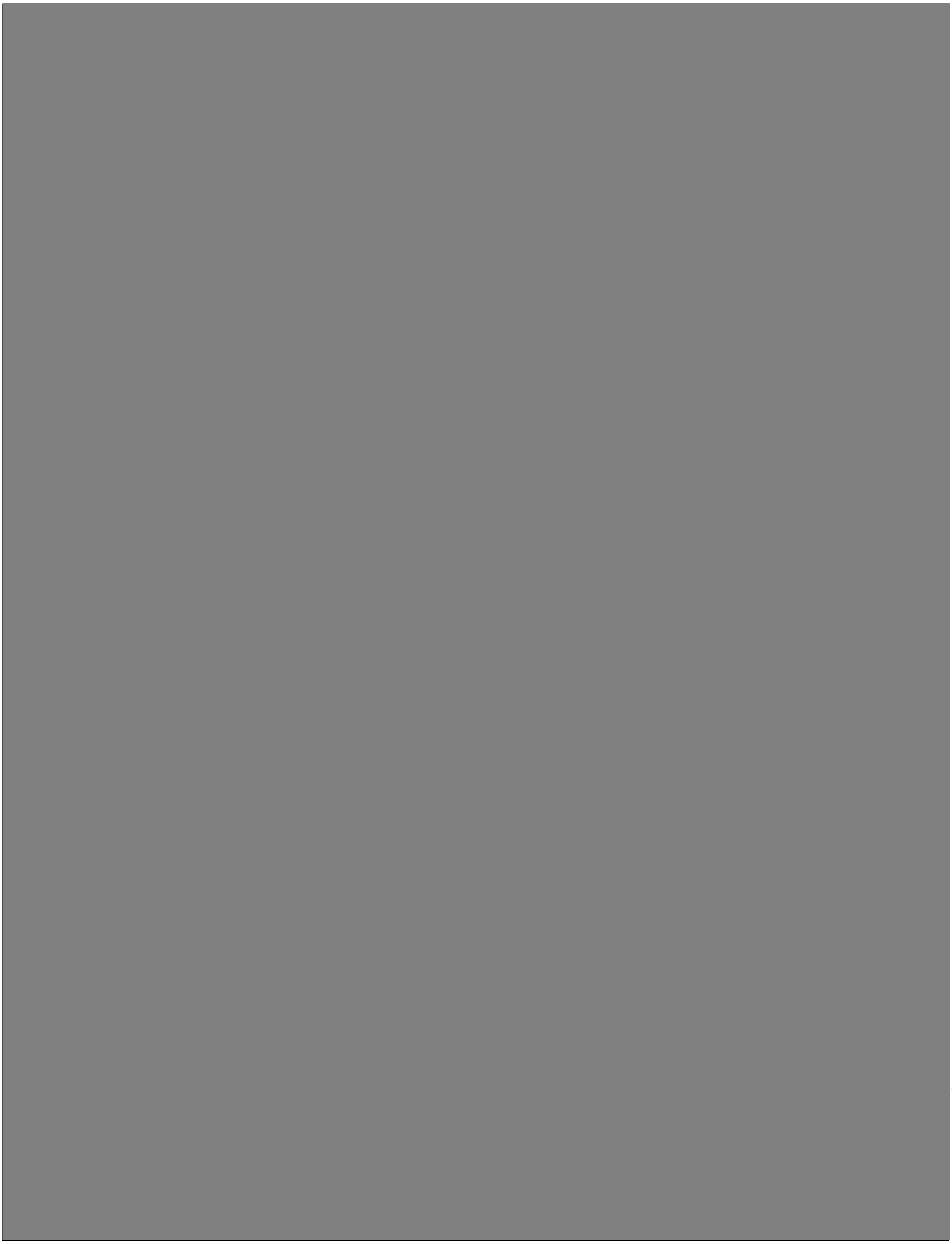
Congratulations to three notable AGS members for their achievements as recognized by the Society of Mining, Metallurgy, and Exploration (SME) in February. **J. Alan Coope** is now a SME Distinguished Member, and ***William Peters*** was awarded the Ben F. Dickerson III Award. AGS Life Member **John Guilbert** was awarded the prestigious Daniel C. Jackling Award for "stellar life-long service to the mining community, for elucidation of porphyry copper deposit geology, for exemplary teaching of exploration geology, for development of Bajo de la Alumbrera, and for his lecture "Linkages Among hydrothermal Ore Deposit Types". Way to go!

Ore Genesis in the Morenci—Metcalf District

by Jackson M. Langton



 Reprinted from Transactions of SME, September 1973, Vol. 254



ARIZONA CONFERENCE

AIME

MINING GEOLOGY

MORENCI
1980

ARIZONA CONFERENCE AIME
MINING GEOLOGY
MORENCI, ARIZONA
MAY 3, 1980

8:00-9:00 A.M.	Registration
9:00-12:00 Noon	Technical Session

Chief Geol →
J. L. Bolles - Welcome
E. M. Schern - Introduction and General Geology
F. J. Menzer - The Laramide Intrusive Complex at Morenci-Metcalf, Arizona

COFFEE BREAK

R. K. Preece - Alteration and Mineralization at Morenci-Metcalf, Arizona
W. W. Willoughby - Mining Geology in Relation to Ore Control at Morenci-Metcalf, Arizona
D. M. Boggess - Industrial Minerals for an Operating Porphyry Copper Mine

12:00-1:00 PM	Bar-B-Que Luncheon
1:00-5:30 PM	Field Trip
6:30-7:15 PM	Cocktail Hour
7:15-9:00 PM	Dinner and Special Presentation "A History of the Clifton-Morenci Mining District (1863-1980)" by W. C. Conger

11300 drill holes
core - .01-.002 Cu

Ls dike

ls

Tert vol $ 20 my

cc blanket just reaches highest
part of primary shell

immature ~~blanket~~? ~~why~~ not partially
destroyed ~~blanket~~?

1,5~~8~~ - Ed
capping bornite

1'5% ~~cc~~ c zone

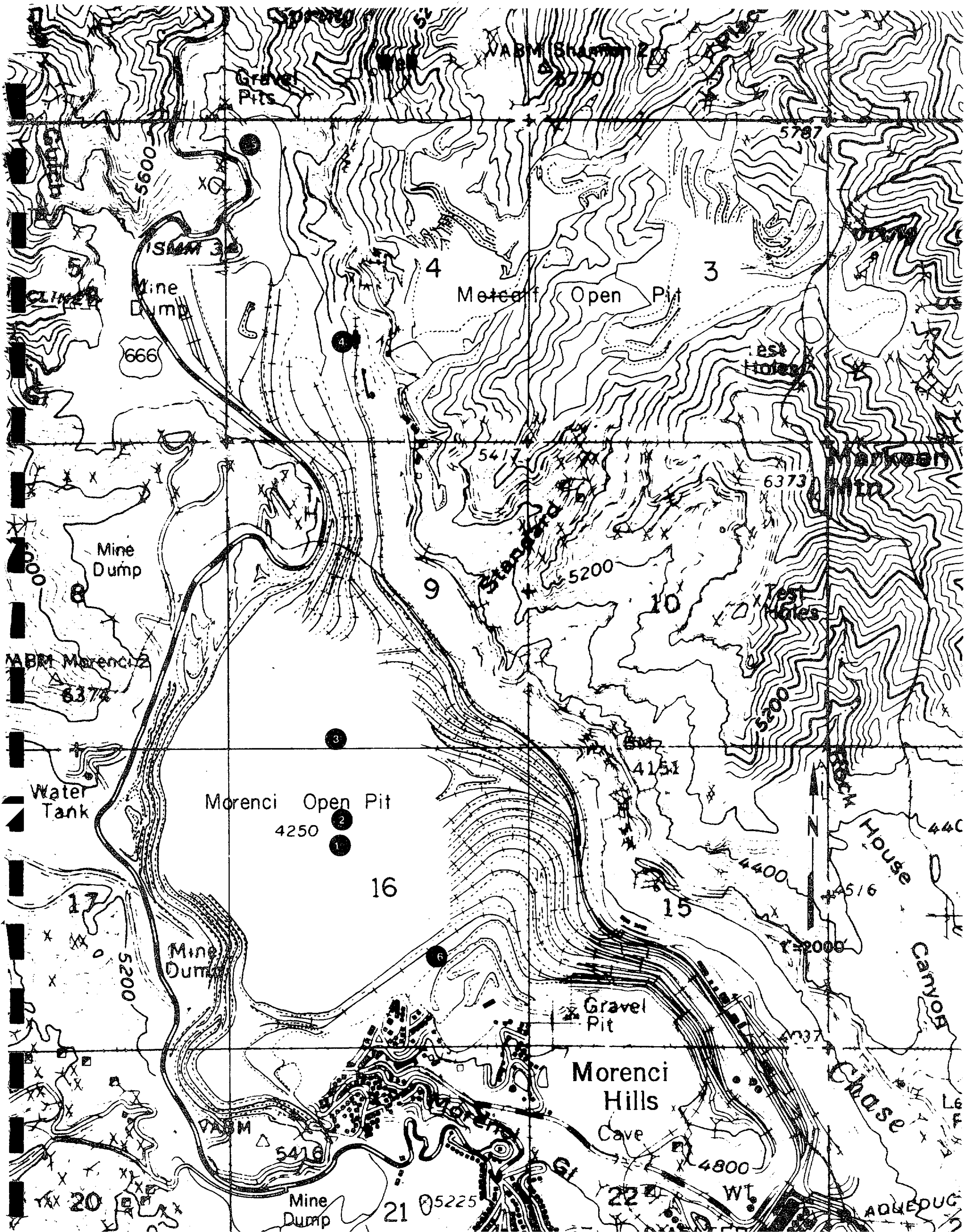
Radial brochantite structure
surviving in leached zone

Diabase under MP —
they associate with diabase
due to avail of phosphate (Capstick?)

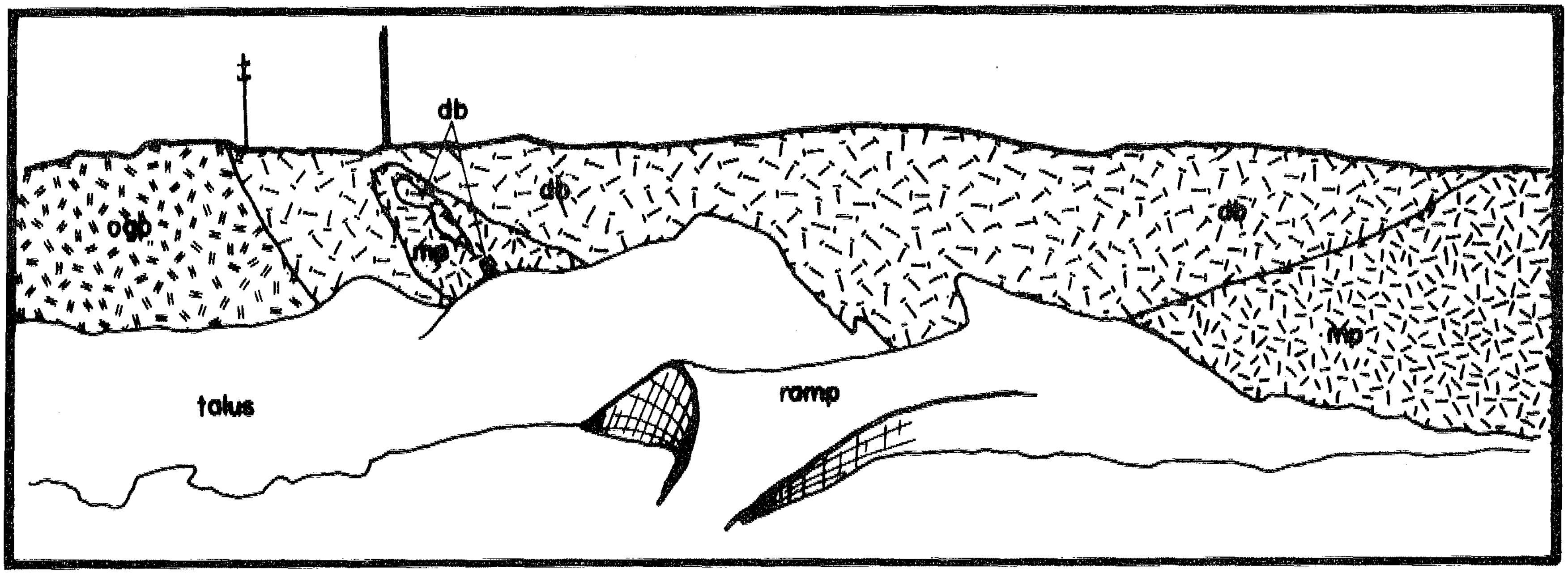
granitic por — silicic

biotite books in cedar Gr Po
Part of potassic alt?

monzonite bx intrusion
diabase frags — potassic alt



Gravel Pits
ABM Shannon 2
5770
5787
5600
5
Mine Dump
666
4
3
Metcalf Open Pit
Test Holes
5417
6373
5200
9
10
Test Holes
Mine Dump
8
ABM Morenci 2
6374
Water Tank
Morenci Open Pit
4250
16
17
15
4151
4400
N
House
Canyon
Chase
Mine Dump
5200
Gravel Pit
Morenci Hills
Cave
4800
WT
ABM
5416
20
Mine Dump
21
5225
22
1
2
3
4
5
6

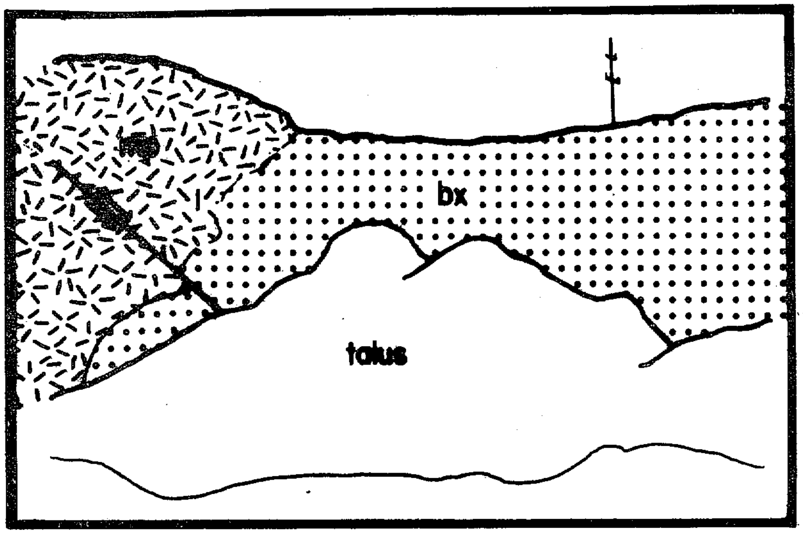


STOP 1 - 4300 LEVEL - MORENCI OPEN PIT

LDB DIKES, LMP, LOGP

GRADE: LDB - 0.3% Cu
LMP - 0.6-0.7% Cu
LOGP - 0.6% Cu

SCALE: 1" = APPROX. 25'



STOP 2 - 4200 LEVEL - MORENCI OPEN PIT

MORENCI BRECCIA, LMP

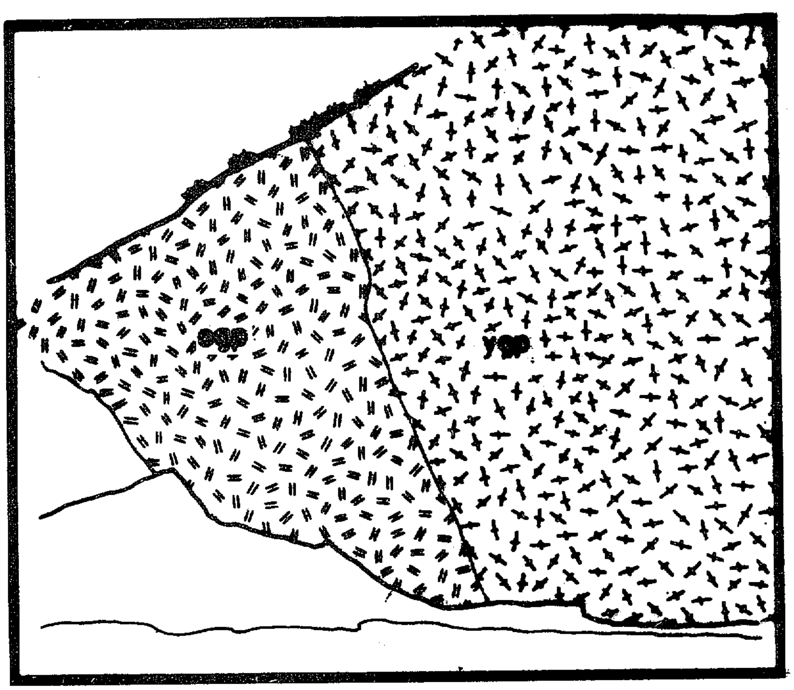
GRADE: BX - 0.6-0.8% CU
LMP - 0.4-0.6% CU

SCALE: 1" = APPROX. 25'

STOP 3 - 4300 LEVEL - MORENCI OPEN PIT

LOGP WITH QUARTZ-KSPAR AND QUARTZ-MoS_2 VEINING

GRADE: OGP - 0.6-0.7% CU
OGP+PY-CC VEINS - +1.2% CU

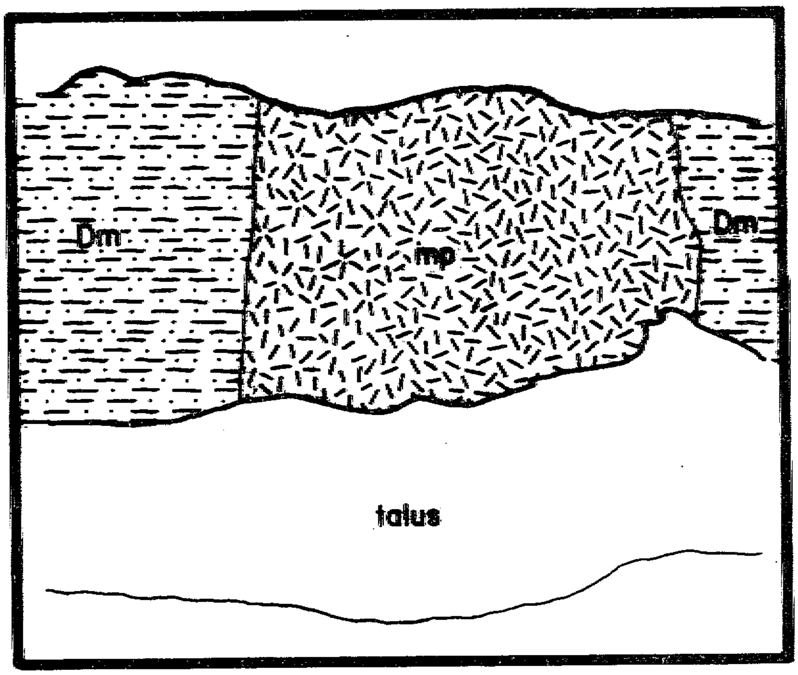


STOP 4 - METCALF IOS

LOGP, LYGP

SCALE: 1" = APPROX. 25'

STOP 5 - Candelaria Breccia



STOP 6 - 4950 Level - Morenci Open Pit

Devonian shale with local sphalerite-galena-pyrite accumulations, Lmp dike with Kspar-epidote-chlorite veining and xenoliths of PCgr and Dsh

GRADE: Dsh - 0.05% Cu
Lmp - 0.10% Cu

NOTES

older
Younger? G P — 16 breccia xncls.

Candelaria bx
intruded by rhy bx pipe
49 my
younger granite por post min
but altered — sulphides?

dikite of Y G.P — peraluminous
high alumina alkla: ratios

NAME	GEOMETRY	HOST ROCK AND CONTACT	FRAGMENTS: ROCK TYPES (~%)	FRAGMENTS: SIZE, SHAPE, & DISTRIBUTION	MATRIX: MINERAL COMPOSITION-%	MATRIX: TEXTURE & DISTRIBUTION	ALTERATION - MINERALIZATION 1) PRE-BRECCIA HYDROTHERMAL 2) SYN-BRECCIA HYDROTHERMAL 3) POST-BRECCIA HYDROTHERMAL 4) SUPERGENE		REMARKS
MORENCI	Oblate lenticular; 250'(E-W) x 75-200'(vert) x 1600' (N-S). Dips 20-28°N par to P€ flts.	Mp laccolith. Grad with apl, apl grad into mp; bx discontinuous beyond mp-ogp ct.	Mp 70 P€gr 15 db 10 P€apl 3 qtzt(?) } 2 sh(?) }	Micro to 3', mode 1-2 in; ang to subrd. Lath-like at cts to ell at center. No void space. Well mixed fgs, increase db fgs to W & gr fgs to E. fg:mtx = 70:30, constant.	K-feld 60 Q 30 Bio 3 Ser 7	Granitoid. Flow lineation at footwall. Transport Sward at 20-28°. Min 85% Rk fl 15%	1) ser & local Sil. 2) partial K-feld. 3) Q-ser vnlts. 4) Str perv arg, except bx mtx.	1) None. 2) None. 3) Diss py, 50:50=fg:mtx; Q-ser-py, Q-mb, Q-ser-cp vnlts. 4) Wk cv-cc on diss py. Turquoise, wavellite, & alunite.	
METCALF	Oval (as exposed), 650' dia, dip unknown, presumed vert.	Ygp plug. Sharp & somewhat sinuous, near vert.	ogp 85 ygp 5 P€gr 5 Q vns 5	Micro to 130', mode 3-4 in; ang to sbrd. Ell to equid. 5% void space. Center 95% ang fgs to 60% sbrd at cts. fg:mtx = 60-80:20-40.	Ser 30-60 K-feld 10-40 Q 0-30	Rhyolitic to fragmental. Minor flow lineation, random. Min 60% Rk fl 40%	1) Q vning & minor K-feld vning in ogp, Q vning in gr. 2) local Sil in fgs 3) Str ser in mtx, wk in fgs, minor Q-ser-spec vnlts. 4) Mod perv arg alt.	1) No data. 2) minor diss py. 3) Q-ser-spec vnlts, str py diss, in flts, & vnlts. Dike to SW has mb-cc-minor cp diss & as mtx. 4) Local chry on fxs. Wk cc on py diss.	
KING	Oval, 600' (E-W)x 700' (N-S) x 700' vert.	Ygp plug. Ct obscured by alt, sinuous & steep dip.	ogp 80 P€gr 10 Q vns 5 mp 4 ygp 1	Micro to 140', mode 2-4 in, ang to sbrd. Ell to equid. 2% void space. Center 95% ang fgs to 50% sbrd at cts. fg:mtx = 60:40.	Ser 30-60 K-feld 10-40 Q 0-30	Rhyolitic to fragmental. Local flow lineation, random. Min 60% Rk fl 40%	1) Q vning in ogp & gr. 2) local Sil in fgs. 3) Str ser mtx, & mod-str ser of fgs. Q-ser-py vnlts. 4) Str perv arg alt.	1) None 2) Wk diss py. 3) cp wk diss, minor Q-py-cp vnlts, str diss py. Str Q-ser-py vnlts. Q-mb & Q-mb-py vnlts. 4) Str cc-cv on py & cp(?) on fxs, vnlts, flts, & diss. Chry & broch on fxs.	Sheeted wall rk at ct.
CANDELARIA	Oval, inverted cone, 2700' (E-W)x 1900' (N-S), vert exposure 1700'.	Ogp stock. Cts sharp, linear, & 50-70°.	ogp 60 P€gr 25 Q vns 8 P€apl 6 P€sch 1	Micro to 100'x50', mode 3-4 in, ang to sbang, Equid. 15-20% void space. Rk zonation-fgs roughly match wall rk types near cts. fg:mtx= 60-80:20-40	Ser 40 Q 35 Op sp 20 Spec 5	Tightly cemented agg by Q, ser, & spec. Local flow lineation, roughly vert. Min 95% Rk fl 5%	1) Q vning in ogp & gr; K-feld vning in ogp. 2) Sil in mtx, str at top of bx; ser bx mtx. 3) Q-ser vnlts, minor Q-ser-py vnlts. 4) Mod to int arg.	1) None. 2) Op sp filling by spec in bx mtx. 3) Py in flts; minor Q-ser-py vnlts. 4) Conichalcite, bisbeeite, chry, & iron oxide at cts; local chry on fxs in bx, cc on py in vnlts, flts, & diss.	Rhy bx as plugs & dikes intrudes central part of bx; has small sbrd to rd fgs of preexisting rk types- ogp, gr, & Q vns.

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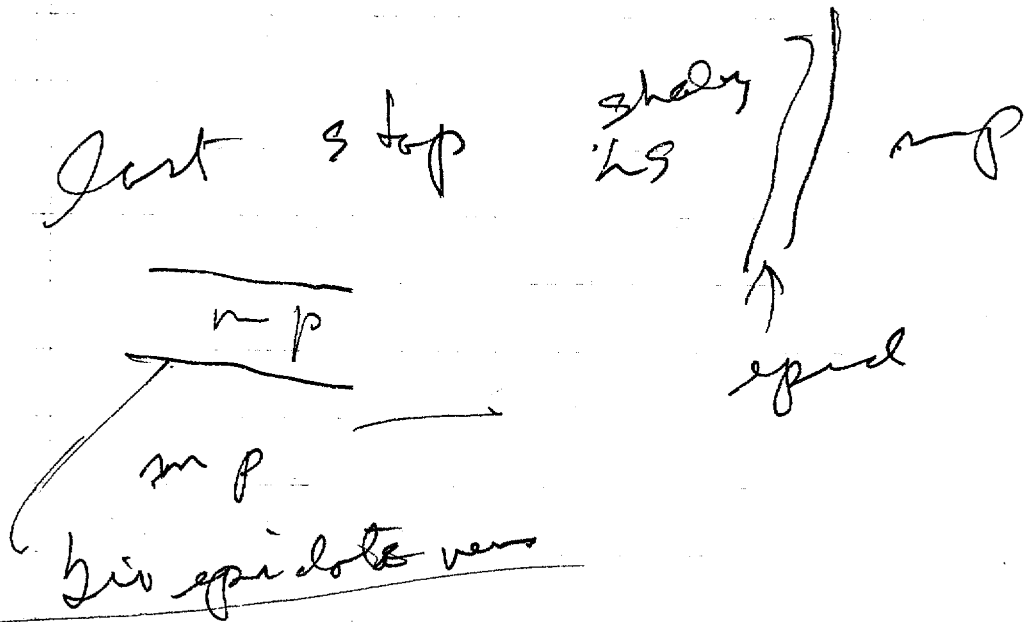
CANDELARIA	Oval, inverted cone, 2700' (E-W)x 1900' (N-S), vert exposure 1700'.	Ogp stock. Cts sharp, linear, & 50-70°.	ogp 60 PЄgr 25 Q vns 8 PЄapl 6 PЄsch 1	Micro to 100'x50', mode 3-4 in, ang to sbang, Equid. 15-20% void space. Rk zonation-fgs roughly match wall rk types near cts. fg:mtx= 60-80:20-40	Ser 40 Q 35 Op sp 20 Spec 5	Tightly cemented agg by Q, ser, & spec. Local flow lineation, roughly vert. Min 95% Rk fl 5%	1) Q vning in ogp & gr; K-feld vning in ogp. 2) Sil in mtx, str at top of bx; ser bx mtx. 3) Q-ser vnlts, minor Q-ser-py vnlts. 4) Mod to int arg.	1) None. 2) Op sp filling by spec in bx mtx. 3) Py in flts; minor Q-ser-py vnlts. 4) Conichalcite, bisbeeite, chry, & iron oxide at cts; local chry on fxs in bx, cc on py in vnlts, flts, & diss.	Rhy bx as plugs & dikes intrudes central part of bx; has small sbrd to rd fgs of preexisting rk types- ogp, gr, & Q vns.

NE quad ~~rant~~ st of ser-pyc veins

moly vein dip — inward
a concentric fract zone



Willowby

King Prec Gr — waste in general

100,000 tpd .80 Cu
2,000 " 25% cu conc

RK Preece
~~F.L. Menzer~~ — Alteration — Morenci 5-3-88

ser vein cuts K spar
Lar aplite cuts veins
Qtz moly latest veins
biotite veins, cut by Q ser veins
Ser vein + py cut moly veins

3.7 335°C fluid incls
Salinity under 20% NaCl

Salvage: qt ser py

magnetite bio alt'n ?
Potassic "

cc blanket confined to
phyllic zone

cc replaces appears to repl by cc
actually cc replaces cpy + bn

steel glance cc observed

4200 bot of pit

D R A F T — October 11, 1977.

FIELD NOTES — Morenci, P.D.
October 6, 1977.

Ken Bennett — chief(?) geologist

Morenci pit --- 60,000 tpd

Metcalf-King 35,000 tpd separate mill,

1st Laramide intr. dio por --- 70 my

" (laccolithic) monz por --- 50 my

plus later monz stock ---

Sequence: oldest to youngest ↓

1. older gr por --- 56 my
2. Morenci Bx qtz vein stockwork
3. Metcalf King Bx
4. Candelaria Bx --- specularite (secondary?) 5/my.
   main stage mineralization
5. Younger gr por 49 my
6. Volcanics --- from 32 my ---

Primary min ~~is~~ in bx same as surrounding rocks, better cc in King bx due to faulting (?)

Morenci bx --- intrusion type, ign. matrix

Metcalf-King bx collapse and intrusion

Candelaria bx --- explosion --- some rounding, total 16 bx pipes

Alteration preceeded min!!

Pervasive phyllic earlier than bx!!

5 deep holes hit K alteration directly beneath Morenci bx ---

Potassic core developed prior, during and after phyllic ---

Hypogene (potassic alteration) shell --- ±.60% Cu fault wedge (small) exposed by erosion of Chase Creek.

Core (under shell) .15% Cu, .025 moly

Supergene up to 1000' thick ---

King: mature cc blanket up-faulted

immature blanket formed below, coincident with sudden drop in water table --- minor oxidation in primary sulph between two blankets

~~coincided?~~

mature blanket now undergoing destruction by leaching, may have formed before volc. (32 my.)

Immature blanket formed <u>after</u> 22 my old basin range faulting

Prod: .5 billion tons .97% Cu.

Reserves plus 1 billion tons (.80?) % Cu

Current mill recovery: 76%

J. H. Courtright.

H. Kreis 1/79

Morenci, Az.

Ariz Dept. of Min. Resources Ap. 1952:

1939-1951   127.33 mm tons of ore mined and they recovered 2,354 mm lbs. of copper; 66,050 oz Au; 4.20 mm oz Ag

Recovered grade of Ag: $\frac{4.20 \text{ mm oz Ag}}{127.33 \text{ tons}}$ = 0.033 oz/ton recov

Recovered grade of Au: $\frac{0.06605 \text{ mm oz Au}}{127.33 \text{ tons}}$ = 0.0005 oz/ton recov.

J.H. Courtright memo of 10-6-1950 (AIME field trip):
Mill recovery: 87% (chalcocite ore) in 1% Cu ore
MoS_2 Grade: 0.005% MoS_2
Zn Grade: 0.10% Zn

REPRINTED FROM

Geology of the PORPHYRY COPPER DEPOSITS

Southwestern North America

Edited by
Spencer R. Titley and Carol L. Hicks

THE UNIVERSITY OF ARIZONA PRESS
Tucson, Arizona, U.S.A.

◆ ◆ ◆ THE MORENCI DISTRICT

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

INTRODUCTION

Location

The Morenci Pit of the Phelps Dodge Corp., the easternmost copper mine in Arizona is in Greenlee County, Arizona, 4 miles northwest of Clifton, the county seat. At the south edge of the mine, at an average altitude of 4,800 feet is the town of Morenci. The concentrator and smelter are 1½ miles southeast of town. The site of the former mining town of Metcalf—now dismantled and chiefly of historical interest—is 5½ miles north of Clifton on Route 666.

History

Discovery. Located far within territory dominated by Apache Indians, the Morenci copper deposits were discovered relatively late. The first report was made in 1865 by an Army patrol in pursuit of Indians, but mining interest began in 1870 when placer gold was found by ranchers from Silver City, New Mexico. Three of these ranchers, Robert and James Metcalf and Joe Yankie, located claims in 1872, and began mining in areas that were to become the towns of Morenci and Metcalf.

Although mining by Americans began 70 years later than at Santa Rita and 20 years later than at Ajo, growth was rapid, and Morenci became the first important copper-producing district in Arizona.

Longfellow Copper Co. The first claims were sold to Henry and Charles Lezinsky, merchants in Las Cruces, New Mexico. The Longfellow Copper Co. was formed to mine oxidized replacement ore and, by 1880, production reached 40 tons per day of ore averaging 20 percent copper. Black copper was smelted from self-fluxing ore, first in mesquite-fueled adobe furnaces, then in water-jacket furnaces, and hauled 1,200 miles by wagon to Kansas City.

Because of the difficulties in hauling ore and fear of imminent caving in the Longfellow mine, the property was sold to the Arizona Copper Co., Ltd. in 1882.

Detroit Copper Co. In 1874, William Church obtained options on four claims and, financed by E. B. Ward, organized the Detroit Copper Co. The community that arose on these claims first became known as Joy's Camp, after the claim surveyor, but the name later was changed to Morenci, after a town in Michigan.

Oxidized ore was mined from the East Yankie mine and smelted in Clifton, which grew up around the early smelters on the San Francisco River. The smelter was moved to Morenci in 1884 because of Indian raids and transportation costs. Church went to New York and, for $50,000, sold half interest in the company to the partnership of Phelps, Dodge and Co., then a mercantile firm.

The first copper concentrator in Arizona, a 50-ton jig mill, was built in 1886 to treat oxidized ores containing 6½ percent copper, and until 1892 the company produced 1½ to 5 million pounds of copper a year. When the price of copper dropped to 10 cents, the company shut down in 1892, and, lacking capital to resume production, Church sold his interest to the Phelps Dodge Co. The old name was retained, and production from the Arizona Central, Copper Mountain, Manganese Blue, Ryerson, and Montezuma mines increased from 7 million pounds of copper in 1897 to 29 million pounds in 1908.

Arizona Copper Co., Ltd. After the purchase of the Longfellow Copper Co. by the Arizona Copper Co., Ltd. in 1882, a railroad was built from the newly completed Southern Pacific main line through Lordsburg, New Mexico, and a new smelter was constructed at Clifton.

James Colquhoun, an engineer who was later to become manager and president, improved smelting and began leaching low-grade ore. The Metcalf, Queen, and Detroit mines were all supplying oxidized ore by 1885, and in 1886 a 100-ton concentrator was built in Clifton. The company survived the critical period after 1892, when the Detroit Copper Co. closed, by leaching the jig-tailing from the mill. A sulfuric acid plant at the Clifton smelter produced 10 tons of acid per day.

Low-grade sulfides in porphyry were explored in 1900 when the carbonate oxide ores were nearly depleted. By 1904, the Humboldt mine, at the south edge of the present mine, was the company's main producer. To treat this 3 to 4 percent ore, the 5,000-ton

COPPER PRODUCTION IN THE MORENCI DISTRICT

1. *Underground production, 1872–1932 (tons of ore treated and tons of copper produced)*

Company	Direct smelting		Treated by concentrators			
	Oxidized ore		Oxidized ore		Sulfide ore	
	Ore (tons)	Copper (tons)	Ore (tons)	Copper (tons)	Ore (tons)	Copper (tons)
Longfellow Copper Co.	50,000	10,000				
Detroit Copper Co.	175,000	35,000	315,000	20,000	6,670,000	135,000
Arizona Copper Co.	200,000	40,000	2,020,000	120,000	14,780,000	295,000
Shannon Copper Co.			1,410,000	85,000		
Phelps Dodge Corp.					17,727,000	368,000
TOTAL	430,000	85,000	3,745,000	225,000	39,177,000	798,000

MORENCI OPEN-PIT MINE

2. *Production, 1937–1963*

Year	Total material (tons)	Ore (tons)	Copper produced (tons)
Prior to 1941	30,242,157	950,460	—
1941	21,269,211	942,876	—
1942	30,611,732	7,713,896	54,126
1943	40,756,353	9,652,316	78,537
1944	31,237,585	11,328,097	104,567
1945	22,018,822	10,432,653	100,522
1946	21,441,215	9,604,670	95,245
1947	35,137,702	14,875,138	148,086
1948	36,006,836	15,637,928	149,028
1949	35,016,445	14,555,594	139,395
1950	42,829,672	16,094,858	151,503
1951	43,986,406	15,537,924	139,981
1952	44,650,524	15,655,997	119,036
1953	46,350,869	16,180,061	119,713
1954	47,201,323	15,463,147	110,501
1955	49,048,202	15,899,410	121,242
1956	54,582,550	16,794,287	123,470
1957	47,376,123	14,767,611	103,829
1958	39,939,037	13,039,187	93,136
1959	29,443,024	10,513,023	73,308
1960	35,713,846	14,499,830	103,221
1961	43,460,076	16,285,698	108,622
1962	43,522,456	16,983,181	118,748
1963	45,126,392	17,140,754	118,776
TOTAL	916,968,558	310,548,596	2,474,592

No. 6 concentrator was built in 1906. Foundations of the structure are still standing above the Morenci athletic field. About 24 million tons of ore had been treated by 1932 when the concentrator was closed. In 1913, the first reverberatory furnace in the district was built south of Clifton and operated until 1932. Only the stack is now standing. In 1920 the Arizona Copper Co. purchased the Shannon Copper Co. In the following year, all property was sold to the Phelps Dodge Corp.

A major achievement of the Arizona Copper Co. was its development of the low-grade sulfide ores and its early success, perhaps the first in the country, in concentrating this porphyry ore.

Shannon Copper Co. The Shannon Copper Co. began operations in 1901 after acquiring the Shannon mine above Metcalf and purchasing several claims from the Arizona Copper Co. A mill and smelter were built at the south edge of Clifton, and mining of carbonate and sulfide ores continued until 1920. The property was then sold back to the Arizona Copper Co.

Phelps Dodge Corp. In 1921 the Phelps Dodge Corp. became the sole operator in the district. Subsequent production was chiefly from the Humboldt mine, where block caving of 2 to 3 percent ores commenced.

Exploration of the disseminated ore body north of the Humboldt mine indicated 200 to 300 million tons of 1 percent ore, which could be mined by open-pit methods. The underground mine was closed in 1932. Open-pit stripping was commenced in 1937. The early ore developed by stripping was stockpiled, and the first ore was delivered to the newly completed 25,000-ton mill and smelter in 1942.

During the war, production was increased using facilities leased and subsequently purchased from the Defense Plant Corp. By the latter part of 1963 the concentrator was processing about 60,000 tons of ore per day.

GENERAL GEOLOGY

Regional Setting

The Morenci district is in a transitional zone between the Basin and Range and the Colorado Plateau physiographic provinces. The region is primarily an intricately faulted plateau covered with volcanic flows, although volcanic rocks are now absent in the central part of the district. The dominant physiography reflects headwater erosion imposed on large faulted blocks of sedimentary, intrusive, and extrusive rocks.

The average altitude in Morenci is 4,800 feet, but precipitous granite ridges north of the mine rise 2,000 feet above the town, and southward-flowing streams have eroded deep canyons in the east and west parts of the district. A wide conglomerate-filled valley, with rolling hills and deeply incised canyons, extends south from the edge of the district.

Rock Types

The rocks in the district comprise an interrupted sequence from the Precambrian basement to Tertiary volcanic flows. The Precambrian rocks consist of schist, quartzite, granite, and granodiorite. Resting unconformably upon the basement is about 1,000 feet of Paleozoic sedimentary rocks consisting of quartzite, limestone, and shale. These are overlain by remnants of Cretaceous shale and sandstone that are as much as 840 feet thick.

Tertiary volcanic flows and intrusive pipes of basalt, andesite, and rhyolite encircle the district. Coarse semiconsolidated Gila Conglomerate is present south of the district.

Precambrian Rocks. *Pinal Schist.* Steeply dipping beds of schist and quartzite have been exposed by the erosion of basalt and rhyolite flows 8 miles north of Morenci. The reddish beds have been termed sericite schist (4) and metaquartzite. They strike east with very steep southward dips and include remnants of tight overturned folds.

The quartzite locally contains abundant specularite or powdery hematite and is often dark red. Veins and replacement masses of milky quartz are abundant, and the quartz commonly occurs as well-rounded cobbles in the Cambrian basal conglomerate.

The schist appears to be predominantly of sedimentary origin. Small bands or masses of amphibolite also have been noted.

Although an intrusive relation with the predominant basement granite has not been verified, the schist and quartzite are considered to be older Precambrian and the oldest rocks found in the Morenci district. The schist appears to be conformable with the older quartzite, and both were involved in folding of larger magnitude than ever again recorded.

Granite-granodiorite complex. Underlying the sedimentary series in the southern part of the district and constituting the principal exposed rock in the northern part is an intrusive Precambrian granite-granodiorite complex.

The granite is reddish, coarse-grained, consists of orthoclase, albite, quartz, and minor biotite, and locally contains dikes and masses of red aplite and porphyritic granite.

The granodiorite is usually green, coarse grained, and consists of oligoclase or andesine and biotite with orthoclase and quartz. A local dark-gray, gabbroic-appearing facies contains hornblende rather than biotite and some labradorite, but the major constituents are those of granodiorite. There is a suggestion that the granodiorite is younger than the granite in age, although the evidence is meager.

Paleozoic and Mesozoic Sedimentary Rocks. *General.* Ages of the sedimentary rock units have been assigned by Lindgren (4) on the basis of limited fossil evidence and by correlation with similar units described by Ransome in Globe and Bisbee. Lindgren's nomenclature will be followed in this paper. All Paleozoic formations appear to be conformable, although—as elsewhere in Arizona—no Silurian rocks are recognized. Cretaceous rocks were deposited after regional tilting and pronounced erosion.

Coronado Quartzite. The thick-bedded tan to maroon Coronado Quartzite of Cambrian age lies on the Precambrian basement. Grain size is generally less than 1 mm, but coarse-graded bedding and intercalated shale are present in the lower part of the formation. The thickness varies from 150 to 250 feet, but the formation is 200 feet thick south of the open pit. Steep-faced remnants remain at the tops of many granite ridges.

A coarse basal conglomerate is present locally but is usually less than 10 feet thick. It consists of well-rounded cobbles and boulders of quartzite, white quartz, and gray schist cemented by sand and feldspathic debris.

Longfellow Limestone. About 400 feet of thin-bedded, gray to buff, argillaceous Ordovician Longfellow Limestone lies conformably on the Coronado Quartzite. The texture of the calcite varies from normally dense to coarsely crystalline. Considerable detrital quartz and clay are present in the limestone, and calcareous shale interbeds occur near the base of the formation.

Several members are discernible; most conspicuous, however, is a moderately thick sandy bed near the base overlain by a thick-bedded series containing thin irregular bands and nodules of chert.

Morenci Formation. Lying above the Longfellow Limestone, and distinguished from it in its lower part chiefly by a black color and knobby or pitted weathered appearance, is the argillaceous limestone member of the Devonian Morenci Formation. Fine grained, and black for the most part, it is 75 feet thick and is overlain by 100 feet of brown shale that comprises the upper member. The shale is normally fissile when unaltered. Where exposed north of the district below volcanic flows, the shale is dark reddish brown and fissile.

Modoc Limestone. In Morenci, the Mississippian Modoc Limestone consists of 170 feet of thick-bedded, gray, fossiliferous limestone. An unconformity between the Devonian and Mississippian formations, which is widely observed elsewhere in Arizona, is not evident.

The formation includes thin beds of a coralline limestone and quartzite, a moderate bed of dolomitic limestone, and a thick bed of crinoidal limestone. The latter is the most dominant and diagnostic member; it is almost pure calcium carbonate and the source for metallurgical limestone in the district. The upper surface of the formation is severely eroded, and the formation is absent 1½ miles southwest of town.

Pinkard Formation. The Cretaceous Pinkard Formation lies unconformably on sedimentary rocks of Ordovician, Devonian, or Mississippian age. All rocks of intervening age are absent.

The formation consists of shale and sandstone and has a maximum known thickness of 840 feet. However, most exposures are less than 200 feet thick. It is present chiefly in the southwest part of the district, but from 2 to 15 feet remain on a dip slope in the eastern part of Morenci. It is absent in the northern part of the district.

The rocks are marine and terrestrial in origin. Brachiopods have been found in calcareous sandstone beds, but large ferns are present in some of the shale. Thin discontinuous beds or masses of limestone occur, but their form and origin are uncertain.

Post-Precambrian Igneous Rocks. *General.* After the intrusion of the Precambrian granite-granodiorite complex, there appears to have been no igneous activity until the Laramide Revolution of Cretaceous-Tertiary time.

The stocks or laccoliths and associated dikes and sills emplaced at that time are almost entirely porphyritic in texture and consist of three distinct stages. These three stages represent, from oldest to youngest, progressive composition variation from diorite to quartz monzonite to granite.

Diorite porphyry. The southwestern part of the intrusive complex is a gray mottled diorite porphyry containing large phenocrysts of hornblende and labradorite. The hornblende and biotite, when present, are altered to epidote and chlorite, but the rock is unmineralized. This intrusive forms a thick sheet or laccolith in Cretaceous shale. It has an exposed thickness of 650 feet and an exposed area of 1½ square miles.

South of Morenci there is a smaller sill that has been eroded to a thickness of 150 feet. Several small remnants are present between the two larger masses, and some degree of continuity probably once existed. Diorite porphyry fragments are prominent in the local Gila Conglomerate.

Most diorite porphyry occurs in Cretaceous shale southwest of the other large intrusives, although it does occur in Morenci Canyon and at Garfield. Forceable intrusion apparently was usually possible only in the relatively shallow Pinkard shale beds and occurred above the sandstone member 200 feet above the base of the formation.

Quartz monzonite porphyry. The monzonite porphyry intrusive has the greatest exposed area and is the principal ore-bearing rock. It consists of small closely-packed phenocrysts of orthoclase, albite, and oligoclase in a microcrystalline groundmass of quartz and feldspar. Small quartz phenocrysts are present only locally, and quartz is generally confined to the groundmass. Biotite appears to have been abundant but rarely preserved. When only weakly altered, the rock is gray, brownish gray, or greenish gray; it is generally strongly altered and light gray or white.

Granite porphyry. Much of the central part of the intrusive complex consists of granite porphyry containing medium to large well-spaced phenocrysts of orthoclase, albite, and quartz.

Several ages of granite porphyry occur and have intrusive contacts and marked textural differences. The youngest granite porphyry contains euhedral quartz phenocrysts as much as 1 cm in diameter and is weakly mineralized. The older granite porphyry usually contains smaller quartz phenocrysts and more closely spaced feldspar phenocrysts. Texturally it appears similar to the quartz monzonite porphyry.

Dikes and sills. Dikes and sills of the three major rock types are present, but those consisting of quartz monzonite porphyry and granite porphyry predominate. Sills are confined to the sedimentary rocks, especially in Morenci where widespread contact alteration has occurred, and northeast-trending dikes occur both within and parallel to the principal intrusive.

Dikes of diorite porphyry are rare, but a transitional or more acid facies is present in the southwestern area. Dikes of granite porphyry are common in the district.

Diabase dikes are also common and consist chiefly of augite, labradorite, and hornblende, which were altered to chlorite, and epidote (6). Small masses of coarse white oligoclase containing biotite, hornblende, and quartz are sometimes present in the dikes. The dikes are dark greenish black or mottled, and the texture varies from finely ophitic to coarsely granular. Rounded partially assimilated fragments of porphyry frequently occur in the dikes, and altered granite fragments may be present. Pyrite and magnetite are abundant, and a small amount of chalcopyrite can be observed. Frequently the dikes do not crop out but are seen in drill-hole cuttings and core.

Tertiary volcanics. Except for the conglomerate and lake beds of the San Francisco and Gila River valleys, the district is encircled by Tertiary lava. The series includes rhyolite, basalt, andesite, rhyolite tuff, and perlite. The final eruption deposited a rhyolite tuff breccia. Plugs and vents are exposed in the basalt north and northeast of the district. The flows appear to have had diverse sources, and the sequence is nowhere present in its entirety.

Structure

Regional. Major regional structures are associated with igneous activity, either the intrusion of porphyry during the Late Cretaceous or early Tertiary Period or the eruption of lavas during the late Tertiary Period. Although features of Precambrian age may have localized the subsequent Laramide intrusions, the nature of this influence is purely speculative.

There is ample evidence, however, that stability prevailed during most and perhaps all the Paleozoic Era. The great disruptions associated with the Laramide intrusion resulted in northeast- or east-striking step faults, which caused a progressive southward lowering of the faulted blocks. Thus, the dominant trend of the main intrusive, associated dikes, veins, and early faults is northeast.

Nature of the Intrusive. *Sequence.* The main intrusive is believed to have been emplaced as a sequence of events of relatively similar age and source. Locally, rocks of transitional appearance are found, but mutual contacts are most frequently abrupt, and the intrusive relation of dikes and apophyses is evident. Many relations are obscured by alteration or erosion, however, and considerable speculation is necessary to build the complete sequence.

The evidence allows us to postulate a series of progressively more acid intrusions, marred by the relatively late intrusion of diabase in the form of minor dikes and masses. The diorite porphyry has not been observed to have intruded any other igneous rocks and may even be gradational into the monzonite porphyry on its northeast border. It is cut by late dikes that also intrude the monzonite porphyry. The centrally located quartz monzonite porphyry intrusive constitutes the present ore body.

The central part of the quartz monzonite intrusive, apparently essentially laccolithic in character, was invaded by a series of successive intrusions of granite porphyry. This intrusive activity repeatedly opened and reopened fractures in the monzonite porphyry making it a ready host for the mineralization following each intrusion.

Diabase dikes, minor in quantity but important in the ore picture, were late in the sequence. The dikes appear to have been intruded prior to the latest granite porphyry dikes, but some overlap may have occurred.

Form of the main intrusive. The Laramide intrusive is exposed for 10 miles along its strike and is 1 to 4 miles wide. It is elongated in a northeast direction, and dikes extend beyond the principal mass at both ends. The northern edge is chiefly in contact with granite, and sedimentary rocks are present along a large part of the southern contact.

The diorite porphyry occurs as a laccolith and thick sills, intruded into Cretaceous shales and more rarely into the Paleozoic sediments. Concordant bottoms are exposed in the small bodies, and peripheral tilting of the sedimentary beds is associated with the large intrusive 2 miles west of Morenci.

The form of the quartz monzonite porphyry appears to be both stocklike and laccolithic with passive engulfments and embayments into the granitic basement and, locally at least, intrusion of thick sheets above the basement and arching of peripheral sedimentary beds.

In parts of the south contact of the ore body there is a distinct doming of the sediments, and porphyry has engulfed and appears to have isolated large sedimentary blocks. However, the sedimentary beds have not lost their stratigraphic position, and no major dislocations have occurred.

The most pronounced tilting of peripheral sedimentary beds occurred in about the southwest part of the intrusive where a small granite porphyry mass was intruded near the monzonite porphyry-sedimentary contact. Sedimentary rocks and their basement beds are tilted 30° to 60°. Present evidence suggests that the intrusive has the form of an elongated stock-dike system with lateral southward spreading near the top of the basement.

The granite porphyry was intruded as dikes and elongated masses along the northeast axis of the monzonite porphyry intrusive and did not extend far into the sedimentary beds. Remnants of Paleozoic sedimentary rocks occur within or on the intrusives in several places. The dike swarm appears to have intruded into tensional fractures produced by arching along the axis of the intrusive.

Structural history of the intrusion. Sedimentary rocks are almost devoid of folds but dip southwest in the district. This gentle but uniform tilting involved the basement, and the dip persists to the lowermost sedimentary beds. North of the district the sparsely exposed beds dip northwest, and a large westward-plunging arch is present whose crest is centered 2 to 3 miles north of the main intrusive.

Post-intrusive structures. The subsequent late Tertiary normal faulting was predominantly northwestern in strike. It displaced the already-formed chalcocite enrichment blanket and initiated the principal southwest-flowing drainage valleys. This faulting probably occurred both before and after the Tertiary volcanic eruptions of basalt and rhyolite, and in many instances it displaced the Pliocene Gila Conglomerate.

The faulting caused large and small dislocations of numerous blocks and directly influenced the present character of the district.

Local Structure. *Breccia pipes.* Three small breccia pipes are present in the district. Two are northeast of the mine in the youngest granite porphyry. They are half a mile apart and are elliptical with long axes of 1,400 and 2,400 feet in length. The breccia consists of angular fragments of granite porphyry and granite cemented by quartz. The fragments are generally less than a foot and commonly only a few inches in diameter. The pipes are more strongly mineralized than adjacent rocks but are deeply oxidized and contain localized unimportant copper mineralization.

In the southeast part of the mine, a cemented breccia of monzonite porphyry and granite fragments is exposed over an area of 1,200 by 200 feet. This is the area where the porphyry occurs as a thick sheet above the basement, and the exposed breccia extends through the porphyry as a northeast-plunging sheet of breccia and intensely shattered granite. This appears to be an explosion breccia at the contact of the sloping granite basement and contains chalcopyrite mineralization at depth.

All the breccia pipes or sheets are elongated west or northwest and are associated in varying degree with porphyry-granite contacts. They apparently were formed by the explosive release of fluids from the late relatively barren granite porphyry.

Fracturing. Intense fracturing in the ore body commonly has broken the quartz monzonite porphyry into fragments only a few inches in diameter. Granite and granite porphyry are generally less fractured and often very blocky.

The fractures are erratic in strike and fairly abundant in all orientations except north-northwest and east-northeast. Several preferential orientations are probable.

North-dipping fractures having a strike between N. 45° E. and N. 65° E. are most persistent and best mineralized. The pronounced sheeting on the west and east sides of the mine and veins in the south and central parts of the mine are examples of this group. Early regional faults having this strike generally dip southward.

Subsidiary fractures occur near N. 75° W. and N. 12° E. The fractures dip in both directions but most commonly south. In the south and east parts of the mine, fractures also occur near N. 35° E. and N. 40° W. These are not associated with post-ore northwest faulting but are mineralized and related to structures into which a diabase dike was emplaced in the southeast part of the mine.

The fractures most commonly dip 30° to 45°, 60° to 80°, or vertically; two-thirds of the fractures dip 60° to 80°. The vertical bisectors of conjugate sets intersect acute angles of 60° to 80°, and the lines of intersection plunge, in a general way, toward the north-central part of the mine.

It is speculated that the principal northeast joints, sheeting, and veins represent both tensional and shear fracturing associated with regional south-dipping faults, which may have localized the emplacement of the porphyry and persisted through the early phases of the intrusion. Two of these faults are present northwest and southeast of the mine but become very wide zones in the porphyry and cannot be easily traced. They are mineralized and locally intruded by mineralized diabase and monzonite porphyry dikes.

ECONOMIC GEOLOGY

General Nature of the Mineralization

The main ore body is roughly elliptical in plan, about 1⅛ by 1 mile, and encompasses about two-thirds of the quartz-monzonite porphyry intrusive. The leached capping that covered the ore body ranged from 50 to 600 feet thick; much of this capping has now been removed by mining operations. The bottom of the capping conformed generally to the topography and sloped southeasterly toward Chase Creek.

The enrichment blanket ranges in thickness from 50 to 1,000 feet. The blanket is thin and high on the west side of the mine and thickens as it dips to the east. The dip is rather uniform, except that the eastern two-thirds of the blanket has been displaced downward about 200 feet by the Copper Mountain fault.

Because of the rapid erosion following the late Tertiary faulting, changing water-table relations, and the probable interruption of enrichment due to temporary volcanic cover, it would appear that the bulk of the capping and enrichment developed during middle Tertiary time. Subsequent weathering caused the leaching of the top of the enrichment blanket and smoothed out the upper step created by the Copper Mountain fault. It is uncertain whether the enrichment blanket was being destroyed or the grade of the blanket was being increased. Recent erosion has cut drastically into the blanket.

There is some evidence which suggests that the present porphyry ore body may have been covered by altered and mineralized sediments, which now have been largely removed by erosion. If this were the case, the oxidation and leaching of replacement-type ore bodies in these sediments could have provided a significant part of the copper that is in the present enrichment blanket.

The mineralization extends for 1,500 feet from the southern contact of the intrusive into the sediments. Chalcopyrite and sphalerite occur locally; supergene enrichment is confined to pyritic veins and noncarbonate rocks. Oxidized veins and replacements in this area were once the principal sources of ore.

The northern edge of the ore body is marked by a gradual decrease in the intensity of the mineralization, accompanied by deep oxidation that has destroyed much of the enrichment in the resistant Precambrian granite. The presence of relict sulfides and oxidation products indicates that the enrichment zone once extended high up on American Mountain northwest of the mine. West of the mine the mineralization weakens rapidly and becomes increasingly more pyritic.

The eastern edge of the mine is bounded by a pyritic zone and by the canyon of Chase Creek, which in part follows the Kingbolt fault. East of the canyon, weak disseminated chalcopyrite (with minor pyrite) mineralization occurs in the Precambrian granite and associated porphyry dikes. Here the oxidized capping is thin, and enrichment is only weakly developed in the disseminated sulfides. Farther to the east there are two northeasterly trending fault veins that contain enriched pyrite and chalcopyrite. There are also several late northwesterly trending faults.

Northeast of the mine some chalcocite enrichment occurs in the granite porphyry and peripheral granite near Metcalf. Here the leached capping ranges in thickness from 200 to 1,000 feet. The enrichment blanket dips to the southwest and vaguely parallels the topography but is cut through by the deeper canyons.

Chalcopyrite mineralization similar to that east of Chase Creek and the Kingbolt fault has been encountered at considerable depths in some exploratory drill holes in the eastern part of the mine. This chalcopyrite-low pyrite mineralization underlies several hundred feet of weakly enriched strong pyritic mineralization. If the areas of chalcopyrite mineralization on either side of the fault are related, a zonal arrangement is indicated in which an area of chalcopyrite is surrounded by a pyritic envelope that is, in turn, surrounded by a large envelope of weak protore. This suggested zoning also is evidenced by a change in the character of the primary alteration in the mine—from argillic on the west side to sericite-quartz alteration on the east side of the mine. The foregoing would imply that the center of the mineralization, and thus presumably an ore conduit, is located in the area east of Chase Creek and has been offset by the Kingbolt fault.

Mineralization

The normal protore consists of small veinlets and disseminations of pyrite, chalcopyrite, molybdenite, sphalerite, rare galena, gold, and silver. It contains 0.10 to 0.15 percent copper and 3½ to 8 percent pyrite. Chalcopyrite, the only primary copper mineral, generally is difficult to observe in most of the protore.

Molybdenite generally occurs in thin films on fractures devoid of other sulfides but also occurs as flakes and parallel streaks in small quartz veinlets. Rarely, blebs of chalcopyrite occur where molybdenite is the earlier formed mineral. Although widely distributed in both the sedimentary and intrusive rocks, the greatest concentration of molybdenite occurs associated with granite porphyry and to a lesser extent with the Precambrian granite.

Zinc is present in the protore in concentrations only slightly less than copper, but sphalerite is normally entirely replaced in the enrichment blanket. Galena has been found with sphalerite in small veinlets in limestone and porphyry south and west of the mine. A single specimen of stibnite has been identified in the porphyry ore, and torbernite was identified in several samples.

The combined value of gold and silver is only a few cents per ton of ore. The average Au:Ag ratio is probably 1:80, although the ratio in mined ore has been 1:50. Gold and silver are sometimes enriched two to three times in the upper part of the enrichment zone or near the base of the oxidized zone. Both are more abundant in porphyry than in granite, although the ratios are similar; both are more abundant in the western part of the mine where primary alteration is less intense, and their ratio increases to 1:30. Ore containing greater amounts of molybdenite and chalcopyrite also tends to contain less gold and silver, particularly in granitic ore low in pyrite. Ore in altered sedimentary rocks contains more gold and silver, with veins in sediments containing a greater amount than replacements.

Gold and silver, therefore, follow a predictable zoning distribution with both, but silver to a greater degree, more abundant in less altered areas away from higher temperature molybdenite-chalcopyrite mineralization.

In the supergene-enriched ore chalcocite has replaced pyrite in varying amounts, dependent on the intensity of enrichment. Covellite is often, although not uniformly, present at the top of the enriched zone and is particularly obvious in very weakly enriched ores.

Native copper is not abundant but occasionally occurs in the lower part of the capping or in oxidized veins. It is present as relatively pure blebs, stringers, or sheets associated with cuprite and limonite. In partially oxidized veins, it may occur in the enriched zone associated with chalcocite and cuprite.

Thin plates and nodules of turquoise occur in close association with a generally buried diabase dike system, which crosses the ore body from northwest to southeast.

Weathering

Weathering of the protore began prior to the period of Tertiary volcanism, and oxidized copper ore has been found in contact with basalt flows. The district is encircled by volcanic flows, and it is probable that the ore body also was once covered. The principal effect of the resumption of weathering and erosion may have been the creation of deep canyons in the enrichment zone.

The major oxidation products are goethite and hematite; jarosite is widespread but most dramatic as an oxidation product of pyritic veinlets in areas of weak enrichment. The oxidized zone is generally devoid of conspicuous copper minerals, except in areas of relatively fresh porphyry adjacent to strong copper mineralization or in porphyry areas recently overlain by mineralized sediments.

Chrysocolla and malachite and smaller amounts of tenorite, cuprite, brochantite, and azurite are most abundant in or near altered sedimentary rocks and in a low-pyrite area of granite porphyry in the northeastern part of the mine. Frequently, the chrysocolla is pseudomorphic after malachite and brochantite.

Around the periphery of the ore body opal, grayish-blue allophane, gypsum, manganese oxides, basic ferric sulfates, and nontronite also are present, the latter confined to the lower part of the oxidized zone above pyritic zones. Only rarely have oxidized molybdenum minerals been detected.

The above-named minerals occur in sheets or pods in fractures and are associated with channels of solution transport or reprecipitation in the oxidized zone. The chief oxidation minerals associated with the sulfide ore are brochantite and chalcanthite. Melanterite, a white fibrous alum, and probably copiopite are present locally; goethite and nontronite may persist in fractures or veinlets.

The bronchantite occurs as mammillary films or minute sperulites on chalcocite and is possibly the first oxidation product formed. The remaining solutions that migrate form chalcanthite when evaporation occurs.

Hydrothermal Alteration

The identity of the primary clay in the Morenci ore body has been almost completely obliterated by the intensity of the supergene alteration with its attendant general kaolinization. Only the sericite has survived the devastation of the supergene solutions. However, the degree of hydrothermal alteration may be appraised readily by estimating the magnitude of the sericitic alteration.

The classic belief that clay alteration precedes sericitic alteration in the hydrothermal-alteration sequence appears without basis in the district. Here, observation of the protore suggests that as the hydrothermal solutions migrated out from fractures and lost their intensity the alteration changed from sericite to primary clay (possibly largely montmorillonite).

A yellowish-brown montmorillonite occurs immediately below the chalcocite zone. It permeates most of the altered rock and fills fractures for several hundred feet into the protore. It is, by analysis, ½ (Fe, Mg, Ca) $O.Al_2O_3 \cdot 5SiO_2 \cdot nH_2O$, and the iron is readily exchangeable. It is believed to have formed by partial neutralization of deeply percolating iron-rich solutions from which copper has been precipitated and may be characteristic of perched supergene deposits.

The deeper protore is dark gray and, in contrast to the enriched ore, the porphyritic texture and some relict biotite or chlorite are evident. The bleached and clayey appearance of the supergene ore is absent.

Contact Alteration

General. Appreciable contact alteration has occurred in the northern part of Morenci for a distance of 1,500 to 2,000 feet from the mine and in the Metcalf area at the northeast end of the intrusive. In both areas Paleozoic sedimentary rocks are in contact with the main intrusive and have been intruded by dikes and sills. These were the centers of early mining.

In general, the rocks were altered to calc-silicate or pelitic hornfels and skarn of the amphibolite facies. The mineral assemblage consists of diopside, epidote, garnet, and tremolite and local actinolite, chlorite, idocrase, magnetite, specularite, serpentine, and talc. Apatite occurs with pyrite, magnetite, and pyrrhotite in one locality. The high-temperature contact minerals such as wollastonite and the aluminous silicates are absent.

Limestone. Fine-grained light-green or gray diopside has replaced much of the limestone near the main intrusive. Except where intricate flowlike banding occurs, primary features are preserved, and the rock appears to be unaltered. Small pods of sphalerite, pyrite, and chalcopyrite or bands of disseminated magnetite commonly are present. Residual calcite is always present and often abundant. Where replacement was incomplete the rock is often a friable gray or green crystalline aggregate containing minute plates of specularite. Chlorite is very abundant in some areas but is most commonly associated with veins.

Garnet and epidote occur in limestone in proximity to dikes. Epidote is formed adjacent to the dikes as a complete replacement of limestone by granular epidote and, in some exposures, tremolite. These bands are from a few inches to 20 feet wide and appear to be widest in the impure limestone and shale.

Andradite garnet occurs beyond the epidote in honey-brown granular to massive sheets. It forms most widely in the pure Modoc Limestone, and beds in the northeast part of Morenci are completely replaced for as far as 100 feet from the dikes. Small variations in composition are due to the substitution of alumina for iron, and magnesia for lime, in a transition toward grossularite garnet. This transition is observed mainly in the aluminous Longfellow Limestone where the garnet is often yellowish or greenish brown. Silvery plates of specularite and small pods of pyrite, chalcopyrite, and sphalerite occur in the garnet, and a thin band of black siderite is sometimes present at the outer edge of the garnet.

Magnetite occurs widely but is most conspicuous in masses adjacent to dikes and as selective replacements of limestone beds. Where associated with dikes, it formed in place of epidote and garnet, perhaps due to a deficiency of silica.

There is no simple dolomitization that is clearly of contact origin, and apparently there is little recrystallization. A few small masses of marble are present, but their relation to the alteration processes is uncertain.

Shale. The fresh shale is very fissile and brown to red brown in color. When altered it is gray or dark green hornfels with streaks of epidote and specks of pyrite. A fibrous green amphibole replaces chlorite, and, locally, there is bleaching with coarse bands of epidote. Fissility is lost, and the rock becomes blocky and hard. There is a small decrease in lime and an increase in alkalies.

Porphyry Dikes. Although the dikes are spatially and apparently genetically closely related to contact alteration, they are only slightly altered themselves. Some biotite or hornblende is almost always present but may be altered to chlorite. Small pods of epidote have often replaced calcic feldspar, and epidote has formed along fractures and at the edges of the dikes. Silicification is common, but rarely pervasive, and generally affects the groundmass locally. Sericite is absent, and sulfides are rare or absent except in sheared dikes adjacent to faults where vein mineralization is most prevalent. Near the main intrusive, sericitic alteration increases.

Processes. The principal metasomatic additions to

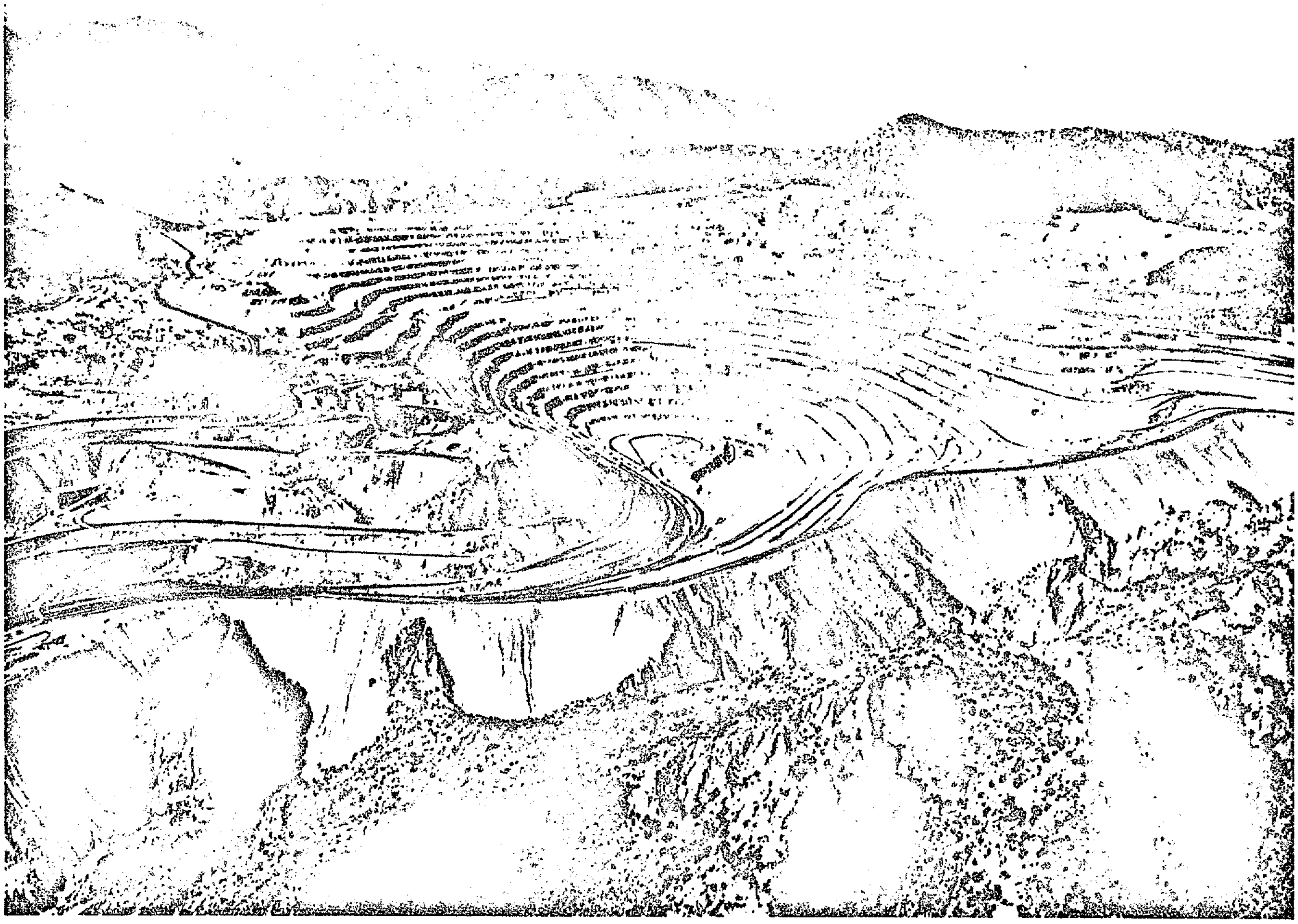


FIGURE 1.—View of the Morenci operation from the southeast.

the altered sediments were silica and magnesia in the diopsidic zones near the main intrusive and silica and iron in the epidote-garnet zones associated with dikes. In both cases, alumina was transported only a short distance from the intrusive. Chemical changes were minor in the shale.

Pervasive alteration extended only a few hundred feet from the main intrusive. It is probable, however, that the temperature of the sedimentary rocks was greatly elevated for a distance of 2,000 feet. Only in this way do the large sheets of garnet associated with small dikes appear to be explainable.

Shale and argillaceous limestone are less dramatically altered than purer limestone, but epidote and pyrite have formed in them more widely. The fine-grained texture may have kinetic significance, but, more probably, the alteration resulted from thermally induced recrystallization in rocks containing higher concentrations of iron and alumina and having no requirement for introduced materials.

Mineralization. Small blebs, stringers, and disseminations of pyrite, sphalerite, and chalcopyrite are present in the altered sedimentary rocks, but the copper is rarely of mineable grade without enrichment.

Early mining was confined to high-grade concentrations of oxidized copper. These were tabular deposits of malachite, azurite, and tenorite located in limestone above or below a nonreactive bed of garnet, shale, or quartzite. Cuprite frequently occurred in the shale.

All these deposits were downdip in a block of limited or interrupted stratigraphic continuity and abutted against a porphyry dike that represented a barrier. The deposits were formed by precipitation of copper in limestone after migration of solutions in the adjacent nonreactive beds, and rich tabular sulfide replacements did not exist.

Secondary chalcocite formed in dikes, quartzite and shale beds, and large pyrite veins as replacement of pyrite. The latter were an important source of oxidized and sulfide ore after the replacement ore bodies were depleted.

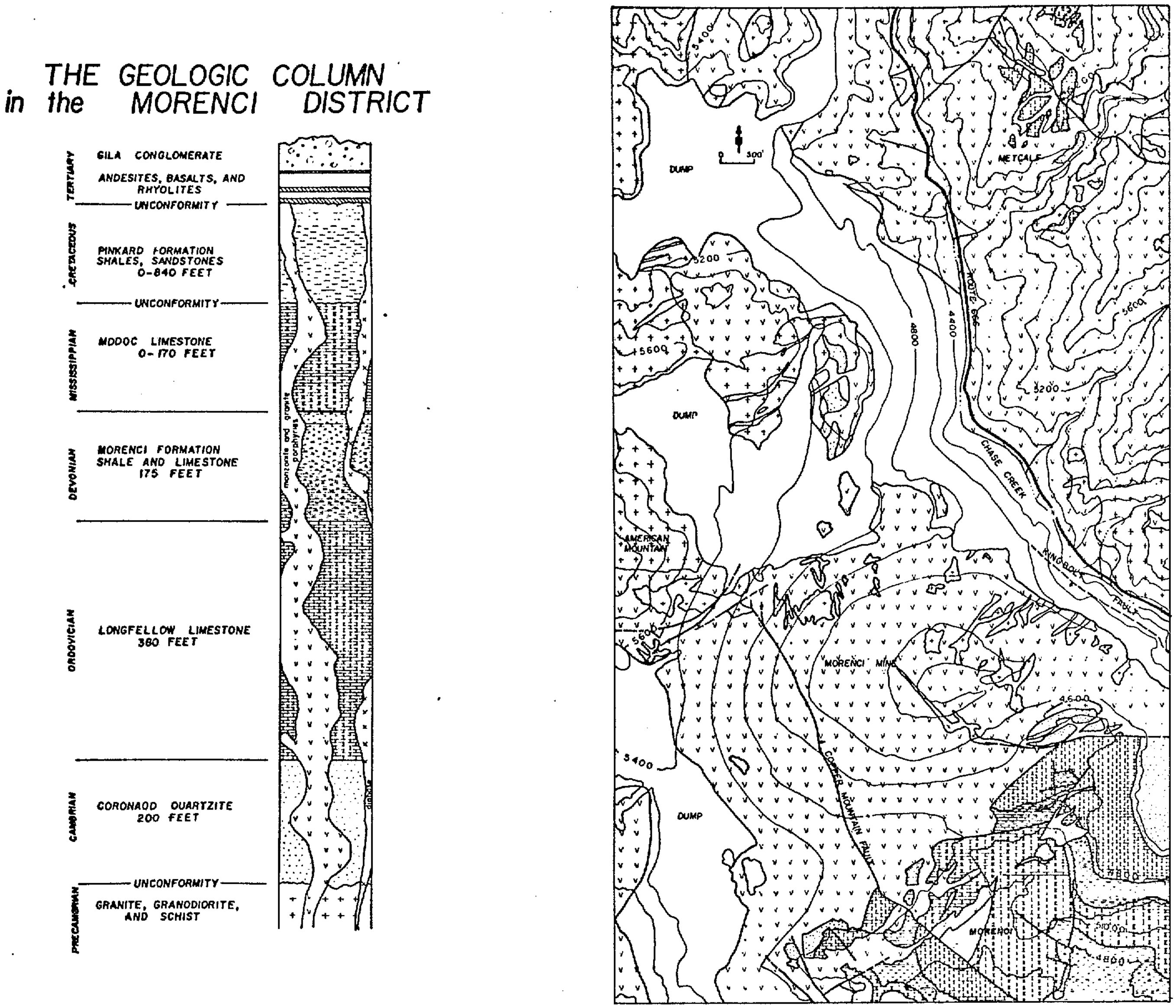


FIGURE 2.—Geologic column and surface geology map of the Morenci district.

SUMMARY

Discovered in 1872, the Morenci district progressed from mining small oxidized replacement deposits, to enriched sulfide veins, to disseminated porphyry ore.

Mining in early 1964 was at the rate of 60,000 tons of ore and 96,000 tons of waste per day. Molybdenum, silver, and gold are recovered as byproducts but are of minor economic importance.

The present ore body was formed by supergene enrichment of a disseminated pyrite-chalcopyrite protore in quartz monzonite porphyry. The chalcocite ore, now averaging less than 1 percent copper, occurs in a blanket 50 to 1,000 feet thick and was overlain by 200 to 600 feet of leached capping.

The elongated Laramide stock was intruded into the Precambrian basement complex and Paleozoic-Mesozoic sedimentary rocks. The complex intrusive consists of diorite, quartz monzonite, and granite porphyry that occur in progressively more acid phases that are age related. Only the younger two are mineralized, although mineralization extends into the basement and peripheral sedimentary rocks. There is a predominant northeast trend to the main intrusive and associated dikes, faults, and veins.

It is proposed that the intrusion was localized along a Precambrian zone of weakness. Final emplacement was centered obliquely across a contact of basement granite and granodiorite, which had the characteristic Precambrian east-west strike.

The enrichment blanket was formed during the Tertiary Period, prior to the late Tertiary volcanism and northwest faulting, and is offset about 200 feet by the Copper Mountain fault. Weathering continued to modify the top of the perched enriched zone as canyons were cut and coarse conglomerate was deposited in the valleys.

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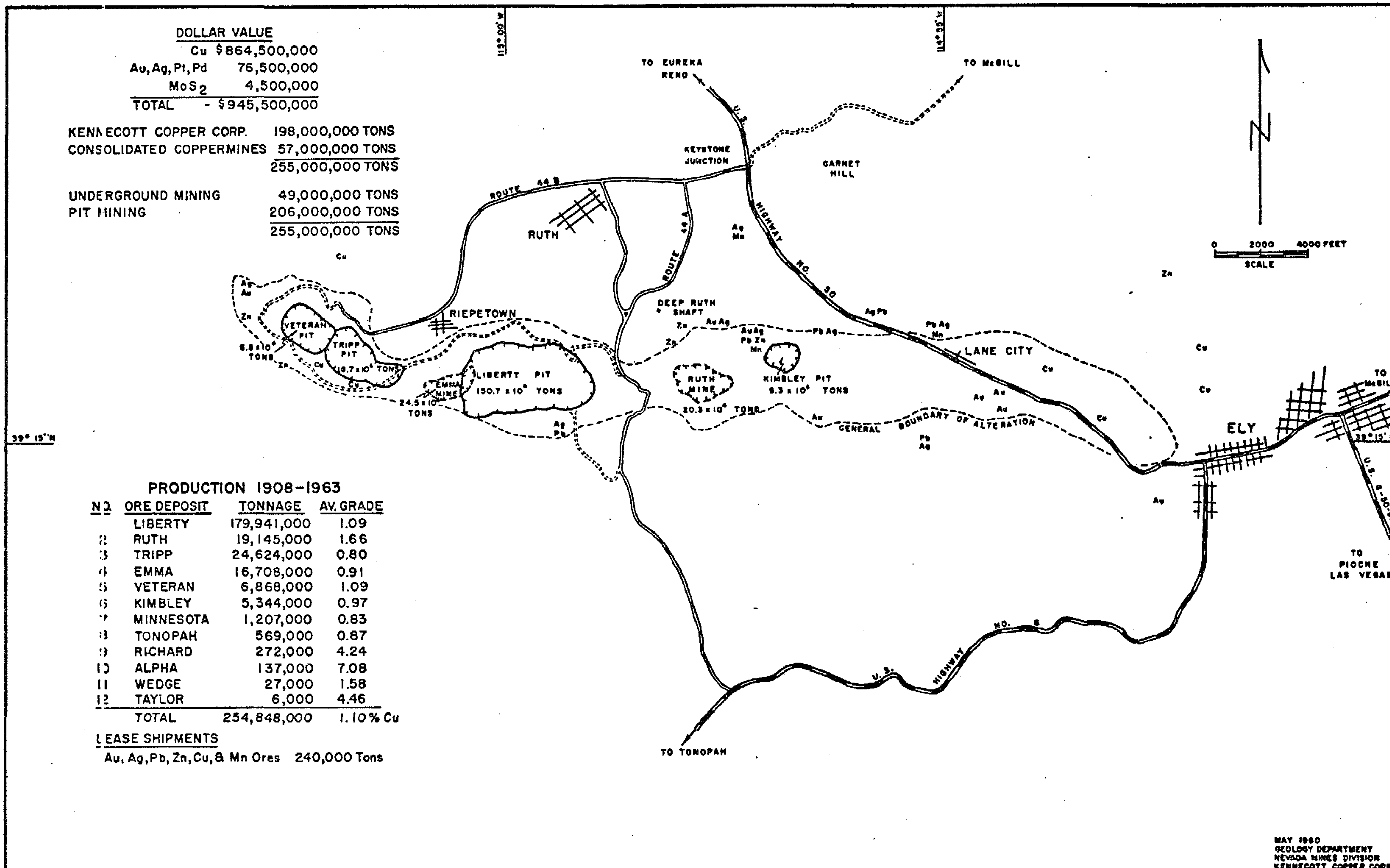

FIGURE 1.—Production map of the Robinson mining district showing the geographic location of copper mines. Chemical symbols show location of base and precious metal production from the peripheral zone.

KURTZ

NAME	GEOMETRY	HOST ROCK AND CONTACT	FRAGMENTS		MATRIX		ALTERATION - MINERALIZATION 1) PRE-BRECCIA HYDROTHERMAL 2) SYN-BRECCIA HYDROTHERMAL 3) POST-BRECCIA HYDROTHERMAL 4) SUPERGENE		REMARKS
			ROCK TYPES (~%)	SIZE, SHAPE, & DISTRIBUTION	MINERAL COMPOSITION-%	TEXTURE & DISTRIBUTION			
MORENCI	Oblate lenticular; 250'(E-W) x 75-200'(vert) x 1600' (N-S). Dips 20-28°N par to P€ flts.	Mp laccolith. Grad with apl, apl grad into mp; bx discontinuous beyond mp-ogp ct.	Mp 70 P€gr 15 db 10 P€apl 3 qtzt(?) } 2 sh(?) }	Micro to 3', mode 1-2 in; ang to subrd. Lath-like at cts to ell at center. No void space. Well mixed fgs, increase db fgs to W & gr fgs to E. fg:mtx = 70:30, constant.	K-feld 60 Q 30 Bio 3 Ser 7	Granitoid. Flow lineation at footwall. Transport Sward at 20-28°. Min 85% Rk fl 15%	1) ser & local Sil. 2) partial K-feld. 3) Q-ser vnlts. 4) Str perv arg, except bx mtx.	1) None. 2) None. 3) Diss py, 50:50=fg: mtx; Q-ser-py, Q-mb, Q-ser-cp vnlts. 4) Wk cv-cc on diss py. Turquoise, wavellite, & alunite.	
METCALF	Oval (as exposed), 650' dia, dip unknown, presumed vert.	Ygp plug. Sharp & somewhat sinuous, near vert.	ogp 85 ygp 5 P€gr 5 Q vns 5	Micro to 130', mode 3-4 in; ang to sbrd. Ell to equid. 5% void space. Center 95% ang fgs to 60% sbrd at cts. fg: mtx = 60-80:20-40.	Ser 30-60 K-feld 10-40 Q 0-30	Rhyolitic to fragmental. Minor flow lineation, random. Min 60% Rk fl 40%	1) Q vning & minor K-feld vning in ogp, Q vning in gr. 2) local Sil in fgs 3) Str ser in mtx, wk in fgs, minor Q-ser-spec vnlts. 4) Mod perv arg alt.	1) No data. 2) minor diss py. 3) Q-ser-spec vnlts, str py diss, in flts, & vnlts. Dike to SW has mb-cc-minor cp diss & as mtx. 4) Local chry on fxs. Wk cc on py diss.	
KING	Oval, 600' (E-W)x 700' (N-S) x 700' vert.	Ygp plug. Ct obscured by alt, sinuous & steep dip.	ogp 80 P€gr 10 Q vns 5 mp 4 ygp 1	Micro to 140', mode 2-4 in, ang to sbrd. Ell to equid. 2% void space. Center 95% ang fgs to 50% sbrd at cts. fg: mtx = 60:40.	Ser 30-60 K-feld 10-40 Q 0-30	Rhyolitic to fragmental. Local flow lineation, random. Min 60% Rk fl 40%	1) Q vning in ogp & gr. 2) local Sil in fgs. 3) Str ser mtx, & mod-str ser of fgs. Q-ser-py vnlts. 4) Str perv arg alt.	1) None 2) Wk diss py. 3) cp wk diss, minor Q-py-cp vnlts, str diss py. Str Q-ser-py vnlts. Q-mb & Q-mb-py vnlts. 4) Str cc-cv on py & cp(?) on fxs, vnlts, flts, & diss. Chry & broch on fxs.	Sheeted wall rk at ct.
CANDELARIA	Oval, inverted cone, 2700' (E-W)x 1900' (N-S), vert exposure 1700'.	Ogp stock. Cts sharp, linear, & 50-70°.	ogp 60 P€gr 25 Q vns 8 P€apl 6 P€sch 1	Micro to 100'x50', mode 3-4 in, ang to sbang, Equid. 15-20% void space. Rk zonation-fgs roughly match wall rk types near cts. fg:mtx= 60-80:20-40	Ser 40 Q 35 Op sp 20 Spec 5	Tightly cemented agg by Q, ser, & spec. Local flow lineation, roughly vert. Min 95% Rk fl 5%	1) Q vning in ogp & gr; K-feld vning in ogp. 2) Sil in mtx, str at top of bx; ser bx mtx. 3) Q-ser vnlts, minor Q-ser-py vnlts. 4) Mod to int arg.	1) None. 2) Op sp filling by spec in bx mtx. 3) Py in flts; minor Q-ser-py vnlts. 4) Conichalcite, bisbeeite, chry, & iron oxide at cts; local chry on fxs in bx, cc on py in vnlts, flts, & diss.	Rhy bx as plugs & dikes intrudes central part of bx; has small sbrd to rd fgs of preexisting rk types- ogp, gr, & Q vns.

Metcalf-King – 16 recognized
largest 650' diameter
xenoliths floating in younger granite-porph plug

4 stages of younger granite porph
1) fragments of same material look like ghosts
2) matrix of granite porph
3) plug
4) ~~plug~~ dikes of g porph

several stages of brecciating – passing – stoping of hood of older granite porph (lots of degassing)
with final ~~clas~~ collapse into younger granite porph plug

Cause of all gassing? – Coronado explosion breccia

K was shown by deep drilling and located at depth along the Morenci bx

Main mineralization cuts all the bx

Alteration 1) qt veins (seen in bx frags as cut off)
2) phyllic – in all fragments but not in groundmass which is qt-K-sericite with pyrite
Mineralization cuts across frags + groundmass.

CCOE 1027 Mo Cqm ~~...~~ .15

500' thick + ore and cut phases 300' below cu zone

Loma Cnt. – seen up to 150' thick

Laramide – oldest – ...
diorite 63
qm-gmp N40E largest intrusion 58? – form of laccolith but overlying my stock in the Morenci area – at Metcalf only stock (N40E strike)
(host of the hypogene shell)

Simic older – g porph stock 56
main stage diss't alt – phyllic + K
Morenci bx
Metcalf-King bx group – all lie with g porph 53
Coronado bx 51
main stage mineralization – mostly veinlets
Younger gt porph occurs still within older g porph 49

Volcanic surround and own covered district 25 (from Blue Ridge) (drilled thru volcanics into Paleozoic)

older granite porph – euhedral qtz pheno – with fluid inclusion halite
abent q.x.
zone plagioclase

younger granite porph plug – partially resorbed bipyramidal qtz phenos
equals degassing
homogeneous
no qt x.
even qt diss
no zoned plagioclase
qtz-sericite groundmass
decrease in 10 to 20 x # of fluid inclusions do not contain any halite

oldest-premineral
Morenci bx – min cuts both matrix and frags
qt-moly
qt-cpy, py, cc
qt Moly
Center equidim frags
edges lath like
intrusion bx = igneous matrix
piping of fluids along thrust sheet (a la Bryant Ridge)
aplite along bottom and around

Metcalf-King = collapse (and intrusion?)
actually ... only ore zone ← Coronado = explosion (occurring due to weathering)
rhyolite dikes intrude Coronado have rounded fragments = secondary Coronado

~ 1,000' depth of blanket
most min in qm + gmp
barren q.x. only in gt porph (mostly old gt porph)
75% of supergene in granite porphyry

FILE: Phelps Dodge

MORENCI Mine

Greenlee Co.

SOCIETY OF MINING ENGINEERS of AIME

345 EAST 47TH STREET, NEW YORK, N. Y. 10017

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W. Kurtz

ORE GENESIS IN THE MORENCI-METCALF DISTRICT

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This paper is to be presented at the AIME Annual Meeting - San Francisco, California - February 20-24, 1972.

INTRODUCTION

The Morenci-Metcalf district is located on the southern slope of the White Mountains in Greenlee County, Arizona. Both porphyry copper deposits are four to six miles northwest of Clifton, the county seat, and the new Metcalf mine is situated approximately one mile northeast of the Morenci open pit (Figure 1). Chase Creek, a south-flowing tributary of the San Francisco River, dissects the district and separates the two ore bodies.

More than 1,200 exploration and development drill holes have been completed in the district and the Morenci-Metcalf ore bodies have been delineated on a 400-foot grid. Recently initiated drilling programs have revealed new data about deeper protore and associated hypogene alteration. This information, correlated with surface mapping and petrographic studies, was utilized to propose a plausible geochronologic sequence for this region. The reasoning behind this study has been helpful in locating new ore beneath leached capping indicative of only protore mineralization.

The scope of this paper is to establish a practical solution to a highly theoretical problem of ore genesis and to familiarize the reader with stratigraphic, structural, and mineralogic events responsible for localizing ore in this district. Continued research will possibly alter the proposed time span and relative displacements, but it is doubtful that the order of events will vary significantly. Geochronologic conclusions are therefore presented as general hypotheses and additional geologic mapping, 72-I-47

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