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VICTOR E. KRAL

COASTAL MINING COMPANY
(THE HANNA MINING COMPANY)

[redacted]

[redacted]
TUCSON, ARIZONA [redacted]

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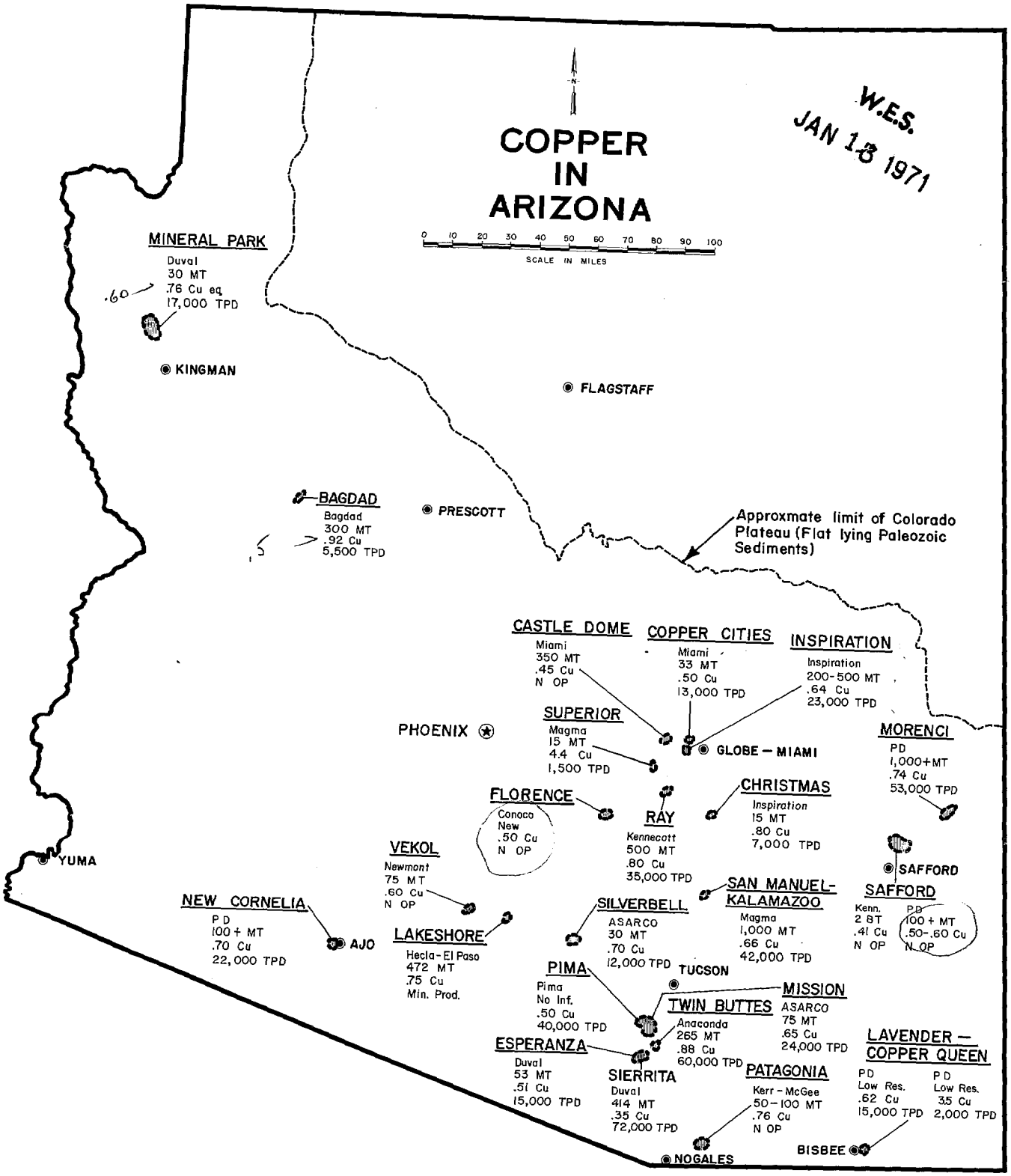

December 1970

Company	Location	Investment $-million	Type of Project	Start-up	Added Capacity	Total Capacity
Government	Titograd		Bauxite-to-ingot complex	1971		55,000 mtpy aluminum
Pechiney supplying technology.						
Combine	Sibenik	88.0	Smelter	1972		60,000 tpy
Project also includes alumina plant at Obrovac which will have 300,000 tpy capacity in 1975. Financing based on $66 million loan from East German government. Operation is a venture of Jadral Co. and Boris Kidric Co. — both of Yugoslavia — and East German partners.						
Combine	Obrovac		Alumina refinery	1972		330,000 tpy
Part of new East German-financed alumina-aluminum complex which includes the Sibenik aluminum smelter.						

Copper — demand spurs numerous new projects

UNITED STATES

Asarco	Casa Grande, Ariz.		Open pit mine, mill			6,000 tpd
Twin orebodies delineated, with the upper to be open pitted, and the lower to be mined by underground methods. Known as the Sacaton deposit.						
Asarco	Tucson, Ariz.		Open pit leach plant	1971		4,000 tpd
New San Xavier operation will treat oxide ore. Cement copper will go to Asarco's Hayden smelter. Reserves total 10.8 million tons averaging about 1% Cu.						
Cities Service Co.	Ducktown, Tenn.	70.0	General plant expansion	1972		
Will result in approximate 25% increase in Cu, Fe and Zn products.						
Cliffs Copper Corp.	Mountain City, Nev.		In situ leaching	1971		4.8 million ppy
Joint venture of Cleveland Cliffs Iron Co. and Du Pont.						
Copper Range Co.	White Pine, Mich.		Mill expansion	1972	7,000 tpd	32,000 tpd
Total copper production capacity will exceed 234 million lbs annually when mill is completed.						
Earth Resources Co.	Cuba, N.M.		Open-pit, mill	1971		3,000 tpd
Operation to be known as Nacimiento mine. Mill, designed by Parsons-Jurden, to cost approximately $5 million. Concentrates to be sold to Asarco.						
Hecla Mining Co.	Casa Grande, Ariz.	100.0	U/G mine, concentrator	1973		32,000 tpy
Lakeshore mine is owned jointly with El Paso Natural Gas Co., and Hecla will manage it.						
Kennecott Copper	Chino, N.M.	4.0	Smelter expansion	1971		
Fourth converter being installed.						
Kennecott Copper	Ely, Nev.	4.0	Smelter expansion	1972		
Company installing fourth converter to give plant standby capacity.						
Kennecott Copper	Ely, Nev.		Open pit	1971		
New Ruth pit will replace other mines in area now being phased out.						
Magma Copper Co.	San Manuel, Ariz.	126.0	Expansion of mine, mill, smelter	1971	20,000 tpd ore	60,000 tpd ore
Prime contractor is Stearns-Roger.						
Magma Copper Co.	San Manuel, Ariz.	34.0	Electrolytic refinery	1971		200,000 tpy
Design allows for increase to 300,000 tpy. Bechtel responsible for engineering, procurement and construction.						
Magma Copper Co.	Superior, Ariz.	55.0	U/G mine, concentrator	1973	20,000 tpy Cu	3,500 tpd ore
Project will double present treatment capacity. New reserves are 10 million tons of 6% Cu. Concentrator being constructed by Stearns-Roger.						
Phelps Dodge	Morenci, Ariz.	100.0	U/G, open pit mines, concentrator	1974		50,000 tpy
Known as the Metcalf mine.						
Phelps Dodge	Tyrone, N.M.		Mine expansion	1972	35,000 tpy copper	90,000 tpy copper
To make up for deferred development of metcalf.						
Pima Mining Co.	Tucson, Ariz.	16.5	Mill expansion	1971	15,000 tpy Cu content	80,000 tpy Cu content
Pima has signed contracts for smelting and refining of the additional output.						
Ponce Mining Company - Cobre Caribe	Puerto Rico	110.0	Open pit, concentrator, smelter	1975		48,000 tpy Cu.
Proposed Amax-Kennecott joint venture pending receipt of mining lease.						

Company	Location	Investment $-million	Type of Project	Start-up	Added Capacity	Total Capacity
U.S. Silver & Mining Corp., Sierra Mineral Management	Mackay, Idaho		Open pit	1971	500 tpm cement copper	
Full production slated for mid-year.						
AUSTRALIA						
Broken Hill South Pty.	Kanmantoo, S.A.	A7.0	Open pit	1971		
EZ Industries Ltd.	Tasmania	A5.0	U/G mine	1971		1,500 tpy concentrate
Rosenberry facilities to double to 600,000 tpy ore.						
Mount Isa Mines Ltd.	Mount Isa, Qld.	20.0	Copper concentrator			13,000 tpy
Company also sinking 3,700-ft shaft. Firm is spending $A70 over next four years to increase copper output by 50%. McKee Pacific Pty. Ltd. awarded contract for the design and engineering of plant.						
Mt. Lyell Mining & Rwy. Ltd.	Tasmania	A30.0	General U/G and plant expansion	1972-1973	9,000 tpy copper	25,000 tpy copper
Pacific Mining Ltd.	Mt. Isa District, Qld.	A7.5	Mine reopening	1971		
Property is the Old Dobbin copper mine.						
Peko-Wallsend Ltd.	Tennant Creek, N.T.		Smelter			
Will also build a crude bismuth bullion plant.						
Peko-Wallsend Ltd.	Tennant Creek, N.T.	A20.0	U/G mine, plant	1972		12,500 tpy
Total capacity of Peko-Wallsend operation at this location to reach 25,000 tpy.						
BOLIVIA						
Comibol	Corocoro	4.0	Shaft sinking			
Shaft to be 661 m deep, 4.27 m in dia.						
BOTSWANA						
Bamangwato Concessions Ltd. (see "Nickel")						
CANADA						
Alwin Mining Co.	Highland Valley, B.C.		U/G mine	1972		500 tpd
Anaconda	Britannia Beach, B.C.		U/G development, mill modernization	1971		60,000 tpm
New ore zone known as the "040." Production started in late 1970, with total capacity to be achieved by mid-1971. Other ore zones at this old mine are now shut down. Plant capacity to stay at about 3,000 tpd ore.						
Granduc Operating Co.	Granduc, B.C.	100.0	U/G mine, concentrator	1971		7,500 tpd
Joint venture (50/50) between Newmont Mining and Asarco. Operation capable of expansion to 9,000 tpd ore. Initial start-up in late 1970.						
Highmont Mining Corp.	Highland Valley, B.C.	60.0	Open pit mine, mill	1972	25,000 tpd	
Teck Corp. to be responsible for operational management and concentrate sales.						
Hudson Bay Mining & Smelting Co.	Manitoba		U/G mine, concentrator	1971		
Dickstone Copper ML will receive 25% of profits.						
Hudson Bay Mining & Smelting Co.	Flin Flon, Man.		U/G mine			
Known as Centennial Mine. Contains about 1.4 million tons averaging 2.06% Cu, 2.6% Zn. Base of deposit not yet delineated.						
Hudson Bay Mining & Smelting Co.	Manitoba		U/G mine	1971		1,000 tpd
Anderson Lake mine.						
Hudson Bay Mining & Smelting Co.	Kluane Lake District, Yukon		U/G mine, concentrator	1972		
Known as the Wellgreen property. Copper-nickel concentrates to be sold to Sumitomo Metal Mining Co. 30-60,000 tpy concentrates to go to Sumitomo Metal Mining for next five years.						
Lornex Mining Corp.	Highland Valley, B.C.	125.0	Open pit, concentrator	1972		38,000 tpd
Rio Algom Mines Ltd. will manage the operation, which will be the largest non-ferrous mine in the nation. 25 tpd MoS_2 concentrate will also be produced.						

Company	Location	Investment $ million	Type of Project	Start-up	Added Capacity	Total Capacity
Mattabi Mines	Sturgeon Lake, Ont.	See "Lead-Zinc"				
Noranda Mines	Babine Lake, B.C.	33.0	Open pit, concentrator	1972		10,000 tpd
Placer Development	Cariboo District, B.C.	74.0	Open pit, concentrator			30,000 tpd
Known as the Gibraltar/Pollyanna properties and owned jointly with Gibraltar Mines Ltd. Proven reserves reported at 206 million tons averaging 0.39% Cu, 0.016% Mo.						
Placid Oil	Fernie, B.C.		Open pit mine, concentrator			750 tpd
Orebody reported to be small but high grade. Construction delayed pending development of satisfactory reclamation program of mined-out land.						
Sherritt Gordon Mines	Ruttan Lake, Man.	60.0	Open pit mine and concentrator	1973		10,000 tpd copper-zinc ore
Reserves to date show 1.27% Cu and 2.27% Zn.						
Similkameen Mining Co.	Princeton, B.C.	72.0	Open pit mine, concentrator	1972		15,000 tpd
Reserves estimated at 74 million tons averaging 0.55% Cu. Bechtel is prime contractor.						
Utah Construction and Mining Co.	Port Hardy, B.C.	70.0+	Open pit mine, concentrator	1972		230,000 tpy concentrate
Mitsui Industrial Group has contracted to purchase 60% of concentrate for a 10-year period. Will also produce 1,800 tpy molybdenum concentrate.						
Valley Copper Mines Ltd.	Highland Valley, B.C.		Open pit, concentrator			
Evaluating potential 25-75,000 tpd operation on reserves thought to approximate 1 billion tons of 0.4% Cu. Cominco is major shareholder; Bethlehem Copper holds 20%.						
CHILE						
Anonima Cuprifera de Sagasco		31.0	Open pit, leach plant	1971		24,000 mtpy
Reserves total 16 million metric tons of 2.16% Cu. Continental Copper & Steel Industries Inc. has majority control. Election of communist government in 1970 has posed no problem in development, which is still on approximate schedule.						
Enami		43.1	Mine expansions	1972	50,000 tpy	
Total Capacity: 100,000 tpy						
Cia. Minera La Disputada		11.7	Open pit and plant expansions	1971		9,800 mtpd
Disputada mine to expand from 5,500 mtpd to 7,000 mtpd and El Soldado to increase 800 mtpd to 2,800 mtpd. Increases to be matched by equivalent plant expansion.						
CONGO (Kinshasa)						
Congo Mining & Development Corp.	Musoshi	75.0	Open pit, concentrator	1972		53,000 tpy
Joint venture of Congo government and Nippon Mining Co. to develop ore deposit reportedly containing 110 million tons of 2.16% Cu.						
Congo Mining & Development Corp.	Kinsenda, Katanga Province			1975		70-80,000 mtpy
Copper content is reported at 5-6%, and reserves are placed at a minimum of 25 million mt. Located near company's Musoshi deposit.						
FINLAND						
Outokumpu Oy	Vuonos	(See listing under "Nickel")				
GREECE						
Chemical Products and Fertilizer Co.	Stratoni (Macedonia)	2.8	Shaft sinking and development	1970-1971		
Deposit contains at least 2 million tons of copper-pyrite ore.						
GUATEMALA						
Basic Resources Int. of Canada	Cahabon		Proposed mine and mill			1,000 tpd
Basic Resources has agreed to sell all concentrates from the Oxec mine to Sumitomo Metal Mining Co. for the next seven years, in return for which Sumitomo will advance funds against future deliveries to permit mill costruction. Proven reserves at Oxec are 1.33 million tons grading 2.58% cu.						
INDIA						
Hindustan Copper Ltd.	Khetri		Mining-milling-smelting project	1974		31,000 mtpy
Will develop Khetri deposit in Rajastahn at 21,000 mtpy rate and Kalihan deposit at 10,000 mtpy rate.						

Company	Location	Investment $1-million	Type of Project	Start-up	Added Capacity	Total Capacity
INDONESIA						
Freeport Indonesia Inc.	West Irian	120	Open pit, mill, shipping facilities	1973		2.5 million tpy ore
Ertsberg Project. Concentrates destined for Japan. Output of copper metal in concentrates will be between 60-65,000 tpy. Subsidiary of Freeport Sulphur Co.						
IRAN						
Selection Trust	Sar Cheshmeh	240.0	Open pit, concentrator			30,000 tpd ore
Operation will produce 150,000 tpy blister copper. Financing still being arranged.						
IRELAND						
Avoca Mines Canada	Avoca		Mine reactivation	1971		2,000 tpd ore
Existing mill, having a 4,000 tpd capacity, is being overhauled.						
ISRAEL						
Timna Copper Co.			U/G mine	1972		
New mine has reported 20-yr life.						
MALAYSIA						
Overseas Mineral Resources Development Co.	Sabah, (Borneo Island)	66	Open pit, concentrator	1972		20,000 tpd
Known as the Mamut mine. OMRDC is a Japanese mining consortium which, with some government participation, holds 51% of the shares. Remainder of shares held by local interests.						
MEXICO						
Asarco Mexicana	Inguaran, Michoacan	12.8	U/G mine, concentrator	1971		2,200 tpd
Reserves estimated at 6 million tons of disseminated chalcopyrite. Operation will produce about 13,000 tons of copper and 78,000 oz of silver annually. Owned 49% by Asarco. Company also developing new mines at Velardena (Durango Province) and Eta Colorado (Chihuahua Province).						
Asarco Mexicana	San Luis Potosi	21.0	Electrolytic copper refinery			120,000 mtpy
Mexicana de Cobre S.A.	Nacozari, Sonora	250.0	Open pit, concentrator, smelter	1974		75,000 mtpy copper
Mine known as La Caridad. Asarco Mexicana S.A. owns approximately 33%, the balance held by Mexican nationals, foreign interests, and the Mexican government. Asarcomex plans to build an electrolytic refinery at a later date to process smelter output, but it will not necessarily be located at Nacozari. Parsons-Jurden conducting study of alternative production rates and effect on investment. Reserves now estimated at 600 million tons with average grade of 0.8% Cu and with associated molybdenum.						
MOROCCO						
Combine	Bou Kerzia		Mine	1971		
Joint venture with Government's Bureau de Recherches et de Participations Minieres (BRPM), Nittetsu Mining and Marubeni Iida. Lead, zinc also to be produced.						
SECOMIS	D'Ijoukak		Mine			3,500 tpy of copper concentrate
Company is fully owned by Moroccan investors.						
NORWAY						
Borregaard	Repptarfijord		Open pit	1973		0.6 million mtpy
Ore reserves estimated at 10 million tons averaging 0.7% copper.						
Consortium			U/G mine, plant	1972		6,000 tpy
Consortium includes A/S Sulitjelma Gruber, Elektrokemist A/S, A/S Sydvaranger, and Aardal og Sunndal VErk.						
OCEANIA						
Bougainville Copper Pty.	Bougainville Island	350.0	Open pit, concentrator	1972		90,000 tpd ore
Will produce 150,000 tpy copper in concentrate. Will also produce approximately 500,000 oz Au per year.						
PERU						
Compania Mineral Del Madrigal	(See listing under "Lead-Zinc")					
Southern Peru Copper Corp.	Moquegua State	100.0	Mine, concentrator			
Known as the Quellaveco mines.						

Company	Location	Investment $-million	Type of Project	Start-up	Added Capacity	Total Capacity
Southern Peru Copper Corp.	Cuajone	355.0	Open pit, concentrator	1976		144,000 tpy concentrates
Orebody estimated to contain 460 million tons grading 1.1% Cu.						
PHILIPPINES						
Atlas Corp.	Cebu Island	20.0	Mine expansion, new concentrator	1971		80,000 mtpy
Present capacity at 50,000 mtpy. Mitsubishi Metal Co., which purchases the concentrates, provided the financing for the expansion.						
SOUTH AFRICA						
Africa Triangle Mining Prospecting and Development Co. Ltd.	Prieska		U/G mine			
Orebody still being delineated but published ore reserves are 25 million tons of 1.5-2% Cu, 3% Zn. Venture is composed of U.S. Steel (30%), Middle Wits (34.3%) and Anglo Vaal (35.7%).						
O'Kiep Copper Company	Nababeep	7.0	Three new shafts			
Expansion not expected to increase copper production, but to maintain company's production levels.						
SOUTH WEST AFRICA						
Falconbridge Nickel Mines	Windhoek		Mine, plant	1971		1,600 tpd ore
Operation will be run by Falconbridge subsidiary Oamites Mining Co. By product silver.						
SWEDEN						
Boliden	Gallivare	30.0	Expansion of open pit, concentrator	1973		5 million tpy
TURKEY						
Etibank Genel Mudurluga		40.0	Mine, mill, smelter	1971		8,500 mtpd mill, 40,000 mtpy smelter
A. G. McKee designed facilities.						
YUGOSLAVIA						
Bor Mining & Smelting Works	Bor	178.0	Mine and mill expansion	1971		130,000 tpy electrolytic copper
New copper and gold electrolysis plant opened in late 1969.						
ZAMBIA						
Rhokana Corp. Nchanga Consolidated Copper Mines Ltd.		48.0	General expansion	1975	125,000 mtpy	500,000 mtpy
Firms associated with Anglo-American Corp. of South Africa Ltd.						
Roan Consolidated Mines Ltd.	Northwest		Open pit copper mine	1971	17,000 mtpy	
Production of 13,000 mt began at Kalengwa in 1970 and will increase to 17,000 mt in 1971 when the construction of the concentrator will be completed. Amax, through its wholly owned subsidiary, RST International, owns 20% of RCM. RST retains a 10-year management contract.						
Roan Consolidated Mines Ltd.	Copperbelt	52	Addition of underground section to open pit mine	1973	24,000 mtpy	48,000 mtpy
Existing open pit mine at Chambishi will be depleted in 7 years, by which time full 48,000 mtpy will be produced from underground mine.						

Iron/Steel — Heavy investments continue

UNITED STATES						
Marcona Corp.	Snettisham Peninsula, Alaska		Open pit mine, pelletizing plant, power plant, ship-loading facilities			4-5 million tpy pellets
Iron ore has titanium content. Project still in negotiating stage.						

JHC

J. H. C.

DEC 15 1970

file Copper

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FIRST GENERATION - PORPHYRY COPPERS

Mine	Type	Start	Ore Reserve at start MT Ore-Grade-MT Cu	MT Cu pro thru '67	Est Ore reserves 1/1/68 MT Ore-Grade- MT Cu	Operating Rate tons/day	Indicated Life-years
Utah*	OP	1905	12.4 @ 2.0% 0.248	9.001	1297.3 @ 0.74% 9.600	99,000	40
Humboldt-Morenci	UG	1907	? @ 1.9% ?	0.625	------DONE--------	------	-----
Nevada Con	OP	1908	8.1 @ 2.0% 0.163	2.042	113.7 @ 0.74% 0.556	22,400	15 ?
Braden	UG	1910	10.0 @ 2.7% 0.272	6,478	445.4 @ 1.83% 8.151	26,600	40
Miami	UG	1911	18.2 @ 2.58% 0.469	1.247	-----DONE--------	------	------
Ray*	OP	1911	50.0 @ 2.25% 1.125	1.861	306.5 @ 0.84% 2.478	25,900	35
Chino*	OP	1912	19.0 @ 2.59% 0.492	2.570	121.5 @ 1.02% 1.579	24,000	15
Inspiration*	OP	1915	45.3 @ 2.0% 0.906	1.939	98.9 @ 0.67% 0.668	20,270	13.7
Chuqui	OP	1915	203.3 @ 2.23% 6.764	9.241	1194.9 @ 1.40% 16.728	66,400	50
Ajo	OP	1917	60.0 @ 1.5% 0.900	2.363	151.9 @ 0.66% 1.003	33,400	25
Sac Hill Bisbee	OP	1923	11.2 @ 1.7% 0.190	0.218	------DONE---------	------	-----
Andes	UG	1927	127.4 @ 1.51% 2.075	1.743	------DONE---------	------	------

Note: * Indicates leach production in addition to milled ore - Production figures include leach

MT Ore & MT Cu indicates millions of tons.

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SECOND GENERATION - PORPHYRY COPPERS

Mine	Type	Start	Ore Reserves at start MT Ore-Grade-MT Cu		MT Cu Pro thru '67	Est Ore reserves 1/1/68 MT Ore-Grade- MT Cu		Operating Rate tons/day	Indicated Life-years
Morenci-Clay*	OP	1942	284.0 @ 1.04%	2.942	3.081	767.1 @ 0.73%	5.600	60,725	40
Bagdad*	OP	1943	36.7 @ 0.98%	0.360	0.275	27.5 @ 0.87%	0.242	6,000	12
Castle Dome	OP	1943	40.4 @ 0.72%	0.290	0.290	-------Done-------		-----	---
Yerington	OP	1953	52.2 @ 0.92%	0.483	0.457	45.2 @ 0.84%	0.380	16,000	10
Lavender*	OP	1954	? ?	0.494	0.485	61.0 @ 0.57%	0.347	17,450	10 ?
Copper Cities*	OP	1954	32.9 @ 0.73%	0.239	0.268	43.5 @ 0.55%	0.242	12,000	10
Silverbell*	OP	1954	32.0 @ 0.90%	0.288	0.299	36.9 @ 0.65%	0.242	11,250	10 ?
San Manuel	UG	1956	457.9 @ 0.75%	3.420	0.899	777.0 @ 0.73%	5.672	40,000	55
Pima	OP	1957	7.8 @ 1.64%	0.128	0.261	118.0 @ 0.58%	0.685	30,000	12
El Salvador	UG	1958	300.0 @ 1.63%	4.890	0.753	253.8 @ 1.63%	4.137	16,000	48
Esperanza*	OP	1959	48.8 @ 0.65%	0.317	0.205	39.9 @ 0.48%	0.192	14,700	8
Toquepala	OP	1960	1100.0 @ 1.00	11.000	1.212	829.4 @ 1.18%	9.787	37,600	70
Mission	OP	1961	80.0 @ 0.92%	0.736	0.294	56.7 @ 0.78%	0.442	17,500	9.5
Mineral Park*	OP	1965	53.4 @ 0.54%	0.288	0.072	42.4 @ 0.51%	0.217	16,800	8
Palabora	OP	1966	315.0 @ 0.68%	2.142	0.151	292.8 @ 0.68%	1.991	33,000	24

Note * Indicates leach production in addition to milled ore - Production figures include leach.

MT ore & MT Cu indicates millions of tons.

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PLANTS PRESENTLY UNDER CONSTRUCTION

Mine	Type	Start	Indicated Ore Reserves	Operating Rate	Indicated Life
Tyrone (PD)	OP	1969	126,750,000 @ 0.78%	25,000	15
Twin Buttes	OP	1969	300,000,000 @ 0.75%	40,000	20
Sierrita	OP	1971	420,000,000 @ 0.355%	60,000	20
Exotica	OP	1970	150,000,000+ @ 1.35%	31,000	13.4

Notes on above: PD in annual report gave only the expected grade and the 25,000 t/d milling rate - Assuming that PD would not tie into one at a $100,000,000 capital cost unless it was good for a minimum of 15 years - the above reserve for Tyrone is estimated from a probable 15 year life.

Anaconda on Twin Buttes has put out only the expected 40,000 t/d milling rate. I have estimated the grade - and on the magnitude of the project costs, figured it had to have a 20 year minimum life - and figured the ore reserve tonnage on this basis.

See the two attached xerox sheets for published data on Duval-Sierrita & Exotica - from which the above ore reserves were taken or deduced.

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rm 15 p.

JHC

Economic Geology
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Geology of the Kalamazoo Orebody, San Manuel District, Arizona

J. David Lowell

Abstract

An exploration project initiated by Quintana Minerals Corporation in 1965 has resulted in the discovery of the faulted segment of the San Manuel orebody. The project was based on a new interpretation of the geology of the San Manuel orebody which assumed that an original cylindrical orebody with concentric alteration zoning had been first tilted approximately 70°, then bisected by the flat San Manuel normal fault into the lower plate San Manuel orebody and an upper plate Kalamazoo orebody.

The deep drill holes of the Kalamazoo project provide an unusually good cross section of porphyry copper wall rock alteration. Vertical mineral and alteration zoning effects down the original vertical axis of the deposit are also exposed because the vertical axis is now nearly horizontal and within drilling depth of the ground surface.

Introduction

In the period 1943–1947, exploration projects were carried out in the San Manuel area by the U. S. Bureau of Mines and Magma Copper Company which resulted in the development of the San Manuel underground block-cave mine which is now in production at a rate of 41,000 tons per day.

Mining claims covering the area immediately west of the San Manuel orebody were staked in 1946 by Frank F. Salas, R. A. Buzan, H. G. Buzan, and W. C. Buzan of Mammoth, Arizona. These claims were optioned to Martha Purcell in 1946, and in the period of 1947–1958 seven churn drill holes ranging in depth from 1,400 to 2,950 feet were drilled by Mrs. Purcell. These holes did not intersect ore and no further deep exploration was attempted prior to the Quintana Minerals Corporation project which began in August, 1965, and which is described in this report.

The Kalamazoo deposit is in Sections 3, 4, 9, 10, T 9 S, R 16 E, Pinal County, Arizona, and it is seven miles east from Oracle, Arizona (Fig. 1).

The writer is indebted to Corbin J. Robertson and Ronald B. Thompson who participated in the exploration planning of this project and to a number of other individuals who contributed to its execution and management. Petrographic work by J. M. Guilbert was used as a basis for rock and alteration classifications.

A paper being prepared by the writer and J. M. Guilbert for publication in Economic Geology will compare the characteristics and genesis of the lateral and vertical alteration-mineralization zoning at San Manuel-Kalamazoo with those of a number of other porphyry copper deposits.

Acknowledgment is gratefully made to Quintana Minerals Corporation for permission to publish information developed during the Kalamazoo project.

Geology of the San Manuel District

The geology of the San Manuel area has been described by Steele and Rubly (1947), Schwartz (1953), Pelletier (1957), Creasey (1965), and Thomas (1966).

Precambrian quartz monzonite of the Oracle granite batholith in the San Manuel area was intruded in Laramide time by swarms of monzonite porphyry dikes and irregular monzonite porphyry masses. The rock classified as monzonite porphyry can be subdivided into a range of rock types including quartz latite porphyry, quartz monzonite porphyry, monzonite porphyry, biotite dacite porphyry, and probably other rock types. Some of these appear to be

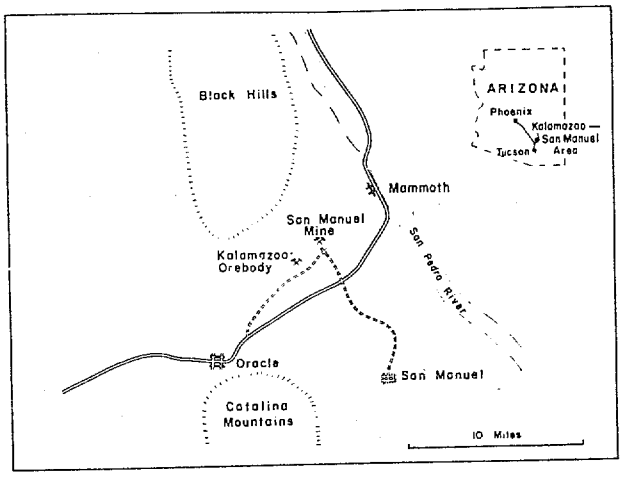


Fig. 1. Location map San Manuel District, Arizona.

slightly later than others, but all are closely related in time and all are apparently pre-ore in age. A few diabase dikes are also present in the Laramide-age dike swarms. Closely related in time with this Laramide intrusive activity was a pulse of porphyry copper-type mineralization that produced the San Manuel-Kalamazoo orebody and its associated concentric hydrothermal alteration zones. The axis of the hydrothermal flowage system seems to have been centered in the middle of one of the monzonite porphyry dike swarms.

Following emplacement of hydrothermal mineralization and alteration, district-wide structural displacements occurred that produced northeasterly tilting and probably resulted in relative elevation of the block which included the San Manuel-Kalamazoo orebody. Erosion cut into this block exposing a small corner of the orebody, and attendant supergene activity produced a thin chalcocite enrichment blanket. At this time the long axis of the orebody may have dipped at an angle of about 65° (Fig. 2). Subsequently, andesitic flows interbedded with detrital sediments and pyroclastics were deposited on this surface. Further igneous activity following the sedimentation resulted in the emplacement of andesite and rhyolite dikes.

The older Tertiary conglomerate unit in the Kalamazoo area has been correlated in published mapping (Creasey, 1965) with the Cloudburst formation of the Mammoth-St. Anthony area two miles to the northeast. The Cloudburst was considered by Creasey to be of post-San Manuel ore, but pre-Mammoth-St. Anthony ore age. Evidence for its post-San Manuel ore age in the Mammoth-St. Anthony area is not entirely convincing. However, the lowest conglomerate unit at Kalamazoo does appear to be of definite postore age; it is less well indurated than the Cloudburst formation and may be considerably younger. It may correlate (Watson, 1967) with the Pantano and Mineta formations of southern Arizona, which are considered to be late Oligocene or early Miocene.

Further tilting, averaging perhaps 15°, followed deposition of the lower conglomerate. It seems likely that tilting was accompanied by renewed elevation of the fault block since the block was again beveled by the erosion surface on which the Gila Conglomerate was later deposited. A third stage of about 30° of tilting moved the Gila Conglomerate into its present inclination and brought the long axis of the San Manuel-Kalamazoo orebody into a 20° west-dipping attitude. As seen on Figure 2, the San Manuel fault then diagonally bisected and offset the orebody into two pieces: the San Manuel and the Kalamazoo. It is uncertain whether the San Manuel fault displacement occurred before or after the last stage of tilting, but the fault has several characteristics commonly associated with low-angle faults including a thick gouge-breccia zone, a rolling fault plane surface, and braiding. It seems likely that the San Manuel fault displacement followed final tilting and that the present 25°–30° dip of the fault represents its original attitude. The fault divided the originally cylindrical San Manuel-Kalamazoo orebody into two mirror-image halves, and the upper (Kalamazoo orebody) half was moved in a down-dip, S55°W direction, about 8,000 feet. Imbricate displacements apparently occurred on overlying San Manuel fault strands which have resulted in one Kalamazoo ore section locally overriding another.

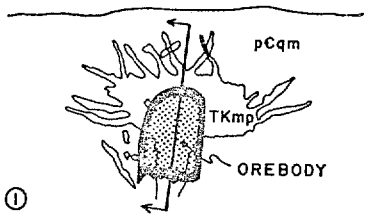
A system of high-angle, northwest-trending faults later produced relatively small, mostly normal fault displacements in both halves of the original orebody, and erosion stripped most of the Gila Conglomerate from the east end of the present San Manuel orebody. This erosion cycle developed extensive leaching and oxidation in the upper part of the San Manuel orebody with limited chalcocite enrichment beneath the oxidized zone. The lower portion of the San Manuel orebody and all of the Kalamazoo orebody were protected from oxidation by thick sections of capping. Erosion in the most recent cycle of erosion has exposed windows of pre-ore rock in the vicinity of both San Manuel and Kalamazoo (Fig. 3). A small area of the San Manuel orebody that had been exposed by erosion led to the original exploration of the area.

The original, unfaulted orebody, as defined by an 0.5% copper limit, has the general shape of a somewhat flattened or elliptical (in cross section) cylinder at least 7,700 feet in long dimension (along the axis of the cylinder) and from 2,500 to 5,000 feet in diameter. The top (east end after tilting) of the cylinder may have had a rounded shape with the bottom (west end after tilting) probably being somewhat irregular in shape. The orebody, like many porphyry copper deposits, had a poorly metallized core or "low-grade center." The wall thickness of the ore shell surrounding the low-grade center varied from about 100 to 1,000 feet. Mineralization and alteration form approximately coaxial cylindrical zones (Fig. 4).

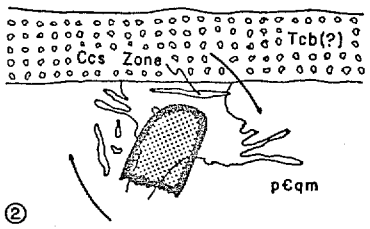
Figure 5 is a longitudinal geologic section of the Kalamazoo orebody and the overlying northeast-dipping Tertiary sediments. Figure 6 is a cross section illustrating the bisected hollow cylindrical shape of the orebody and shows a cross section of the mullion structure in the San Manuel fault zone.

Mineralization

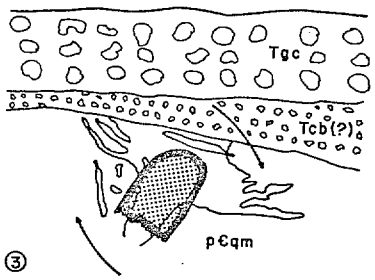
Ore mineralization is about equally distributed between coarse-grained Precambrian quartz mon-



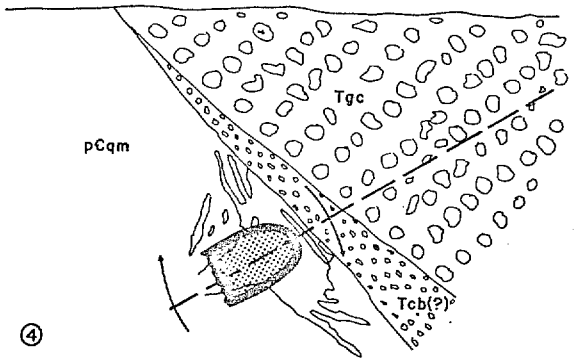
1. Precambrian quartz monzonite (pCgm) was intruded by a Laramide age monzonite porphyry (TKmp) dike swarm. A hollow cylindrical or pipe-shaped orebody with dimensions of approximately 8,000 × 3,500 feet was formed. It was probably nearly vertical and centered on the monzonite dike swarm. (Section line shows position of Figure 7.)



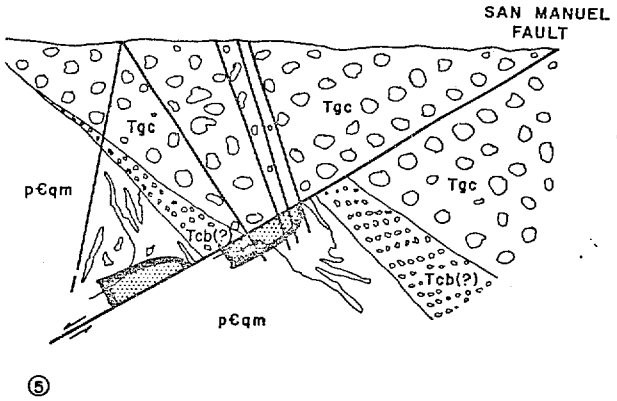
2. Tilting of the orebody was followed by erosion, then deposition of conglomerate and interbedded volcanics (Tcb?). A thin chalcocite blanket (Ccs) was formed at the water table.



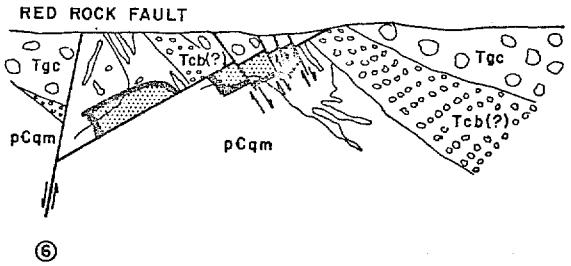
3. Continued tilting was followed by erosion of conglomerate and quartz monzonite and deposition of middle Tertiary Gila Conglomerate (Tgc).



4. Orebody is now at a flat angle due to continued tilting. An erosion surface is cut on the tilted quartz monzonite and Gila Conglomerate. Incipient San Manuel fault is formed.



5. Upper portion of orebody is displaced approximately 8,000 feet down the dip of the San Manuel fault. Some imbricate displacement may have occurred in the Kalamazoo segment.



6. High-angle normal fault displacements produced small offsets in the San Manuel orebody and a large displacement on the Red Rock fault west of the Kalamazoo orebody. Erosion exposed intrusive rocks and a corner of the San Manuel orebody and produced oxidation and limited chalcocite enrichment in the upper portion of the San Manuel orebody.

FIG. 2. Schematic drawings showing possible origin of Kalamazoo orebody.

zonite and Laramide monzonite porphyry host rocks. Ore in the Precambrian quartz monzonite tends to be slightly higher in grade.

Primary ore minerals in the San Manuel-Kalamazoo orebody are pyrite, chalcopyrite, molybdenite, and rare bornite. Oxide copper minerals, principally chrysocolla, have been developed in the upper portion of the San Manuel orebody. Chalcocite is common in the lower portion of the oxide zone and near the top of the chalcopyrite mineralization in the San

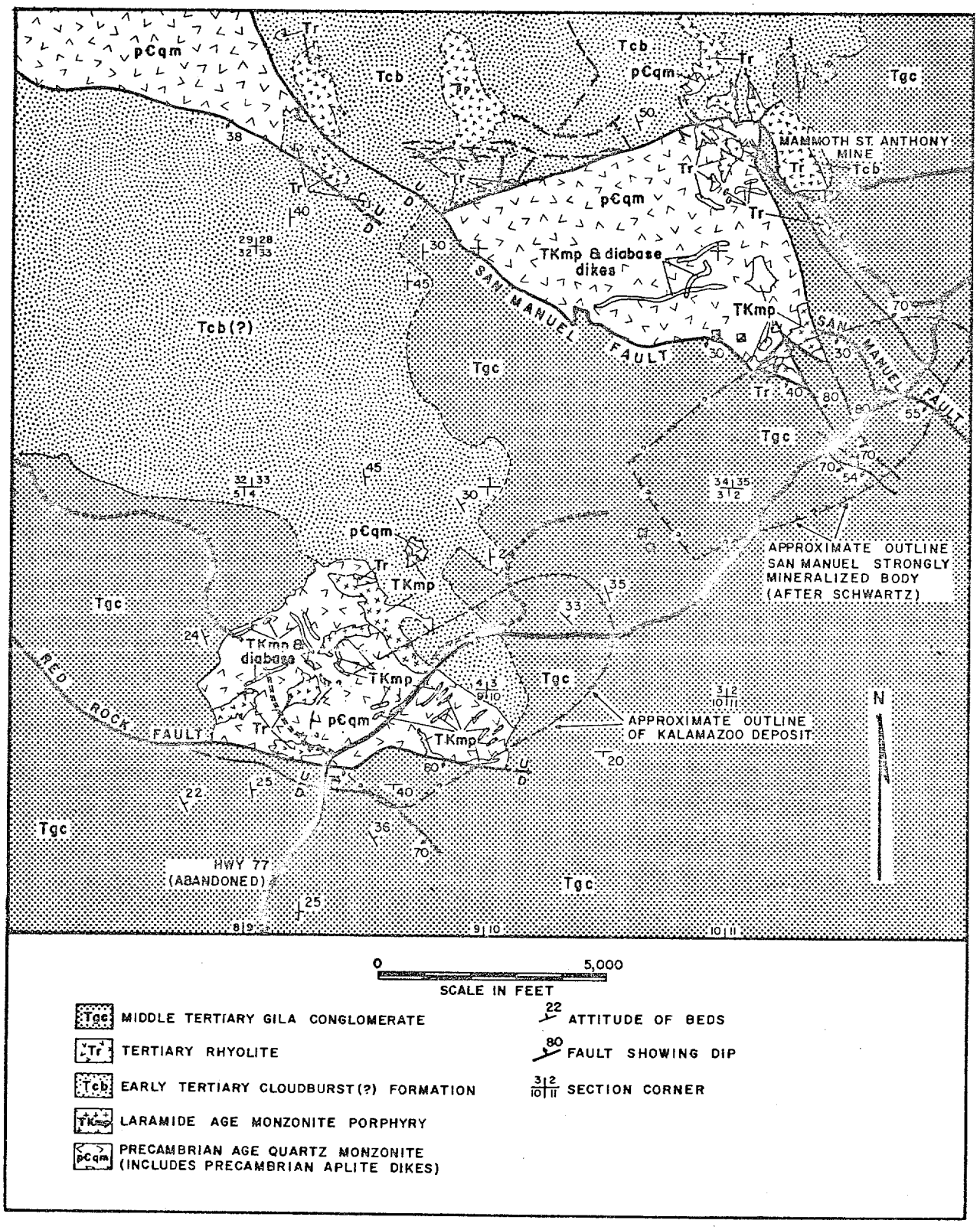


FIG. 3. Geologic map of the San Manuel area.

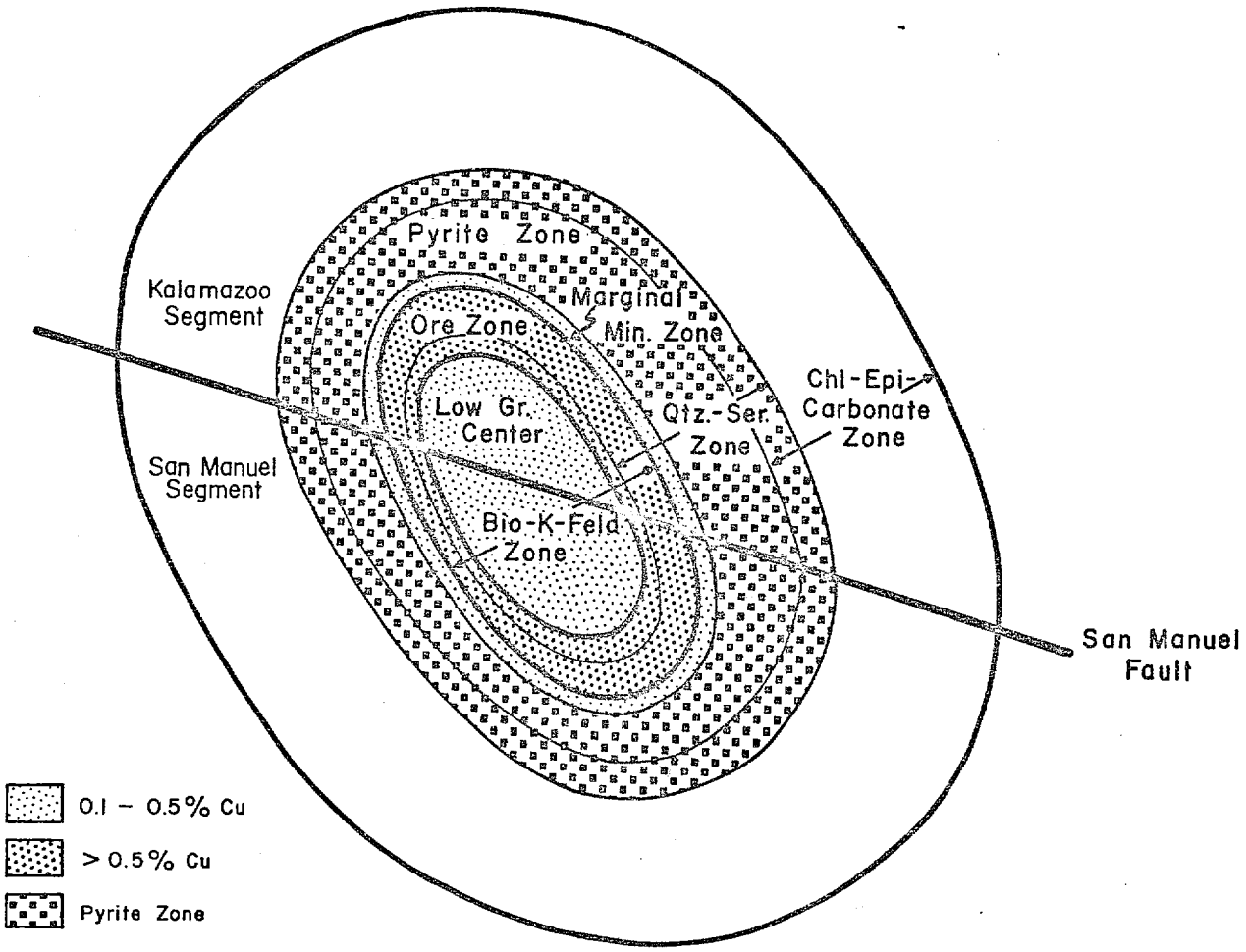


FIG. 4. Schematic horizontal plan showing alteration and mineralization zones.

Manuel orebody, but both chalcocite and oxide minerals are absent in the Kalamazoo.

Zones of Mineralization (Fig. 4).—1. The low-grade center zone averages about 2,600 feet in diameter and about 0.3% Cu in grade. Total sulfide content is low with a pyrite-to-chalcopyrite ratio of about 1:2.

2. The ore shell averages about 600 feet in thickness and ranges in grade from 0.5%–1.0% Cu. The pyrite-to-chalcopyrite ratio is about 1:1.

3. The marginal mineralization zone which surrounds the ore shell averages about 200 feet in thickness and ranges in grade from 0.1%–0.5% Cu. The pyrite-to-chalcopyrite ratio is about 10:1.

4. The pyritic zone that surrounds the marginal mineralization zone ranges in thickness from about 1,000–1,500 feet and ranges in grade from 0.01%–0.10% Cu, averaging about 0.03% Cu. It contains from 6%–25% pyrite by weight, averaging about 10% pyrite.

Total volume of sulfide minerals increases progressively from the center of the concentric mineralization-alteration system out to a point of maximum sulfide content in the inner portion of the pyritic zone. Outward beyond this point sulfide content progressively decreases. Copper content increases progressively from the center of the system out to a point of maximum copper grade in the center of the ore shell, then decreases by steps to the outer margin of the zone of marginal mineralization. Beyond this point copper rarely occurs as recognizable copper minerals, and the 0.01%–0.10% Cu content of the pyritic zone is probably included in the crystal structure of the pyrite.

Alteration

Alteration zones in this deposit, as in most porphyry copper deposits, are rather poorly defined and overlapping. Various host rocks respond in different ways to alteration solutions to produce

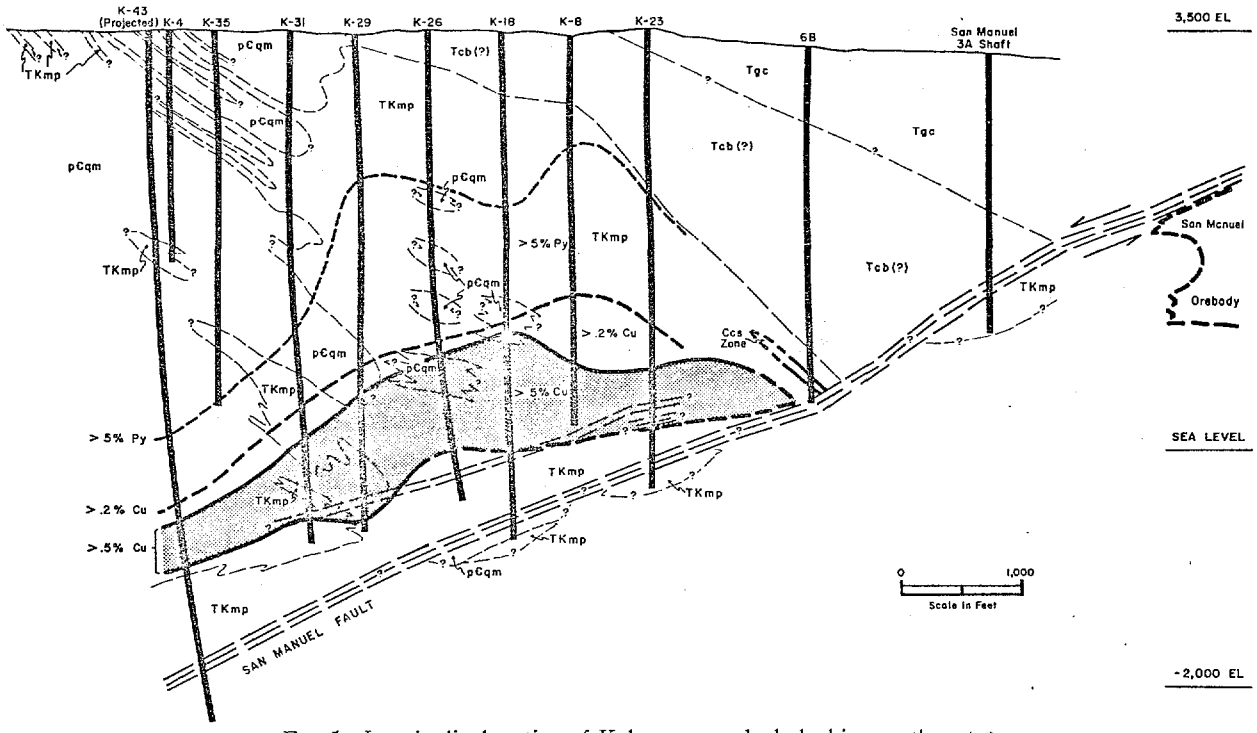


FIG. 5. Longitudinal section of Kalamazoo orebody looking northwest.

somewhat different alteration products within the same zone. Alteration zones are more clearly defined here than in most porphyry deposits, however, because the original San Manuel-Kalamazoo orebody had unusually uniform boundaries and a well-developed symmetrical configuration. This probably resulted from the fact that alteration and mineralization affected intrusive host rocks that were of generally similar chemical composition and of essentially isotropic fabric.

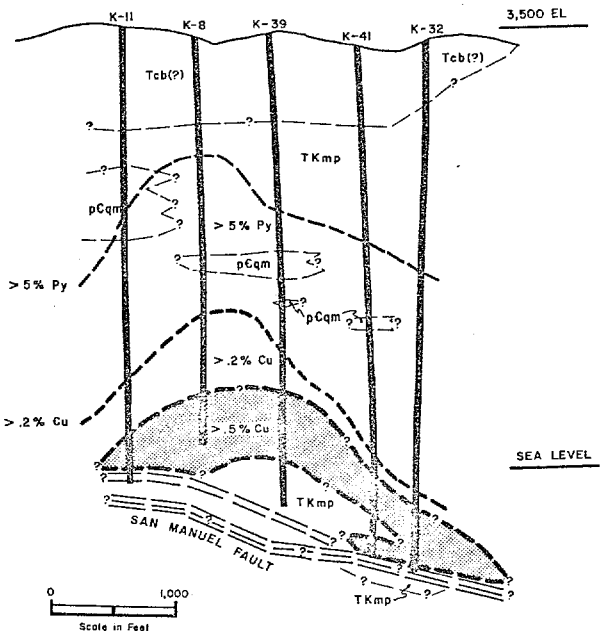


FIG. 6. Cross section of Kalamazoo orebody looking northeast.

Horizontal Alteration Zones.—These are zones distributed laterally in and around the orebody at a given depth at the time of ore formation. They consist of:

1. The inner alteration zone of the San Manuel-Kalamazoo orebody consists of biotite K-feldspar alteration (Fig. 4).

Several authors, especially Hemley and Jones (1964), have discussed the potassic alteration environment. Hemley and Jones delimit an environmental interface between K-feldspar and sericite stabilities consistent with late magmatic or early hydrothermal conditions in the K-feldspar-sericite-kaolin (pyrophyllite) system. Expansion of the system to include iron and magnesium should bring biotite, K-feldspar, sericite, and quartz into consideration, an assemblage increasingly often noted in porphyry copper deposits (Creasey, 1966) and assignable to the late magmatic-early hydrothermal "deuteric" environment. Such a biotite K-feldspar alteration assemblage with quartz, sericite, anhydrite, pyrite, chalcopyrite, and molybdenite generally constitutes the low-grade center and part of the ore shell of the Kalamazoo deposit. Conditions approaching

those of wholesale remobilization of the porphyry concurrent with potassic alteration are suggested by coarsely vermicular and diffuse intrusive contacts between host rock and porphyry masses within the orebody.

It is certain in any case that this intense potassic alteration produced fresh-looking secondary minerals which led to the incorrect conclusion on the part of some previous workers that this alteration zone represented alteration weaker than that of the surrounding zones. The intense phase of biotite K-feldspar alteration tends to alter monzonite porphyry to a coarser-grained rock that somewhat resembles in texture the fresh Precambrian quartz monzonite. This alteration is not nearly as obvious as other alteration effects in the surrounding quartz-sericite zone which represent weaker hydrothermal conditions but more obvious destruction of rock textures.

At depth the biotite K-feldspar zone is partly replaced by a core of quartz-sericite-chlorite ± K-feldspar alteration as will be discussed later in this paper. This assemblage appears to represent a high-temperature environment in which sericite, chlorite, and minor carbonates appear.

2. A zone of quartz-sericite alteration generally includes all of the marginal mineralization and pyritic zones and overlaps the biotite K-feldspar alteration in the outer part of the ore shell. Sericite tends to be more abundant in the inner part of this zone with clay minerals and hydromica becoming more abundant towards the margins of the zone. In the inner portion of this zone, rock textures have been largely destroyed. The zone contains sections of spectacular, pervasive pyrite mineralization in which pyrite in some cases constitutes more than 20 percent by weight of the rock. Specularite is common towards the margins of the zone. A zone of hydrothermal magnetite mineralization appears to interfinger with and possibly replace this zone towards the west end (original bottom prior to tilting).

3. Surrounding and overlapping the quartz-sericite zone is a zone of propylitic alteration in which chlorite, epidote, and minor carbonates are developed. Pyrite content by weight averages 4 percent.

This zone gradually fades and may have a total thickness of 2,000 feet or more. The configuration of the alteration zone is apparently not related in detail to the distribution of monzonite porphyry bodies.

Vertical Alteration Zones.—The San Manuel-Kalamazoo orebody has unique genetic significance in the study of porphyry copper deposits because of the great length of the original vertical column of mineralization exposed. If the orebody has been tilted approximately 70° as postulated, then the west end represents ore mineralization which was originally about 8,000 feet deeper than the east end. Including mineralization in drill intercepts in the lower plate of the San Manuel fault below the Kalamazoo orebody, it is possible to partially reconstruct vertical mineral zoning changes over an original vertical column of 13,000 feet or more.

Figure 7 is a schematic section that illustrates vertical zoning relationships interpreted for the original San Manuel-Kalamazoo orebody. Concentric mineralization and alteration zones were roughly cylindrical in shape, but several zones appear to have converged upward, and the overall configuration of the system may have been beet shaped with a restricted root in depth. The hydrothermal magnetite and quartz-sericite-chlorite ± K-feldspar zones occurred only near the bottom of the orebody, and little is known regarding their configurations.

1. The core of the concentric alteration system or low-grade center mineral zone grades upward from quartz-sericite-chlorite ± K-feldspar alteration to biotite K-feldspar.

2. The ore-shell mineral zone progressively transgresses upward across the contact of the biotite K-feldspar and quartz-sericite zones. The upper portion of the ore shell is entirely within the quartz-sericite zone. Chalcopyrite mineralization appears to grade from predominantly bleb and veinlet type at the bottom to predominantly fine-grained disseminated at the top.

3. The zone of marginal mineralization surrounding the ore shell grades from chlorite-sericite-magnetite at the bottom to quartz-sericite alteration through most of the length of the orebody.

4. Magnetite substitutes for pyrite to a large extent in the bottom portion of the pyritic zone. Sericite content appears to decrease with the decrease in pyrite downward and to increase with the increase of pyrite content upward. The strongest pyrite mineralization was near the original top of the orebody.

5. Alteration surrounding the pyritic zone grades upward from disseminated and veinlet magnetite, chlorite, sericite, epidote at depth to chlorite, epidote, carbonate. Little is known of the general configuration of this zone because it has been partially destroyed by erosion and most of the present surface area is covered by postore formations. It seems likely that the overall configuration was beet shaped with a constricted root.

Geological Premises for Kalamazoo Project

The initiation of the Kalamazoo project was based upon the assumptions by the writer that (1) the San Manuel low-grade center and its potassic alteration represented the most, rather than the least, intense alteration zone present and, therefore, perhaps the

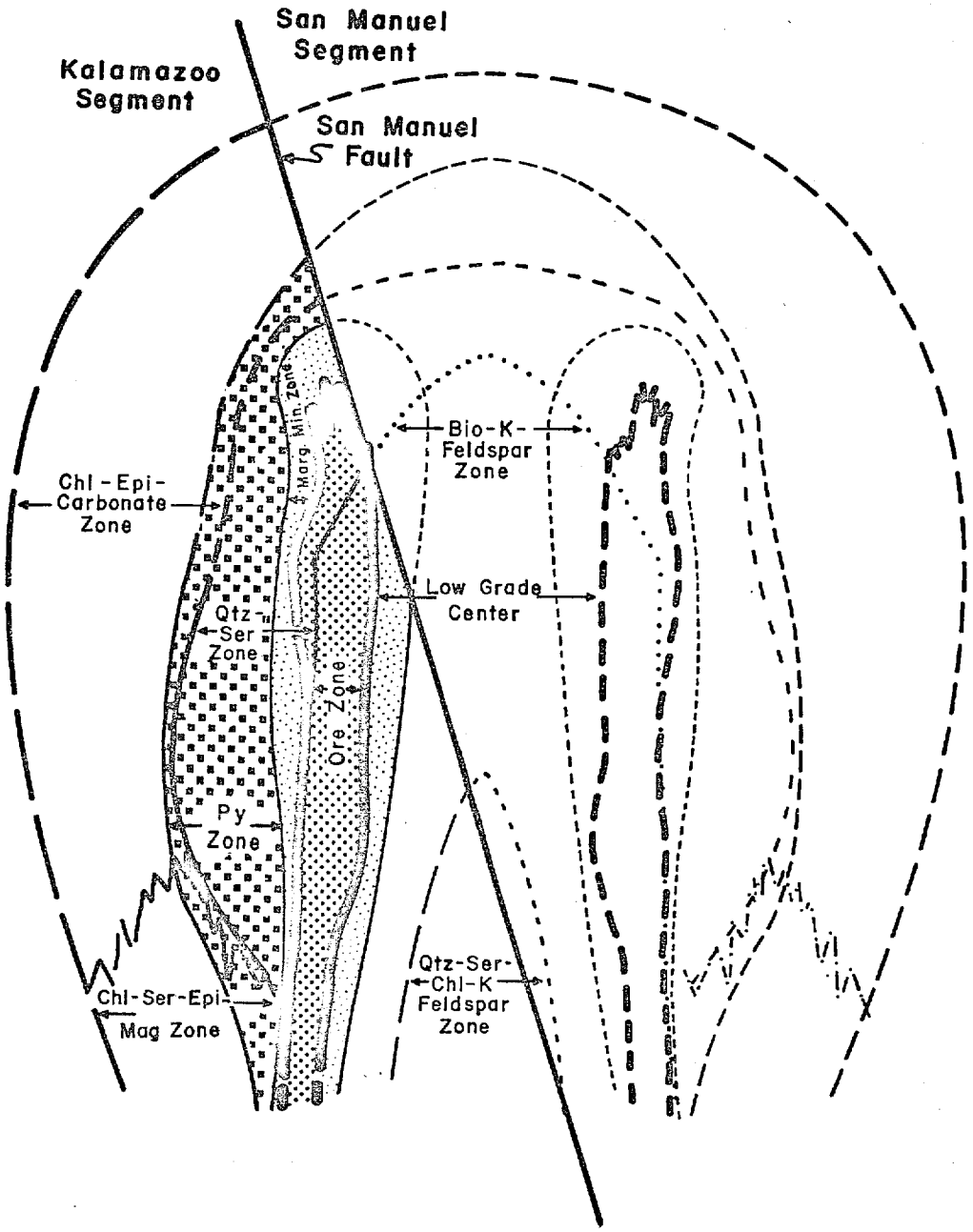


FIG. 7. Schematic section of San Manuel-Kalamazoo orebody showing vertical alteration and mineralization zones. Solid lines and shaded areas represent observed geology, and broken lines indicate extrapolated information. (See Fig. 2 for position of this section relative to final configuration of orebodies.)

core of an original cylindrical-shaped orebody, and that this original orebody would have had coaxial alteration and mineralization zones which would complete the cylindrical symmetry found truncated at San Manuel; (2) evidence existed for at least 45° of tilting of this cylindrical-shaped orebody and that it was reasonable to postulate additional tilting in pre-Cloudburst time so that the cylinder could have been originally in a near-vertical position typical of pipe-like porphyry copper deposits; and (3) the direction of displacement in the San Manuel fault could more logically have been in a down-dip direction as proposed by Steele and Rubly (1947) and Schwartz (1953) rather than having "had a domi-

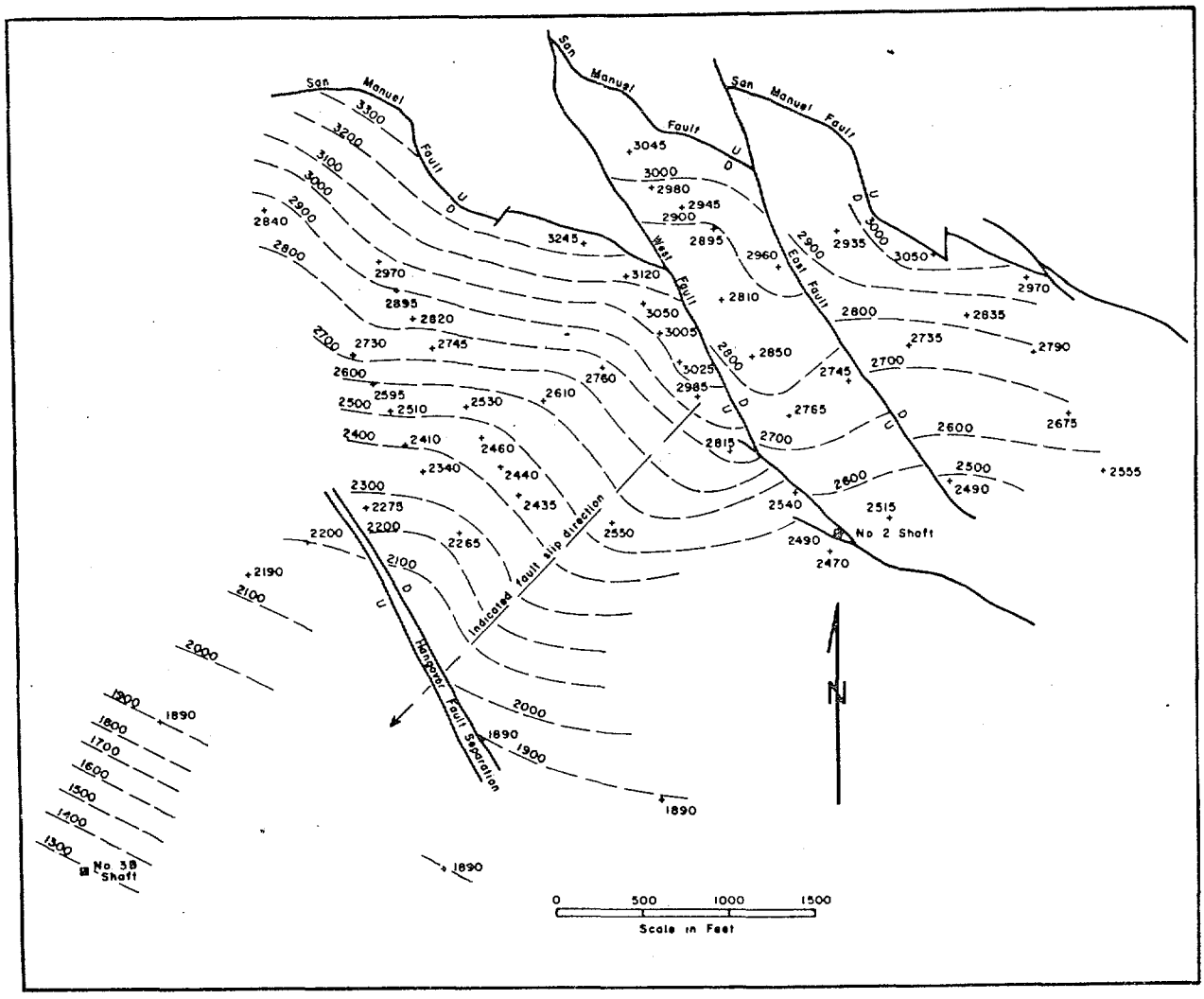


FIG. 8. Structure contour map of the San Manuel fault plane. Elevations are shown in feet above sea level.

nant component of right-lateral strike-slip movement" as postulated by Creasey (1965, p. 28) or having had reverse fault displacement as proposed by Wilson (1957) and Heindl (1963).

Kalamazoo Exploration Project

Initial investigation involved reviewing the geologic and assay logs and drill cuttings samples from the old Purcell drill holes. It was found that four of these holes apparently penetrated from weakly pyritic propylitic alteration into a strongly pyritic, quartz-sericite zone at depth, and one hole apparently bottomed in mineralization typical of the San Manuel marginal mineralization zone. The geometry of these intersections together with the projection of the San Manuel fault plane approximately determined the position of the cylindrical-shaped Kalamazoo pyritic zone.

A geochemical soil survey was carried out in the pre-ore outcrop area of the Purcell claims. This survey produced a moderately well-defined copper and molybdenum anomaly which was later found to overlie the Kalamazoo orebody. The anomaly probably represents the outcrop of a cylindrical shell of comparatively copper-rich (±0.04% Cu) propylitic alteration. Assaying the soil samples for total Fe produced a less well-defined anomaly approximately centered on the orebody which is thought to represent the outcrop of a shell of pyrite mineralization within the propylitic zone but outside the strong pyritic zone. The geochemical survey was not diagnostic in itself but did serve as additional evidence for the location of the faulted segment.

Elevations of intersections of San Manuel drill holes with the San Manuel fault were compiled from U.S.G.S. Professional Paper 256 and were contoured

by W. F. Chester and the writer in a structure contour map of the San Manuel fault. This map (Fig. 8) showed large ridges and valleys in the fault surface which formed a large-scale mullion structure consistent with dip-slip normal fault displacement. The Kalamazoo orebody was located by the first drill hole that was spotted according to the normal faulting interpretation and the other evidence cited.

The first Quintana Minerals Corporation drill hole penetrated through Gila Conglomerate and Cloudburst formation into monzonite porphyry with, first, propylitic and then quartz-sericite alteration. The hole passed from the pyritic and marginal mineralized zones into ore-grade mineralization at about 2,500 feet. From structural considerations it appeared that the axis of the Kalamazoo orebody might have an orientation of N57°E. A 600-foot rectangular drill grid on a N33°W and N57°E orientation was laid out centered on the first drill hole. The unique opportunity for extrapolating geology and symmetry of mineral zones from the San Manuel deposit has made it possible to intersect the Kalamazoo orebody with every hole completed to date.

Typical holes in the project were drilled to a depth of about 3,000 feet by the relatively cheap rotary drilling method. The rotary cuttings were assayed using a field analytical method and, when the assays reached 0.2% copper, coring was begun. The final intercept of approximately 1,000 feet which contains the marginal and ore zones was completed with NX wireline core drilling by the same drill rig. No casing was used. Holes were drilled with oil field type rotary drill rigs equipped with 95-foot masts, automatic bit pressure controls, and geolograph recorders. Drill operations in the project were planned and managed by the Quintana Minerals Corporation drilling department.

The Kalamazoo orebody has the shape of an overturned canoe, and the first ore block mined will be the relatively wide and flat canoe bottom. This ore block will be overlain by the marginal mineralization zone so that block-cave dilution material will contribute some values to the mill heads. The ore lacks any chalcocite enrichment but is also free of oxide copper content. The molybdenum content falls in the same range as in the San Manuel orebody, and the ore contains a small recoverable amount of gold and silver. The rock in the Kalamazoo orebody appears to be suited to block-caving mining under conditions similar to those found in the nearby San Manuel mine.

Consulting Geologist,
Tucson, Arizona,
March 18; April 20, 1968

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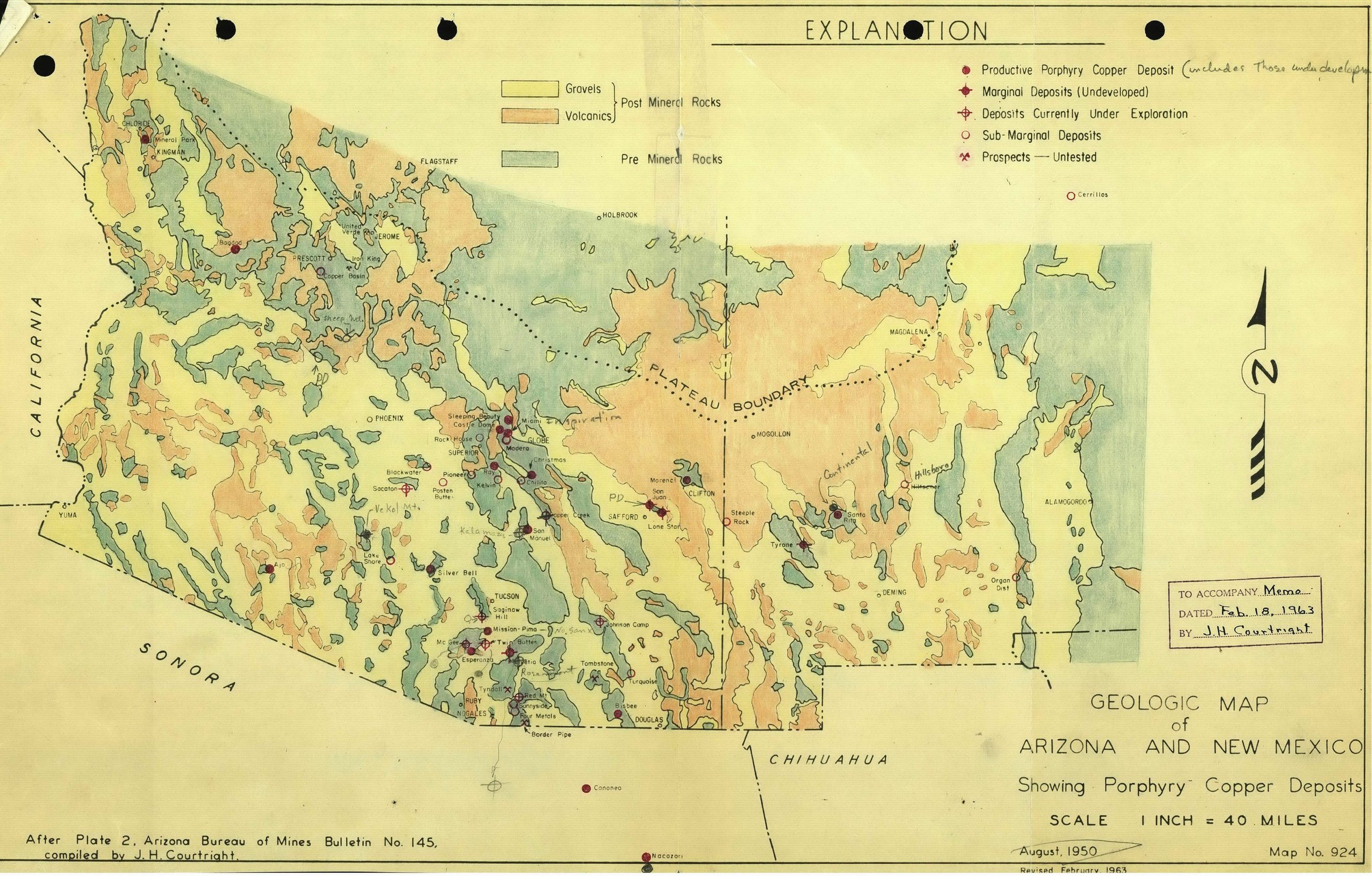


After Plate 2, Arizona Bureau of Mines Bulletin No. 145, compiled by J. H. Courtright.

EXPLANATION

Alluvium + Conglomerate
~~Gravels~~
Volcanics } Post Mineral Rocks

Pre Mineral Rocks

Commercial (Includes those undeveloped)
~~Productive~~ Porphyry Copper Deposits ~~(Includes Those Under Development)~~
Marginal Deposits ~~(Undeveloped)~~
Deposits ~~Currently Under Exploration~~ Partially Explored
Sub-Marginal Deposits
Prospects — Untested

Cerrillos

GEOLOGIC MAP of ARIZONA AND NEW MEXICO

Showing Porphyry Copper Deposits

SCALE 1 INCH = 40 MILES

August, 1950 Map No. 924

Revised February 1968

After Plate 2, Arizona Bureau of Mines Bulletin No. 145, compiled by J. H. Courtright.

EXPLANATION

Gravels
Volcanics } Post Mineral Rocks

Pre Mineral Rocks

Productive Porphyry Copper Deposit (Includes Those Under Development)
Marginal Deposits (Undeveloped)
Deposits Currently Under Exploration
Sub-Marginal Deposits
Prospects — Untested

CALIFORNIA
SONORA
CHIHUAHUA
PLATEAU BOUNDARY

CHLORIDE
Mineral Park
KINGMAN
FLAGSTAFF
HOLBROOK
Cerrillos
Bagdad
United Verde Ext
JEROME
PRESCOTT
Iron King
Copper Basin
Sheep Mt
P.D.
MAGDALENA
PHOENIX
Sleeping Beauty
Castle Dome
Miami-Inspiration
GLOBE
Rock House
Madera
SUPERIOR
MOGOLLON
Christmas
Blackwater
Pioneer
Ray
Kelvin
Chilito
Morenci
CLIFTON
San Juan
Hitscher
Sacaton
Santa Cruz
Posten Butte
Lost Horse
Reward Mine
Copper Creek
SAFFORD
Lone Star
Steeple Rock
Santa Rita
ALAMOGORDO
YUMA
Kalamazoo
San Manuel
Heymont (Vekol Mt)
Tyrone
Ajo
Lake Shore
Greenback
Silver Bell
DEMING
Organ Dist
TUCSON
Saginaw Hill
No-San Xavier
Mission-Pima
Johnson Camp
Mc Gee
Twin Buttes
Helvetia
Esperanza
Rosemont
Tombstone
Turquoise
Tyndall
RUBY
NOGALES
Red Mt
Sunnyside
Four Metals
Bisbee
DOUGLAS
Border Pipe
Cananea
Nacozari
plot La Candad

After Plate 2, Arizona Bureau of Mines Bulletin No. 145, compiled by J. H. Courtright.

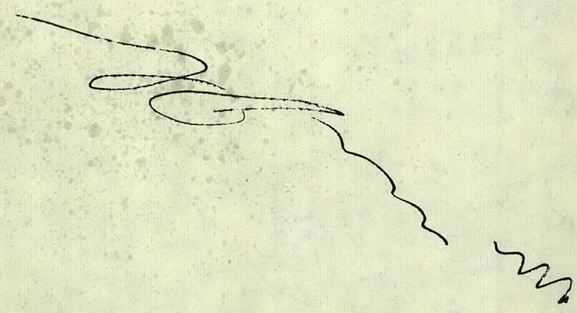
GEOLOGIC MAP of ARIZONA AND NEW MEXICO

Showing Porphyry Copper Deposits

SCALE 1 INCH = 40 MILES

August, 1950 Map No. 924

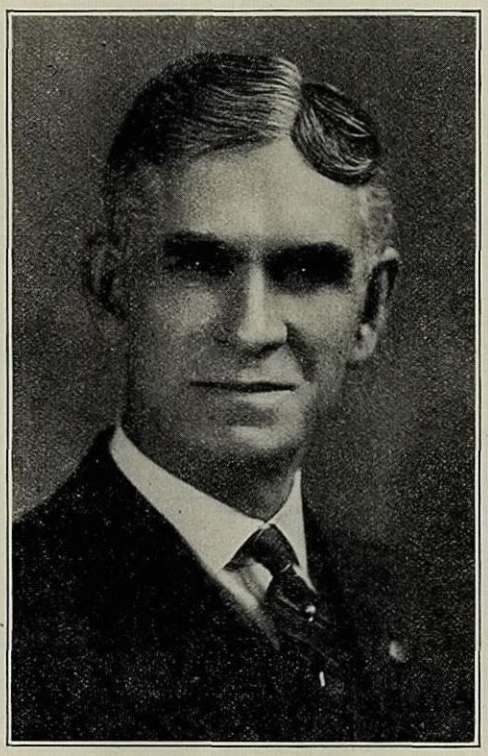
Revised ~~February, 1968~~ Oct 1975



Northwestern Porphyry Copper Prospects

By ROBERT N. BELL

Reprinted from THE MINING JOURNAL, Phoenix, Arizona



Robert N. Bell, Boise, Idaho. Mr. Bell's many years of active mining in Idaho have given him an intimate knowledge of mining and mining prospects in the Idaho-Oregon territory, which he covers in the following article.

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Northwestern Porphyry Copper Prospects

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B O S T O N A N D K E W E E N A W

AN ETCHING IN COPPER

by

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Battelle Memorial Institute
Columbus, Ohio

Read before the
Newcomen Society of England

Boston, Massachusetts
March 22, 1945

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B O S T O N A N D K E W E E N A W

AN ETCHING IN COPPER

It was a strange but highly fruitful marriage -- that union of hardy explorers seeking the rich treasures of copper in the Lake Superior wilderness, with Boston's aristocracy of brains, capital, and enterprise. This historic wedlock, which has continued happily to the present day, was the means by which the wealth of Lake Superior's copper was won for the use and benefit of an expanding America.

One branch of this family tree, the western branch, begins with prehistoric Indian miners, embraces the early French explorers of the Upper Lakes, and finally includes the British and American pioneers who reduced the vague rumors of copper to known fact and actually began the mining of copper in the wilderness. The other branch, the New England line, begins with the Mayflower, runs down through three centuries of Massachusetts history, and includes not a few of Boston's financial and intellectual leaders of the eighteen seventies, eighties, and nineties.

The fecundity of this union of east and west has been remarkable. Since its consummation less than a century ago, its issue has included America's first great mining boom, her first great copper-producing district, many important engineering triumphs, much pioneering in enlightened labor relations, one of the world's greatest mining schools, and a generation of mining men who have opened and operated important mines in every corner of the globe.

Picture, if you will, the 400-mile sweep of Lake Superior, greatest of unsalted seas, whose clear blue waters have provided a convenient highway alike for birchbark canoe and giant ore carrier. A rugged peninsula in the center of the

south shore, the most conspicuous feature of the whole intricate coastline, juts out nearly a hundred miles toward the center of the lake. This finger of land is the Copper Country; its name, the Keweenaw peninsula.

The scale of this lake is heroic, like the scale of the industries it has fostered. If we could transplant it to New England and New York, it would stretch from Boston almost to Buffalo. Its greatest width would run from the Connecticut-Massachusetts line northward to Plattsburg, and the Copper Country would be centered at Albany, its base forty miles to the southwest in the Catskills, and its tip in the Green Mountains of Vermont.

The lake's shores are rugged in the extreme, as rocky as the coast of Maine, indented with hundreds of coves, harbors and bays, and dotted with islands up to forty miles in length. One of these, Isle Royale, lies opposite the Keweenaw peninsula and is practically its twin geologically.

By a lucky chance, the copper of the Lake Superior district occurs in the pure metallic state. Pieces large enough to serve as tools or weapons could be pried out of soil or rock by primitive men and hammered into spearheads, axes, or tomahawks, without any smelting. Almost everywhere else in the world the copper is locked up in chemical compounds, chiefly copper sulphides, the utilization of which had to await the discovery of rudimentary smelting methods to extract the metal. So it happened that several centuries before Columbus -- the date is known only by archeological inference -- an unidentified race, presumably of Indians, found this metallic copper, discovered its malleability and strength, and from it made many thousands of copper implements. No doubt they first used loose or "float" copper found in river beds, along the beaches, or in the bouldery glacial soil that covers most of the area; but when the visible supply of "float" had been exhausted, these primitive men attacked the solid rock itself wherever large pieces of the metal

could be seen. Hundreds of pits were thus dug by these prehistoric miners on the Keweenaw peninsula, and more on Isle Royale. We shall presently hear more of one of these Indian pits.

The French priests of the Society of Jesus were the first white men to explore systematically the vast region of the upper lakes. Imbued with religious zeal, which was mixed with a keen eye for commercial possibilities and an understandable ambition to enhance the power of the French throne in the New World, the Jesuit explorers from 1660 onwards persistently related to their superiors the stories of copper deposits which they heard from friendly Indians. In 1667 Father Claude Allouez actually saw copper on the shore of the lake -- possibly the first white man to do so. But neither he nor any other Jesuit ever tried seriously to mine the copper. These Frenchmen were missioners, traders, explorers, but not miners; and they left this bonanza untouched from their earliest arrival until, more than a century later, the region passed from French to British sovereignty.

No sooner was the British flag hoisted at the Sault in 1763 than English traders and adventurers began to cast an appraising eye on the fabulous deposits of copper. In eight years they did what the French had failed to do in a hundred -- a mining company was organized in London, a group of English miners was sent to the New World, and actual mining operations were started. Working through the long, cold winter when the ground was deeply frozen, these men tunnelled into a clay bank at a point where they had observed a trickle of green copper-bearing water, and they encountered many pieces of float. With the warm days of spring their tunnel roof of frozen clay thawed and caved in, and the miners, unfamiliar with the geology of the area and tired of their lonely life, returned to the Sault. Probably it never occurred to them that the real bonanzas would be found not in the glacial clays but

in the solid rock. Thus ended the first abortive effort of white men to develop the area. And it was the last serious attempt under the British flag, for a dozen years later, in 1783, the south shore of the lake, and Isle Royale as well, passed from the flag of Britain to that of the United States.

How it happened that Isle Royale, though lying close to the Canadian shore, was included in the territory of the young republic is worth recording. It is a small chapter in the life of a distinguished native of Boston - Benjamin Franklin.

Through his wide circle of friends in Paris, Franklin was well acquainted with the Jesuits' reports of copper in the Lake Superior country. He knew, as did very few English or American statesmen, that Isle Royale appeared to have been the chief center of prehistoric mining, and he naturally expected that the white man would find mining on the island highly profitable. When the boundary negotiations in Paris with the representatives of the British crown had reached the proper stage, it is related that Franklin took the official map, traced the agreed-upon boundary up the St. Lawrence and through the center of Lakes Ontario, Erie, and Huron and into Lake Superior, but at that point he deflected his quill pen northward and passed between the Canadian mainland and the supposedly copper-bearing island. No one seems to have questioned the northward bend through Lake Superior, and Franklin later remarked that his inclusion of Isle Royale in United States territory might some day prove to be his greatest single contribution to his country. Such an outcome now seems highly improbable, for the great deposits have turned out to be on the Keweenaw peninsula which would have been United States territory in any event.

It was August 1796 when American sovereignty was finally established in this remote region, and the first pound of commercially mined copper from Lake

Superior was yet to be produced and sold. Indeed, four more decades were to pass before the energies of the young republic should be directed to solving the problem of the Lake Superior copper; for Uncle Sam was exceedingly busy with other matters and virtually ignored the copper legends. But a change came eventually, and here, as in many another turning point in history, it was brought about by one strong man, working with single-minded devotion for a cause. This man was Douglass Houghton.

Douglass Houghton had been graduated in 1828 from Rensselaer, America's first engineering college, and soon thereafter had been invited by Lewis Cass, Governor of Michigan territory, to come to Detroit and give a series of lectures on botany, chemistry, and geology. Finding the community to his liking, he settled in Detroit and soon became a leader in the state of his adoption, to which he was destined to render services of immense and lasting value. In 1830 he joined the Schoolcraft expedition to the sources of the Mississippi; and his imagination was fired by the limitless possibilities of the north country and by the opportunities to develop the mineral wealth of the Keweenaw that had been talked of for nearly two hundred years.

Houghton foresaw that the youthful science of geology might be the key that would unlock these mineral treasures; and when Michigan became a State, his enlightened and contagious enthusiasm led to the establishment of a state geological survey and to his appointment as its first chief. In 1840 he began his exploration of the Lake Superior region, and his report of 1841, though written with all the caution appropriate to a scientist working in an almost unknown field, aroused widespread interest. Few documents in scientific literature reveal better balance between caution and courage, between proof and intuition. Let me quote a few lines from a long letter which supplemented the report itself:

"I do not mean", said Houghton, "that copper is to be found in that region, as is the popular opinion, pure and without labor, but that capital may safely be

invested in the raising and smelting of the ores, with profit to the capitalist . . . . The collection of minerals I have brought from the region of Lake Superior have turned the heads of most of those persons who have examined them, but . . . I know full well the many difficulties and embarrassments which will surround the development of the resources of this district. That it will eventually prove of great value to our citizens there can scarcely be a shadow of doubt, but the time when this can be done must in a great measure depend upon the general policy of our government." And he goes on to advocate policies that will stimulate individual enterprise, and to urge the building of a canal at the Sault as a necessary first step to opening up the mineral lands. Houghton was 31 years old when he wrote this penetrating analysis.

But the sober judgment of a scientist could not prevail against the mad rush that soon followed the publication of the Houghton reports. On March 23, 1843, the signing of the treaty with the Chippewas opened the country to settlement; and America's first mining boom was on. Adventurers poured in by schooner from the Sault and by pack train from Green Bay. Towns mushroomed at Eagle Harbor and Copper Harbor, where vessels could unload in protected waters, and even at Eagle River, where the crude pier was at the mercy of every storm. These were the roistering days when hopes were high, when whispers of new finds filled the air, when a prospector of two weeks' standing was an old-timer, and any new arrival in a black frock coat could pass as a mining expert.

The Keweenaw, in the early forties, was still public domain. Mining was carried on under Federal permits which, however, could not be bought at any government office nearer than Sault Ste. Marie, two hundred miles away. Soon a brisk local trade in permits sprang up to accommodate, at a price, those adventurers who had neglected to secure them before leaving the Sault. Needless to say, any resemblance between the price of the permit and the value of the tract it covered was

purely coincidental. Far more money was paid for permits in those early months than for all the copper ever produced thereunder. A promoter had only to display a few choice nuggets of copper, and the fatal magic of hidden treasure would soon get in its work.

David Henshaw, a "solid man of Boston" and the secretary of the Navy under President Tyler, was one of the first to buy permits. He and his associates organized the Lake Superior Copper Company in 1844 and appointed Dr. Charles T. Jackson, a conspicuous figure in science and research in Boston, as the first manager. In his first annual report, Dr. Jackson quoted an assay showing values in copper and silver of more than $3,000 per ton of rock.

The effect of this incautious announcement was electric. There were no comparable figures by which to judge this assay, no past experience to serve as a guide. Few people stopped to inquire whether this one test was typical; they simply assumed that their luck would be at least as good as Henshaw's. And so another crop of eager pioneers set out for the lake, most of them devoid of mining experience, equipment, or even proper clothing.

Succeeding annual reports of the Lake Superior Copper Company were just as optimistic; the second stated that there was "an adequate quantity of rich ore to render the work very profitable", and that there was no danger of exhausting the ore for "generations to come". Copper was, indeed, produced in moderate amounts, but at a net loss. By 1849 the mine had accumulated a deficit of $105,000, and the Lake Superior Copper Company gave up the ghost. From the ashes of this inauspicious beginning rose a new corporation, known most appropriately as the Phoenix Copper Company; but the mine proved just as unprofitable under the new name as under the old. All-told, the Lake Superior Copper Company and its several successor companies, the first strongly financed and systematically prosecuted venture in the Copper Country,

cost the investors nearly two and a half millions in paid-in capital and yielded just $20,000 in return.

This disastrous record, which even the august sponsorship of Henshaw and the scientific reputation of Jackson could not conceal, might well have discouraged other investors and postponed for many years the development of more profitable mines, if another company, the Pittsburgh and Boston, had not had a far happier history. In August 1845, this company found a small vein high up on a greenstone cliff some three miles south of the village of Eagle River. The vein widened toward the bottom, and on the advice of Dr. Jackson and of another Bostonian, J. D. Whitney, United States geologist, a tunnel was driven in the vein. Some 70 feet from the mouth, the miners encountered the first mass of copper to be found in the district by systematic mining -- a discovery of the greatest importance, for it restored waning confidence throughout the district, and it also settled the basic question as to whether the vast amount of "float" copper that had been found on the surface was derived from near-by sources which might be found and worked, or had been transported, as some people were beginning to think, by icebergs or some other mysterious agency from Isle Royale, sixty miles away. This find marked the beginning of real mining in the district as distinguished from prospecting. The mine, known as the Cliff, was the first in the world to mine native copper as its chief product.

The company, however, was not yet out of the financial woods. By the following year all available cash had been exhausted, and receipts from the sale of copper could not yet support the growing mine. The Boston stockholders, sobered perhaps by the disappointments of the Henshaw enterprise, refused to vote a further assessment. Fortunately, the Pittsburgh shareholders felt more optimistic. The president of the company, a Pittsburgh doctor named Avery, whose bank credits at the moment amounted to $82,000, offered $80,000 of that sum as a loan to allow the

company to open the vein at greater depth. When $60,000 had been spent without return, and Dr. Avery was beginning to regret his enthusiasm, rich deposits were found which made the mine self-supporting. A year and a half later the loan was returned and the first dividend paid -- first not only of the dividends of this mine, but of the whole district; first of the golden flood which was destined to flow into the coffers of the shareholders of this and the other successful mines in the district. This one mine, the Cliff, in its productive period from 1845 to 1880, produced 38,000,000 pounds of copper and returned to the investors slightly more than 2,000 percent on the paid-in capital.

These two companies, built largely on Boston capital, were the conspicuous pioneers: one a dismal failure, the other a spectacular success. Meanwhile, prospecting went on actively all over the mineral belt, and Douglass Houghton, now in the employ of the Federal government, was vigorously pushing his surveys in order to complete the gradually unfolding picture of the basic geology that controlled the location of copper deposits. But on a stormy night in October 1845, while trying to complete his season's field work before the onset of winter, Houghton risked a dangerous coasting trip in an open boat, and was drowned near Eagle River at the age of 36. His career, brief as it was, made him easily the most distinguished man of his generation in the Lake Superior region. Though diminutive of figure and not very robust of constitution, his keen eyes, his resolute and decisive manner, his boundless energy and his unswerving devotion to his scientific studies as a tool for developing the region, made him both a natural leader and a great scientist.

In May of the next year Congress put an end to the clumsy permit system and offered the land for outright sale, first at $5.00 an acre and later at $1.25. With this improvement the copper rush gained new momentum. In 1848 the exploration fever reached its height, and the old-timers, the real pioneers and true prospectors,

began to feel crowded. That autumn the air was full of whispers of gold in the creek bottoms of California; and when spring came, these frontiersmen shook the dust of the Keweenaw from their feet and headed toward the golden sunset. Many a California '49-er first caught the mining fever in the Keweenaw and learned the rudiments of mining in the clear, sharp air of Superior.

The position, size, and richness of orebodies in the earth are, quite obviously, geologic matters. Douglass Houghton's exploration had shown that the Keweenaw peninsula consisted of several hundred sheets of lava and beds of sandstone and conglomerate, laid one upon another like a great deck of cards miles in length, and then turned rather steeply on edge. The stresses that accompanied this mighty upheaval also caused the layers of rock to break here and there in small cross fissures. Later, the dissolved copper, rising from great depths, filtered slowly upward into the more porous parts of the structure, there to be deposited both in the cross fissures and in certain porous sections of the lava flows and conglomerates. Not every bed, by any means, nor every part of any bed, was rich in copper, but only those areas where nature provided just the right environment. Great copper masses, sometimes weighing tons in a single piece, were characteristic of the cross fissures, but in the lava flows and conglomerates most of the copper was in small pin-head or pin-point specks.

The early miners worked almost entirely in the cross fissures. As they followed these veins across a succession of lava flows and conglomerates, they must have seen scattered particles of copper in the exposed edges of these beds; but they were looking for great masses of the metal, and paid only slight attention to the possibility of mining the other beds for their less spectacular contents. The factor they overlooked was the vital one of tonnage. The fissures might be profitable for a few hundred feet at most, but the porous lavas and conglomerates ran

continuously for miles, and might carry copper in far greater total amount than the fissures. The discovery of the first of these orebodies in the lava itself was the next great development.

In the center of the Keweenaw peninsula and far to the south of the mines thus far described, there is a gap occupied by Portage Lake. Prospecting for cross fissures in this locality had been fruitless; but in 1856 the great Pewabic lode was discovered - not in a fissure, but in one of the great lava flows just north of Portage Lake. Though not so rich as the best of the cross fissures, the Pewabic was far greater in extent, and thus lent itself to more systematic mining. As the Quincy Mining Company, which controlled much of this find, settled down to steady production, the miners throughout the area began to realize that the real bonanzas might be found, not in the small cross fissures, but in the much more extensive lavas and conglomerates. The Quincy development took place just before the Civil War, with the result that when that conflict broke out the company was in a position to furnish the Federal arsenals with all the copper needed for military uses. The Quincy and its associated companies began to pay dividends in 1862 and continued to pay at least one dividend a year, almost without a break, until the 1920's.

This changeover from fissure to lode mining soon revolutionized the industry. The fissures, no matter how rich, were too small to provide the basis for a stable, permanent community. Their development was essentially the gamble of the small speculator. But the lodes soon proved to be immense in tonnage, of great depth, and uniform in character over considerable distances.

One of the men who witnessed this revolution was Edwin J. Hulbert, a young civil engineer. Reaching the Copper Country in 1853, he first acquired a little practical mining experience and then received, with several others, a contract to survey a military road from Portage Lake to Copper Harbor, near the tip of the

peninsula. He soon became a prominent figure in the Keweenaw, known for his energy and shrewdness -- two qualities which were tragically to desert him a few years later when he tried to exploit his discovery of the fabulously rich Calumet conglomerate.

While conducting his survey for the military road in 1858, Hulbert came across a prehistoric pit which he naturally assumed to have been opened by the Indians on a rich copper-bearing outcrop. Searching for other evidence which might help to establish the trend of the outcrop, he found, a few hundred feet distant, a great boulder of conglomerate, the pebbles of which were cemented together by copper.

Hulbert very logically assumed that the huge copper-bearing boulder had not been moved very far from its original bed, and that the ancient pit was also on the same bed. He thus had two points which could be assumed to be on the outcrop. Drawing a line through the two points, he determined the hypothetical position of the conglomerate below the soil. Keeping all this strictly to himself, he went on with his road survey, and as soon as possible made quiet attempts to buy the land on which the discovery had been made. This he was unable to do, but he did succeed in buying 1,920 acres a little farther north, on the continuation of the same line. In 1861, in order to get capital to develop his tract, he deeded a three-quarters interest in the property to J. W. Clarke, Horatio Bigelow, and other Boston men, and together with them formed the Hulbert Mining Company. Later that year he bought 200 additional acres on the same line, and by a similar arrangement formed the Calumet Mining Company. On the land of this latter company Hulbert's theory seemed to be vindicated, for in 1864 workings actually disclosed the Calumet conglomerate, which proved to be by far the richest lode in the district.

All this was based on the tenuous assumptions already mentioned, one of which was that the ancient pit discovered by Hulbert was, like all the others then known, an old Indian mine. When the pit was finally explored, some years after

these purchases, it was found to contain some twenty tons of green copper carbonate, the deeply altered remains of pure copper fragments left there centuries earlier. But there was not a single stone hammer or other prehistoric tool, and the surrounding rock was found to be barren of copper. The pit was, in fact, in a dense, non-porous bed of a type which never contains copper in workable quantity. It is now believed that this particular pit was not an ancient mine, but a kind of primitive safe deposit vault -- a cache which because of the huge boulder not far away in the woods, could be readily found by its owners after a long absence. By the most fantastic and improbable chance, this storage pit had been dug only a few feet to one side of the rich conglomerate! Hulbert's carefully drawn scientific assumptions turned out to be without foundation; but the results were just the same as if he had been right. Surely the gods of chance were on his side.

Hulbert now had two promising mines, the Hulbert and the Calumet, but realizing that some of the best land carrying the extension of the conglomerate was still in the hands of others, he went to Boston, already the center of copper finance, and in 1865 met Quincy A. Shaw. From him he borrowed $16,800 to finance further land purchases for the Calumet company, and in return for his services Hulbert received enough Calumet stock to give him a controlling interest. In order to give Hulbert, as the manager, the greatest incentive to bring the property into profitable operation, the mine was leased to Hulbert and Shaw as operators, under a contract designed to be profitable both to the company and to the lessees. Hulbert, acting as resident manager, promptly began mining. Every foot of opening in the conglomerate seemed to be richer than the one before, and all would have been well if Hulbert had kept his head. But the amazing wealth that Dame Fortune had practically laid in his lap was too much for him. He threw caution to the winds, and forgetting the dictates of ordinary business judgment, he tried to mine the narrow and

steeply dipping lode by opening great surface pits which filled with water in the summer and with snow and ice in winter. Instead of building at the first opportunity a treatment plant of his own, he ordered the ore hauled by wagon 13 miles to a mill owned by others. Living only for the moment, he failed to lay in adequate supplies at the mine, so that the winter of 1866-67 found him dependent on such supplies as could be purchased at inflated prices in the towns of Hancock and Houghton. With a little forethought, the income from the mine might have paid even the fantastically high expense which he was daily incurring; but Hulbert's ability to maintain production was no greater than his skill at holding costs down. At the very time when his energy and shrewdness were most needed, Hulbert became a spendthrift.

Meanwhile, the Huron mine, a property fifteen miles farther south which Hulbert also managed for Shaw, was in serious financial straits from poor ore as well as from dubious management; and Hulbert either had to raise money to pay its debts, or else admit its failure. He seems to have had high hopes for the Huron, for he sold large blocks of his Calumet stock to finance the Huron, losing thereby his controlling interest in the Calumet. Heartbreaking as this must have been to Hulbert, it proved to be the salvation of the Calumet, for with Hulbert no longer in a position to dictate, the directors in Boston terminated the Hulbert-Shaw lease, ousted Hulbert, and in March 1867, sent Shaw's brother-in-law, Alexander Agassiz, to the Lake to try to rescue the rich but desperately mismanaged mine. Shaw and his friends meanwhile had purchased the land to the south of the Calumet and organized the Hecla Mining Company; and this, too, passed from Hulbert's to Agassiz's management.

Born in 1835 and the son of the great Swiss-American naturalist Louis Agassiz, Alexander had been reared to follow in his father's professional footsteps. Zoology did, indeed, become his principal life-work, and it seems almost incredible

that he could have been a great leader in two fields so dissimilar as scientific investigation and the management of a large mine. Yet he did play this double role, and played it superbly well. Just before leaving Boston for the Lake, this young naturalist, 31 years old, said to his friend Charles W. Eliot, then a professor at Boston Tech, "Eliot, I am going to Michigan for some years as superintendent of the Calumet and Hecla mines. I want to make money; it is impossible to be a productive naturalist in this country without money. I am going to get some money if I can, and then I am going to be a naturalist. If I succeed, I can then get my own papers and drawings printed". How well he brought these things to pass can be recounted here only in so far as the mine is concerned. For the rest, suffice it to say that through the fortune built on his management of the mines, he produced a volume and a quality of scientific research beyond the fondest dreams of many an able scientist.

Then began one of those notable chapters of human fortitude and indomitable determination which have so often illumined the annals of mining and given it the color of picturesque adventure. Agassiz arrived at Calumet none too soon. Everything was in confusion. Supplies were exhausted and cash was low. Lines of authority were tangled, and no one was willing to accept responsibility. Worst of all, there was nearly unanimous sympathy for Hulbert and distrust and suspicion of the inexperienced intruder from Boston. Not one man in the Copper Country could Agassiz count as a trusted friend and confidential adviser; and with Shaw a fortnight's journey away in Boston, Agassiz had to meet every daily problem utterly alone.

Agassiz quickly realized that lieutenants must be found and trained. But this would take time; and meanwhile copper must be produced to keep the sheriff at arm's length. Someone had to stop the incredible waste and confusion and create a passion for productivity. These were tasks that could not be delegated. Working day and night, Agassiz tried to inspect frequently every major operation to make sure

that nothing lost momentum. "The thing I drive and look after", he wrote Shaw, "is the only thing that goes . . . . There is not a thing, even down to seeing that the cars get unloaded when they come here with materials, which I don't have to look after myself." Through many weary months the two brothers-in-law, one in Boston and one in Calumet, strove against heavy odds to rescue the mine from disaster. Agassiz, with insufficient funds, was trying to bring order out of chaos at the mine, and at the same time to train a few men to carry a share of responsibility. Shaw, loaded with debts, was struggling to obtain funds from a community which had lost faith in the enterprise. Men less determined would have given up a dozen times. Years later, Agassiz remarked, "If Quin had known when he was beaten we should never have pulled the thing off".

By the late summer of 1868, Agassiz began to see daylight. A few men had been trained, the daily work had been put into a sensible routine, the fiscal wastage had been stopped. Agassiz decided that he could leave the mines in the hands of his mining boss, Captain Hardie, and prepared to sail for home. But Hulbert, according to legend, had one last fling at revenge. Men reputed to be in his employ caused the Calumet dam to be cut, thus depriving the mill of necessary water. But the spirit of the community was very different from the suspicion which had greeted Agassiz on his arrival at the Lake. Men promptly repaired the break before Hulbert could get the injunction with which he had sought to embarrass the company for a longer time. Soon thereafter Agassiz left for Boston, though for many years he continued to direct the Calumet and the Hecla through lengthy visits every spring and autumn. In 1871 the two companies were consolidated, with two others, to form the Calumet & Hecla. Shaw continued to serve on the Board until his death in 1908, and Agassiz as president from 1871 until his death in 1910.

Hulbert, on the other hand, seemed doomed to ill fortune. After his ouster

from the Calumet and the Hecla, he continued for a time to operate Shaw's smaller venture, the Huron. But its ores, though plentiful, were far too lean; and once again Hulbert drank the bitter cup of failure. As a recognition of Hulbert's discovery of the Calumet conglomerate, Shaw then gave him a thousand shares of Calumet and Hecla stock, which were worth $300,000 at the time, and later were valued at slightly over a million. But Hulbert gambled it away in mining speculation. Shaw then gave him a generous pension for life, whereupon Hulbert moved to Italy, married a member of the Caruso family, and dropped out of Copper Country affairs except for an occasional attack upon his former associates through the columns of newspapers.

Agassiz's semiannual trips to the Copper Country permitted him to guide general policy, as was his intent, but not to look after details of management as he had done at the beginning. A strong general manager was needed to operate the mines, mills, and smelter. The most notable of these managers was James MacNaughton, who took charge in 1901; and Agassiz writes of his feeling of relief to have such a man in Calumet. MacNaughton had grown up in the Copper Country, practically in the shadow of the plant. He continued as general manager, and later as president, until his retirement in 1940. Now again the presidency has returned to a Bostonian in the person of Endicott R. Lovell, who makes his headquarters, however, in Calumet.

The growth of the Calumet & Hecla exceeded all expectations. In 1906 it produced nearly 100,000,000 pounds of copper, and in 1907 the price of the stock reached $1,000 a share. Dividends have amounted to about $200,000,000, or some 8,000 percent on the capital invested.

In 1898 a young scientist from Cornell, Harry Benedict by name, joined the Calumet & Hecla staff as a metallurgist. Probably no one then guessed that this young man would soon develop a process whereby the company's gross dividends would

be increased by many millions from material hitherto discarded as waste. In crushing and treating the copper-bearing rock for the purpose of extracting the copper, it is inevitable that some of the copper should remain in the waste sands thus produced. In the early days, these losses were high. The idea of recovering some of the wasted copper was an old and favorite dream, but no means were known whereby this could be done at a profit. It was the guiding genius of Harry Benedict that finally evolved a process that made such recovery both a technical and a financial triumph. Waste sands from the early operations are now dredged up from the lake bottom, ground almost to the fineness of flour, and chemically leached of their copper. A half billion pounds of copper have been recovered from these sands that once were thrown away, and the net earnings of $30,000,000 from this reclamation work represent more than one-seventh of all the dividends paid by the company. The efficiency of this operation is one of the masterpieces of American metallurgical skill.

Nearly all the developments thus far mentioned took place north of Portage Lake. The southern part of the district has a history no less interesting, though its large producing mines were developed a little later, and they never reached the colossal proportions of the Calumet & Hecla. One company in particular must be mentioned -- the Copper Range. As early as 1884 W. A. Paine of Paine, Webber and Co. organized the Copper Range Company to build a railroad along the undeveloped southern part of the mineral belt, where orebodies might be found. In 1899 the company invited Dr. L. L. Hubbard, state geologist of Michigan, to join their staff as chief geologist, and within three months he found one of the best copper showings in the entire district. Here the Copper Range Company established the Champion mine. Adjoining the Champion property, another Bostonian of more spectacular hue, Thomas W. Lawson, controlled a property known as the Trimountain mine. It appeared to be workable, but under Lawson's control had never made any money. It did, to be sure, pay

one dividend under his direction, though the company was deeply in debt at the time. In 1903, soon after this dividend payment, the Copper Range secured control of the Trimountain and also of other adjoining properties such as the Baltic, and soon the Copper Range Company's production and profits were second only to those of the great Calumet & Hecla.

Orebodies inevitably are exhausted in time; many a mining district has reverted to wilderness in twenty or thirty years. The Copper Country, after a century, is still producing copper, though on a greatly reduced scale. When the accumulated postwar demand for copper has been satisfied, and when the low-cost reclamation of old sands has ended, what will happen to this historic mining district? Is there any chance of finding more great orebodies? The answer to this question brings us face to face with the most important question in metal mining -- the question of where to invest venture capital, where to look for ore.

There are, of course, only two places to look: either in virgin territory where no great orebodies are known, or around the margins and in the unexplored gaps of established mining districts. Geologists are interested in both; capital should be interested in both.

It happens that orebodies are frequently rather gregarious; if you find one, others are likely to be near. It follows that the re-examination of old districts is a promising activity. In the Keweenaw, most of the potential ore-bearing ground has been explored only by widely spaced drill holes; perhaps only a tenth of the spots where an orebody might lurk have been adequately studied. Every great mining district is being or will be re-examined as known reserves are consumed, and in some of these districts, perhaps in the Keweenaw, great orebodies may yet be found. If they are not found by present methods of scientific exploration, they will yield to the higher powered prospecting tools of the future. There is no certainty

and much of speculation in this, as in all prospecting; but with all due concessions to these uncertainties, it would be contrary to all the laws of chance to assert that every orebody in the Copper Country has been discovered. The problem is how to find those that remain at a reasonable cost.

Mining is well recognized as a hazardous financial venture. There must be a possibility of occasional great gain to justify the great risk and to compensate for the frequent losses. The Keweenaw is a spectacularly successful mining district. Let us look at the record, now that hindsight is available, and see what our chances would have been if we had been looking for a mining investment when the Copper Country was new.

The Keweenaw comprises some 3,000 square miles of forest-clad slopes, all of which must have looked much alike to the early prospector. Today, we know that not more than 400 square miles of it could possibly have been worth prospecting by the methods available to the pioneer. If he bought a permit at random, there were 7 chances out of 8 that the ground wouldn't even be worth looking at.

In the 400 square miles of the mineral belt, there are about 400 lava flows and conglomerate and sandstone beds which might have come to the attention of our early prospector. Of these, only 13 have yielded copper commercially, and only 9 have repaid to stockholders a single dollar of their investment.

Of the 23 fissures that were mined by organized companies, only 7 have paid anything back to the investors.

Of the 110 mining companies of record, only 27 ever made any return whatever to the investors.

If we except the dividends of two hundred millions yielded thus far by the Calumet & Hecla, it is estimated that the dividends paid by all the other companies combined would have been insufficient to repay the total capital invested, to

say nothing of paying interest on the capital.

But the benefits of the Copper Country development did not end with a money profit of some two hundred millions, useful as that has been. Certain intangible assets of great worth have also accrued. Among these were many engineering triumphs, such as the development of safe methods of opening and working mines at depths of more than a mile. On the surface of the ground, too, these companies achieved some of the finest engineering in the world. Steam hoists, air compressors, and pumps of leviathan proportions and unsurpassed efficiency dot the landscape. Some of these machines were among the first great steam engines to utilize the principle of triple expansion. Agassiz retained the Boston engineer, E. D. Leavitt, to design the earlier engines. Later, in the nineties, the great Finnish engineer, Bruno Nordberg, settled at Milwaukee and blazed new trails in efficient steam machinery of giant size. The Nordberg hoists, pumps, and compressors scattered through the Keweenaw make the Copper Country one vast monument to Nordberg's genius. The last of the Nordberg steam hoists serves the Quincy Shaft No. 2. Its mammoth revolving drum, as high as a three-story building, is designed to hoist from a depth of 13,300 feet, and the main shaft, driven by four huge steam pistons, is a steel forging weighing 410,000 pounds.

Many another pioneer step in engineering was taken in the Copper Country. It was at the suggestion of Mabbs, a copper mine manager, that Rand developed the portable compressed-air drill for use in mines; and half a dozen important inventions for the concentrating of ores first saw the light of day in the mills along the Copper Country lake shores.

In the field of labor relations the progressive and humanitarian record of the Lake Superior copper companies deserves much more attention than we can give it here. Early in his career Alexander Agassiz set a high standard in such matters as

housing, medical care, industrial safety, and employee welfare. The major companies have thus built an attractive community whose happy surroundings have been reflected in a century of productive effort almost unmarred by industrial strife.

Mining, especially when carried on in large scale, is a job for engineers. Precision, efficiency, freedom from breakdown, are the order of the day; and these qualities do not thrive where the management follows rules of thumb. To meet the growing demand for mining engineers and metallurgists, the State of Michigan in 1882 established the Michigan College of Mines at the village of Houghton. Not only has the school supplied the local market for engineering talent; in addition, her graduates run many of the greatest mines, mills, and smelters in all parts of the world.

Like every other great enterprise, the copper mines of Lake Superior are a reflection of men; of the prehistoric miners, the Jesuits, the pioneers and sourdoughs, the scientists and engineers of later years. The mines are in no small measure a reflection of such men as Quincy A. Shaw, the man who refused to know when he was beaten. But most of all, they are a reflection of two men of great and noble spirit: Douglass Houghton and Alexander Agassiz. One was the geologist, the seeker after truth, whose ambition was to lay a sound scientific foundation for systematic mining, and who, in the few fleeting years before his tragic death, paved the way for all the developments that were to come. The other was the planner, the doer, the practical operator, who learned intellectual integrity in the uncompromising school of science, and through sheer strength of will built a great mine where for a time most men would have said the odds were impossible. Both were men of courageous and determined spirit; both had their eyes fixed on bright and distant goals. May their memory be always green; and may their tribe increase!