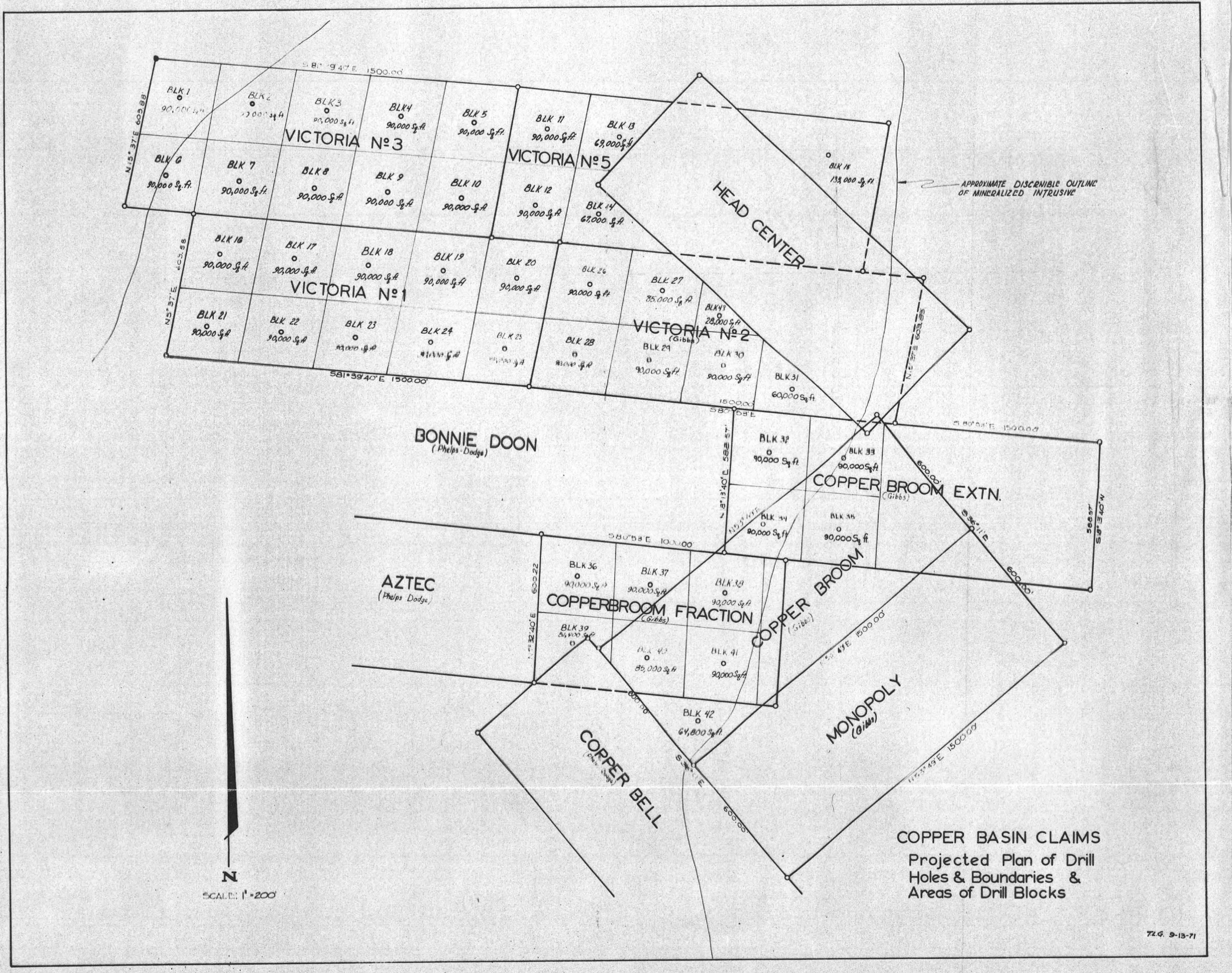
CONTACT INFORMATION
Mining Records Curator
Arizona Geological Survey
416 W. Congress St., Suite 100
Tucson, Arizona 85701
602-771-1601
http://www.azgs.az.gov
inquiries@azgs.az.gov


VICTORIA Nº3
VICTORIA Nº5
VICTORIA Nº1
VICTORIA Nº2 (Gibbs)
HEAD CENTER
BONNIE DOON (Phelps-Dodge)
AZTEC (Phelps Dodge)
COPPER BROOM EXTN. (Gibbs)
COPPERBROOM FRACTION (Gibbs)
COPPER BROOM (Gibbs)
COPPER BELL (Phelps Dodge)
MONOPOLY (Gibbs)
APPROXIMATE DISCERNIBLE OUTLINE OF MINERALIZED INTRUSIVE
BLK 1 90,000 Sq.ft.
BLK 3 90,000 Sq.ft.
BLK 4 90,000 Sq.ft.
BLK 5 90,000 Sq.ft.
BLK 6 90,000 Sq.ft.
BLK 7 90,000 Sq.ft.
BLK 8 90,000 Sq.ft.
BLK 9 90,000 Sq.ft.
BLK 10 90,000 Sq.ft.
BLK 11 90,000 Sq.ft.
BLK 12 90,000 Sq.ft.
BLK 13 69,000 Sq.ft.
BLK 14 67,000 Sq.ft.
BLK 15 133,000 Sq.ft.
BLK 16 90,000 Sq.ft.
BLK 17 90,000 Sq.ft.
BLK 18 90,000 Sq.ft.
BLK 19 90,000 Sq.ft.
BLK 20 90,000 Sq.ft.
BLK 21 90,000 Sq.ft.
BLK 22 90,000 Sq.ft.
BLK 23
BLK 24
BLK 26 90,000 Sq.ft.
BLK 27 85,000 Sq.ft.
BLK 28
BLK 29 90,000 Sq.ft.
BLK 30 90,000 Sq.ft.
BLK 31 60,000 Sq.ft.
BLK 32 90,000 Sq.ft.
BLK 33 90,000 Sq.ft.
BLK 34 90,000 Sq.ft.
BLK 35 90,000 Sq.ft.
BLK 36 90,000 Sq.ft.
BLK 37 90,000 Sq.ft.
BLK 38 90,000 Sq.ft.
BLK 39
BLK 40 85,000 Sq.ft.
BLK 41 90,000 Sq.ft.
BLK 42 64,800 Sq.ft.
S81°39'40"E 1500.00'
N5°37'E
S80°58'E 1000.00'
600.00'
1500.00'
N
SCALE: 1" = 200'
COPPER BASIN CLAIMS
Projected Plan of Drill Holes & Boundaries & Areas of Drill Blocks
T.L.G. 9-13-71

356 Hassayampa Dr;
Prescott, Ariz;
II/4/7I

Mr.Francis X.Cannaday,
Nuclear Dynamics, Inc.
P.O.Box 20766

Dear Mr.Cannaday:-

On my return yesterday from a trip to Oregon I found your letter of October I9th relative to Copper Basin.

You have my permission to look at our claims in Copper Basin but I suggest that it would be best if I accompanied you for the reason that otherwise you would'nt know when you were on our claims or those of Phelps Dodge as we are bounded on both sides by their property. They are presently engaged in a comprehensive drilling campaign and do not allow any outsider on their property.

I suggest that you phone or write me several days before your proposed trip so that I will be sure to be available.

Sincerely yours,

Fred Gibbs.

Fred Gibbs.

FRED GIBBS
MINING ENGINEER
PRESCOTT, ARIZONA

REPLY

Phoenix

Francis X. Cannaday

Manager, Base & Precious Metals

October 19, 1971

Mr. Fred Gibbs,
356 N. Hassayampa Drive,
Prescott, Arizona.

Dear Mr. Gibbs:

Mr. Frank Gibbs, geologist for Phillips Petroleum Minerals Division in Prescott, has called to our attention your property in Copper Basin, I understand, with your approval. Some general information, maps and a thesis by Johnston on the area has been shown us.

I would like to look at the property with your permission.

Thanking you very much for your attention to this matter, I hope to hear from you soon.

Sincerely,

Francis X. Cannaday

Francis X. Cannaday.

FXC/dmh

NUCLEAR DYNAMICS, INC. PHOENIX, ARIZONA 85036 • P. O. BOX 20766 • 2871 SKY HARBOR BLVD. • 602 : 267-0581
PRESCOTT, ARIZONA 86301 • P. O. BOX 2337 • 100 UNION STREET • 602 : 445-0834

UG #5	0-290'	0.39 % Cu
GM #2	0-276'	0.24 % Cu
GM #1	16-303'	0.40 % Cu
S-1	0-70'	0.42 % Cu
S-2	0-135'	0.23 % Cu
S-3	0-70'	0.37 % Cu

2/15/71

Some thoughts on possible negotiations with a third party (assuming Phelps Dodge as second party) by owners of Gibbs' (first parties) claims in Copper Basin.

(I) Because of the relatively scant amount of factual knowledge presently at hand concerning tonnages and grades of possible ore occuring to any given depth below surface on first parties property, the initial step should consist of a drilling program comprehensive enough to provide information to both parties to a degree necessary for the negotiation of a purchase and lease contract which would be fair to both parties.

(2) First parties must recognise and make allowance for the fact that third party would in all probability enter into a deal with second party, and therefore any purchase payments made in the first ten years of a contract should be small ones.

(3) Phelps Dodge is currently initiating a development drilling program on its property and it is reasonable to assume that the program will require several years to complete before a pit can be designed and plant construction initiated.

(4) If (3) proves to be a valid assumption it seems reasonable to assume further that mining would be initiated by second party not later than eight years hence.

(5) It is completely unreasonable to assume that second party would confine its thinking and planning to a project limited just to the ore minable on its own property without prior acquisition of first parties claims because of the probable large amount of its own ore which otherwise would be tied up in the pit bank along the common boundary with first parties.

(6) The very limited amount of drilling completed to date on first parties claims would seem to indicate that it is reasonable to expect that half of the ore will be of concentrating grade using a cut-off of 0.25% copper equivalent, and a quarter will be leach grade running from 0.10% copper to 0.20%, and that recoverable gold-silver values in the concentrating ore would probably amount to 20¢ per ton. In addition, tests made by Kennecott indicate that rhenium is present and would have a recoverable value equal to that of the combined gold-silver.

With the above thoughts in mind, and particularly No.2 thereof, first parties suggest that a fair deal for a third party might involve the following stipulations:-

"A":- An initial lease period of three years duration during which third party would complete a drilling program to 1,000' depth on a 300' grid pattern,- third party to pay first parties $5,000 annually over the 3-year term, but with the right to terminate the project at any time.

"B":- An option to purchase at the end of the 3 year drilling period (or before if desired), at a price determined by multiplying the number of tons of concentrating grade ore found to a depth of 750' by 7¢ per ton and the number of tons of leach grade ore found to the same depth by 2¢ per ton, but with a maximum purchase figure set at $4,000,000 regardless of the figure arrived at by the above method of evaluation. The option to purchase, if exercised, would convey mining rights to a depth of 750 feet.

"C":- A 50 year lease on all ore occuring below 750' to be paid for when and as mined at the rate of 5¢ per ton regardless of whether it wqs leach grade or concentrating grade.

"D":- Conditions "B" and "C" would be applicable only if the IRS ruled that the payment made under "B" would be considered for tax purposes as sale of a capital asset, while the royalty paid under "D" would be considered as 100% taxable income.

Stock ? Price on some? ... ?

"E":- Payments on the purchase price would be $25,000 a year for the first two years of the option period, $50,000 a year during each of the following 5 years, and the remainder of the price payable in equal installments over the following ten years.

"D":- A provision which would have the effect of nullifying any of the above provisions and substitute in their stead an outright purchase price for the entire property in the event that leaching in place after nuclear fracturing or any other type of fracturing should be used instead of the conventional pit mining and concentrating methods now in use.

****

The above thoughts are offered as a possible basis for discussions looking toward a mutually satisfactory agreement for both parties. First parties feel that an agreement along the suggested lines would provide third parties plenty of latitude in eventually making a deal with second party, particularly in view of the fact that they do not make any provision for remuneration to first parties for the "location value" of their claims, which, as above mentioned, is very considerable in view of the probable large tonnage of second party's ore that would be tied up in bank slope along the common boundary. This value would enter into negotiations between second and third parties, and would constitute "cream" to third party.

F.Gibbs.
2/15/71
F.G.

Prescott
3/17/70

SOME INFORMATION ON GIBBS' COPPER BASIN CLAIMS:

Property:

8 Claims:- 6 Patented,- 2 Unpatented.

Mineralization:-

Mineralized monzonite porphry and related rocks intrusive into Bradshaw granite. Ore occurs as chalcopyrite and molybdenite with minor gold-silver values in breccia pipes and interpipe material. Oxide zone very shallow with primary sulphides showing on surface in bottoms of shallow gulches.

Exploration:-

(I) Numerous shallow shafts and tunnels all in the oxide zone.

(2) 8 drill holes:- 4 rotary and 4 core.
Deepest hole,-I200 feet (core)
Total drill footage,- 2,764 feet.

(3) Assays:- Weighted average of 2,764 feet:-

I6I8' (59%) assayed 0.4I% (copper equivalent)
704' (25%) assayed 0.15% copper.
442' (I6%) assayed 0.07% copper.

In addition to copper-moly values, numerous assays mostly from drill holes on claims formerly owned by Gibbs but now owned by Phelps Dodge, indicate an average of 0.I0oz silver and very erratic gold values. At present metal prices recoverable gold-silver would average 20¢ per ton.

Mining:-

There would be practically no waste stripping over the mineralized body. Waste stripping would be confined to side boundary material removable to provide pit slope. To I500' depth the stripping ratio would be about ½ to I.

Probable Ore Tonnage:- (Based on drilling results to date)

There are 84 acres enclosed within discernible surface boundaries of the mineralized intrusive. Not included in the above are about 25 acres in the eastern portion of the property covered by alluvials (about I5' thick) and therefore not discernible as to mineralization.

To a depth of I500' there are 429,000,000 tons of mineralized material which may assay out about as stated above. Only a comprehensive drilling program can provide the actual facts.

Possible tonnage of ore on Phelps Dodge claims tied up by pit slope to a depth of I500 feet if Gibbs' claims are not acquired by that Company:-

On S.W. common boundary 3800' long,-350,000,000 tons.
On N.E. " " I400' " ,-87,000,000 tons.

On Gibbs' claims if mined separately without acquisition of any Phelps Dodge ground on southwest and northeast sides the minable ore would be somewhere between 40,000,000 and 50,000,000 tons.

<u>Miscellany:-</u>

An Arizona Public Service power line runs within a mile of the property.

Gibbs claims cover control of the surface drainage problem.

<u>Conclusion:-</u>

Very little is known of the metal values in the Copper Basin intrusive and only drilling can provide the ultimate necessary economic facts.

Tonnage figures given above are based on the assumption that the results obtained in the very limited drilling and near-surface exploration will be borne out by future work.

F.Gibbs.

F.G.

<u>II/I/70 - Addendum:</u>

<u>Some Property History:-</u>

<u>Gibbs.</u>

Gibbs became interested in Copper Basin in 1943 at which time he acquired via lease and option the Loma Prieta group of patented claims on the east side of the Basin and the Copper Hill group on the west side.

These two groups were sold to Ranwick, Inc. (a sub of Ventures, Ltd.) in 1955-56. Ranwick sold (or leased) these two groups to Phelps Dodge in 1960.

Of Gibbs' present holdings, four unpatented claims were purchased from the Estate of Martin Schuber in 1949. Three of these, the Copper Broom Fraction, Copper Broom Extension, and Monopoly were patented by Gibbs in 196I. The fourth, the Copper Broom, is still unpatented.

In 1950 Gibbs located the Victoria No.I, No.2, and No.3 claims and had these patented in 196I. The Victoria No.5 was located in 1960 and is not patented.

All of the above eight claims are in one contiguous group which cuts transversly across the elliptical-shaped northeast-southwest trending mineralized intrusive just to the northeast of the probable center of the intrusive. The group is bounded on the southwest and northeast by Phelps Dodge patented claims.

Phelps Dodge Property.

Phelps Dodge inherited the nucleus of its holdings from the old Commercial Mining Company which first operated the claims and had them patented back in the 80's.

After acquisition, Phelps Dodge did no work of any kind on the claims and in the early 40's leased them to Fred Schemmer, a practical miner from Prescott. Schemmer, over a period of I2 or I4 years mined and shipped to the Douglas smelter several hundred thousand tons of siliceous carbonate ore.

In I960 the Company located approximately 80 claims contiguous to and surrounding the original property.

In I966-67 McFarland & Hullinger, under a lease agreement, shipped siliceous carbonate ores from surface operations to Douglas.

Between I960 and I970 the Company drilled I0 or I2 holes at various locations on their patented claims to unknown depths, the deepest, according to rumour, to a depth of I600 feet.

This year, I970, the Company located over 500 claims, mostly to the south and west, contiguous to previous holdings.

Bibliography of Geological Reports:

Various reports have been written covering Copper Basin geology, copies of which Gibbs has. They are:-

(I) "Report on the Loma Prieta Mine" by Dr.Chas. A. Anderson (U.S.G.S.) in I943.

(2) "Report on the Copper Hill Mine" by Donald H.Kupfer, (U.S.G.S.) in I943.

(3) "Report on Geology and Diamond Drilling-Copper Basin Project" by Sidney Alderman Jr. for United Geophysical Company in I955.

(4) "Geology and Ore Deposits of the Copper Basin Mining Dsitrict" by Dr.Wm.P.Johnston in I955. This is his thesis presented to University of Utah as part of requirement for Ph.D. degree.

(5)"Report on Copper Basin Properties" by J.David Lowell for Ranwick Inc, in I956.

(6)" Geology and Orgin of Mineralized Breccia Pipes in Copper Basin" by W.P.Johnston and J.David Lowell for publication in Economic Geology, Vol.56, in I96I.

F. Gibbs.

COPPER BASIN

9/I/68

Assays of No.I Drill Hole (No.3 on Drill Map) Assays by Root & Norton.

Individual Sample No's.	Footage	Average of Individual Assays % Cu.	Average of Individual Assays % Mo.	Equivalent % Cu. with Mo. translated to copper at present prices	Composite Assays % Cu.	Composite Assays % Mo.	Equivalent % Cu. with Mo. translated to copper (Present prices)	Vertical Block Averages.
I to 5	I6'-65'	0.85	.055	I.05	0.54	.06	0.77	
6 - I0	65'-II3'	0.40	.058	0.65	0.40	.055	0.62	
II - I6	II3 -I69'	0.38	.043	0.57	0.3I	.035	0.44	3I9'
I7 - 2I	I69'-2I6'	0.30	.045	0.48	0.28	.055	0.49	0.52% Cu.
22 - 26	2I6'-264.5	0.22	.044	0.39	0.2I	.035	0.34	(Mo. translated to Cu.)
27- 32	264.5'-3I9'	0.30	.042	0.47	0.26	.050	0.46	
	Ave.	*0.41*		*319' - Ave*	*0.33*	*.048*	*0.52*	
33 - 37	3I9' - 367'	0.08	.034		0.08	.035		
38 - 42	367' - 4I5	0.07	.030		0.07	.030		
43 - 47	4I5' - 463	0.06	.030		0.06	.035		I92' Waste
48 - 52	463' - 5II'	0.09	.035		0.09	.035		
	Ave.	*0.07*	*.032*	*192' - Ave.*	*0.07*		*0.20*	
53 - 57	5II'-558'	0.I2	.040		0.I2	.040		
58'-62'	558- 605.5	0.07	.032		0.07	.035		
63'-67	605.5-653.5	0.I3	.04I		0.I2	.035		
68 -72	653'-700	0.20	.032		0.I9	.040		
73 -77	700'-747'	0.25	.026		0.24	.030		
78 -82	747'-795'	0.I8	.032		0.I7	.025		524'
83 -87	795'-843'	0.I3	.030		0.II	.025		0.I45% Cu.
88 -92	843'-89I'	0.I0	.027		0.09	.030		Leach ore.
93 -97	89I'-939'	0.09	.032		0.09	.035		
98 -I02	939'-986'	0.I0	.050		0.09	.050		
I03 -I07	986'-I035'	0.2I	.043		0.2I	.040	*0.36*	
	Ave.	*0.14*		*524' - Ave*	*0.14*	*.035*	*0.27*	
I08 -II2	I035'-I083'	0.26	.055	0.47	0.26	.045	0.43	
II3 - II7	I083'-II3I'	0.27	.040	0.42	0.26	.035	0.39	I65'
II8- I22	II3I'-II79'	0.24	.026	0.33	0.23	.025	0.32	0.40% Cu.
I23- I25	II79'-I200'	0.29	.030	0.40	0.29	.030	0.40	(Mo translated to Cu.)
	Ave.	*0.26*		*Ave.*	*0.26*	*.034*	*0.40*	

Average Cu assay for 1200 ft. ---- 0.20%

October 1968

COPPER BASIN

Assays by Root & Norton.

Assays of No.2 Drill Hole (No.7 on Drill Map)

Individul Sample No's.	Footage	Average of Individual Assays % Cu.	% Mo.	Equivalent % Cu. with Mo translated to Cu. (Present prices)	Composite Assays % Cu	% Mo.	Equivalent % Cu. with Mo. translated to copper. Present prices	Vertical Block Averages
I to 5	0.0-5I.5	0.22	0.024	0.30	0.20	0.0I5	0.30	
6 to I0	5I.5-98.0	0.23	0.029	0.34	0.22	0.025	0.34	
II to I5	98 -I44	0.23	0.030	0.34	0.23	0.025	0.34	
I6 to 20	I44 - I9I	0.3I	0.040	0.46	0.3I	0.030	0.46	276'
2I to 25	I9I - 238	0.23	0.043	0.39	0.2I	0.025	0.39	0.36% Cu.
25 to 29	238 -276.5	0.23	0.034	0.36	00.26	0.035	0.36	(Mo translated to Cu.)
	Ave.	0.24			.24	.026	Ave. 0.37	

6) 1.43 = .24

6) 1.55 = .026

6) 2.245 = .37

DRILLING RESULTS ON GIBBS CLAIMS TO I/I/'70

Drilled By:	Hole No.	Total Depth	Interval	Footage	% Cu.	% Mo.	% Cu. Equivalent Mo. translated to Cu. at 1968 prices.	Ore Classification
United Geophysical	3	453'	0'-50'	50'	Overburden		--------	Waste
			50'-160'	110'	0.09	0.018	--------	Waste
			160'-453'	293'	0.18	0.027	0.278	Concentrating
	5	290'	0'-290'	290'	0.39	0.028	0.495	Concentrating
Rarwick, ltd.	S-I	70'	0'-70'	70'	0.42	0.044	0.590	Concentrating
	S-2	135'	0'-135'	135'	0.23	0.018	0.290	"
	S-3	70'	0'-70'	70'	0.37	0.008	0.390	"
	V-I	270'	0'-90'	90'	0.037	0.044	--------	Waste
			90'-200'	110'	0.210	0.013	0.252	Leaching &
			200'-270'	70'	0.130	0.014	--------	Leaching
General Minerals	I	1200'	0'-319'	319'	0.330	0.048	0.520	Concentrating
			319'-511'	192'	0.07	0.032	--------	Waste
			511'-1035'	524'	0.140	0.035	0.270	Concentrating
			1035'-1200'	165'	0.260	0.034	0.390	"
	2	276'	0'-276'	276'	0.240	0.026	0.330	Concentrating

Total Footage of Each Class:
(Waste-0.07% Cu. 442' 16% of total
(Leach-0.15% Cu. 704' 25% of total
(Conc.-0.41% Cu. 1618' 59% of total.

Total Footage Drilled 2764'

Economic Geology
Vol. 56, 1961, pp. 916–940

GEOLOGY AND ORIGIN OF MINERALIZED BRECCIA PIPES IN COPPER BASIN, ARIZONA

W. P. JOHNSTON AND J. DAVID LOWELL

CONTENTS

ABSTRACT

The Copper Basin district, Yavapai County, Arizona, contains a "porphyry copper" type copper-molybdenum deposit in which the bulk of ore mineralization appears to have been controlled by pipe structures. Mineralization is associated with a composite stock of presumed Laramide age which has intruded older Precambrian metamorphosed sediments and intrusive rocks. The Laramide stock is thought to have an elongated "beet" shape with a restricted orifice at depth. Its intrusive units range in composition from diorite to aplite, but mineralization appears to be most closely associated with quartz monzonite and quartz monzonite porphyry units. Mineral deposits of the district have a rough zonal arrangement with copper-molybdenum mineralization in the center surrounded by an aureole of lead-zinc-silver occurrences.

Mineralized breccia pipes are roughly cylindrical, near vertical structures ranging in diameter from 50 to 600 feet. A composite pipe is composed of a central core of heterogeneous, rotated, angular to rounded rock fragments surrounded by a zone of none-rotated crackle breccia. The fragments are cemented by quartz and may be mineralized with pyrite, chalcopyrite and molybdenite.

The pipes are thought to have been conduits through which late magmatic fluids, collecting near the restricted root of the stock, passed upward. An individual pipe was initiated by passage of fluid upward along a vertical line such as an intersection of faults or fractures. From this channel fluid worked into the adjacent fractured rocks and corroded fragments that were eventually loosened and moved in the conduit, gradually enlarging the pipe. Quartz later precipitated filling all of the open space and choking the conduit. Successive flexures of the stock or recurrent movement on regional-faults fractured this quartz in some of the pipes, and later hydrothermal solutions tended to follow these conduits, both because of their location on deep-seated structures and because the fractured quartz provided relatively high permeability.

Hydrothermal solutions, preceding and accompanying ore deposition, spread outward from the pipes and formed overlapping aureoles of alteration. Pyrite, chalcopyrite, and molybdenite were deposited along fracture surfaces throughout a large area in Copper Basin, but higher grade mineralization was generally confined to fractured pipe structures.

INTRODUCTION

THE Copper Basin district is located in central Arizona about 10 to 15 miles southwest of Prescott in Yavapai County (Fig. 1). The area is in the mountain region that separates the Colorado Plateau from the Basin and Range Province. The terrane is essentially a complex of igneous and metamorphic rocks of older Precambrian age intruded by a composite stock of Laramide (?) age and by late Tertiary (?) rhyolite.

Copper Basin is a north-trending oval shaped depression formed by differential erosion of the less resistant Copper Basin stock of Laramide (?) age from the more resistant older Precambrian rocks. Elevations range from 4,800 feet in the basin floor to 7,150 feet at the top of West Spruce Mountain at the northern edge of the district.

Major ore deposits of Precambrian age in nearby areas include the famous United Verde and United Verde Extension mines at Jerome about 25 miles to the northeast and the currently active Iron King mine near Humboldt, about 15 miles to the east (Fig. 1). Bagdad, a porphyry copper deposit of Laramide (?) age is about 35 miles west of Copper Basin. Numerous smaller mines and prospects are present in widely distributed mining districts in the region, many of which have not been studied in detail or classified. Prior to this investigation, Copper Basin was one of the little studied districts, although it has a long history of sporadic production of copper, lead, zinc, gold, and silver from deposits of different ages and different structural settings. Of particular interest is the origin of the mineralized pipe-like ore bodies. Although production to date probably has not exceeded $3,000,000, larger deposits of low-grade copper-molybdenum ore are known.

Johnston's (13) original work in Copper Basin, from which much of this paper is taken, classified the igneous and metamorphic rock types in space and time, related the ore deposits to this classification and described the pipe-like deposits as to significant features of origin and mode of emplacement. Lowell, who has spent much time in active exploration in the district, contributed information on the mineralogy and structure of the breccia pipes from detailed mapping and drilling data.

The first general study of the region, including the northern half of Copper Basin, was published by Wheeler (23) in 1876. References to Copper Basin are included in a reconnaissance of quicksilver prospects by

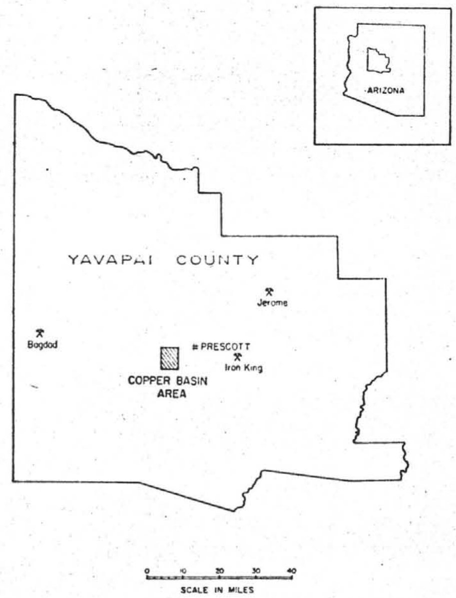


FIG. 1. Index map.

Lausen and Gardner (14) and a description of the placer deposits by Wilson (24). Anderson (1) has prepared a U. S. Geological Survey open file report on the Loma Prieta mine.

Acknowledgments.—Part of this paper is taken from a Ph.D. thesis submitted to the University of Utah by the first named author, who is greatly indebted to Dr. A. J. Eardley, Dean of the College at the University of Utah, under whose supervision the research was conducted. The criticisms in the field of Dr. C. A. Anderson and Dr. Medora Krieger of the United States Geological Survey are greatly appreciated. Thanks are due the officials of Phelps Dodge Corporation and Ranwick, Inc. for permitting access to their properties. Messrs. Fred Gibbs and Fred Schemmer, local property owners and mine operators, gave freely of their knowledge of the district. Thanks are due Dr. T. F. O'Neill and Mr. Hollis G. Peacock for criticism of this manuscript and contributing many valuable suggestions.

GENERAL GEOLOGY

The igneous-metamorphic terrane of the Copper Basin area poses a difficult problem in the establishment of a definite time classification because there are no sedimentary marker beds present. A tentative three-fold classification is presented consisting of (1) metasediments and igneous rocks of older Precambrian age, (2) composite stock and dike rocks of late Cretaceous (?) or early Tertiary (?) age, and (3) a rhyolite sequence of late Tertiary (?) age (Fig. 3). The precise age of igneous rocks in this region will ultimately depend upon a comprehensive program involving modern age determination methods.

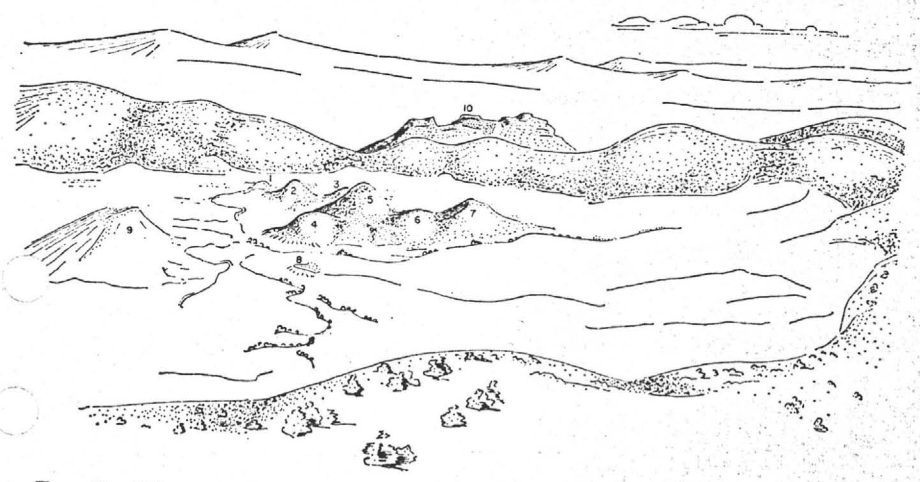


FIG. 2. View of Copper Basin looking west. 1. Red Hill pipe, 2. Copper Hill pipe, 3. Quartz Hill pipe, 4. Smelter Hill pipe, 5. Commercial pipe, 6. Red Bird pipe, 7. Victoria pipe, 8. Loma Prieta dump, 9. Rhyolite plug, 10. Rhyolite volcanic neck.

Older Precambrian Rocks.—The sequence of metamorphic and igneous rocks designated as older Precambrian include, from oldest to youngest, a metasediment unit, amphibolite unit, and four units of granitic igneous rocks mapped as quartz diorite, granodiorite porphyry, aplite, and granodiorite (Fig. 3). There is no definite proof within the Copper Basin district of the age of these rocks, but Anderson and Creasey (4, p. 46) have demonstrated the Precambrian age of similar rocks that lie under sandstone of Cambrian age in the Jerome area.

Metasediments are present as one large unit near the Boston-Arizona mine and as small xenoliths and roof pendants throughout the district (Fig. 3). Textural types observed in this unit include argillite, slate, phyllite, hornfels, and, locally, schist. The original sedimentary rocks were, for the most part, probably bedded andesitic tuffs, siliceous shales, and fine-grained sandstones. A few bands of gray, dense limestone, less than 6 inches thick, are intercalated with siliceous beds in Finch Wash about an eighth of a mile north from the rhyolite tuff unit (Fig. 3).

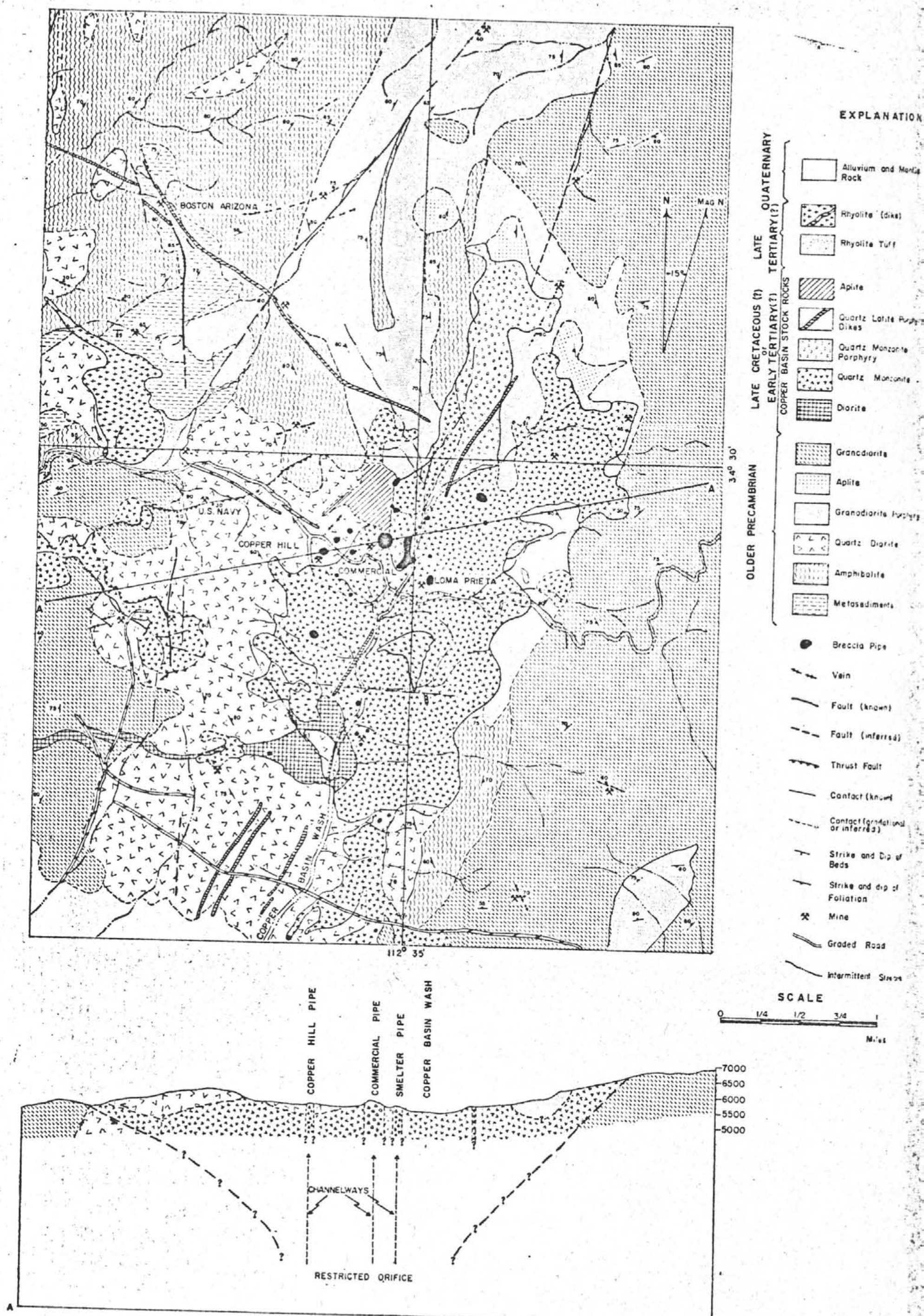


FIG. 3. Geologic map and cross section of the Copper Basin mining district, Yavapai County, Arizona.

The amphibolite unit embraces a variety of basic rock types covering a large part of the northern half of the area and one elongate band bordering the east side of the Copper Basin stock. This unit comprises a basic assemblage of rocks in which medium to coarse grained amphibolites dominate, but fine grained basic and siliceous bands are common. Dikes ranging from ultra basic to aplitic types are abundant in this unit. Much of the banded rock within the amphibolite is suggestive of original andesite and basalt flows separated by tuffaceous beds, but no relict pillow structures as described by Anderson and others (3) at Bagdad were observed. Some irregular shaped bodies probably represent basic intrusives.

Quartz diorite, presumed to be the oldest of the granitic units, is represented by one large mass and many smaller bodies in the western half of the district. The central part of the larger mass is relatively uniform in texture and composition, but the contact zones are commonly interfingered with the metasediment and amphibolite units. A foliation, ranging from barely perceptible to schistose was observed in all exposures. Metamorphism has affected much of this unit, but the comparatively fresh rock is composed of andesine feldspar, quartz, orthoclase, hornblende and accessory minerals including magnetite, zircon, apatite, augite and sphene.

Precambrian granodiorite porphyry occurs as a large mass in the north-central part of the area and as isolated bodies east of Copper Basin. A definite foliation is present which ranges from a barely perceptible planar direction to a strong foliation dominating the rock appearance. This unit includes rocks ranging in composition from quartz diorite to granite; however, about 75 percent is composed of a coarse grained granodiorite porphyry containing large zoned plagioclase crystals set in a matrix of alkaline feldspars, quartz, hornblende and biotite. Contact metamorphic and aplitic borders are common along contacts of this unit and the older rocks. The three aplite bodies shown as of Precambrian age on Figure 3 appear to be closely related to the granodiorite porphyry.

The granodiorite unit is a comparatively uniform granitic-textured rock bordering the entire eastern side and part of the southwestern side of the district. Some foliated border zones are gradational with other units and contain numerous basic clots, but the interiors of the large bodies are free of perceptible planar features and in the field appear similar to igneous rocks younger than Precambrian. However, in thin section much granulation and mortar structures are apparent in most of the minerals and strong undulatory extinction is apparent in the quartz. Minerals present include oligoclase-andesine, orthoclase, microcline, quartz, biotite, hornblende, iron ores, sphene, zircon, and augite.

Late Cretaceous (?) or Early Tertiary (?) Rocks.—The composite Copper Basin stock, which is irregular in outline and approximately 5 miles long and one mile wide, occupies the floor of the north-trending, oval-shaped Copper Basin. Apophyses of the stock occur in small circular depressions west of the main basin (Fig. 3). The Copper Basin stock has been divided into the following intrusive units from oldest to youngest: diorite, quartz monzonite, quartz monzonite porphyry, quartz latite porphyry, and aplite.

Direct evidence is lacking for a definite age for the Copper Basin stock rocks, however, a late Cretaceous (?) or early Tertiary (?) age is suggested on the basis of the following facts and inferences:

(1) The composite stock intruded all of the Precambrian units as mapped.
(2) The stock rocks show no indication of regional metamorphism.
(3) The general textural and structural features suggest a nearer-surface emplacement than the coarser-grained Precambrian rocks.
(4) The Copper Basin stock bears a striking resemblance to stock rocks of known late Cretaceous (?) or early Tertiary (?) age throughout the area bordering the Colorado Plateau and specifically those at Bagdad, only 35 miles to the west, as described by Anderson and others (3, p. 21–25).
(5) A pyrite-chalcopyrite-molybdenite mineralization, closely associated with the Copper Basin stock, is remarkably similar in character to mineralization in porphyry copper deposits in the Southwest, none of which have been assigned a Precambrian age.

It was found in thin sections that Copper Basin stock rocks could be separated from the adjacent Precambrian igneous rocks on the basis of lack of undulatory extinction in quartz in the younger rocks.

The earliest intrusive assigned to the Copper Basin stock is a fine-grained, dark green diorite plug exposed on the southwest side of the basin. The diorite is composed essentially of andesine feldspar and hornblende. Minor accessory minerals include zircon, apatite, and magnetite.

Quartz monzonite, the largest intrusive unit of the Copper Basin stock, occupies the central floor of the basin. This rock is the least resistant to weathering of any of the igneous rocks in the area and most of the unit is covered by residual soil and by terrace gravels along and east of Copper Basin Wash. The general rock type is a fine to medium-grained, equigranular biotite quartz monzonite, which grades transitionally into a fine-grained hornblende border facies; however, a slightly porphyritic facies is locally present. It is likely that this unit is composed of multiple intrusions instead of one individual intrusive. The rock is composed essentially of andesine, orthoclase, quartz, biotite, and locally hornblende. Minor accessory minerals include apatite, zircon, and iron ores. Of interest is the lack of strain shadows, granulation, and mortar structures in the minerals.

The next youngest intrusive, a light to medium gray quartz monzonite porphyry, is present in the north end of Copper Basin as an elongate band averaging about 1,500 feet wide and some 2 miles in length. The quartz monzonite porphyry exhibits relatively sharp contacts with adjacent rocks. These contacts are marked locally by intrusive breccias. Oligoclase-andesine and biotite phenocrysts compose about 30 percent of the rock and the remainder is a fine-grained equigranular mosaic of oligoclase-andesine, orthoclase, quartz, biotite, and minor accessory minerals including magnetite, zircon, and apatite. Oligoclase-andesine phenocrysts range from 2 mm to 2 cm and average about 5 mm, and biotite, in hexagonal plates, ranges from 1 to 4 mm in diameter and averages about 2 mm.

Porphyry dikes, having a wide range in texture and composition, are included as quartz latite porphyry. Many of these dikes are identical in composition with the quartz monzonite porphyry and are similar texturally except the groundmass is much finer-grained. One major trend of these dikes is N 20° E, parallel to the long axis of the quartz monzonite porphyry body and continuous to the south at least 3 miles beyond this unit. One quartz latite porphyry dike, traced from Copper Basin for 2 miles northwest to beyond the Boston-Arizona mine, was indispensable in interpretation of some structures and the age of ore deposits. A close spatial relation exists between the quartz latite porphyry dikes and the copper-molybdenum mineralization. The dikes range in color from light to dark gray and show a mottled appearance due to the large white feldspar phenocrysts. The darker color of some of the dikes may be due to a finer-grained groundmass or more mafics in the groundmass. Phenocrysts of feldspar, biotite, and hornblende form from 10 to 30 percent of the dike rock, and the remainder is a fine-grained to microgranular mosaic of feldspar, quartz and mafic minerals.

Small bodies and dikes of white to pale pink, non-foliated aplitic rocks cut all of the Copper Basin stock rocks, but no evidence was found to indicate that all of this aplite is of the same age. Many small bodies of aplite found near the quartz monzonite may have formed at essentially the same time. Normal pegmatites are rare in the area of Laramide (?) rocks; however, small masses and veins of coarse glassy quartz are present, which locally contain microcline or perthite crystals as much as one inch long.

Late Tertiary (?) and Quaternary Rocks.—Rhyolitic rocks of late Tertiary (?) age include a volcanic neck, two rhyolite plugs, numerous dikes, and one small exposure of bedded tuff (Fig. 3). The high rugged buttes, forming a landmark on the west side of the district, represent a volcanic neck consisting of breccia, blocks of bedded tuff, and much intrusive rhyolite. Two rhyolite plugs form conspicuous light colored hills in central Copper Basin within the area of the composite Laramide (?) stock. Rhyolite dikes are prominent in Copper Basin and a rhyolite and rhyolite breccia dike "swarm" is present in the extreme southwest part of the map area (Fig. 3).

The rhyolite intruded all of the Copper Basin stock rocks, and mapping suggests a period of erosion separates the two periods of intrusion. The distribution of the bedded tuff, which fills canyons adjacent to the volcanic neck near the western border of the district, indicates there has been little change in the surface features since deposition.

Quaternary deposits are surficial accumulations of unconsolidated or semi-consolidated alluvium, terrace gravels, talus, and mantle rock. Stream terrace material, associated with Copper Basin Wash and tributary gulches, is irregularly distributed on the floor of Copper Basin. The terrace gravel, attaining a maximum thickness of 35 feet, is composed of a heterogeneous mixture of material ranging from stream boulders 3 feet in diameter to a coarse to fine-grained sand and clay matrix. These gravels are of importance in that they contain oxidized copper deposits and some of the gold placer.

STRUCTURE

The Copper Basin district has undergone a complex structural history since early Precambrian time, and interpretation is difficult since regional deformation and several periods of igneous intrusion have obscured much of the evidence.

Foliation in the Precambrian rocks in areas not disturbed by faulting or intrusion strikes north to N 30° E and dips steeply westward in general conformance with the regional folding in older Precambrian rocks in Arizona as described by Anderson (2). The foliation has imparted a definite grain to the country and has exerted a profound influence on the subsequent intrusive and structural history.

Two distinct fault-fissure systems of Precambrian age are recognizable by steeply dipping tourmaline-quartz veins: one set strikes N 60°–75° W, and the other strikes N 55°–70° E. Two faults of probably regional magnitude, exposed in the northern half of the area, pre-date the Copper Basin stock rocks and may have had their origin in Precambrian time. The westernmost of these faults strikes N 30°–40° E and displaces a Precambrian quartz vein laterally about 2000 feet but does not displace a Laramide (?) quartz latite porphyry dike (Fig. 3). The easternmost of these two faults strikes N 10°–20° E and can be traced as a lineament on air photos for several miles north from Copper Basin. Since these two regional (?) faults strike more or less parallel with the foliation direction, the magnitude of displacement could not be ascertained within the area mapped.

The easternmost regional (?) fault and the foliation direction are thought to have been important in controlling the emplacement of the Copper Basin stock. The southward extension of this fault parallels the longitudinal axis of the Copper Basin stock and one major trend of quartz latite porphyry dikes. The junction of several Precambrian units may have helped serve as a structural locus for point of entry for the stock (Fig. 3). The large massive block of granodiorite on the east side of Copper Basin may have helped concentrate later structures along its western contact. A thrust fault that is well-exposed in the U. S. Navy mine has been intruded by quartz monzonite. This fault probably originated in the thrusting aside of the west wall by the intrusion of the Copper Basin stock.

The east contact of the quartz monzonite unit dips 45°–60° west toward Copper Basin. The contact of this same intrusive on the west side of the basin is essentially horizontal and represents the stock roof in this area. The true west contact of the stock is thought to be marked by the quartz monzonite occupying the east-dipping thrust fault a mile west of Copper Basin. These data suggest that the quartz monzonite could be a funnel-shaped stock or ethmolith having a restricted "nozzle" or "root" occupying a central position and extending in depth to the original underlying magma chamber (Section Fig. 3). The "root" is visualized as being elliptical in plan and having an elongation in a N 10°–20° E direction. It is further suggested that the individual intrusives of the composite stock pushed their way up through the restricted orifice and expanded in the direction of least resistance at that particular time.

A north-trending, steeply dipping fault zone on the west side of the district was traced for some three miles from the Boston-Arizona mine on the north to about a mile south of the U. S. Navy mine. The most productive zinc, lead, and silver deposits are closely associated with this fault. Ore within the fault zone is of a later age than the quartz latite porphyry dike at the Boston-Arizona mine. However, a post-mineralization period of faulting along this same zone produced a horizontal displacement in the quartz latite porphyry dike of about 1,200 feet in the mine area.

Numerous faults of small displacement are associated with and parallel to most of the previously discussed structures. Certain of these faults are of importance as ore controls within the Copper Basin stock and may represent minor adjustments of regional faults or movements within the magma chamber after solidification of the roof portion. Prominent minor fault trends observed within Copper Basin are as follows: 1 N 10–30° W; 2 N 10–30° E; 3 N 70–80° E; 4 N 60–80° W.

Prominent joint sets are parallel to the above fault systems, although many joints appear to have random orientation. Some of the minor faults are occupied by late Tertiary (?) rhyolite dikes and some have post-rhyolite displacement.

MINERALIZED BRECCIA PIPES IN COPPER BASIN

Some 25 exposed mineralized pipes are associated with the Copper Basin stock rocks within Copper Basin (Figs. 2, 3, 4). The main cluster of pipes, including the productive ones, form round reddish brown hills on the west side of Copper Basin north of the main road. The Commercial, Copper Hill, and Loma Prieta mines have exploited three separate pipes to depths ranging from 300 to 600 feet. The Commercial mine has supplied most of the copper ore produced from the district.

Most of the pipes are resistant to weathering and protrude above the basin floor as low round hills having a relief of less than 300 feet. However, the Loma Prieta and several other pipes on the east side of Copper Basin Wash have no topographic expression.

Shape.—Most of the pipes appear to be nearly vertical columnar bodies having a roughly circular or elliptical plan, although some have irregular projections on one or more sides. Pipes where exposed by mine openings and drill holes range in diameter from 50 to 600 feet. The largest pipe, having a diameter of about 600 feet, is developed by the Commercial mine. The Loma Prieta and Copper Hill mines have explored pipes approximately 300 feet in diameter. Numerous small exposures of breccia may represent pipes in the early stages of development, and in one locality a single rotated fragment was observed at a joint intersection.

Vertical changes in shape could not be determined from the limited exposures, but it is likely that the pipes will show irregularities in depth. Exploration data indicate that the Loma Prieta pipe retains a cylindrical shape to a depth of at least 400 feet. Two small pipes appeared to bottom, locally at least, on flat faults, but the relationships are uncertain.

Relation to Enclosing Rocks.—The pipes are spatially related to the composite Copper Basin stock of postulated Laramide (?) age. The main group of strongly mineralized pipes are clustered around the south contact of the quartz monzonite porphyry unit, but none occur wholly within this rock

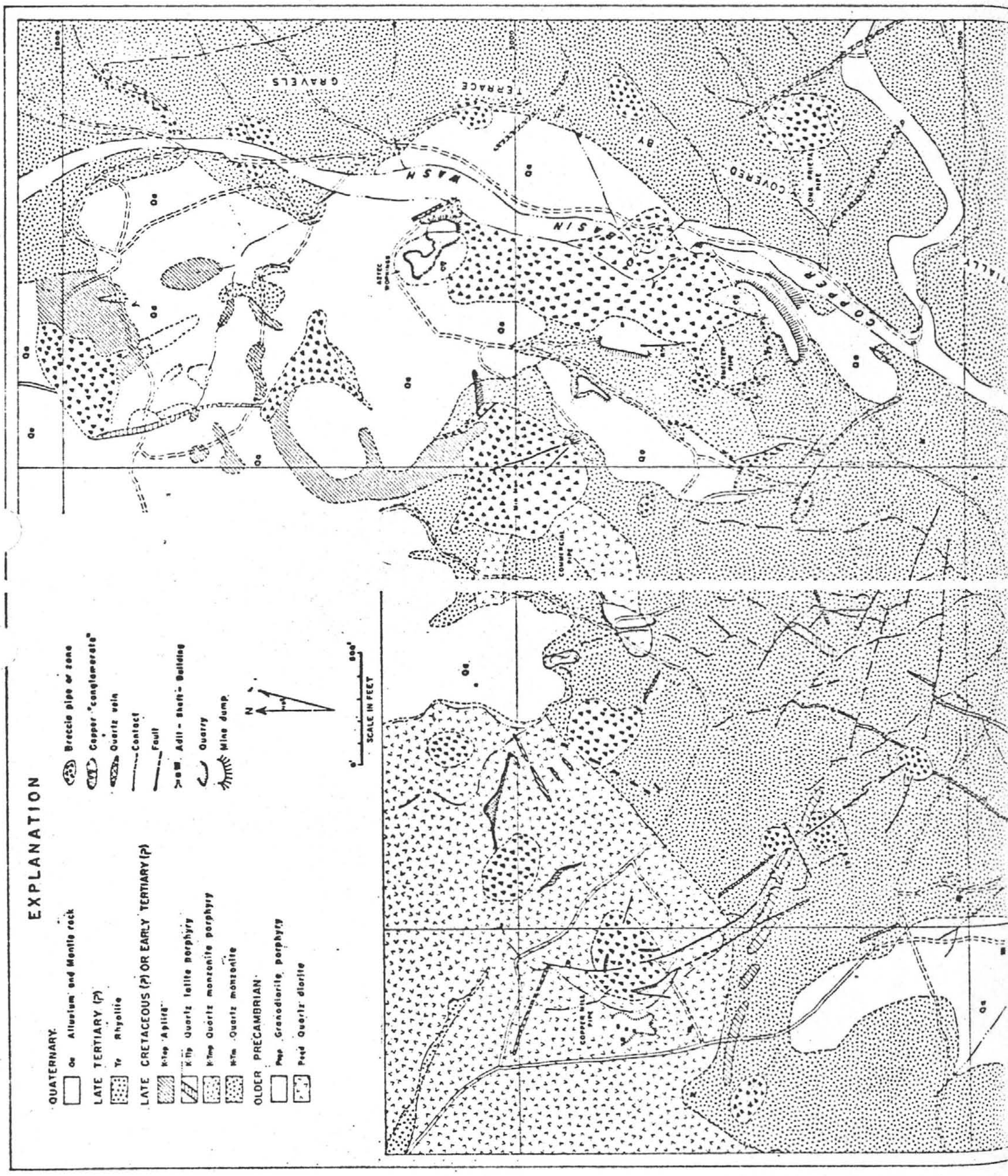


FIG. 4. Geologic map of main breccia pipe area, Copper Basin mining district.

(Fig. 4). The main pipe-like body at the Commercial mine is located at the junction of several rock types including quartz monzonite, quartz monzonite porphyry, quartz latite porphyry, and aplite, all of Laramide (?) age, and quartz diorite of Precambrian age. Several pipes, including the Loma Prieta, are entirely within the quartz monzonite unit. The Copper Hill and two adjacent pipes are in Precambrian quartz diorite at the surface but drilling and underground workings expose the quartz monzonite unit in depth.

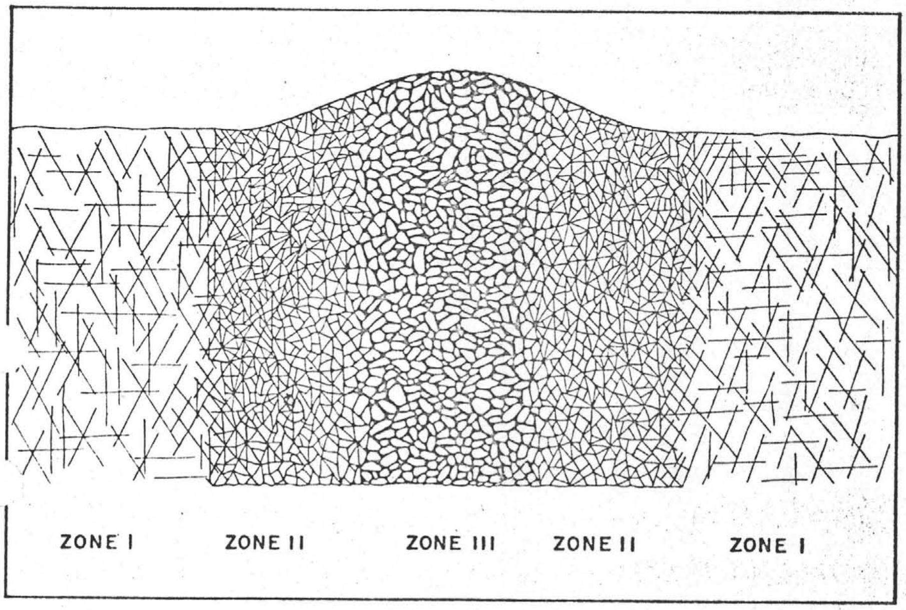


FIG. 5. Idealized diagram of Copper Basin Breccia Pipe. Zone I—Mineralized joint and fracture system. Zone II—Angular "crackle" breccia cemented by quartz and sulfides, no marked rotation or mixing of fragments. Zone III—Angular to rounded "boulder" breccia exhibiting marked rotation and mixing of fragments. Cementing materials (black) are quartz and sulfides. Zones II and III, combined, range from 50 to 600 feet in diameter.

Fragments from all of the intrusive rocks of the Copper Basin stock were found in some of the pipes indicating that, in general, pipe formation followed the stock intrusion. The rhyolite dikes cut the pipes and associated mineralization and are thought to be much later in age.

Spatial distribution of the pipes appears to be a critical factor in the question of origin. The main group, including all strongly mineralized pipes, is located directly above the postulated position of the restricted orifice or root area through which the separate intrusions that formed Copper Basin stock rocks are thought to have been injected.

Nature of Fragments.—Individual fragments show a wide diversity in size, shape, and composition within each pipe, and their physical properties can be best understood by discussion of the different zones shown on the idealized diagram (Fig. 5). Locally the contact between two zones is sharp, but in general the contacts are gradational and somewhat arbitrary.

Zone 1 represents fractured and jointed ground adjacent to the pipes and in the inter-pipe areas, and, although it is rather ill-defined, it roughly includes most of the area shown in Figure 4. Smaller areas representing Zone 1 are present around the non-productive pipes in South Copper Basin. It comprises closely-spaced joints, fractures, and minor faults that have been partially mineralized by vein quartz, pyrite, and chalcopyrite, or by their oxidized equivalents. The host rock is slightly to moderately altered by conversion of mafic minerals to mica and by argillic and sericitic alteration of feldspars. Certain joint and fracture sets dominate within small areas, but no definite overall pattern was determined. The dominant joints and fractures are normally spaced from about 3 inches to 3 feet apart; however, when the rock is broken, numerous irregular, incipient, iron-stained cracks become apparent. There is little or no rotation of the joint and fracture blocks in Zone 1.

Zone II is characterized by angular to sub-angular fragments ranging from 1 inch to 10 feet in diameter but in general averaging between 2 to 12 inches. There is no marked rotation or mixing of fragments although some movement has taken place in parts of this zone, probably by subsidence or dilation. The non-rotational character of the fragments is indicated by the common attitude of the foliation in Precambrian quartz diorite in the Copper Hill adit. Much of this zone resembles the stockwork breaking or "crackle" breccia of the porphyry copper deposits. An individual fragment may be transected by a finer network of fractures. The fragment size is normally smaller than in Zone I and non-rotational movement locally obscures the original pattern of joints and fractures; however, parallel fissures occupied by vein quartz and sulfides do occur in this zone. The mineralization in general is much more intense than in Zone I, including stronger wallrock alteration and more quartz and sulfides cementing the fragments.

Zone III, where present, represents the innermost or central zone of the pipes as shown on Figure 5. This zone is commonly composed of a heterogeneous mixture of fragments showing marked rotation. The fragments are rounded, sub-rounded, or angular and are about the same size as in Zone II. Many of the rounded or sub-rounded fragments have been cracked into smaller angular pieces by incipient fractures. The rounded fragments resemble stream boulders and can best be described as "boulder" breccia. Sharp contacts generally separate Zones III and II, but some contacts are gradational over a width of 10 to 30 feet. Zone III is not exposed or could not be recognized in many of the pipes but is well-developed in the Loma Prieta (1), Copper Hill, and parts of the Commercial mine. Figure 6 shows the rounded to sub-rounded fragments of gneissic Precambrian quartz diorite mixed with Laramide (?) quartz monzonite fragments and cemented by quartz and sulfides.

Associated Mineralization.—An interesting feature of the Copper Basin pipes is that the fragments are generally cemented by quartz and minor amounts of other minerals and not by igneous material or finely ground rock derived from the fragments themselves.

Quartz deposition ranged from pervasive silicification, to partial replacement of fragments, to filling of pre-existing open spaces. Much structural adjustment took place during mineralization, and recementing of earlier quartz by later quartz is common. It appears that the replacement quartz formed at an early stage, probably in confined areas, whereas the inter-fragment quartz formed later in through-going trunk channels. There is

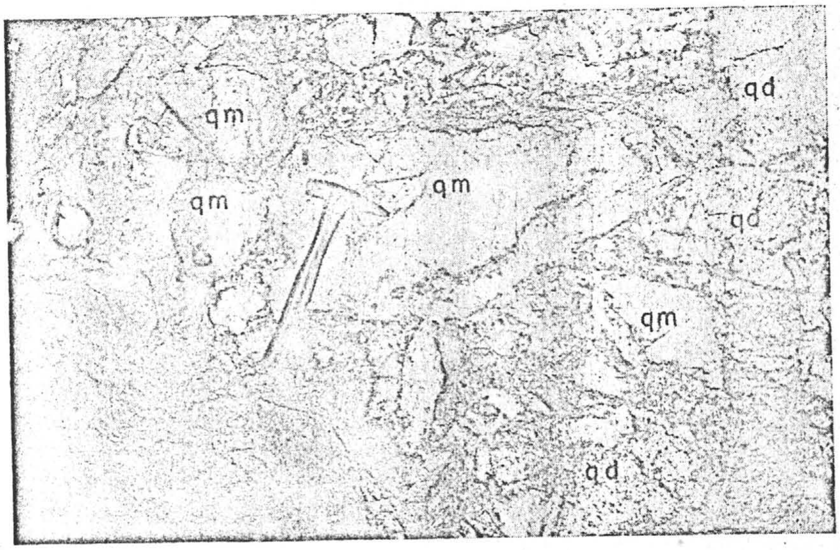


FIG. 6. Mixed rounded breccia fragments in Copper Hill adit level. Precambrian quartz diorite (qd) and late Cretaceous (?) or early Tertiary (?) quartz monzonite (qm) fragments.

some evidence suggesting that the following sequence of quartz mineralization may have taken place:

(a) formation of the main group of pipes in a cluster slightly over one mile in diameter (Fig. 4).

(b) choking of some pipes with replacement quartz. Those pipes west of Copper Basin Wash, in general, underwent more pervasive silicification than those east of Copper Basin Wash.

(c) introduction of inter-fragment quartz followed by copper and molybdenum mineralization in some pipes.

This process resulted in pipes in the northeast portion of the original cluster that received little quartz of either stage, pipes in the north central area that received first stage but little second stage quartz, the Loma Prieta pipe that received second stage but little first stage quartz, and the Commercial and Copper Hill pipes that received quartz of both stages.

Much of the replacement quartz is a white to gray, dense variety and is commonly associated with orthoclase. Both minerals, together or individually, replace fragments. Some of this material resembles aplite or alaskite and is quite similar to material described by Gilluly (8, p. 74–76) at the Ajo porphyry copper deposit. The elongate breccia mass about 600 feet east of the Commercial pipe is strongly silicified and original fragments can be distinguished only with difficulty.

The open-space filling type quartz is commonly granular to glassy in appearance. Some is coarse-grained, and crystals as much as one inch in long dimension were observed projecting into vugs between breccia fragments. A few lenticular veins of coarse glassy quartz as much as 10 feet wide are prominent in or near the pipes (Fig. 4) and narrow quartz veins are abundant in certain parts of some pipes. The massive glassy quartz locally contains a few isolated feldspar crystals.

Alteration, other than quartz and orthoclase described above, was not studied in detail. Iron-staining and secondary argillic alteration tends to mask the primary alteration in the oxidized zone. Where observed, it appears that the original mafic minerals have been bleached and altered to biotite, chlorite, and serpentine. Magnetite was altered to hematite and pyrite. Feldspars have undergone varying degrees of sericitization and local argillic alteration. Locally the original textures of the igneous rocks have been completely destroyed, but in general the alteration is weak to moderate. Where fragments are well-mixed there is a difference in intensity of alteration among adjacent fragments—probably due to original physical and chemical differences of the individual fragments. The quartz monzonite porphyry and quartz latite porphyry fragments were especially resistant to replacement and alteration.

Sulfides, essentially pyrite, chalcopyrite, molybdenite, and minor bornite, followed deposition of most of the quartz, and for the most part, were deposited in cracks and voids within the quartz. Minor blebs and veinlets of sulfide worked out into the altered rock fragments. In general the molybdenite appears to be somewhat later than the other sulfides and locally is concentrated in fractures devoid of other sulfides. It also shows less tendency than the pyrite and chalcopyrite to form "disseminated" mineralization surrounding strongly mineralized zones. The overall mineralization is remarkably similar to the common porphyry copper type in the Southwest. Minerals in the oxidized zone include limonite, jarosite, hematite, chrysocolla, chalcocite, cuprite, black copper oxides, native copper, malachite, azurite, and ferrimolybdite.

Normally the primary sulfide mineralization was concentrated in quartz cement and veinlets in Zones II and III; however, in cases where pervasive silicification has taken place in all or part of these zones there may be an increase in the concentration of ore minerals in the adjacent parts of Zone I.

Structural Considerations.—The pipes are within well-jointed, fractured, and faulted igneous rocks, and most pipes are located near the contact of one or more igneous rock units. It is probable that no single structural element is responsible for the location of the pipes.

Faults of known major displacement were not observed within the limits of the composite Copper Basin stock, but some could exist since much of this area is covered by mantle rock. As has been previously mentioned, a regional fault striking N 10–20° E is thought to have been a controlling factor in the emplacement of the stock. Two sets of fractures and faults striking N 10–30° W and N 10–30° E are prominent in the Copper Hill and Commercial pipes. Post-mineralization movement is evident in many of these faults, but numerous parallel quartz veinlets indicate an earlier origin. The N 10–30° E fault system controlled a main trend of quartz latite porphyry dikes thought to represent the last intrusives prior to mineralization. Faults striking N 60–80° W are prominent in and near some of the nonproductive pipes. It appears likely that fault, fracture, and joint intersections played an important role as initial loci for the trunk channels in the pipes. The more intensive fracturing in these intersection areas undoubtedly influenced the overall permeability and contributed to the fracture and brecciation pattern.

Three of the most strongly mineralized pipes are located at the contact of two or more igneous rocks. As shown on Figure 4, the Commercial pipe is at the junction of five igneous rock units including quartz latite porphyry dikes not shown on the map. The Loma Prieta and Copper Hill pipes are at the contact of at least two igneous units. These contact zones in conjunction with the faults, fractures, and joints may have also served as loci for pipe formation. However, the shape of the pipes and nature of the enclosing breccia does not suggest a simple tectonic origin.

Existing Theories.—The problem of origin and classification of steep columnar or tabular bodies of fractured or brecciated rock has received much attention in the literature. Some of the publications reviewing the literature or offering a classification have been written by Butler (5), Emmons (6), Kuhn (11), Walker and Walker (22), and McKinstry (19). The origin of most of the pipelike deposits has been explained by the following theories or by modification and/or combination of them: (1) explosion, (2) tectonic, (3) igneous intrusion, (4) fluid intrusion, (5) solution and replacement, (6) mineralization stoping, (7) shrinkage.

(1) Explosive action, generally thought to be associated with vulcanism, is responsible for openings (diatremes) blown out by gas. The openings may be filled with fragments of igneous material or country rock. Richards and Courtright (21) have suggested gaseous explosion for the origin of breccia pipes at Toquepala, Peru. Hack (9) and Lowell (18) have described characteristic features of diatremes in the Hopi Buttes volcanic field, Arizona.

(2) Tectonic breccia or fractured rock at the intersection of two or more faults or shear zones or at bends in faults may form columnar pipes. Commonly this type is irregular and changes notably as it passes from one wall rock to another. However, fault intersections are important as loci for pipes essentially formed by other agencies as described by Butler (5, p. 126)

in the San Francisco area, Utah, and Kuhn (11, p. 527) at Copper Creek, Arizona.

(3) The direct formation of breccia columns or dikes by the physical force of intrusion has been described by many authors. Lovering (16, p. 8) states:

> An intrusive push at a late stage in the solidification of a magma may cause the fracturing of a stock along lenticular or chimney-like zones that usually have their longest dimension parallel to the original platy structure of the intrusion. In such masses the small opening produced by intensive brecciation may be subsequently enlarged by reactive mineralizing solutions which dissolve some of the rock adjacent to the individual fractures—the first step in mineralization stoping as suggested by Augustus Locke.

Lovering (17, p. 12) has described some of the pebble dikes at Tintic, Utah, as representing material riding on top of monzonite or dragged along the edge of viscous monzonite bodies.

(4) Fluid intrusion has been advocated as another means of pipe or dike formation. This theory has much in common with the explosion theory but is apparently more restricted and has characteristic intrusive phenomena. The fluid involved is assumed to be gas or liquid of possible magmatic derivation but not magma as such. Farmin (7, p. 370) advocated the following for the pebble dikes at Tintic, Utah: ". . . fragments were broken from the underlying rocks by magma, or by fluids ejected from the magma during volcanism and were forced upward into rocks above by a relatively thick mud."

(5) Corrosion by ascending solutions was advocated by Butler (5, p. 126) for pipes in the San Francisco region, Utah as follows: "The rock has been brecciated apparently by slight movement, as no considerable fault can be traced from the ore zone. Solutions passing through this breccia zone have greatly corroded the rock, so that in places the fragments have the appearance of rounded boulders. In this manner the amount of open space must have greatly increased. Later this space was largely filled by ore and gangue minerals." Butler further suggested that the solutions were relatively confined and the dissolving action strong. Kuhn (11, p. 527) applied essentially the same theory to the pipes in Copper Creek, Arizona, but in addition emphasized simultaneous replacement.

(6) Locke (15) proposed the mineralization stoping theory to account for the formation of certain pipe deposits. This theory is somewhat analogous to the block-caving method of mining. Locke (15, p. 431) states that: ". . . removal of rock along trunk channels by rising solutions during an early stage of their activity, collapse and brecciation of the rock thus left unsupported, and deposition of ore and gangue minerals in the brecciated mass."

A prerequisite for application of this theory is proof for downward movement of the breccia mass.

(7) Hulin (10, p. 47) suggests the estimated 10 percent volume shrinkage on crystallization is responsible for much fracturing and brecciation in certain stocks or chonoliths. He states: "The result would be unsystema-

tized fracturing and shattering with attendant volume increase, structural features so characteristic of the porphyry copper ores. . . . In the absence of such autobrecciation the subsidiary ground might move downward within the limits of an encircling, crudely cylindrical fault surface, or within a nest of such surfaces."

Origin of Copper Basin Pipes.—In considering the origin of the roughly circular to elliptical pipelike deposits in Copper Basin it should be emphasized that other types of breccia and fractured ground are also present. All of the rock units of the Copper Basin composite stock are thought to have been intruded into their present position, and contact or intrusive breccia is present in many places. Since several pipes formed at intrusive contacts, some of the brecciation may have been inherited from previous intrusive phenomena, but this is not thought to be a critical factor in the origin of the pipes in general.

Fracturing and brecciation associated with faults were observed in many places, but these breccia zones are apt to be linear and highly irregular. However, faulting is assumed to have served as the original locus for at least some of the pipes, and fault breccia may have been present locally.

Summary of Data on Origin of Copper Basin Pipes.—The literature indicates that the origin of mineralized pipes is still a controversial subject. For this reason available factual information on Copper Basin will be summarized before an interpretation is given.

1. The pipes are spatially related to the composite Copper Basin stock and underlie the postulated orifice or root of the stock. They formed after solidification of all of the Copper Basin stock rocks but prior to the emplacement of the late Tertiary (?) rhyolite. The majority of the pipes were formed at the contact of two or more igneous rock units, though some were formed within one rock unit.

No faults of major displacement were observed in the vicinity of the pipes, but pronounced joint systems and minor faults are abundant. The two most important fracture directions appear to be N 10–30° W and N 10–30° E.

2. The pipes are roughly circular or elliptical in plan and appear to be near-vertical except for minor irregularities and displacements by post-pipe faulting. The depth extension is known only to a maximum of 600 feet.

3. The breccia fragments in the pipes range from about 1 inch to 10 feet in diameter, but the average size range is 2 to 12 inches. Fragments in Zone II are angular to sub-angular and those in Zone III are angular to well rounded. Movement in Zone III has been rotational and has resulted in the mixing of fragments (Fig. 5). The matrix surrounding the fragments is not composed of finely ground rock as is sometimes the case in other districts, but is made up principally of quartz. In certain pipes quartz, orthoclase and locally sericite, biotite and chlorite replace the borders of fragments. Pervasive silicification is present in some pipes, but more commonly quartz was deposited in interstices between fragments and in veinlets. A wide variation in the intensity of hydrothermal alteration of fragments is present. Comparatively fresh fragments of one rock type may be present near strongly altered fragments of another rock type. Alteration minerals recognized in the hypogene zone include quartz, orthoclase, sericite, clay minerals, chlorite, serpentine, biotite, calcite, hematite and pyrite.

4. Fracturing and faulting occurred after some quartz deposition and prior to the introduction of sulfides. Pyrite, chalcopyrite and molybdenite were intro-

duçed later than most quartz mineralization and filled fractures and vugs in the quartz. Minor amounts of these sulfides were deposited in fissures and intergranular spaces in the fragments.

Interpretation of Origin of Pipes.—1. Pipe formation was associated with a late magmatic stage of the Copper Basin stock. Late magmatic fluids gradually concentrated around the root area of the composite stock after solidification of the roof portion and formation of a joint and fracture system.

2. Evidence is lacking as to the exact state and pressures of the early ascending fluids. It is assumed that the fluids gradually collected in several individual chambers in the vicinity of the composite stock root.

3. The fluids under high pressures ascended along the lines of least resistance which may have been fault or fracture intersections, openings along a single fault, or intersections of faults or fractures with igneous contacts. Local fracturing at minor fault intersections may have been the most important locus for the initial channelways. Once the fluids from an individual chamber reached the near-surface area, a trunk channel resulted along the zone of maximum pressure gradient.

4. There is no positive evidence to support explosive action at the elevation of exposure of the pipes. The non-rotational aspect of Zone II and the absence of Zone III in some pipes suggest that explosive action was not important. There is no definite proof in Zone III as to whether the fragments moved up or down; however the occurrence of quartz monzonite fragments in the Copper Hill pipe suggests one period of upward movement (Section Fig. 3).

5. Early fluids moving up trunk channels penetrated the adjoining wall along existing joint and fracture surfaces. Some of the fluids replaced the rock adjacent to the joint and fracture surfaces with quartz and orthoclase and formed a partially cemented and partially replaced breccia.

6. The fluid in the more open trunk channels removed much material and left open spaces in the interstices separating fragments. The fragments in these trunk channels were rounded, rotated, and mixed together. The process by which the material was removed is open to question. It is suggested that incipient alteration of the fragments loosened the mineral grains along the borders. This loosening effect was accentuated by contemporaneous movement and attrition of the fragments. The through-going fluids removed the finely ground material.

7. In the later part of this stage of development, as overall pressures decreased, most of the movement of the fragmental mass may have been downward as the whole pipe slumped from continual removal of the fine abraded material. Zone III continued to work outward from the trunk channel into Zone II. After the pipe was well developed, portions of Zone II probably tended to slump in toward Zone III; thus forming more open space in the Zone II.

8. Following the formation of the open mass of "crackle" breccia and "boulder" breccia in Zones II and III, quartz was deposited in the open interfragment spaces as well as in available joints and fissures. During and after deposition of quartz, structural adjustment, by renewed movement on regional faults or general flexures caused by movements in the underlying magma chamber, fractured some of the early cementing and replacement minerals. Then sulfides were deposited in these fractures, showing a strong preference for those in quartz.

9. Faulting and fracturing continued after the sulfide stage, and portions of several pipes have been displaced as much as 200 feet.

ORE PIPES VERSUS BARREN PIPES

An interesting and somewhat perplexing problem in the study of mineralized pipe areas or districts is why some pipes are ore-bearing and some are not. Joralemon (12) has discussed this problem in relation to the

Copper Creek district, Arizona, where only a few out of dozens of pipes contain ore bodies.

In Copper Basin some pipes among those tested are known to be ore-bearing whereas some are known to be essentially barren and could be called "alteration" pipes. It appears that a critical factor in ore deposition in the Copper Basin pipes was a period of structural deformation that followed the formation of the pipes and the clogging of the pipes by quartz replacement and cementing material. The sulfide minerals were deposited largely in the fractured, relatively brittle, inter-fragment or vein quartz, and when this quartz was not fractured prior to or during this sulfide stage, the pipe remained as an "alteration" pipe, largely devoid of ore minerals. Movement along faults striking N 10–30° W and N 10–30° E appear to have been important in keeping critical channelways open and in fracturing the various types of quartz in the ore-bearing pipes. Higher grade lenses within the ore-bearing pipes appear related to these faults. Where silicification has been intense the post-quartz deformation may be effective only on the outer edges of the pipe leaving a barren central plug. It is thought the strongly mineralized pipes resulted from the combination of (1) the deep-seated structure that localized the breccia pipe and could potentially reopen a through-going ore fluid channel, and (2) the presence of fractured quartz, a relatively permeable host rock in the pipes.

RELATION OF MINERALIZED BRECCIA PIPES TO PORPHYRY COPPER DEPOSITS

The geological environment in Copper Basin is strikingly similar in many respects to that of the typical porphyry copper deposit in the Southwest and especially to the nearby deposit at Bagdad. The composite Copper Basin stock including equigranular quartz monzonite, quartz monzonite porphyry, and finer grained dike equivalents, is similar to rock sequences in many of the porphyry copper deposits. The hypogene sulfide mineralization, generally classified as mesothermal in porphyry copper deposits, consists essentially of pyrite, chalcopyrite, and molybdenite at Copper Basin. The hydrothermal alteration is not as intense as in some porphyry copper deposits but is similar in composition. Spectrographic analyses of fresh and altered quartz monzonite suggest that alteration has removed sodium, calcium and magnesium and has increased the potassium content.

The fracture patterns in Zones I and II (Fig. 5) are common to the porphyry copper deposits. The present top of the water table roughly coincides with the floor of Copper Basin and the oxidation zone is largely restricted to the upper portions of pipes represented by the conical hills. Exploration to date indicates that the primary mineralization in the inter-pipe (Zone I) areas everywhere contains an appreciable copper content.

The literature does not indicate a common association of mineralized pipes with porphyry copper deposits in the southwestern United States, although Anderson and others (3, p. 75) observed mineralized breccia pipes near the Bagdad deposit and Walker and Walker (22, p. 152) describe a breccia pipe adjacent to the Sacramento Hill stock at Bisbee, Arizona. In

South America there appears to be a closer relationship of pipes to some porphyry copper deposits and Richards and Courtright (21) describe a large central breccia pipe surrounded by smaller satellitic pipes as important features of the Toquepala, Peru, porphyry copper deposit.

It is suggested that erosion in Copper Basin may have revealed the lower portion of a porphyry copper deposit and that the pipes served as main conduits or channelways for the ore depositing solutions. Pipes serving as the main channelways for the ore depositing solutions within a restricted orifice or root portion of a composite stock, as in Copper Basin, may be a plausible explanation as to why some porphyry copper deposits are restricted to a certain part, in plan, of the associated stock rocks as observed at or near the surface.

ORE DEPOSITS

The ore deposits of the Copper Basin district have been tentatively divided on the basis of their relationship to the three groups of rocks of known or assumed age. The proposed age classification used is (1) Precambrian, (2) Laramide (?) and (3) late Tertiary (?) and Quaternary.

Precambrian deposits have yielded minor gold and copper ores associated with tourmaline-quartz veins.

Laramide (?) deposits, which have yielded the bulk of the district production, include copper and molybdenum associated with pipes, and zinc-lead-silver fissure-filling and replacement veins.

Late Tertiary (?) and Quaternary deposits include mercury prospects associated with rhyolite and gold placers.

The early history is obscure but the Copper Basin district was officially recognized about 1890. Gold seekers had undoubtedly been in the area long before this date. Production has been mainly from direct shipping siliceous copper fluxing ores. Three main periods of activity were 1914 to 1919, 1942 to 1950, and 1955 to the present time. Most of this copper production has come from the Commercial mine owned by Phelps Dodge Corporation. Small shipments of zinc, lead, silver and gold have been made from numerous mines and prospects, but largely from the U. S. Navy and Boston-Arizona mines. Sporadic gold placer operations have been carried on since the discovery of the district.

Precambrian Deposits.—Precambrian tourmaline-quartz veins containing small, irregular ore shoots of gold and copper ore have been exploited largely in the western part of the district. Coarsely crystalline, milky to glassy, quartz veins, locally containing black tourmaline and brown carbonate, fill two main fissure systems striking N 60°–75° W, and N 55°–70° E. Sulfide minerals include pyrite, chalcopyrite and minor dark brown sphalerite. Gold appears closely associated with dark bronze colored, cubic pyrite or the oxidized gossan derivative. Oxidation has rarely extended to more than 50 feet below the surface. The massive pyrite portions of the veins have been oxidized to cellular and massive, varnish-type gossans.

Laramide (?) Deposits.—The bulk of production from the district has been from disseminated copper-molybdenum mineralization above the presumed root of the composite stock, but a rough zonal arrangement of metals characteristic of porphyry copper deposits is present in Copper Basin. This consists of the central, disseminated copper-molybdenum zone surrounded by vein-type zinc-lead-silver deposits.

Most of the lead-zinc-silver deposits are concentrated along either a north trending high-angle fault, or the Navy thrust fault on the west side of Copper Basin. The Boston-Arizona mine, approximately two miles northwest of the composite stock, has been shown by Johnston (13, p. 112) to be clearly related in space and time to a quartz latite porphyry dike that radiates out from the composite stock.

Disseminated copper-molybdenum mineralization is distributed throughout an area of approximately one-half square mile (Zone I as described under the Section on Mineralized Breccia Pipes). Most known ore bodies in this area consist of mineralization in pipes, but ore also occurs in bodies peripheral to pipes and as mineralization in shear zones. In several ore bodies the ore mineralization was to some extent controlled by N 10°–30° E and N 10°–30° W faults. Higher grade lenses and poorly defined "veins" within the ore bodies are oriented by these structures suggesting that they were open during the main period of ore deposition.

Each mineralized pipe is the center of an aureole of alteration. The :eoles have different diameters depending on the intensity of hydrothermal activity, and where pipes are closely spaced they overlap, producing a complex alteration pattern. Mineralization differs in grade between ore bodies —both as to copper content and copper-molybdenum ratio. Ore reserves published for the Ranwick, Inc. ground in 1957 (20) listed 4,000,000 tons averaging 0.913% Cu and 0.124 MoS_2.

Both supergene and hypogene ore bodies are present in Copper Basin. An example of the former is the Copper Hill mine where drilling has disclosed a supergene enriched blanket about 80 feet thick in which the primary copper grade has been approximately doubled by the addition of chalcocite, copper carbonate, oxide minerals, and native copper. Interestingly enough, the Copper Hill ore body also contains a zone of secondary enrichment of molybdenum which occurs just above, and in the upper part of the zone of copper enrichment. The secondary molybdenum mineral is ferrimolybdite, a bright yellow oxide. Some ore bodies such as the Loma Prieta do not have a significant zone of secondary enrichment. Secondary enrichment is controlled by (1) the top of the water table, which stands approximately at the general floor elevation of Copper Basin, and (2) the association of most of the ore with quartz that resists the weathering processes except where fractured by post-ore deformation.

At several localities in Copper Basin, deposits of terrace gravels have been cemented by copper carbonate and oxide minerals. The largest of these is probably the Aztec deposit at the north end of the Smelter Hill pipe, but deposits also occur at the south end of Smelter Hill and in the bottom of Copper Basin wash east of the Aztec workings. Apparently the oxidation of pyrite produced ferrous sulfate and sulfuric acid, which dissolved copper. Copper in solution emerged from the side of Smelter Hill and followed down the bedrock surface until a change in PH caused precipitation of the copper in the lower few feet of gravel. Copper minerals form coatings on detrital grains ranging in size from fine grained sand to boulders three feet in diameter.

Magnetic and Soil Sampling Data.—Vertical intensity magnetometer surveys in Copper Basin were conducted in an effort to locate negative magnetic anomalies. These, in theory, may represent areas in which hydrothermal alteration has been intense and the original magnetite of the intrusive host rock has been altered to iron minerals such as limonite and pyrite with relatively low magnetic susceptibilities.

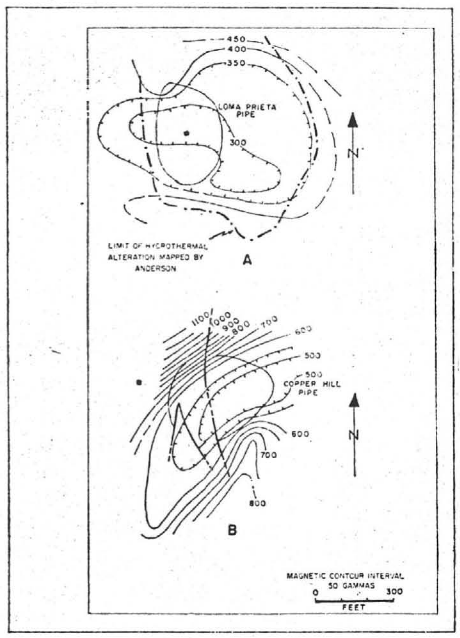


FIG. 7. Negative magnetic anomalies centered on Loma Prieta and Copper Hill breccia pipes. These anomalies are related to hydrothermal alteration which has spread outward from the pipes. Areas within circles are altered rock.

Figure 7 shows magnetometer contour lines in relation to the Loma Prieta and Copper Hill pipes. In these areas the anomaly location corresponded closely to observable strong hydrothermal alteration. In some localities no anomaly was found over mineralized pipes—this probably is due to the fact that aureoles of alteration from adjacent pipes had overlapped, leaving no unaltered rock between.

Samples were collected corresponding to (1) intense alteration and minimum magnetic susceptibility, (2) medium alteration and medium magnetic susceptibility, and (3) fresh rock with high magnetic susceptibility. Thin sections and spectrographic analyses of these samples indicate that the conversion of magnetite to limonite and pyrite increased progressively with sericitization of plagioclase, kaolinization of potassium feldspar, and chloritization of mafic minerals. It has been concluded that the method, under favorable circumstances, can be used for the location of covered pipes or altered zones in Copper Basin.

Limited soil sampling was done in leached outcrops of mineralized pipes in an effort to establish prospecting guides to ore. Analyses were made of copper and molybdenum content, and by comparison with drill hole information it was found that the soil content of copper was erratic and bore no relationship to underlying primary mineralization, but that the soil content of molybdenum was approximately equal to that of the primary ore body. The usefulness of this relationship is limited by the unpredictable ratio of copper to molybdenum in the primary ore bodies of the district.

Late Tertiary (?) and Quaternary Deposits.—Small amounts of cinnabar, associated with pyrite, hematite, and limonite, have been found in and near rhyolite and rhyolite breccia dikes in the southwest corner of the district. No mercury production has been reported from lode deposits but natural amalgam has been reported in gold placers from streams that drain the area.

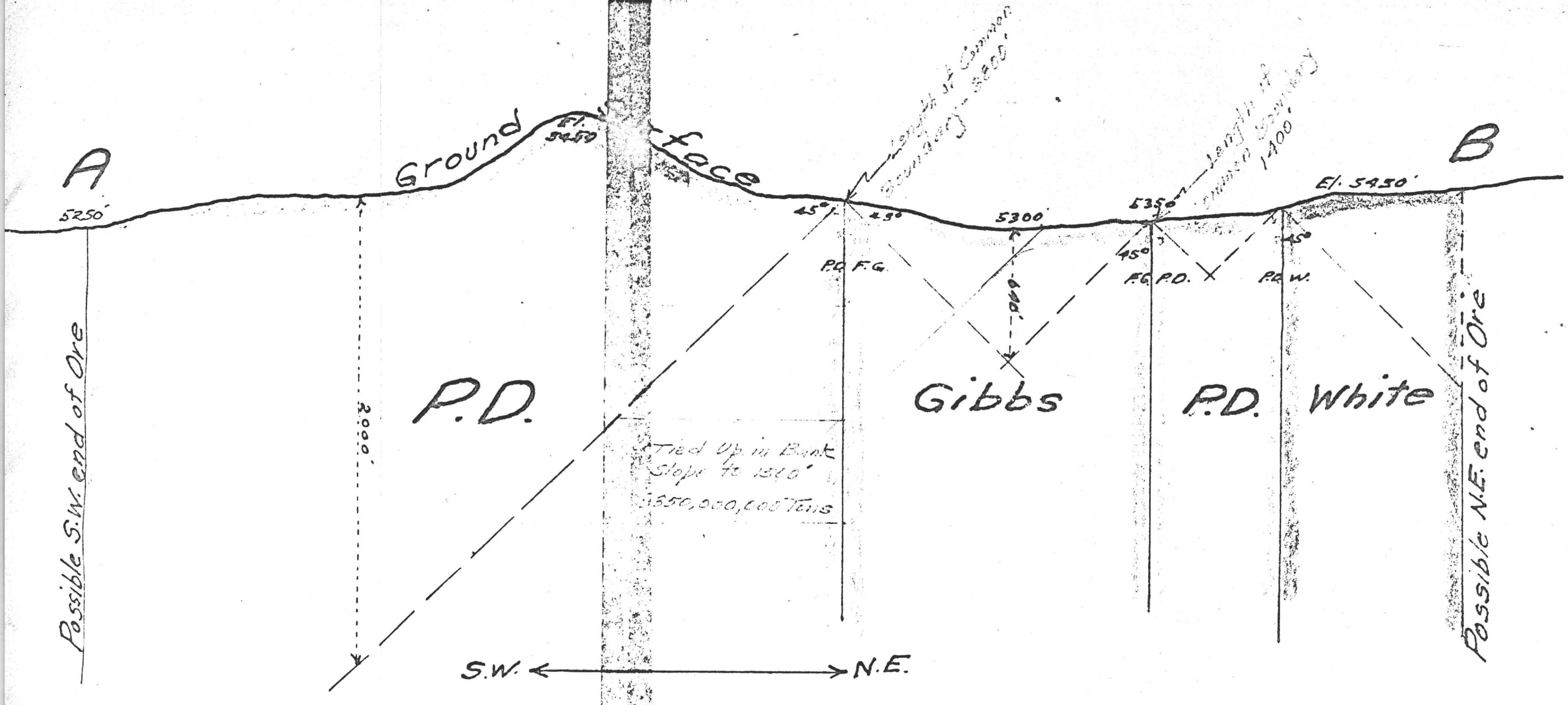
Wilson (24) has described the Copper Basin gold placer deposits in some detail. The only active record period of activity was from 1929 to '937. The source of the gold, especially the coarser nuggets, was undoubtedly the Precambrian tourmaline-quartz veins.

210 West Second Street,
Reno, Nevada
and
Utah Construction & Mining Co.,
550 California St.,
San Francisco 4, California,
Jan. 16, 1961

REFERENCES

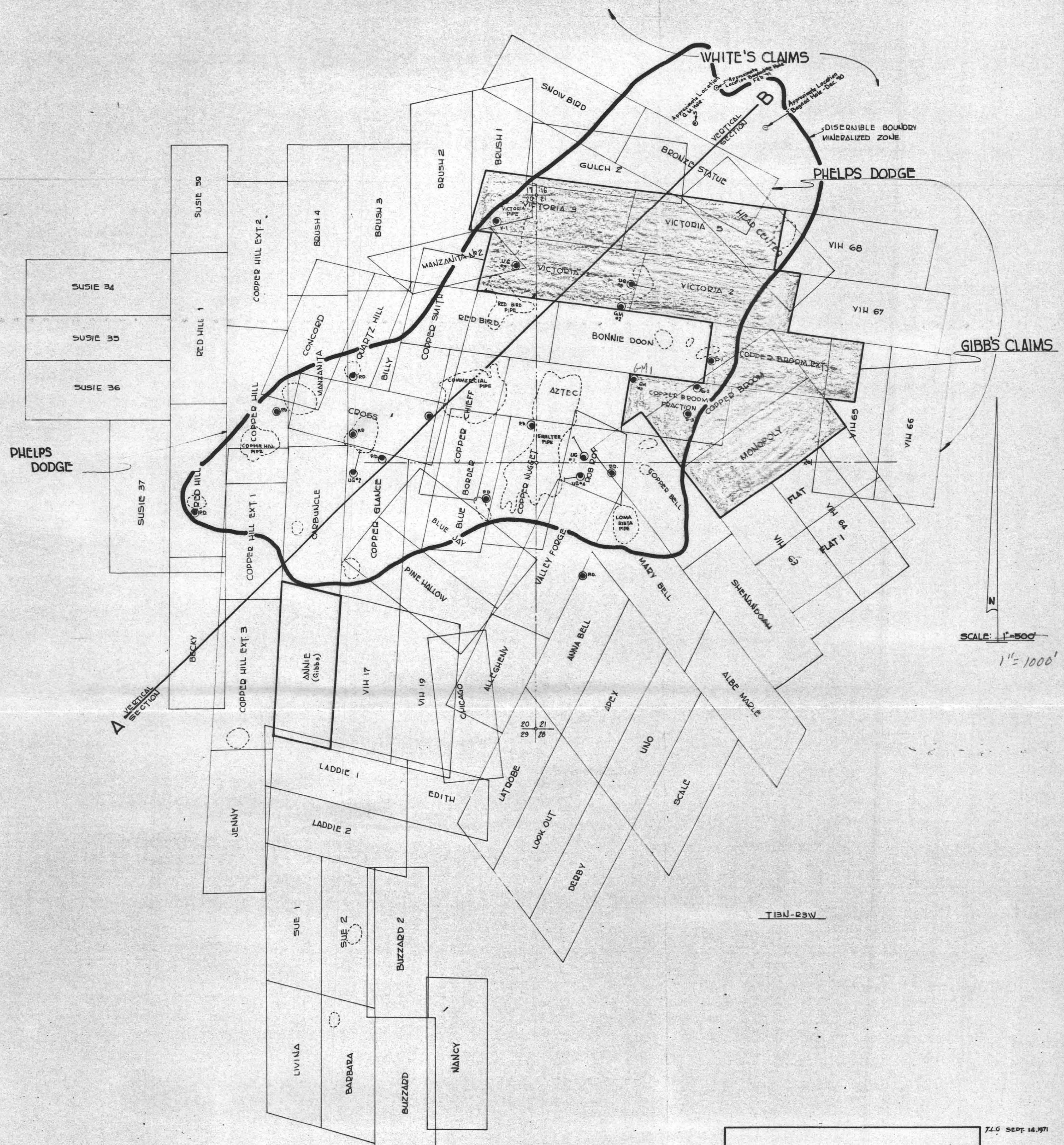
1. Anderson, C. A., 1945, Loma Prieta mine, Copper Basin, Yavapai County, Arizona: U. S. Geol. Survey open file report.
2. ——, 1951, Older Precambrian structure in Arizona: Geol. Soc. America Bull., v. 62, p. 1331–1346.
3. ——, and others, 1955, Geology and ore deposits of the Bagdad area, Yavapai County, Arizona: U. S. Geol. Survey Prof. Paper 278.
4. ——, and S. C. Creasey, 1958, Geology and ore deposits of the Jerome area, Yavapai County, Arizona: U. S. Geol. Survey Prof. Paper 308.
5. Butler, B. S., 1913, Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, p. 126–129.
6. Emmons, W. H., 1938, Diatremes and certain ore-bearing pipes: Am. Inst. Min. Met. Eng. Tech. Pub. No. 891, p. 170–180.
7. Farmin, Rollin, 1934, Pebble dikes and associated mineralization at Tintic, Utah: Econ. Geol., v. 29, p. 356–370.
8. Gilluly, James, 1946, The Ajo mining district, Arizona: U. S. Geol. Survey Prof. Paper 209.
9. Hack, J. T., 1942, Sedimentation and volcanism in the Hopi Buttes, Arizona: Geol. Soc. America Bull., v. 53, p. 335–372.
10. Hulin, C. D., 1948, Factors in the localization of mineralized districts: Am. Inst. Min. Met. Eng. Trans., v. 178, p. 35–52.
11. Kuhn, T. H., 1941, Pipe deposits of Copper Creek area, Arizona, Econ. Geol., v. 36, p. 512–538.
12. Joralemon, I. B., 1952, Age cannot wither, or varieties of geologic experience: Econ. Geol., v. 47, p. 253–256.

13. Johnston, W. P., 1955, Geology and ore deposits of the Copper Basin mining district, Yavapai County, Arizona: Ph.D. Thesis, Univ. of Utah (Unpublished).
14. Lausen, Carl, and Gardner, E. D., 1927, Quicksilver resources of Ariz.: Arizona Bur. Mines, Bull. 29, p. 35–44.
15. Locke, A., 1926, The formation of certain ore bodies by mineralization stoping: Econ. Geol., v. 21, p. 431–453.
16. Lovering, T. S., 1942, Physical factors in the localization of ore: Ore Deposits as Related to Structural Features: Princeton University Press, p. 5–9.
17. ——, 1949, Rock alteration as a guide to ore, East Tintic District, Utah: Econ. Geol. Monograph 1.
18. Lowell, J. David, 1956, Occurrence of Uranium in Seth-la-kai Diatreme, Hopi Buttes, Arizona: Am. Jour. Sci., v. 254, no. 7, p. 404–412.
19. McKinstry, H. E., 1955, Structure of hydrothermal ore deposits: Fiftieth Anniversary Volume, Pt. I, Econ. Geol. Publishing Co., p. 207–214.
20. Mining World, July 1957, p. 43 (International Panorama).
21. Richards, K., and Courtright, 1958, Geology of Toquepala, Peru: Mining Engineering, v. 10, p. 262–266.
22. Walker, R. T., and Walker, W. J., 1956, The Origin and Nature of Ore Deposits; published by Walker Associates, p. 133–155.
23. Wheeler, G. M., 1876, Geologic atlas projected to illustrate geographical exploration and surveys west of 100th meridian: U. S. Army Corps of Engineers.
24. Wilson, E. D., 1937, Arizona gold placers and placering: Arizona Bur. Mines Bull. 142, p. 41–44.



Vertical Section thru Long Axis
Copper Basin Mineralized Zo[ne]

Scale: 1"=33[...]



APPROXIMATE CLAIM LOCATIONS
COPPER BASIN
YAVAPAI COUNTY, ARIZ.

GEOLOGY AND ORE DEPOSITS OF THE COPPER BASIN MINING DISTRICT, YAVAPAI COUNTY, ARIZONA

by

William Percy Johnston

A thesis submitted to the
faculty of the

University of Utah

in partial fulfillment of

the requirements for the degree of

DOCTOR OF PHILOSOPHY

Department of Geology

University of Utah
June, 1955

This Thesis for the Ph.D. Degree

by

William Percy Johnston

has been approved by

Chairman, Supervisory Committee

Reader, Supervisory Committee

Reader, Supervisory Committee

Reader, Supervisory Committee

Reader, Supervisory Committee

Head, Major Department

Dean, Graduate School

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

ABSTRACT

The Copper Basin mining district is in the mountain region bordering the southwest side of the Colorado Plateau in central Arizona.

The igneous and metamorphic terrane has been divided into older Precambrian, late Cretaceous (?) or early Tertiary (?), late Tertiary (?), and Quaternary rocks. Older Precambrian rocks form 80 percent of the area and include, from oldest to youngest: metasediments, amphibolite, quartz diorite, granodiorite porphyry, aplite, granodiorite, and a multitude of basic dikes. The metasediments and amphibolites represent a volcanic sequence of flows, tuffs, and intercalated siliceous sediments.

A late Cretaceous (?) or early Tertiary (?) composite stock includes, from oldest to youngest, diorite, quartz monzonite, quartz monzonite porphyry, quartz latite porphyry, and aplite. The composite stock is funnel-shaped and the separate intrusions were injected through a restricted orifice at depth.

Late Tertiary (?) rocks are a bedded rhyolitic tuff, a rhyolite volcanic neck, two rhyolits plugs, and dikes. Quaternary deposits are terrace gravels, alluvium, and mantle rock.

Precambrian rocks have been affected by regional metamorphism of the greenschist facies, thermal metamorphism of

of pyroxene hornfels, amphibolite and albite-epidote-amphibolite facies, and dynamic metamorphism.

A foliation direction, prominent in the metasediments, amphibolite, and quartz diorite, strikes N. 10° - 30° E., where not deformed by intrusions. Recognized Precambrian faults strike N. 60° - 75° W. and N. 55° - 75° E. Regional (?) faults striking N. 10° - 50° E. of unknown displacement and age preceded the intrusion of Laramide (?) igneous rocks.

A Laramide (?) composite stock intruded along a N. 10°-20° E. fault and provided space by thrusting the west wall. A north-striking fault on the west side of the area was laterally displaced 1500 feet after emplacement of the composite stock.

About 25 approximately circular or elliptical, nearly vertical, columnar breccia pipes near the top of the composite stock are spatially related to the postulated root portion of the stock. The pipes formed by replacement, corrosion, and attrition caused by late magmatic fluids which followed the youngest composite stock intrusion. The pipes are composed of crackle breccia consisting of angular to subrounded fragments showing no marked rotation, and rubble breccia showing pronounced rounding and rotation of fragments. The fragments are cemented by quartz, orthoclase, and sulphides.

Metal production from copper, zinc, lead, silver, and gold ores is estimated at $2,000,000. Precambrian deposits comprise minor gold and copper ores associated with tourmaline-quartz veins. Laramide (?) deposits are copper and molybdenum associated with breccia pipes and an outer aureole of zinc-lead-silver fissure filling and replacement veins. The productive zinc-lead-silver mines are within a north-trending belt along the west side of Copper Basin.

INTRODUCTION

General Statement

The Copper Basin mining district is located in central Arizona about 10 to 15 miles southwest of the town of Prescott, Yavapai County. The area is in the "mountain region" (Ransome, 1919, pp. 174-175) which borders the southwest margin of the Colorado Plateau. The terrane is composed essentially of a complex of igneous and metamorphic rocks of older Precambrian age which has been intruded by a composite stock of late Cretaceous (?) or Tertiary (?) age and late Tertiary (?) rhyolite.

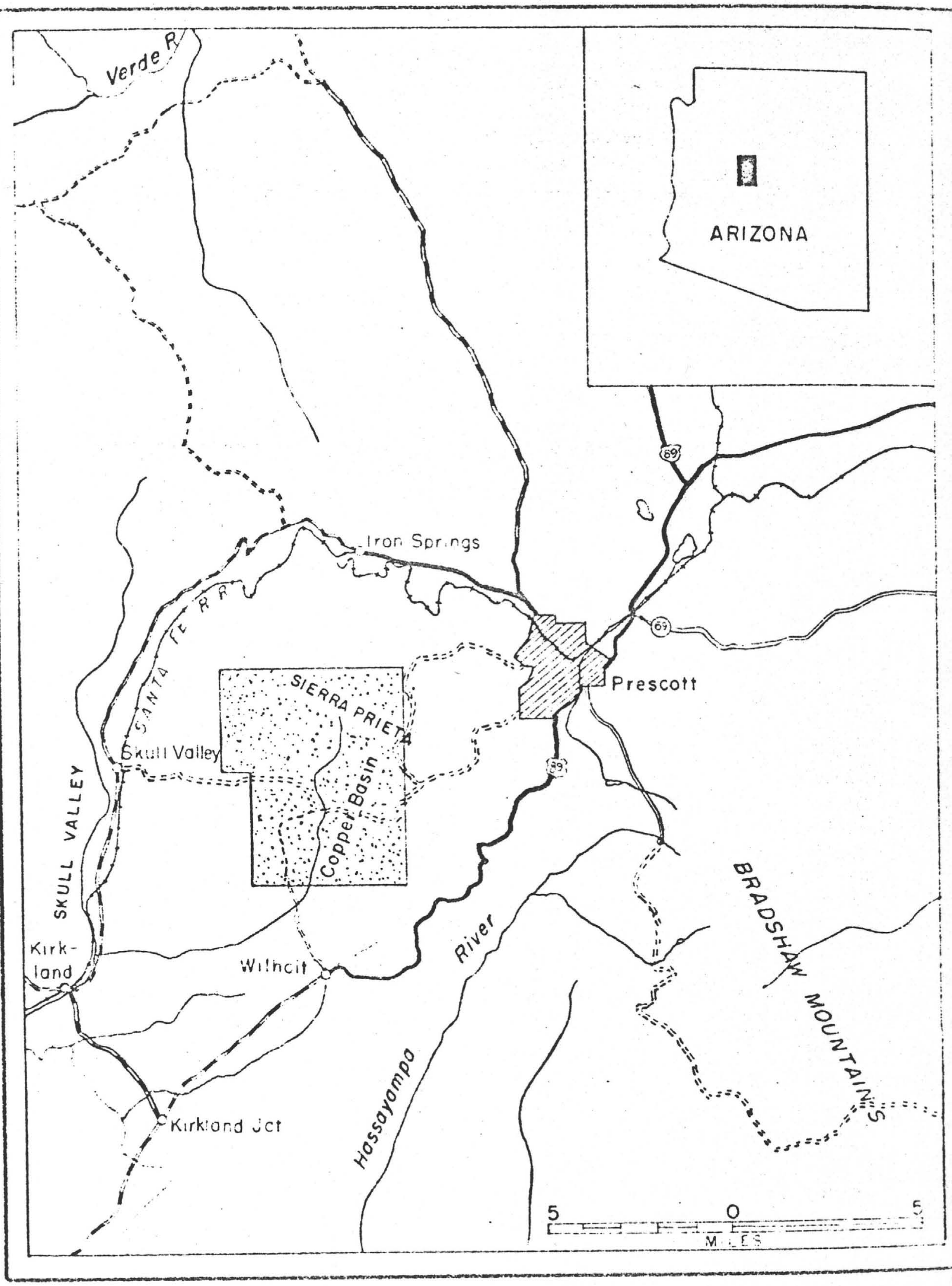
Major ore deposits of Precambrian age in nearby areas include the famous United Verde and United Verde Extension mines at Jerome and the Iron King mine near Humboldt (Plate III). Bagdad, a porphyry copper deposit of late Cretaceous (?) or early Tertiary (?) age, is about 35 miles west of Copper Basin. Innumerable smaller mines and prospects are present in several widely distributed mining districts in the region, many of which have not been studied in detail or classified. Prior to this investigation the Copper Basin mining district was one of the little-studied districts. It has, however, had a long history of sporadic production of copper, lead, zinc, gold, and silver from deposits of different ages and various structural settings. Although the recorded production is only about $2,000,000, the geologic history is of considerable importance with respect to classification of the ore deposits and regional geology of central Arizona.

Location and Physiography

The Copper Basin mining district lies along the southwest slopes and foothills of the Sierra Prieta Range, (Plate I). The Sierra Prieta Range is the northwestward extension of the Bradshaw Mountains, a major northwest-trending mountain range in central Arizona.

Physiographically, Copper Basin is a north-trending, oval-shaped depression formed by the differential erosion of a relatively soft composite stock of late Cretaceous (?) or early Tertiary (?) age and more resistant rocks. The basin drainage is toward the south by way of Copper Basin Wash, an intermittent stream that gradually veers to the west and joins Kirkland Creek near the small farming community of Kirkland (Plate I). The mapped area, in addition to Copper Basin, includes a western part that drains west into Skull Valley, and a small area in the southeast corner that drains into the Hassayampa River.

Elevations range from 4800 feet, where Copper Basin Wash crosses the south boundary of the map, to 7150 feet at the top of West Spruce Mountain in the north-central part of the area.



INDEX MAP: Showing location of area mapped in the Copper Basin Mining District.

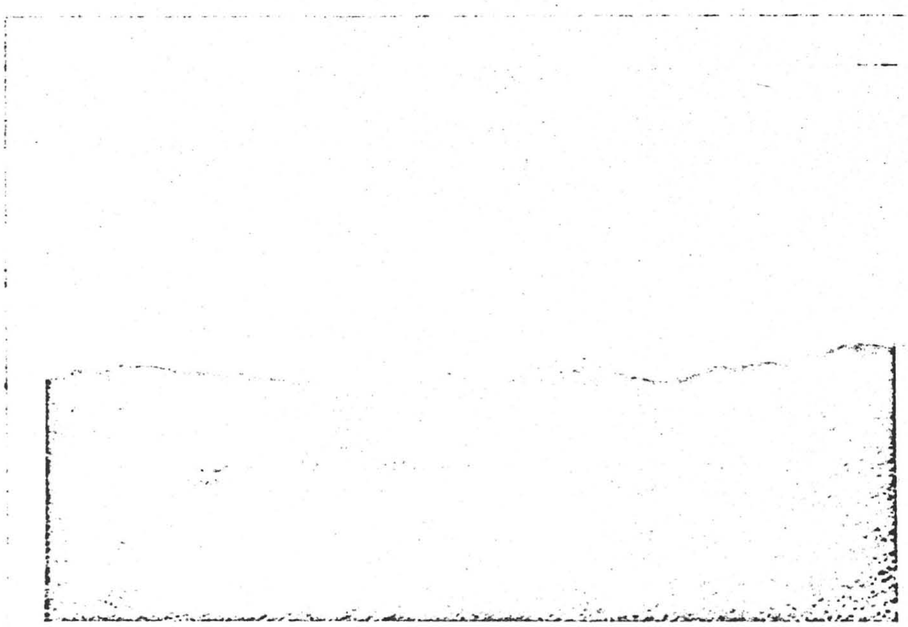
The mapped area comprises 28 square miles in two quadrangles; 15 square miles in the southeast part of Iron Springs Quadrangle and 13 square miles in the northeast part of the south-adjoining Kirkland Quadrangle. The area is in T. 13 N., R. 3 and 4 W., Gila and Salt River Meridian.

Access to the area is via a county maintained mountain road, locally called the "Copper Basin" road, that connects Prescott with the railroad station at Skull Valley (Plate I). The Prescott-Copper Basin segment of this road, about 10-15 miles in length, is closed for short periods during the winter months by snow and rock slides. A longer but more dependable access route is over the partially paved "Iron Springs" road which follows the Santa Fe Railroad for 20 miles along a northwest to southwest loop which extends from Prescott to the "Copper Basin" road junction at Skull Valley. From this junction, the "Copper Basin" road leads 6 miles eastward to the central part of the district.

Purpose

The primary objective of the research presented in this report was to differentiate and classify the igneous and metamorphic rock types of the Copper Basin mining district in space and time, and to relate the ore deposits to the component elements of the classification. A second objective was to describe the breccia pipe deposits and to discuss their mode of emplacement and other significant features of origin.

A. View looking west across north Copper Basin. West Spruce Mountain in right background.



B. View west across Copper Basin. Main breccia pipe area in central foreground. Rhyolite volcanic neck in central background.

The Precambrian terrane of central Arizona has received much geologic attention in the last decade, and it is hoped that this research will contribute further to the knowledge of the regional geology and ore deposits.

Procedure and Scope

Field work was done during the period from February through August, 1952, inclusive. The area was mapped on 1:24,000 scale topographic sheets prepared by enlargement of standard U.S. Geological Survey topographic sheets of 1:62,500 scale. Field mapping was accomplished by use of an open sight alidade and a plane table board mounted on a camera tripod. Detailed mapping was done in the main breccia pipe area with a standard plane table and telescopic alidade on a scale of 1:2,400. Some of the accessible underground workings were mapped by use of brunton and tape.

Previous Work

The first general study of the region, including the north half of Copper Basin District, was made by Wheeler (1876). Jaggar and Palache (1905) proposed a general classification of the Precambrian rocks in the Bradshaw Mountains southeast of the Copper Basin area. Lindgren (1926) discussed the ore deposits of the area previously described by Jaggar and Palache and extended his work to include the Jerome Quadrangle to the north.

Since 1945, the United States Geological Survey has been making detailed studies, under the direction of C. A. Anderson, of several quadrangles to the east of Copper Basin, and Anderson (1951), Creasey (1952), and Krieger (1952) have published brief reports on certain aspects of this project.

Butler and Wilson (1938), and Anderson (1948, 1950, and 1951) have described the geology and ore deposits of the Bagdad area about 35 miles west of Copper Basin.

Although much geologic investigation of the mineral deposits has probably been done by mining companies, nothing has been published from this source. Arizona Bureau of Mines publications include a reconnaissance of quicksilver prospects by Lausen and Gardner (1927, pp. 34-42) and a description of the placer deposits by Wilson (1937, pp. 41-44). During World War II a joint program was sponsored by the Reconstruction Finance Corporation, the U. S. Geological Survey and Fred Gibbs; the Loma Prieta and Copper Hill mines were dewatered and sampled, and a diamond drilling project was initiated at the latter mine. Anderson (1945) prepared a U. S. Geological Survey open file report on the Loma Prieta mine.

Acknowledgements

The author is greatly indebted to Dr. A. J. Eardley, Dean of the College of Mines and Mineral Industries at the University of Utah, under whose supervision the research was conducted. Dr. Eardley, accompanied by Mr. M. P. Erickson, visited the writer in the field and offered many helpful suggestions throughout the course of the research.

Many thanks are due Dr. C. A. Anderson of the United States Geological Survey who visited the writer in the field and gave many helpful suggestions throughout the field season. The author also wishes to express his appreciation to Dr. Medora Krieger of the United States Geological Survey, who is conducting geologic investigation in the adjoining Prescott Quadrangle, for visiting the field area and freely discussing mutual problems.

Mr. Fred J. Gibbs, property owner in the district, was most generous in giving information and permitting free access to his properties.

Special thanks are due Dr. N. C. Williams for critically reading the manuscript and also for making many useful suggestions for report preparation.

The research was aided considerably by a research fellowship grant awarded by the Graduate Research Committee of the University of Utah.

ROCK UNITS

Classification

The igneous-metamorphic terrane of the Copper Basin district imposes a difficult problem in the establishment of a definite time classification. Since there are no fossils or sedimentary marker beds present, the relations were established by careful mapping of the intrusive and metamorphic rock types. By comparison of regional similarities and trends, a tentative three-fold time classification was made consisting of (1) metasediments and igneous rocks of older Precambrian age, (2) composite stock and dike rocks of late Cretaceous (?) or early Tertiary (?) age, and (3) a rhyolite sequence of late Tertiary (?) age.

The precise age relationships of igneous rocks in central Arizona will ultimately depend upon a comprehensive program involving radioactive age determination methods.

Older Precambrian Rocks

General statement

The sequence of metamorphic and igneous rock types designated as older Precambrian comprises approximately 80 percent of the area studied. These rocks include, from oldest to youngest, a metasedimentary unit of siliceous shales and interbedded tuffaceous sediments, an amphibolite unit of basic volcanics and intrusive diorite-gabbro, and four units of granitic igneous rocks consisting of a quartz diorite, a granodiorite porphyry, an aplite, and a granodiorite (Plate X).

There is no definite proof within the Copper Basin district that these rock units are Precambrian. Nevertheless, Anderson (1951, p. 1341) has demonstrated the Precambrian age of rocks in the nearby Prescott-Jerome area where Cambrian (?) sandstone lies unconformably on these same older rocks. A comparison of regional trends, lithology, and regional metamorphism in the Prescott-Jerome area, Copper Basin mining district, and Bagdad (Anderson, 1948, pp. 170-180) indicates a Precambrian age for certain large groups of similar rock types. However, a correlation of the smaller individual units cannot be justified at this time.

The granodiorite that dominates the east side of the area is a continuation of the unit that Krieger (1954) refers to as the Prescott granodiorite in the adjoining Prescott Quadrangle. Krieger believes the Prescott granodiorite to be younger than the Government Canyon granodiorite in Groom Creek, about 7 miles south of the town of Prescott. Age determination of the Government Canyon granodiorite made by the Larsen Zircon method shows an age of 910,000,000 years.* Thus by analogy, the granodiorite unit, the youngest of the major Precambrian units in Copper Basin is less than approximately 910,000,000 years old.

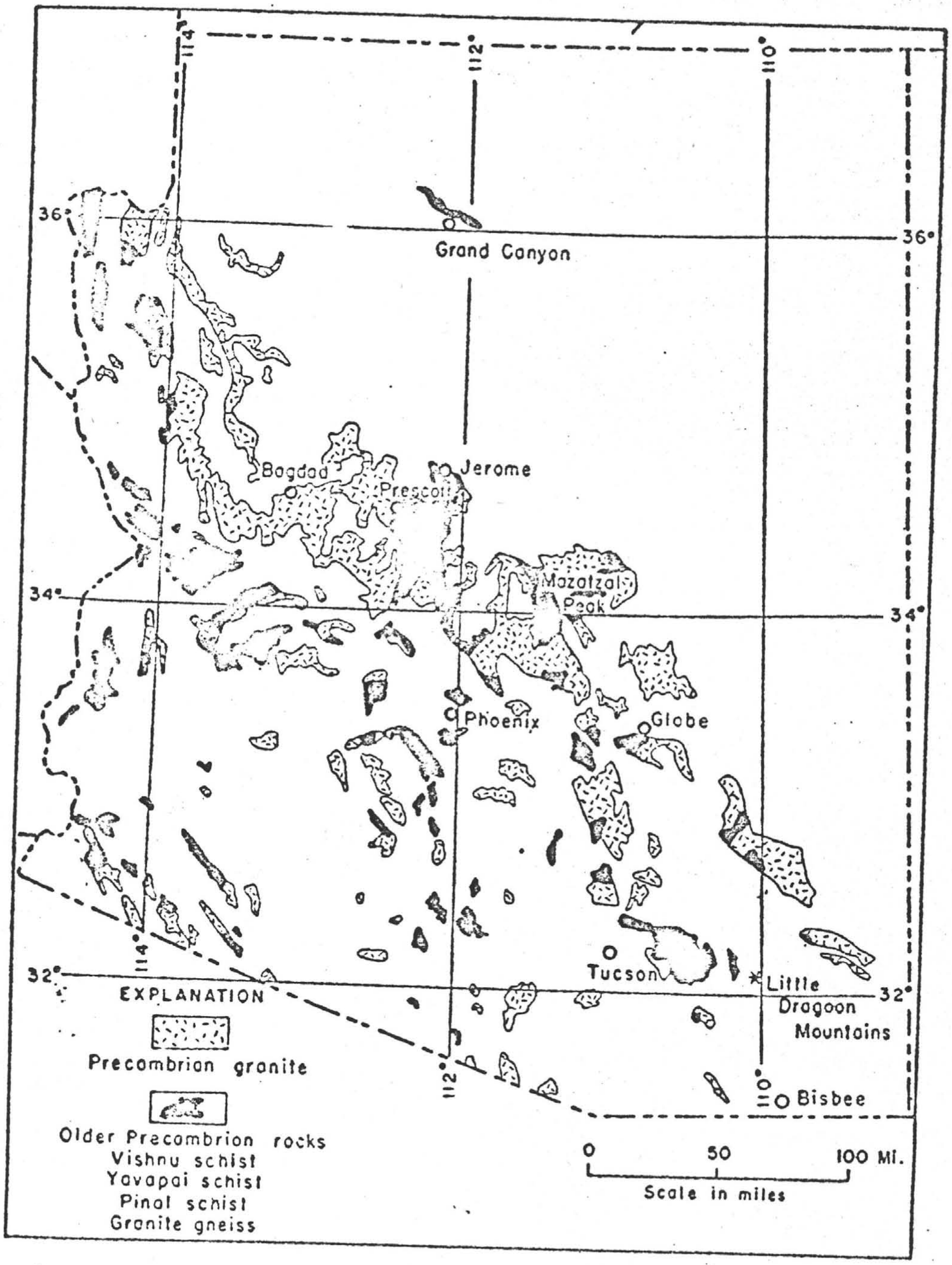
---

* C. A. Anderson, written communication; determination by Howard W Jaffe, U S Geological Survey

Anderson (1951, pp. 1333-1334) has written a thorough discussion on the classification of Precambrian rocks in Arizona. (See Plate III and Table I). Butler and Wilson (1938, p. 11) were first to refer to the Precambrian rocks of Arizona as older and younger Precambrian instead of the two major systems commonly used, Archean and Algonkian. Anderson has adapted this usage in the Prescott-Jerome and Bagdad areas. Wilson (1939, p. 1143) named the apparently widespread orogenic period between the older and younger Precambrian the Mazatzal Revolution.

	Grand Canyon (Noble and Hunter, 1917; Darton, 1925)	Bradshaw Mts. (Lindgren, 1926)	Mazatzal Mts. (Wilson, 1939)	Globe (Ransome, 1903)
Younger Precambrian	Grand Canyon series {Chuar group Unkar group	Unconformity	Apache group	Apache group
	Orogeny - intrusion of granitoid magmas			
Older Precambrian	Vishnu schist	Yavapai schist	Mazatzal quartzite Maverick shale Deadman quartzite Yavapai group {Alder series Red Rock rhyolite Yaeger greenstone	Pinal schist

Table I Correlation Table of Precambrian Rocks of Arizona
(After Anderson.)



DISTRIBUTION OF OLDER PRECAMBRIAN ROCKS COPIED FROM TECTONIC MAP OF THE UNITED STATES, PUBLISHED BY THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, 1944. (AFTER ANDERSON, 1951.)

Hinds (1935, pp. 100-101) suggested that there may be two periods of granitic intrusion prior to younger Precambrian time but as yet there is no evidence known to support this view. No evidence exists in the Copper Basin mining district that suggests more than one Precambrian orogenic episode. Future age determinations of the multitude of granitic intrusives present in Arizona will perhaps put an end to speculation on this problem.

Since the older Precambrian rock units of Copper Basin will, in part at least, be correlated eventually with formations and igneous units already named in nearby quadrangles, the writer has refrained from suggesting formational names for them. For this reason the rocks are designated only as lithologic types.

Metasediments

Bodies of metasediments large enough to be mapped are represented by five irregular bodies in the northwest part of the area (Plate X). Other small, irregular, and discontinuous bands and lenses too small for representation on the map are included in an amphibolite unit and as xenoliths in the older Precambrian granitic units. Textural types of metasediments include argillite, slate, phyllite, hornfels, and locally, schist. The original sedimentary rocks were probably bedded andesitic tuffs, siliceous shales, and fine-grained sandstones. A few bands of gray, dense limestone, less than 6 inches thick are intercalated with siliceous beds in the metasediments in Finch Wash, north of the rhyolite volcanic neck. Some generally concordant, basic bands of questionable origin are included in the map unit; some probably represent thin basic lavas and others may be basic sills or dikes.

The metasediment and the amphibolite units, thought to include much volcanic material, jointly comprise the oldest rocks within the area. Relict primary structures of use in determining the tops of beds or flows are scarce and of questionable value, and the relative age of the metasediments and amphibolite units could not be ascertained. Xenoliths of metasediments are present in all the granitoid units of older Precambrian age, and the quartz diorite and the granodiorite porphyry actually intrude one of the larger bodies of metasediments.

The metasediment bodies, where not affected by thermal metamorphism, form low rolling hills. This is especially true along the northwest border of the area where they have been eroded to an alluvial-covered pediment. Near the Boston-Arizona mine (Plate X) the metasediments have been more or less subjected to higher grade metamorphism and in general are more resistant to erosion than elsewhere.

The beds weather to mottled rusty and pale green or gray outcrops. In most cases fresh surfaces are darker shades of green and gray except for the interbedded, lighter siliceous material.

Well-defined original bedding is observable in most places and parallels the plane of foliation. The westernmost exposures contain beds ranging from 5 to 50 feet thick, although some thin-bedded bands in which the individual beds are less than 1 inch thick are present (Plate X). The eastern exposures comprise at least 2,000 feet of thinly-bedded argillaceous sediments in which intercalated gray and green beds, ranging from 1 to 12 inches in thickness, are present. Locally there is gradation to thicker beds as noted in the western exposures. There is a gradation along strike northward, toward the Boston-Arizona mine, to thicker tuffaceous beds and local intercalated basic flows (?)(Plate X).

Much of the thin-bedded metasediment south of the Boston-Arizona mine resembles the "argillite" of the Belt Series in Montana and Idaho. Original bedding is distinct and superposed foliation is weak to absent. In parts of the unit slates and phyllites are common. The northwest corner of the area includes much phyllite which exhibits incipient segregation banding of dark and light minerals. True schists containing coarse micaceous minerals are only locally present along shear zones in some of the less competent beds. Hornfelses are common in the metasediments in areas adjacent to plutonic igneous rocks, particularly the Precambrian granodiorite porphyry.

The overall metamorphic geology is complicated by compositional variations in different beds, overlapping contact metamorphic aureoles from numerous intrusive bodies superimposed on older regional metamorphism, and displacement by faults. Because of these complications and the difficult to impossible task of making correct mineral identifications in the fine-grained rocks, it was not considered feasible to attempt to map in detail the metamorphic facies. However, enough specimens were collected for petrographic study to allow generalizations of the metamorphic types and facies involved.

Regional metamorphism is represented by the greenschist facies as defined by Williams, Turner, and Gilbert (1954, p. 210) and is similar to the low grade metamorphism described by Anderson (1951, p. 1344) and Creasey (1952, p. 27) in the Humboldt-Jerome area. Thermal or contact metamorphism, controlled by proximity to granitic rocks has produced hornfelses ranging from pyroxene-hornfels facies to albite-epidote-amphibolite facies as designated by Williams, Turner, and Gilbert (1954, pp. 180-181).

The three main mineral assemblages recognized in the greenschist facies of the argillite, slate, phyllite and basic rocks are: (1) muscovite-chlorite-quartz-albite, (2) albite-chlorite-epidote-calcite, and (3) albite-chlorite-actinolitic hornblende-epidote. The first assemblage is typical of siliceous rocks which contain 50 to 90 percent angular quartz grains ranging from .01 to 0 3 mm. in diameter. The other two assemblages represent low grade metamorphism of basic rocks, and relict igneous textures suggest either basic crystal tuff or sheared basic igneous rocks, probably thin andesite or basalt flows. Turner and Verhoogen (1951, p. 465) allows actinolitic hornblende in the highest part of the greenschist facies; however, the actinolitic hornblende may represent the outermost aureole of contact metamorphism in this area.

Hornfelses of the pyroxene-hornfels facies were recognized only from specimens taken within 100 feet of the granodiorite porphyry contact. Pyroxene-hornfels, observed petrographically, is a fine-grained granoblastic mosaic of labradorite-diopside-hypersthene in which many relict structures of the original basic crystal tuffs and andesite-basalt (?) flows are present.

Fine-grained hornfelsic rocks of the amphibolite facies are more widespread than the pyroxene-hornfels facies. Mineral assemblages include granoblastic mosaics of (1) plagioclase-actinolitic hornblende-diopside-biotite, and (2) quartz-plagioclase-microcline muscovite-biotite. The plagioclase ranges from oligoclase to andesine in composition. Relicts of original feldspar, pyroxene, and amphibole phenocrysts are common.

The outer aureole of thermal metamorphism is probably an indefinite zone in which the effects of regional metamorphism merge with those of thermal metamorphism. Granoblastic textures of the hornfelses give way to foliated slate, phyllite, and, locally, schist. Spotting of slates and phyllites by large porphyroblasts of intergrown albite and white mica is common. Albite-epidote (zoisite)-actinolitic hornblende is the most common mineral assemblage in this transition zone. Albite, epidote, and white mica occur as partial replacement of original plagioclase phenocrysts, and albite also forms individual porphyroblasts.

Amphibolite

The amphibolite unit embraces a variety of basic rock types covering a large part of the northern half of the area and one elongate band averaging 1500 feet wide and a mile and a half long bordering the east side of the Copper Basin stock (Plate X). In general the rocks in this unit are relatively resistant and form many of the high ridges. The outcrops range in color from dark reddish brown to dark green, and at a distance often appear black.

The unit comprises a basic assemblage of rocks in which medium to coarse-grained amphibolites dominate, but fine-grained basic and siliceous bands are common. Numerous basic dikes having a considerable range in composition and texture are widespread. Many tongues and tabular bodies of the Pre-brian granitic rocks are locally present, especially in and near the gradational contact zones. Aplite, in thin dikes and irregular patches, is abundant in many parts of the unit.

Much of the amphibolite unit is composed of banded rocks in which the individual bands strike and dip parallel to the original bedding in the metasedimentary rocks. A foliation, ranging from weak to strong and generally paralleling the contacts, is present within the individual bands and is also characteristic of the more massive rocks. The individual bands range from 1 to 100 feet; the narrow bands being much finer textured than the thick bands, though many exceptions were observed. Jaggar and Palache (1905, p. 4) described similar banded rocks in the Bradshaw Mountains as the "Crooks Complex" and offered no explanation as to origin. The unit resembles rocks in the Bagdad area about 35 miles to the west which Anderson (1951, p. 1336) describes as a series of andesitic-basaltic flows and minor sedimentary interbeds in which the lavas have recrystallized to massive black amphibolites. Much of the banded rock within the amphibolite unit is highly suggestive of original andesite and basalt flows separated by tuffaceous sedimentay beds, although no relict pillow structures as described by Anderson (1951, p. 1336) were observed. Irregular-shaped bodies which appear to cut across the regional bedding-foliation direction probably represent basic intrusives. Whether these bodies represent feeders to the lavas or belong to a later intrusive period was not determined. In any case all of these rocks have been affected by regional metamorphism and by the later thermal metamorphism which accompanied the emplacement of the

Precambrian granitic magmas. A swarm of dikes and sills of diabase and lamprohyres occur within the unit. These bodies range from 6 inches to 50 feet in thickness. Many are not foliated and may be post-Precambrian in age.

Contacts of the amphibolites with other units range from sharp to extremely gradational. The contact with the metasediment unit was arbitrarily placed where amphibolite bands exceed the metasediment layers. Contacts with the later Precambrian igneous rocks are comparatively sharp where the contact is parallel to the foliation, but extremely gradational where the contact crosses the foliation. Contacts with the Copper Basin stock rocks of late Cretaceous or early Tertiary (?) age are sharp.

The amphibolite unit comprises more than one metamorphic facies, but about 80 percent is a medium to coarse-grained, moderately foliated, actinolitic hornblende-plagioclase rock. Minor quartz and relict pyroxene are locally present. Some greenschist facies and contact pyroxene-hornfels facies are present.

The effects of metamorphism are somewhat more difficult to assess in this unit than in the metasediment unit inasmuch as many of the original igneous minerals have changed little in certain grades or may have only recrystallized. In the greenschist facies the plagioclase feldspars have been altered to a mosaic of albite, epidote (or zoisite) and white mica, but the outlines of the original crystals are visible in many places. The original mafic minerals have been changed to chlorite or fine-grained radiating clusters of actinolitic hornblende. The original mafic minerals were augite and hornblende.

The pyroxene-hornfels facies is sparingly represented next to the granodiorite porphyry contacts by a coarse granoblastic textured mass. This rock is composed of labradorite, having sutured borders, which is intergranular to large, more or less equidimensional porphyroblasts of diopside up to ½ inch in diameter. These large, roughly circular porphyroblasts give a "spotted" appearance to the rock.

The pyroxene-hornfels facies grades imperceptibly into the amphibolite facies with the same textural qualities, but the labradorite is replaced by a clear, locally twinned oligoclase-andesine feldspar and the pyroxene is replaced by radiating clusters of actinolitic hornblende (uralite). In many places the stubby pyroxene crystal outline is retained, but in other places tabular porphyroblasts of actinolitic hornblende attain a length of 1 inch and a few were found as long as 3 inches. The large porphyroblasts of actinolitic hornblende are separated by a fine-grained mosaic of actinolitic hornblende, plagioclase, magnetite, and locally sphene.

The above pyroxene-hornfels and the coarse amphibolite are found within a 500 to 1,000 foot zone bordering the granodiorite porphyry contact. Within this zone the foliation has been completely destroyed.

Between the greenschist facies and the narrow band of coarse textured hornfelsic rocks adjacent to the granodiorite porphyry are rocks in the amphibolite and albite-epidote-amphibolite facies. They comprise approximately 80 percent of the amphibolite unit. They have visible foliation for the most part, but locally recrystallization has completely destroyed it. In the field these rocks commonly appear as foliated diorite or gabbro, but in thin section the metamorphic and replacement textures are distinct. The more basic plagioclases have been partially replaced by clear oligoclase-andesine or by a mosaic of albite, epidote (zoisite) and white mica. Original augite and hornblende have been replaced or recrystallized to fibrous actinolitic hornblende. Abundant igneous textures are retained in some of the rocks and some of the changes are probably due to metasomatism. As previously mentioned, the contact between the albite-epidote-amphibole facies and the upper limit of the greenschist facies is indefinite.

Quartz Diorite

The Precambrian quartz diorite is represented by a large mass in the southwest portion of the area and by many smaller bodies in the northwest quadrant. The central parts of the larger masses are relatively uniform in texture and composition, but the contact zones, especially those parallel to regional foliation, are contaminated. Contacts with the amphibolite unit are interfingering and transitional in places. Some of the smaller bodies in the vicinity of the Boston-Arizona mine have relatively sharp contacts which include intrusive breccias. The contacts with the granodiorite unit were difficult to determine in some areas because of the metamorphic effects and poor exposures.

The quartz diorite is relatively resistant to erosion and forms high ridges west of the central part of the district. The steep slopes are covered with a coarse, salt and pepper patterned, sandy soil. Locally, joint blocks weather into angular to sub-rounded boulders which may or may not be in place. Where not affected by thermal metamorphism the outcrops are a medium gray to light brown, when viewed from a distance and show mottling by dark minerals on close inspection.

A foliation, ranging from barely perceptible to schistose, was observed in all exposures. This foliation is the result of parallelism of mafic minerals, less commonly feldspars, and cataclastic deformation of all minerals, especially quartz. In general the foliation is weak in the larger masses except near the borders. Segregation banding as in true gneiss is scarce to absent. Large scale banding is present near contacts where the quartz diorite interfingers with bands of amphibolite and metasediments.

The rock is a medium to coarse-grained, granitic-textured, hornblende quartz diorite. Average grain sizes range from 3 to 10 mm., the coarser sizes dominating. Essential minerals and percentage ranges are: andesine, 55-80 percent; orthoclase, 3-10 percent; quartz, 3-25 percent; hornblende, 10-20 percent; and accessory minerals, 2-5 percent. A general average from estimated modes is 60 percent andesine, 5 percent orthoclase, 15 percent quartz, 15 percent hornblende, and 5 percent accessories. Andesine and hornblende occur in relatively fresh rock as euhedra and subhedra and quartz and orthoclase are present as interstitial anhedra. Andesine is commonly zoned and some of the cores may be as basic as labradorite. Near contacts with amphibolite, labradorite is partially replaced by andesine. Quartz generally shows strong undulatory extinction. Accessory minerals include magnetite, zircon, apatite, augite, and sphene. Large diamond-shaped sphene crystals as much as 10 mm. in length are present.

Most of the quartz diorite has been altered by either deuteric action, regional metamorphism, thermal metamorphism, or hydrothermal solutions. Regional metamorphism of the greenschist or albite-epidote-amphibolite facies has undoubtedly affected much of the unit. Andesine has been altered to a mass of epidote or zoisite, albite and white mica (saussurite), and hornblende has been partially altered to biotite and/or dark green chlorite. Shreds of chlorite and biotite are developed out in one direction beyond the original hornblende crystal, imparting a foliated appearance to the rock. Granulated quartz showing much mortar structure was found in several thin sections.

The origin of the foliation in the Precambrian granitic igneous rocks is a difficult problem having several contributing factors. If the quartz diorite was emplaced during regional metamorphism, it is likely that the noticeable orientation of hornblende, and in some cases andesine, may have been inherent in the primary crystallization. Some parallel structures may have been inherited from replacement or injection along bedding-foliation of older rocks. The foliation has been accentuated by stringing out of chlorite, biotite, and cataclastic quartz.

Granodiorite Porphyry

Precambrian granodiorite porphyry occurs in a northwest-trending band averaging 3000 feet wide in the central part of the area and a connecting northeast-trending band in the vicinity of Finch Wash and Copper Basin (Plate X). The northwest-trending body has been divided into three segments by later intrusions. The Copper Basin stock split the granodiorite porphyry into two segments north of the Commercial mine and a third small segment in the southeast corner of the map area appears to be a xenolith in Precambrian granodiorite.

The northwest-trending segments have relatively sharp contacts with the adjacent units. Strong thermal metamorphism along contacts of these segments resulted in some of the pyroxene-hornfels and amphibolites included and discussed in the amphibolite unit.

The northeast-trending bodies in the vicinity of Finch Wash and north of Copper Basin are generally concordant with the regional foliation and include parallel bands of amphibolite as much as 100 feet wide. Granodiorite porphyry intrudes the metasediment and amphibolite units and is thus younger in age. The quartz diorite and granodiorite porphyry units do not have mutual contacts in the mapped area and the relative ages are questionable. The quartz diorite unit was placed below the granodiorite porphyry unit in the map legend (Plate X) because the former unit appears to have been affected to a greater extent by regional metamorphism. The granodiorite porphyry is intruded by tongues and dikes of the granodiorite unit in the northeastern corner of the area.

At a distance the unit appears light grey or light brown. On closer inspection these colors are mottled by black and dark green due to presence of mafic minerals and local basic clots. Weathering patterns depend on strength of foliation and presence or absence of included basic bands. The unit weathers into basins where the basic bands are absent and foliation is weak; this is true for the northwest-trending bands. In the vicinity of Finch Wash the adjacent high ridges are held up by included amphibolite within the granodiorite porphyry unit.

A definite foliation exists in this unit throughout the mapped area. It ranges from a barely perceptible planar direction to a strong foliation which dominates the rock appearance. A general alignment of large plagioclase and hornblende phenocrysts in relatively undisturbed masses is probably due to primary flow of magma. In areas of stronger foliation there are abundant cataclastic structures such as granulated quartz, alignment of chlorite and biotite from altered hornblende, and mortar along borders of plagioclase. These structures may have resulted from regional metamorphism or force exerted by later intrusions.

This unit includes igneous rocks ranging from quartz diorite to granite. Textural differences from medium-grained to coarse porphyritic phases are present. However, the "type rock", comprising over 75 percent of the unit, is a coarse-grained granodiorite porphyry containing large plagioclase phenocrysts set in a matrix of alkaline feldspars, quartz, hornblende, and biotite. The plagioclase phenocrysts range from ½ to 2 inches in long dimension and average about 1 inch. The phenocrysts are zoned andesine which commonly displays frayed borders partially replaced by alkaline feldspars. In places large areas of phenocrysts are replaced by a clear alkaline feldspar and only remnants of twinning remain. An insufficient number of thin sections were studied to determine the extent of this replacement and it is possible that the average of the unit, by chemical analysis, would show it to be quartz monzonite or possibly a granite.

The interstitial essential minerals include: euhedral hornblende and biotite, anhedral to subhedral microcline and orthoclase, and anhedral quartz. Hornblende occurs as bladed phenocrysts as much as ½ inch long. The hornblende phenocrysts are normally poikelitic and include euhedra of apatite, magnetite and zircon which give the host crystal a mottled luster. Biotite and chlorite are present as alteration products after hornblende, but much biotite occurs as primary hexagonal books.

Interstitial feldspars include orthoclase and locally abundant microcline. Percentage estimates of feldspar in thin sections are of no consequence because of the large phenocrysts. Numerous estimates in the field indicate a ratio of about two-thirds plagioclase phenocrysts (disregarding partial replacement) to one-third interstitial alkaline feldspar. However, in many places, especially in the south exposures in Finch Wash, the large phenocrysts are sparse and the rock approaches a true granite.

Quartz content ranges from 15 to 30 percent of total constituents and averages about 20 percent. Interstitial quartz anhedra generally exhibit strong undulatory extinction and not uncommonly are crackled and have mortar structures along the borders.

Accessory minerals include euhedral to anhedral magnetite and euhedral zircon, apatite, and sphene.

Late magmatic and regional metamorphic effects are difficult to separate in this unit. Some of the plagioclase is altered to a mosaic of epidote (or zoisite), white mica, and alkaline feldspar and may reflect regional metamorphism. Some chlorite and biotite after hornblende accompanies the alteration. More commonly, however, the plagioclase is replaced by alkaline feldspar without the epidote-white mica association and is reminiscent of late magmatic effects. Strong cataclastic deformation has resulted in bent albite twins, undulatory quartz, and local mortar structures along the edges of many of the minerals.

Granodiorite

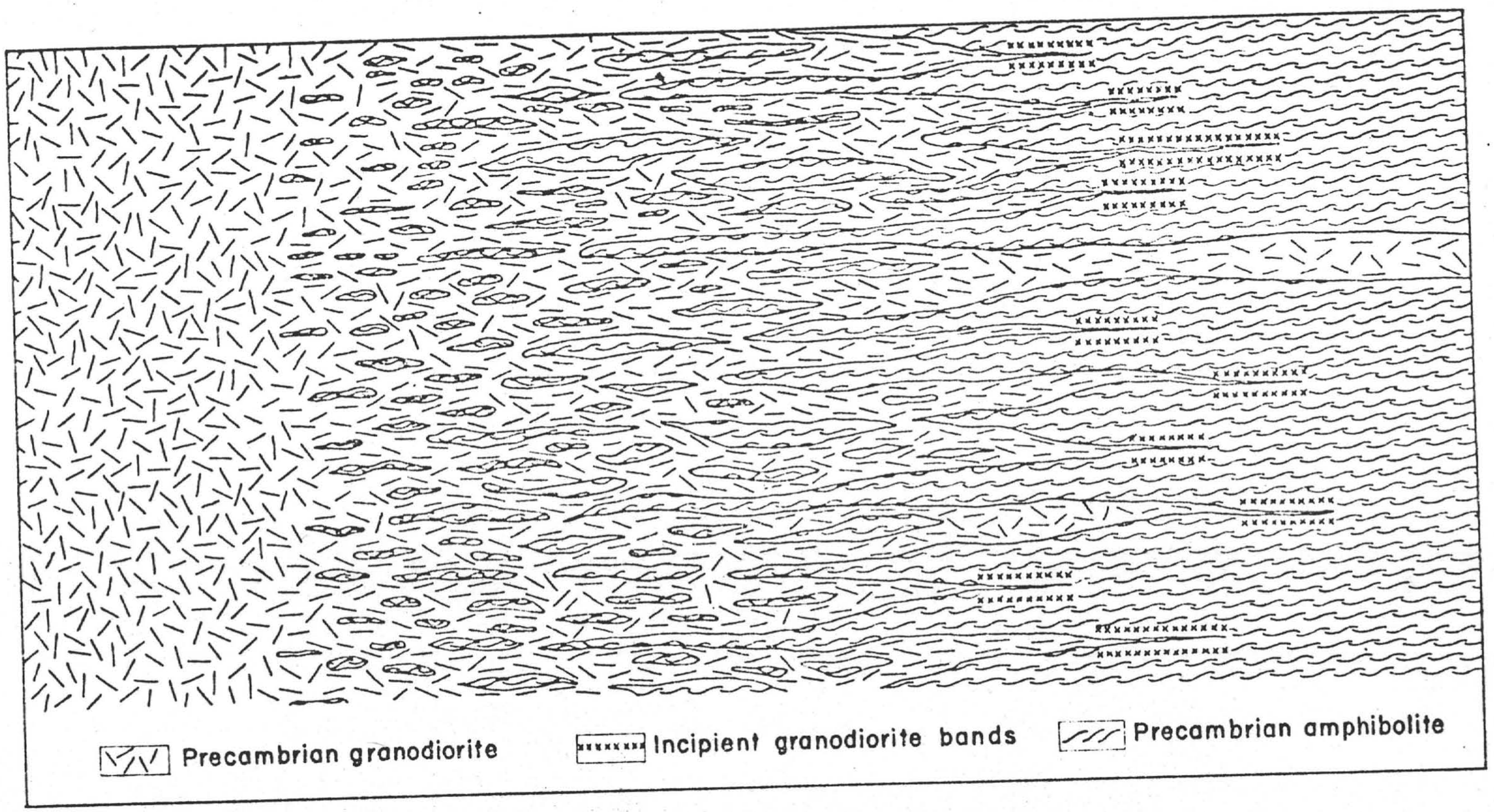
The granodiorite unit comprises a rather uniform granitic-textured rock bordering the entire eastern side of the area and another smaller body in the southwest corner. This unit was traced into the Prescott Quadrangle and is equivalent to the "Prescott" granodiorite of Krieger (1954). According to Krieger "Prescott" granodiorite is later than the "Government Canyon" granodiorite which has an indicated radioactive age of 910,000,000 years.

The granodiorite appears to be the youngest of the Precambrian units previously described.

The unit weathers readily to a coarse gray arkosic-type soil and outcrops comprise only about 25 percent of the area mapped. However, rounded to sub-rounded boulders, ranging from 5 to 20 feet in diameter, are usually present and in most places have not traveled far. Light gray or light brown outcrops are common along ridge tops and road cuts.

Contacts with amphibolite are relatively sharp if parallel to foliation and gradational if crosscutting in nature. If crosscutting, a transition can be traced from incipient growth of feldspars along foliation planes in amphibolite (Plate V-B) to a zone comprised of alternating bands of amphibolite and granodiorite; the individual bands ranging from 1 inch to 20 feet in width. Toward the main granodiorite mass the amphibolite bands become narrower and finally part along the strike into elongate, spindle-shaped lenses or clots resembling boudinage structures (Plates IV and V). Balk (1948, pp. 10-13) described basic clots of this type as being either foreign inclusions or segregations of normal ferromagnesian minerals. He believes that regardless of origin the clots were plastic at one time. The above transition from normal amphibolite to basic clots included in granodiorite indicates their origin as foreign material.

As the clots are traced farther into the granodiorite there is a gradual transition within the clot to material resembling the host rock. The final observable stage in replacement is a ghost outline of the original clot which can

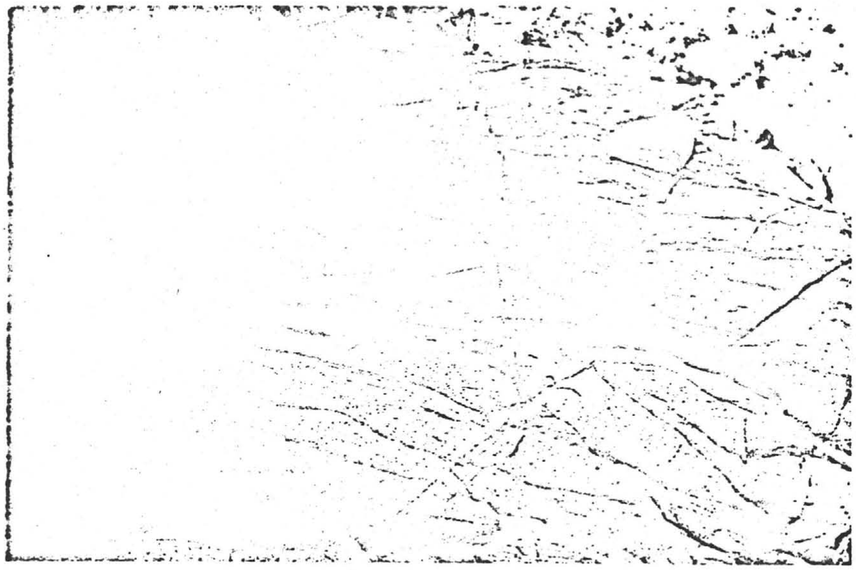


Idealized diagram of transitional contact zone between older Precambrian granodiorite and amphibolite units. Type locality is in gulch a quarter mile west of Hagen Ranch. (Transition zone ranges from 2000 to 3000 feet parallel to foliation.)

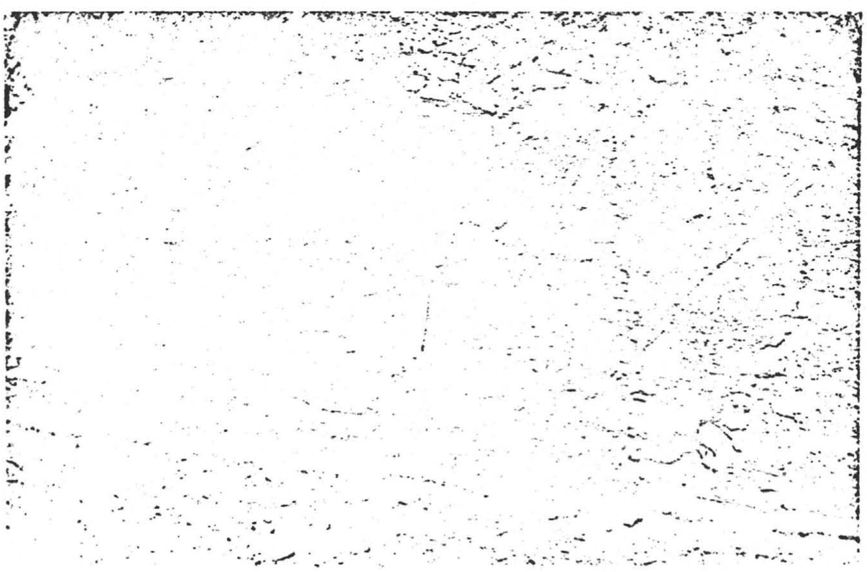
only be seen in subdued lighting. The length of this transition zone, where present, ranges from 1000 to 3000 feet. This transition may be considered a border zone of mixed rocks in which injection and replacement were both operative.

Much of the granodiorite unit in the mapped area is free from perceptible foliation. In the large eastern mass foliation is prominent only in a west border zone, ½ to 1 mile wide. In the normal coarser-grained border rocks there is an alignment of biotite and hornblende and commonly strong cataclastic deformation has crushed and oriented all minerals. Regional metamorphic effects present in older rocks are absent to weak. It is suggested that the granodiorite was emplaced at or near the end of the orogenic cycle. The border foliation appears to be due to primary flow structure and cataclastic deformation. The latter may have been caused by the intrusive force of the later Copper Basin stock rocks or by forces exerted from further intrusion of the central part of the large granodiorite mass itself, after crystallization of the border zone (protoclastic borders of Waters and Krauskauf, 1941, pp. 1355-1418).

Textural differences are prominent in border zones, but interior areas are generally uniform and consist of a medium-grained granitic textured rock. Locally there is a porphyritic appearance due to slight increase in size of plagioclase over other minerals. In the border zones the general grain size has decreased and the percentage of dark minerals is less.



A. Basic clots and bands in Precambrian granodiorite a half mile west of Hagen Ranch.



B. Incipient growth of granodiorite bands in amphibolite. View of north road cut about a quarter mile west of Hagen Ranch.

In thin section the mineral suite is fairly uniform although percentages differ considerably. The essential minerals are oligoclase-andesine, orthoclase, microcline, quartz, biotite, and hornblende. Accessory minerals include iron ores, sphene, zircon, and augite. An estimated general mode is plagioclase 50 percent, alkali feldspar 15 percent, quartz 25 percent, biotite 7 percent, hornblende 1 percent, and accessories 2 percent.

Plagioclase occurs as subhedral to euhedral crystals ranging from 1 to 10 mm in greatest dimension and averaging about 3 mm. Andesine is the most common plagioclase, but oligoclase is locally present. Zoning is present but not prominent. Estimated percentages range from 35 to 65 percent and average about 50.

Orthoclase and microcline occur in various proportions as interstitial anhedra, although euhedral microcline is locally present. Orthoclase is generally more abundant than microcline. Perthite is sparingly present in some thin sections. Total alkali feldspar ranges from 3 to 25 percent and averages about 15 percent.

Quartz is present as interstitial anhedra as much as 5 mm. in diameter if it is not cataclastically deformed. Most of the quartz exhibits strong undulatory extinction and commonly is granulated into clusters of smaller sutured grains, all having the same extinction. Quartz ranges from 15 to 35 percent and averages about 25 percent.

Biotite is present in relatively non-foliated specimens as hexagonal plates ranging from 1 to 5 mm. and averaging about 3 mm. In foliated specimens the biotite is partially altered to chlorite and has been strung out in parallel shreds. Hornblende, in quantities as much as 3 percent, is commonly altered to chlorite, epidote, and iron ore. Sphene is the most noticeable accessory mineral because the long diamond-shaped crystals attain a maximum length of 1 cm. and can be easily identified in hand specimens.

Alteration is weak in this unit as compared to previous units described. Sericitization and argillic alteration of plagioclase were found in some slides and absent in others. Microcline is usually fresh and orthoclase shows some cloudiness. Biotite is locally altered to chlorite and hornblende is generally changed to chlorite, epidote, and iron ores.

Cataclastic deformation was strong in the border zones. Mortar structures are common along the feldspar borders, quartz is granulated, and the mafic minerals have been smeared into oriented shreds.

Thin section studies of basic clots gave disappointing results, because cataclastic deformation and alteration obscured much of the replacement phenomena. However, resorbed skeletal phenocrysts of labradorite, partially replaced by more acid plagioclase, were recognized. Biotite, epidote, zoisite and chlorite formed from earlier mafic minerals. Quartz is present in much smaller quantities than in the granodiorite host.

Aplites, Pegmatites, and Basic Dikes

Dikes exhibiting a wide range in composition and textural types are locally numerous within the area. Most of the dikes are too narrow and discontinuous to show on the areal map. A majority appear to antedate the late Cretaceous (?) or early Tertiary (?) igneous rocks and are assumed to be satellitic to the Precambrian granitic rocks.

Aplite dikes, generally ranging from 1 inch to 20 feet in thickness and notably discontinuous along the strike, are abundant in the area. Dikes exhibiting a definite foliation are assumed to be of Precambrian age because aplites associated with late Cretaceous (?) or early Tertiary (?) rocks are free of planar structures. Three larger masses of foliated aplite in the northern end of Copper Basin were mapped (Plate X). These exposures appear to be closely associated with the Precambrian granodiorite porphyry unit. For this reason the Precambrian aplite, shown on the map legend, was placed between the granodiorite porphyry and granodiorite unit. However, much unmapped aplite cuts the granodiorite unit and appears less foliated than the mapped aplite.

Pegmatites are not abundant and where present are represented by narrow, irregular, discontinuous bodies, only a few of which are wider than 5 feet and longer than 100 feet. Some pegmatites appear to be associated with contact zones bordering the granodiorite porphyry unit. The general type is composed of microcline or perthite phenocrysts that range from $\frac{1}{4}$ to 1 inch in longest dimension, and that are set in a matrix of coarse, granular, glassy quartz.

Numerous basic dikes were not differentiated in detail but include pyroxenite, gabbro, diorite, diabase, and lamprophyres.

Summary of Metamorphism

The metamorphism of the area was divided into three general types, although it was not mapped on this basis. The three types, as defined by Turner and Verhoogen (1951, p.371) are: (1) regional metamorphism, (2) thermal (contact) metamorphism, and (3) kinetic (cataclastic) metamorphism. The transition from one type to another is complicated by overlapping boundaries.

Regional metamorphism, as used here, is a type which does not bear a definite relation to the granitic igneous rock contacts. In the mapped area it is more or less confined to the low grade greenschist facies. There is some actinolitic hornblende locally, but Turner (1948, p. 93-98) allows the presence of this mineral in the highest part of the greenschist facies. The regional metamorphism of the older Precambrian terrane in the Humboldt area, 30 miles to the west, is also characterized by the greenschist facies (Creasey, 1952, p. 27).

Thermal metamorphism is characterized by hornfelses, as defined by Williams, Turner, and Gilbert (1954, pp. 180-181), which range from the pyroxene-hornfels facies bordering the granitic masses through the amphibolite facies to the albite-epidote-amphibolite facies. The latter facies is superimposed on the greenschist facies and in places the transition zone may be represented by spotted slates and phyllites.

Kinetic metamorphism is prominent in zones adjacent to or within the borders of some of the larger granitic bodies. It is especially noticeable in and near the west contact of the granodiorite unit along the east side of the mapped area. The cataclastic deformation has resulted in much granulation, mortar structures, and shredding of soft minerals. There appears to be little or no chemical reconstitution. The origin of the forces involved is not clear. Continued movement of magma after the border zones had solidified may have produced protoclastic structures. The subsequent emplacement of nearby igneous masses may also have been responsible.

Regional metamorphism imposed a foliation on the then-existing rocks. Subsequently, contact metamorphism associated with emplacement of granitic rocks destroyed much of the foliation and produced a hornfelsic texture. Later, in part at least, kinetic deformation was imposed on the regional and contact metamorphic types.

A problem in interpretation exists as to how much the individual granitic rock units were affected by regional metamorphism. The general presence of the regional foliation direction in the quartz diorite suggests that this unit was emplaced during the active orogenic period. Whereas the relatively non-foliated contact zones bordering the granodiorite porphyry and granodiorite units may indicate that the foliation and alteration, where present, are due mostly to primary flow and post-magmatic effects.

Origin of Older Precambrian Rocks

The metasediment and amphibolite units exhibit lithologic and textural characteristics which indicate that these rocks comprise a volcanic sequence intercalated with fine-grained siliceous sediments. Undetermined quantities of diorite-gabbro and fine-grained basic dikes intruded this earlier sequence.

The mode of emplacement of granitic bodies has long been one of the controversial problems of geology, and, though the present study involves a very limited area within a large region of Precambrian granitic and metamorphic rocks, certain features appear worthy of comment.

Supporting evidence is lacking for the theory of metamorphic evolution of granitic rocks at an extreme stage of metamorphism accompanied by extensive development of magmatite. Argillite, slate, and phyllite are locally abundant in interintrusive areas and were observed within 1000 feet of igneous contacts. Thin beds of dense blue-gray limestone, as much as 6 inches thick, were found intercalated with argillite beds in Finch Wash. The limestone shows little sign of recrystallization although granodiorite porphyry is present within 1000 feet.

The oldest of the granitic units, the quartz diorite, exhibits a weak to strong gneissoid foliation throughout the area. The foliation generally parallels the regional trend and, in part at least, was probably formed by regional metamorphism. However, there is some evidence to support the idea that some of the foliation represents original bedding or flow banding in replaced metasediments or amphibolites. Smaller quartz diorite bodies in the northeast portion of the area exhibit relatively sharp contacts, intrusive breccias, and are in part discordant to the regional foliation.

The granodiorite porphyry and granodiorite units display fine-grained aplitic borders, contact metamorphic aureoles, possible protoclastic borders, and uniform igneous minerals and textures in the interior parts of larger masses. Locally, where the contacts cross regional foliation, there are transitional border zones (Plate IV) in which injection and metasomatism both may be important. Replacement of this type is here considered to be associated with the adjacent granitic bodies which exhibit the magmatic criteria listed above, for the most part. The granodiorite porphyry and granodiorite units appear to be "post-kinetic" or "post-tectonic" granitic rocks (Williams, Turner, and Gilbert, 1954, p. 229).

Late Cretaceous (?) or Early Tertiary (?) Rocks

General statement

A composite stock, irregular in outline but approximately 5 miles long and averaging about 1 mile wide, occupies the floor of the north-trending, oval-shaped Copper Basin. Apophyses of the stock occur in small circular depressions west of a ridge bordering the west side of Copper Basin (Plate X).

The composite stock, here named the Copper Basin stock, was mapped as five separate intrusives, closely related in space and probably in time. The Copper Basin stock comprises the following intrusive unit from oldest to youngest:

(1) an east-trending diorite body exposed on the southwest side of Copper Basin,

(2) an equigranular quartz monzonite body occupying the central part of Copper Basin,

(3) an elongate quartz monzonite porphyry unit at the north end of Copper Basin,

(4) quartz latite porphyry dikes, and

(5) small irregular bodies of aplite and pegmatite.

Direct evidence is lacking for a definite age for the Copper Basin stock rocks. However, a late Cretaceous (?) or early Tertiaty (?) age is suggested for these rocks on the basis of the following facts and inferences:

(1) The composite stock intruded all of the Precambrian units.

(2) The Copper Basin stock rocks show no indication of regional metamorphism or cataclastic deformation in areas removed from faulting. Strain shadows are rare to absent in the interstitial quartz anhedra.

(3) The general textural and structural features suggest a nearer surface emplacement than for the medium to coarse-grained Precambrian igneous rocks.

(4) The Copper Basin stock rocks bear a striking resemblance to stock rocks of known or inferred late Cretaceous (?) or early Tertiary (?) age throughout the area bordering the Colorado Plateau.

(5) A pyrite-chalcopyrite-molybdenite mineralization associated with the Copper Basin stock is remarkably similar in character to the porphyry copper deposits of the Southwest This type of mineralization has not been described in deposits of Precambrian age in the Southwest.

(6) The Copper Basin stock and related ore deposits closely resemble a quartz monzonite stock and related deposits at Bagded, about 35 miles to the west. Anderson (1948, p. 173) has classified the quartz monzonite and related deposits at Bagdad as late Cretaceous (?) or early Tertiary (?). The writer has adopted this same classification for the Copper Basin stock rocks.

Diorite

The earliest intrusion of the composite Copper Basin stock is represented by a fine-grained, dark green diorite plug exposed on the southwest side of Copper Basin. The plug is roughly 2500 feet in diameter but has a dike-like tongue extending at least a mile and a half west (Plate X).

The diorite intrudes the Precambrian quartz diorite and granodiorite units and is in turn intruded by later intrusives of the Copper Basin stock.

The diorite is less resistant to weathering than the adjacent Precambrian units and the west-projecting tongue forms a gap in the north-trending ridge bordering the west side of Copper Basin. The outcrops weather to a dark green and the resulting soils are dark brown.

The rock is a fine-grained, dense, equigranular diorite which exhibits no foliation or lineation. The grain size ranges from 0.1 to 2 mm. and averages about 1 mm. The essential minerals are andesine (approximately two-thirds) and hornblende (approximately one-third). Fresh anhedral andesine laths, averaging 1 mm. in long dimension, are set in a matrix of pale green, anhedral to subhedral hornblende crystals. The hornblende is poikelitic and includes andesine and magnetite euhedra. Much of the hornblende is altered to chlorite, epidote, and anhedral magnetite. Accessory minerals are zircon, apatite, and magnetite.

Quartz Monzonite

An equigranular quartz monzonite, the largest intrusive unit of the Copper Basin stock, occupies the central floor of the basin. The rock is the least resistant to weathering of any of the igneous rocks in the area and much of the unit is covered by residual soil and by terrace gravel along Copper Basin Wash.

The normal rock type is a fine to medium-grained biotite quartz monzonite which grades transitionally into a fine-grained hornblende quartz monzonite border facies. The border facies is most prominant in the south half of the unit and in the apophyses in the vicinity of the McNary mine (Plate X).

The quartz monzonite intruded the earliest member of the Copper Basin stock, the diorite unit. Diorite fragments are included in the borders of the quartz monzonite mass. The contacts with all other units are relatively sharp and intrusive breccias can be observed in many places, especially along the east contact zone.

The east contact dips 45-60° west at several places where relief and outcrops permitted observations. The west contact in Copper Basin is essentially horizontal and represents the top of the intrusive. A relatively gentle east-dipping thrust fault in the vicinity of the U. S. Navy and McNary mines is occupied by quartz monzonite and represents the true west contact of the intrusive. Thus, the overall picture in cross section is a funnel-shaped stock or ethmolith which includes a root-like extension in depth that probably served as an orifice for the original magma. This concept is of fundamental importance in the structural and mineralization history of the ore deposits and will be discussed in detail later.

The quartz monzonite tends to weather into low relief and is commonly expressed by a mottled gray to light brown arkosic-type soil. The rock is more resistant in areas which are slightly porphyritic and especially in the fine-grained border facies. Part of the more resistant border facies crops out along the steep east side of the basin and weathers into rounded to sub-rounded boulders exhibiting some exfoliation. The ratio of dark to light minerals is higher in this facies and soils are correspondingly darker.

Although there is considerable variation in the textures, the compositional differences are confined to rather narrow limits. An estimated average mode of the main biotite quartz monzonite is andesine 38 percent, orthoclase 34 percent, quartz 15 percent, biotite 10 percent, hornblende 2 percent, and accessories 1 percent. The essential minerals and their percentage range are as follows: andesine (30-50), orthoclase (25-50), quartz (10-20), biotite (5-15), hornblende (1-15). Accessories including apatite, zircon, and iron ores rarely compose more than 2 percent of the rock.

Plagioclase is present as fresh euhedral crystals of andesine, ranging from 1 to 5 mm. and averaging about 2 mm. In certain areas the maximum size dominates and imparts a porphyritic appearance to the rock. Zoning is locally abundant but not pronounced. Insignificant kaolin and sericite occur sporadically and show a definite preference for the inner zones.

Orthoclase occurs as interstitial anhedra and also as poikelitic, euhedral to subhedral crystals which contain as much as 50 percent included crystals of hornblende, andesine, quartz, magnetite, apatite, and zircon. The orthoclase is turbid and locally is coated by incipient clay minerals. Microcline is sparingly present in some thin sections.

Biotite is the main mafic mineral in the normal unit, but hornblende dominates in the fine-grained border facies. Biotite occurs as hexagonal plates as much as 5 mm. in diameter and also as irregular cleavage fragments. Hornblende makes up as much as 15 percent of the total in some of the darkest parts of the border facies. It is present as prismatic crystals as much as 1 cm. long which exhibit no observable orientation. Chlorite is present as an alteration product of biotite or hornblende.

Quartz is present as interstitial anhedra which range from .1 to 5 mm. and average about 1 mm. The outstanding feature of the quartz, when compared with quartz in the Precambrian units, is the absence of strain shadows, granulation, or mortar structure.

Magnetite was present in all slides studied but in smaller quantities than in the Precambrian igneous rocks. Apatite and zircon are likewise only sparingly present.

Contact metamorphic effects associated with the quartz monzonite are relatively weak and are rarely noticeable more than 1000 feet from the contact. Green actinolitic hornblende is locally prominent in bladed crystals as much as 1 inch in length. Some actinolitic hornblende occurs in zones as much as 12 inches thick composed of parallel bands of actinolitic hornblende ranging from ½ to 1 inch thick which are separated by bands of aplitic material composed of andesine and orthoclase ranging from ¼ to ½ inch thick. The bands were observed cutting the quartz monzonite as well as the bordering Precambrian rocks.

Quartz Monzonite Porphyry

The next youngest unit of the Copper Basin stock is a light to medium gray biotite quartz monzonite porphyry. It is present in the north end of Copper Basin as an elongate band averaging 1500 feet wide and 2 miles in length. The long axis of the band trends N. 20° E.

The quartz monzonite porphyry exhibits sharp contacts with adjacent rocks and no contact metamorphic effects were observed. The southwest contact with the earlier quartz monzonite unit is marked by some intrusive breccia. Breccia fragments of quartz monzonite are included in the porphyry unit.

The quartz monzonite porphyry is a competent rock and generally forms higher ground than the nearby quartz monzonite. Joint blocks of the porphyry have weathered into angular to sub-rounded blocks as much as 15 feet in diameter along the steep slopes at the north end of Copper Basin. Some blocks are still in place and others form large rubble heaps.

Oligoclase-andesine and biotite phenocrysts compose about 30 percent of the rock and the remainder is a fine-grained equigranular mosaic of oligoclase-andesine, orthoclase, quartz, biotite, and accessory minerals.

Oligoclase-andesine is present as prominent phenocrysts ranging from 2 mm. to 2 cm. and averaging 5 mm. Zoning is common and sericite alteration is concentrated in the outer zones. Plagioclase in the groundmass is difficult to estimate, but the total, including the phenocrysts, is probably from 30 to 40 percent.

Biotite phenocrysts, in hexagonal plates from 1 to 3 mm. in diameter and averaging 2 mm., compose 5 to 7 percent of the rock. Many of the plates have been partially or wholly altered to chlorite and iron ores.

The equigranular groundmass has an average grain size of about 2 mm. and comprises a mosaic of orthoclase, quartz, plagioclase, magnetite, apatite and zircon. Orthoclase is estimated at 30 to 40 percent and quartz from 10 to 15 percent. Iron ore is abundant as euhedra and irregular grains from alteration of mafic minerals.

Quartz Latite Porphyry

Porphyry dikes, having a wide range in texture and composition, are included as quartz latite porphyry on the map (Plates X and XI). Many of these dikes are identical in composition with the quartz monzonite and are similar texturally except the groundmass is much finer-grained.

A major trend of some of these dikes is north to N. 20° E., parallel to the long axis of the quartz monzonite porphyry body but continuous to the south at least 3 miles beyond the south extension of the latter intrusive. The dikes intrude the quartz monzonite porphyry but are probably closely associated with it in time.

One quartz latite porphyry dike was traced continuously from the north part of Copper Basin to the Boston-Arizona mine, 2 miles to the northwest. This one dike was the only one of its kind found in the northwest part of the area and was indispensible in the interpretation of some structures and age relations of certain ore deposits.

Textural differences involve the ratio of light to dark minerals, ratio of phenocrysts to groundmass, and also differences in grain size of groundmass and phenocrysts. Phenocrysts form from 10 to 30 percent of the rock and the remainder consists of a groundmass which grades from fine-grained to micro-granular in texture. The fresh rock ranges from light to dark gray and is mottled by large white feldspar phenocrysts. The darker color of some dikes may be due to a finer-grained groundmass or more mafics are included in the groundmass.

Insufficient petrography was done to give a detailed description or general mode of these rocks, but all are characterized by phenocrysts of zoned oligoclase ranging in size from 2 mm. to 2 cm. and roughly averaging 5 mm. Locally the feldspar phenocrysts are crushed and rounded. Some dikes have biotite phenocrysts, as much as 1 cm. in diameter as the principal mafic mineral, and others have chiefly prismatic needles of hornblende as much as 1 cm. long. Some dikes contain a few large rounded grains of glassy quartz as much as 1 cm. in diameter but most of the quartz is in the groundmass. The groundmass is generally a fine-grained mosaic of orthoclase, plagioclase, quartz, and in the darker rocks there is some hornblende and magnetite.

The ratio of minerals could not be determined in rocks where the groundmass was microgranular, but an overall estimate from the coarser-grained rocks suggests a more or less equal amount of plagioclase and orthoclase, totalling 60-75 percent, 5 to 20 percent quartz, 5-20 percent mafics including biotite and hornblende, and 1-3 percent magnetite, zircon and apatite.

The dike rocks are generally fresh, but chlorite, sericite, magnetite, epidote, and zoisite are locally abundant as alteration products.

Aplite, Pegmatite, and Basic Dikes

Dikes and irregular bodies of aplite are locally abundant in and near the Copper Basin stock. The aplite is a white to pale pink, non-foliated rock which can generally be separated from the foliated aplites of Precambrian age. Aplite cuts all of the Copper Basin stock rocks, but no evidence was found to indicate that all of the aplite followed the quartz latite porphyry dikes. Many small bodies of aplite were found adjacent to the quartz monzonite contacts and may have formed essentially at the same time.

The aplites exhibit typical aplitic texture and appear "sugary." They are composed of a mosaic of grains averaging from 1 to 2 mm. in diameter. The rock is essentially composed of orthoclase, perthite or microcline, and quartz. Strongly kaolinized plagioclase rarely exceeds 5 percent.

Normal pegmatites are rare to absent in the vicinity of the Copper Basin stock. However, local masses and veins of coarse glassy quartz are present which exhibit a pseudo cleavage due to shear. Locally a microcline or perthite crystal as much as 1 inch long was observed in the quartz.

Some non-foliated basic dikes, especially prominent along the east contact of the Copper Basin stock, are thought to be associated with the stock or possibly they are much later in age. Several hornblende porphyry dikes intrude the quartz monzonite in and near the contact zone north of the