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James Doyle Sell Mining Collection

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JHC

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File No.

From to

Subject: GEOCHEMISTRY - COPPER IN BIOTITE

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

JHC 2-25-72

J. H. C.

MAR 6 1972

February 18, 1972

Geochem
Copper in Biotite

Mr. J. J. Collins
Director of Exploration
New York Office

Dear Sir:

I am transmitting Mr. Graybeal's report "Copper in Biotite as a Guide to Porphyry Copper Deposits", which is an abridged version of his presentation at the Annual Exploration Meeting held at Palm Springs. I have added an appendix which contains additional analytical data (mainly lead and zinc); several tables that show the analytical differences between unclean (less than 95% pure biotite) and clean biotite concentrates; and, also, analytical data of single samples vs. composite samples (both whole rock and biotite concentrates). The data included in the appendix was mostly developed by John King and included in a report by him.

Both Mr. Graybeal and Mr. King strongly recommend a biotite program be implemented to help guide the search for porphyry coppers in the southwest. I believe the data they have developed justifies such a program and I have selected seven Laramide stocks to be mapped and sampled in the initial phase of the program. It is anticipated that this mapping and sampling will need to be augmented by drilling beneath cover for additional biotite samples to lead us to the mineralized zone. This would be a case of an effective use of a Geologic Information Drill.

A certain amount of petrographic work will accompany the biotite program. I am not yet convinced that it is as critical as Mr. Graybeal and Mr. King indicate, since the Ruby Star, Tyrone, Three Peaks, and Schultze appear to have been correctly interpreted without the benefit of petrographic studies.

I anticipate our initial phase of mapping and sampling the seven Laramide stocks will take six weeks field time and two weeks office study after receiving the analytical results. The chances of locating a porphyry copper target are considered good.

All biotite concentrates will be kept so that, if ever warranted, additional analyses may be made at some future date.

Very truly yours,

W. L. Kurtz

WLK:lad
Encs.

cc: JHCourtright - w/enc.
LDJames - w/enc.
FTGraybeal - w/o enc.
JRKing - w/o enc.

P.S. John: The enclosed report will be distributed to the Spokane, Vancouver and Denver offices.

WLK

TAB

Appendix

TABLE 4 TYRONE QUARTZ MONZONITE

Sample Number	BIOTITE CONCENTRATE ppm								WHOLE ROCK COMP. ppm				ONE ROCK	RATIOS Biotite / Whole rock comp.	
	Cu		Pb		Zn		Mo		Cu	Pb	Zn	Mo	Analysis by R. M. G. C. Cu ppm	Cu / Cu	Cu / Cu
	unclean	clean	unclean	clean	unclean	clean	unclean	clean						clean	unclean
TY-1	260	135	51	NA	610	NA	<1	NA	560	NA	NA	NA	95	.2	.5
2	1500	1210	420		670		1		900				200	1.4	1.7
3	1160	620	400		225		<1		300				75	2.1	3.9
4	220	113	33		300		<1		168				-5	.7	1.3
5	840	480	104		485		1		404				85	1.2	2.1
6	1640	920	80		890		1		760				310	1.2	2.2
7	300	171	29		380		<1		28				10	6.1	10.7
8	100	58	20		285		<1		24				70	2.5	4.2
9	600	700	47		130		60		60				NS	11.8	10
10	240	114	26		435		<1		28				-5	4.1	8.6
11	20	8	22		405		<1		8				-5	1	2.5
12	380	199	23		330		<1		28				10	7.1	13.6
13	2000	1080	23		550		<1		110				85	9.8	18.2
14	40	6	21		505		<1		18				-5	3	2.2
15	40	7	25		500		<1		6				NS	1.2	6.7
16	40	7	21		545		<1		66				-5	.1	.6
17	2800	IS	160		175		1		312				NS	IS	8.9

TABLE 4 TYRONE QUARTZ MONZONITE

Sample Number	BIOTITE CONCENTRATE ppm								WHOLE ROCK COMP. ppm				ONE ROCK	RATIOS Biotite / Whole rock comp.	
	Cu		Pb		Zn		Mo		Cu	Pb	Zn	Mo	Analysis by R. M. G. C. Cu ppm	Cu / Cu	Cu / Cu
	unclean	clean	unclean	clean	unclean	clean	unclean	clean						clean	unclean
TY-18	800	420	32	NA	220	NA	< 1	NA	700	NA	NA	NA	45	.6	1.1
19	500	280	24		195		< 1		560				200	.5	.9
20	480	260	100		205		< 1		400				75	.7	1.2
21	600	480	68		420		< 1		560				120	.9	1.1
22	220	122	55		320		< 1		360				-5	.3	.6
23	500	260	28		360		<1		400				45	.7	1.3

TABLE 1 RUBY STAR GRANODIORITE

Sample Number	BIOTITE CONCENTRATE ppm									COMP. WHOLE ROCK ANALYSES					RATIOS Biotite / Whole rock		
	Cu			Zn		Pb		Mo		ppm				ppb		Cu / Cu	
	unclean	clean	v.clean	unclean	clean	unclean	clean	unclean	clean	Cu	Zn	Pb	Mo	Hg		unclean	clean
RS-1	530	590	NA	390	NA	50	NA	2	NA	190	12	14	6.0	158		2.8	3.1
2	450	440		430		40		5		570	23	12	9.7	130		.8	.8
3	200	180		470		70		6		74	13	12	2.4	120		2.6	2.4
4	135	230		IS		IS		IS		76	27	14	6.7	173		1.8	3.0
5	20	21		500		20		1		71	26	20	<1	182		.3	.3
6	70	180		IS		IS		IS		18	14	12	1.8	118		3.9	1.0
7	80	59		575		40		3		35	27	8	1.8	141		2.3	1.7
8	560	590		450		20		2		77	20	6	6.0	163		7.3	7.6
9	790	1350		420		30		IS		102	3	13	6.7	172		7.7	13.3
10	720	900		280		40		7		500	9	12	14.5	288		1.4	1.8
11	40	35		390		30		12		13	20	7	1.8	171		3.1	2.8
12	560	580		240		28		1.4		260	18	12	.6	NA		2.1	2.2
13	1460	1530		340		24		6		1310	43	8	38.0			1.1	1.6
14	1180	1200		400		32		2.8		610	42	9	10.0			1.0	1.0
15	1040	1070		280		28		1.8		420	32	6	1.2			2.5	2.5
16	1290	1270		250		32		8.8		1450	39	6	28.6			.9	.9
17	1000	1030		300		32		5.6		880	39	7	52.0			1.1	1.2

TABLE 1 RUBY STAR GRANODIORITE

Sample Number	BIOTITE CONCENTRATE ppm									COMP. WHOLE ROCK ANALYSES					RATIOS Biotite / Whole rock		
	Cu			Zn		Pb		Mo		ppm				ppb		Cu / Cu	
	unclean	clean	v.clean	unclean	clean	unclean	clean	unclean	clean	Cu	Zn	Pb	Mo	Hg		unclean	clean
RS-18	40	16	15	NA	540	NA	15	NA	< 1	22	NA	NA	NA	NA		NS	.7
19	80	21	20		545		14		<1	12							1.7
20	120	60	60		670		15		<1	14							4.2
21	360	200	225		650		22		<1	40							5.6
22	40	24	23		535		23		<1	8							2.9
23	20	23	20		540		15		<1	8							2.5
24	NA	680	260		NA		NA		NA	1880							.14

TABLE 3 THREE PEAKS STOCK

Sample Number	BIOTITE CONCENTRATES ppm						WHOLE ROCK ppm								RATIOS	
	From composite sample			One hand sample			Composite rock sample				Single rock sample				Biotite comp. / Whole rock	Biotite comp. / Whole rock
	Cu	Zn	Mo	Cu	Zn	Mo	Cu	Pb	Zn	Mo	Cu	Pb	Zn	Mo	Cu	Zn
TP- 1	78	244	2.4	44	244	3.2	66	5	66	.1	11	12	59	.4	1.2	3.7
2	146	248	1.6	170	252	2.4	72	4	53	.1	57	16	53	.5	2.0	4.7
3	76	348	2.4	94	352	2.4	15	5	48	.15	12	14	55	.5	5.1	7.2
4	59	388	1.6	50	364	2.4	18	5	54	.05	9	13	47	.4	3.3	7.1
5	84	348	1.6	74	360	2.4	14	7	49	.1	13	14	45	.3	6.0	7.1
6	94	332	1.6	82	360	1.6	13	5	54	.1	12	13	55	.3	7.2	6.1
7	88	376	2.4	74	392	2.4	14	4	54	.1	12	13	51	.3	6.3	6.9
8	126	232	2.4	82	252	2.4	86	6	65	.1	35	15	60	.3	1.5	3.6
9	100	232	2.4	84	256	2.4	65	13	56	.2	39	18	56	.4	1.5	4.1
10	110	284	1.6	120	280	2.4	86	12	53	.1	55	15	53	.3	1.3	5.4
11	64	420	2.4	20	508	3.2	11	7	48	.2	11	16	46	.2	5.8	8.7
12	52	412	2.4	112	368	2.4	10	7	47	.1	11	14	48	.2	5.2	8.8
13	64	320	1.6	56	352	1.6	13	3	36	.1	13	13	35	.2	4.9	8.9
14	64	332	2.4	50	364	1.6	10	3	41	.1	10	12	38	.2	6.4	8.1
15	74	340	1.6	72	368	1.6	9	9	46	.1	9	13	43	.2	8.2	7.4
16	64	360	1.2	80	352	2.4	9	5	45	.1	10	14	45	.2	7.1	8.0
17	22	400	2.4	36	380	2.4	9	14	51	.4	8	11	33	.3	2.4	7.8

TABLE 3 THREE PEAKS STOCK

Sample Number	BIOTITE CONCENTRATES ppm						WHOLE ROCK ppm								RATIOS	
	From composite sample			One hand sample			Composite rock sample				Single rock sample				Biotite comp. / Whole rock	Biotite comp. / Whole rock
	Cu	Zn	Mo	Cu	Zn	Mo	Cu	Pb	Zn	Mo	Cu	Pb	Zn	Mo	Cu	Zn
TP-18	78	376	1.6	32	424	2.4	24	22	47	.4	15	13	48	.2	3.3	8
19	1280	576	39.2	2100	456	43.6	230	NA	NA	NA	460	NA	NA	NA	10.1	NS
20	110	324	2.4	82	332	2.4	16	NA	NA	NA	16	NA	NA	NA	6.9	NS

TABLE 2 SCHULTZE GRANITE

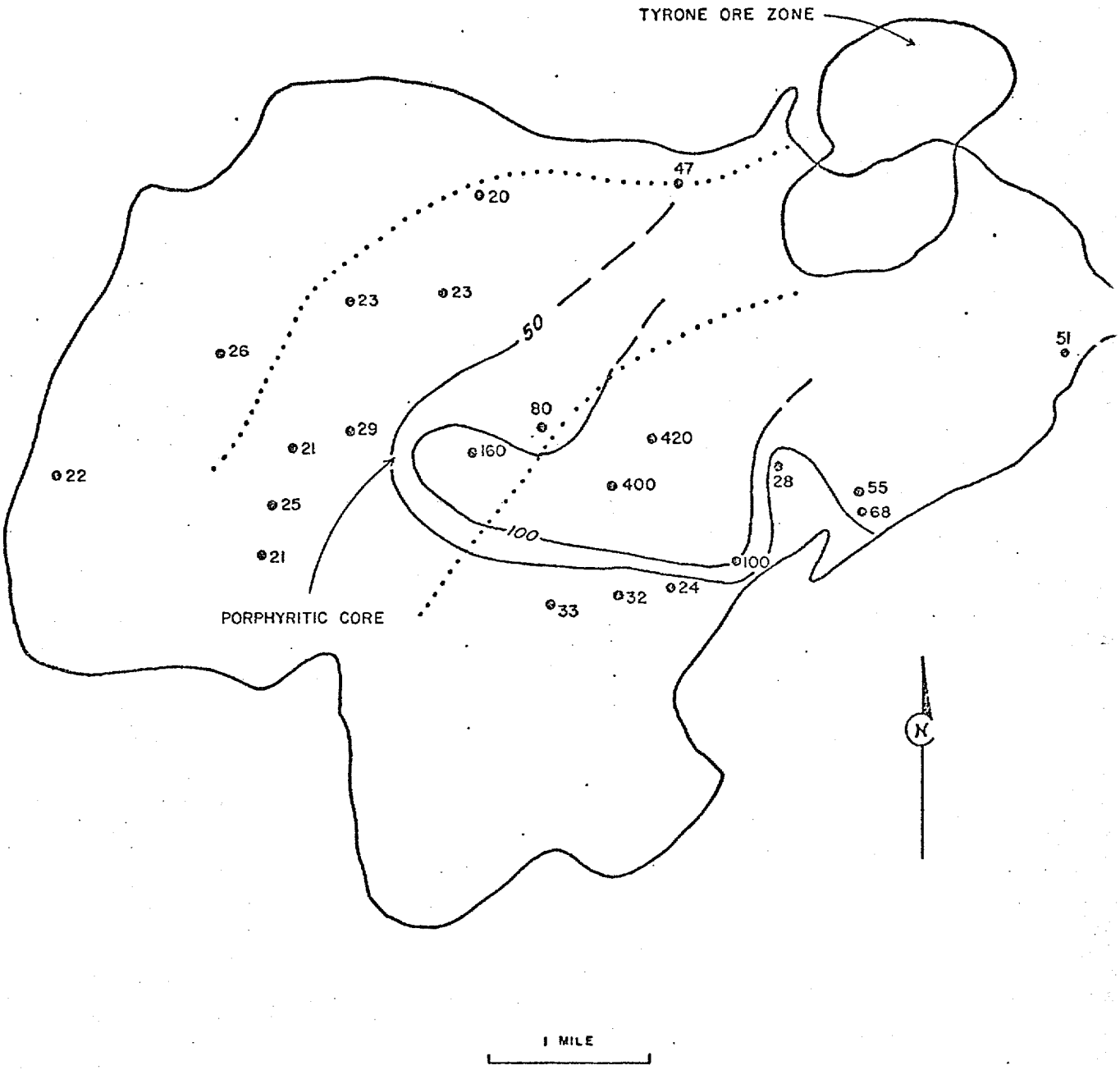
Sample Number	BIOTITE CONCENTRATE ppm										WHOLE ROCK ANALYSES ppm					RATIOS Biotite/Whole rock		
	Cu		Zn		Pb		Mo		Fl %		Cu	Zn	Pb	Mo	% Fl	Cu/Cu	Cu/Cu	
	unclean	clean	unclean	clean	unclean	clean	unclean	clean	unclean	clean						unclean	clean	
SG-1	30	23	480	NA	104	NA	.6	NA	NA	NA	11	23	7	.1	NA	2.7	2.1	
2	450	260	480		32		1.2				119	29	13	.1		3.8	2.2	
3	81	44	590		28		2.0				7	33	15	.1		11.6	6.3	
4	12	14	410		32		.1				7	26	10	<.1		1.7	2.0	
5	112	230	510		32		.1				29	27	11	.2		3.9	7.9	
6	18	18	620		292		.4				7	29	10	.1		2.6	2.6	
7	123	54	230		44		1.8				30	17	7	.2		4.1	1.8	
8	81	98	550		32		.8				43	47	16	.1		1.8	2.3	
9	82	20	550		16		3.2				9	25	11	.4		9.1	2.2	
10	21	14	570		32		.8				5	22	9	.2		4.2	2.8	
11	132	99	500		NA		2.2		2.14		41	28	NA	.4	.380	3.2	2.4	
12	41	12	440				3.4		1.98		13	44		.2	.480	3.1	.9	
13	23	7	500				1.6		2.14		8	28		.2	.400	2.9	.9	
14	34	15	500				3.6		1.70		6	30		.2	.480	5.6	2.6	
15	14	14	560				.8		1.84		6	28		.3	.510	2.3	2.3	
16	120	73	400				3.3		1.98		120	28		.2	.540	1.0	1.6	
17	27	27	820				.9		1.84		15	50		.2	.270	1.7	1.8	

TABLE 2 SCHULTZE GRANITE

Sample Number	BIOTITE CONCENTRATE ppm										WHOLE ROCK ANALYSES ppm					RATIOS Biotite/Whole rock		
	Cu		Zn		Pb		Mo		Fl %		Cu	Zn	Pb	Mo	% Fl	Cu/Cu	Cu/Cu	
	unclean	clean	unclean	clean	unclean	clean	unclean	clean	unclean	clean						unclean	clean	
SG-18	22	10	800	NA	NA	NA	1.4	NA	1.70	NA	10	44	NA	.3	.440	2.2	1.0	
19	28	13	680				1.4		2.14		14	92		.2	.380	2.0	.9	
20	700	700	240				1.4		2.48		660	26		.3	.400	1.1	1.1	
21	9	12	680				.6		2.48		11	26		.2	.460	.8	1.1	
22	12	16	600				.6		1.84		6	24		.4	.420	2.0	2.7	
23	32	11	540				2.4		1.98		8	32		.3	.400	4.0	1.4	
24	62	44	320				1.5		2.14		64	20		.2	.660	.9	.7	
25	16	18	400				.6		2.32		6	16		.2	.400	2.7	3.0	
26	17	23	740				1.3		1.59		7	24		.2	.360	2.4	3.3	
27	46	28	460				1.8		1.98		18	18		.2	.350	2.6	1.5	
28	20	11	266				1.4		1.98		9	16		.2	.380	2.2	1.2	
29	120	13	380				8.3		1.84		9	22		.2	.340	13.3	1.4	
SG-DH-30	620	95	180				13.3		1.84		120	24		1.0	.300	5.0	.8	
SG-30	NA	13	NA				NA		NA		NA	NA		NA	NA	NA	NA	
31		6																
32		16																
33		10																
34		122																

FROM SKing

Figure 4-D



TYRONE QUARTZ MONZONITE

Pb IN BIOTITE

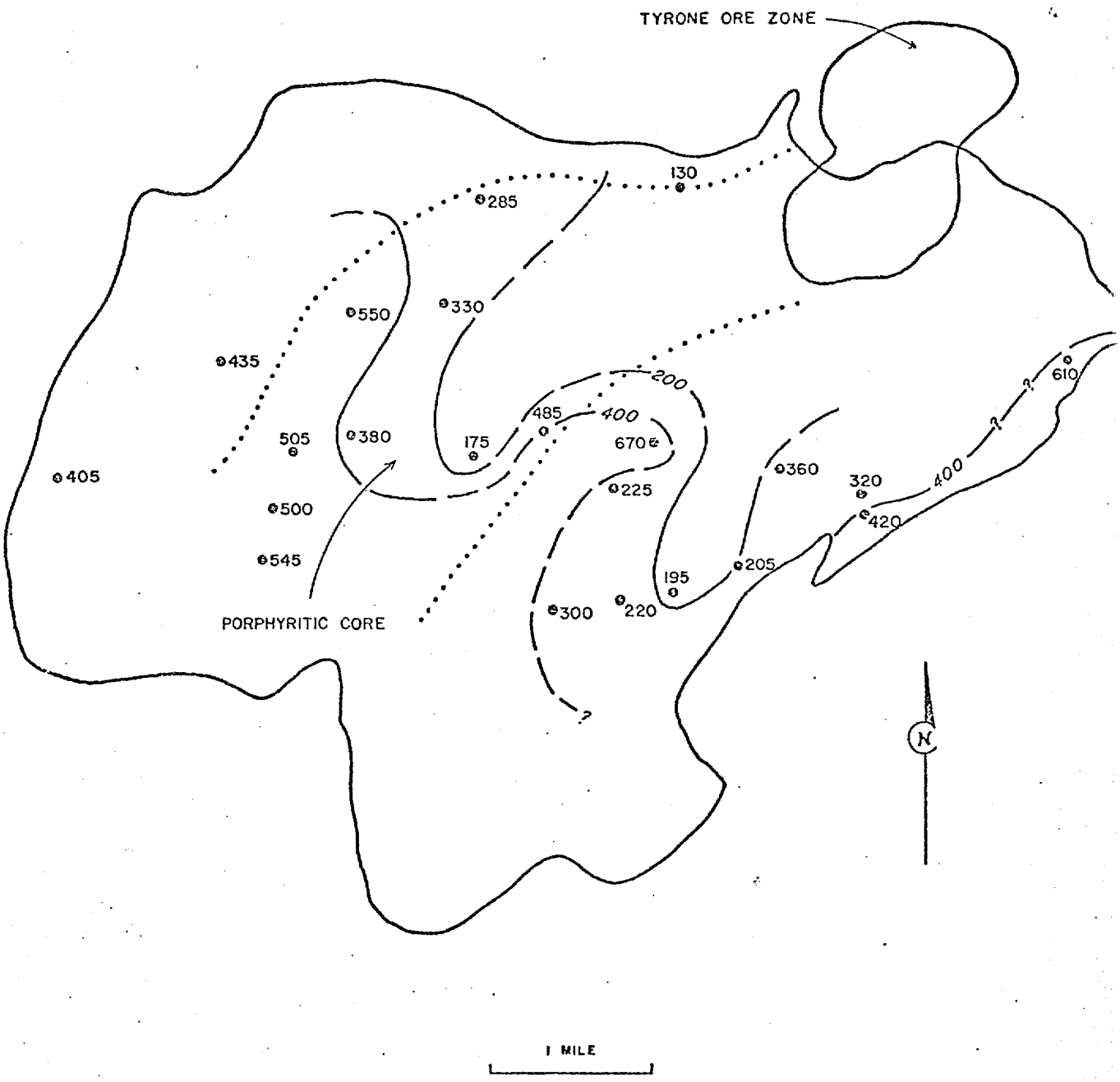
ppm Values

(Unclean)

2529-d

From J King

Figure 4-E



TYRONE QUARTZ MONZONITE

Zn IN BIOTITE

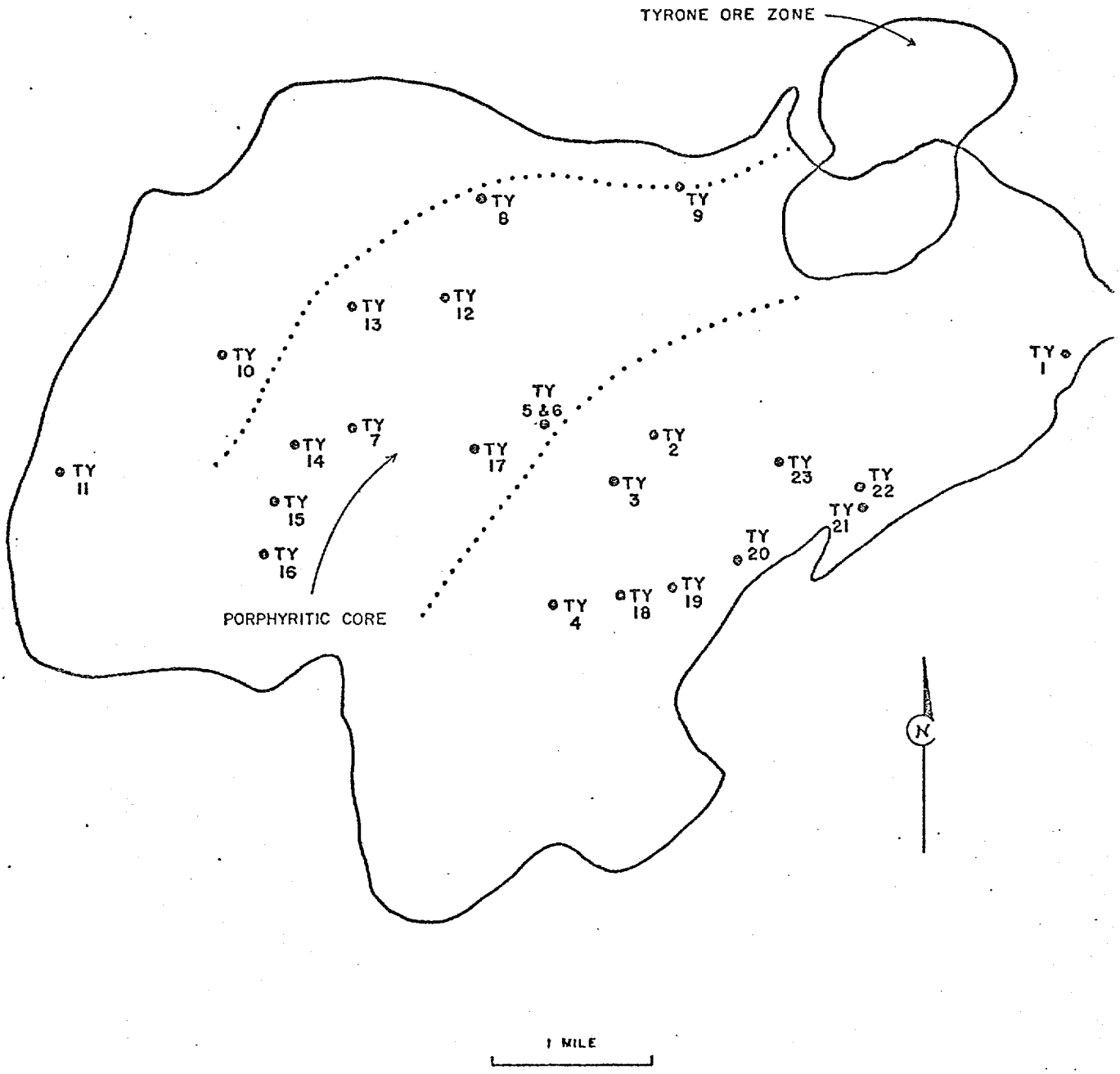
ppm Values

(Unclean)

2529-e

FROM J King

Figure 4-F



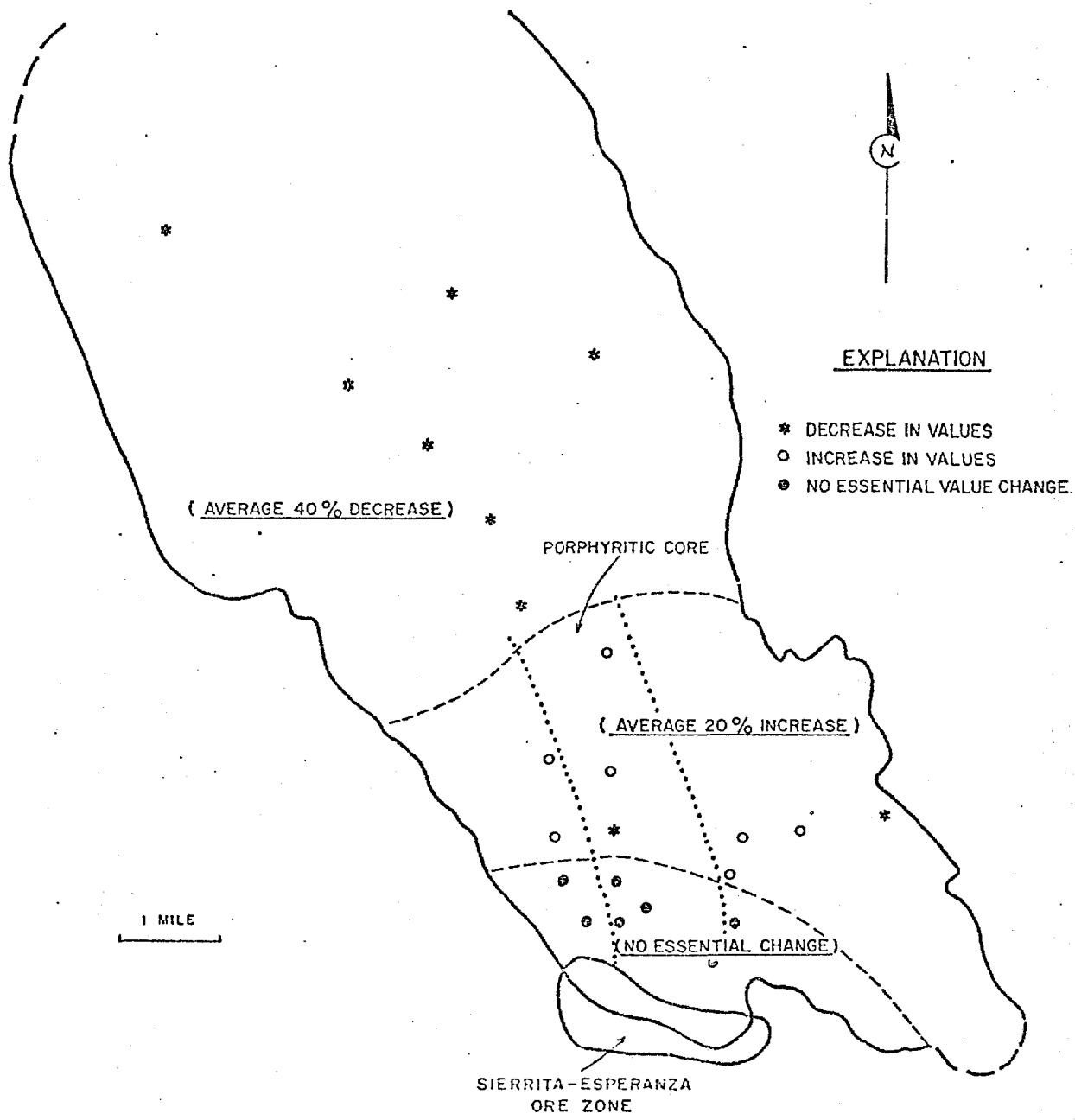
TYRONE QUARTZ MONZONITE

SAMPLE NUMBERS

2529-f

FROM SKWG

Figure I-D



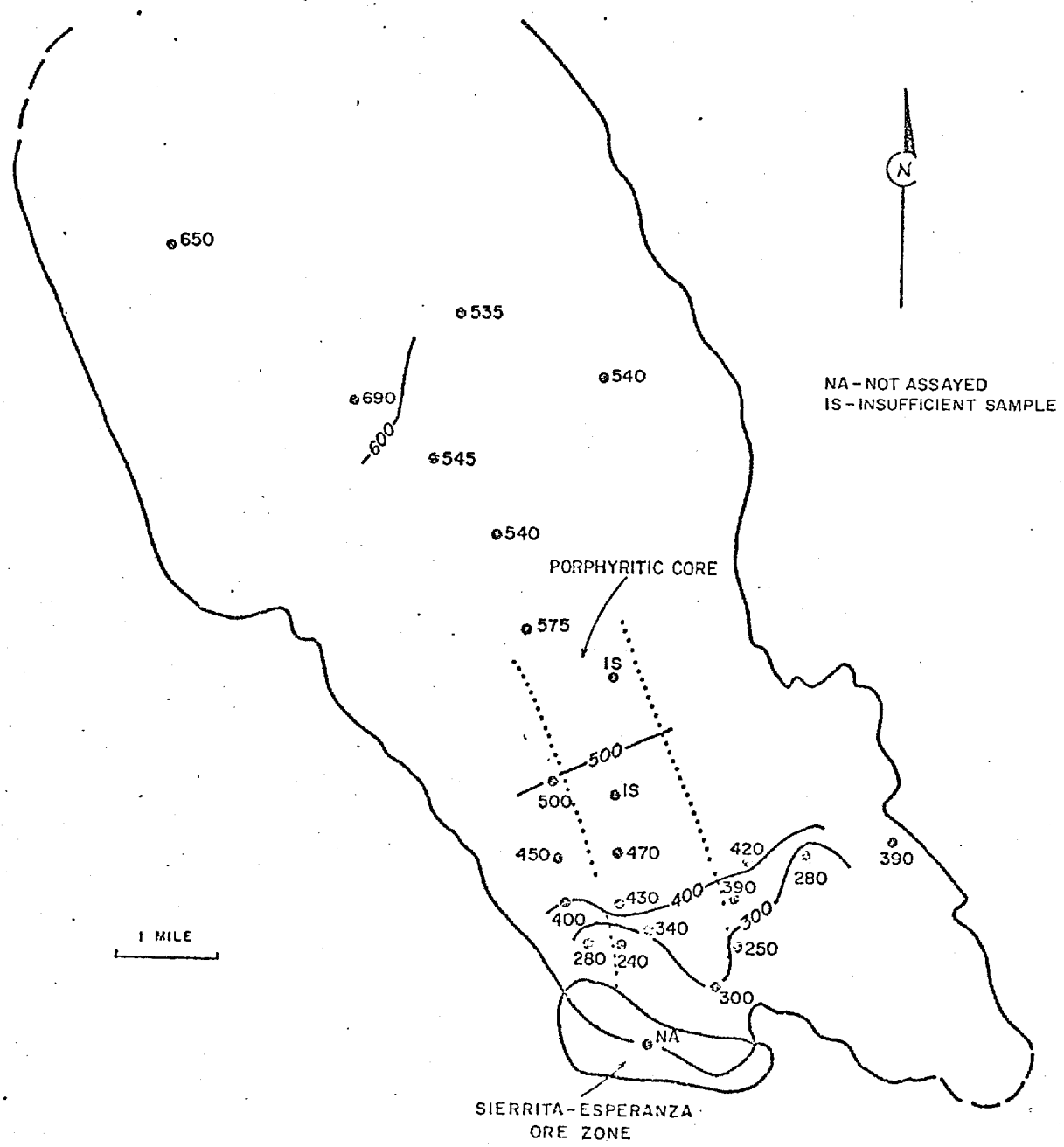
RUBY STAR GRANODIORITE

AVERAGE % CHANGE IN COPPER VALUES
AS GREATER SAMPLE PURITY IS ACHIEVED

2526-d

From J King

Figure 1-E

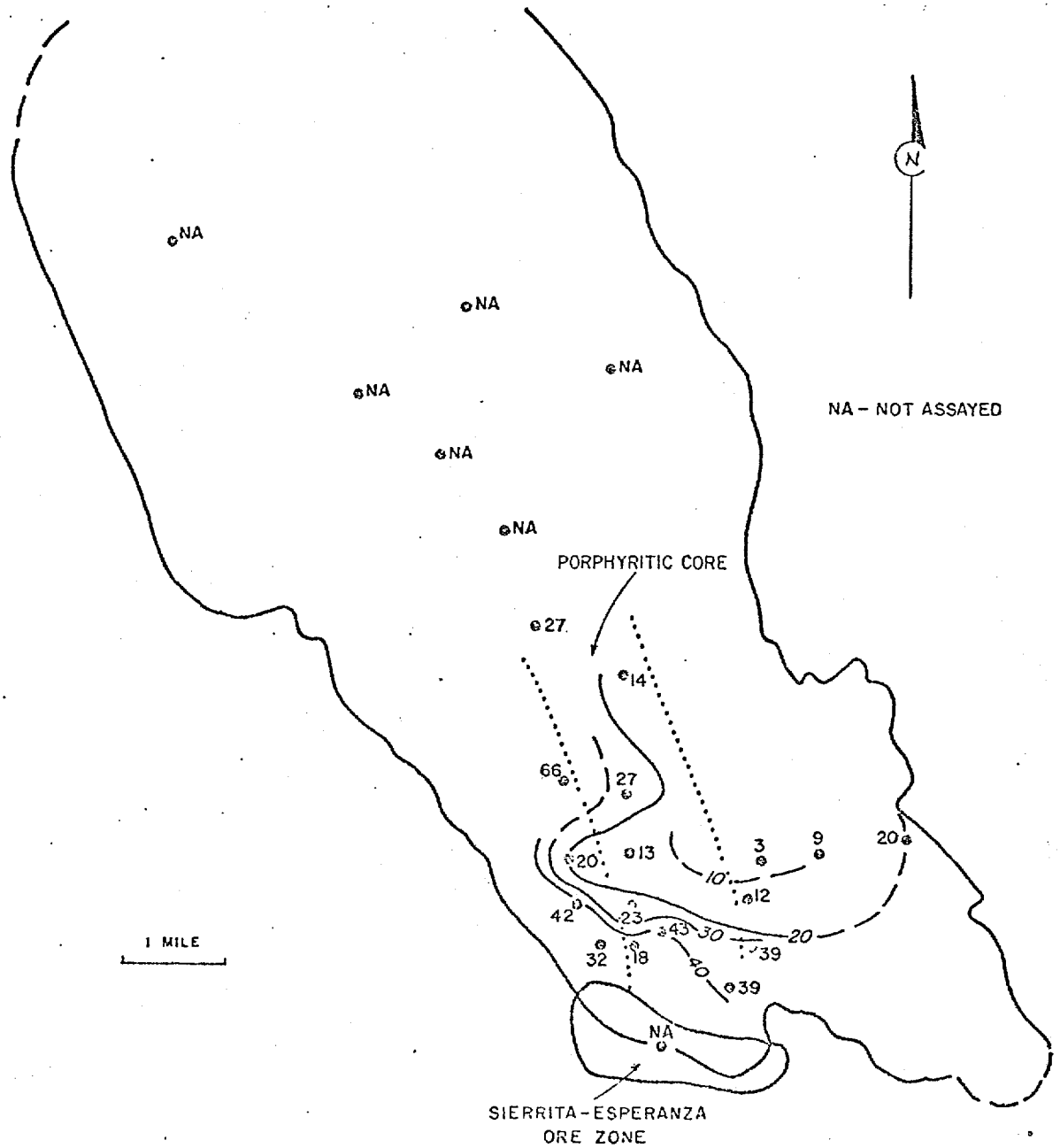


RUBY STAR GRANODIORITE
Zn IN BIOTITE
ppm Values
(Unclean)

2526-E

FROM J King

Figure 1-F

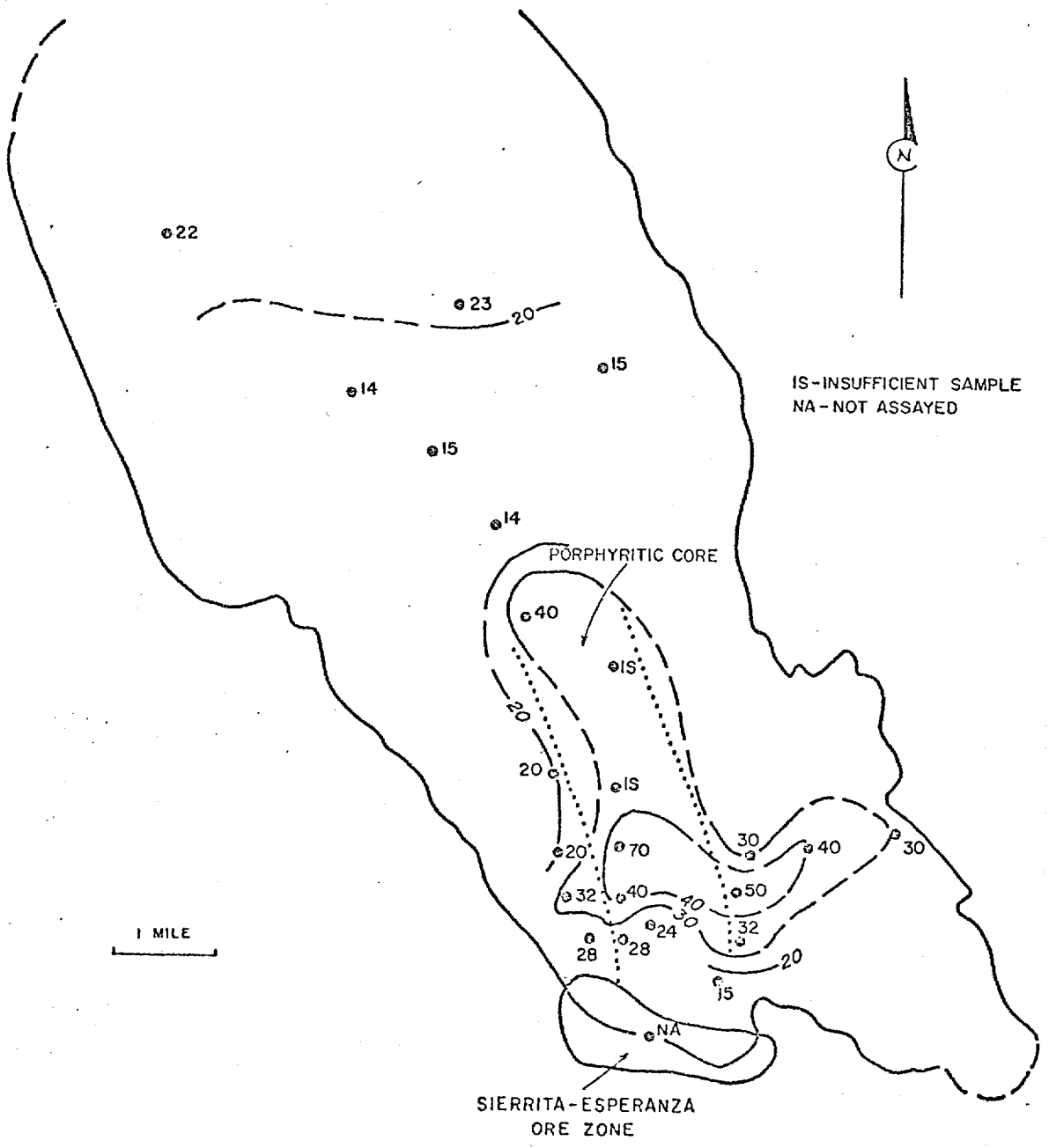


RUBY STAR GRANODIORITE
Zn IN WHOLE ROCK
ppm Values
(Unclean)

2526-1

From J King

Figure 1-G



RUBY STAR GRANODIORITE

Pb IN BIOTITE

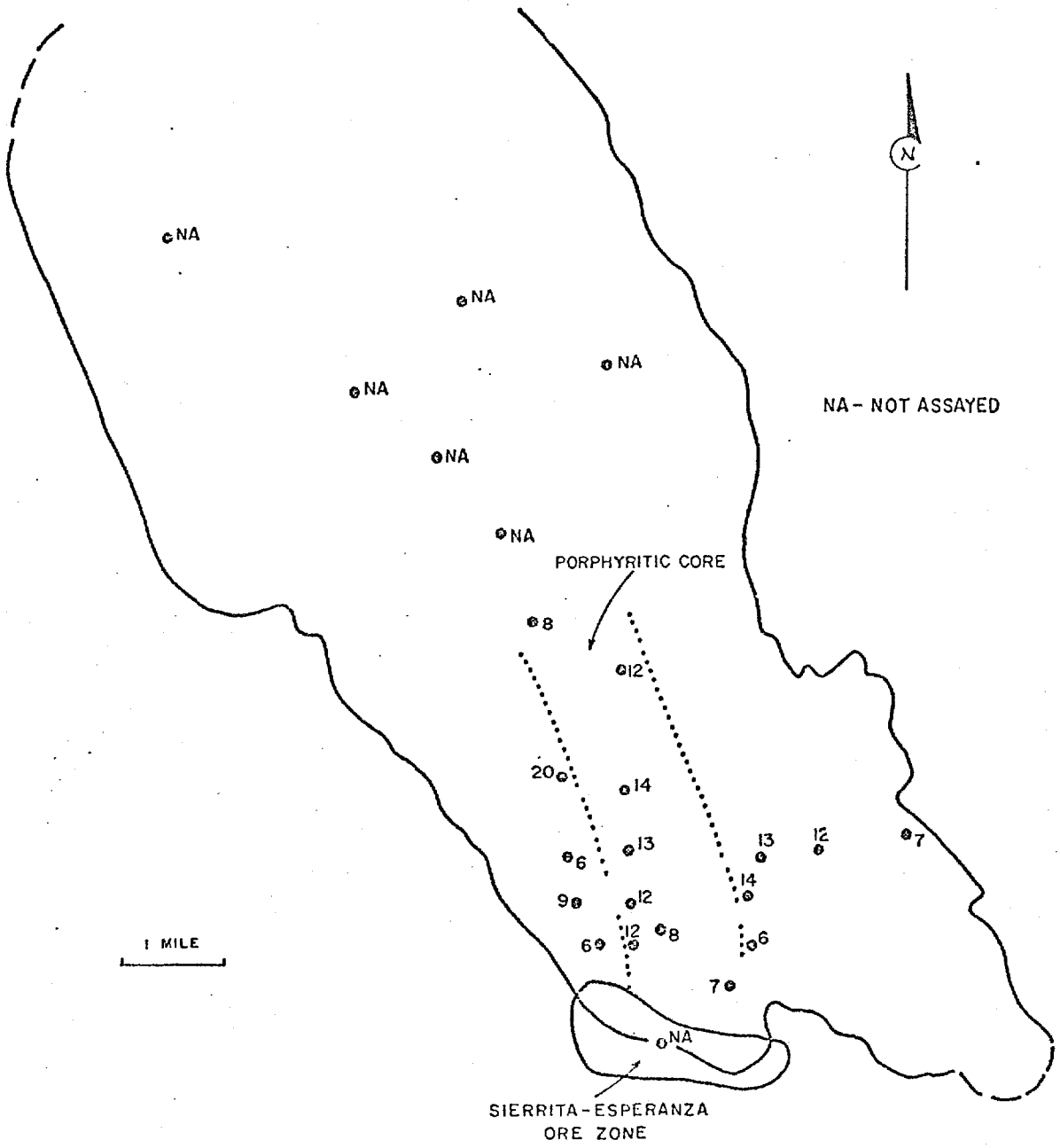
ppm Values

(Unclean)

2526-g

From J King

Figure I-H



RUBY STAR GRANODIORITE

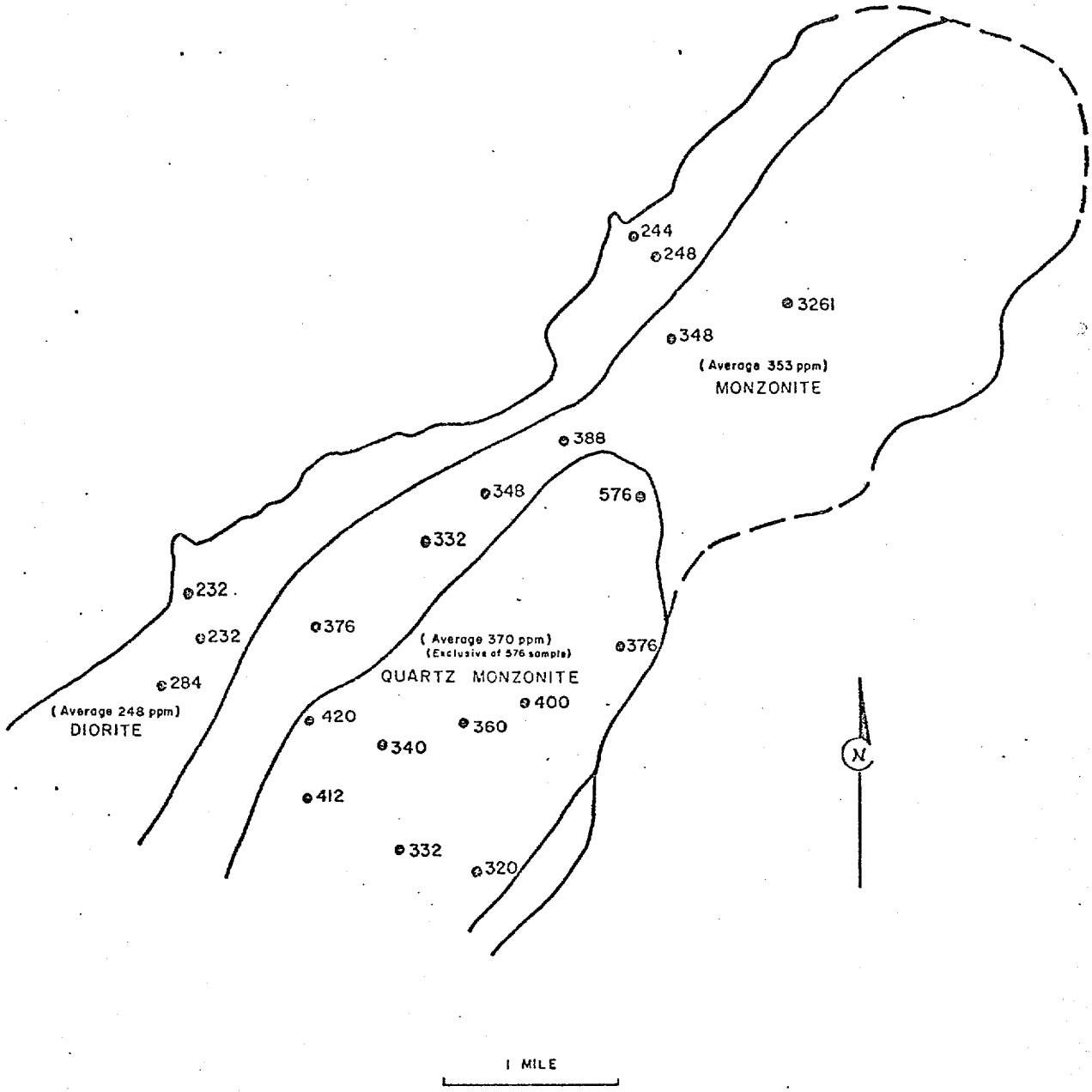
Pb IN WHOLE ROCK

ppm Values
(Unclean)

2526-h

FROM Skiny

Figure 3-D



THREE PEAKS STOCK

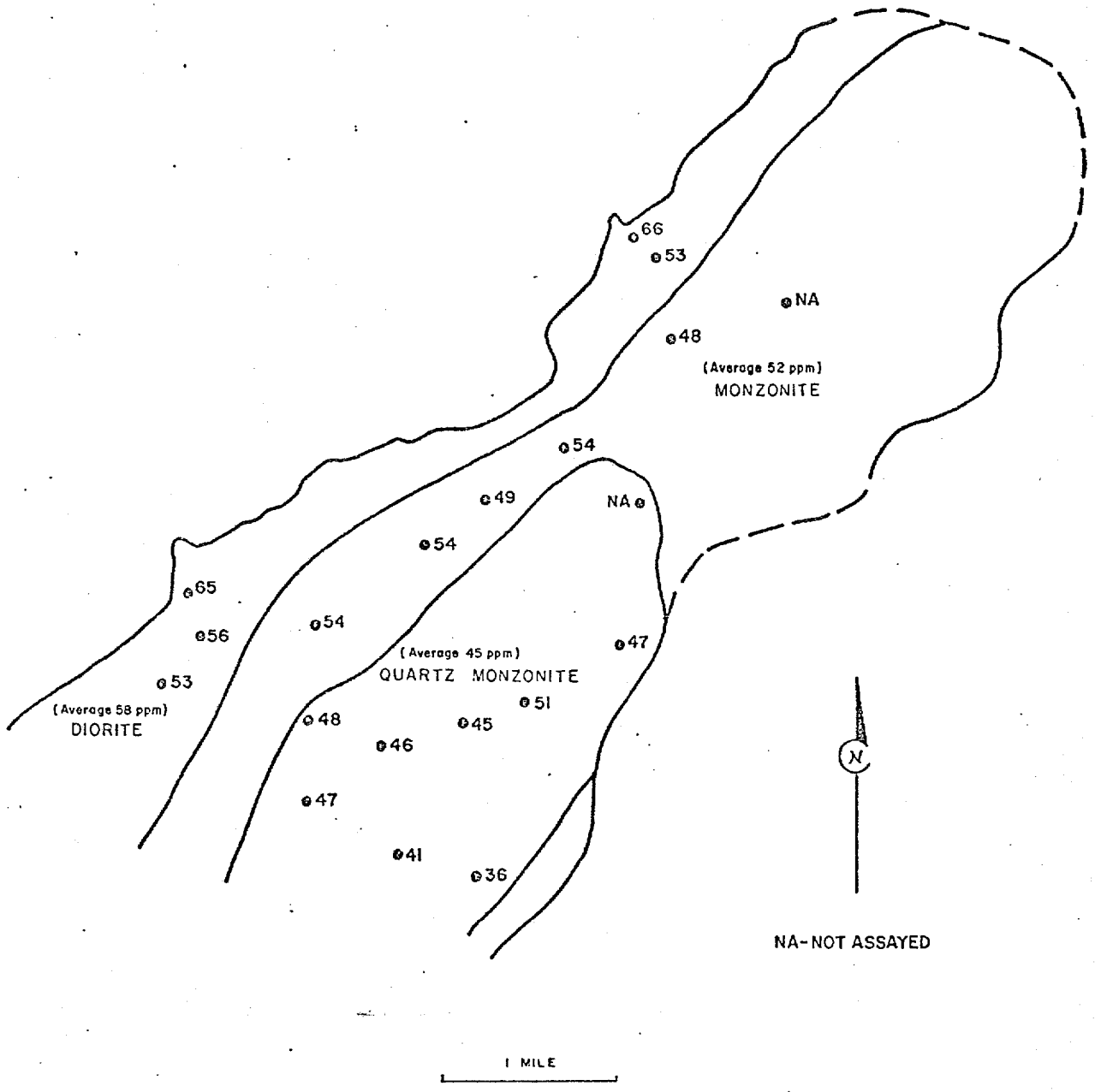
Zn IN BIOTITE (COMPOSITE)

ppm VALUES

2528-d

FROM J King

Figure 3-E



THREE PEAKS STOCK

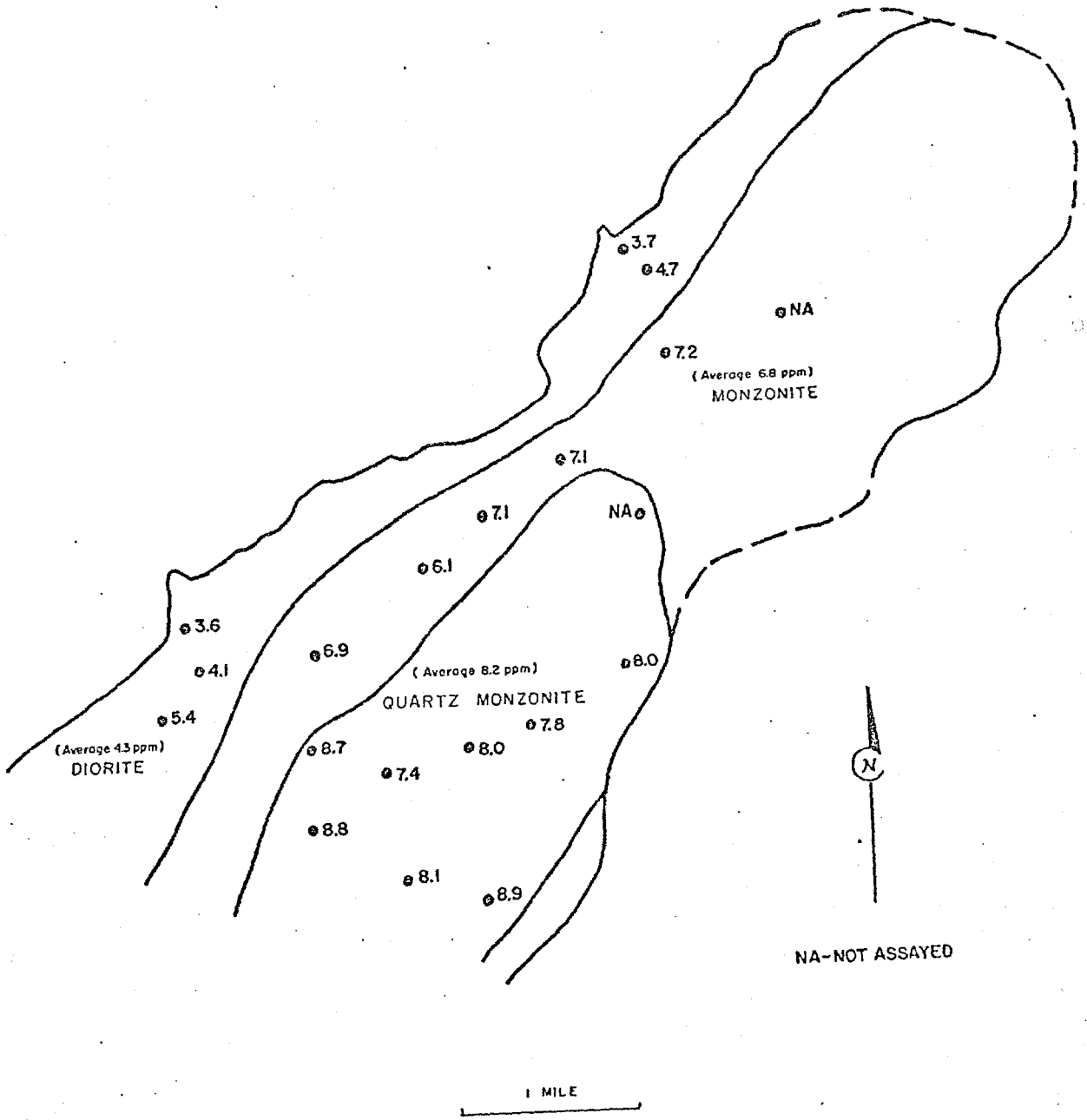
Zn IN WHOLE ROCK (COMPOSITE)

ppm VALUES

2528-e

FROM JKing

Figure 3-F



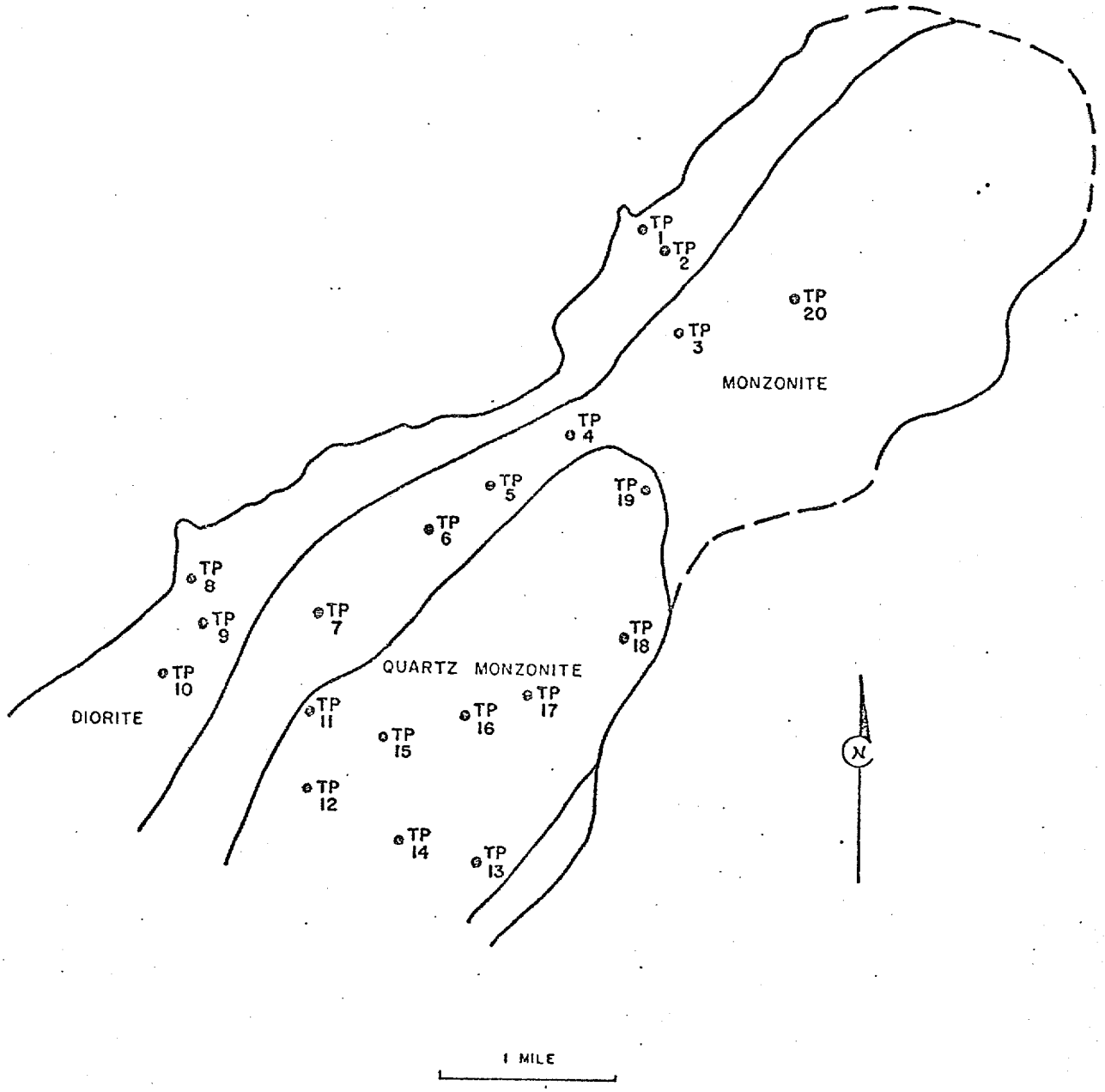
THREE PEAKS STOCK

$$Zn - \frac{\text{composite biotite}}{\text{composite whole rock}}$$

2528-

From JKing

Figure 3-G



THREE PEAKS STOCK

SAMPLE NUMBERS

2528-g

COLORADO SCHOOL OF MINES RESEARCH INSTITUTE

J. R. K

OCT 21 1971

MEMORANDUM

To: John R. King
American Smelting and Refining Co.

Date: October 19, 1971

Project No. 311009

From: Norman Bennett NB

Subject: Biotite separation of 23 samples

Introduction

In compliance with your request, 23 rock samples labelled TY1-TY23 were crushed and biotite was concentrated from them by screening and two heavy liquid separations. The objective of this work was to obtain biotite concentrates from these samples for shipment to you.

Details of Investigation

Each sample was jaw crushed to minus 1/2 inch, roll crushed to minus 10 mesh, and Raymond milled to approximately minus 65 mesh. The Raymond Mill fraction was screened into plus 65 mesh, minus 65 plus 150 mesh, and minus 150 mesh fractions. The biotite was concentrated from the plus 65 mesh fraction by screening. The plus 65 mesh fraction was selected for screening since a binocular microscope examination indicated this to be an optimum grain size for biotite concentration.

The biotite in the plus 65 mesh fraction was then further concentrated by the use of heavy liquids. Each sample was separated into sink and float fractions using Certigrav (specific gravity 2.90). The fraction with a specific gravity greater than 2.90 was further separated using Methylene Iodide (specific gravity 3.3). The fraction with a specific gravity greater than 2.90 and less than 3.3 contained the biotite concentrate.

The biotite concentrates are being shipped to you under separate cover. If you have any questions, please contact me.

/laj

COLORADO SCHOOL OF MINES RESEARCH INSTITUTE
P.O. Box 112
GOLDEN, COLORADO 80401

J. R. K.

APR 9 1971

MEMORANDUM

To: Mr. Lloyd James
Geophysical Division
American Smelting & Refining Co.

March 30, 1971

From: W. T. Caneer

Project 301217

Subject: Electron Probe Studies of Copper in Biotite

In compliance with your request we have made electron probe studies on two rock samples (RS-5 and RS-10) submitted by you. The purpose of these studies was to determine the nature of copper which is contained in the biotite. In addition, similar studies were made on biotite concentrates from samples RS-1 and RS-8 which were previously obtained at the Research Institute. The authorization for work on the latter two samples was obtained from Mr. R. J. Lacy during a telephone conversation between Mr. Lacy and me on March 19, 1971.

Electron probe studies were initially made on rock samples RS-5 and RS-10. The results of these studies showed that the copper occurs in the biotite along planes parallel to the biotite cleavage. These planes vary up to only a few microns wide, but often extend across biotite grains which are a few millimeters in diameter. Figure 1 illustrates this occurrence. Photograph No. 1 is a backscattered electron image at 200x magnification across a biotite grain (in RS-10) which contains copper. Backscattered electron images are similar to optical photomicrographs. However, backscattered electron images give additional information inasmuch as areas which contain heavier elements appear as whiter areas on the photographs. Photograph No. 2 shows the copper distribution (white) across the same area as shown for the backscattered electron image. As may be seen, the copper occurs along two lines which extend diagonally across the photograph. The only other element detected with the copper was carbon. The copper and carbon were in approximately the proper proportions for the mineral malachite [$CuCO_3.Cu(OH)_2$] or possibly azurite [$2CuCO_3.Cu(OH)_2$]. Since the electron probe is capable of analysis for all elements except the first four in the periodic table plus oxygen, the oxygen and hydrogen contents cannot be determined.

The copper occurrence in the biotite in rock samples RS-5 was similar to that described for sample RS-10, but to a lesser extent than in RS-10.

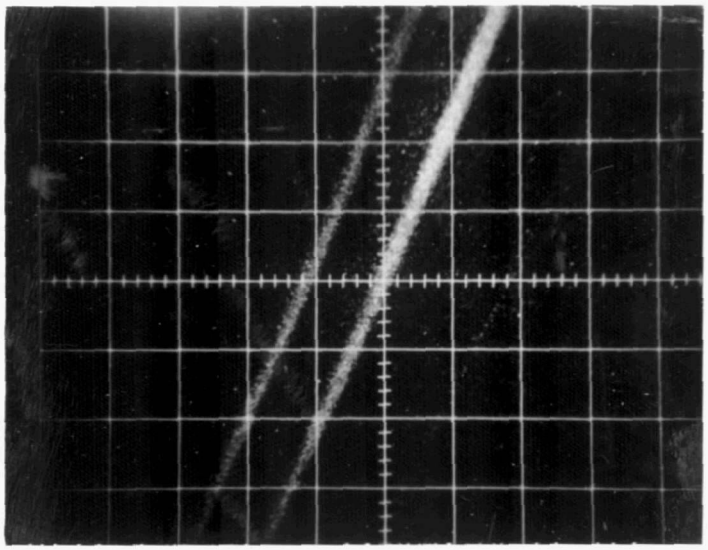
Except for a small amount of the malachite in the non-biotite portion of sample RS-10, all of the copper observed in RS-5 and RS-10 was associated with the biotite as described above.

Electron probe examinations of biotite concentrates from samples RS-1 and RS-8 showed that the copper in these samples also occurs along very thin planes parallel to the biotite cleavage as described for rock samples RS-5 and RS-10.

If we can be of further service to you, or, if you have any questions regarding this project please contact me.

cc: Mr. R. J. Lacy

JHC - Original pictures for WL Kurtz's file.



1. Backscattered Electron Image

2. Copper Distribution

Figure 1

Backscattered electron image plus copper distribution across a copper-bearing biotite grain in sample RS-10, 200x

ADDITIONAL REFERENCES
COMPILED BY JOHN KING

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2-16

From: J. J. Collins

To: Mr Kurty

& return

& copy to me too

RECEIVED
FEB 18 1972
S. W. U. S. EXPL. DIV.

~~FIG~~, ~~FBS~~, ~~OBK~~, ~~JCB~~

RECEIVED
FEB 14 1972
S. W. U. S. EXPL. DIV.
W. L. K.
FEB 18 1972

EXPLORATION SERVICES DIVISION
3422 SOUTH 700 WEST
SALT LAKE CITY, UTAH 84119

February 10, 1972

Mr. W. L. Kurtz
Tucson Office

Dear Bill,

I recently received a copy of Mr. J. King's excellent compilation of his own and others work within Asarco entitled "Copper in Biotite" (January 28, 1972). I agree with his main conclusion that data on copper concentrations in biotite and composite whole rock samples from Laramide stocks can often provide evidence of the presence of porphyry copper type mineralization under adjacent post-mineral cover. It is to be concluded that we have a new potentially valuable exploration tool.

Not to be done
I distributed
ETG rpt with
an appendix of
additional material

If it has not already been done it would certainly be worth considering distributing copies of Mr. King's report to the other exploration divisions.

In view of the possible value of other elements in this type of study I plan to analyze various of the available biotite and composite whole rock samples for Pb, Zn, Hg and Cl, etc., in order to fill in the gaps in our present data.

Yours very truly,

L. D. James

L. D. JAMES

LDJ:db

cc:J.J.Collins
J.H.Courtright
J. R. King

W. L. K.
DEC 1 1971

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

December 8, 1971

TO: W. L. Kurtz

FROM: J. R. King

Biotite Separation

On December 7th, Jim Link, Manager, Mining Division, Colorado School of Mines Research Institute, visited ASARCO. During our conversation, he expressed the opinion that costs could be significantly reduced if ASARCO presented them with work on a more continuous basis.

The greatest cost reduction would come from incorporation of scientific procedure developed by F. T. Graybeal into their separation program. Also, lower salaried personnel could be used by CSMRI if they knew enough continuous work would be presented to them.

They seemed very interested in continuing to serve ASARCO and to develop cheaper means of concentrating biotites. Current direct costs for concentration (including shipping) are between $22 and $24 per sample. It would not be hard to cut these costs in half.

John R. King

John R. King

JRK:lad

cc: FTGraybeal

WLIC

File Biotite Studies

EXPLORATION SERVICES DIVISION
3422 South 700 West
SALT LAKE CITY, UTAH 84119

July 14, 1971

AUG 10 1971
W. L. K.
RECEIVED
JUL 15 1971
S. W. U. S. EXPL. DIV.
W.E.S.
JUL 19 1971

MEMORANDUM to W. E. SAEGART:

SCHULTZE GRANITE,
PINAL COUNTY, ARIZONA
Cu CONTENT OF BIOTITES

We have just completed the Cu analyses of the biotite fractions obtained from the samples of Schultze Granite recently collected and sent to the Geochemical Laboratory by Mr. J. R. King. (Reference his letter of June 2, 1971). The resultant data are shown on the attached sketch map. It verifies the presence of an area of high Cu concentration in the biotites from the western extremity of the central portion of the west limb of the Schultze Granite adjacent to the Dacite Plateau. Also of possible significance is the anomalously high Cu concentration (660 ppm) detected in biotite from the Schultze Granite (?) intersected by DDH M-1A beneath the Dacite Plateau. The analytical data sheets will be sent to you as soon as they are complete.

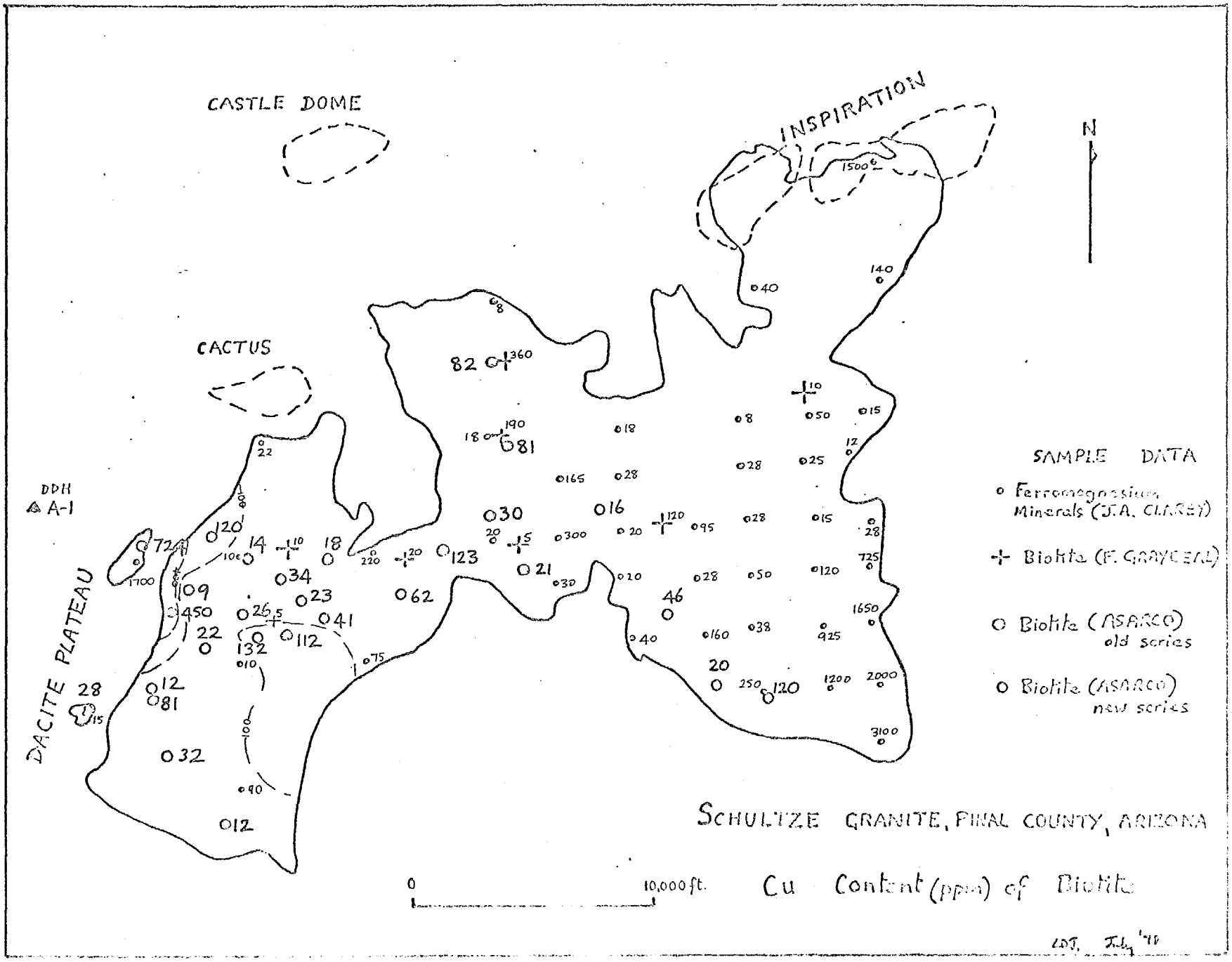
L. D. James

L. D. JAMES

LDJ:db
Encl.

cc:J.J.Collins w/encl.
J.H.Courtright "
J.R.King "
J.D.Sell "

makes A-1 look like good site
WES


CASTLE DOME
INSPIRATION
CACTUS
DACITE PLATEAU
DDH A-1
DDH M-1A
660
N
SAMPLE DATA
Ferromagnesian Minerals (J.A. CLAREY)
Biotite (F. GRAYCEAL)
Biotite (ASARCO) old series
Biotite (ASARCO) new series
0
10,000 ft.
SCHULTZE GRANITE, PINAL COUNTY, ARIZONA
Cu Content (ppm) of Biotite

Circulate-Staff

WLK
Gen. geochemistry technique

GEOPHYSICAL DIVISION

3422 South 700 West
SALT LAKE CITY, UTAH 84119

May 19, 1971

RECEIVED
MAY 20 1971
S. W. U. S. EXPL. DIV.

W.E.S.
MAY 27 1971

MEMORANDUM to W. E. SAEGART:

RUBY STAR GRANODIORITE
SIERRITA MOUNTAINS ARIZONA--
BIOTITE GEOCHEMISTRY

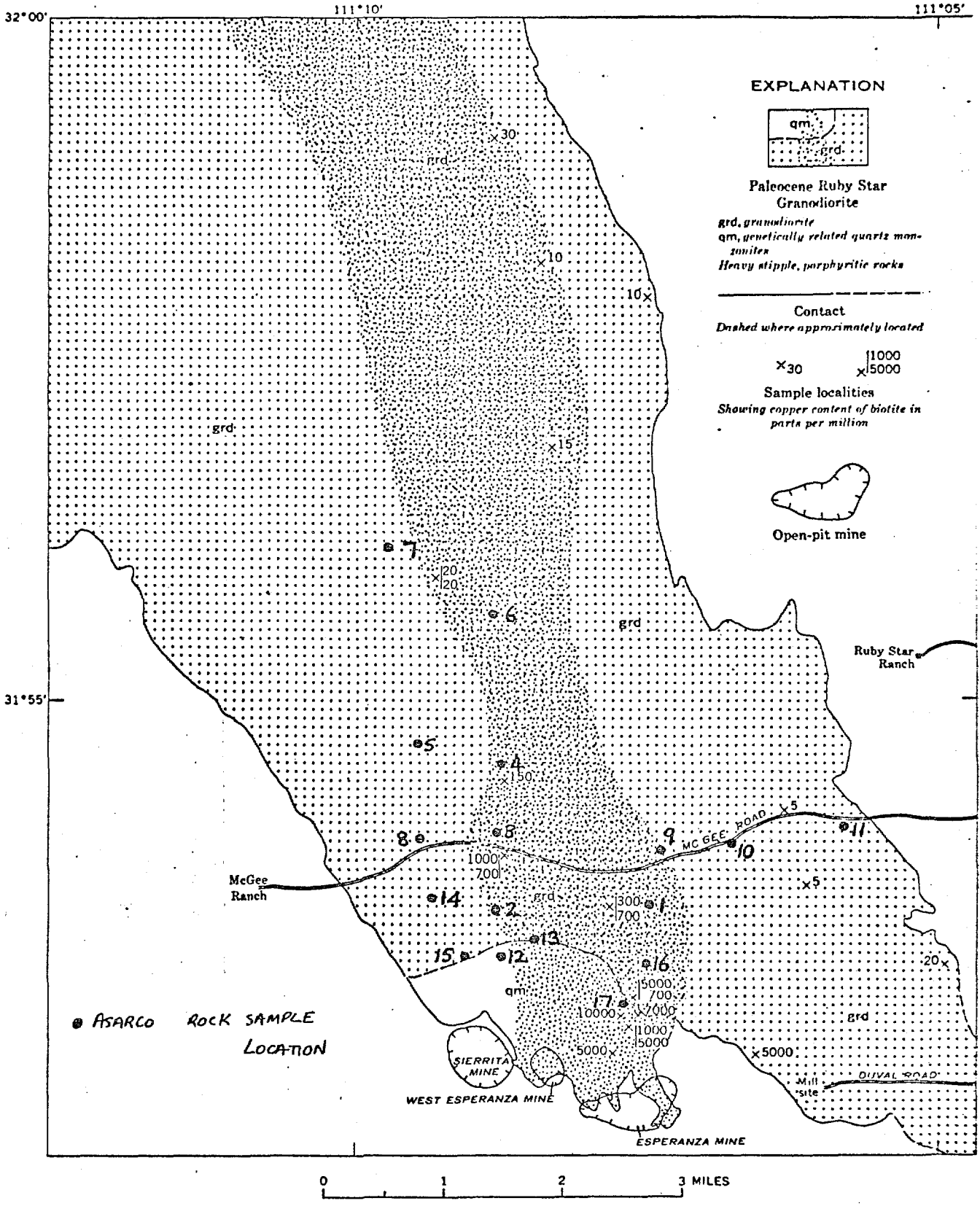
Geochemical analysis of biotite fractions from additional samples (i.e. RS 12 through 17) of the Ruby Star Granodiorite, collected and submitted to the Geochemical Laboratory by Mr. J. R. King, has recently been completed. The resultant new data, together with the old, are shown on the attached figures. The new data does not significantly change the picture obtained from the original U.S.G.S. and Asarco data. Cu displays a general tendency to increase and Zn to decrease in concentration as the porphyry mineralization is approached.

L. D. James

L. D. JAMES

LDJ:db
Encl.

cc: J.J.Collins w/encl.
J.H.Courtright w/encl.
J.R.King w/encl.



~~FIGURE 9~~.—Generalized map of composite stock and associated ore deposits in the southwestern part of the Pima mining district, east of the Sierrita Mountains, showing sample localities and copper content of biotite.

Fig. 1 — Location and numbers of Asarco rock samples.

Biotite

Cu

(Total digestion + A.A.)

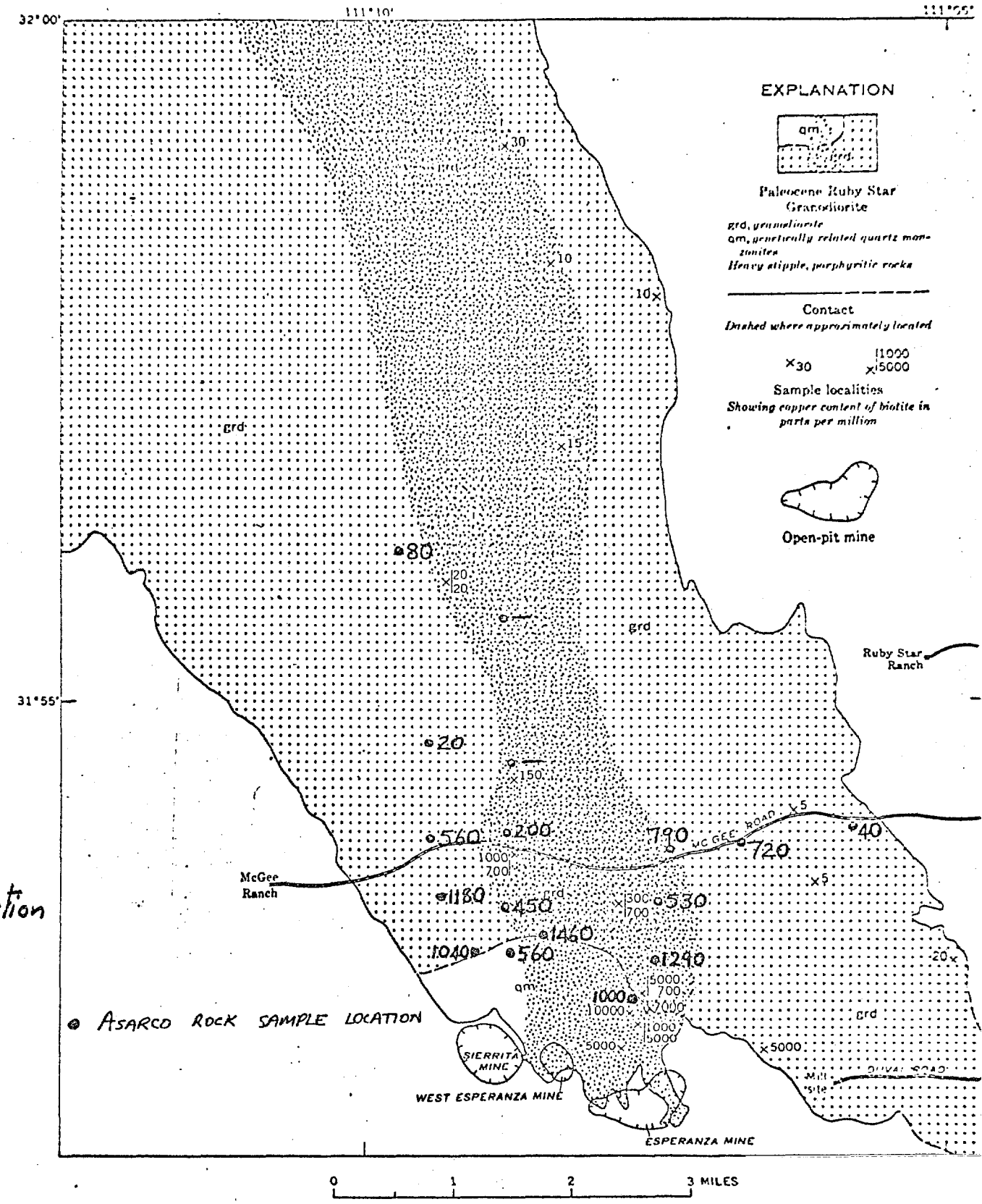
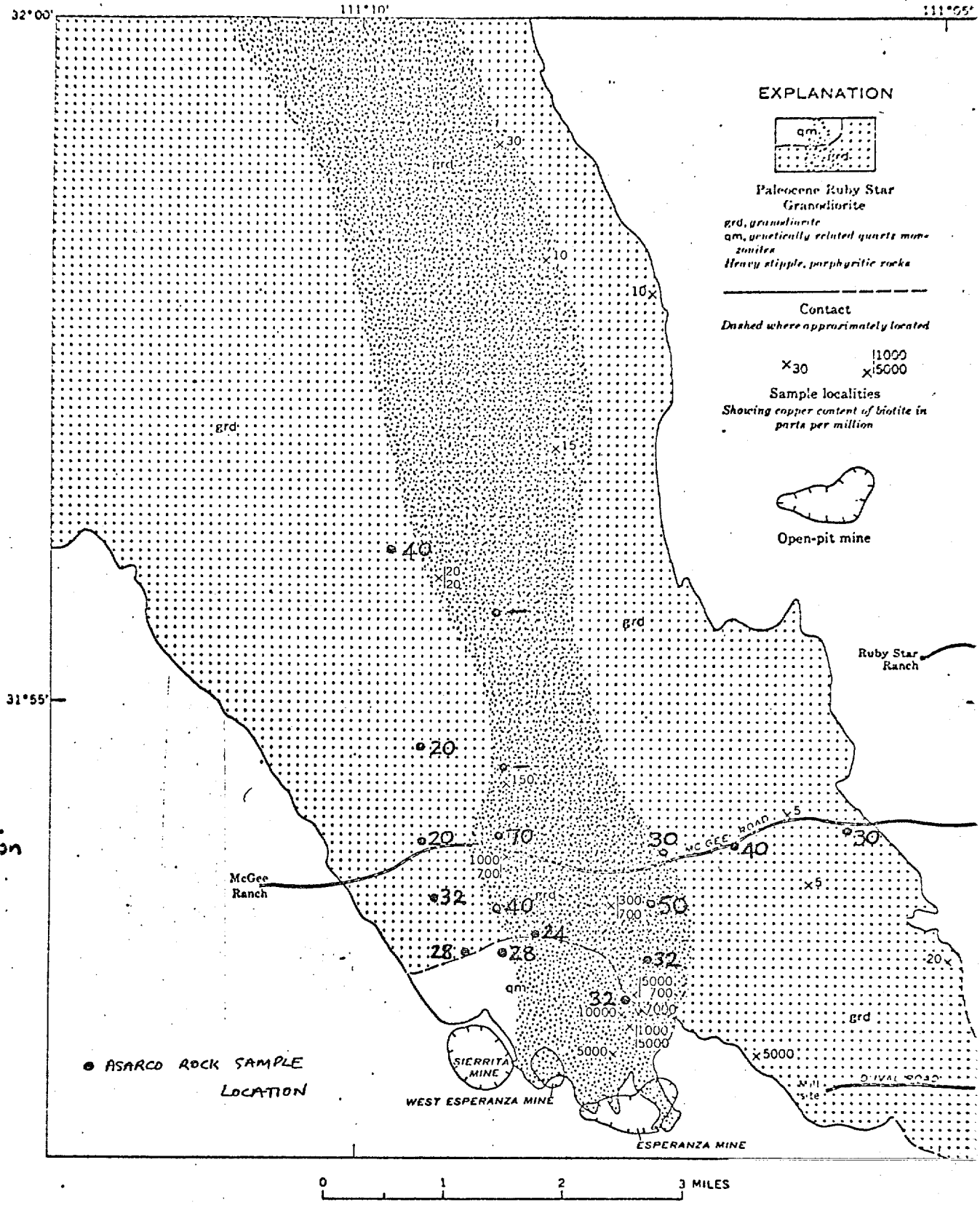


Fig. 2a

FIGURE 2.—Generalized map of composite stock and associated ore deposits in the southwestern part of the Pima mining district, east of the Sierrita Mountains, showing sample localities and copper content of biotite.

Cu content (ppm) of biotite in Asarco Rock samples
(analysis by Geochemical Laboratory using an A.A.technique)



Biotite

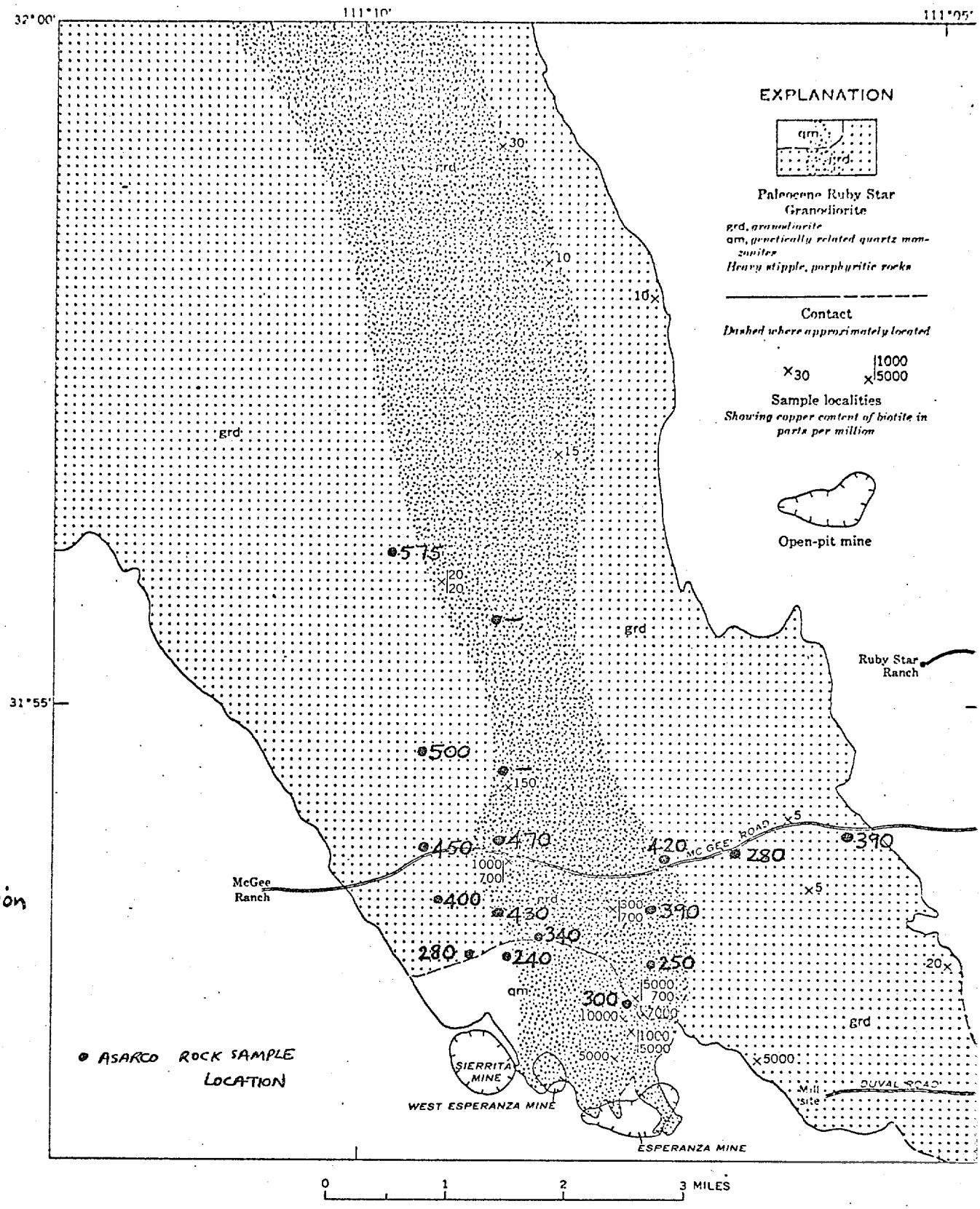
Pb

(Total digestion & A.A.)

Fig. 3a

FIGURE 2.—Generalized map of composite stock and associated ore deposits in the southwestern part of the Pima mining district, east of the Sierrita Mountains, showing sample localities and copper content of biotite.

Pb content (ppm) of biotite in Asarco rock samples
(Analysis by Geochemical Laboratory using an A.A. technique)



Biotite

Zn

(Total digestion & A.A.)

Fig. 4a

FIGURE 2.—Generalized map of composite stock and associated ore deposits in the southwestern part of the Pima mining district, east of the Sierrita Mountains, showing sample localities and copper content of biotite.

Zn content (ppm) of biotite in Asarco rock samples
(Analysis by Geochemical Laboratory using an A.A.technique)

BIOTITE

Mo

(Total digestion + colorimetric)

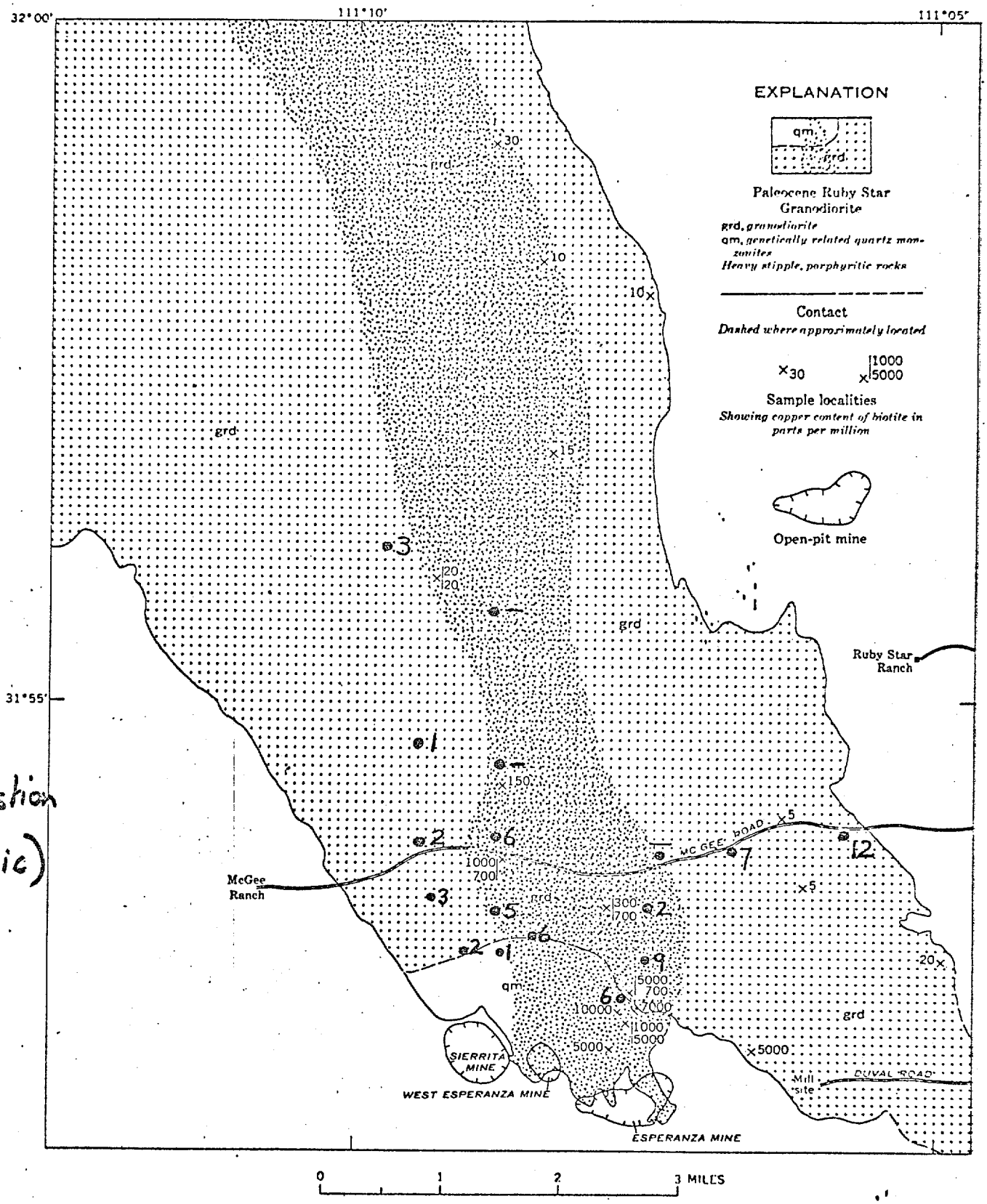


Fig. 5a Generalized map of composite stock and associated ore deposits in the southwestern part of the Pima mining district, east of the Sierrita Mountains, showing sample localities and copper content of biotite.

Mo content (ppm) of biotite in Asarco rock samples
(analysis by Geochemical Laboratory using a colorimeter technique)

Cpy for GSS, JCB, JDS

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

SEP 1 1971
W.L.K.

September 1, 1971

TO: W. L. Kurtz

FROM: G. S. Barnett

Biotite Studies

A memo was circulated concerning areas of potential application for biotite or mafic minerals' separation and analysis as an exploration guide. However, an orientation survey has not been conducted for this method, other than to check the results obtained by the USGS in selected areas. I am not aware of the exact nature of studies we have, or are conducting, nor am I aware of the entire background information available. However, it would seem to me that more information must be available for us to be able to effectively use this method. It would also seem that we are not actively seeking this type of information, but rather waiting for others to do it. Inevitably it seems that any data of this nature which might be collected is done so as a sideline by a geologist whose primary responsibility must (and does) lie with some "more important" project and/or reconnaissance work. The data which needs to be collected is often of such a large volume that we leave it to the USGS or some other group to do. I think what little information we do have concerning this method should be encouraging enough to lead us to conduct a well organized, full scale determination of the value and applicability this method may have.

With this in mind and realizing that when and if enough information is available to absolutely prove the validity of this technique, then everyone will have this technique at their disposal (and will probably be using it). I would suggest that we conduct orientation surveys around as many known deposits as possible, especially our own. By using a pre-determined grid along radial (?) traverse lines leading into deposits we could obtain this information. Access to operating properties is a problem, however, we really aren't interested in ore-grade or nearly ore-grade material -- as when this is at or near the surface it has been claimed or is being mined -- but rather in what the periphery looks like, geochemically and physically.

Immediate applications of this technique would be propylitically altered areas where lateral or vertical zoning could lead to discovery (as Silver Bell East?) Kalamazoo brought this out dramatically and has caused many such areas to be drilled -- possibly not in the most favorable sites. A sampling of the

monzonite southwest of the Oxide Pit at Silver Bell would give an indication of the type of changes we could expect where essentially barren, propylitically altered rock comes within 2000' of the pit.

The number of deposits and length of time required for a study of this nature may require that we offer this problem to a masters candidate, have it done by a consulting firm, turn it over to the Exploration Services Division or hire someone specifically to conduct this and/or related studies. The importance of determining the validity and applying this method is extremely high at this time when we are looking for deeper and/or concealed deposits. A guide with this potential should be worth checking out completely.

I would also suggest that a group of our geologists get together, analyze maps of the known porphyry coppers and plan the spacing and location of sampling traverses. The elements analyzed for can be either pre-determined, random sampled or selected on a spot basis. With a pre-determined spacing or grid, we could also put the results on computer cards, run an analysis and graph the results from tape. This would aid in determining the distribution pattern, whether logarithmic or linear and allow for multiple runs deleting certain values to determine necessary and valuable sample taking intervals.

George S. Barnett

George S. Barnett

GSB:lad

JHC —

interesting running battle

Kurt

FROM: J. H. COURTRIGHT

TO: WLK

This argument would very likely not be settled by sampling the subout crop on the SW, but agree that a few shallow holes might help and the cost would be minor

ASARCO

Exploration Department

TELECOPIER

DATE: 8/31/92

TO:

NAME: Kristine Carroll-Porczynski

LOCATION: Legal Dept., New York Office

FROM: Mary E. Kavanagh

MESSAGE:

Copy sent to FTG. 8/31/92 (FAX)

You will receive 27 page(s) of copy including this sheet.
If you do not receive all pages, please call: 602-792-3010 Ext. 324

This transmission ____ will X will not be confirmed by mail.

ASARCO Incorporated P.O. Box 5747 Tucson, Az 85703
1150 North 7th Avenue FAX (602) 792-3934 Phone (602) 792-3010

ASARCO

Exploration Department

TELECOPIER

DATE: 9/31/92

TO:

NAME: F.T. Graybeal

LOCATION: Exploration Dept., New York

FROM: W.L. Kurtz

MESSAGE:

For your information. Attached was Faxed to Kristine Carroll-Porczynski, Legal Dept. today.

You will receive 27 page(s) of copy including this sheet.
If you do not receive all pages, please call: 602-792-3010 Ext. 324

This transmission ____ will X will not be confirmed by mail.

ASARCO Incorporated P.O. Box 5747 Tucson, Az 85703
1150 North 7th Avenue FAX (602) 792-3934 Phone (602) 792-3010

from the desk of

GEORGE J. STATHIS 7-6-72

TO Bill Kurtz

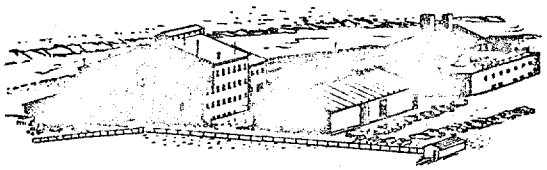
For your information
The two attached
CSM bills
represent cost of
the biotite work
on 90 samples
Texas Canyon - Cochise
Ruby Star - Juniper Flat

CC: F.T.G

$16.66 per sample

RBC → [illegible] Biotite

[illegible] 7/10/72



INVOICE
P. O. BOX 112
GOLDEN, COLORADO 80401
279-2581

INVOICE DATE		
6	21	72
MONTH	DAY	YEAR

INVOICE NO.
22167

COLORADO SCHOOL OF MINES RESEARCH INSTITUTE

American Smelting & Refining Co.
Southwestern Exploration Division
P. O. Box 5747
Tucson, Arizona 85703
ATTN: Mr. John R. King

PROJECT NUMBER: 311009

CUSTOMER NUMBER: T-9981

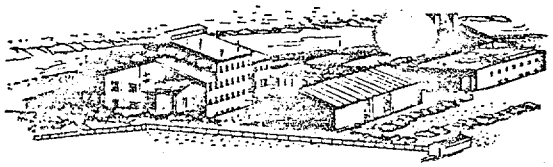
PROJECT TITLE: Mineralogical Studies

CHARGES INCURRED IN: May & June

DESCRIPTION	AMOUNT	
Staff Charges	508	72
Overhead Charges	508	72
Stores Issued	23	15
Handling Charges	5	79
Colorado Sales Tax		69
Telephone Charges	13	05
Postage	1	15
TOTAL →	1,061	27

MINERAL INDUSTRY RESEARCH

Pd - 5/9/72



INVOICE
P. O. BOX 112
GOLDEN, COLORADO 80401
279-2581

INVOICE DATE		
5	01	72
MONTH	DAY	YEAR

INVOICE NO.
21999

COLORADO SCHOOL OF MINES RESEARCH INSTITUTE

MR JOHN R KING
AMERICAN SMELTING AND
REFINING COMPANY
SOUTHWESTERN EXPLORATION DIV
P O BOX 5747
TUCSON ARIZONA 85703

PROJECT NUMBER: 311009

CUSTOMER NUMBER: T-9981

PROJECT TITLE: MINERALOGICAL STUDIES

CHARGES INCURRED IN APRIL

DESCRIPTION	AMOUNT
STAFF CHARGES	147.04
OVERHEAD CHARGES	147.04
STORES ISSUED	5.50
HANDLING CHARGES	1.38
COLORADO SALES TAX	.17
TELEPHONE CHARGES	5.23
TRUCK USAGE	.15
MISC FREIGHT & POSTAGE	192.40
TOTAL →	498.91

COPY

Bretta (Attention)

MINERAL INDUSTRY RESEARCH

Biotite Program

W. L. K.
JUN 12 1972

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

June 8, 1972

Mr. Ernie Phillips
ASARCO
Salt Lake City Office

Dear Ernie:

Ninety biotite concentrates were sent to you this morning via Registered Airmail (Insured-Return Receipt Requested). The samples are labelled as follows:

a) RS-24 thru RS-47
b) JF-1 thru JF-5
c) MFB-1
d) CS-1 thru CS-27
e) TC-1 thru TC-33

Please run the biotites for Cu, Mo, Pb, and Zn. Return the concentrates and the package containing the light fraction material to this office when the assaying is completed. Also, could you put each biotite concentrate in some sort of a screw-top plastic vial. Thanks.

Sincerely yours,

George

George J. Stathis

GJS:lad

cc: FTGraybeal
WLKurtz

Biotite Separation

April 7, 1972

Mr. Bill Reid
Colorado School of Mines Research Institute
P. O. Box 112
Golden, Colorado 80401

Dear Bill:

Ninety-two rock samples were sent to you Wednesday afternoon via Greyhound Express. The samples are labelled as follows:

a) RS-24 thru RS-47
b) JF-1 thru JF-5
c) MFG-1
d) CS-1 thru CS-27
e) TC-1 thru TC-33

We would like biotite separations to be made on these samples. Please save about a 200 gram split of each sample after first crushing and before the biotite separation. Samples with low biotite content, such as the JF series, we would probably want 400 grams or so saved. Return the 200 gram splits to the Tucson office and send the biotite concentrates to Mr. Lloyd James of our Salt Lake City office.

I mentioned over the phone this morning to Mr. T. Caneer that we had sent the samples to you.

Sincerely yours,

George J. Stathis
Geologist

GJS:lad

cc: LDJames
FTGraybeal
SRDavis
JRKing

WTCaneer, Asst. Mgr.
Mining Division
Col. School of Mines Research Inst.

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

April 5, 1972

Mr. L. D. James
ASARCO
Salt Lake City Office

Dear Lloyd:

Enclosed are comments by Mr. Graybeal on Colorado School of Mines Research Institute's letter of March 31, 1972 concerning biotite separation.

Very truly yours,

W. L. Kurtz

W. L. Kurtz

WLK:lad
Enc.

cc: FTGraybeal

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

April 5, 1972

Memorandum to: W. L. Kurtz

From: F. T. Graybeal

Commentary on the CSMRI Biotite Separation Techniques

I have several comments on the results of the CSMRI investigation (letter to L. D. James, March 31, 1972) to develop a better biotite separation technique. It is unfortunate that they only ran one test of the sedimentation procedure, after it was determined it was the only method tried which would work satisfactorily. I assume the sample is dried before heavy liquid separation and I would recommend that the sample be flushed with distilled water to remove any copper-bearing tap water used during the sedimentation step.

The report mentions crushing of the sample to 6 mesh and then grinding to liberate mica, but without reducing the overall particle size. Although it is not entirely clear to me how this is possible, my experience is that biotite is not completely liberated at sizes larger than about 35 mesh and I would recommend that separation be performed only on -48 mesh material. In addition, for sizes at -150 mesh, surface tension phenomena become more important than differences in specific gravity, thus making heavy liquid separations very difficult. Care should be taken in the grinding stage to reduce as little of the sample as possible to -150 mesh.

With respect to heavy liquid separation (this is the slow step), a specific gravity of 2.71 to sink biotite is far too low. The specific gravity of magmatic biotite generally varies from 2.94 - 3.04 and use of a liquid of 2.71 SG will permit a large amount of unliberated biotite-feldspar, etc., grains to sink. In addition, chlorite in the sample will also sink, as chlorite derived from the above biotites will generally run about 0.10 SG less than the biotite (thus 2.84-2.94). Thus, I am of the opinion that a one-step heavy liquid separation would be most effective at a 2.89 SG. This will float essentially all unliberated biotite and chlorite. Incidentally, a large amount of concentrate in the separatory funnel will not permit a clean separation regardless of the specific gravity of the liquid due to overcrowding of the system.

If a rock contains magnetite, hornblende, pyronene, or epidote, the biotites may have to be floated. Undoubtedly some hornblende will be received in the sedimentation stage and an even greater amount will occur as unliberated biotite-hornblende aggregates. If these minerals occur, the biotite can easily be cleaned by floating at about 3.05. However, this involves use of methylene iodide which is considerably more expensive and toxic than bromoform. Franz separation would be adequate for magnetite but useless for removal of hornblende, pyronene, epidote, or chlorite from the biotite. The need for floating the biotite can be anticipated by an

examination of the rocks as they are collected and recommended after inspection of the concentrate. Perhaps the methylene iodide separations could be accomplished in Lloyd James' laboratories for specific samples as needed.

It is important to remember that no two rocks will respond alike to a mineral separation flowsheet regardless of their chemical or mineralogical similarities. Thus, an examination of each concentrate should be made before the analysis is performed.

F.T. Graybeal
Head

F. T. Graybeal

FTG - please review and comment

COLORADO SCHOOL OF MINES RESEARCH INSTITUTE
P.O. BOX 112
GOLDEN, COLORADO 80401

RECEIVED
APR 3 1972
S. W. U. S. EXPL. DIV.
W. L. K.
APR 3 1972

March 31, 1972

Mr. Lloyd D. James
American Smelting & Refining Company
Geophysical Division
3422 South 700 West
Salt Lake City UT 84119

Dear Mr. James:

Attached are data sheets for tests investigating the use of flotation for recovering chlorite and biotite from exploration samples. Since a requirement for the processing was that it be relatively inexpensive, procedures used were kept as simple as possible.

The feed for the first flotation test was obtained from simply screening out the coarse material (the original sample was essentially all minus 4 mesh) and removing the slimes. The latter is normally required for flotation with cationic reagents. Later tests employed some grinding primarily to ensure the liberation of slimes, although more mica was also liberated, because it was soon learned that it was beneficial to retain the mica as coarse as possible. Fine feldspar tended to float with chlorite and biotite, even during cleaning, and always lowered final concentrate grade. Since the amount of mica in some samples would not permit the number of cleanings required to drop the feldspar and still recover the necessary amount of product, and since the scope of the project did not permit an investigation into chemical means for obtaining a more selective float, screening the concentrate at 200 mesh was tried and showed that a considerable upgrading of mica could be effected in this manner. Mica content (by visual estimation under a microscope) of about 90% could be readily achieved, but this was still much below the approximate 99% desired. Because of this and the necessity for uniformly high grade products from any type of feed, it was concluded that eventual treatment by heavy liquid methods would always be required.

Consequently, an alternate method for preparing feed for heavy liquid treatment was sought, and in the one trial of a sedimentation procedure (see Sedimentation Test 1) very good results were obtained. The results from this test indicated that a possible treatment of coarse ore samples would be to crush the material to about 6 mesh, grind for a short period to liberate more mica but not reduce overall particle size to any degree, and then recover a rougher mica concentrate by sedimentation. A heavy liquid, specific gravity about 2.71, would then be used to effect the separation of

mica from gangue. An advantage to this procedure is that since the mica is relatively coarse, the separation can be made without centrifuging. Another possible advantage might be that any heavy minerals in the ore would sink with the waste during the sedimentation step and therefore an additional heavy liquid treatment for their removal would not be required.

Although feed for heavy liquid processing could be prepared by either flotation or sedimentation, it is believed that sedimentation would be more applicable to most samples. The cost for the sedimentation-heavy liquid procedure, when done in quantity, is estimated at $10 to $12 per sample.

Please contact Bill Reid if you have any questions concerning future processing, and I shall be glad to answer any questions you may have about the work which was done.

Yours very truly,

M. E. Defoe

M. E. Defoe
Project Manager
Metallurgical Division

MED/psk

Attachment

cc: Mr. W. L. Kurtz

EXHIBIT _____

Project No. 320317

Flotation Test No. 1

Date: _____

Purpose: To recover a hi grade chlorite - biotite concentrate

Sample: Approx 250 gms sample R.S 18, as received

Test Conditions:

	Time min	Solids %	pH Start	pH Finish	Reagents, lb/ton of ore H_2SO_4	Fuel oil	Armac			
Screen @ 35M										
Desline @ 400M										
-35 + 400		15	3.8		✓	0.2	0.4			

Results:

Product	Weight g	Weight %	Chemical Analysis %	%			Percent Distribution			

Test Notes and Observations: Floated too much much fold in and keeping a of cleaning

EXHIBIT _____

Project No. 320317

Flotation Test No. 2

Date: _____

Purpose: SAME AS TEST 1 ; TRYING A DIFFERENT COLLECTOR.

Sample: Approx. 250 gms R.S. 18, AS RECEIVED

Test Conditions:

	Time min	Solids %	pH Start	pH Finish	Reagents, lb/ton of ORE H_2SO_4	FuCl Oil	AZAMINE F10A			
GRIND (REGRIND)	5	50								
DESLIME @ 400 M.										
+400 MESH										
CONDITION	1		3.8		✓					
DESLIME										
CONDITION	3		4.3		✓	0.4				
CONDITION	1/2		4.3		✓		0.1			
ROUGHER FLOTATION	1 1/2	15	4.3				0.2			
Cleaner Flotation	1/2		4.3		✓		0.05			
Cleaner Flotation	1/2						0.05			

Results:

Product	Weight g	Weight %	Chemical Analysis Mica %	ll %			Percent Distribution			
TOTAL FEED		100.0								
Cleaner Conc 1										
+100 MESH		0.2	90							
-100+200 MESH		0.3	50							
-200 MESH		1.0	10							
Cleaner Conc 2		1.3								
Cleaner Tailing		8.4	10							
Rougher Tailing		43.6								
-400 MESH SLIMES		45.2								

ll ESTIMATED FROM BINOCULAR EXAMINATION.

Test Notes and Observations: AMINE STAGE ADDED FOR THE ROUGHER FLOTATION. Two separate concentrates were pulled during cleaning. The first concentrate was screened at the sieve sizes shown to determine if this would help to eliminate fine feldspar pulled with the mica.

EXHIBIT 1

Project No. 320317

Flotation Test No. 3

Date:

Purpose: To float biotite-chlorite from raw alkaline pulp, and without desliming.

Sample: Approx 300 gms Sample RS.18, as received

Test Conditions:

	Time min	Solids %	pH Start	pH Finish	Reagents, lb/ton of ore: Kerosene	Organ A	Oleic acid	Azamine F10A		
Grind (as rec'd)	3	50								
Conditioning	5	30			0.4	0.4				
Conditioning	4						0.4			
Conditioning	1							0.6		
Flotation	2	20								

Results:

Product	Weight g	Weight %	Chemical Analysis %	%			Percent Distribution			
Flotation Feed		100.0								
Concentrate		7.0								
Tailing		93.0								

Test Notes and Observations: Floated slimes mostly. Concentrate too low and contains too little chlorite-biotite to pursue further processing.

EXHIBIT _____

Project No. _____

Flotation Test No. 4

Date: _____

Purpose: SAME AS THAT FOR TEST NO 1

Sample: Approx 400 gms Sample R.S. 18, as received

Test Conditions:

	Time min	Solids %	pH Start	pH Finish	Reagents, lb/ton of ORE H_2SO_4		AZAMINE FIOA			
GRIND (BALL MILL)	2 1/2	50								
SCREEN @ 20 M.										
DESLIME @ 400 M										
-20 + 400 MESH										
pH ADJUSTMENT				4.3	✓					
ROUGHER FLOTATION	3	25					0.5 L			

L 1 STAGE ADDED

Results:

Product	Weight g	Weight %	Chemical Analysis Mica %	%			Percent Distribution			
TOTAL -20 MESH		100.0								
ROUGHER CONCENTRATE										
+200 M		1.2	90							
-200 M		2.0	15							
FLOTATION TAILINGS		74.5								
SLIMES		22.3								
+20 MESH				DISCARDED						

Test Notes and Observations: _____

EXHIBIT 1

Project No. 320317

Flotation Test No. 5

Date:

Purpose: SAME AS TEST FOR TEST #01

Sample: Approx 1000 gms Sample K.S 19, AS RECEIVED

Test Conditions:

	Time min	Solids %	pH Start	pH Finish	Reagents, lb/ton of ORE H_2SO_4		AZAMINE F10A			
GRIND (LABMILL)	3	50								
SCREEN @ 20 and 325 M.										
-20 + 325 FRACTION										
pH ADJUSTMENT				4.3	✓					
ROUGHER FLOTATION	2	25	4.3		✓		0.4 [1]			
CLEANER FLOTATION	1		4.3		✓		0.05			

Results: [1] STAGE ADDED

Product	Weight g	Weight %	Chemical Analysis Mica %	%			Percent Distribution			
TOTAL - 20 MESH		100.0								
Cleaned Conc. +200M		0.4	98							
-200M		0.6	10							
Cleaner Tailing +200M		1.1	50							
-200M		2.7	10							
ROUGHER TAILING		83.5								
SLIMES.		11.7								

Test Notes and Observations:

EXHIBIT _____

Project No. [illegible]

Flotation Test No. 6

Date: _____

Purpose: SAME AS THAT FOR TEST 1C1

Sample: APPROX. 400 g. SAMPLE RS 20, AS RECEIVED

Test Conditions:

	Time min	Solids %	pH Start	pH Finish	Reagents, lb/ton of ORE H_2SO_4		N2 AMINE FIDA			
GRIND (BALL MILL)	3	50								
SCREEN @ 20 & 325 M.										
-20 + 325 FRACTION										
pH ADJUSTMENT			4.3		✓					
ROUGHER FLOTATION	2	25					0.4			
CLEANER FLOTATION	1		4.3		✓		0.1			

4 STAGE ADDED

Results:

Product	Weight g	Weight %	Chemical Analysis Mica %	%			Percent Distribution			
FLOTATION FEED		100.0								
CLEANED CONC +200			85							
-200		10.6	10							
CLEANER TAILING		14.4								
ROUGHER TAILING		75.0								

Test Notes and Observations: _____

EXHIBIT 1

Project No. [illegible]

Flotation Test No. 7

Date:

Purpose: SAME AS THIS FOR TEST NO 1.

Sample: 900 gms ARENTS CREEK, CRUSHED TO -4 MESH

Test Conditions:

	Time min	Solids %	pH Start	pH Finish	Reagents, lb/ton of ORE H_2SO_4		AERMIN FIOA			
Grind Ball Mill	7	50								
Screen @ 20 & 325M										
-20 + 325 M. Fraction										
pH adjustment			4.3		✓					
Rougher Flotation							0.5 [1]			
Cleaner Flotation							0.1			

[1] STAGE ADDED

Results:

Product	Weight g	Weight %	Chemical Analysis Mica %	%			Percent Distribution			
Flotation Feed										
Cleaned Conc +200M			90							
-200M			25							
Cleaner Tailing			10							
Rougher Tailing										

Test Notes and Observations:

EXHIBIT _____

Project No. 320317

SEDIMENTATION Test No. 1 Date: _____

Purpose: TO DETERMINE IF CHLORITE - BIOTITE CAN BE RECOVERED FROM THE SAMPLE BY SEDIMENTATION AND THEN UPGRADED BY HEAVY LIQUID SEPARATION.

Sample: Approx 900 gms ALENTY CREEK, MINUS 1/8 INCH

Procedure: THE SAMPLE WAS GROUND FOR 8 MIN. @ 50% SOLIDS, THEN TRANSFERRED TO A CONTAINER (PLASTIC BUCKET). THE PULP WAS DILUTED WITH ADDITIONAL WATER, STIRRED, AND DECANTED THRU A 200 M SCREEN AFTER ALLOWING 10-15 SEC SETTLING TIME. THIS WAS REPEATED SEVERAL TIMES, EACH TIME COLLECTING THE MATERIAL RETAINED BY THE SCREEN, UNTIL IT WAS EVIDENT THAT MUCH OF THE MICA HAD BEEN RECOVERED. THE CONCENTRATE BULK WAS REDUCED BY REPEATING THE ABOVE PROCEDURE WITH THIS MATERIAL ONLY, AND THEN THIS PRODUCT WAS SEPARATED INTO A MICA AND A GANGUE

Results: PRODUCT BY PROCESSING WITH HEAVY LIQUID OF 2.71 S.G.

Product	Weight g	Weight %	Chemical Analysis %	%		Per Cent Distribution		

Observations: THE SINK PRODUCT WAS ESSENTIALLY (MORE THAN 99%) CHLORITE - BIOTITE

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

March 20, 1972

MEMORANDUM TO STAFF:

Biotite Program

You are all hereby instructed not to discuss the procedures ASARCO is using to make biotite separation. Further and more importantly, you are not to inform anyone that ASARCO's samples are being prepared by the Colorado School of Mines Research Institute.

WLK

W. L. Kurtz

WLK:lad

cc: JJCollins
JHCourtright
LDJames

Copper in Biotite

AMERICAN SMELTING AND REFINING COMPANY
EXPLORATION SERVICES DIVISION
3422 SOUTH 700 WEST
SALT LAKE CITY, UTAH 84119

R. J. LACY
SUPERVISOR

RECEIVED
MAR 15 1972
S. W. U. S. EXPL. DIV.

March 13, 1972

W. L. K
MAR 17 1972

Mr. M. E. Defoe
Colorado School of Mines Research Institute
P. O. Box 112
Golden, Colorado 80401

Dear Mr. Defoe:

In your letter of March 9 you outline a program designed to determine the feasibility of using flotation to effect biotite separation from 3 or 4 rock samples provided by the Southwestern U. S. Division of Asarco's Exploration Department. You are hereby authorized to proceed with this project on the understanding costs will not exceed $500.00. No expenditures beyond this amount should be assumed without prior consultation with this office.

We look forward to receiving the results of this study.

Yours very truly,

L. D. James.

L. D. JAMES

LDJ:am

cc: W. L. Kurtz

Bill

This procedure won't be able to separate biotite from either chlorite, muscovite, or (probably) clay minerals.

Heavy liquids will still have to be used and the Franz will be needed to separate the small occluded magnetite grains in biotite from pure biotites.

I wonder why they didn't propose this while we were still in the research stage. I also wonder about the transition metal content of their flotation reagents.

Fred

W. L. K.

MAR 21 1972

~~ETG/JRK~~ Biotite

COLORADO SCHOOL OF MINES RESEARCH INSTITUTE
P.O. Box 112
GOLDEN, COLORADO 80401

RECEIVED
MAR 13 1972
S. W. U. S. EXPL. DIV.

March 9, 1972

W. L. K.
MAR 13 1972

REFER TO
620317

COPY

Mr. Lloyd D. James
American Smelting & Refining Co.
Geophysical Division
3422 South 700 West
Salt Lake City, Utah 84119

Dear Mr. James:

Bill Reid has informed me of your interest in pursuing the biotite-chlorite method for examining porphyry deposits for copper, and has suggested flotation as a method for recovering biotite-chlorite from the field sample.

A cursory investigation, on three samples, to determine the feasibility of using flotation is estimated at $500. The procedure would involve grinding a representative portion of each sample to roughly minus 65 mesh, desliming at 325 mesh, and floating the plus 325 mesh fraction at conditions normally suitable for mica flotation. A more comprehensive program will be required, however, should there be minerals present which have flotation characteristics similar to mica.

We shall be pleased to perform this service for you and need only your authorization to proceed with the work.

Sincerely,

M. E. Defoe
Project Manager
Metallurgical Division

/laj
cc: W. L. Kurtz

AMERICAN SMELTING AND REFINING COMPANY
SOUTHWESTERN EXPLORATION DIVISION
P. O. BOX 5747, TUCSON, ARIZONA 85703

1150 NORTH 7TH AVENUE
TELEPHONE 602-792-3010

March 9, 1972

Mr. Bill Ried
Colorado School of Mines Research Institute
Golden, Colorado 80401

Samples for Research on
Biotite Separation

Dear Mr. Ried:

Being shipped to you by air freight are four samples for your research on biotite separation. Three of these samples have been run once for biotite separation and the fourth sample is still in rock form. Should you need additional rock samples, please let us know.

Please send rsults of your work to us and also to Mr. Lloyd James of our Salt Lake City office. Your invoice for this work should be sent to Mr. James.

Very truly yours,

W. L. Kurtz
Manager of Exploration

WLK:lad

cc: LDJames
ASARCO
3422 S. 700 West
Salt Lake City, Utah 84119

TO W. L. Kurtz

FROM J. R. King

SUBJECT Ruby Star Samples

DATE 3 / 7 / 72

MESSAGE Three samples, Nos. 18, 19 and 20, have been run once for biotite separation. The fourth sample is from Arnett Creek near Superior and it is still in rock chip form.

I hope these will do for your purposes.

SIGNED John R King /lad

REPLY

SIGNED

DATE / /

SEND PARTS 1 AND 3 WITH CARBON INTACT - PART 3 WILL BE RETURNED WITH REPLY

Rediform® 4S 472

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

February 29, 1972

Mr. L. D. James
Salt Lake City Office

Biotite Separation

Dear Lloyd:

Mr. Bill Ried, of the Colorado School of Mines Research Institute, has informed us that he believes an easier, quicker, and therefore cheaper method of separating biotite from rock is possible. He has requested that Asarco support his work to prove or disprove the method in the amount of $300.00. I would recommend that Asarco spend this money, if you believe Ried has a usable method.

I suggest you call Ried and talk with him about his proposed method and make a decision whether Asarco should support Reid's work. This should be done immediately, since we are currently beginning a biotite sampling program.

Very truly yours,

Bill

W. L. Kurtz

WLK:lad

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

February 22, 1972

CONFIDENTIAL

Mr. S. A. Anzalone
Vancouver Office

Dear Sal:

The enclosed report "Copper in Biotite as a Guide to Porphyry Copper Deposits" is being sent to you at the request of Mr. Collins. The data contained in this report is confidential and should not be Xeroxed. Also, I request that none of your staff discuss the fact that Asarco is using biotite as a guide to ore.

Our sampling procedure and analytical procedure will be sent to you if you start a copper-in-biotite program.

Very truly yours,

W. L. Kurtz

WLK:lad
Enc.

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

February 22, 1972

CONFIDENTIAL

Mr. Keith Whiting
Spokane Office

Dear Keith:

The enclosed report "Copper in Biotite as a Guide to Porphyry Copper Deposits" is being sent to you at the request of Mr. Collins. The data contained in this report is confidential and should not be Xeroxed. Also, I request that none of your staff discuss the fact that Asarco is using biotite as a guide to ore.

Our sampling procedure and analytical procedure will be sent to you if you start a copper-in-biotite program.

Very truly yours,

W. L. Kurtz

WLK:lad
Enc.

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

February 22, 1972

CONFIDENTIAL

Mr. R. K. Kirkpatrick
Denver Office

Dear Roger:

The enclosed report "Copper in Biotite as a Guide to Porphyry Copper Deposits" is being sent to you at the request of Mr. Collins. The data contained in this report is confidential and should not be Xeroxed. Also, I request that none of your staff discuss the fact that Asarco is using biotite as a guide to ore.

Our sampling procedure and analytical procedure will be sent to you if you start a copper-in-biotite program.

Very truly yours,

W. L. Kurtz

WLK:lad
Enc.

COPPER IN BIOTITE AS A GUIDE TO PORPHYRY COPPER DEPOSITS

F. T. Graybeal

INTRODUCTION

Numerous papers have appeared in the last decade concerning the application of trace element analyses of biotite during base metal exploration. The emphasis of this work was on copper because it tends to vary over a much greater range of concentration than other trace elements. Although statistical correlations with productive and barren intrusions were often demonstrated, the causes of the significant variations found were largely unexplained.

The present paper, as indicated by the change in title, is an abridged version of the talk given at the annual exploration meeting in November 1971. The purpose is to summarize briefly the behavioral characteristics of the distribution of copper in biotite and to evaluate some of the possible applications to exploration for porphyry copper deposits in light of available sample results. The details of the behavior of copper in biotite, as given at the exploration meeting, are briefly summarized below. These details are discussed in depth in my dissertation to which the reader is referred for greater understanding (Graybeal, 1971).

BEHAVIOR OF COPPER IN BIOTITE

The copper content of biotite is controlled only by magmatic processes operating in the Laramide plutons investigated, and is uneffected by adjacent hydrothermal alteration. It is probable that this conclusion may be applied to all Laramide plutons, and perhaps to all plutons genetically related to porphyry copper deposits. The copper content of biotite does not appear to be effected by surface weathering until the biotite itself is destroyed.

The magmatic processes which cause the greatest change in the copper content of biotite can be correlated with variations in rock types and with textural variations in a single rock type. Knowledge of these variations, gained through reconnaissance mapping and petrographic work, is necessary to interpret correctly the analytical data and can usually be obtained by an experienced geologist in a minimum amount of time.

It was also established from an evaluation of chlorite-biotite equilibria that the copper content of biotite is equivalent to the minimum concentration of copper in the coexisting trapped hydrothermal solution. The copper content of biotite thus provides a direct semi-quantitative estimate of the amount of copper in the hydrothermal solution, which is the amount available to form a mineral deposit.

It is emphasized that all biotites studied in this investigation were of unquestioned magmatic origin, and that the above conclusions only apply to biotites similarly formed. Judging from the known intimate association of hydrothermal biotite with primary copper mineralization, if a sample contained a significant amount of hydrothermal biotite the question of its origin and the use of the biotite sampling technique would be rendered moot by the presence of accompanying sulfides.

APPLICATIONS

Parry and Nackowski (1961) were the first to show that the copper content of biotite was increased in quartz monzonite stocks related to porphyry copper deposits in Utah and Nevada. A recent paper by Lovering, Cooper, Drewes, and Cone (1969) demonstrated that the copper content of biotite in the Ruby Star Granodiorite increased from a background of 15 ppm copper to 10,000 ppm copper adjacent to the Sierrita Mine. These large variations in concentrations and correlations with productive intrusions have generated considerable previous interest in the analysis of copper in biotite as an exploration tool.

The basis for analyzing biotite rather than the whole rock sample from which the biotite was separated is due to a greater contrast between background and anomaly for biotite. In addition, the size of the anomaly formed by copper in biotite is greater than the anomaly formed by the whole rock sample. Regardless of the absolute values, if the contrasts were the same for biotite and whole rock then the rock would be the preferred sample due to a greater ease of preparation.

The theory behind the use of biotite analyses is graphically illustrated in Figure 1. This shows that the copper content of biotite rises faster and at a greater distance from the altered zone than does the copper content of the whole rock. The lower portion of this same figure also illustrates that the ratio of copper distributed between biotite and whole rock samples also rises very rapidly. As will be seen below, the idealized behavior shown on Figure 1 has been verified by field work from several different intrusions associated with porphyry copper deposits.

The locations of the plutons studied in this investigation are shown on Figure 2. This is a combination of plutons studied by myself and by John King. The results of all copper analyses completed to date are plotted in ppm on the accompanying figures.

Tyrone Quartz Monzonite

The Tyrone quartz monzonite pluton is medium to coarse grained with a possibly porphyritic core which parallels the long axis of the intrusion. The Tyrone ore body is a chalcocite blanket which has formed

in the quartz monzonite and in the Precambrian granite wall rock within a zone of strong shearing.

The copper contents of biotite in the Tyrone quartz monzonite are given on Figure 3 (sampling by John King and Barry French). An irregular but strong copper in biotite anomaly is present which extends roughly 3 miles southwest of the ore zone. This anomaly appears to follow the porphyritic zone in the central portion of the quartz monzonite. Several high values are also found along the southeast side of the pluton.

The whole rock copper values for the same samples are given on Figure 4. These values indicate a strong anomaly along the southeast side of the quartz monzonite pluton in an area of low-grade copper oxide mineralization. Thus, the whole rock analyses do not provide a good guide to the zone of ore grade copper sulfide mineralization.

The ratios of copper in biotite/whole rock are given on Figure 5. These ratios show a strong and regular increase toward the ore zone which corresponds closely with the porphyritic core. It is particularly important to note that anomalously high values for the ratio of copper in biotite/whole rock and in biotite alone extend for 1.5-2 miles beyond any visible hydrothermal alteration associated with the Tyron ore body, and thus provide a much more extensive and accurate guide to the ore than the copper content of the whole rock samples.

Schultze Granite

The Schultze granite is a medium to coarse grained quartz monzonite (mineralogically and chemically) with orthoclase grains occasionally reaching phenocryst size. This intrusion is extremely homogenous with the exception of small zones of granite porphyry along the north side. The Schultze and genetically related intrusions are the hosts for three major porphyry copper ore bodies.

The Schultze granite was sampled both by myself and by John King. The results of my work are given on Figure 6. This illustrates that the copper content of biotite rises from a background of roughly 10 ppm to 360 ppm along the north contact. All known porphyry copper ore bodies in the district are located along this contact indicating that the variations of copper in biotite are quite compatible with the known geology.

The results of Mr. King's more detailed sampling are shown on Figure 7 and are not easily comparable with Figure 6. The significance of the several high values detected along the west end of the Schultze granite is not yet known. The copper contents of whole rock samples are given on Figure 8 which also shows several high values in the western portion of the Schultze granite. The ratios of copper in biotite/whole rock are shown on Figure 9. These ratios are erratic and do not show any wide or systematic variations.

The data from the Schultze granite suggest that detailed sampling may be unnecessary. The lack of systematic variations noted in the detailed work may be due to the current level of exposure being deep within the intrusion, although this assumption lacks proof.

Ruby Star Granodiorite

The Ruby Star granodiorite is medium grained with a more porphyritic core which parallels the long axis of the intrusion. Quartz monzonite porphyry phases of this pluton have been mapped in the Sierrita pit. This intrusion and genetically related offshoots were the sources of three major porphyry copper ore bodies.

The copper content of biotite in the Ruby Star granodiorite is given on Figure 10 (sampling by John King). This shows a copper in biotite anomaly which extends 3 miles north of the Sierrita-Esperanza ore zone. The anomaly is well defined and appears to follow a porphyritic core within the pluton. The highest value found in this work is 1530 ppm Cu, as compared to 10000 ppm Cu reported by Lovering et al (1969). However, the Lovering samples were impure and I regard Mr. King's results as more accurate.

A well-defined copper in whole rock anomaly is shown on Figure 11. The 500 ppm contour extends outward 1-2 miles from the Sierrita - Esperanza ore zone and coincides roughly with the limit of visible hydrothermal alteration in the granodiorite. In this pluton variations in the copper content of biotite give the geologist an additional 1-2 miles of anomalous halo and provide exploration guidance which would not otherwise be available from geologic mapping or whole rock analyses.

The ratios of copper in biotite/whole rock are shown in Figure 12. The values appear to rise abruptly to 10 approaching the ore zone and then fall quite rapidly at a point about 2 miles north of the ore body. The ratios also rise to the north where the pluton disappears under the gravel cover on the San Xavier Indian Reservation.

Three Peaks Pluton

This pluton is compositionally zoned with the three phases elongate parallel to the long axis of the pluton. The rocks are all medium grained, equigranular, and everywhere fresh where exposed. The projection of this pluton extends through the Santa Cruz deposit which lies about 5 miles to the southwest.

The copper content of biotite in the Three Peaks pluton is shown on Figure 13. (Sampling by John King and John Balla.) This illustrates that the copper content of biotite is highest in the border diorite phase, although not anomalously higher than the central quartz monzonite phase. Figure 14 gives the copper content of the whole rock which is also highest in the border diorite phase. The whole rock variation can be related to the much higher biotite content of the border diorite as compared to the central quartz monzonite phase.

The ratio of copper in biotite/whole rock is shown on Figure 15. The ratios are highest in the quartz monzonite core where they average 6 and lowest in the border diorite where they average 1.5. The interpretation of this variation is uncertain at the present time; however, the high ratio in the core may be considered favorable in the absence of any other positive data.

Cornelia Pluton

The Cornelia pluton contains concentrically distributed separate intrusive phases which become younger and progressively more felsic toward the core. The New Cornelia mine, which lies about 1 mile east, is interpreted to be the down-faulted hood portion of the area shown in Figure 16. The transitional and core phases, although larger, have a shape similar to the ore zone in the pit suggesting that the level of the pluton now exposed is the root zone of a porphyry copper deposit.

The copper content of biotite in the Cornelia pluton is shown on Figure 16 (sampling by F. T. Graybeal). This shows that the copper content of biotite rises as the rock becomes more felsic but falls rapidly in the rock most closely associated with the ore - the porphyritic micro-quartz monzonite. Average values of copper in biotite for each rock type are given in Table 1. This variation suggests that copper was removed from the innermost portions of the pluton by hydrothermal solutions which ultimately formed the then overlying New Cornelia ore body. Subsequent crystallization of a copper-impoverished prophyritic micro-quartz monzonite melt resulted in the formation of biotite which contained only small amounts of copper. Thus copper is lowest in biotites which occur in rocks most closely associated with ore deposition.

TABLE 1

Variation of copper in biotite with rock type in the Cornelia pluton

Rock type	ppm Cu
granodiorite	66
equigranular quartz monzonite	70
transitional porphyritic micro-quartz monzonite	170
porphyritic micro-quartz monzonite	7

Patagonia granodiorite

The central portion of this pluton is an equigranular granodiorite which changes gradually to a porphyritic granodiorite along the eastern contact. Numerous mineralized structures occur in the outer portions of the porphyry and this area has been drilled several times as a copper prospect. The porphyry is clearly a rock in which volatiles were concentrated during crystallization of the pluton. Gradual degassing of the magma in this area caused the central portions to quench progressively more rapidly developing the porphyritic texture.

The copper content of biotite in the Patagonia granodiorite is shown on Figure 17 (sampling by F. T. Graybeal). Although quite variable, the copper content of biotite is generally high throughout the equigranular granodiorite and then falls to very low levels in the porphyritic granodiorite. This variation of copper in biotite with texture is shown on Table 2. The depletion of copper in biotite from the porphyritic granodiorite was clearly caused by a removal of copper from the magma during a progressive degassing of the remaining magma. Thus, the biotite from the inner still-molten portions of the pluton crystallized in a melt relatively impoverished in copper. The important point to note here is that the productive portion of this intrusion actually carries biotites with very low copper content.

TABLE 2

Variation of copper in biotite with texture in the Patagonia granodiorite

Texture	ppm Cu
equigranular	1029
weakly porphyritic	338
moderately porphyritic	46

CONCLUSION

Data from the Cornelia and Patagonia intrusions clearly demonstrate that the rocks most closely related to ore deposition contain biotites with abnormally low copper contents. The interpretation given for this behavior, that these biotites grew in a melt which was previously stripped of its copper, is entirely consistent with the magmatic history of these intrusions. Similar behavior may also be indicated for the Three Peaks and Ruby Star plutons. It is concluded that high or low copper concentrations in biotite can have favorable exploration implications, and that the proper interpretation of the analytical results depends on a clear understanding of the cooling history of the intrusion. However, as the ore-forming portions of an intrusion are often destroyed during alteration so also are the contained copper-impoverished biotites. Thus, high concentrations of copper in biotite would probably be the more common occurrence.

It has also been demonstrated that the copper content of biotite is a better exploration guide to porphyry copper deposits than the copper content of whole rock samples. Analyses of copper in biotite provide:

1.) Greater contrast between background and anomaly

2.) A wider anomalous halo than could be detected by whole rock analyses or geologic mapping

3.) Better correlation with the ore-bearing areas and with textural variations in the igneous rock.

The ratios of copper for biotite/whole rock can also be useful, and emphasize the need for whole rock analyses.

IMPLEMENTATION OF A PROGRAM

An exploration program for porphyry copper deposits using variations in the copper content of biotite could be applied to several different situations. These would include intrusions which extend under post-mineral cover, intrusions intersected by deep drill holes but which are otherwise unexposed, and intrusions in remote areas.

The sampling done during the work by myself and John King was performed on a character basis (sample locations were adjusted to rock type, not to a grid), and was done after the geology had been mapped. The average number of samples taken was less than 1 per square mile. A similar procedure would be recommended for any new work, but should be modified as follows:

1) At least 2 samples should be taken from each phase adjacent to cover.

2) A closer spacing is necessary near cover, as compared to a wider spacing in well-exposed areas.

The samples should be taken from a single outcrop and should weight 10-15 pounds. In addition a small hand specimen should also be collected from the same site.

The importance of supporting geologic mapping and petrographic work cannot be overemphasized. The mapping and petrography provide the geologic framework in which the analytical results can be interpreted. Mapping also reduces the number of samples needed by eliminating excessive sampling of any one phase, and may result in a considerable saving of money and time. A large number of samples is unnecessary as this is not a statistical method; rather, each sample provides solid quantitative data interpretable as such. It should also be noted that the type of mapping necessary can be done rapidly and again the cost is not excessive.

The time interval between mailing of the sample and receipt of analytical results varies from about 3 to 4 weeks. The mineral separation costs at the Colorado School of Mines Research Institute average about $21 per sample. To date they have done excellent work and since sample purity is one of the most important aspects to be considered in the entire program, this cost is not considered excessive.

The biotite sampling technique could best be used where detailed work is already progressing and further exploration guidance is needed. It could also be used on selected other intrusions depending on their age, their occurrence along productive lineaments, and other favorable geological characteristics. I estimate that one pluton could be mapped and sampled in approximately 2-3 weeks in Arizona. The total cost per pluton is estimated to be $1000-$1200, assuming an average of 20 samples is collected.

An attempt should be made by the group doing the mineral separations to recover as much biotite as possible. Although the present work, and subsequent data to be summarized by Mr. King, has been restricted to analyses of trace amounts of base metals in biotites, much further information is available. In a recent paper Stollery et al (1971) have noted the potential use of chlorine analyses of biotite, and fluorine might also be sought. In addition, data from my dissertation indicate that variations in the iron-magnesium ratio of biotite is directly related to the presence or absence of a hydrothermal phase. Further research concerning the application of these or other ideas to porphyry copper exploration will await time and need; however, access to clean biotite samples would greatly reduce the cost and increase the speed of such work.

Sufficient research of the technique has been completed to establish its value, and a recommendation is hereby made for the initiation of a carefully controlled biotite sampling program. At this particular time, I believe that ASARCO has significant lead in the understanding of the complexities involved. However, S. A. Anzalone informed me that Noranda considered work of this type adjacent to their Brenda deposit, and I have learned from Continental Oil that they are investigating the method for possible use in Arizona.

REFERENCES

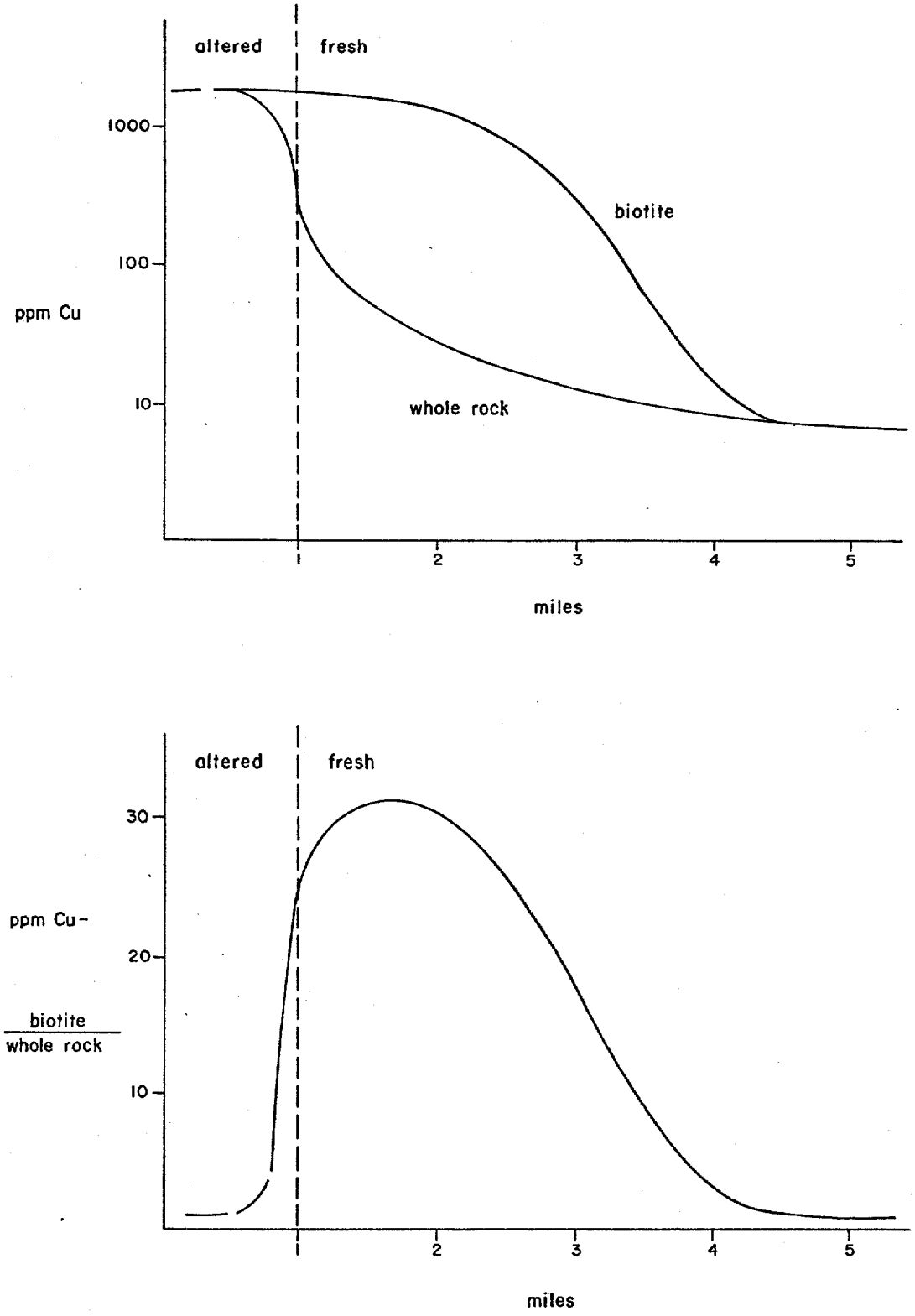
1.) Graybeal, F. T., 1971, The partition of trace elements among coexisting minerals in some Laramide intrusive rocks in Arizona: Univ. of Arizona PhD dissertation.

2.) Lovering, T. G., J. R. Copper, H. Drewes, and G. C. Cone, 1970, Copper in biotite from igneous rocks in southern Arizona as an ore indicator: U.S.G.S. Prof. Paper 700-B, p. B1-B8.

3.) Parry, W. T., and M. P. Nackowski, 1963, Copper, lead, and zinc in biotites from Basin and Range quartz monzonites: Econ. Geol., 58, p. 1126-1144.

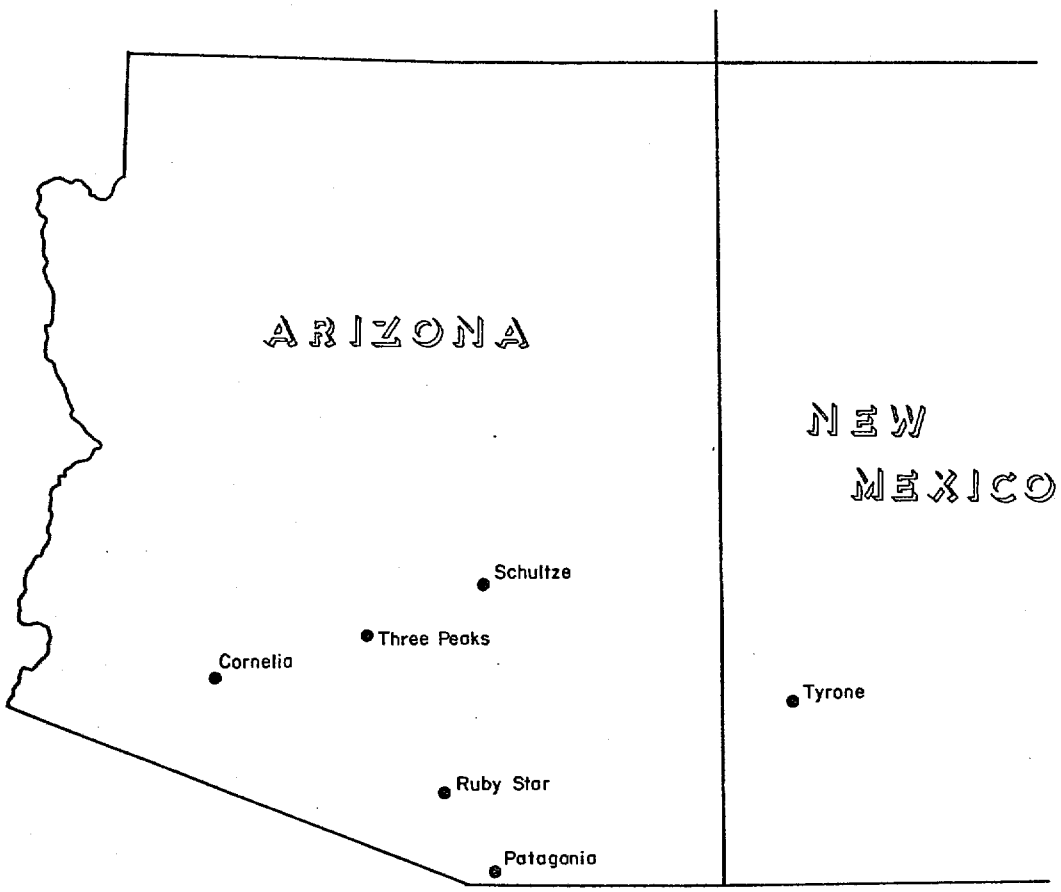
4.) Stollery, G., M. Borcsik, and H. D. Holland, 1971, Chlorine in intrusives: A possible prospecting tool: Econ. Geol., 66, p. 361-367.

Figure 1



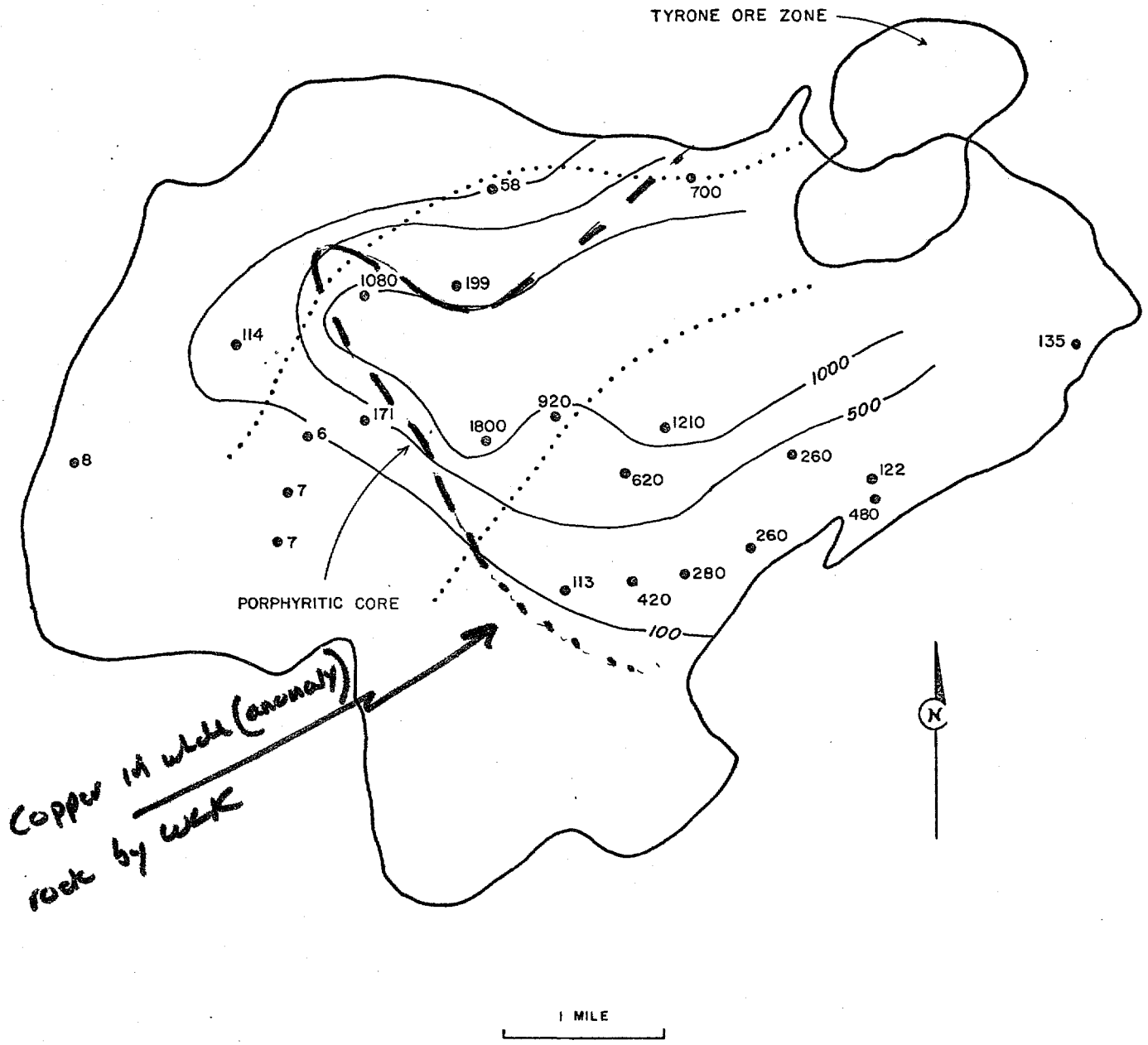
Idealized behavior of Cu in biotite and whole rock samples from a porphyry copper - bearing intrusion.

Figure 2



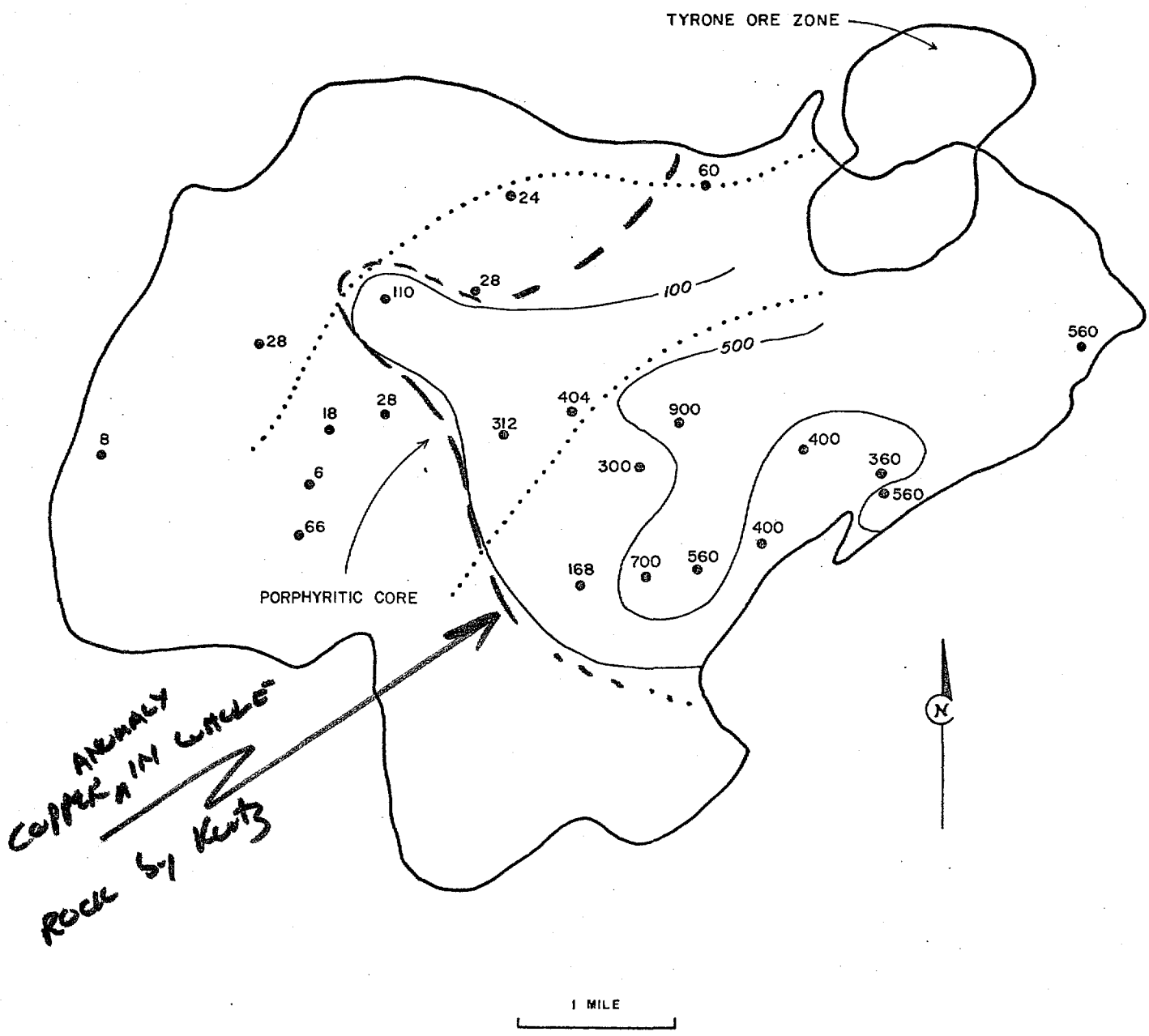
LOCATION MAP OF AREA INVESTIGATED

Figure 3



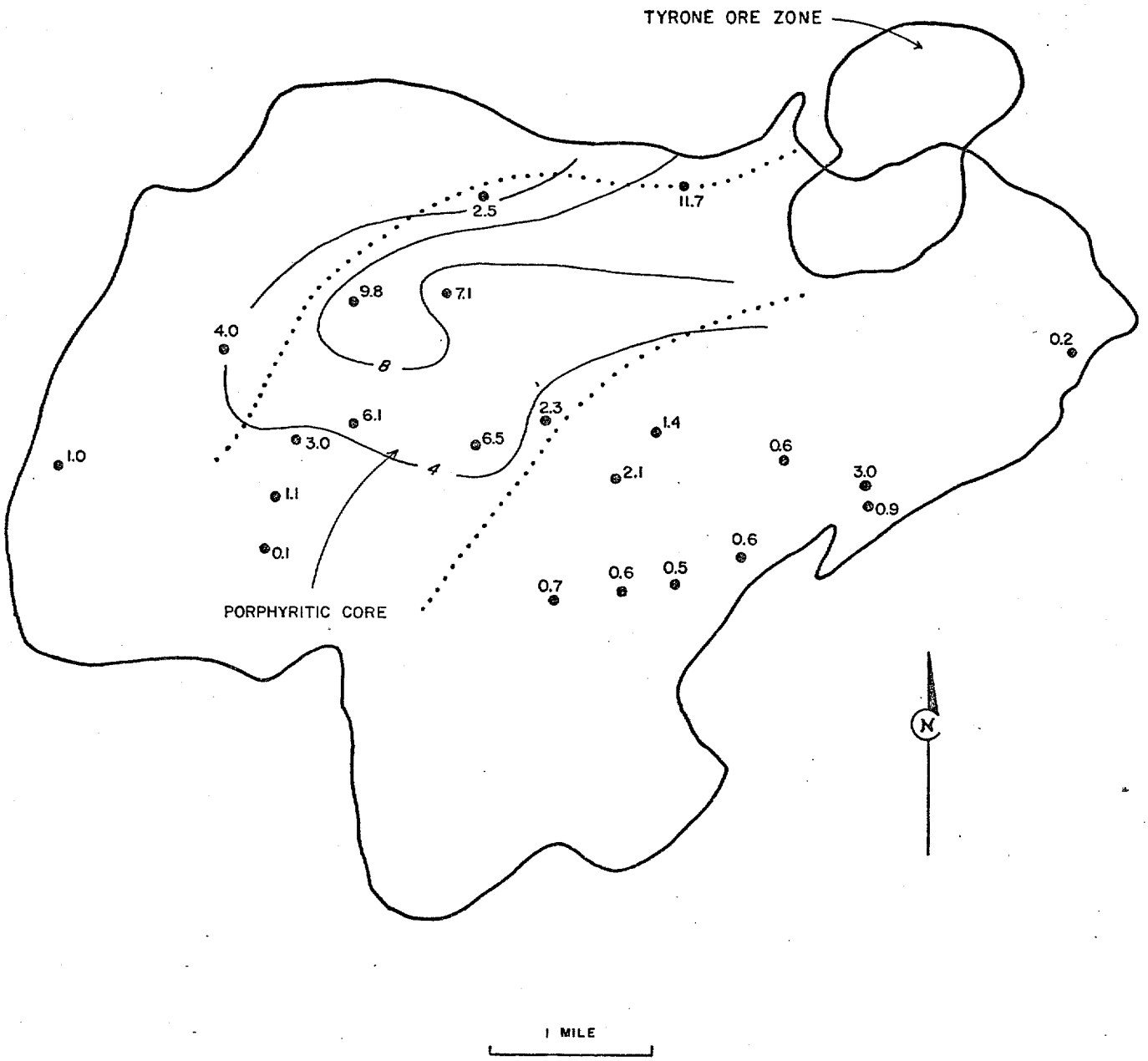
TYRONE QUARTZ MONZONITE
COPPER IN BIOTITE

Figure 4



TYRONE QUARTZ MONZONITE
COPPER IN WHOLE ROCK

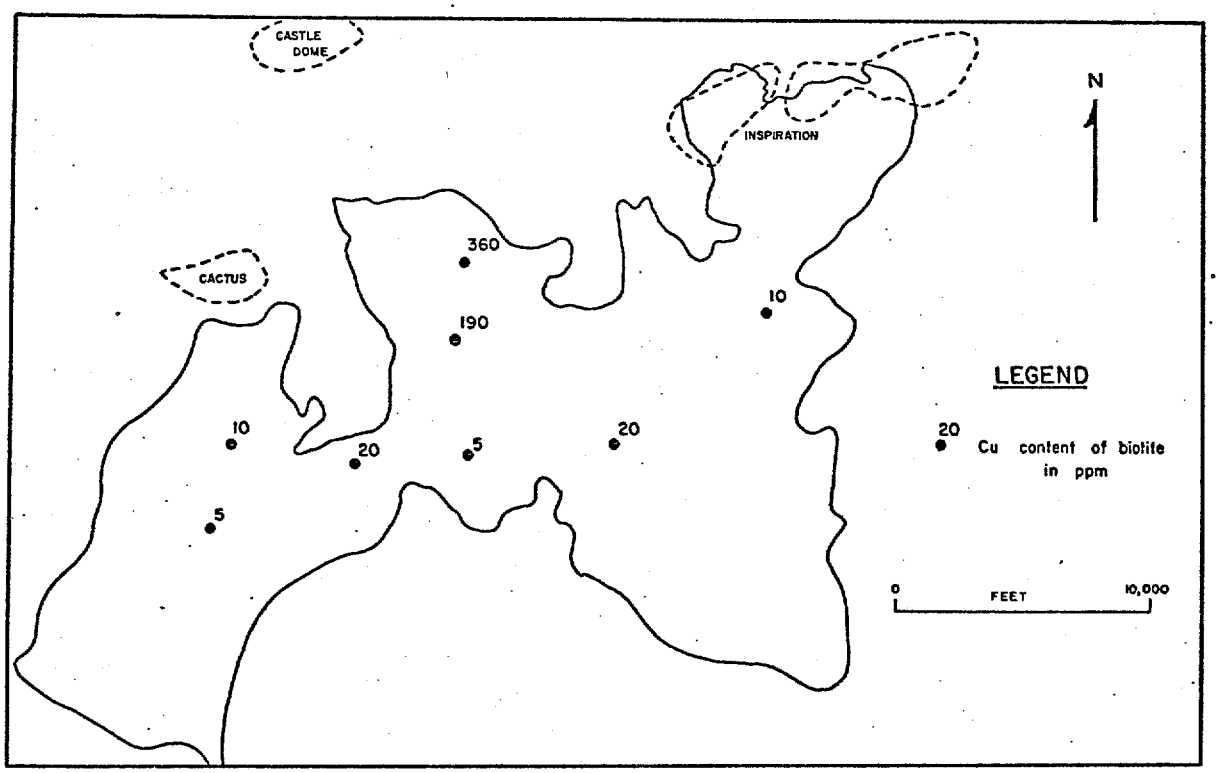
Figure 5



TYRONE QUARTZ MONZONITE

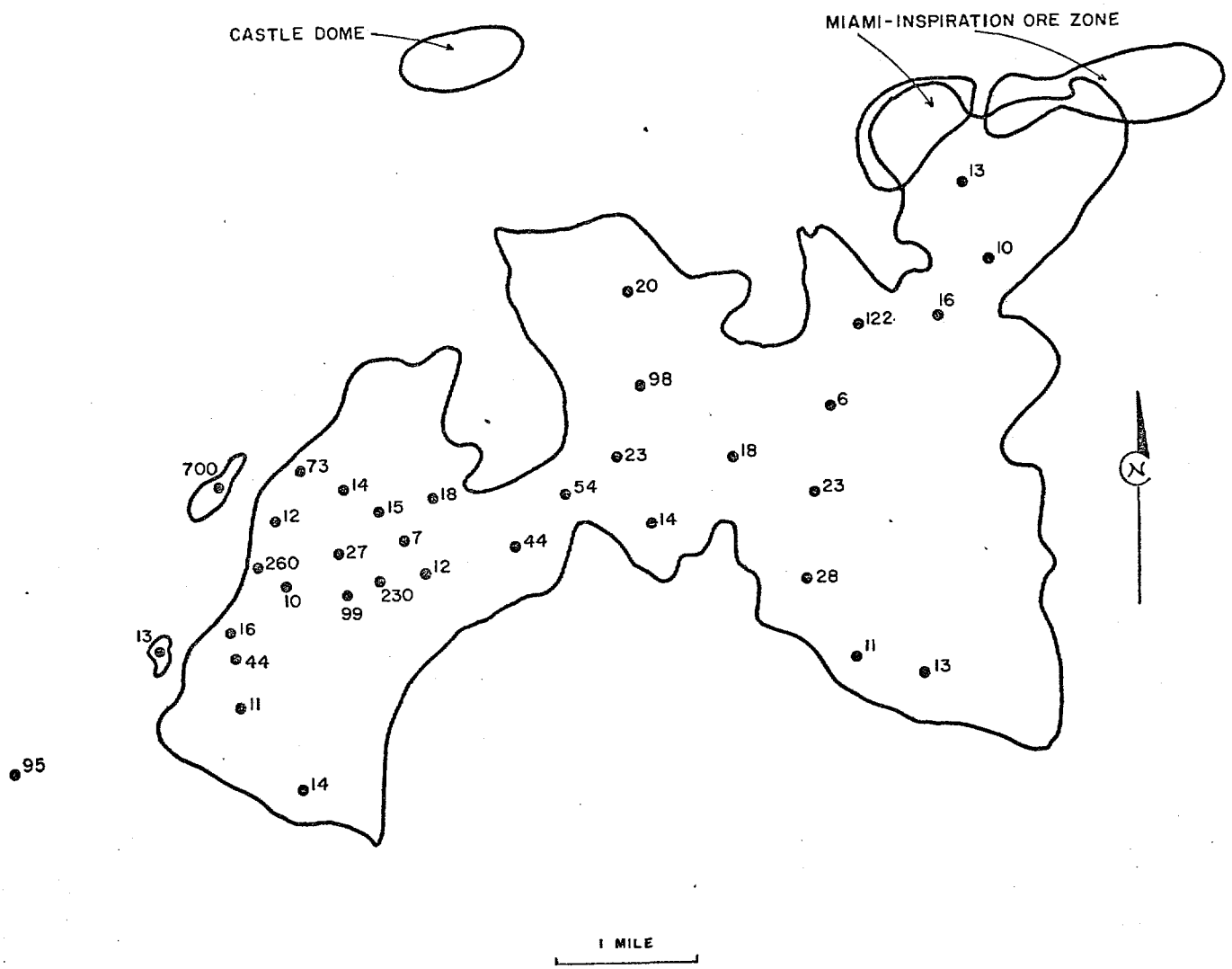
COPPER – $\frac{\text{biotite}}{\text{whole rock}}$

Figure 6



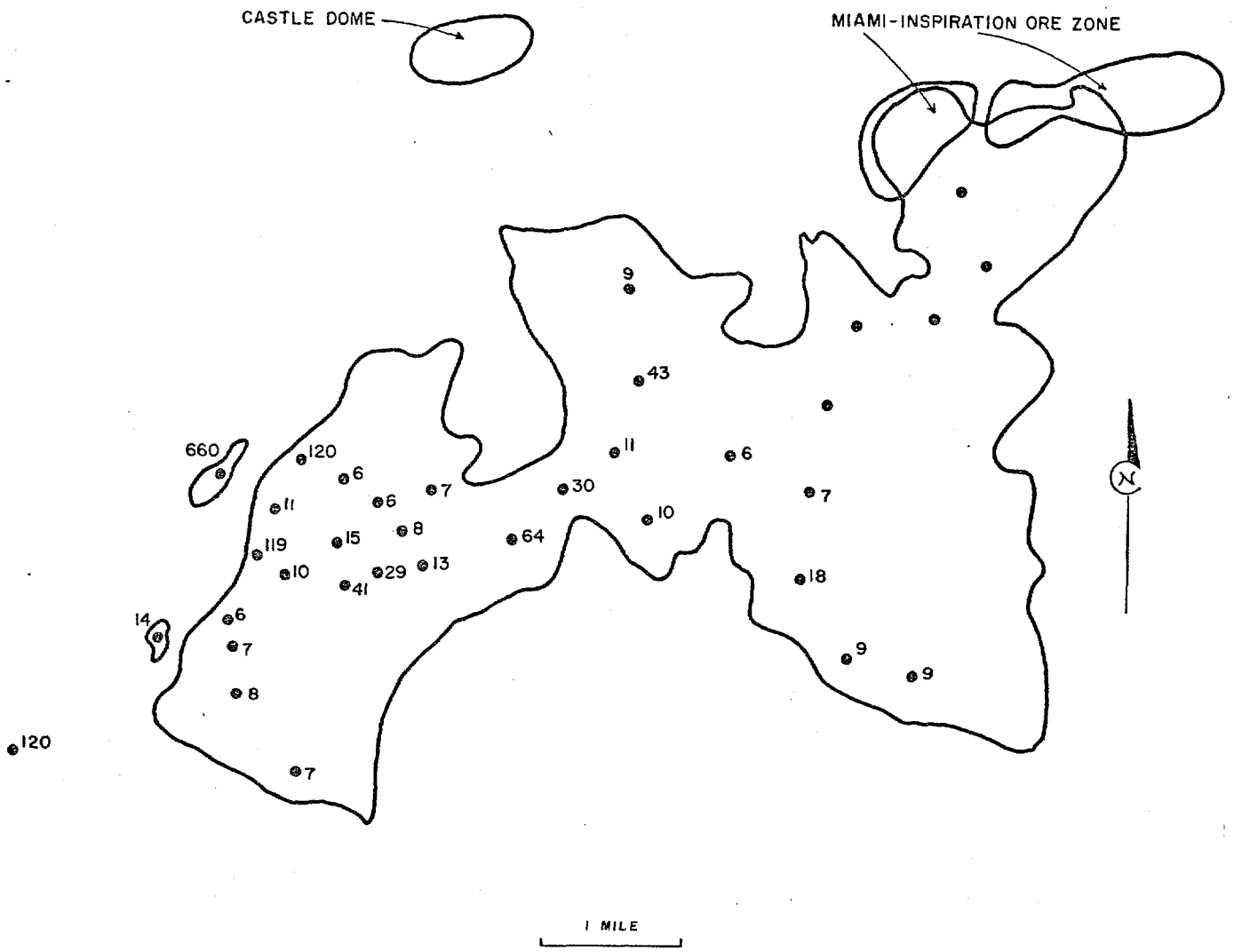
SCHULTZE GRANITE
COPPER IN BIOTITE

Figure 7



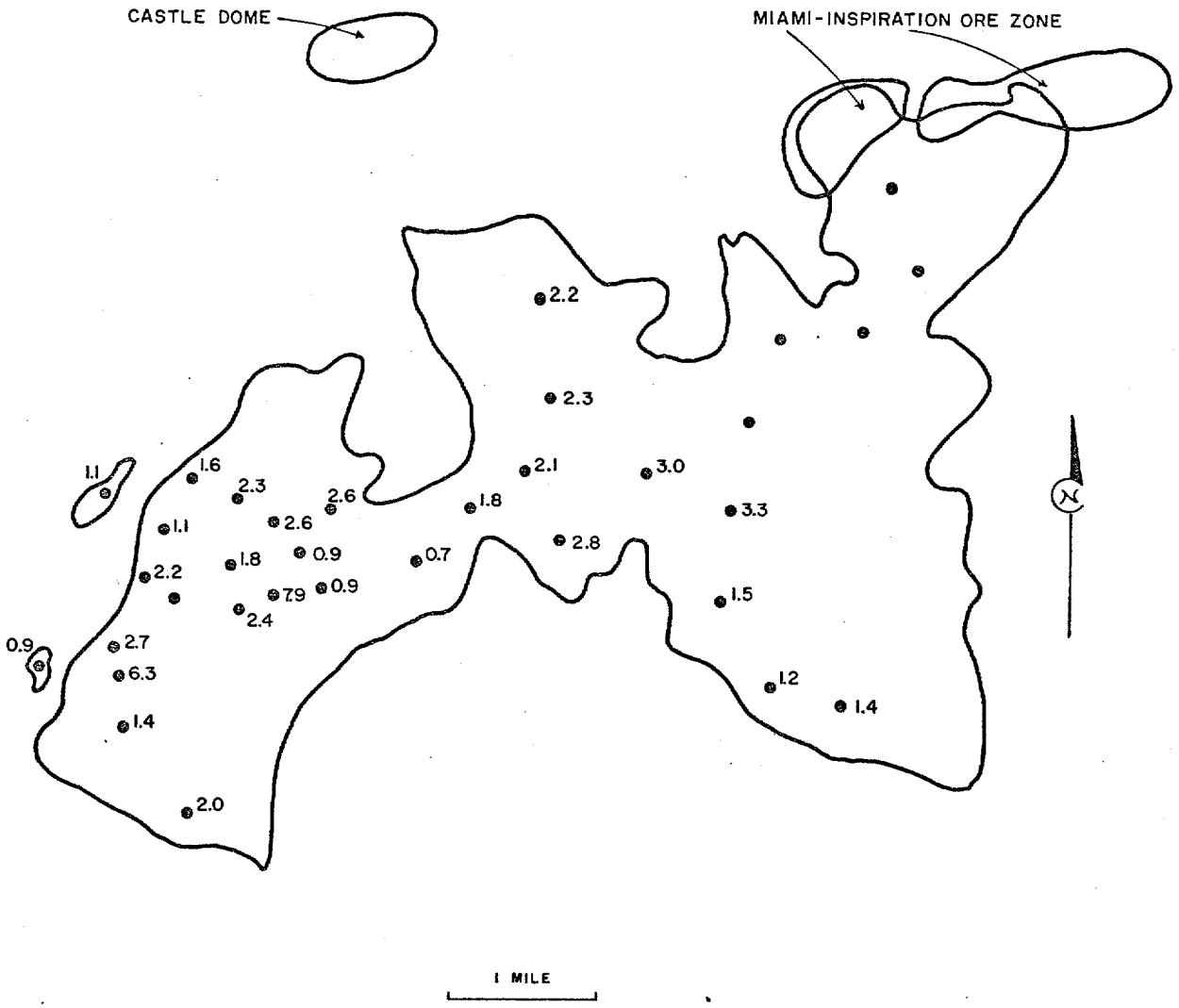
SCHULTZE GRANITE
COPPER IN BIOTITE

Figure 8



SCHULTZE GRANITE
COPPER IN WHOLE ROCK

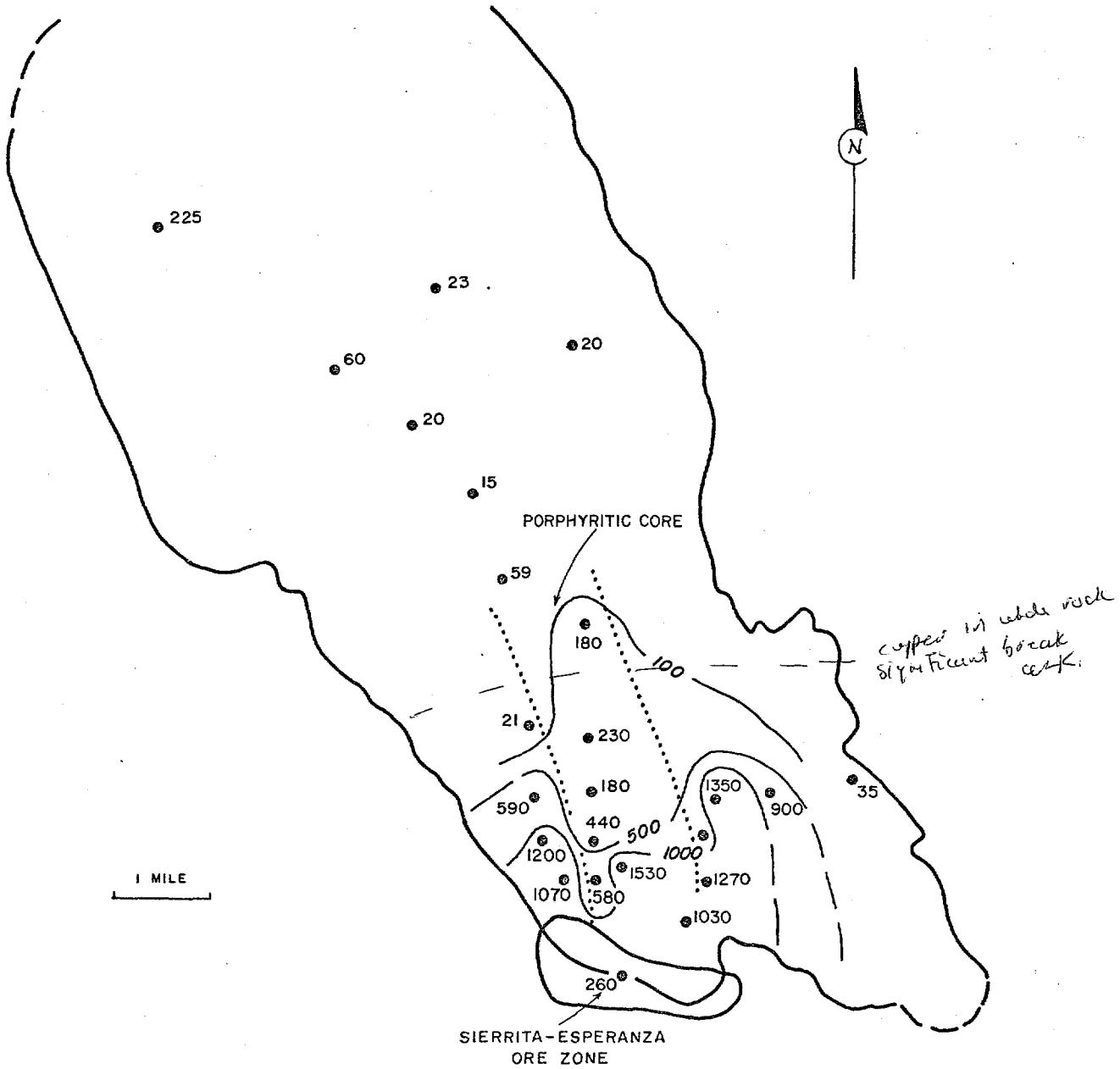
Figure 9



SCHULTZE GRANITE

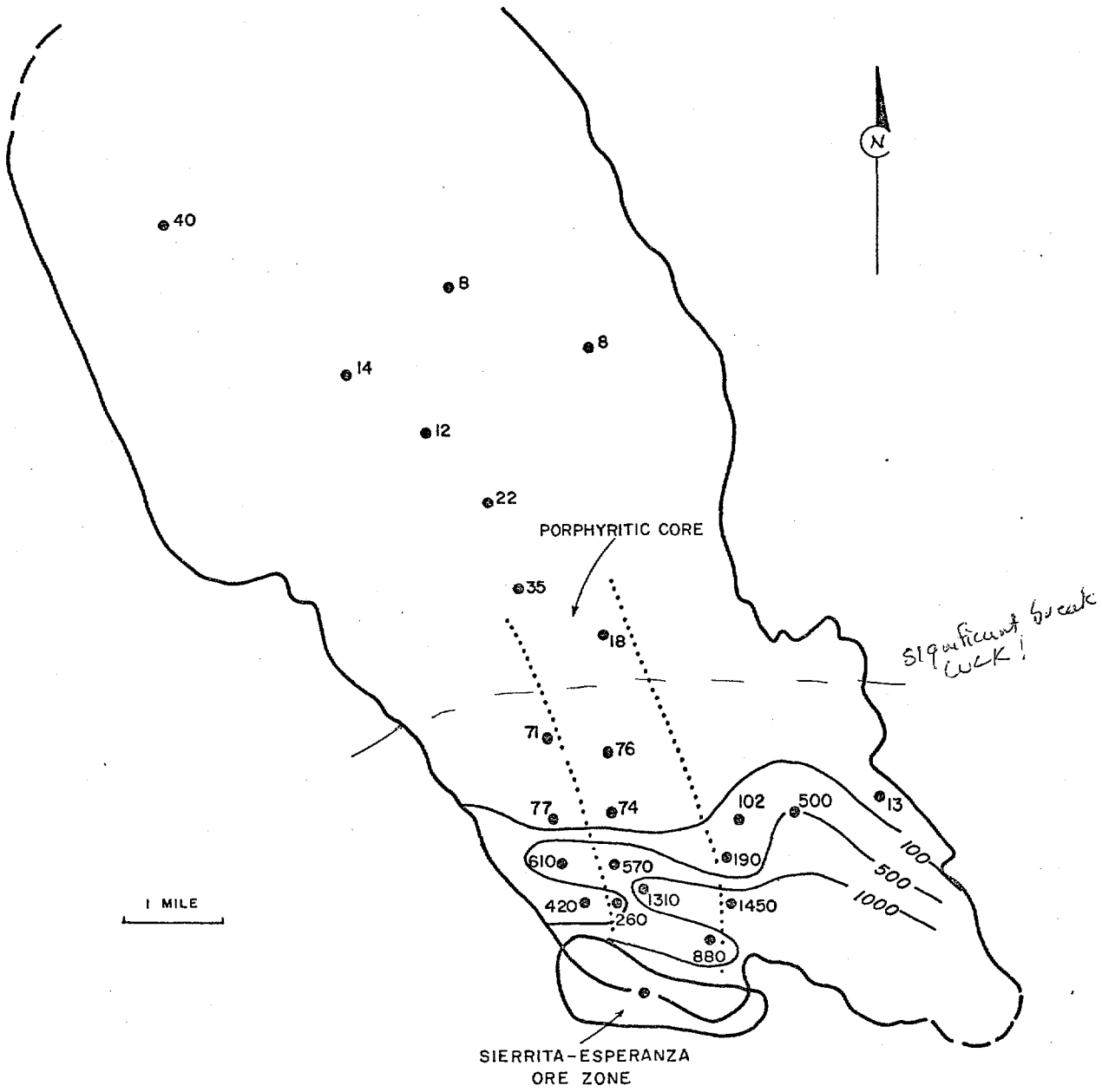
COPPER – $\frac{\text{biotite}}{\text{whole rock}}$

Figure 10



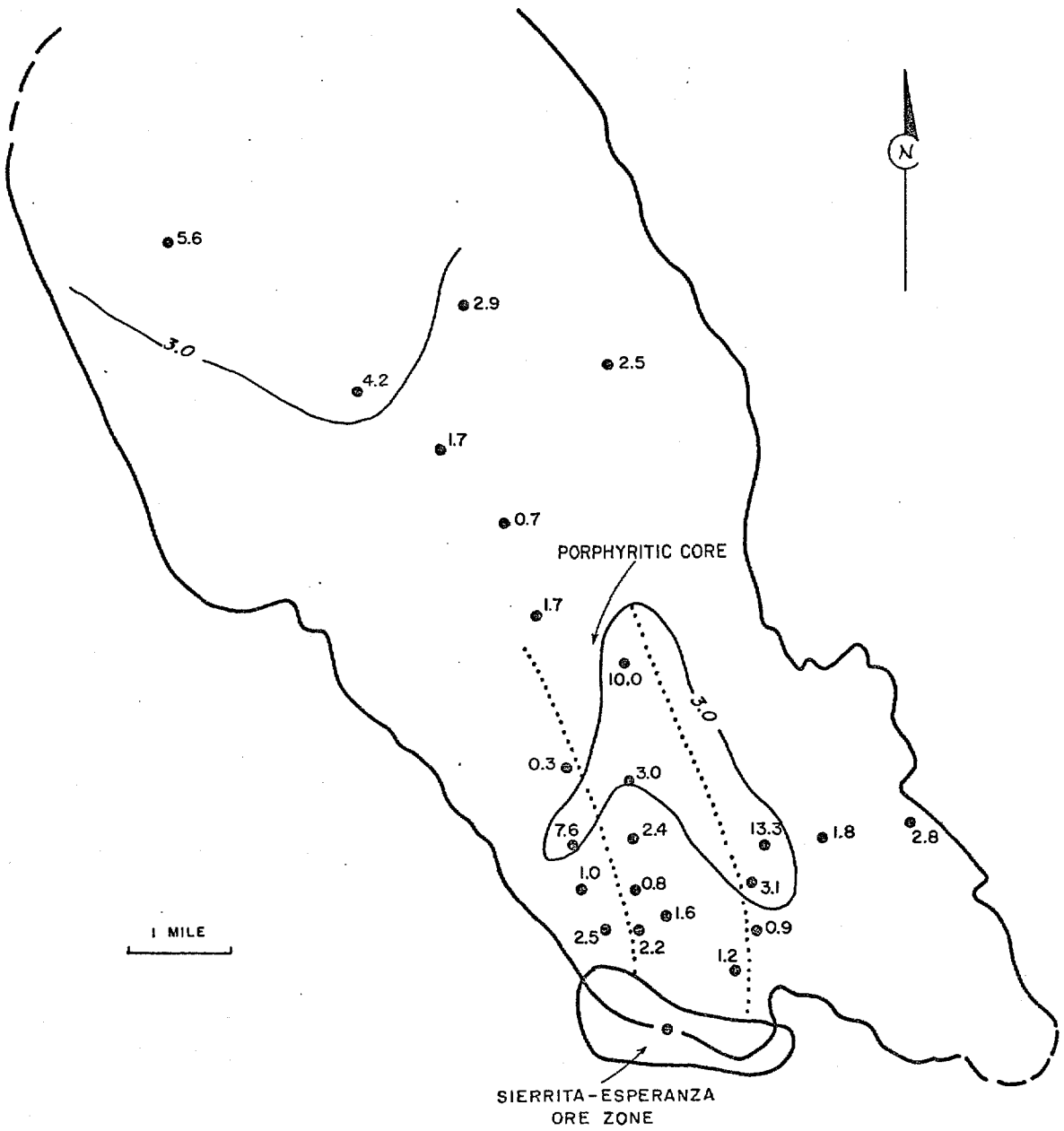
RUBY STAR GRANODIORITE
COPPER IN BIOTITE

Figure 11



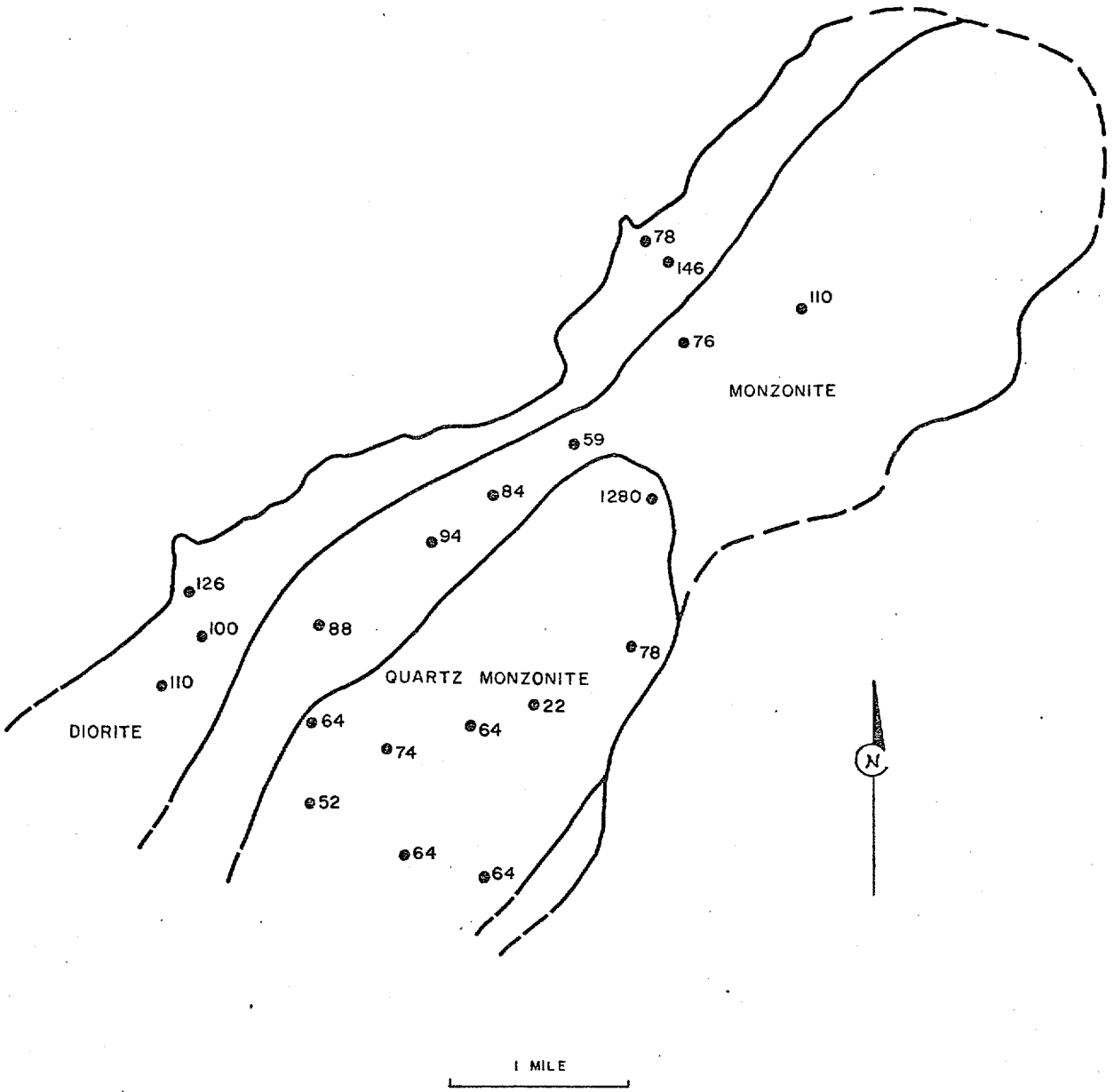
RUBY STAR GRANODIORITE
COPPER IN WHOLE ROCK

Figure 12



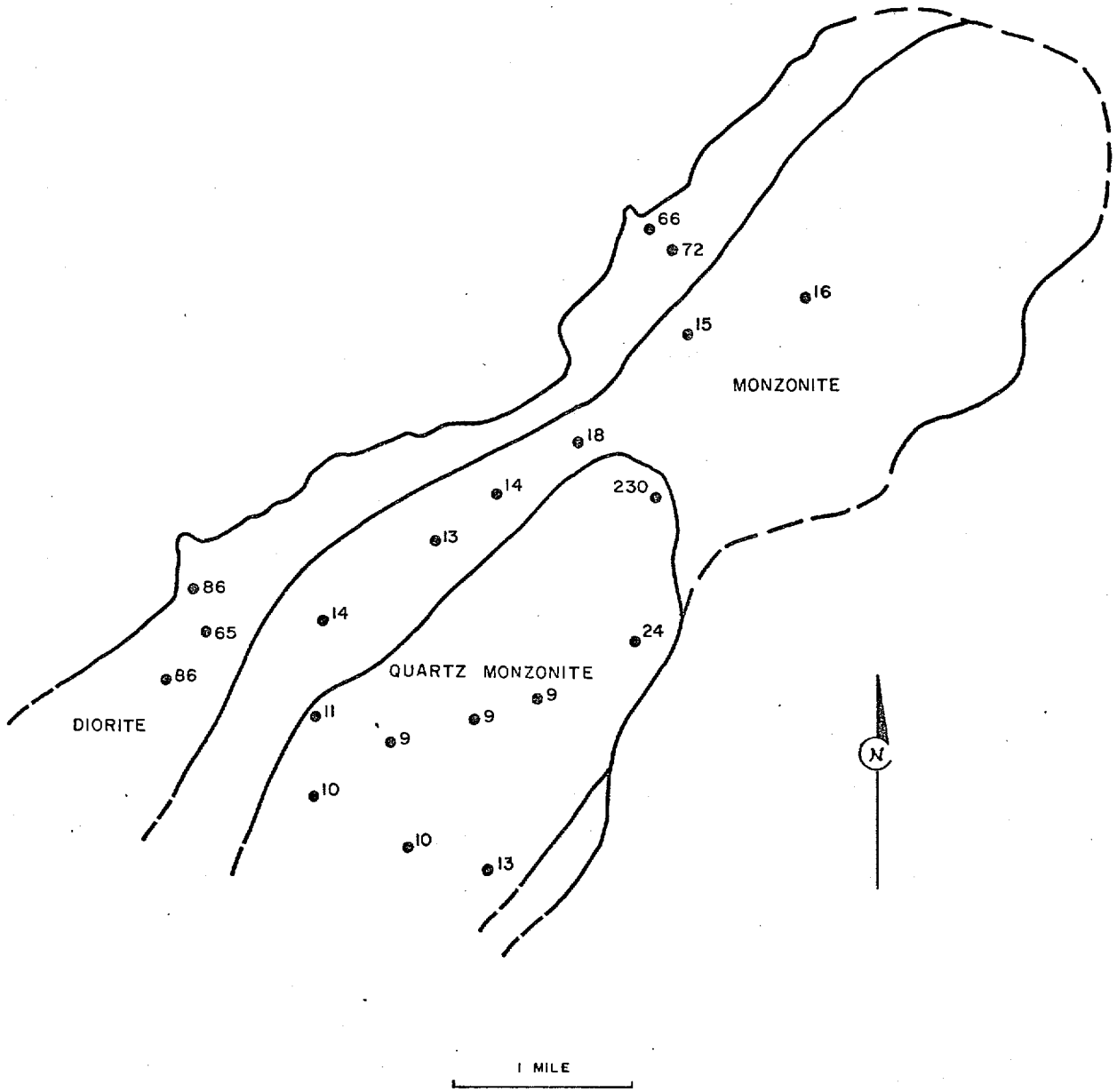
RUBY STAR GRANODIORITE

COPPER - $\frac{\text{biotite}}{\text{whole rock}}$



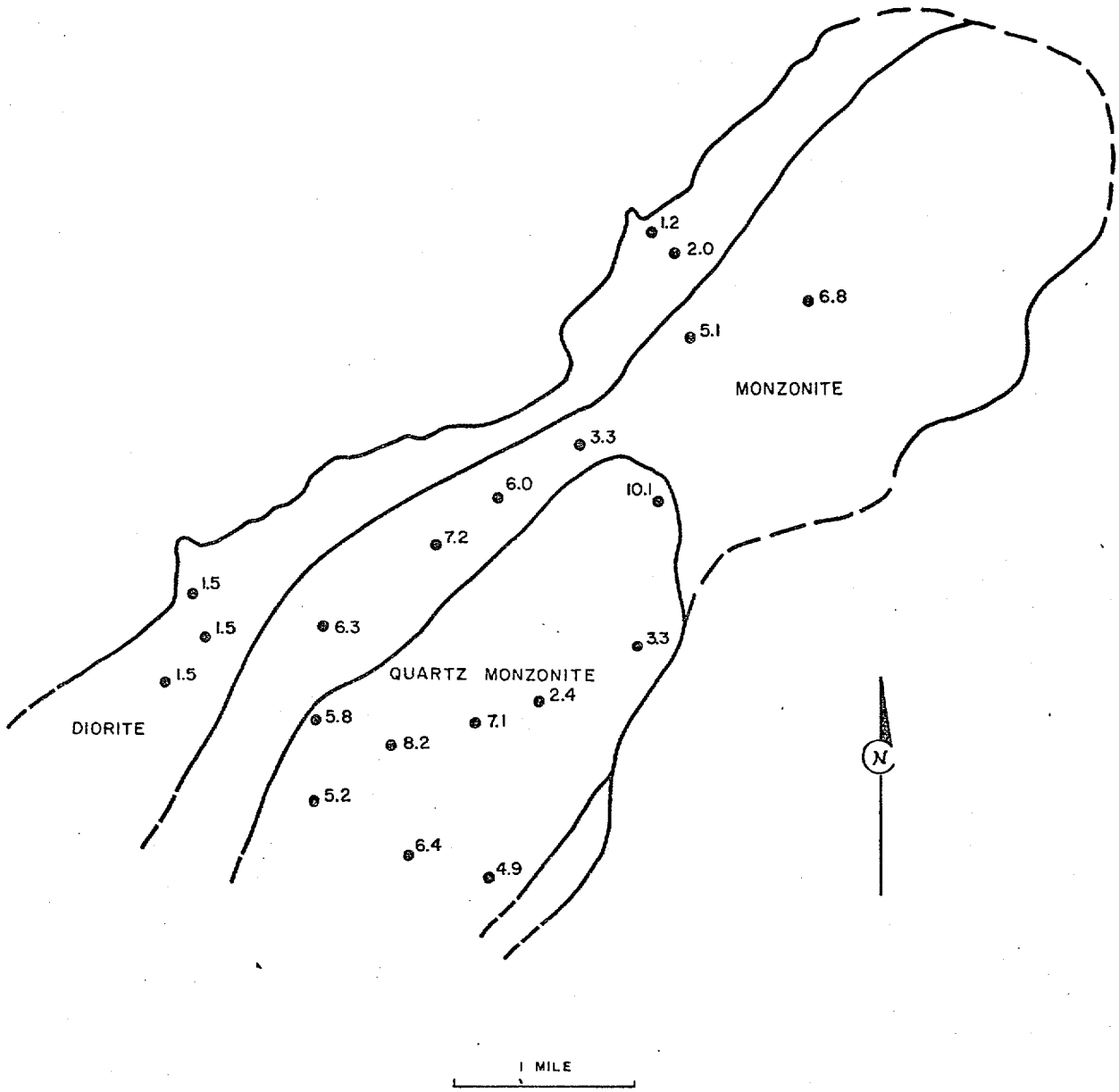
THREE PEAKS STOCK
COPPER IN BIOTITE

Figure 14



THREE PEAKS STOCK
COPPER IN WHOLE ROCK

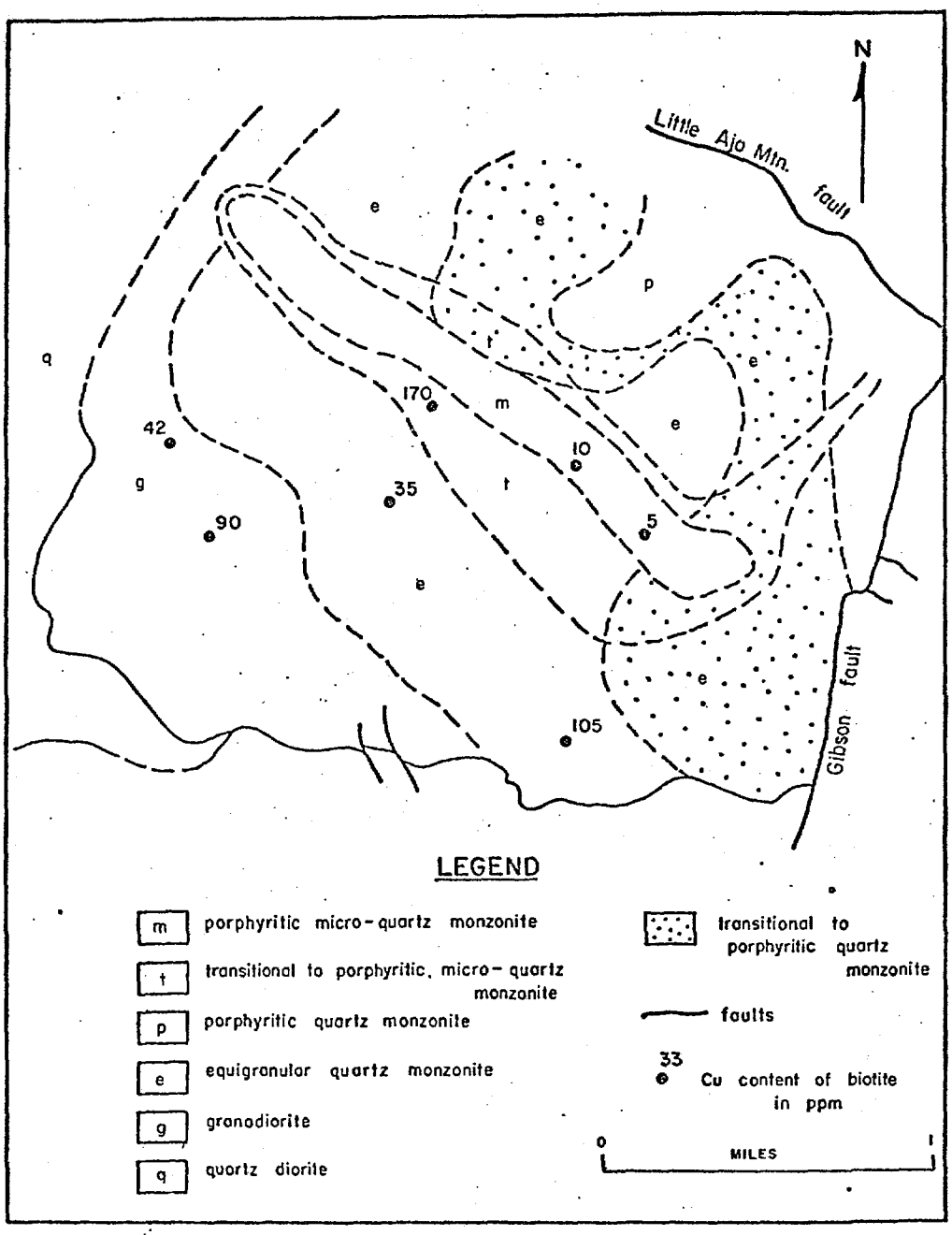
Figure 15



THREE PEAKS STOCK

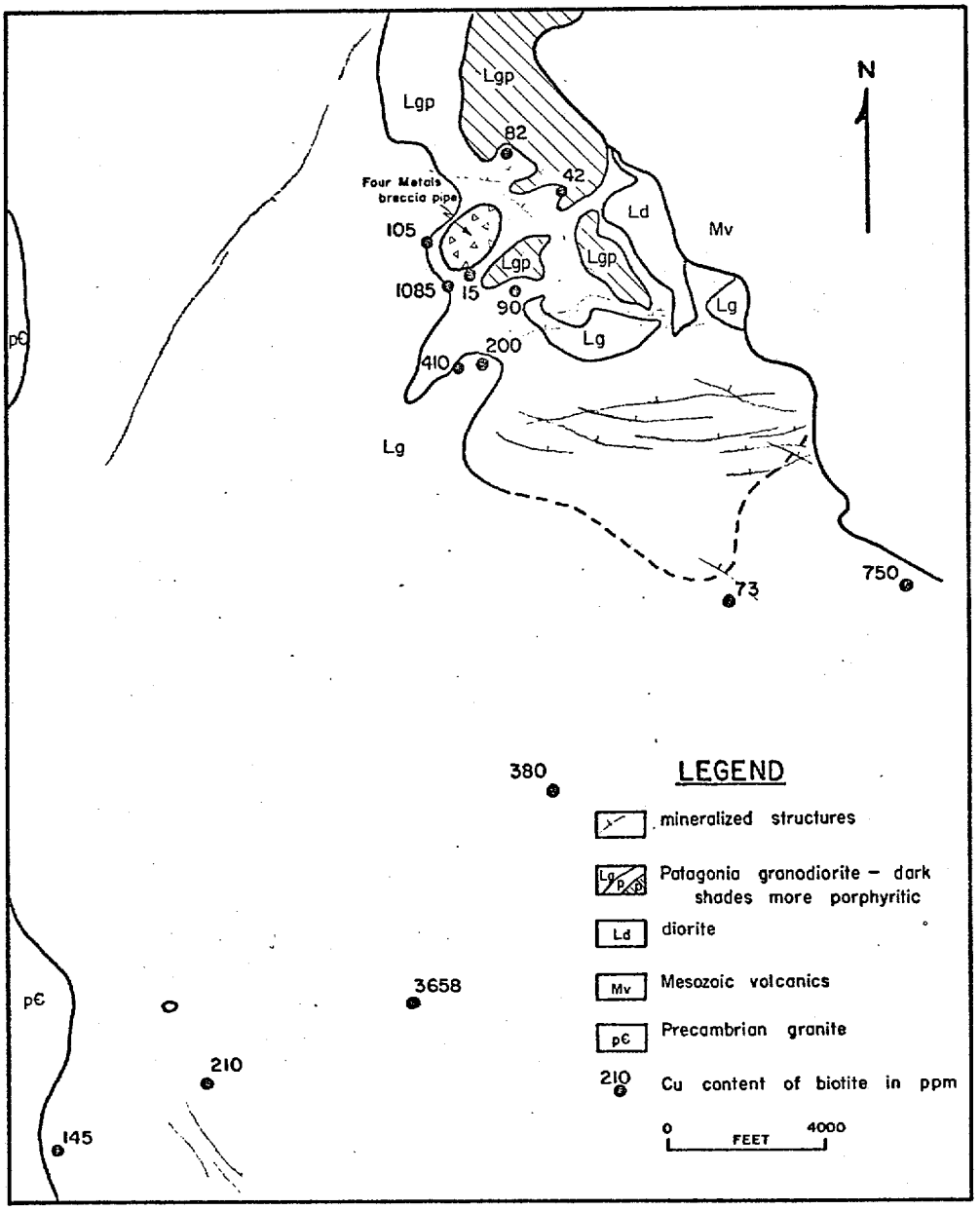
COPPER – $\frac{\text{biotite}}{\text{whole rock}}$

Figure 16



CORNELIA PLUTON
COPPER IN BIOTITE

Figure 17



PATAGONIA GRANODIORITE
COPPER IN BIOTITE

X = samples

Age Dates Greenback -22my

FTG = recommended July 11, 1972

File - Bisbee (copper)

ASARCO

COCHISE

X — (A) TEXAS CANYON STOCK 2 weeks

[Tombstone Scheifelin FTG.
Cantland - Gleason FTG

X — (B) STRONGHOLD GRANITE (22 my)

Silver Bell FTG

X — (A) JUNIPER FLAT 2 weeks

W. L. K.
FEB 20 1972

(B) SOUTH OF BOWIE

PIMA

X — [(A) SIERRITA] 2 - 3 days

Amado

~~(A) GONSALEZ~~ No - small 2 weeks

Comomo Sonsi (Sell?) FTG

(B) TUCSON MTNS No permission granted by Nat'l Mon.

Brownell FTG
Tortilla FTG

~~FTG~~

[(A) Lake shore] — 2-3 days

FTG Santa Rosa (Sell)

FTG Cimarron (Sell)

PIMA (A) MT Greenback 1-2 weeks

MARICOPA (A) White Tanks 1-2 weeks

Harquahala

Yuma FTG Granite Wash

~~Har~~

(OAG)

Graham FTG Stanley - Arawipa

[illegible]

[illegible]

X

X

(55 ml)

X

X

X = [illegible]

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

July 11, 1972

Memorandum to: W. L. Kurtz

From: F. T. Graybeal

Continuation of the Biotite Sampling Program

SUMMARY AND RECOMMENDATIONS

Continuation of the biotite sampling program is recommended. Sampling should be concentrated along the edge of post-mineral cover with as few samples as possible being collected in the interior of the plutons. The 10 areas suggested for exploration using this method are listed in Table 1. Roughly 147 samples should be collected using a 3/4 mile spacing. Sample preparation charges will be roughly $2,550 not including field work and analyses. Approximately 3 months will be required to complete this program.

DISCUSSION

The results of the first phase of the biotite sampling program, as summarized by G. Stathis, were generally unfavorable. It is my feeling that these results were due to a lack of genetically related mineralization in the intrusions sampled rather than any conceptual problems inherent in the method. The absence of any anomalous zones in the Texas Canyon pluton was surprising; however, there appears to be reasonable doubt at the present time that the rock sampled is genetically related to the adjacent mineralization.

I therefore recommend that the biotite program be continued. Procedures to be used in the future should be similar to those followed in the past. Particular attention should be directed toward the recognition of cooling or separate intrusive phases during sampling. Plutons with abundant hydrous minerals such as biotite should be carefully examined as these minerals may indicate the former presence of high water concentrations and, thus, a phase in which base metals might be collected and transported.

It does not appear necessary to sample the entire pluton. Rather, samples should be collected along the edge of post-mineral cover. It is probable that enough of these samples will be sufficiently low to define a background value without excessive work being done in the barren central portion of the pluton. If all samples along the post-mineral contact are high, then further sampling away from this area may be necessary. The

density of samples necessary is hard to estimate, although I would guess that spacing should not exceed 3/4 mile.

Table 1 lists the plutons recommended for sampling during the second phase of the biotite program and their locations are shown on Figure 1. They were selected either because of their association with significant amounts of known mineralization or their occurrence along strong lineaments. In addition to these plutons, additional work was suggested at the south end of the Ruby Star to clarify the anomaly before any more samples were collected from under gravel cover at the north end. A brief investigation should also be made of the isolated highs in the Stronghold granite.

The ten areas listed in Table 1 involve 98 miles of contact with post-mineral cover as estimated from an examination of the Geologic Map of Arizona. This results in a total of 147 samples assuming a 3/4 mile spacing. The cost of biotite separation during the first phase of the program, including mailing, was $17.33/sample. Using this figure, the cost of sample preparation during the second phase of the biotite program would be $2,547.51 rounded to $2,550. This is in addition to the geologist's time in the field and analytical charges. A very rough estimate indicates that about 3 months would be needed for one geologist to complete this program, including office work.

F. T. Graybeal

F. T. Graybeal

FTG:lad
Attachs.

Table 1: INTRUSIONS PROPOSED FOR BIOTITE SAMPLING

Area	Miles of Contact With Post-Mineral Cover	Remarks
1) Tombstone	20	All outliers in the Charleston-Fairbanks area should be examined.
2) Gleeson	8	Jurassic-Triassic age.
3) Silver Bell	5	Both the granodiorite west of Ragged Top and the granite porphyry in the West Silver Bell Mtns.
4) Comobabi Mtns.	15	North and south portions.
5) Brownell Mtns.	3	
6) Santa Rosa Mtns.	7	Two separate plutons.
7) Cimarron Mtns.	6	
8) Santa Teresa	20	12 miles at north end are on the San Carlos Reservation.
9) Tortilla Mtns.	6	West side of Grayback granodiorite, exact length of post-mineral contact unknown.
10) Granite Wash Mtns.	8	

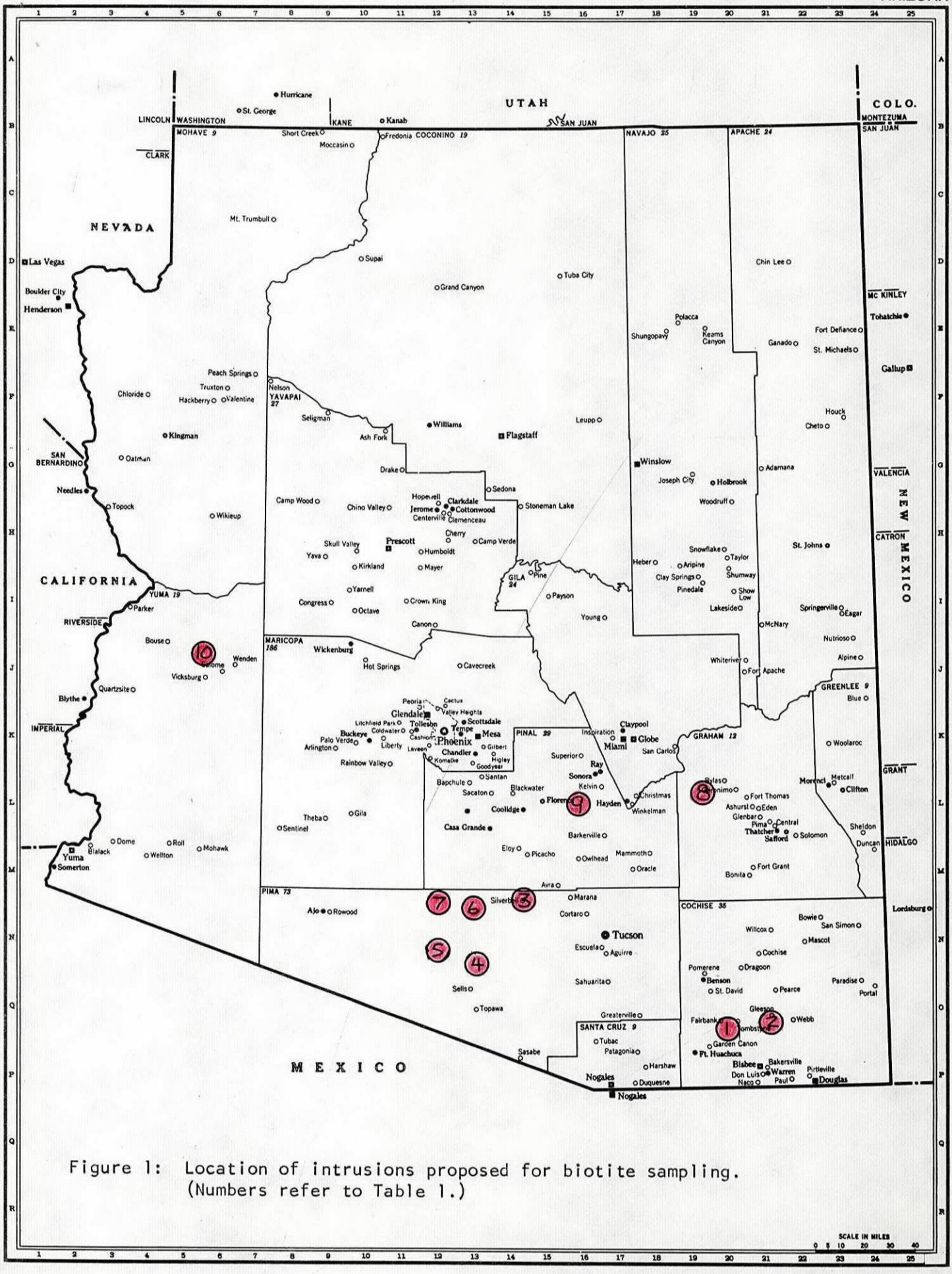


Figure 1: Location of intrusions proposed for biotite sampling. (Numbers refer to Table 1.)

Circulate ASARCO Geologists and return to WES

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

W.E.S.
MAY 28 1971

May 24, 1971

TO: W. E. Saegart

FROM: J. R. King

Re: BIOTITE PROJECT

In referrence to L. D. James' memorandum of 19 May 1971, I wish to point out that I believe the new data on the Rudy Star intrusive not only confirms the picture obtained from the original U.S.G.S. and ASARCO data, but delineates a working model to be applied to exploration. As now can be seen, a 500 ppm Cu anomaly surrounds the Sierrita Esperanza mines for a distance of one to three miles.

I have reviewed most of the literature on Cu content in ferromaguesium minerals over the past several months and I now believe the following statements are valid conclusions resulting from this investigation.

It is statistically probable that Cu will be anomalously concentrated in biotites with proximity to hydrothermal copper mineralization. The more significant the mineralization is, the greater is the probability that a geochemically observable "Cu in biotite" halo will exist several miles away from the mineralization.

J. R. King

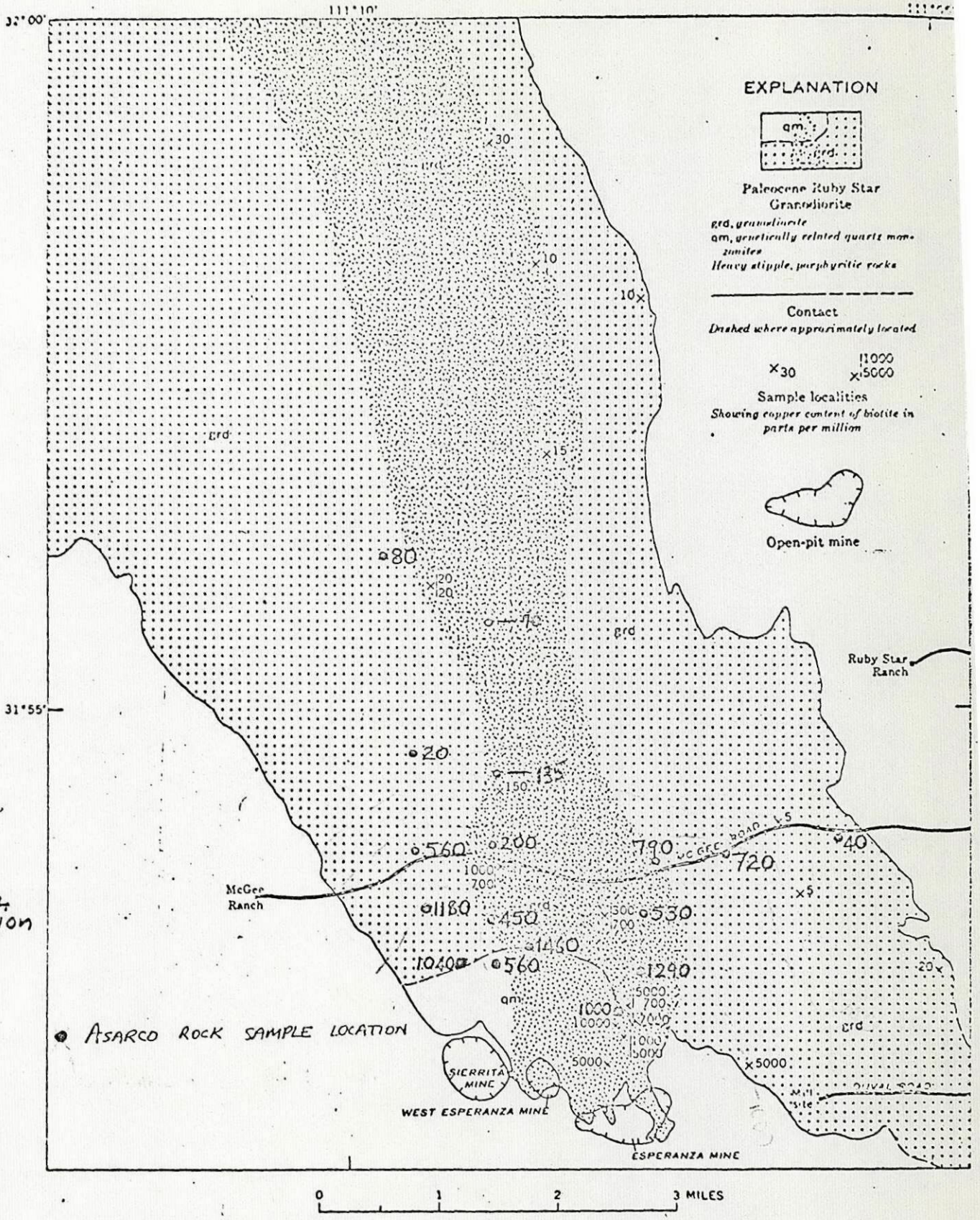
J. R. King

JRK:sh

Note to all ASARCO Geologists:

I agree that applicability of technique appears to be demonstrated. Now we need the benefit of our collective thinking to select areas for application (exploration - not research). Add your recommendations to list attached.

WES



Biotite

Cu

stal digestion
+ A.A.)

9. 2a

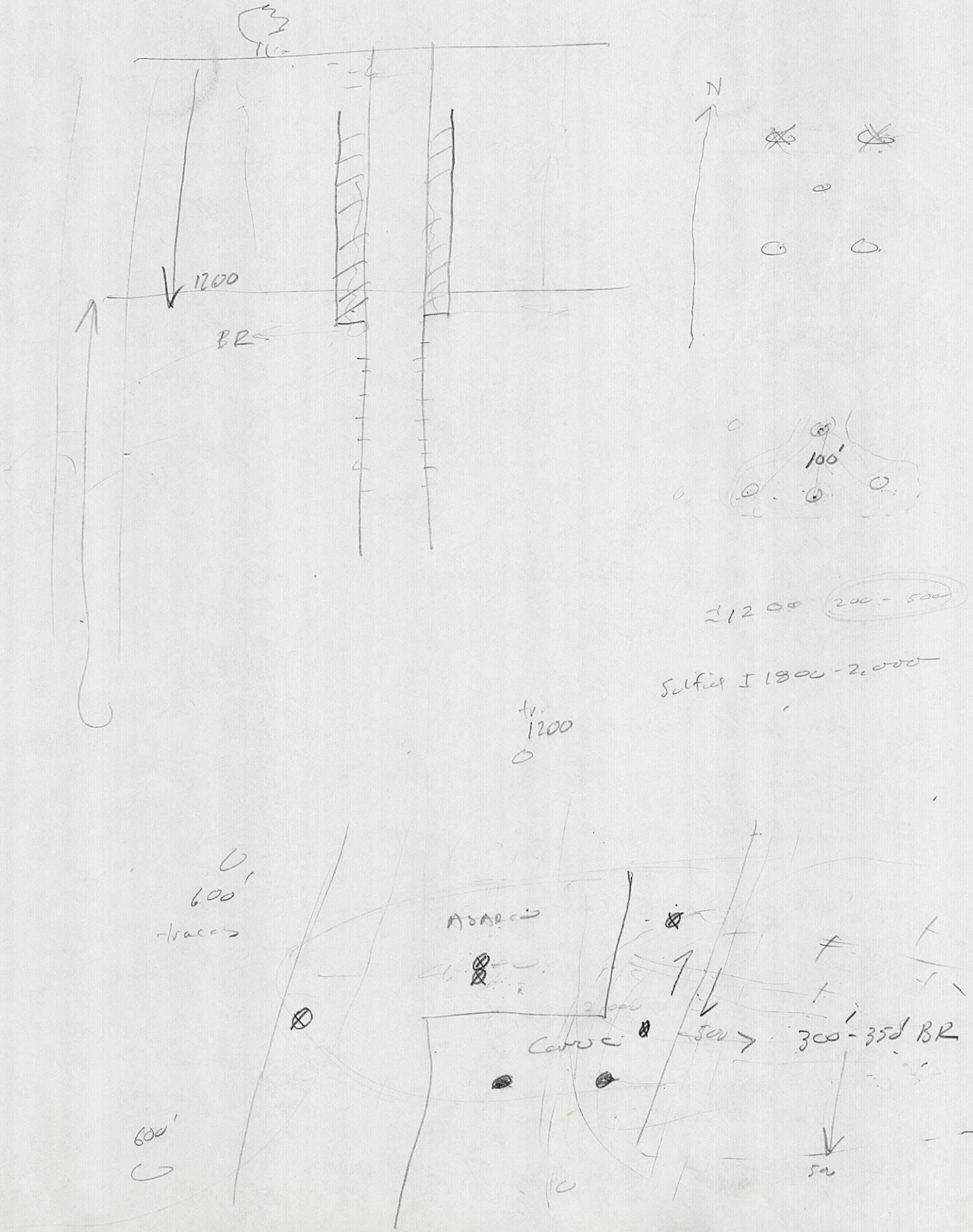
FIGURE 2.—Generalized map of composite stock and associated ore deposits in the southwestern part of the Plata mining district, east of the Sierrita Mountains, showing sample localities and copper content of biotite.

Cu content (ppm) of biotite in Asarco Rock samples
(analysis by Geochemical Laboratory using an A.A.technique)

LIST OF GRANITIC PLUTONS

Recommended for Cu in Biotite geochem sampling — as proposed by ASARCO geologists

Locality	Recommended by
South End of Texas Canyon stock where some alteration in shear zones (?) exist.	JDSell - (& JRK) & SI W. end
Three Peaks stock } Sawtooth Peaks stock } Sawtooth	J.C.B. (& JRK)
North end of Ruby Star stock	JCB
Mineral Mountain Qtz monzonite	JCB
Stronghold granite	JCB
Juniper Flat granodiorite	JCB
Continental granodiorite	JCB
Madera Canyon granodiorite	JCB
Schieffelin granodiorite	JCB
Gleason qtz monzonite	JCB
Copper Belle monzonite	JCB
Mtn Tumbill intrusive complex	JRK
Patagonia Mtns Granod.	S.R.D
How about the intrusives on the West side of the Sierrita Mts. (alaskite, granite, qtz. monz, diorite, etc.) as mapped by Blucher ?	NPW
S. Comobabi Mts., Dos Cabezas Mts., & NW and SE ends of the Pinaleno Mts.	BEF


1200
BR
N
100'
≈1200
200 - 500
Sulfid I 1800 - 2,000
1200
600'
traces
600'
300' - 350' BR
50

J. H. C.

FEB 6 1973

JAN 15 1973

W. L. K.

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

January 15, 1973

TO: W. L. Kurtz

FROM: J. R. King

Texas Canyon Stock
Biotite Program
(personal evaluation)

The accompanying map shows the Texas Canyon stock and the preliminary results of the biotite sampling program conducted by Steve Davis. The contouring is my interpretation of the data. I know little about the geology of this area and am relying strictly on Steve Davis' mapping for interpretation of the sample results.

Briefly, I believe this data shows exactly what we hoped to see by using the biotite program:

1. a weak but definite, contourable anomaly at the edge of a porphyritic Laramide intrusive which disappears under post-mineral cover;

2. a general trend of contours pointing in the direction of most favorable exploration potential; and

3. (as an added bonus) a discernible increase in alteration along with the copper in biotite anomaly at the edge of cover.

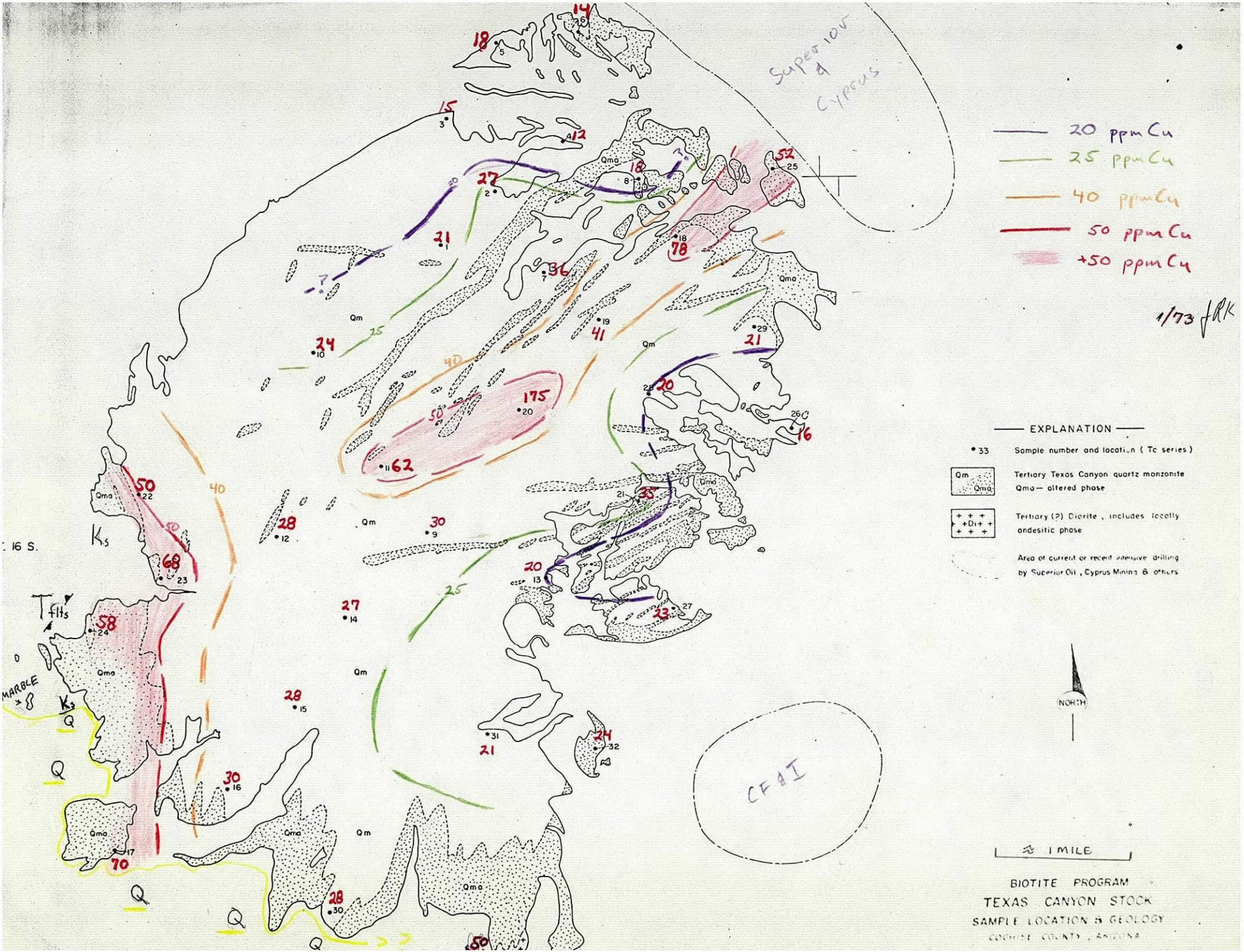
This data, when interpreted in light of ASARCO's research, is delineating a permissible target area of high priority. If the data is real, then the acquisition of available State land sections lying to the SW and the compilation of a land status map for this area (for eventual drilling by the geologic drill) is advisable.

Above all else, I feel that this data shows that the biotite program is extremely useful in basic porphyry copper exploration and should be actively used while we still have the jump on the competition.

John R. King

J. R. King

JRK:lb
Attach.


20 ppm Cu
25 ppm Cu
40 ppm Cu
50 ppm Cu
+50 ppm Cu
1/73 JRK
Superior & Cyprus
EXPLANATION
33 Sample number and location (Tc series)
Qm Qma Tertiary Texas Canyon quartz monzonite
Qma — altered phase
Di Tertiary (?) Diorite , includes locally andesitic phase
Area of current or recent intensive drilling by Superior Oil , Cyprus Mining & others
NORTH
≈ 1 MILE
CF&I
MARBLE
BIOTITE PROGRAM
TEXAS CANYON STOCK
SAMPLE LOCATION & GEOLOGY
COCHISE COUNTY , ARIZONA

Bill,

Will try to remain open-minded on a subject I obviously have rather strong opinions toward - but I will always be ready and all-too-willing to argue the subject.

Re: further work at the SW end of the Texas Canyon intrusion, I know so little I hesitate to comment, but it looks like a reasonable bet. Also, the alignment of increased Cu-in-biotite can be (I did) interpreted as a magmatic phenomenon giving us an indication of the internal phase structure. Thus, using John Ballis thoughts the NE or SW ends would be attractive places to look.

Fred.

EFG- appreciate your comments, see more at end.

W. L. K.

FEB 2 1973

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

January 22, 1973

TO: W. L. Kurtz

FROM: F. T. Graybeal

Commentary on the results of biotite sampling in the Texas Canyon stock, Cochise County, Arizona

A recent evaluation of biotite sampling by S. R. Davis of the Texas Canyon stock was made by J. R. King (Jan. 15, 1973). I wish to correct several errors in Mr. King's memo and to suggest a more specific criteria for the recognition of anomalous values.

Mr. King incorrectly states (para. 2, #1) that a weak contourable anomaly exists along the southwest contact of the intrusion. Using his map, the average background of Cu in biotite in this area appears to be 27-30 ppm. The so-called anomalous values vary from 50-70 ppm averaging perhaps 65 ppm. This is a contrast of roughly 2. Reference to previous reports by myself and Mr. King clearly demonstrates that much higher thresholds are associated with porphyry copper mineralization.

Mr. King concludes, also incorrectly (para. 3), that the data demonstrate ...."a permissible target area of high priority". Actually a brief inspection of the data shows that "anomalous" amounts of Cu in biotite also occur in the central portion of the intrusion, a well-exposed area containing no significant mineralization. I am forced to conclude that the gradual, but systematic, variations of Cu in biotite result from the normal course of differentiation and crystallization of the intrusion. I also conclude that, even if a deposit is present near the southwest end of the intrusion, no indication of its presence can be inferred from the biotite data and, thus, that this particular set of data does not demonstrate the usefulness of the biotite program.

Previous reports by both myself and Mr. King do not contain any explicit statements concerning anomaly threshold values. Threshold values were generally assumed to occur where a sharp rise from the background values of Cu in biotite was encountered. To hopefully facilitate the interpretation of further data, I present a list of approximate background and threshold values obtained from an inspection of maps of previous sampling results:

	Cu content of biotite in ppm		threshold / background contrast
	background	threshold	
Tyrone	7	100	14
Schultze (FTG)	10	200	20
Schultze (JRK)	20(?)	100-200(?)	~~10-20~~
Ruby Star	35	200	6
Patagonia	200(?)	1000-3000(?)	5-15

This tabulation suggests that a reasonable anomaly threshold for a Cu-in-biotite anomaly is 10 times the average background, although it could perhaps be lowered to 5-7 times if other favorable criteria were present.

Mr. King and I are both strongly of the opinion that the biotite program can be a valuable tool for the evaluation of potentially productive intrusions. Care should be taken not to draw conclusions based on too little data or incorrect interpretations because work to date indicates that if an anomaly is present it will be easy to recognize. Failure to locate an anomalous area indicates either that 1) the intrusion is not genetically associated with mineralization, or 2) the samples were taken too far from existing mineralized zones, but does not cast doubt upon the validity of the method. It has been casually suggested that the absence of an anomalous set of values in the recent first pass at biotite sampling indicates the method doesn't work. It would be equally accurate to assume that the absence of an anomalous set of values in a group of rock chip samples indicates that rock chip sampling doesn't work.

F. T. Graybeal

F. T. Graybeal

FTG:lb

I don't believe this statement is correct — like all of geology we like to have models yet most all ore deposits have their own unique characteristics — The first pass sampling was not as encouraging as we might have wanted — re: Bisbee (where other geologic facts are interesting however), Texas Canyon (where Johnson Camp — Dragoon not well, if at all, suggested but maybe we didn't sample right intrusive (what's the mineralizer for Superior anyway?)

I agree your comments Re Texas Canyon may well be right — a few more samples to the SW (under alluvium) are probably well justified to try and ~~that~~ see if an increase occurs in this direction near edge of stock. Kurtz

beneath Qal

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

February 5, 1973

TO: W. L. Kurtz

FROM: J. R. King

Texas Canyon Stock
Biotite Program
Re-evaluation

In reference to F. T. Graybeal's commentary on my evaluation of the Texas Canyon stock, I wish to state that after talking to Fred I still am encouraged by the biotite data from the Texas Canyon.

I stand by my previous statements with the exception of the usage of "high" priority. Fred and I disagree on the definition of anomaly and on the relative potential of a hidden porphyry copper zone lying to the southwest as indicated (or not) by the biotite data.

If a geologic drill becomes available, then I feel that this area should be considered for drilling, barring more favorable results from other areas.

John R. King

John R. King

JRK:lb

WLK
File with Biotite

AMERICAN SMELTING AND REFINING COMPANY
EXPLORATION DEPARTMENT
P.O. BOX 5747, TUCSON, ARIZONA 85703

J. H. COURTRIGHT
CHIEF GEOLOGIST

1150 NORTH 7TH AVENUE
TELEPHONE 602-792-3010

June 8, 1972

W. L. K
JUN 12 1972

Mr. Eric Swanson
Asarco
Canada - Buchans Unit
Buchans, Newfoundland

CHLORITE

Dear Mr. Swanson:

Enclosed is a memo by Mr. Graybeal on the possible application of variations in the Fe/Mg ratio of chlorite to exploration at Buchans.

Ratio variations may be detected with standard petrographic equipment by making quantitative estimates of birefringence either in oil emersions or thin section.

In view of the high density of diamond drill holes in and around Buchans ore bodies, there should be ample opportunity to determine ratios existing at various distances from one or more of the deposits. If these results proved favorable, the investigation could then be extended to outlying, wider spaced holes.

Very truly yours,

J. H. Courtright

J.H. Courtright

JHC:kre
Encl: as noted
cc: J.J. Collins w/encl.
F.T. Graybeal w/o encl.

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

June 7, 1972

FILE MEMORANDUM

Variation of the Fe/Mg Ratio
In Chlorite as an Ore Guide

The association of chlorite with sulfide mineralization, particularly in the stratiform massive sulfide deposits in volcanic rocks, has been known for many years. However, the occurrence of chlorite in many different rocks, in many different chemical and structural forms, and as an ubiquituous constituent of greenstone, has apparently restricted use of this association as an ore guide.

The first attempt to understand the spatial distribution and chemistry of chlorite associated with sulfide ores and to apply this knowledge to ore finding was made by Price (1934). He noted that the Fe/Mg ratio changed in a regular way with distance from ore and was able to recognize these differences petrographically, thus determining both association with and direction toward ore. Recent work of a very similar nature has been reported by Miller (1961), Eckstrand (1963), and in a more general way in the book edited by Tatsumi (1970). Eckstrand's work indicated that ore-associated changes in the Fe/Mg ratio of chlorite in the Chibougamau district could be detected over 400 feet from the veins.

Differences in the Fe/Mg ratio of the chlorites exert a strong control on the birefringence, or difference between the high and low indices of refraction (n). Quantitative estimates of the birefringence can be made from immersion mounts of grains in oils of different n (Eckstrand, 1963) and from thin sections by using a Berek compensator. In addition, qualitative estimates of the Fe/Mg ratio can be made by measurement of the sign of elongation (Albee, 1962). These techniques can all be utilized with standard petrographic equipment. Other observations, including degree of crystallinity, grain size, and mixing of compositionally different types of chlorite, can also be shown to be related to distribution of ore.

My own experience with this technique is limited to examination of a few samples from the Bathurst-Newcastle district in New Brunswick, the Boliden district in Sweden, and the United Verde and several porphyry copper mines in Arizona. This work indicates that a reasonable finesse can be acquired in a short time. The relative simplicity and low cost of this technique suggest possible applications to the search for additions to the rapidly diminishing ore reserves at the Buchans Unit.

F. T. Graybeal

F. T. Graybeal

FTG:lad

cc: JHCourtright

References

1) Albee, A.L., 1962, Relationships between the mineral associations, chemical composition, and physical properties of the chlorite series: Amer. Mineral., 47, p. 851-870.

2) Eckstrand, O. R., 1963, Crystal chemistry of chlorite: Harvard Univ. Ph.D. thesis.
(This will soon be available at the Tucson office; it can't be purchased through University Microfilms.)

3) Miller, R. J. M., 1961, Wall rock alteration at the Cedar Bay mine, Chibougamau district, Quebec: Econ. Geol., 56, p. 321-330.

4) Price, Peter, 1934, The geology and ore deposits of the Horne mine, Noranda, Quebec: Trans. C.I.M.M., 37, p. 108-140.

5) Tatsumi, T. (ed), 1970, Volcanism and ore genesis: Tokyo, Univ. of Tokyo Press.

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

February 22, 1972

MEMO FOR: G. J. Stathis
S. R. Davis
N. P. Whaley

FROM: W. L. Kurtz

BIOTITE SAMPLING OF INTRUSIVES

This will confirm our meeting of February 18, 1972. The each of you will map and sample (for copper-in-biotite program), in the manner we discussed, the following intrusives:

Stathis - Juniper Flat (Bisbee)
North end Sierrita Granite

Davis - Texas Canyon Stock
Stronghold Granite

Whaley - Gunsight Hills Granite
Quijotoa Granite
Tucson Mtn. Granite

W. L. Kurtz

W. L. Kurtz

WLK:sg

cc: FTGraybeal
JCBalla

P.C. - Biotite

Jour. Research U.S. Geol. Survey
Vol. 2, No. 2, Mar.-Apr. 1974, p. 195—211

DISTRIBUTION OF COPPER IN BIOTITE AND BIOTITE ALTERATION PRODUCTS IN INTRUSIVE ROCKS NEAR TWO ARIZONA PORPHYRY COPPER DEPOSITS

By NORMAN G. BANKS, Menlo Park, Calif.

Abstract.—Biotite and its alteration products (primarily chlorite) from igneous rocks around the Ray and Esperanza (Esperanza-Sierrita) porphyry copper deposits, Arizona, were analyzed for copper by electron microprobe. The copper occurs in amounts >90 p/m (limit of detection) in most of the chlorites analyzed, is concentrated at the optical and chemical boundary of chlorite and biotite, and is not associated with sulfur. Most unaltered igneous and hydrothermal biotites analyzed contain <90 p/m Cu, and except for one sample, all copper that was detected can be explained as contamination by copper from chlorite grains. The paucity of detectable copper in igneous and hydrothermal biotite and its presence in daughter chlorite suggest that the positive association noted by some workers between the proximity of an ore deposit and the copper content of biotite might be partly the result of increased amounts of chloritization of biotite near a deposit coupled with difficulty in physically cleaning the biotite separates. Additionally, previous speculations that (1) part of the copper in a deposit may come from altered biotite, and (2) copper in biotite indicates how copper behaves in a differentiating magma, are of doubtful value if based on data derived from analyses of bulk mineral separates.

The copper, sulfur, and major-element contents of biotite and its alteration products from igneous rocks associated with the Ray and Esperanza (Esperanza-Sierrita) porphyry copper deposits were determined by microprobe analyses. The results do not agree with some of the published data about the distribution of copper in biotite nor with some of the speculations drawn from that data.

The Ray samples, collected 2–11 km from the deposit, consist of 2 ore specimens and 21 igneous rocks representing 5 intrusive types. All five intrusive types are cut by sulfide-bearing veinlets in and around the Ray deposit. The deposit is located about 120 km north of Tucson, Ariz. The intrusive rocks temporally associated with the deposit range in composition and texture from hornblende diorite (andesite) to quartz monzonite (quartz latite) (Cornwall and others, 1971; Banks and others, 1972). Intrusion began about 70 m.y. ago and continued to about 60–61 m.y. ago—the Laramide age of the youngest intrusive body (Granite Mountain Porphyry) within the commercial limits of the deposit (Creasey and Kistler, 1962; Banks and others, 1972; Banks and Stuckless, 1973). Sulfide mineralization followed, and the deposit cooled below 100°C about 60 m.y. ago (Banks and Stuckless, 1973).

The Esperanza deposit, about 40 km south of Tucson, is associated with the Ruby Star Granodiorite, also Laramide in age (Creasey and Kistler, 1962; Damon and Mauger, 1966). T. G. Lovering kindly supplied igneous biotite, separated from seven samples collected from this intrusive body, 0.8–4 km from the center of mining activity at Esperanza.

ANALYTICAL METHODS

Extreme care was taken to eliminate contamination of copper by external sources. Rock chips (Ray samples) and mineral grains (Esperanza samples), plastic mounted onto glass slides and cut to 40- to 50-μm thickness by diamond saw, were ground and polished on glass plates in several steps, using diamond powder as an abrasive to remove any copper smeared onto the specimens from brass in the saw blade. Between each step, the slides were agitated in an ultrasonic cleaner, then positioned so that the direction of polishing was 90° from the previous direction. Finally, the slides were polished four more times on nylon over glass with alumina powder, agitated in an ultrasonic cleaner, and again rotated 90° between each polishing step.

Several mounts were polished on a lead-bronze lap with diamond powder, analyzed, repolished by use of the four-step alumina method, and finally reanalyzed to check if any copper physically smeared onto the sample was actually removed by the polishing with alumina. Copper in erratic but measurable concentrations (parts per million) was detected on some biotite grains in the slides polished on the lead-bronze lap (not on well-polished nonlayer silicates) but was not detected on the same grains after the alumina polishing. Thus, sample contamination by copper sources external to the sample is believed to have been eliminated by this polishing.

Contamination of minerals by copper from other minerals in the slide could not be eliminated. However, the sources of contamination are identified, and as explained later, the contamination does not alter the conclusions drawn here.

The copper and sulfur analyses were made with an ARL (Applied Research Lab.) model EMX-SM electron microprobe

using a LiF crystal for copper and an ADP crystal for sulfur, an excitation voltage of 20 kV, a sample current of 3×10^{-8} A on brass, and chalcocite (Cu_2S) as a standard. Integration times of 200±2 s were obtained by termination of counting on fixed-beam current. For most analyses the electron beam was fully focused. Buildup of carbon contamination and noticeable loss of volatile components were avoided by moving the beam with magnetic deflectors to sweep areas as much as 10 by 8 μm. If the shape of the grain did not permit sweeping of areas of at least 5 by 4 μm, a defocused beam (2–3 μm diam) was used, and the sample was moved under the beam about once every 20 s.

X-ray intensity data (counts) were obtained by averaging 2–40 (usually 6–8) observations on each grain. Initially, correction of the raw intensity data was done by computer and included drift, background, and matrix corrections (mass absorption, secondary fluorescence, and atomic number effects; Beeson, 1967; Beaman and Isasi, 1970). Individual backgrounds for each grain were determined by observing counts above and below the peak wavelengths of copper and sulfur. Major-element data required for the corrections and data in table 3 and figures 6 and 7 were obtained at an excitation voltage of 15 kV and count times of 20±0.5 and 40±1 s. It developed, however, that the computer correction factor for trace amounts of copper and sulfur (50–5,000 p/m) is nearly constant for each mineral type studied regardless of its exact major-element composition. Thus, in the later part of the study and for most of the data on tables 1 and 2, a matrix correction for copper and sulfur in each mineral type (derived in the initial study) was applied by hand. During this stage of the study, usually magnesium or potassium was monitored as a check on the purity of the mineral grains.

A homogeneous synthetic glass containing about 400 p/m Cu and 520 p/m S was repeatedly analyzed under the above operating conditions. The one standard deviation of error from the average amount of copper present in the glass was 10 percent (8 percent for S), and the maximum deviation was 20 percent (15 percent for S). Detection levels were established at three times the square root of the average background counts (Birks, 1963); thus, copper is considered detectable at about 90 p/m (50 p/m for S) at the above operating conditions in the minerals analyzed.

COPPER AND SULFUR CONTENTS OF THE MINERALS

The copper and sulfur contents of hydrothermal biotite from the Ray deposit and of igneous biotite and its alteration products (chlorite, epidote, sphene, and hydrogarnet?) from five intrusive rock types located near the deposit are listed in table 1. Similar data for igneous biotite and its alteration products from the Ruby Star Granodiorite near the Esperanza deposit are presented in table 2.

Chlorite formed by alteration of biotite near both the Ray and Esperanza deposits contains significantly more copper than the unaltered igneous biotite analyzed (fig. 1). Most of the biotite grains (80 percent of the Ray and 75 percent of the Esperanza biotite), including those of hydrothermal origin, do not contain detectable amounts of copper, whereas 65 percent of the Ray chlorite grains analyzed and 90 percent of the Esperanza chlorite grains analyzed contain detectable amounts of copper.

LOCATION OF COPPER IN CHLORITE

Sulfur and copper in the biotite and chlorite were monitored during the analyses on a memory oscilloscope or on Polaroid film over a nonrecording oscilloscope to determine whether sulfide or sulfate inclusions might account for the copper in the chlorite or biotite. With one possible exception (a chlorite grain in sample 2GM14, not listed in table 1), no such inclusions were found. Furthermore, it is unlikely that the copper is present in sulfide or sulfate grains that are smaller than can be detected on the oscilloscope because increases in the amount of copper in either biotite or chlorite are not accompanied by corresponding increases in the amount of sulfur (fig. 2). For example, the ratio of copper to sulfur should be 1 to 1 if the copper were present in chalcopyrite inclusions and 4 to 1 if the supposed inclusions were chalcocite; these ratios are not found (fig. 2). In addition, several quantitative analyses for Mo, Zn, Pb, Mn, Cl, and F (by microprobe) indicate that the copper in the grains also is not associated with these elements. The presence of copper carbonates or nitrates was not checked directly because the sections were carbon coated, and an analyzing crystal suitable for nitrogen analyses was not immediately available. A direct check for the presence of copper silicates and an indirect check for the presence of copper carbonates, oxides, and nitrates by analyzing the grains for silicon and oxygen was not possible because the copper occurs in a silicon-oxygen matrix (biotite and chlorite) having approximately the same silicon or oxygen contents as the known copper carbonates, oxides, nitrates, and silicates. Thus, any variations in silicon or oxygen intensity data caused by the presence of minute quantities (parts per million range) of these minerals would be masked by analytical uncertainty in such data. Quantitative analyses for Se, W, As, Sb, Te, I, V, and P (the other elements occurring in known copper-bearing minerals) were not made, but qualitative scans were. As noted in the tables, the copper in chlorite is often distributed inhomogeneously and, as discussed below, is locally concentrated in sufficient quantities so that X-ray images of its distribution can be observed on and photographed from an oscilloscope. Similarly, if Se, W, As, Sb, Te, I, V, or P were present in amounts comparable to the copper, they could be observed on the X-ray images; they were not.

Table 1.—*Copper and sulfur in biotite and its alteration products from the intrusives near the Ray porphyry copper deposit, Arizona*

[Values in regular type denote element is present at or above detection level (about 90 p/m for Cu and 50 p/m for S). Values in italic type indicate real or fictitious element contents resulting from higher-than-background counts at the peak wavelength of the element. Copper and sulfur values are not significant to three figures. Precision is lower in grains in which copper and sulfur are not homogeneously distributed]

Rock type	Sample	Grain	Mineral	Copper (p/m ±10 percent)	Sulfur (p/m ±10 percent)
Tortilla Quartz Diorite.	217-1	1BI	Biotite	*0*	
		2BI	..do..	*0*	
		3BI	..do..	*0*	138
		5BI	..do..	*0*	161
		2CL	Chlorite	*0*	
		4CL	..do..	*42*	*20*
		5CL	..do..	*16*	*0*
		6CL	..do..	*0*	*0*
		7CL	..do..	*24*	*23*
		6EP	Epidote	*42*	52
		7EP	..do..	*0*	*0*
	217-28	1BI	Biotite	386*	167
		3BI	..do..	*39*	199
		4BI	..do..	*52*	
		5BI	..do..	109	
		BTM1	..do..	*21*	199
		1CL	Chlorite	206*	59
		2CL	..do..	244*	
		4CL	..do..	149	86*
		5CL	..do..	120	*45*
		4M	Hydrogarnet?	151*	79
		3EP	Epidote	*40*	*28*
	248-29	2CL	Chlorite	*60*	
		3CL	..do..	190	
Rattler Grano-diorite.	246-99B ..	3BI	Biotite	697	172
		1CL	Chlorite	569	74
		2CL	..do..	432	50
	46-11G ..	BI	Biotite	*0*	
		CL	Chlorite	2237	
		EP	Epidote	2000*	
	246-11G ...	1BI	Biotite	*26*	
		3BI	..do..	*28*	199
		4BI	..do..	*0*	181
		7BI	..do..	110	146
		BTM1	..do..	*0*	197
		1CL	Chlorite	626	
		5CL	..do..	*51*	*1*
		6CL	..do..	105	*0*
		CLM1	..do..	*0*	*10*
		CLM2	..do..	*0*	*6*
		2EP	Epidote	*10*	*41*
		6SP	Sphene	*53*	82*
	61-25	BIGM	Biotite	*0*	
		BI1	..do..	*0*	
		BI2	..do..	*0*	
		CL2	Chlorite	291	
		EP2	Epidote	157	
	261-25	1BIA	Biotite	*0*	209
		1BIB	..do..	*0*	283
		3BI	..do..	*0*	184
		5BI	..do..	*0*	156
		2CLA	Chlorite	*0*	*0*
		2CLB	..do..	*0*	*0*
		4CL	..do..	*0*	*5*
		5CL	..do..	*0*	*0*
		1EP	Epidote	*0*	*0*
		4EP	..do..	*0*	*0*
Rattler Grano-diorite—Con.	260-113D ..	2BI	Biotite	*0*	189
		3BI	..do..	*0*	256
		4BI	..do..	*0*	190
		5BI	..do..	*0*	254
		3CL	Chlorite	*0*	*0*
		4CL	..do..	*0*	*0*
		3M	Hydrogarnet?	*0*	*0*
		1EP	Epidote	*0*	*0*
		5EP	..do..	*0*	*15*
	246-11A ...	1BI	Biotite	256*	
		1BIA	..do..	245	
		2BI	..do..	*0*	A313
		4BI	..do..	405*	
		5BI	..do..	*57*	294
		5BIA	..do..	119*	
		BIM1	..do..	496*	280
		BIM2	..do..	*0*	282
		1CL	Chlorite	2218*	*21*
		1CLA	..do..	1368	
		3CL	..do..	460	*14*
		3CLA	..do..	2000*	*10*
		4CL	..do..	405	
		4CLA	..do..	3138*	
		4CLB	..do..	617	
		5CLA	..do..	2397*	
		5CLB	..do..	4118*	
		5CLC	..do..	8340*	
		CLM1	..do..	1432*	*20*
		CLM2	..do..	9842*	*0*
	260-96A...	1BI	Biotite	*52*	214
		3BI	..do..	*0*	191
		4BI	..do..	*0*	220
		5BI	..do..	*0*	185
		2CL	Chlorite	754*	254
		2CLA	..do..	416	262*
		3CL	..do..	1160*	54
		6CL	..do..	674*	112*
		1EP	Epidote	608*	*22*
		6SP	Sphene	*94*	*0*
Rhyodacite dike	2GM100...	1BI	Biotite	*51*	290
		2BI	..do..	*36*	243
		3BI	..do..	*15*	274
		2CL	Chlorite	*0*	*44*
		4CL	..do..	102	105
		5CL	..do..	*66*	117
		4EP	Epidote	*0*	*0*
		5EP	..do..	130*	*0*
		4SP	Sphene	*0*	*0*
		5SP	..do..	*0*	*0*
Granite Mountain Porphyry.	GM14.....	BI	Biotite	*0*	
		CL1	Chlorite	*0*	

Table 1.—*Copper and sulfur in biotite and its alteration products from the intrusives near the Ray porphyry copper deposit, Arizona*—Continued

Rock type	Sample	Grain	Mineral	Copper (p/m±10 percent)	Sulfur (p/m±10 percent)
Granite Mountain Porphyry—Con.	GM14	CL2	..do..	582	
		CL3	..do..	34	
		EP	Epidote	0	
		SP6	Sphene	0	
	2GM14....	1BI	Biotite	20	311
		2BI	..do..	0	
		2BIA	..do..	0	202
		3BI	..do..	198	273
		4BI	..do..	0	237
		6BI	..do..	0	
		BTM1	..do..	0	158
		2CL	Chlorite	110	0
		5CL	..do..	42	11
		6CL	..do..	5	68
		CLM1	..do..	79	75
	GM12R....	2BIX	Biotite	0	208
		3BI	..do..	111	237
		3BIA	..do..	144	180
		4BI	..do..	110	156
		5BI	..do..	125	152
		3CL	Chlorite	699	26
		3CLA	..do..	294	26
		4CL	..do..	297	44
		5CL	..do..	527	98
	GM6GR ...	BI1	Biotite	0	
		BIA	..do..	0	
		3BIA	..do..	0	120
		4BIA	..do..	0	190
		3CLA	Chlorite	3440*	0
		4CLA	..do..	80	0
		CLA	..do..	266	
	2GM6GR ..	2BIM	Biotite	0	190
		3BIM	..do..	0	
Granite Mountain Porphyry—Con.	2GM6GR..	4BIM	..do..	0	
		3CLM1	Chlorite	261	
		3CLM 2	..do..	442	
		4CLM	..do..	125	
	3GM6G....	BI1	Biotite	0	
		BI2	..do..	0	
		BI3	..do..	0	
		CL1	Chlorite	385	
		CL2	..do..	382	
		CL3	..do..	414	
	2GM4V....	BIB	Biotite	110	
		1BIA	..do..	0	
		3BIA	..do..	0	
		3BIB	..do..	0	
		1CL	Chlorite	915*	
		1CLA	..do..	818*	
		3CL	..do..	105	
	2GM1A....	2CL	..do..	324	
		2CLA	..do..	275	
		2CLB	..do..	311	
		CLM	..do..	1537*	
Teapot Mountain Porphyry.	TTM.....	ICL	Chlorite	1235*	
		3CL	..do..	1172*	
		CLM1	..do..	1006*	
		1SP	Sphene	145	
		3SP	..do..	124	
Hydro-thermal biotite.	2P70-22 ...	1BI	Biotite	80	90
		2BI	..do..	46	486
	T123R	BI1	Biotite	26	189
		BI2	..do..	37	113
		BI3	..do..	64	156
		BI4	..do..	30	197
		BI5	..do..	33	191

*Element not distributed homogeneously in the grain. Criterion used was whether standard deviation from mean of counts divided by the square root of the average counts is >3 (Boyd, 1969).

The copper reported for chlorite in tables 1 and 2 was probably not smeared over the chlorite from other copper-bearing phases in the mounts because (1) the distribution of copper in the chlorite (discussed next) precludes such a source, (2) the copper content of the chlorite grains does not reflect the proximity, size, or even presence of copper sulfides in a given slide (always <200 p/m including chalcopyrite), and (3) except for sample 246-99B (table 1), copper was not found in other igneous silicate, oxide, or phosphate phases in the samples in amounts equal to or greater than that found in chlorite. Contamination of the chlorite with copper from chalcopyrite in veinlets was avoided by using probe mounts that contain no veinlets.

The amount of copper in chlorite is highest near the chlorite-biotite contact. Chlorite more than 50 μm from the mineral contact contains about 600–1,000 p/m Cu, biotite more than 50 μm from the contact contains copper in amounts just at or below the detection level, and about 1.5 percent Cu is found in the chlorite at the mineral contact (fig. 3A, sample 2GM4V, grain 1 CL). The amount of copper (about 1.5 percent) at the mineral contact is probably low because the material excited by the beam and secondary radiation extends beyond the visible mineral contact. Likewise, the broadness of the copper peak (fig. 3A) may be partly the result of excitation of copper in the contact zone by secondary radiation from points located in chlorite and biotite near the mineral contact.

The concentration of copper in chlorite along another biotite-chlorite boundary is shown as X-ray images photographed from an oscilloscope (fig. 4). The chlorite contains about

Table 2.—*Copper and sulfur in biotite and its alteration products from Ruby Star Granodiorite near the Esperanza porphyry copper deposit, Arizona*

[Values in regular type denote element is present at or above detection level (about 90 p/m for Cu and 50 p/m for S). Values in italic type indicate real or fictitious element contents resulting from higher-than-background counts at the peak wavelength of the element. Copper and sulfur values are not significant to three figures. Precision is lower in grains in which copper and sulfur are not homogeneously distributed]

Sample	Grain	Mineral	Copper (p/m, ±10 percent)	Sulfur (p/m, ±8 percent)	Chlorite in separate (percent)
T454R....	BT5	Biotite	*63*	106	*0.1*
	BTM1	..do..	*0*	180	
	BT5A	..do..	*0*	139	
	BT5C	..do..	*0*	138	
	BT5C1	..do..	*0*	125	
	CL5	Chlorite	*0*	*17*	
T455R....	BT1	Biotite	*21*	141	*3.5*
	BT2	..do..	*45*	126	
	BT3	..do..	*73*	126	
	BT4	..do..	*6*	160	
	BT5	..do..	200*	87	
	CLM1	Chlorite	4758*	68	
	CLM2	..do..	161	*0*	
	CL1	..do..	2040*	*6*	
T465R....	BT1	Biotite	*0*	69	*0.7*
	BT2	..do..	145	119	
	BT3	..do..	*0*	156	
	BTM1	..do..	*0*	140	
	BTM2	..do..	*0*	102	
	BTM3	..do..	*0*	125	
	CL1	Chlorite	175	*20*	
	SP1	Sphene	255	56	
T467R....	BT1	Biotite	654*	172	*11.2*
	BT2	..do..	511*	140	
	BTM1	..do..	*28*	275	
	BTM2	..do..	173	263	
	BTM3	..do..	*43*	232	
T467R.....	BTM4	Biotite	152	243	
	BTM5	..do..	*0*	197	
	CL1	Chlorite	766*	*0*	
	CL2	..do..	3418*	*0*	
	CL3	..do..	3024*	*7*	
	CLM1	..do..	1335	*0*	
	CLM2	..do..	1060	*14*	
T468R....	BT1	Biotite	*49*	201	*12.4*
	BT2	..do..	*3*	345	
	BT3	..do..	*0*	239	
	BT4	..do..	*0*	221	
	CL1	Chlorite	924*	*0*	
	CL2	..do..	9700*	96	
	CL3	..do..	10,000*	*36*	
	CL4	..do..	4500*	*32*	
T8R.....	BT1	Biotite	*0*	141	*17.6*
	BT2	..do..	616*	97	
	BT3	..do..	*0*	167	
	BT4	..do..	*32*	125	
	BT5	..do..	129	109	
	CL1	Chlorite	403	*0*	
	CL2	..do..	323*	*16*	
	CL3	..do..	669*	*0*	
	CL4	..do..	1656*	*30*	
	CL5	..do..	429	*10*	
	SP1	Sphene	*57*	*23*	
	SP2	..do..	333	65	
	SP4	..do..	*0*	*49*	

*Element not distributed homogeneously in the grain. Criterion used was whether standard deviation from mean of counts divided by the square root of the average counts is >3 (Boyd, 1969).

5,000 p/m Cu at the mineral contact and about 500 p/m (average) away from it. Although sulfur counts were collected for longer times than the copper counts, corresponding sulfur counts (fig. 4*C*, *F*) are lacking where the copper is concentrated. Background sulfur in biotite (300 p/m) was not detected in figure 4*C* and *F*.

Figure 3*B* shows a paucity of copper in compositionally pure biotite, a high concentration of copper in chlorite at the compositional chlorite-biotite contact, and a decrease in amount of copper in chlorite as it becomes chemically purer (as demonstrated by loss of K). Thus, copper is both spatially and compositionally associated with the biotite-chlorite transition, which implies that the copper was introduced in the fluids that destroyed the biotite and formed the chlorite. The fact that other elements known to coexist in previously described copper minerals were not concentrated with the copper suggests that the copper probably is present in either lattice or more loosely attached sites in the chlorite or other silicate minerals formed during transition of the biotite to chlorite. In the compositionally purer chlorite, the copper may be partly in exchangeable sites and partly in lattice sites. Dodge, Smith, and Mays (1969) and Parry and Nackowski (1963) point out that the radius of Cu^{+2} is appropriate for its camouflage in Fe^{+2} and Mg^{+2} (octahedral) positions. In the transitional material, the amount of copper present and the fact that cold concentrated nitric acid leaches copper from the Esperanza biotite-chlorite grains exposed in a rock-slab surface (T. G. Lovering, oral commun., 1972) might suggest a cation exchange position for part of the copper. The nature of the attachment of copper in this transitional material is discussed more fully in a later section.

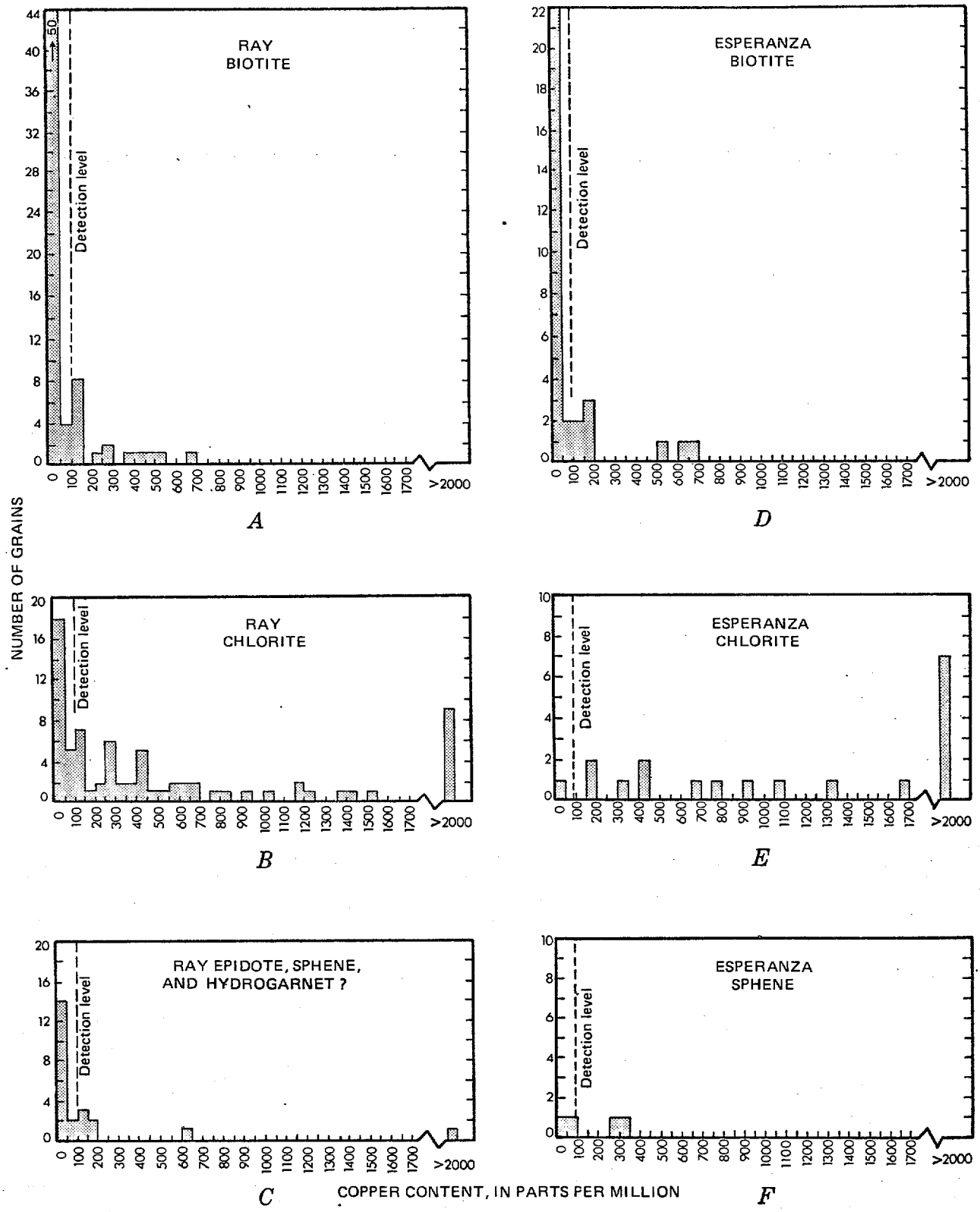


Figure 1.—Frequency histograms showing copper contents of biotite (*A* and *D*), chlorite (*B* and *E*), epidote, sphene, and hydrogarnet? (*C*), and Sphene (*F*) from Laramide intrusive rocks near the Ray and Esperanza copper deposits, Arizona. Detection levels established at three times the square root of the average background counts (Birks, 1963).

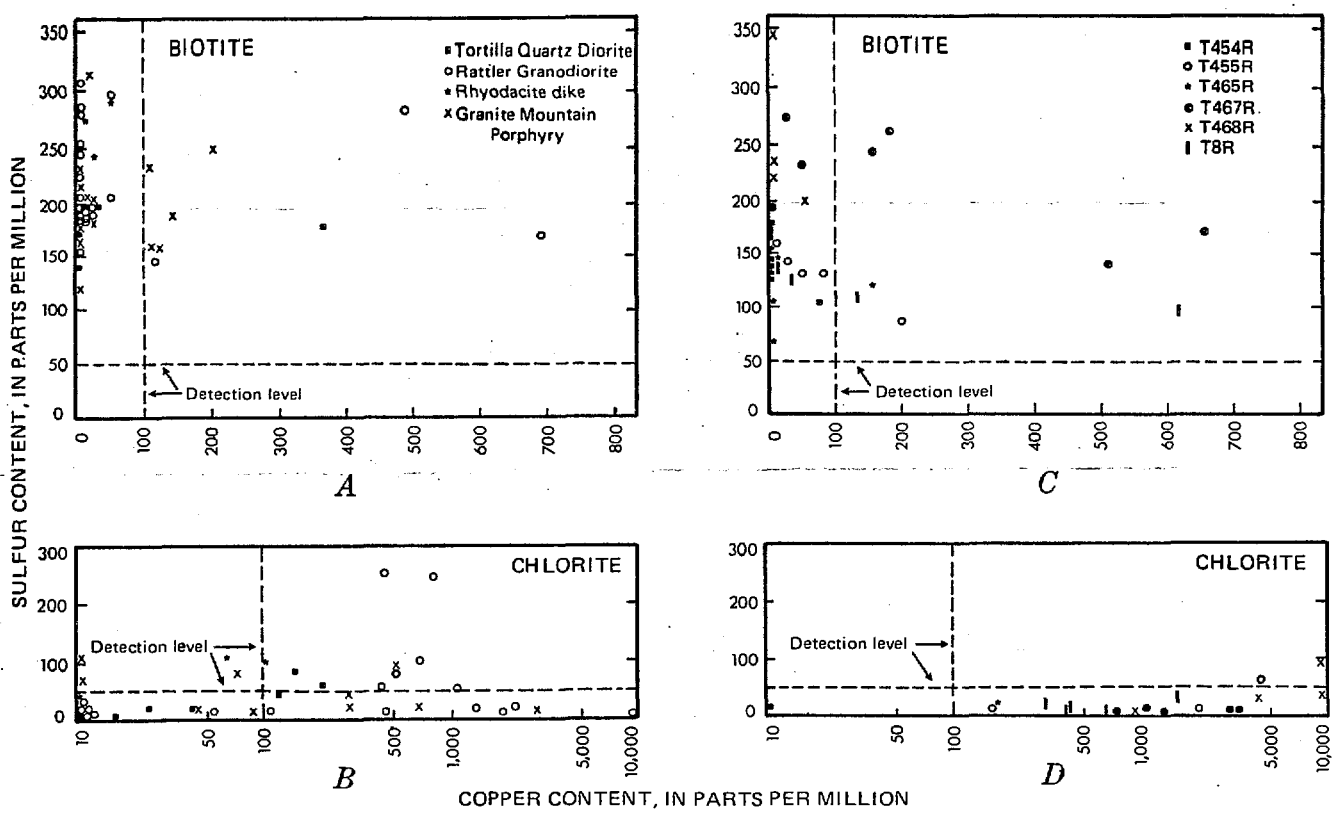


Figure 2.—Plots of copper versus sulfur contents of igneous biotite (*A* and *C*) and chlorite (*B* and *D*) derived from the biotite from rocks near the Ray and Esperanza copper deposits, Arizona. Note that different scales are used to plot copper in chlorite and copper in biotite. Three points from the Rattler Granodiorite and one from the Tortilla Quartz Diorite plot at the origin of *B*. Some points are slightly offset for plotting purposes. Detection levels were established at three times the square root of the average background counts (Birks, 1963).

CONTAMINATION ORIGIN FOR COPPER IN BIOTITE

The increase in copper content from parent biotite to daughter chlorite is probably even more striking than figure 1 shows because most biotite grains having detectable amounts of copper come from samples that contain chlorite having considerably more copper than the biotite. Thus part or all of the detectable copper reported for biotite may be copper from chlorite that has been smeared over the biotite during polishing. There is no simple relation between the degree of alteration of biotite in a sample and the presence or number of copper-bearing biotite grains analyzed in a sample. This is not surprising because the amount of copper smeared over the biotite would depend upon the proximity of copper-bearing chlorite, the amount of copper in the chlorite, and the position of a biotite grain relative to a copper-bearing chlorite and the final direction of polishing. However, the samples that have very little biotite alteration or that have no chlorite grains with detectable copper also have no biotite grains with detectable copper. In addition, biotite precipitated from copper-bearing fluids (hydrothermal biotite, table 1) does not contain detectable copper except immediately adjacent to chalcopyrite (these analyses were not reported in table 1 because of likelihood of copper contamination from the sulfide). Therefore, it is likely that the igneous biotite (with the possible exception of sample 246-99B, grain 3BI) does not contain copper in amounts detectable by the probe and that the copper in all but one biotite reported in tables 1 and 2 may be best explained by autocontamination. The exception, sample 246-99B, grain 3BI, is not easily explained by contamination with copper from chlorite because only the two grains of chlorite, both completely chloritized with no biotite-chlorite contact, occur in the sample, and the biotite contains more copper than the chlorite (table 1). Copper in this biotite also is not easily explained by contamination with copper from sulfides because no chalcopyrite occurs in the probe sample, and the pyrite contains less copper (300 p/m) than the biotite. Hornblende in the sample may contain copper (<95-percent confidence), but also in lesser amounts than the biotite.

The significance of the presence of copper in biotite and its possible presence in hornblende in sample 246-99B is not

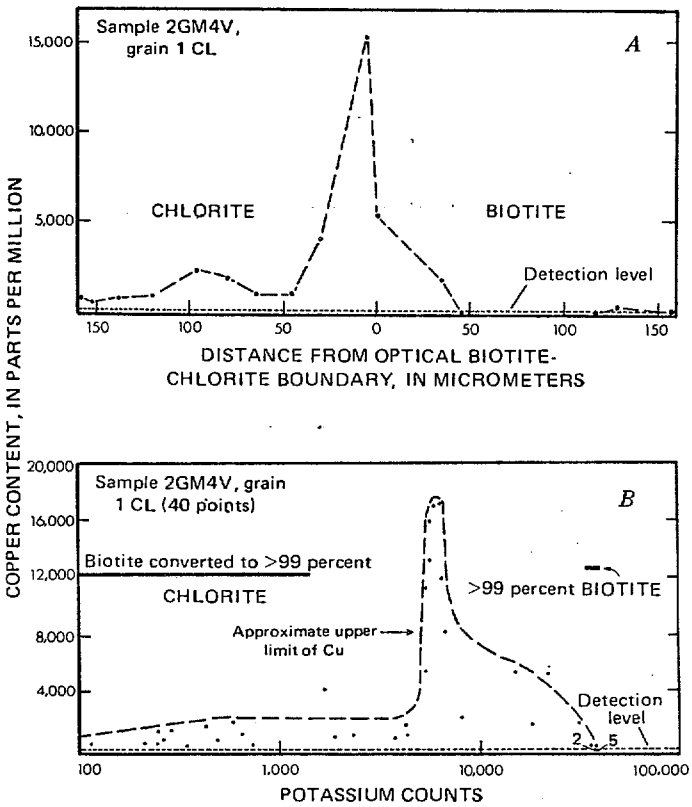


Figure 3.—Distribution of copper in biotite, chlorite, and transitional material. Bars indicate range of potassium (K) counts that designates relatively pure chlorite (<0.1 percent K_2O) and biotite (K counts equal to the average of K counts for biotite grains with no chloritization in the same mount). Counting time is 200 s, terminated on fixed beam current. Detection level was established at three times the square root of the average background counts (Birks, 1963). *A*, Distribution of copper in biotite and chlorite relative to the optical mineral boundary. *B*, Distribution of copper in chlorite, biotite, and transitional material relative to concentration of potassium.

clear. The sample is from the most mafic facies (diorite) of the Rattler Granodiorite, a fact that might suggest that copper actually is incorporated in biotite in mafic bodies during crystallization. However, biotite in equally mafic rock (Tortilla Quartz Diorite, table 1) and more mafic rock (diabase, unpub. data) does not contain detectable copper. Thus no trend of increasing copper content of biotite with decreasing silica content of the host rock is established for the rocks of the Ray area.

COPPER-RICH BLEACHED ZONES IN BIOTITE

Some biotite grains in the Granite Mountain Porphyry and older Laramide intrusive rocks have bleached (golden colored) zones oriented parallel to the (001) plane. The zones are sometimes offset along fractures that developed in the biotite prior to consolidation of the magma. Many of these zones are obvious extensions of chloritized layers, but others do not grade into optically perceivable chlorite at either the middle of the bleached zone or the edge of the grain. Some of the bleached zones contain unexpectedly large amounts of copper (table 3). A copper X-ray image of two such zones is shown in figure 5*A*. The wider zone is the one analyzed in mount 3GM6G of table 3.

As the small amounts of sulfur in the copper-rich zones indicate (table 3 and fig. 5*C*), the copper is not present in the form of submicroscopic copper sulfide or sulfate inclusions. In addition, X-ray images of the following elements indicate that they are not present in more than parts per million amounts in the bleached zones: F, Na, P, Cl, Ca, Sc, V, Cr, Co, Ni, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In, Sb, Te, I, Cs, Ba, La, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, Tl, Pb, Bi, Th, Pa, and U.

Because of the carbon coating and lack of a suitable analyzing crystal, it could not be determined directly whether carbonates or nitrates account for the copper in the zones. However, the amount of silica in the zones suggests that the copper is not explained by the presence of known carbonates and nitrates, or even known oxides and silicates. Significantly less silica is present in such minerals than in chlorite (0–20 versus 26–27 percent). Therefore, if the zones were simply a mixture of known copper carbonates, nitrates, oxides, silicates, chlorite, and biotite, the amount of silica in the zones having appreciable amounts of copper (analyses G, O, P, Q, R, S, table 3) should be, but is not, measurably less than the amount of silica in chlorite.

It is not within the scope of this report to determine the exact mineralogic composition of the zones, but some speculation is warranted. The zones are assumed to represent incipient chloritization of biotite by fluids that may or may not carry copper, because chlorite occurs at grain edges along many of the zones and copper is concentrated at many optical biotite-chlorite boundaries (figs. 3, 4). However, except for SiO_2 and K_2O, the amounts of individual constituents and structural formulas of the copper-rich zones (analyses B, E, G, H, K, L, O, P, Q, R, S, U, and V, table 3) are not uniformly intermediate between the amounts of individual constituents and structural formulas of the parent biotites (analyses A, D, F, J, N, and T, table 3) and those of chlorite along the same zone or in the same rock sample (analyses C, I, M, and W, table 3). Although an increase in density of the zones relative to chlorite and biotite resulting from replacement of K, Ti, Mg, Fe, and Mn by Cu could account for some of the discrepancies in the nonuniform transition in chemistry between the zones and chlorite and biotite, the density shift is somewhat compensated by the amount of water required in the zones in order to arrive at reasonable totals of the constituents (the qualitative scans eliminate significant contribution to the totals of elements other than H and O). Thus it is apparent that the material in the zones is more than a simple mixture of well-formed chlorite and biotite. In addition, the large amount

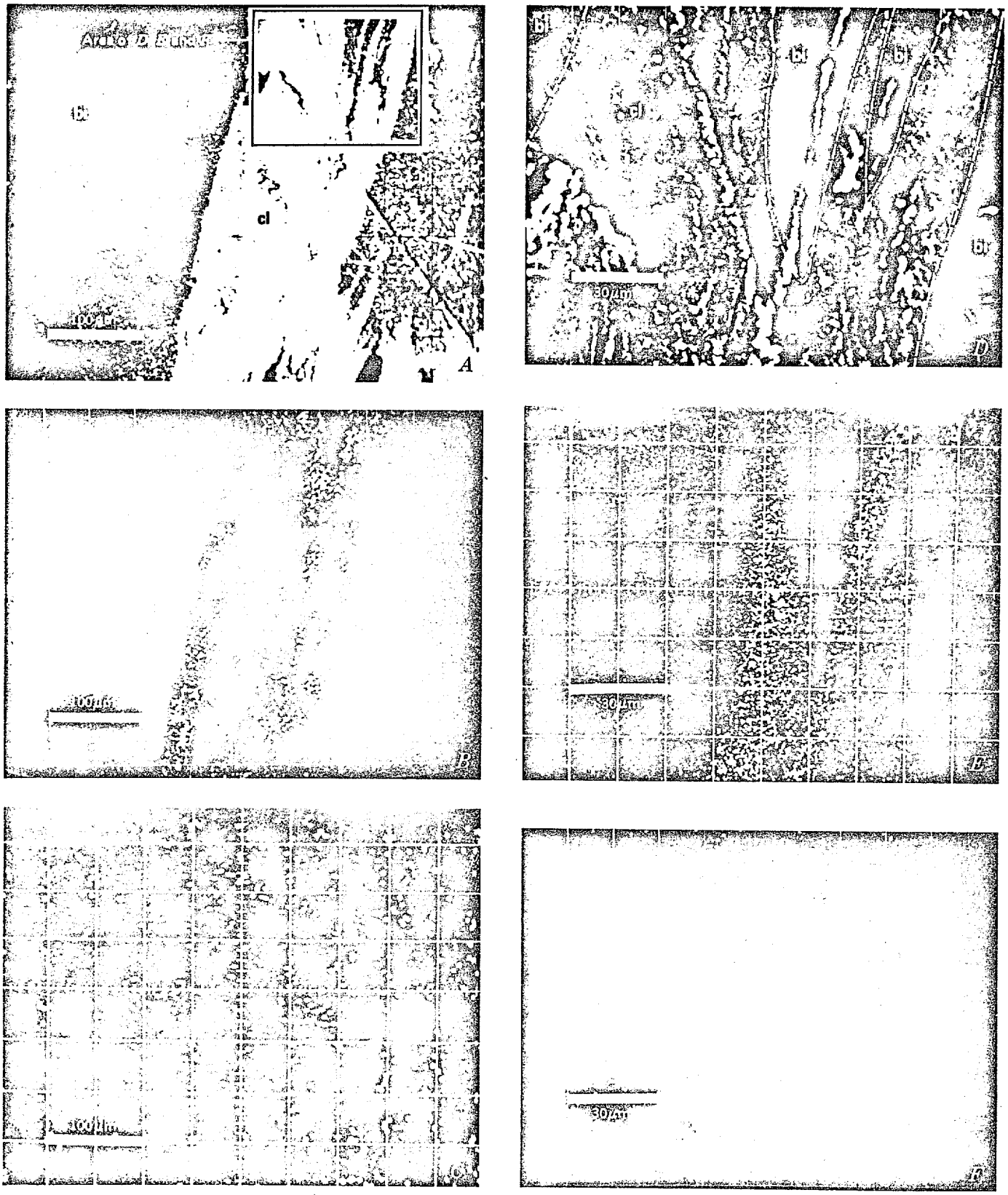


Figure 4.—Photographs of electron-beam scans of a biotite-chlorite grain in sample 46-11a. *A*, Scan for sample current of biotite-chlorite grain. The lighter area represents chlorite (cl), and dark areas are biotite (bi). *B*, Scan for copper (same area as *A*), showing its concentration at the mineral boundaries. Exposure time, 2 minutes. *C*, Scan for sulfur (same area as *B*). Note lack of sulfur at the mineral boundaries. Exposure time, 8 minutes. *D*, Scan for sample current of area designated in *A*. *E*, Scan for copper in same area as *D*. Exposure time, 1 minute. *F*, Scan for sulfur in same area as *E*. Exposure time, 4 minutes.

Table 3.—*Microprobe analyses and structural formulas for biotite, chlorite,*

Mount No.	2GM4V					GM6G
Grain No.	1			3		
Area analyzed	BIA	BI	CL	BIA	BI	BIA
Mineral	Biotite	Copper-rich zone	Chlorite	Biotite	Copper-rich zone	Biotite
Letter reference in text	A	B	C	D	E	F
Microprobe analysis (percent)						
SiO_2	37.6±0.2	32.7±1.2	27.4±0.3	38.1±0.3	37.2±0.4	36.5±.03
Al_2O_3	15.5±0.1	15.6±0.5	16.8±0.2	14.5±0.1	15.0±0.2	15.6±0.1
FeO[1]	17.4±0.2	19.4±0.7	24.3±0.2	17.6±0.1	17.6±0.1	18.4±0.2
MgO	11.4±0.1	14.4±0.4	16.2±0.1	12.4±0.1	11.5±0.05	11.4±0.1
CaO	(2)	.....	.....	.....	.....	.....
MnO	.46±0.01	.32±0.03	.64±0.02	.42±0.02	.42±0.02	.59±0.05
CuO	ND[3]	1.1±0.2	.11±0.02	ND	1.4±0.4	ND
TiO_2	3.2±0.1	.74±0.41	.09±0.010	3.4±0.03	3.5±0.1	2.5±0.1
K_2O	9.7±0.1	2.3±0.07	.09±0.018	9.9±0.1	9.0±0.5	9.5±0.2
Cl	.02±0.004	ND	ND	.03±0.006	.03±0.008	.02±0.006
F	.77±0.06	.18±0.17	.16±0.03	.86±0.04	.81±0.05	.66±0.06
S	.....	.....	.....	.....	.....	.01±0.001
Σ	96.1	86.7	85.8	97.2	96.5	95.2
Less O≡Cl+F	.3	.1	.1	.4	.3	.3
Σ	95.8±0.4	86.6±1.7	85.7±0.4	96.8±0.4	96.2±0.8	94.9±0.5
Structural formulas[4]						
Anions per formula	22	22	28	28	22	22	28	22
Si^{+4}	5.68	5.35	6.82	5.91	5.71	5.64	7.17	5.60
Al^{IV}	2.32	2.65	1.18	2.09	2.29	2.36	.83	2.40
	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Al^{VI}	.45	.37	2.65	2.18	.27	.32	2.58	.43
Ti^{+4}	.36	.09	.12	.01	.38	.40	.51	.29
Mg^{+2}	2.57	3.51	4.47	5.21	2.77	2.60	3.31	2.61
Cu^{+2}	.....	.13	.17	.02	....	.16	.20	....
Fe^{+2}	2.20	2.66	3.38	4.38	2.21	2.23	2.84	2.36
Mn^{+2}	.06	.04	.06	.12	.05	.05	.07	.08
	5.64	6.80	11.46	11.94	5.68	5.76	11.72	5.77
K^{+1}	1.87	.48	.61	.02	1.89	1.74	2.21	1.86

[1] Total Fe calculated as FeO.

[2] Blanks indicate no analysis was made for the component.

and copper-rich zones in biotite from Granite Mountain Porphyry

GM6G—Continued					
3—Continued			4		
Cu1	Cu3	CLA	BIA	Cu1	Cu3
Copper-rich zone		Chlorite	Biotite	Copper-rich zone	
G	H	I	J	K	L
Microprobe analysis (percent)—Continued					
32.9±2.4	34.9±2.3	26.6±0.4	37.0±0.4	33.4±2.9	36.3±0.7
13.5±0.7	14.3±0.7	17.3±0.2	14.7±0.2	13.5±1.3	14.0±0.3
15.3±0.9	17.0±0.7	24.2±0.2	17.6±0.1	16.2±0.3	17.4±0.4
9.5±1.3	11.3±0.7	16.4±0.1	11.9±0.1	10.6±0.2	11.4±0.5
.....	.....	.....	.....	.....	.....
.46±0.05	.51±0.05	.86±0.03	.56±0.01	.46±0.03	.05±0.028
13.5±0.9	4.6±0.9	.43±0.04	ND	1.0±0.6	5.3±0.8
3.5±0.7	4.8±3.8	.08±0.02	3.8±0.1	3.0±0.6	3.5±0.1
4.6±1.9	7.7±1.9	.09±0.03	9.4±0.1	5.5±0.7	8.1±1.2
ND	ND	ND	.03±0.006	.06±0.03	.04±0.007
.70±0.13	.79±0.17	.09±0.08	.69±0.04	.86±0.14	.73±0.09
.01±0.001	.01±0.001	ND	.02±0.002	.02±0.002	.02±0.002
94.0	95.9	86.1	95.7	84.6	96.8
.4	.3	.....	.3	.4	.3
93.6±3.7	95.6±5.1	86.1±0.5	95.4±0.5	84.2±3.4	96.5±1.8
Structural formulas[4]—Continued					
22 28	22 28	28	22	22 28	22 28
5.69 6.80 } 8.00 } 8.00	5.40 6.87 } 8.00 } 8.00	5.74 } 8.00	5.63 } 8.00	5.69 7.24 } 8.00 } 8.00	5.57 7.09 } 8.00 } 8.00
2.31 1.20	2.60 1.13	2.26	2.37	2.31 .76	2.43 .91
.40 2.09	.01 2.19	2.14	.26	.40 2.69	.10 2.31
.38 .54	.56 .71	.01	.43	.38 .49	.40 .51
2.69 2.92	2.61 3.32	5.28	2.70	2.69 3.42	2.61 3.32
.13 5.98 2.10 } 11.59	.54 5.99 .68 } 11.72	.07 } 12.05	.... } 5.70	.13 5.98 .16 } 11.30	.61 6.02 .78 } 11.79
2.31 2.65	2.20 2.80	4.37	2.24	2.31 2.94	2.23 2.84
.07 .08	.07 .09	.16	.07	.07 .08	.07 .01
1.19 1.21	1.52 1.93	.02	1.82	1.19 1.52	1.59 2.02

[3] ND means component not detected at the following amounts: 0.01 percent CuO, 0.03 percent TiO_2, 0.005 percent S, 0.01 percent Cl, 0.04 percent F.

[4] Structural formula calculated on an anhydrous basis using computer program of Jackson and others (1967). Formulas exclude Ca, S, Cl, and F.

Table 3.—*Microprobe analyses and structural formulas for biotite, chlorite,*

Mount No.	GM6G-Con.	3GM6G			
Grain No.	4-Con.	1			
Area analyzed	CLA	G	A	C	D
Mineral	Chlorite	Biotite	Copper-rich zone		
Letter reference in text	M	N	O	P	Q
Microprobe analysis (percent)—Continued					
SiO_2	26.6±0.2	37.4±0.2	31.1±0.9	30.4±0.2	30.8±0.8
Al_2O_3	19.2±0.2	14.9±0.2	14.5±0.1	14.4±0.1	14.1±0.6
FeO[1]	22.5±0.3	18.5±0.2	14.5±0.3	13.9±0.2	13.5±0.6
MgO	16.4±0.2	12.3±0.1	10.3±0.2	9.8±0.1	9.7±0.4
CaO	.....	ND	.34±0.07	.24±0.05	.15±0.03
MnO	.96±0.07	.50±0.02	.32±0.02	.31±0.02	.28±0.02
CuO	.01±0.001	ND	12.6±0.6	12.1±0.4	14.4±0.8
TiO_2	.16±0.03	3.9±0.1	3.0±0.1	3.0±0.1	3.0±0.1
K_2O	.11±0.03	9.6±0.3	2.2±0.5	1.8±0.2	1.9±0.4
Cl	ND	.....	.....	.....	.....
F	.16±0.03	.....	.....	.....	.....
S	ND	.....	.....	.....	.....
Σ	85.9	97.1	88.9	86.0	87.8
Less O≡Cl+F	.1	.....	.....	.....	.....
Σ	85.8±0.5	97.1±0.5	88.9±1.3	86.0±0.6	87.8±1.2
Structural formulas[4]—Continued					
Anions per formula	28	22	22	28	22	28	22	28
Si^{+4}	5.66	5.58	5.22	6.65	5.25	6.68	5.25	6.68
Al^{IV}	2.34	2.42	2.78	1.35	2.75	1.32	2.75	1.32
	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Al^{VI}	2.48	.21	.09	2.30	.17	2.40	.08	2.28
Ti^{+4}	.03	.44	.38	.48	.39	.50	.38	.49
Mg^{+2}	5.20	2.74	2.58	3.28	2.52	3.21	2.46	3.14
Cu^{+2}	....	....	1.60	2.03	1.58	2.01	1.85	2.36
Fe^{+2}	4.01	2.31	2.04	2.59	2.01	2.55	1.92	2.45
Mn^{+2}	.17	.06	.06	.06	.04	.04	.04	.05
K^{+1}	.03	1.83	.47	.60	.40	.50	.41	.53
	11.92	5.76	6.75	11.34	6.71	11.21	6.73	11.30

[1] Total Fe calculated as FeO.

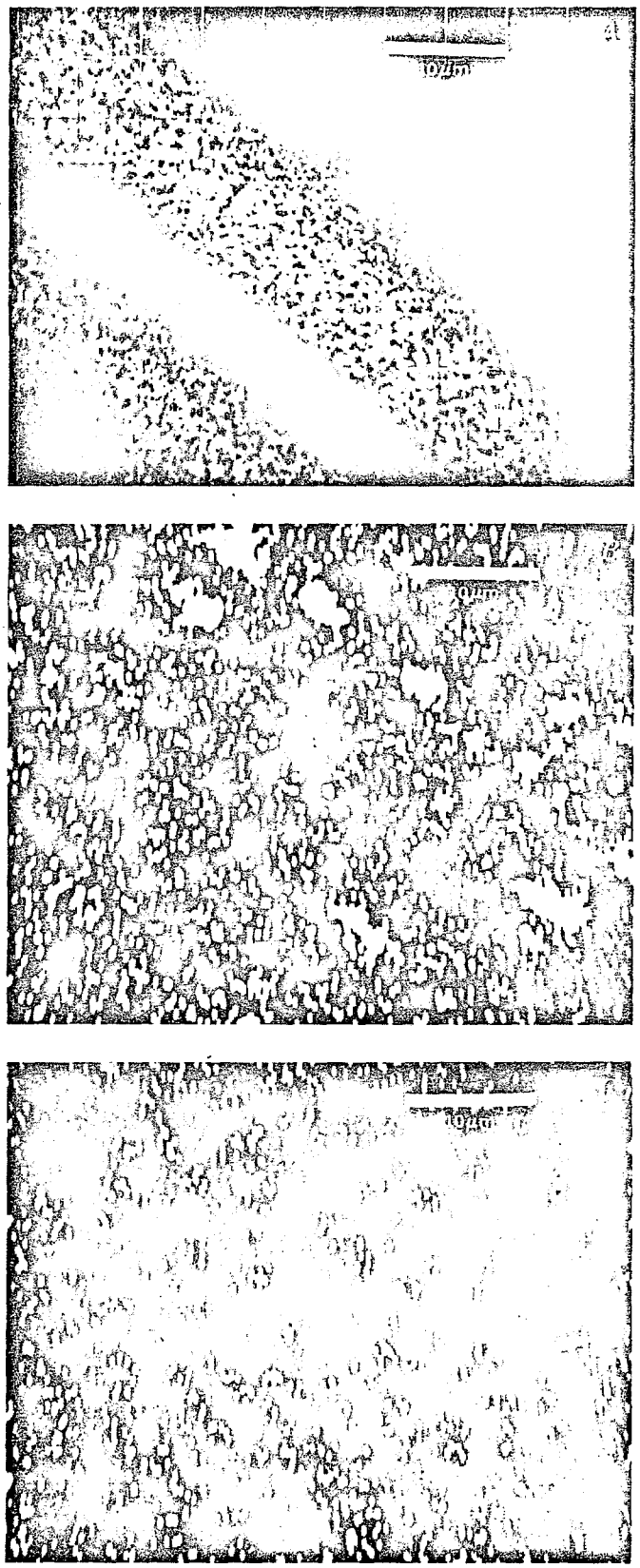
[2] Blanks indicate no analysis was made for the component.

and copper-rich zones in biotite from Granite Mountain Porphyry —Continued

3GM6G—Continued		GM12			
1—Continued		2			3
E	F	BIX	BIA	BIB	CL
Copper-rich-zone—Continued		Biotite	Copper-rich zone		Chlorite
R	S	T	U	V	W
Microprobe analysis (percent)—Continued					
30.7±0.6	31.4±0.7	37.1±0.1	37.0±0.5	37.3±0.8	27.4±0.2
14.6±0.2	15.1±0.2	14.4±0.4	13.5±0.4	13.4±0.3	17.9±0.3
15.1±0.5	14.8±0.3	18.0±0.1	14.9±0.5	14.9±0.3	22.9±0.2
9.8±0.3	10.2±0.3	11.8±0.1	13.1±0.4	13.3±0.4	17.2±0.1
.25±0.24	.17±0.02	.....	.....	.....	.....
.30±0.02	.35±0.04	.69±0.05	.46±0.2	.45±0.03	.93±0.03
15.3±0.7	10.1±1.5	ND	.19±0.04	.19±0.04	.09±0.01
3.1±0.1	3.3±0.1	4.1±0.1	3.2±0.1	3.3±0.1	.05±0.009
2.6±0.1	4.2±0.5	9.4±0.1	7.3±0.2	7.6±0.1	.18±0.03
.....	.....	.03±0.01	.03±0.02	.01±0.007	ND
.....	.....	.69±0.05	.90±0.13	.91±0.12	.14±0.02
.....	.....	.02±0.002	.01±0.001	.01±0.001	.....
91.8	89.6 . . .	96.2	90.6	91.4	86.8
.....	.....	.3	.4	.4	.1
91.8±1.1	89.6±1.8	95.9±0.5	90.2±0.9	91.0±1.0	86.7±0.4
Structural formulas[4] —Continued					
22	28	22	28	22	22	28	22	28	28
5.09, 2.86 } 7.95	6.48, 1.52 } 8.00	5.21, 2.79 } 8.00	6.63, 1.37 } 8.00	5.63, 2.37 } 8.00	5.82, 2.18 } 8.00	7.41, .59 } 8.00	5.82, 2.18 } 8.00	7.41, .59 } 8.00	5.80, 2.20 } 8.00
....	2.11	.16	2.39	.20	.32	2.59	.29	2.55	2.27
.39	.49	.41	.52	.47	.38	.48	.39	.49	.01
2.42	3.08	2.52	3.21	2.67	3.07	3.91	3.10	3.94	5.43
1.91 } 6.85	2.44 } 11.53	1.27 } 6.45	1.61 } 11.54	.... } 5.71	.02 } 5.81	.03 } 11.44	.02 } 5.81	.03 } 11.50	.01 } 12.00
2.09	2.66	2.05	2.62	2.28	1.96	2.49	1.95	2.48	4.06
.04	.05	.04	.06	.09	.06	.08	.06	.08	.17
.55	.70	.89	1.13	1.82	1.46	1.86	1.51	1.93	.05

[3] ND means component not detected at the following amounts: 0.01 percent CuO, 0.03 percent TiO_2, 0.005 percent S, 0.01 percent Cl, 0.04 percent F.

[4] Structural formula calculated on an anhydrous basis using computer program of Jackson and others (1967). Formulas exclude Ca, S, Cl, and F.



of copper in the transitional material is not easily explained by either substitution or attachment of copper in well-formed chlorite and biotite in view of the relatively low amount of copper in well-formed chlorite and biotite (fig. 3; tables 1 and 2).

Whether the material is partly destroyed biotite, poorly formed chlorite, another well or poorly formed sheet silicate, or a mixture of these cannot be determined from existing data. However, the data do restrict the type or amount of possible sheet silicates that could make up the material in the bleached zones. The silica content of the zones, being less than biotite, indicates that if no chlorite is present in the zones and biotite either is or is not present, the sheet silicates that could make up the zones are septechlorite, clintonite, xanthophyllite, margarite, silica-poor montmorillonite, or vermiculite. The small amount of calcium in the zones (analyses O, P, Q, R, and S, table 3) indicates that of these, margarite, clintonite, and xanthophyllite probably are not present. On the basis of the color of the zones, their refractive index, birefringence, the leachability in acid of copper in biotite-chlorite grains (mentioned earlier), and the number of exchange sites available, vermiculite or montmorillonite seem to be more likely alternatives to septechlorite, if indeed another sheet silicate is present in the zones. Montmorillonite is possibly less likely than vermiculite because smaller amounts of alumina are expected in silica-poor montmorillonite. Alternatively, if chlorite composes part of the zones, the data do not negate the presence of a sheet silicate having more silica than biotite; however, the amount of such a silicate that could be present is limited by the amount of chlorite required to dilute the higher amounts of silica in these minerals to those observed in the zones. Thus if most of the copper were present in a high-silica silicate, the amount required is much more than that required in vermiculite.

The zones often include apatite grains and are wider around them. In addition, the zones commonly contain or are near swarms of suboptical-sized apatite as determined by electron-beam scans of the zones for calcium and for phosphorus (fig. 5*B*). Thus it is suspected that the bleached zones (which range in thickness from <1 to 20 μm) extend completely through 3-mm-sized biotite grains and in places are offset along fractures that developed prior to consolidation of the magma because of favorable permeability conditions in the biotite resulting from the deformation and expansion of the grains by the apatite inclusions.

Figure 5.—Photographs of electron-beam scans of copper-rich zones in mount sample 3GM6G. *A*, Scan for copper. Exposure time, 1 minute. *B*, Scan for phosphorus of same area as *A*. Exposure time, 1 minute. *C*, Scan for sulfur of same area as *A*. Exposure time, 10 minutes.

COMPARISON OF MAJOR-ELEMENT CHEMISTRY OF THE COPPER-RICH AND COPPER-POOR CHLORITES

The presence or absence of copper in chlorite could possibly be attributed to its formation at different times or from different fluids; hence, the resulting chlorites might be differentiated on the basis of chemistry. However, preliminary data indicate that except for the presence of copper, chlorite that contains copper is similar in chemistry to chlorite that does not contain copper (fig. 6). In fact, the composition of chlorite appears dependent in larger part on the composition of the parent biotite than on the copper-depositing characteristics of the altering fluid (fig. 7). Preliminary observations also revealed no optical dissimilarity between copper-bearing and copper-poor chlorite. Thus it could not be established whether chlorite formed in the rocks at two different times from two fluids.

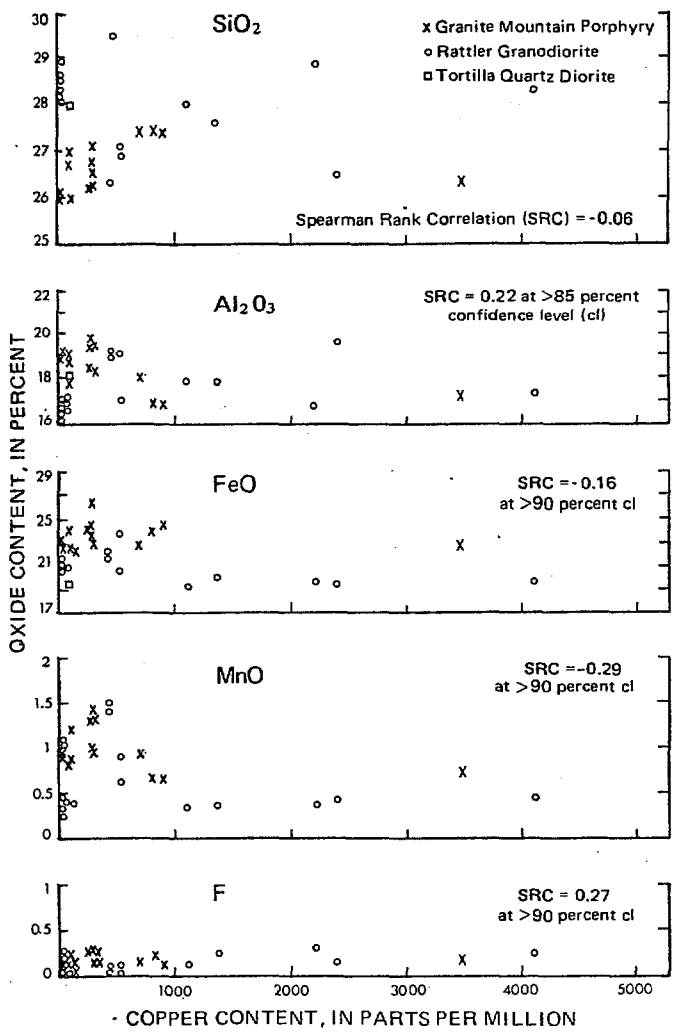


Figure 6.—Graphs showing amounts of representative chemical components in chlorite in relation to amount of copper in chlorite. Some points are offset slightly for plotting purposes. Four additional points (three for Rattler Granodiorite and one for Tortilla Quartz Diorite) plot near the origin of the F versus Cu diagram.

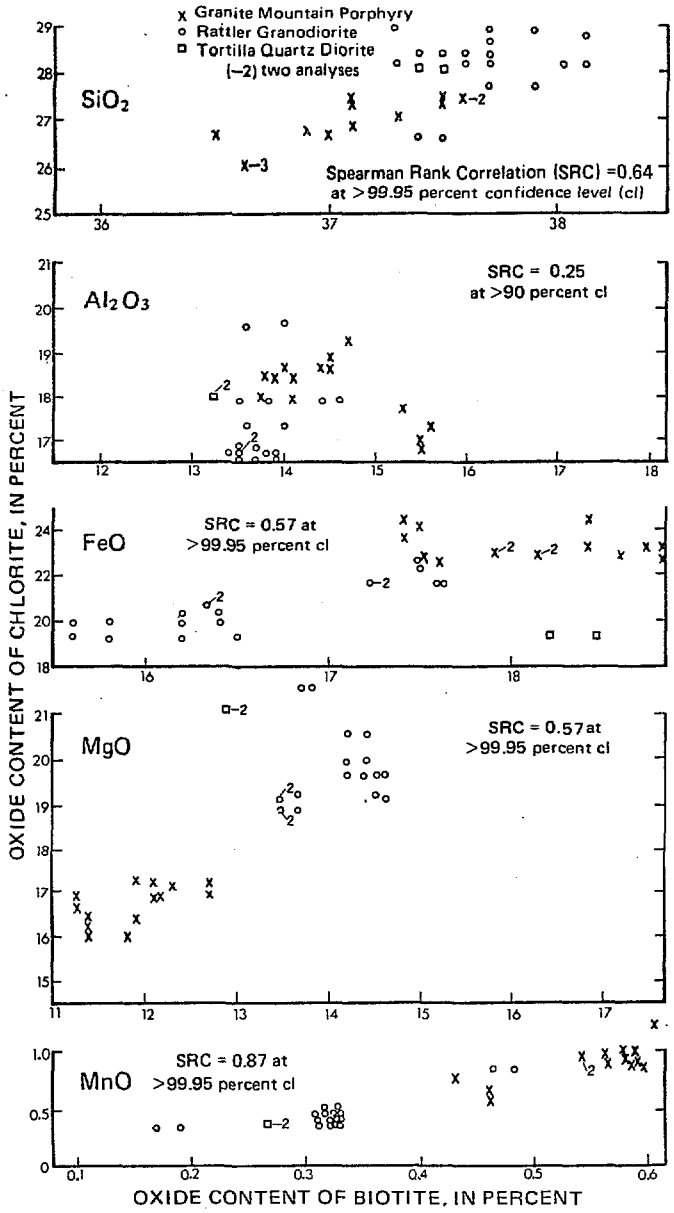


Figure 7.—Graphs showing the amount of oxide in biotite in relation to the amount of oxide in chlorite derived from the biotite. Some points are slightly offset for plotting purposes. The statistics include two biotite-chlorite pairs that plot off the diagrams.

VALUE OF THE COPPER CONTENT OF CHLORITE AS AN INDICATOR OF ORE

The occurrence of copper-bearing chlorite derived from igneous biotite near two ore deposits suggests that the amount of copper in chlorite might serve as a geochemical indicator for

a nearby copper ore deposit. However, copper in chlorite does not seem to show a simple positive relation with the proximity of the sample to a presently recognized deposit (fig. 8). This lack of correlation may result from inadequate data or from the possibility that the copper content of chlorite depends on factors other than, or in addition to, the distance of the chlorite grain from a minable deposit.

Inadequacy in the data is suggested by the extreme variation in the amount of copper in chlorite both between grains in the same probe mount (thin section, 1-in. diam) and within

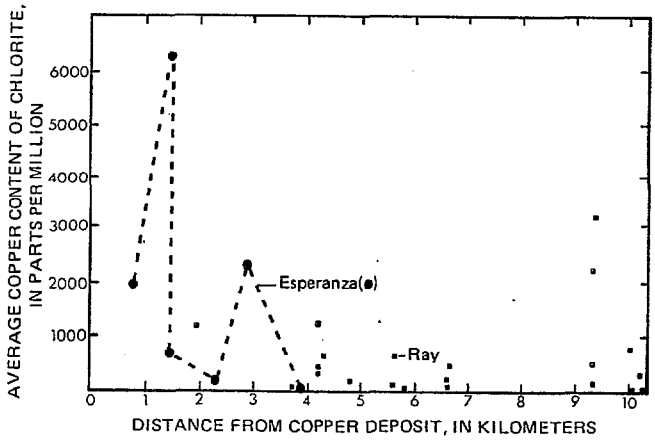


Figure 8.—Plot of average amount of copper in chlorite in a given sample in relation to distance of the sample from the nearest recognized commercial deposit.

individual grains (figs. 3, 4; tables 1, 2). Thus determination of the true average abundance of copper in chlorite in each rock sample is too expensive to refine with microprobe analyses because a prohibitive number of grains must be analyzed in a prohibitive number of mounts. The alternative method of determining the true abundance of copper in chlorite by conventional analyses of separates may also be limited by the various types of bias that are built into mineral separations (magnetic, electrostatic, specific gravity, and optical)—the resulting separation may be 100 percent chlorite, but in view of the irregular distribution of copper in chlorite and of the fact that much copper resides in the more poorly crystallized chlorite, the mineral separate is likely to contain copper in an amount not representative of the average.

These observations do not rule out the potential use of copper abundance in chlorite as a geochemical indicator. If standardized separation techniques are used, it is still possible that the content of either leachable or total copper in mica or chlorite separates may correlate roughly with proximity of the sample to a deposit. Additionally, the copper content of chlorite may be of limited usefulness as a broader indicator of ore; that is, it might point out potential copper-producing provinces. For example, the copper content of chlorite from Sierra Nevada rocks (Dodge, 1973) with no known associated porphyry-type deposits is much less than that of chlorites reported here. However, this again may reflect mineral separation problems because Dodge analyzed clean mineral separates that probably were relatively free of poorly crystallized chlorite.

Finally, assuming that the true average abundance of copper in chlorite (or an abundance determined by analysis of concentrates separated in a standardized way) could be determined, caution should be used in its application as a geochemical indicator of ore because there is reason to suspect that this abundance could be influenced by factors other than the distance of the sample from a minable copper deposit. These factors include the rate of chloritization, percentage of partial chloritization, number and size of grains chloritized, the number of potential fluid conduits (fractures) per unit volume of rock, the proximity of the chlorite to a fracture, and the concentration of copper in the fluid immediately adjacent to the biotite; the first three factors would control the number of sites suitable for copper capture, and the latter three are measures of the availability of the chlorite to the copper in the supplying fluid.

CONCLUSIONS

Copper occurs in chlorite derived from igneous biotite in Laramide intrusions around two Arizona porphyry copper deposits and, further, is concentrated at the boundary between parent biotite and chlorite. However, the copper content of igneous and hydrothermal biotite near these deposits was found to be much less than that of chlorite and was not detected in most of the grains analyzed. In view of the difficulty in cleaning chlorite from biotite separates, these observations suggest that caution should be used in speculations about what the abundance of copper in biotite derived from bulk-analyzed mineral separates might mean with respect to the genesis or proximity of ore deposits and with respect to the behavior of copper in a differentiating magma. Additionally, because a potentially large part of the copper in a whole-rock sample of "granitic" rock may be in alteration products of biotite and thereby conceivably have had its source outside the analyzed sample, caution should be applied to petrologic and genetic interpretations of whole-rock copper abundance data.

ACKNOWLEDGMENTS

The manuscript benefited greatly from thoughtful reviews by N. J Page and R. P. Ashley. T. G. Lovering kindly supplied the biotite separates from Esperanza-Sierrita samples. Hydrothermal biotite from the Ray deposit was collected with the helpful cooperation of the staff of the Kennecott Copper Corp., Ray Mines Division. Walter S. Snyder aided in construction of the illustrations.

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Cuneen fayi Copper — Bedaki

made by mine personnel on a cyclical basis. The maintenance of

posse.

O.K. Cu may occur in chlorite - where has the Cu & chlorite come from -- a good chance the Cu is related to a ore deposition event -- In that case -- it's a good thing that the chlorite is difficult to clean from the biotite G.J.S.

JRK WLK ~~GJS~~ FLG

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Mr. W. L. Kurtz
Tucson Office

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GEOCHEMISTRY BIOTITE

Dear Bill,

I have just come across a U.S.G.S. paper, published earlier this year, dealing with the distribution of copper in intrusive rocks near porphyry copper deposits ("Distribution of Copper in Biotite and Biotite Alteration Products in Intrusive Rocks Near Two Arizona Porphyry Copper Deposits" by Norman G. Banks, Jour.Research U.S.G.S., Vol. 2, No. 2, 1974). I have attached a copy in case your people have not previously seen it.

The data (obtained by electron microprobe) presented in the paper suggest serious limitations for the application of copper concentrations in biotite as an exploration tool. In his conclusions the auther states:--

"Copper occurs in chlorite derived from igneous biotite in Laramide intrusions around two Arizona porphyry copper deposits, and, further, is concentrated at the boundary between parent biotite and chlorite. However, the copper content of igneous and hydrothermal biotite near these deposits was found to be much less than that of chlorite and was not detected in most of the grains analyzed. In view of the difficulty in cleaning chlorite from biotite separates, these observations suggest that caution should be used in speculations about what the abundance of copper in biotite derived from bulk-analyzed mineral separates might mean with respect to the genesis or proximity of ore deposits and with respect to the behavior of copper in a differentiating magma. Additionally, because of potentially large part of the copper in a whole-rock sample of "granitic" rock may be in alteration products of biotite and thereby conceivably have had its source outside the analyzed sample, caution should be applied to petrologic and genetic interpretations of whole-rock copper abundance data".

like where? possibly after biotite? G.J.S.

Yours very truly,

Lloyd James.

L. D. JAMES

LDJ:db
Encl.

cc:T.C.Osborne w/o encl.
J.H.Courtright w/o encl.

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Porph Copper
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Graham Expl. Tech. — Biotite

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DISTRIBUTION OF COPPER IN BIOTITE AND BIOTITE ALTERATION PRODUCTS IN INTRUSIVE ROCKS NEAR TWO ARIZONA PORPHYRY COPPER DEPOSITS

By NORMAN G. BANKS, Menlo Park, Calif.

Abstract.—Biotite and its alteration products (primarily chlorite) from igneous rocks around the Ray and Esperanza (Esperanza-Sierrita) porphyry copper deposits, Arizona, were analyzed for copper by electron microprobe. The copper occurs in amounts >90 p/m (limit of detection) in most of the chlorites analyzed, is concentrated at the optical and chemical boundary of chlorite and biotite, and is not associated with sulfur. Most unaltered igneous and hydrothermal biotites analyzed contain <90 p/m Cu, and except for one sample, all copper that was detected can be explained as contamination by copper from chlorite grains. The paucity of detectable copper in igneous and hydrothermal biotite and its presence in daughter chlorite suggest that the positive association noted by some workers between the proximity of an ore deposit and the copper content of biotite might be partly the result of increased amounts of chloritization of biotite near a deposit coupled with difficulty in physically cleaning the biotite separates. Additionally, previous speculations that (1) part of the copper in a deposit may come from altered biotite, and (2) copper in biotite indicates how copper behaves in a differentiating magma, are of doubtful value if based on data derived from analyses of bulk mineral separates.

The copper, sulfur, and major-element contents of biotite and its alteration products from igneous rocks associated with the Ray and Esperanza (Esperanza-Sierrita) porphyry copper deposits were determined by microprobe analyses. The results do not agree with some of the published data about the distribution of copper in biotite nor with some of the speculations drawn from that data.

The Ray samples, collected 2–11 km from the deposit, consist of 2 ore specimens and 21 igneous rocks representing 5 intrusive types. All five intrusive types are cut by sulfide-bearing veinlets in and around the Ray deposit. The deposit is located about 120 km north of Tucson, Ariz. The intrusive rocks temporally associated with the deposit range in composition and texture from hornblende diorite (andesite) to quartz monzonite (quartz latite) (Cornwall and others, 1971; Banks and others, 1972). Intrusion began about 70 m.y. ago and continued to about 60–61 m.y. ago—the Laramide age of the youngest intrusive body (Granite Mountain Porphyry) within the commercial limits of the deposit (Creasey and Kistler, 1962; Banks and others, 1972; Banks and Stuckless, 1973). Sulfide mineralization followed, and the deposit cooled below 100°C about 60 m.y. ago (Banks and Stuckless, 1973).

The Esperanza deposit, about 40 km south of Tucson, is associated with the Ruby Star Granodiorite, also Laramide in age (Creasey and Kistler, 1962; Damon and Mauger, 1966). T. G. Lovering kindly supplied igneous biotite, separated from seven samples collected from this intrusive body, 0.8–4 km from the center of mining activity at Esperanza.

ANALYTICAL METHODS

Extreme care was taken to eliminate contamination of copper by external sources. Rock chips (Ray samples) and mineral grains (Esperanza samples), plastic mounted onto glass slides and cut to 40- to 50-μm thickness by diamond saw, were ground and polished on glass plates in several steps, using diamond powder as an abrasive to remove any copper smeared onto the specimens from brass in the saw blade. Between each step, the slides were agitated in an ultrasonic cleaner, then positioned so that the direction of polishing was 90° from the previous direction. Finally, the slides were polished four more times on nylon over glass with alumina powder, agitated in an ultrasonic cleaner, and again rotated 90° between each polishing step.

Several mounts were polished on a lead-bronze lap with diamond powder, analyzed, repolished by use of the four-step alumina method, and finally reanalyzed to check if any copper physically smeared onto the sample was actually removed by the polishing with alumina. Copper in erratic but measurable concentrations (parts per million) was detected on some biotite grains in the slides polished on the lead-bronze lap (not on well-polished nonlayer silicates) but was not detected on the same grains after the alumina polishing. Thus, sample contamination by copper sources external to the sample is believed to have been eliminated by this polishing.

Contamination of minerals by copper from other minerals in the slide could not be eliminated. However, the sources of contamination are identified, and as explained later, the contamination does not alter the conclusions drawn here.

The copper and sulfur analyses were made with an ARL (Applied Research Lab.) model EMX-SM electron microprobe

using a LiF crystal for copper and an ADP crystal for sulfur, an excitation voltage of 20 kV, a sample current of 3×10^{-8} A on brass, and chalcocite (Cu_2S) as a standard. Integration times of 200±2 s were obtained by termination of counting on fixed-beam current. For most analyses the electron beam was fully focused. Buildup of carbon contamination and noticeable loss of volatile components were avoided by moving the beam with magnetic deflectors to sweep areas as much as 10 by 8 μm. If the shape of the grain did not permit sweeping of areas of at least 5 by 4 μm, a defocused beam (2–3 μm diam) was used, and the sample was moved under the beam about once every 20 s.

X-ray intensity data (counts) were obtained by averaging 2–40 (usually 6–8) observations on each grain. Initially, correction of the raw intensity data was done by computer and included drift, background, and matrix corrections (mass absorption, secondary fluorescence, and atomic number effects; Beeson, 1967; Beaman and Isasi, 1970). Individual backgrounds for each grain were determined by observing counts above and below the peak wavelengths of copper and sulfur. Major-element data required for the corrections and data in table 3 and figures 6 and 7 were obtained at an excitation voltage of 15 kV and count times of 20±0.5 and 40±1 s. It developed, however, that the computer correction factor for trace amounts of copper and sulfur (50–5,000 p/m) is nearly constant for each mineral type studied regardless of its exact major-element composition. Thus, in the later part of the study and for most of the data on tables 1 and 2, a matrix correction for copper and sulfur in each mineral type (derived in the initial study) was applied by hand. During this stage of the study, usually magnesium or potassium was monitored as a check on the purity of the mineral grains.

A homogeneous synthetic glass containing about 400 p/m Cu and 520 p/m S was repeatedly analyzed under the above operating conditions. The one standard deviation of error from the average amount of copper present in the glass was 10 percent (8 percent for S), and the maximum deviation was 20 percent (15 percent for S). Detection levels were established at three times the square root of the average background counts (Birks, 1963); thus, copper is considered detectable at about 90 p/m (50 p/m for S) at the above operating conditions in the minerals analyzed.

COPPER AND SULFUR CONTENTS OF THE MINERALS

The copper and sulfur contents of hydrothermal biotite from the Ray deposit and of igneous biotite and its alteration products (chlorite, epidote, sphene, and hydrogarnet?) from five intrusive rock types located near the deposit are listed in table 1. Similar data for igneous biotite and its alteration products from the Ruby Star Granodiorite near the Esperanza deposit are presented in table 2.

Chlorite formed by alteration of biotite near both the Ray and Esperanza deposits contains significantly more copper than the unaltered igneous biotite analyzed (fig. 1). Most of the biotite grains (80 percent of the Ray and 75 percent of the Esperanza biotite), including those of hydrothermal origin, do not contain detectable amounts of copper, whereas 65 percent of the Ray chlorite grains analyzed and 90 percent of the Esperanza chlorite grains analyzed contain detectable amounts of copper.

LOCATION OF COPPER IN CHLORITE

Sulfur and copper in the biotite and chlorite were monitored during the analyses on a memory oscilloscope or on Polaroid film over a nonrecording oscilloscope to determine whether sulfide or sulfate inclusions might account for the copper in the chlorite or biotite. With one possible exception (a chlorite grain in sample 2GM14, not listed in table 1), no such inclusions were found. Furthermore, it is unlikely that the copper is present in sulfide or sulfate grains that are smaller than can be detected on the oscilloscope because increases in the amount of copper in either biotite or chlorite are not accompanied by corresponding increases in the amount of sulfur (fig. 2). For example, the ratio of copper to sulfur should be 1 to 1 if the copper were present in chalcopyrite inclusions and 4 to 1 if the supposed inclusions were chalcocite; these ratios are not found (fig. 2). In addition, several quantitative analyses for Mo, Zn, Pb, Mn, Cl, and F (by microprobe) indicate that the copper in the grains also is not associated with these elements. The presence of copper carbonates or nitrates was not checked directly because the sections were carbon coated, and an analyzing crystal suitable for nitrogen analyses was not immediately available. A direct check for the presence of copper silicates and an indirect check for the presence of copper carbonates, oxides, and nitrates by analyzing the grains for silicon and oxygen was not possible because the copper occurs in a silicon-oxygen matrix (biotite and chlorite) having approximately the same silicon or oxygen contents as the known copper carbonates, oxides, nitrates, and silicates. Thus, any variations in silicon or oxygen intensity data caused by the presence of minute quantities (parts per million range) of these minerals would be masked by analytical uncertainty in such data. Quantitative analyses for Se, W, As, Sb, Te, I, V, and P (the other elements occurring in known copper-bearing minerals) were not made, but qualitative scans were. As noted in the tables, the copper in chlorite is often distributed inhomogeneously and, as discussed below, is locally concentrated in sufficient quantities so that X-ray images of its distribution can be observed on and photographed from an oscilloscope. Similarly, if Se, W, As, Sb, Te, I, V, or P were present in amounts comparable to the copper, they could be observed on the X-ray images; they were not.

Table 1.—*Copper and sulfur in biotite and its alteration products from the intrusives near the Ray porphyry copper deposit, Arizona*

[Values in regular type denote element is present at or above detection level (about 90 p/m for Cu and 50 p/m for S). Values in italic type indicate real or fictitious element contents resulting from higher-than-background counts at the peak wavelength of the element. Copper and sulfur values are not significant to three figures. Precision is lower in grains in which copper and sulfur are not homogeneously distributed]

Rock type	Sample	Grain	Mineral	Copper (p/m ±10 percent)	Sulfur (p/m ±10 percent)
Tortilla Quartz Diorite.	217-1	1BI	Biotite	*0*	
		2BI	..do..	*0*	
		3BI	..do..	*0*	138
		5BI	..do..	*0*	161
		2CL	Chlorite	*0*	
		4CL	..do..	*42*	*20*
		5CL	..do..	*16*	*0*
		6CL	..do..	*0*	*0*
		7CL	..do..	*24*	*23*
		6EP	Epidote	*42*	52
		7EP	..do..	*0*	*0*
	217-28	1BI	Biotite	386*	167
		3BI	..do..	*39*	199
		4BI	..do..	*52*	
		5BI	..do..	109	
		BTM1	..do..	*21*	199
		1CL	Chlorite	206*	59
		2CL	..do..	244*	
		4CL	..do..	149	86*
		5CL	..do..	120	*45*
		4M	Hydrogarnet?	151*	79
		3EP	Epidote	*40*	*28*
	248-29	2CL	Chlorite	*60*	
		3CL	..do..	190	
Rattler Grano-diorite.	246-99B	3BI	Biotite	697	172
		1CL	Chlorite	569	74
		2CL	..do..	432	50
	46-11G	BI	Biotite	*0*	
		CL	Chlorite	2237	
		EP	Epidote	2000*	
	246-11G	1BI	Biotite	*26*	
		3BI	..do..	*28*	199
		4BI	..do..	*0*	181
		7BI	..do..	110	146
		BTM1	..do..	*0*	197
		1CL	Chlorite	626	
		5CL	..do..	*51*	*1*
		6CL	..do..	105	*0*
		CLM1	..do..	*0*	*10*
		CLM2	..do..	*0*	*6*
		2EP	Epidote	*10*	*41*
		6SP	Sphene	*53*	82*
	61-25	BIGM	Biotite	*0*	
		BI1	..do..	*0*	
		BI2	..do..	*0*	
		CL2	Chlorite	291	
		EP2	Epidote	157	
	261-25	1BIA	Biotite	*0*	209
		1BIB	..do..	*0*	283
		3BI	..do..	*0*	184
		5BI	..do..	*0*	156
		2CLA	Chlorite	*0*	*0*
		2CLB	..do..	*0*	*0*
		4CL	..do..	*0*	*5*
		5CL	..do..	*0*	*0*
		1EP	Epidote	*0*	*0*
		4EP	..do..	*0*	*0*
Rattler Grano-diorite—Con.	260-113D	2BI	Biotite	*0*	189
		3BI	..do..	*0*	256
		4BI	..do..	*0*	190
		5BI	..do..	*0*	254
		3CL	Chlorite	*0*	*0*
		4CL	..do..	*0*	*0*
		3M	Hydrogarnet?	*0*	*0*
		1EP	Epidote	*0*	*0*
		5EP	..do..	*0*	*15*
	246-11A	1BI	Biotite	256*	
		1BIA	..do..	245	
		2BI	..do..	*0*	A313
		4BI	..do..	405*	
		5BI	..do..	*57*	294
		5BIA	..do..	119*	
		BIM1	..do..	496*	280
		BIM2	..do..	*0*	282
		1CL	Chlorite	2218*	*21*
		1CLA	..do..	1368	
		3CL	..do..	460	*14*
		3CLA	..do..	2000*	*10*
		4CL	..do..	405	
		4CLA	..do..	3138*	
		4CLB	..do..	617	
		5CLA	..do..	2397*	
		5CLB	..do..	4118*	
		5CLC	..do..	8340*	
		CLM1	..do..	1432*	*20*
		CLM2	..do..	9842*	*0*
	260-96A	1BI	Biotite	*52*	214
		3BI	..do..	*0*	191
		4BI	..do..	*0*	220
		5BI	..do..	*0*	185
		2CL	Chlorite	754*	254
		2CLA	..do..	416	262*
		3CL	..do..	1160*	54
		6CL	..do..	674*	112*
		1EP	Epidote	608*	*22*
		6SP	Sphene	*94*	*0*
Rhyodacite dike	2GM100	1BI	Biotite	*51*	290
		2BI	..do..	*36*	243
		3BI	..do..	*15*	274
		2CL	Chlorite	*0*	*44*
		4CL	..do..	102	105
		5CL	..do..	*66*	117
		4EP	Epidote	*0*	*0*
		5EP	..do..	130*	*0*
		4SP	Sphene	*0*	*0*
		5SP	..do..	*0*	*0*
Granite Mountain Porphyry.	GM14	BI	Biotite	*0*	
		CL1	Chlorite	*0*	

Table 1.—*Copper and sulfur in biotite and its alteration products from the intrusives near the Ray porphyry copper deposit, Arizona*—Continued

Rock type	Sample	Grain	Mineral	Copper (p/m±10 percent)	Sulfur (p/m±10 percent)
Granite Mountain Porphyry—Con.	GM14	CL2	..do..	582	
		CL3	..do..	34	
		EP	Epidote	0	
		SP6	Sphene	0	
	2GM14....	1BI	Biotite	20	311
		2BI	..do..	0	
		2BIA	..do..	0	202
		3BI	..do..	198	273
		4BI	..do..	0	237
		6BI	..do..	0	
		BTM1	..do..	0	158
		2CL	Chlorite	110	0
		5CL	..do..	42	11
		6CL	..do..	5	68
		CLM1	..do..	79	75
	GM12R....	2BIX	Biotite	0	208
		3BI	..do..	111	237
		3BIA	..do..	144	180
		4BI	..do..	110	156
		5BI	..do..	125	152
		3CL	Chlorite	699	26
		3CLA	..do..	294	26
		4CL	..do..	297	44
		5CL	..do..	527	98
	GM6GR ...	BI1	Biotite	0	
		BIA	..do..	0	
		3BIA	..do..	0	120
		4BIA	..do..	0	190
		3CLA	Chlorite	3440*	0
		4CLA	..do..	80	0
		CLA	..do..	266	
	2GM6GR ..	2BIM	Biotite	0	190
		3BIM	..do..	0	
Granite Mountain Porphyry—Con.	2GM6GR ..	4BIM	..do..	0	
		3CLM1	Chlorite	261	
		3CLM 2	..do..	442	
		4CLM	..do..	125	
	3GM6G....	BI1	Biotite	0	
		BI2	..do..	0	
		BI3	..do..	0	
		CL1	Chlorite	385	
		CL2	..do..	382	
		CL3	..do..	414	
	2GM4V....	BIB	Biotite	110	
		1BIA	..do..	0	
		3BIA	..do..	0	
		3BIB	..do..	0	
		1CL	Chlorite	915*	
		1CLA	..do..	818*	
		3CL	..do..	105	
	2GM1A....	2CL	..do..	324	
		2CLA	..do..	275	
		2CLB	..do..	311	
		CLM	..do..	1537*	
Teapot Mountain Porphyry.	TTM.....	ICL	Chlorite	1235*	
		3CL	..do..	1172*	
		CLM1	..do..	1006*	
		1SP	Sphene	145	
		3SP	..do..	124	
Hydrothermal biotite.	2P70-22 ...	1BI	Biotite	80	90
		2BI	..do..	46	486
	T123R	BI1	Biotite	26	189
		BI2	..do..	37	113
		BI3	..do..	64	156
		BI4	..do..	30	197
		BI5	..do..	33	191

*Element not distributed homogeneously in the grain. Criterion used was whether standard deviation from mean of counts divided by the square root of the average counts is >3 (Boyd, 1969).

The copper reported for chlorite in tables 1 and 2 was probably not smeared over the chlorite from other copper-bearing phases in the mounts because (1) the distribution of copper in the chlorite (discussed next) precludes such a source, (2) the copper content of the chlorite grains does not reflect the proximity, size, or even presence of copper sulfides in a given slide (always <200 p/m including chalcopyrite), and (3) except for sample 246-99B (table 1), copper was not found in other igneous silicate, oxide, or phosphate phases in the samples in amounts equal to or greater than that found in chlorite. Contamination of the chlorite with copper from chalcopyrite in veinlets was avoided by using probe mounts that contain no veinlets.

The amount of copper in chlorite is highest near the chlorite-biotite contact. Chlorite more than 50 μm from the mineral contact contains about 600–1,000 p/m Cu, biotite more than 50 μm from the contact contains copper in amounts just at or below the detection level, and about 1.5 percent Cu is found in the chlorite at the mineral contact (fig. 3A, sample 2GM4V, grain 1 CL). The amount of copper (about 1.5 percent) at the mineral contact is probably low because the material excited by the beam and secondary radiation extends beyond the visible mineral contact. Likewise, the broadness of the copper peak (fig. 3A) may be partly the result of excitation of copper in the contact zone by secondary radiation from points located in chlorite and biotite near the mineral contact.

The concentration of copper in chlorite along another biotite-chlorite boundary is shown as X-ray images photographed from an oscilloscope (fig. 4). The chlorite contains about

Table 2.—*Copper and sulfur in biotite and its alteration products from Ruby Star Granodiorite near the Esperanza porphyry copper deposit, Arizona*

[Values in regular type denote element is present at or above detection level (about 90 p/m for Cu and 50 p/m for S). Values in italic type indicate real or fictitious element contents resulting from higher-than-background counts at the peak wavelength of the element. Copper and sulfur values are not significant to three figures. Precision is lower in grains in which copper and sulfur are not homogeneously distributed]

Sample	Grain	Mineral	Copper (p/m, ±10 percent)	Sulfur (p/m, ±8 percent)	Chlorite in separate (percent)
T454R....	BT5	Biotite	*63*	106	*0.1*
	BTM1	..do..	*0*	180	
	BT5A	..do..	*0*	139	
	BT5C	..do..	*0*	138	
	BT5C1	..do..	*0*	125	
	CL5	Chlorite	*0*	*17*	
T455R....	BT1	Biotite	*21*	141	*3.5*
	BT2	..do..	*45*	126	
	BT3	..do..	*73*	126	
	BT4	..do..	*6*	160	
	BT5	..do..	200*	87	
	CLM1	Chlorite	4758*	68	
	CLM2	..do..	161	*0*	
	CL1	..do..	2040*	*6*	
T465R....	BT1	Biotite	*0*	69	*0.7*
	BT2	..do..	145	119	
	BT3	..do..	*0*	156	
	BTM1	..do..	*0*	140	
	BTM2	..do..	*0*	102	
	BTM3	..do..	*0*	125	
	CL1	Chlorite	175	*20*	
	SP1	Sphene	255	56	
T467R....	BT1	Biotite	654*	172	*11.2*
	BT2	..do..	511*	140	
	BTM1	..do..	*28*	275	
	BTM2	..do..	173	263	
	BTM3	..do..	*43*	232	
T467R.....	BTM4	Biotite	152	243	
	BTM5	..do..	*0*	197	
	CL1	Chlorite	766*	*0*	
	CL2	..do..	3418*	*0*	
	CL3	..do..	3024*	*7*	
	CLM1	..do..	1335	*0*	
	CLM2	..do..	1060	*14*	
T468R....	BT1	Biotite	*49*	201	*12.4*
	BT2	..do..	*3*	345	
	BT3	..do..	*0*	239	
	BT4	..do..	*0*	221	
	CL1	Chlorite	924*	*0*	
	CL2	..do..	9700*	96	
	CL3	..do..	10,000*	*36*	
	CL4	..do..	4500*	*32*	
T8R.....	BT1	Biotite	*0*	141	*17.6*
	BT2	..do..	616*	97	
	BT3	..do..	*0*	167	
	BT4	..do..	*32*	125	
	BT5	..do..	129	109	
	CL1	Chlorite	403	*0*	
	CL2	..do..	323*	*16*	
	CL3	..do..	669*	*0*	
	CL4	..do..	1656*	*30*	
	CL5	..do..	429	*10*	
	SP1	Sphene	*57*	*23*	
	SP2	..do..	333	65	
	SP4	..do..	*0*	*49*	

*Element not distributed homogeneously in the grain. Criterion used was whether standard deviation from mean of counts divided by the square root of the average counts is >3 (Boyd, 1969).

5,000 p/m Cu at the mineral contact and about 500 p/m (average) away from it. Although sulfur counts were collected for longer times than the copper counts, corresponding sulfur counts (fig. 4*C*, *F*) are lacking where the copper is concentrated. Background sulfur in biotite (300 p/m) was not detected in figure 4*C* and *F*.

Figure 3*B* shows a paucity of copper in compositionally pure biotite, a high concentration of copper in chlorite at the compositional chlorite-biotite contact, and a decrease in amount of copper in chlorite as it becomes chemically purer (as demonstrated by loss of K). Thus, copper is both spatially and compositionally associated with the biotite-chlorite transition, which implies that the copper was introduced in the fluids that destroyed the biotite and formed the chlorite. The fact that other elements known to coexist in previously described copper minerals were not concentrated with the copper suggests that the copper probably is present in either lattice or more loosely attached sites in the chlorite or other silicate minerals formed during transition of the biotite to chlorite. In the compositionally purer chlorite, the copper may be partly in exchangeable sites and partly in lattice sites. Dodge, Smith, and Mays (1969) and Parry and Nackowski (1963) point out that the radius of Cu^{+2} is appropriate for its camouflage in Fe^{+2} and Mg^{+2} (octahedral) positions. In the transitional material, the amount of copper present and the fact that cold concentrated nitric acid leaches copper from the Esperanza biotite-chlorite grains exposed in a rock-slab surface (T. G. Lovering, oral commun., 1972) might suggest a cation exchange position for part of the copper. The nature of the attachment of copper in this transitional material is discussed more fully in a later section.

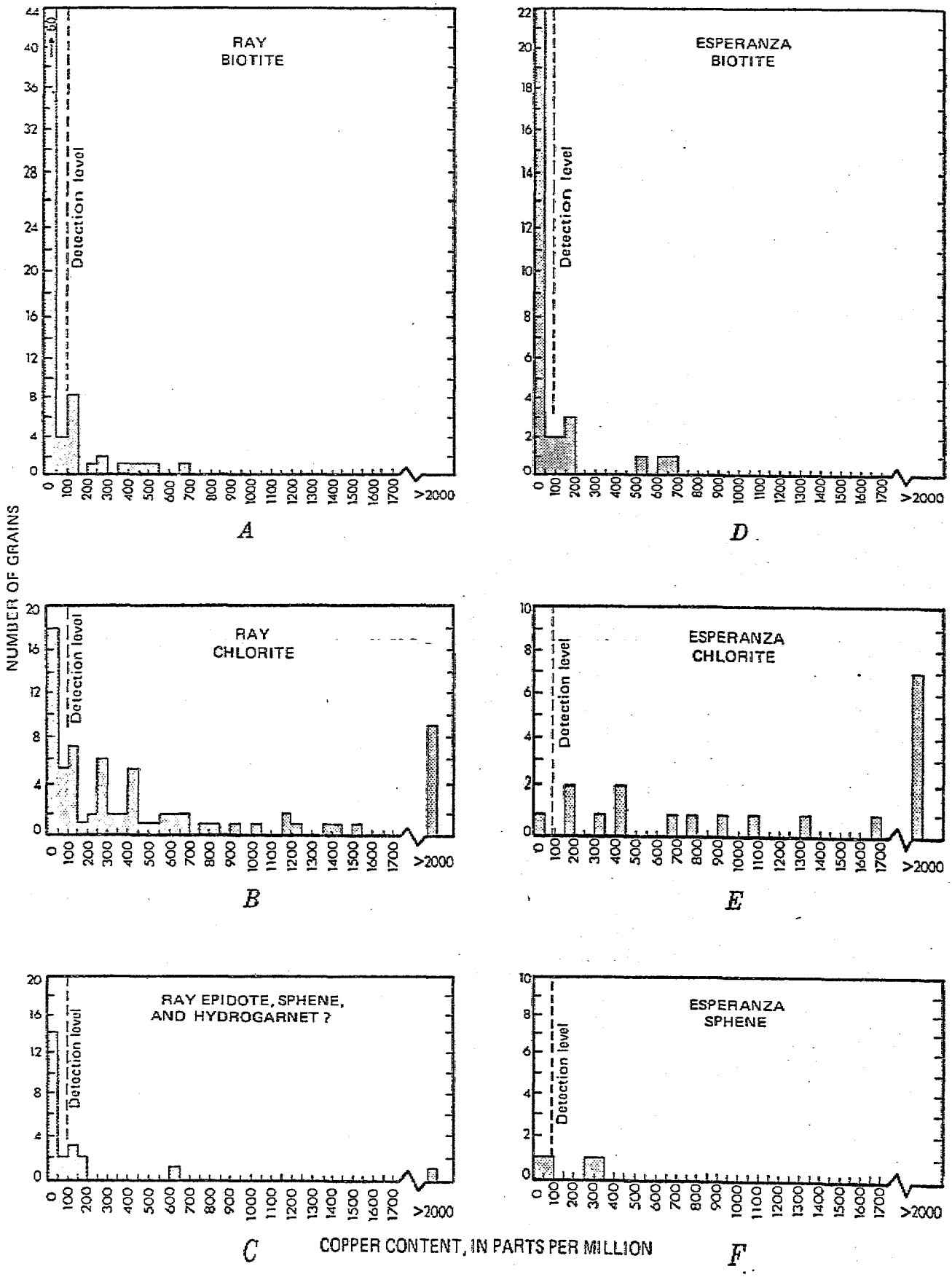


Figure 1.–Frequency histograms showing copper contents of biotite (*A* and *D*), chlorite (*B* and *E*), epidote, sphene, and hydrogarnet? (*C*), and Sphene (*F*) from Laramide intrusive rocks near the Ray and Esperanza copper deposits, Arizona. Detection levels established at three times the square root of the average background counts (Birks, 1963).

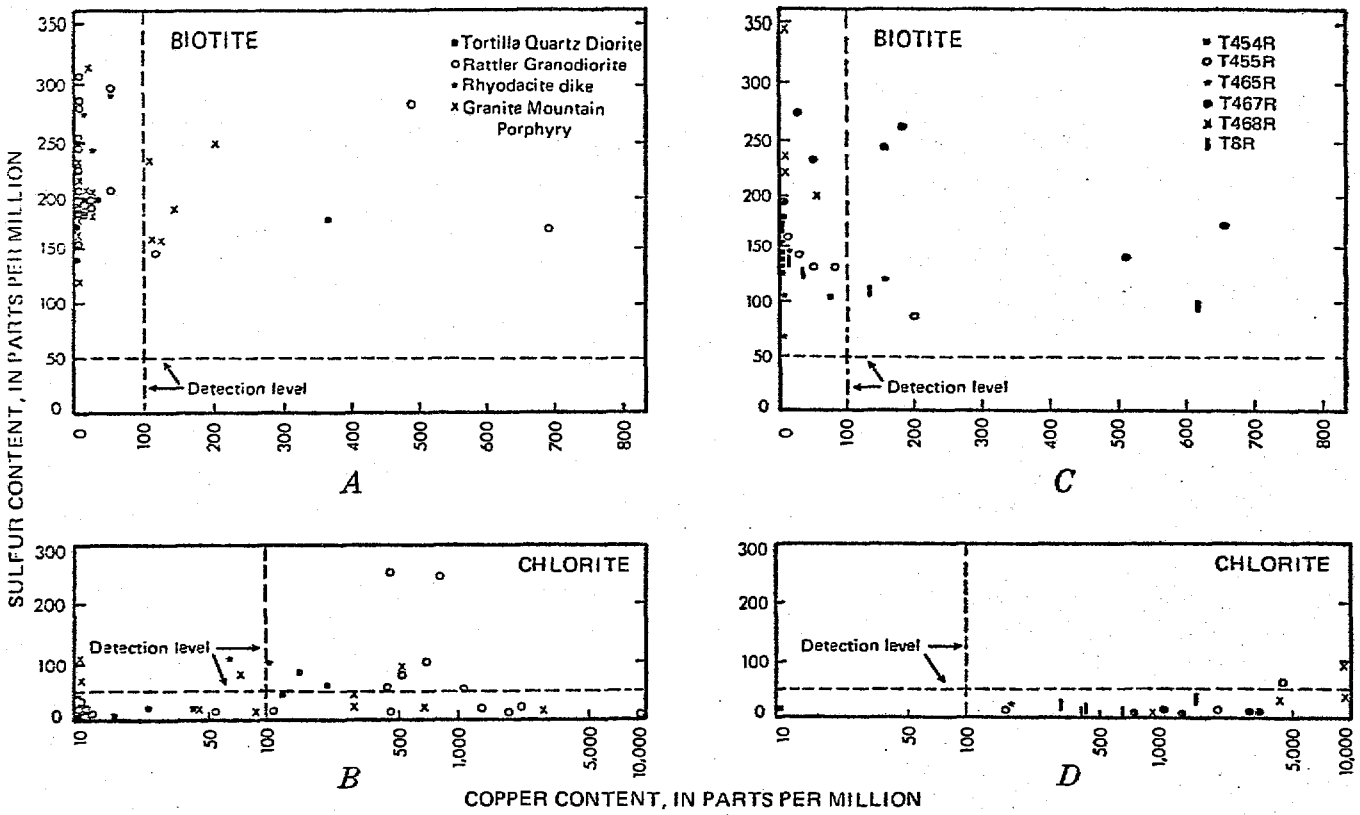


Figure 2.—Plots of copper versus sulfur contents of igneous biotite (*A* and *C*) and chlorite (*B* and *D*) derived from the biotite from rocks near the Ray and Esperanza copper deposits, Arizona. Note that different scales are used to plot copper in chlorite and copper in biotite. Three points from the Rattler Granodiorite and one from the Tortilla Quartz Diorite plot at the origin of *B*. Some points are slightly offset for plotting purposes. Detection levels were established at three times the square root of the average background counts (Birks, 1963).

CONTAMINATION ORIGIN FOR COPPER IN BIOTITE

The increase in copper content from parent biotite to daughter chlorite is probably even more striking than figure 1 shows because most biotite grains having detectable amounts of copper come from samples that contain chlorite having considerably more copper than the biotite. Thus part or all of the detectable copper reported for biotite may be copper from chlorite that has been smeared over the biotite during polishing. There is no simple relation between the degree of alteration of biotite in a sample and the presence or number of copper-bearing biotite grains analyzed in a sample. This is not surprising because the amount of copper smeared over the biotite would depend upon the proximity of copper-bearing chlorite, the amount of copper in the chlorite, and the position of a biotite grain relative to a copper-bearing chlorite and the final direction of polishing. However, the samples that have very little biotite alteration or that have no chlorite grains with detectable copper also have no biotite grains with detectable copper. In addition, biotite precipitated from copper-bearing fluids (hydrothermal biotite, table 1) does not contain detectable copper except immediately adjacent to chalcopyrite (these analyses were not reported in table 1 because of likelihood of copper contamination from the sulfide). Therefore, it is likely that the igneous biotite (with the possible exception of sample 246-99B, grain 3BI) does not contain copper in amounts detectable by the probe and that the copper in all but one biotite reported in tables 1 and 2 may be best explained by autocontamination. The exception, sample 246-99B, grain 3BI, is not easily explained by contamination with copper from chlorite because only the two grains of chlorite, both completely chloritized with no biotite-chlorite contact, occur in the sample, and the biotite contains more copper than the chlorite (table 1). Copper in this biotite also is not easily explained by contamination with copper from sulfides because no chalcopyrite occurs in the probe sample, and the pyrite contains less copper (300 p/m) than the biotite. Hornblende in the sample may contain copper (<95-percent confidence), but also in lesser amounts than the biotite.

The significance of the presence of copper in biotite and its possible presence in hornblende in sample 246-99B is not

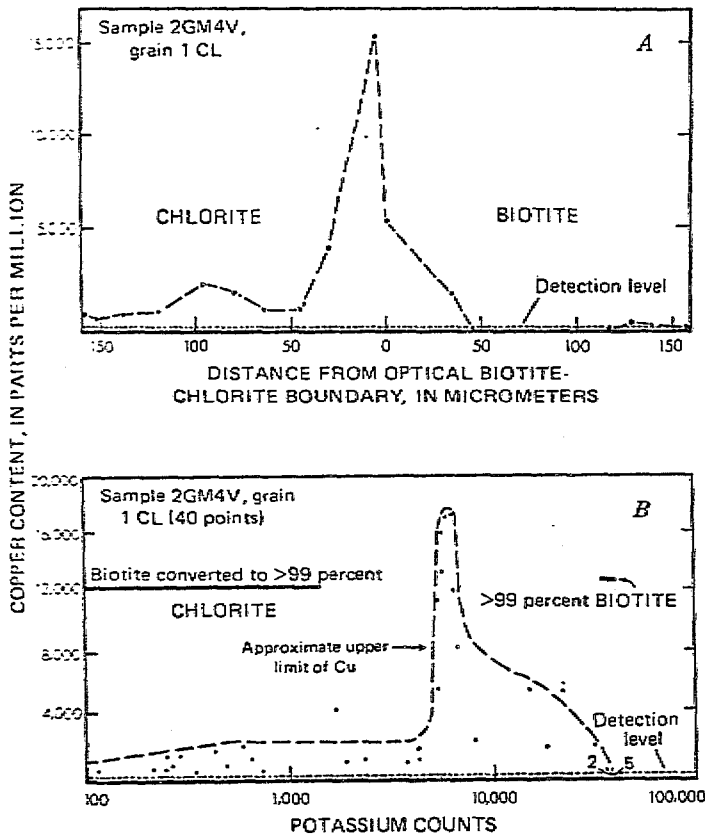


Figure 3.—Distribution of copper in biotite, chlorite, and transitional material. Bars indicate range of potassium (K) counts that designates relatively pure chlorite (<0.1 percent K_2O) and biotite (K counts equal to the average of K counts for biotite grains with no chloritization in the same mount). Counting time is 200 s, terminated on fixed beam current. Detection level was established at three times the square root of the average background counts (Birks, 1963). *A*, Distribution of copper in biotite and chlorite relative to the optical mineral boundary. *B*, Distribution of copper in chlorite, biotite, and transitional material relative to concentration of potassium.

clear. The sample is from the most mafic facies (diorite) of the Rattler Granodiorite, a fact that might suggest that copper actually is incorporated in biotite in mafic bodies during crystallization. However, biotite in equally mafic rock (Tortilla Quartz Diorite, table 1) and more mafic rock (diabase, unpub. data) does not contain detectable copper. Thus no trend of increasing copper content of biotite with decreasing silica content of the host rock is established for the rocks of the Ray area.

COPPER-RICH BLEACHED ZONES IN BIOTITE

Some biotite grains in the Granite Mountain Porphyry and older Laramide intrusive rocks have bleached (golden colored) zones oriented parallel to the (001) plane. The zones are sometimes offset along fractures that developed in the biotite prior to consolidation of the magma. Many of these zones are obvious extensions of chloritized layers, but others do not grade into optically perceivable chlorite at either the middle of the bleached zone or the edge of the grain. Some of the bleached zones contain unexpectedly large amounts of copper (table 3). A copper X-ray image of two such zones is shown in figure 5*A*. The wider zone is the one analyzed in mount 3GM6G of table 3.

As the small amounts of sulfur in the copper-rich zones indicate (table 3 and fig. 5*C*), the copper is not present in the form of submicroscopic copper sulfide or sulfate inclusions. In addition, X-ray images of the following elements indicate that they are not present in more than parts per million amounts in the bleached zones: F, Na, P, Cl, Ca, Sc, V, Cr, Co, Ni, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Nb, Mo, Tc, Ru, Rh, Pd, Ag, Cd, In, Sb, Te, I, Cs, Ba, La, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, Tl, Pb, Bi, Th; Pa, and U.

Because of the carbon coating and lack of a suitable analyzing crystal, it could not be determined directly whether carbonates or nitrates account for the copper in the zones. However, the amount of silica in the zones suggests that the copper is not explained by the presence of known carbonates and nitrates, or even known oxides and silicates. Significantly less silica is present in such minerals than in chlorite (0–20 versus 26–27 percent). Therefore, if the zones were simply a mixture of known copper carbonates, nitrates, oxides, silicates, chlorite, and biotite, the amount of silica in the zones having appreciable amounts of copper (analyses G, O, P, Q, R, S, table 3) should be, but is not, measurably less than the amount of silica in chlorite.

It is not within the scope of this report to determine the exact mineralogic composition of the zones, but some speculation is warranted. The zones are assumed to represent incipient chloritization of biotite by fluids that may or may not carry copper, because chlorite occurs at grain edges along many of the zones and copper is concentrated at many optical biotite-chlorite boundaries (figs. 3, 4). However, except for SiO_2 and K_2O, the amounts of individual constituents and structural formulas of the copper-rich zones (analyses B, E, G, H, K, L, O, P, Q, R, S, U, and V, table 3) are not uniformly intermediate between the amounts of individual constituents and structural formulas of the parent biotites (analyses A, D, F, J, N, and T, table 3) and those of chlorite along the same zone or in the same rock sample (analyses C, I, M, and W, table 3). Although an increase in density of the zones relative to chlorite and biotite resulting from replacement of K, Ti, Mg, Fe, and Mn by Cu could account for some of the discrepancies in the nonuniform transition in chemistry between the zones and chlorite and biotite, the density shift is somewhat compensated by the amount of water required in the zones in order to arrive at reasonable totals of the constituents (the qualitative scans eliminate significant contribution to the totals of elements other than H and O). Thus it is apparent that the material in the zones is more than a simple mixture of well-formed chlorite and biotite. In addition, the large amount

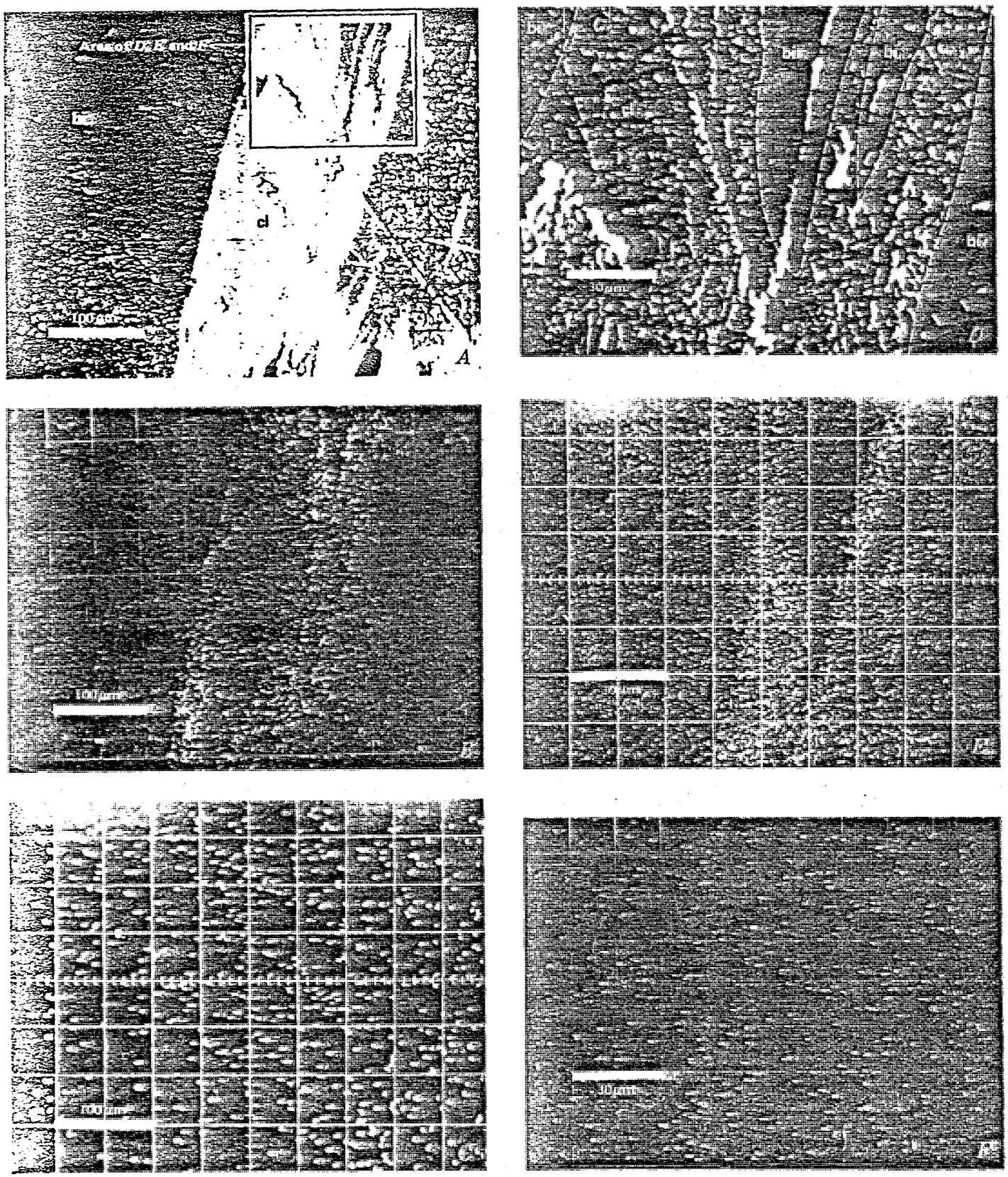


Figure 4.—Photographs of electron-beam scans of a biotite-chlorite grain in sample 46-11a. *A*, Scan for sample current of biotite-chlorite grain. The lighter area represents chlorite (cl), and dark areas are biotite (bi). *B*, Scan for copper (same area as *A*), showing its concentration at the mineral boundaries. Exposure time, 2 minutes. *C*, Scan for sulfur (same area as *B*). Note lack of sulfur at the mineral boundaries. Exposure time, 8 minutes. *D*, Scan for sample current of area designated in *A*. *E*, Scan for copper in same area as *D*. Exposure time, 1 minute. *F*, Scan for sulfur in same area as *E*. Exposure time, 4 minutes.

Table 3.—*Microprobe analyses and structural formulas for biotite, chlorite,*

Mount No.	2GM4V					GM6G
Grain No.	1			3		
Area analyzed	BIA	BI	CL	BIA	BI	BIA
Mineral	Biotite	Copper-rich zone	Chlorite	Biotite	Copper-rich zone	Biotite
Letter reference in text	A	B	C	D	E	F
Microprobe analysis (percent)						
SiO_2	37.6±0.2	32.7±1.2	27.4±0.3	38.1±0.3	37.2±0.4	36.5±.03
Al_2O_3	15.5±0.1	15.6±0.5	16.8±0.2	14.5±0.1	15.0±0.2	15.6±0.1
FeO[1]	17.4±0.2	19.4±0.7	24.3±0.2	17.6±0.1	17.6±0.1	18.4±0.2
MgO	11.4±0.1	14.4±0.4	16.2±0.1	12.4±0.1	11.5±0.05	11.4±0.1
CaO	(2)	.....	.....	.....	.....	.....
MnO	.46±0.01	.32±0.03	.64±0.02	.42±0.02	.42±0.02	.59±0.05
CuO	ND[3]	1.1±0.2	.11±0.02	ND	1.4±0.4	ND
TiO_2	3.2±0.1	.74±0.41	.09±0.010	3.4±0.03	3.5±0.1	2.5±0.1
K_2O	9.7±0.1	2.3±0.07	.09±0.018	9.9±0.1	9.0±0.5	9.5±0.2
Cl	.02±0.004	ND	ND	.03±0.006	.03±0.008	.02±0.006
F	.77±0.06	.18±0.17	.16±0.03	.86±0.04	.81±0.05	.66±0.06
S	.....	.....	.....	.....	.....	.01±0.001
Σ	96.1	86.7	85.8	97.2	96.5	95.2
Less O≡Cl+F	.3	.1	.1	.4	.3	.3
Σ	95.8±0.4	86.6±1.7	85.7±0.4	96.8±0.4	96.2±0.8	94.9±0.5
Structural formulas[4]						
Anions per formula	22	22	28	28	22	22	28	22
Si^{+4}	5.68	5.35	6.82	5.91	5.71	5.64	7.17	5.60
Al^{IV}	2.32	2.65	1.18	2.09	2.29	2.36	.83	2.40
	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Al^{VI}	.45	.37	2.65	2.18	.27	.32	2.58	.43
Ti^{+4}	.36	.09	.12	.01	.38	.40	.51	.29
Mg^{+2}	2.57	3.51	4.47	5.21	2.77	2.60	3.31	2.61
Cu^{+2}	.....	.13	.17	.02	....	.16	.20	....
Fe^{+2}	2.20	2.66	3.38	4.38	2.21	2.23	2.84	2.36
Mn^{+2}	.06	.04	.06	.12	.05	.05	.07	.08
	5.64	6.80	11.46	11.94	5.68	5.76	11.72	5.77
K^{+1}	1.87	.48	.61	.02	1.89	1.74	2.21	1.86

[1] Total Fe calculated as FeO.

[2] Blanks indicate no analysis was made for the component.

and copper-rich zones in biotite from Granite Mountain Porphyry

GM6G—Continued					
3—Continued			4		
Cul	Cu3	CLA	BIA	Cul	Cu3
Copper-rich zone		Chlorite	Biotite	Copper-rich zone	
G	H	I	J	K	L
Microprobe analysis (percent)—Continued					
32.9±2.4	34.9±2.3	26.6±0.4	37.0±0.4	33.4±2.9	36.3±0.7
13.5±0.7	14.3±0.7	17.3±0.2	14.7±0.2	13.5±1.3	14.0±0.3
15.3±0.9	17.0±0.7	24.2±0.2	17.6±0.1	16.2±0.3	17.4±0.4
9.5±1.3	11.3±0.7	16.4±0.1	11.9±0.1	10.6±0.2	11.4±0.5
.....	.....	.....	.....	.....	.....
.46±0.05	.51±0.05	.86±0.03	.56±0.01	.46±0.03	.05±0.028
13.5±0.9	4.6±0.9	.43±0.04	ND	1.0±0.6	5.3±0.8
3.5±0.7	4.8±3.8	.08±0.02	3.8±0.1	3.0±0.6	3.5±0.1
4.6±1.9	7.7±1.9	.09±0.03	9.4±0.1	5.5±0.7	8.1±1.2
ND	ND	ND	.03±0.006	.06±0.03	.04±0.007
.70±0.13	.79±0.17	.09±0.08	.69±0.04	.86±0.14	.73±0.09
.01±0.001	.01±0.001	ND	.02±0.002	.02±0.002	.02±0.002
94.0	95.9	86.1	95.7	84.6	96.8
.4	.3	.....	.3	.4	.3
93.6±3.7	95.6±5.1	86.1±0.5	95.4±0.5	84.2±3.4	96.5±1.8
Structural formulas[4]—Continued					
22 / 28	22 / 28	28	22	22 / 28	22 / 28
5.69, 2.31 } 8.00; 6.86, 1.20 } 8.00	5.40, 2.60 } 8.00; 6.87, 1.13 } 8.00	5.74, 2.26 } 8.00	5.63, 2.37 } 8.00	5.69, 2.31 } 8.00; 7.24, .76 } 8.00	5.57, 2.43 } 8.00; 7.09, .91 } 8.00
.40, .38, 2.69, .13, 2.31, .07 } 5.98; 2.09, .54, 2.92, 2.10, 2.65, .08 } 11.59	.01, .56, 2.61, .54, 2.20, .07 } 5.99; 2.19, .71, 3.32, .68, 2.80, .09 } 11.72	2.14, .01, 5.28, .07, 4.37, .16 } 12.05	.26, .43, 2.70, ..., 2.24, .07 } 5.70	.40, .38, 2.69, .13, 2.31, .07 } 5.98; 2.69, .49, 3.42, .16, 2.94, .08 } 11.30	.10, .40, 2.61, .61, 2.23, .07 } 6.02; 2.31, .51, 3.32, .78, 2.84, .01 } 11.79
1.19 / 1.21	1.52 / 1.93	.02	1.82	1.19 / 1.52	1.59 / 2.02

[3]ND means component not detected at the following amounts: 0.01 percent CuO, 0.03 percent TiO_2, 0.005 percent S, 0.01 percent Cl, 0.04 percent F.

[4]Structural formula calculated on an anhydrous basis using computer program of Jackson and others (1967). Formulas exclude Ca, S, Cl, and F.

Table 3.—*Microprobe analyses and structural formulas for biotite, chlorite,*

Mount No.	GM6G-Con.	3GM6G			
Grain No.	4-Con.	1			
Area analyzed	CLA	G	A	C	D
Mineral	Chlorite	Biotite	Copper-rich zone		
Letter reference in text	M	N	O,	P	Q
Microprobe analysis (percent)—Continued					
SiO_2	26.6±0.2	37.4±0.2	31.1±0.9	30.4±0.2	30.8±0.8
Al_2O_3	19.2±0.2	14.9±0.2	14.5±0.1	14.4±0.1	14.1±0.6
FeO[1]	22.5±0.3	18.5±0.2	14.5±0.3	13.9±0.2	13.5±0.6
MgO	16.4±0.2	12.3±0.1	10.3±0.2	9.8±0.1	9.7±0.4
CaO	.....	ND	.34±0.07	.24±0.05	.15±0.03
MnO	.96±0.07	.50±0.02	.32±0.02	.31±0.02	.28±0.02
CuO	.01±0.001	ND	12.6±0.6	12.1±0.4	14.4±0.8
TiO_2	.16±0.03	3.9±0.1	3.0±0.1	3.0±0.1	3.0±0.1
K_2O	.11±0.03	9.6±0.3	2.2±0.5	1.8±0.2	1.9±0.4
Cl	ND	.....	.....	.....	.....
F	.16±0.03	.....	.....	.....	.....
S	ND	.....	.....	.....	.....
Σ	85.9	97.1	88.9	86.0	87.8
Less O≡Cl+F	.1	.....	.....	.....	.....
Σ	85.8±0.5	97.1±0.5	88.9±1.3	86.0±0.6	87.8±1.2

Structural formulas[2]—Continued

Anions per formula	28	22	22	28	22	28	22	28
Si^{+4}	5.66 } 8.00	5.58 } 8.00	5.22 } 8.00	6.65 } 8.00	5.25 } 8.00	6.68 } 8.00	5.25 } 8.00	6.68 } 8.00
Al^{IV}	2.34	2.42	2.78	1.35	2.75	1.32	2.75	1.32
Al^{VI}	2.48	.21	.09	2.30	.17	2.40	.08	2.28
Ti^{+4}	.03	.44	.38	.48	.39	.50	.38	.49
Mg^{+2}	5.20	2.74	2.58	3.28	2.52	3.21	2.46	3.14
Cu^{+2}	.... } 11.92	.... } 5.76	1.60 } 6.75	2.03 } 11.34	1.58 } 6.71	2.01 } 11.21	1.85 } 6.73	2.36 } 11.30
Fe^{+2}	4.01	2.31	2.04	2.59	2.01	2.55	1.92	2.45
Mn^{+2}	.17	.06	.06	.06	.04	.04	.04	.05
K^{+1}	.03	1.83	.47	.60	.40	.50	.41	.53

[1] Total Fe calculated as FeO.

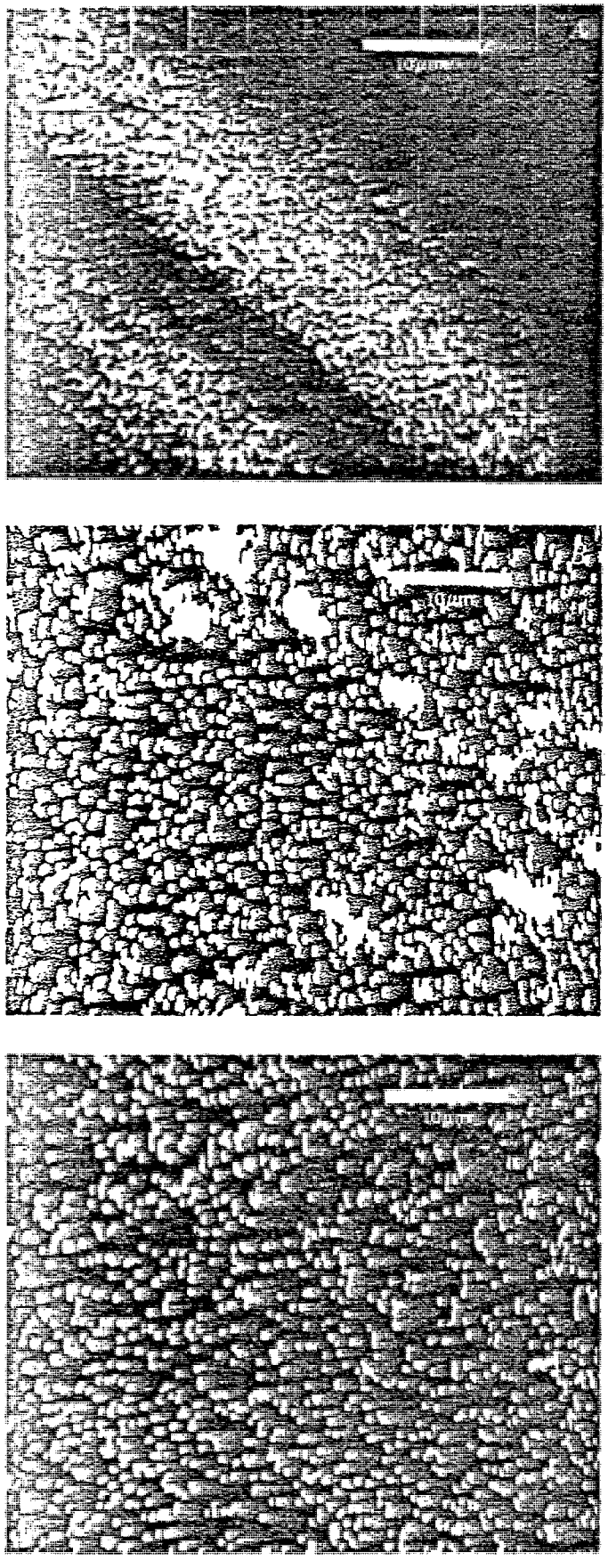
[2] Blanks indicate no analysis was made for the component.

and copper-rich zones in biotite from Granite Mountain Porphyry —Continued

3GM6G—Continued		GM12			
1—Continued		2			3
E	F	BIX	BIA	BIB	CL
Copper-rich-zone—Continued		Biotite	Copper-rich zone		Chlorite
R	S	T	U	V	W
Microprobe analysis (percent)—Continued					
30.7±0.6	31.4±0.7	37.1±0.1	37.0±0.5	37.3±0.8	27.4±0.2
14.6±0.2	15.1±0.2	14.4±0.4	13.5±0.4	13.4±0.3	17.9±0.3
15.1±0.5	14.8±0.3	18.0±0.1	14.9±0.5	14.9±0.3	22.9±0.2
9.8±0.3	10.2±0.3	11.8±0.1	13.1±0.4	13.3±0.4	17.2±0.1
.25±0.24	.17±0.02	.....	.....	.....	.....
.30±0.02	.35±0.04	.69±0.05	.46±0.2	.45±0.03	.93±0.03
15.3±0.7	10.1±1.5	ND	.19±0.04	.19±0.04	.09±0.01
3.1±0.1	3.3±0.1	4.1±0.1	3.2±0.1	3.3±0.1	.05±0.009
2.6±0.1	4.2±0.5	9.4±0.1	7.3±0.2	7.6±0.1	.18±0.03
.....	.....	.03±0.01	.03±0.02	.01±0.007	ND
.....	.....	.69±0.05	.90±0.13	.91±0.12	.14±0.02
.....	.....	.02±0.002	.01±0.001	.01±0.001	.....
91.8	89.6 . . .	96.2	90.6	91.4	86.8
.....	.....	.3	.4	.4	.1
91.8±1.1	89.6±1.8	95.9±0.5	90.2±0.9	91.0±1.0	86.7±0.4
Structural formulas[4]—Continued					
22 / 28	22 / 28	22 / 28	22 / 28	22 / 28	28
5.09, 2.86 } 7.95 / 6.48, 1.52 } 8.00	5.21, 2.79 } 8.00 / 6.63, 1.37 } 8.00	5.63, 2.37 } 8.00	5.82, 2.18 } 8.00 / 7.41, .59 } 8.00	5.82, 2.18 } 8.00 / 7.41, .59 } 8.00	5.80, 2.20 } 8.00
.... / 2.11	.16 / 2.39	.20	.32 / 2.59	.29 / 2.55	2.27
.39 / .49	.41 / .52	.47	.38 / .48	.39 / .49	.01
2.42 / 3.08	2.52 / 3.21	2.67	3.07 / 3.91	3.10 / 3.94	5.43
1.91 } 6.85 / 2.44 } 11.53	1.27 } 6.45 / 1.61 } 11.54	.... } 5.71	.02 } 5.81 / .03 } 11.44	.02 } 5.81 / .03 } 11.50	.01 } 12.00
2.09 / 2.66	2.05 / 2.62	2.28	1.96 / 2.49	1.95 / 2.48	4.06
.04 / .05	.04 / .06	.09	.06 / .08	.06 / .08	.17
.55 / .70	.89 / 1.13	1.82	1.46 / 1.86	1.51 / 1.93	.05

[3] ND means component not detected at the following amounts: 0.01 percent CuO, 0.03 percent TiO_2, 0.005 percent S, 0.01 percent Cl, 0.04 percent F.

[4] Structural formula calculated on an anhydrous basis using computer program of Jackson and others (1967). Formulas exclude Ca, S, Cl, and F.



of copper in the transitional material is not easily explained by either substitution or attachment of copper in well-formed chlorite and biotite in view of the relatively low amount of copper in well-formed chlorite and biotite (fig. 3; tables 1 and 2).

Whether the material is partly destroyed biotite, poorly formed chlorite, another well or poorly formed sheet silicate, or a mixture of these cannot be determined from existing data. However, the data do restrict the type or amount of possible sheet silicates that could make up the material in the bleached zones. The silica content of the zones, being less than biotite, indicates that if no chlorite is present in the zones and biotite either is or is not present, the sheet silicates that could make up the zones are septechlorite, clintonite, xanthophyllite, margarite, silica-poor montmorillonite, or vermiculite. The small amount of calcium in the zones (analyses O, P, Q, R, and S, table 3) indicates that of these, margarite, clintonite, and xanthophyllite probably are not present. On the basis of the color of the zones, their refractive index, birefringence, the leachability in acid of copper in biotite-chlorite grains (mentioned earlier), and the number of exchange sites available, vermiculite or montmorillonite seem to be more likely alternatives to septechlorite, if indeed another sheet silicate is present in the zones. Montmorillonite is possibly less likely than vermiculite because smaller amounts of alumina are expected in silica-poor montmorillonite. Alternatively, if chlorite composes part of the zones, the data do not negate the presence of a sheet silicate having more silica than biotite; however, the amount of such a silicate that could be present is limited by the amount of chlorite required to dilute the higher amounts of silica in these minerals to those observed in the zones. Thus if most of the copper were present in a high-silica silicate, the amount required is much more than that required in vermiculite.

The zones often include apatite grains and are wider around them. In addition, the zones commonly contain or are near swarms of suboptical-sized apatite as determined by electron-beam scans of the zones for calcium and for phosphorus (fig. 5*B*). Thus it is suspected that the bleached zones (which range in thickness from <1 to 20 μm) extend completely through 3-mm-sized biotite grains and in places are offset along fractures that developed prior to consolidation of the magma because of favorable permeability conditions in the biotite resulting from the deformation and expansion of the grains by the apatite inclusions.

Figure 5.—Photographs of electron-beam scans of copper-rich zones in mount sample 3GM6G. *A*, Scan for copper. Exposure time, 1 minute. *B*, Scan for phosphorus of same area as *A*. Exposure time, 1 minute. *C*, Scan for sulfur of same area as *A*. Exposure time, 10 minutes.

COMPARISON OF MAJOR-ELEMENT CHEMISTRY OF THE COPPER-RICH AND COPPER-POOR CHLORITES

The presence or absence of copper in chlorite could possibly be attributed to its formation at different times or from different fluids; hence, the resulting chlorites might be differentiated on the basis of chemistry. However, preliminary data indicate that except for the presence of copper, chlorite that contains copper is similar in chemistry to chlorite that does not contain copper (fig. 6). In fact, the composition of chlorite appears dependent in larger part on the composition of the parent biotite than on the copper-depositing characteristics of the altering fluid (fig. 7). Preliminary observations also revealed no optical dissimilarity between copper-bearing and copper-poor chlorite. Thus it could not be established whether chlorite formed in the rocks at two different times from two fluids.

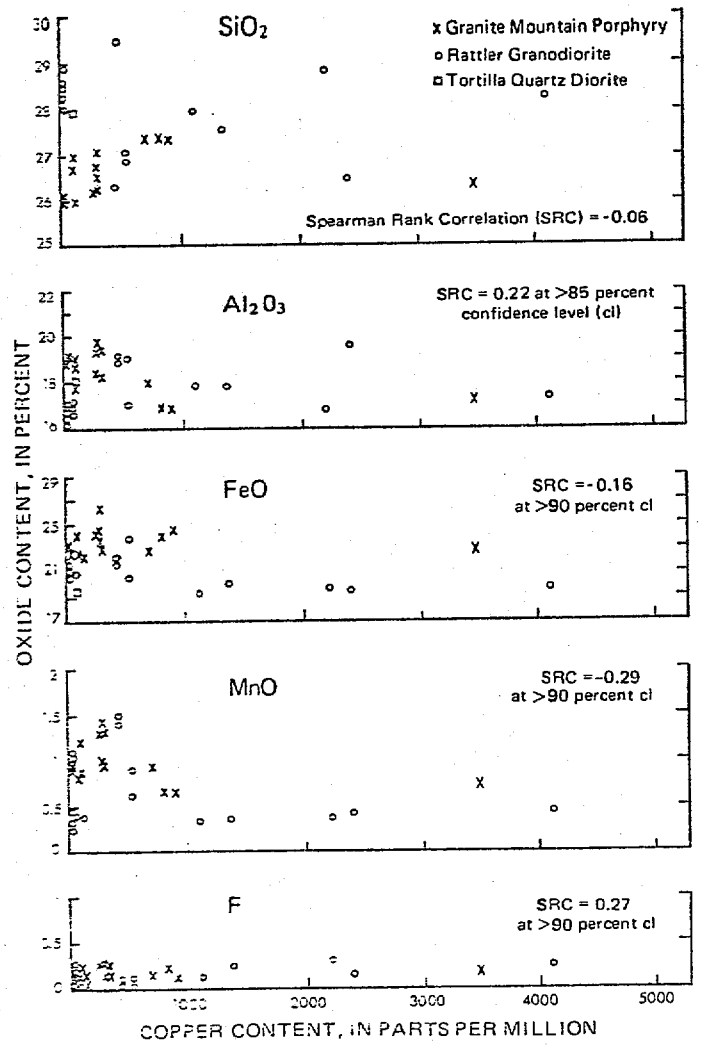


Figure 6.—Graphs showing amounts of representative chemical components in chlorite in relation to amount of copper in chlorite. Some points are offset slightly for plotting purposes. Four additional points (three for Rattler Granodiorite and one for Tortilla Quartz Diorite) plot near the origin of the F versus Cu diagram.

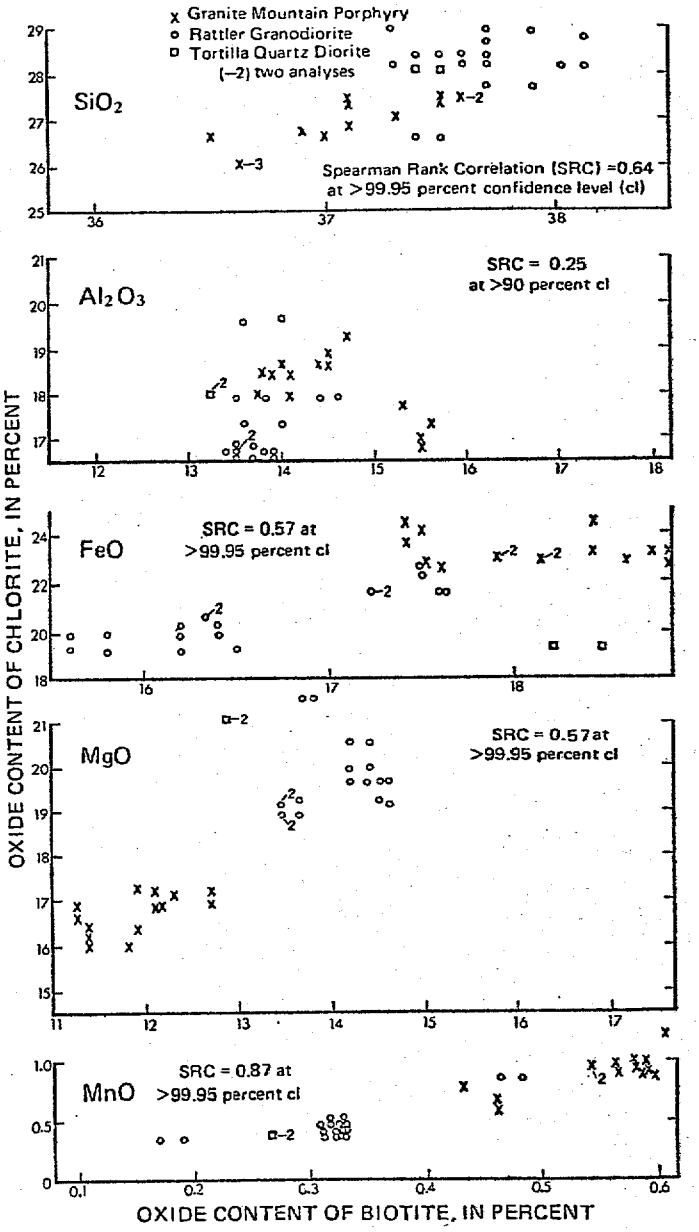


Figure 7.—Graphs showing the amount of oxide in biotite in relation to the amount of oxide in chlorite derived from the biotite. Some points are slightly offset for plotting purposes. The statistics include two biotite-chlorite pairs that plot off the diagrams.

VALUE OF THE COPPER CONTENT OF CHLORITE AS AN INDICATOR OF ORE

The occurrence of copper-bearing chlorite derived from igneous biotite near two ore deposits suggests that the amount of copper in chlorite might serve as a geochemical indicator for

a nearby copper ore deposit. However, copper in chlorite does not seem to show a simple positive relation with the proximity of the sample to a presently recognized deposit (fig. 8). This lack of correlation may result from inadequate data or from the possibility that the copper content of chlorite depends on factors other than, or in addition to, the distance of the chlorite grain from a minable deposit.

Inadequacy in the data is suggested by the extreme variation in the amount of copper in chlorite both between grains in the same probe mount (thin section, 1-in. diam) and within

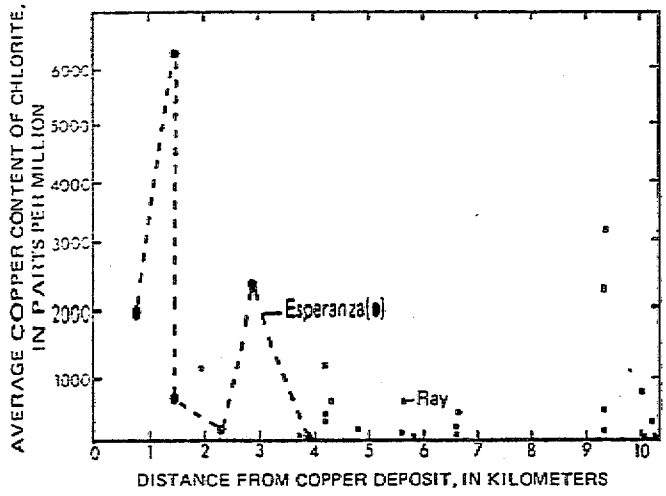


Figure 8.—Plot of average amount of copper in chlorite in a given sample in relation to distance of the sample from the nearest recognized commercial deposit.

individual grains (figs. 3, 4; tables 1, 2). Thus determination of the true average abundance of copper in chlorite in each rock sample is too expensive to refine with microprobe analyses because a prohibitive number of grains must be analyzed in a prohibitive number of mounts. The alternative method of determining the true abundance of copper in chlorite by conventional analyses of separates may also be limited by the various types of bias that are built into mineral separations (magnetic, electrostatic, specific gravity, and optical)—the resulting separation may be 100 percent chlorite, but in view of the irregular distribution of copper in chlorite and of the fact that much copper resides in the more poorly crystallized chlorite, the mineral separate is likely to contain copper in an amount not representative of the average.

These observations do not rule out the potential use of copper abundance in chlorite as a geochemical indicator. If standardized separation techniques are used, it is still possible that the content of either leachable or total copper in mica or chlorite separates may correlate roughly with proximity of the sample to a deposit. Additionally, the copper content of chlorite may be of limited usefulness as a broader indicator of ore: that is, it might point out potential copper-producing provinces. For example, the copper content of chlorite from Sierra Nevada rocks (Dodge, 1973) with no known associated porphyry-type deposits is much less than that of chlorites reported here. However, this again may reflect mineral separation problems because Dodge analyzed clean mineral separates that probably were relatively free of poorly crystallized chlorite.

Finally, assuming that the true average abundance of copper in chlorite (or an abundance determined by analysis of concentrates separated in a standardized way) could be determined, caution should be used in its application as a geochemical indicator of ore because there is reason to suspect that this abundance could be influenced by factors other than the distance of the sample from a minable copper deposit. These factors include the rate of chloritization, percentage of partial chloritization, number and size of grains chloritized, the number of potential fluid conduits (fractures) per unit volume of rock, the proximity of the chlorite to a fracture, and the concentration of copper in the fluid immediately adjacent to the biotite; the first three factors would control the number of sites suitable for copper capture, and the latter three are measures of the availability of the chlorite to the copper in the supplying fluid.

CONCLUSIONS

Copper occurs in chlorite derived from igneous biotite in Laramide intrusions around two Arizona porphyry copper deposits and, further, is concentrated at the boundary between parent biotite and chlorite. However, the copper content of igneous and hydrothermal biotite near these deposits was found to be much less than that of chlorite and was not detected in most of the grains analyzed. In view of the difficulty in cleaning chlorite from biotite separates, these observations suggest that caution should be used in speculations about what the abundance of copper in biotite derived from bulk-analyzed mineral separates might mean with respect to the genesis or proximity of ore deposits and with respect to the behavior of copper in a differentiating magma. Additionally, because a potentially large part of the copper in a whole-rock sample of "granitic" rock may be in alteration products of biotite and thereby conceivably have had its source outside the analyzed sample, caution should be applied to petrologic and genetic interpretations of whole-rock copper abundance data.

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Porphyry Copper General
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COPPER IN BIOTITE FROM IGNEOUS ROCKS IN SOUTHERN ARIZONA AS AN ORE INDICATOR

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Abstract.—In the Sierrita and Santa Rita Mountains of southern Arizona, rocks from igneous intrusive bodies that are genetically associated with copper deposits contain as much as 0.03 percent copper; however, biotite separated from these rocks contains as much as 1 percent copper. Rocks from igneous intrusives in the same area that are not associated with copper deposits contain from a few parts to a few tens of parts per million of copper, and the biotites separated from them contain at most 200 ppm copper. The large composite stock on the east side of the Sierrita Mountains shows a well-defined increase in the copper content of biotite, from a few parts per million in the northern part to as much as 1 percent near the copper deposits at its southern end. Copper anomalies in biotite in the rocks in this area provide a more sensitive and extensive indication of associated copper mineralization than do those in the whole-rock samples.

Biotite has been separated from samples of four kinds of intrusive rocks, of Precambrian to Paleocene age, in the Santa Rita and Sierrita Mountains of southern Arizona. These separates were analyzed spectrographically to investigate compositional variation among biotite samples from (1) different intrusives of similar ages, (2) similar intrusives of different ages, and (3) a single large ore-related stock.

The greatest variation in trace-element content was found in the copper of these biotites. Copper content ranges from a few parts per million to 1 percent, and the highest copper values are in biotite from rocks that are genetically and spatially related to copper ore deposits. The ore-related biotites consistently contain from one thousand to several thousand parts per million of copper, in contrast to biotites from "barren" intrusives, whose copper content is generally only a few tens of parts per million.

All the biotite samples in which molybdenum was detected (≥ 10 ppm) also contain > 500 ppm (parts per million) copper; however, many of the samples that contain high copper concentrations show no detectable molybdenum. None of the other minor elements in the biotite show any consistent relationship to the copper content.

The ability of copper to substitute for iron and magnesium in the biotite lattice and the relatively high concentration of copper in biotites from quartz monzonite stocks in Utah and Nevada that are genetically related to copper ore deposits have been discussed by Parry and Nackowski (1963, p. 1127, 1137, 1140–1141). Putman and Burnham (1963) also reported sporadic, but locally high, concentrations of copper in ferromagnesian mineral concentrates, which consist largely of primary biotite, from their Boriana Granodiorite in the Hualapai Mountains south at Kingman, Ariz. These biotites with high copper content are associated with minor primary chalcopyrite and come from an area that shows copper and molybdenum mineralization (Putman and Burnham, 1963, p. 60, 72, 78–79, 82, 92). However, Bradshaw (1967, p. 143–144) found that the copper content of biotite from ore-related granitic rocks in Cornwall and Wales is consistently less than 50 ppm and that it does not differ significantly from that of biotite from barren granitic intrusives elsewhere in Great Britain.

The biotite in many of the older intrusives of the Santa Rita Mountains shows strong chloritic alteration. Copper analyses are reported here only on those mineral separates that were optically determined to consist of more than 80 percent biotite.

Spectrographic copper analyses had previously been made on some whole-rock samples of the same rocks from which biotite separates had been made. The copper content of ore-associated intrusive rocks is higher than that of barren rocks, but it is more than an order of magnitude lower than the copper content of the biotite.

Samples of the freshest rock obtainable were taken

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for biotite separates; the biotite is a primary mineral in all but one of them (a Precambrian granodiorite from the Santa Rita Mountains which contains secondary biotite of Paleocene age). Many of the pre-Tertiary stocks in the Santa Rita Mountains are not represented in this study because of the intense chloritic alteration of their biotite.

Thirteen biotites were analyzed from the Santa Rita Mountains, and twenty-two from the Sierrita Mountains. Samples from the Santa Rita Mountains comprise three from a large Precambrian stock, two from an Upper Cretaceous stock, four from small barren Paleocene stocks, and four from ore-related Paleocene plugs (fig. 1). All the samples from the Sierrita Mountains were taken from a large composite Paleocene stock that is related to the Esperanza and Sierrita copper deposits of the Pima mining district (fig. 2).

GEOLOGIC SETTING

The Santa Rita and Sierrita Mountains contain plutonic and closely related hypabyssal rocks. In the Santa Rita Mountains these rocks are of Precambrian, Triassic, Jurassic, Late Cretaceous, Paleocene, and late Oligocene ages. In the Sierrita Mountains they are of Precambrian, Triassic, Jurassic, and Paleocene ages. The larger stocks in both areas are composite bodies whose main phases commonly range in composition from granodiorite to quartz monzonite. The Santa Rita Mountains also are intruded by numerous small homogeneous stocks of granodiorite and quartz monzonite and plugs of quartz latite porphyry. Only the intrusive bodies from which biotite samples were taken for this study are shown on figure 1.

The copper deposits of the Helvetia, Rosemont, and Greaterville mining districts in the Santa Rita Mountains are associated with Paleocene quartz latite porphyry plugs. Those of the Pima mining district in the Sierrita Mountains are related to Paleocene quartz monzonite porphyry which occurs as plugs and as a facies of Paleocene granodiorite stocks.

METHOD OF MINERAL SEPARATION AND ANALYSIS

Rock samples were crushed, ground, and sieved. The 60- to 150-mesh fraction was used for separation and analysis. The ground sample was then placed in bromoform to float quartz, feldspar, and other light minerals. The heavy-mineral concentrate from the bromoform, including the biotite, was washed, dried, and placed in a methylene iodide solution to float the biotite and sink all heavy minerals of specific gravity greater than 3.3. The biotite concentrate was again washed and dried and was then run through a Frantz magnetic separator at different settings to obtain as pure a biotite fraction as possible. Mineral impurities other than chlorite were estimated to constitute less than 5 percent of this fraction. Chlorite, which cannot be removed mechanically by this method of mineral separation, ranged from 1 percent to at least 50 percent. All biotite concentrates were examined optically, and only the analyses of those in which chlorite was less than 20 percent are reported in this paper.

Both whole-rock samples and biotite concentrates were analyzed by a six-step semiquantitative spectrographic method which is similar to the three-step method of Myers, Havens, and Dunton (1961). Results from the six-step method identify geometric intervals that have the boundaries 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12, 0.083, and so forth, and are reported as midpoints of these intervals by the numbers 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, and so forth. The interval identified by the reported midpoint contains the analyst's best estimate of the concentration present. The precision of a reported value is approximately plus or minus one interval at 68-percent confidence, or two intervals at 95-percent confidence.

SANTA RITA MOUNTAINS

Petrography

Rocks sampled in the Santa Rita Mountains include the Precambrian Continental Granodiorite; the Upper Cretaceous Madera Canyon Granodiorite; the "barren" Paleocene stocks of the Helvetia mining district; and the ore-associated Paleocene plugs of the Greaterville, Rosemont, and Helvetia mining districts (fig. 1). These rocks, mapped by Drewes (1970a, b), are briefly described here; more complete descriptions are planned for future publication.

The Continental Granodiorite forms a large composite stock in the northern part of the Santa Rita Mountains. It is exposed in an eastward-tilted structural block of Precambrian rock that is unconformably overlain by Paleozoic and Mesozoic sedimentary rocks and that is intruded by Paleocene stocks and plugs. The main phase of the stock is a medium-gray to dark-gray very coarse grained porphyritic biotite granodiorite that grades to a quartz monzonite. Mafic minerals, chiefly biotite and chlorite, form a meshwork pattern around the felsic minerals. Phenocrysts of light-pinkish-gray microcline or orthoclase as much as 4 cm long constitute 5-10 percent of the rock. A mode of typical Continental Granodiorite contains, to the nearest percent, quartz, 28; plagioclase, 42; orthoclase, 18; biotite, 9; and accessory ilmenitic magnetite, apatite, sphene, and zircon, 3. This rock is isotopically dated as Precambrian (Drewes, 1968).

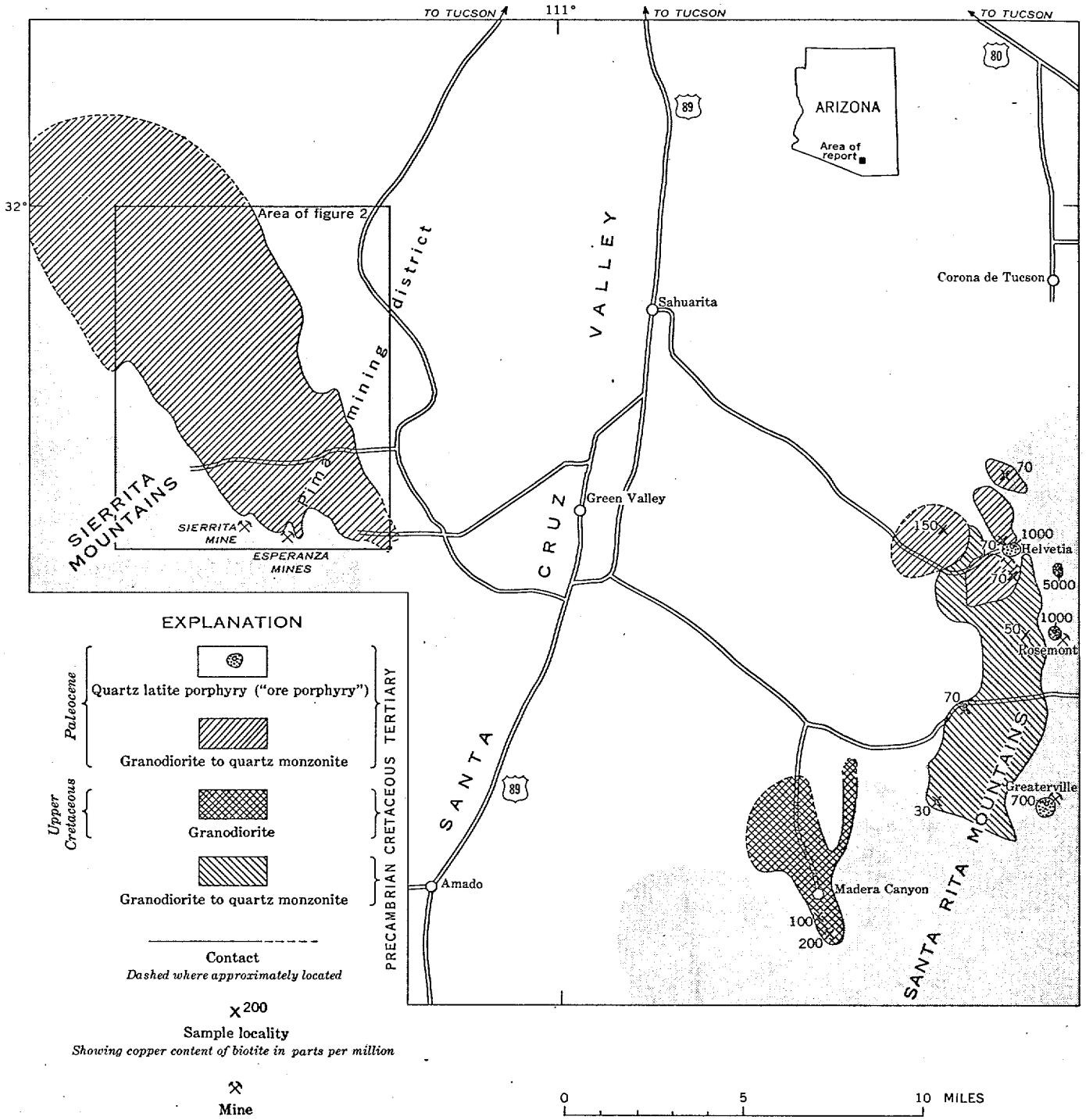

FIGURE 1.—Index map showing location of Sierrita and Santa Rita Mountains (light tone), plutons sampled, locality and copper content of biotite samples from the Santa Rita Mountains, and area of figure 2.

The Madera Canyon Granodiorite is the northernmost of a swarm of stocks of Late Cretaceous age in the southern part of the Santa Rita Mountains. Samples were obtained from a light-gray phase of this rock, which also exhibits porphyritic and melanocratic phases (Drewes, 1970a, b). The light-gray phase is extensively exposed along Madera Canyon, where it has a medium- to coarse-grained hypidiomorphic granular texture. A representative sample contains, to the nearest percent, quartz, 22; orthoclase, 26; plagioclase, 42; hornblende, 5; biotite, 4; and accessory sphene, ilmenitic magnetite, apatite, and zircon, 1. This rock

has been dated as about 68 m.y. (million years) (P. E. Damon, written commun., 1964; Drewes, 1968, p. C13).

Six small elliptical stocks of Paleocene age, which consist largely of light-gray granodiorite, intrude the structurally complex rocks near Helvetia (Drewes, 1970b). Four of them were sampled for this study (fig. 1). The composition of these stocks is variable, ranging from granodiorite to quartz monzonite. Their inhomogeneity is exemplified by a stock in which the biotite content ranges from 1 to 10 percent. The rocks of these stocks are distinguishable from the Continental Granodiorite by their fresher appearance, the absence of phenocrysts, and the habit of their biotite, which forms discrete books. Modes of these rocks vary widely; that of the sample from the northernmost stock shown on figure 1, which is fairly representative of the granodiorite, is, to the nearest percent, quartz, 30; plagioclase, 45; microcline, 13; biotite, 10; and accessory ilmenitic magnetite, apatite, zircon, and sphene, 1. The stocks of Helvetia are not associated with the mineralization of the district. They have been isotopically dated as about 53 m.y. (Drewes and Finnell, 1968, p. 323; R. F. Marvin, written commun., 1968), but geologic field relations indicate that they may be slightly older.

Quartz latite porphyry, locally referred to as the "ore porphyry," forms six small irregular plugs and many dikes in the Greaterville, Rosemont, and Helvetia mining districts. The four plugs sampled are shown on figure 1. The plugs are surrounded by aureoles of low-grade metamorphosed and mineralized rock. Copper, lead, zinc, and silver are the principal metals produced in these districts, but other metals are also present (Schrader 1915; Creasey and Quick, 1955; Drewes, 1970c). The porphyry is typically a grayish-orange-pink, closely fractured rock with a saccharoidal groundmass. It contains abundant bipyramidal quartz phenocrysts, sparse small biotite phenocrysts, and traces of disseminated sulfides. Modes of the porphyry are very uniform; the average of the modes of seven specimens, to the nearest percent, is quartz, 26; plagioclase, 45; potassium feldspar (largely sanidine), 25; biotite, 3; and accessory sphene, apatite, magnetite, zircon, and sulfides, 1. Biotite from three of these plugs has been isotopically dated as about 56 m.y. (R. F. Marvin, written commun., 1967).

The quartz latite porphyry appears to have been emplaced at a higher temperature than that at which the barren intrusives were emplaced, as indicated by its bypyramidal quartz and sanidine. The extremely irregular shapes of these plugs also suggest that the parent magma of the plugs was highly fluid, a condition that would be favored both by high temperature and by high volatile content. A high metal content of this magma is also indicated by the genetically related ore deposits.

Biotite concentrates and their copper content

Biotite from the Precambrian Continental Granodiorite is olive green and contains less than 5 percent mineral impurities, which are chiefly chlorite.

Biotite from the Cretaceous Madera Canyon Granodiorite is moderate brown and contains about 10 percent ilmenite and sphene as poikilitic inclusions. Approximately 10 percent each of hornblende and chlorite is present in the mineral concentrates as discrete grains.

Biotite from the Paleocene granodiorite and quartz monzonite porphyry stocks that have no known copper deposits associated with them is dark yellowish brown and contains about 5 percent hematite, apatite, and zircon as inclusions. About 5–10 percent chlorite and minor amounts of sphene and plagioclase are present as accessory minerals in the concentrates.

Four samples were collected from the quartz latite porphyry plugs, which are closely related to copper deposits. These plugs are nearly the same age as the barren monzonite porphyry. Biotite from this "ore porphyry" ranges from light brown to moderate brown, and contains about 5 percent apatite, rutile, and ilmenite as inclusions and 5–10 percent chlorite and sphene as accessory minerals in the concentrate.

Copper concentrations in the biotites of the four rock types in the Santa Rita Mountains that were sampled are summarized in table 1. This table illustrates the marked increase in copper content of biotite samples from the "ore porphyry" relative to such samples from both the unmineralized older granodiorite and the quartz monzonite stocks of approximately the same age as the mineralized quartz latite porphyry plugs.

Copper also increases slightly in whole-rock samples of the ore porphyry, but the copper in biotite separates

TABLE 1.—*Copper content of biotite samples from selected igneous rocks of the Santa Rita Mountains*

[J. L. Finley, analyst]

Rock type	Number of samples	Copper content (ppm)	
		Range	Mean
Precambrian granodiorite and quartz monzonite.	3	30–70	50
Cretaceous granodiorite	2	100–200	150
Barren Paleocene quartz monzonite.	4	70–150	90
Productive Paleocene quartz latite porphyry.	4	700–7,000	3,400

TABLE 2.—*Comparison of copper content of whole rock and biotite in selected samples from the Santa Rita Mountains*

Rock type	Copper content (ppm)	
	Whole rock[1]	Biotite[2]
Precambrian granodiorite	10	70
Cretaceous granodiorite	20	200
Paleocene quartz monzonite	10	70
Paleocene quartz latite porphyry	50	5,000

[1] J. L. Harris, analyst.
[2] J. L. Finley, analyst.

from these samples shows a far greater increase (table 2).

PIMA MINING DISTRICT, SIERRITA MOUNTAINS

Petrography

All biotite samples from the Pima mining district came from a large composite stock of Paleocene age, which is genetically related to the Esperanza and Sierrita porphyry copper deposits (fig. 2). This stock and several smaller ones, which are described and shown on a preliminary geologic map by Cooper (1960, pl. 1),[1] are mainly granodiorite. The large granodiorite body in the western part of the Pima mining district was named Ruby Star Granodiorite for the Ruby Star Ranch by Livingston, Mauger, and Damon (1968), a name which is here formally adopted. The type area is in parts of Tps. 17 and 18 S., Rs. 12 and 13 E. The granodiorite intrudes intensely deformed rocks of Precambrian to Late Cretaceous age and is overlain unconformably by Quaternary alluvium. The Esperanza and Sierrita ore deposits are near the south end of the large stock, where part of the roof of the stock is exposed.

The composite stock consists of two granodiorite facies and, near the ore deposits, of several quartz monzonite facies not distinguished from one another on figure 2. Modal analyses of four specimens from which the analyzed biotites were obtained are shown in table 3.

The equigranular, border-phase granodiorite (table 3, analysis 1) is a light-gray medium-grained rock, which is characterized in hand specimen by recognizable quartz, twinned plagioclase, untwinned potassium feldspar, equidimensional books of biotite, hornblende, and small honey-colored crystals of sphene. This rock

[1] The "atypical granodiorite" of Cooper (1960, p. 70) shown in the southwest corner of this preliminary map is now known to be part of a Triassic or possibly Jurassic intrusive. The granitic rock west of the San Xavier thrust shown near the north edge of the map, which was provisionally assigned to the Precambrian by Cooper (1960, p. 68), is now believed to be slightly younger than the adjacent stock from which the biotite samples were obtained.

TABLE 3.—*Modal analyses of rocks in and near the Pima mining district from which biotites were obtained*

[Leaders (--) indicate not present]

	Granodiorite		Quartz monzonite	
	1	2	3	4
Quartz	25.1	33.2	27.4	26.4
Potassium feldspar and perthite	20.6	19.2	35.4	30.1
Plagioclase	45.0	42.8	33.2	38.3
Myrmekite	Trace	.3	--	--
Biotite and chlorite	5.9	3.4	2.8	3.7
Hornblende	2.0	--	--	--
Opaque minerals	.8	.8	.8	1.0
Sphene	.4	.2	--	.1
Apatite and zircon	.2	.1	.2	Trace
Leucoxene, epidote, and red iron oxide	--	--	.2	.4
Total	100.0	100.0	100.0	100.0

1. Equigranular granodiorite, average of three specimens from eastern border zone of stock.
2. Porphyritic granodiorite, average of two specimens from core of pluton 2.3 miles northwest of Esperanza mine.
3. Quartz monzonite porphyry, "ore porphyry," average of three specimens from two masses 0.5–0.7 mile north of Esperanza mine.
4. Aplitic quartz monzonite 0.5 mile north of Esperanza mine.

has gradational contacts with the porphyritic core-phase granodiorite.

The porphyritic core phase (table 3, analysis 2) is much like the border phase, but lacks hornblende and contains from 2 to 10 percent phenocrysts of potassium feldspar which are ½–3 inches long. It generally contains less biotite, more quartz, and plagioclase of a less calcic composition than the border phase. Two potassium-argon age dates on the granodiorite facies are 60 m.y. (Creasey and Kistler, 1962) and 59 m.y. (Damon and Mauger, 1966).

The quartz monzonitic part of the stock near the ore deposits (fig. 2) includes rocks distinguishable from the granodiorite only by their mineral proportions, and also finer grained quartz monzonite porphyry and aplitic quartz monzonite phases. The quartz monzonite porphyry has sharp intrusive contacts with the granodiorite at a few places, but gradational contacts at others. The aplitic quartz monzonite phase was called biotite-bearing aplite by Anderson and Kupfer (1945, p. 5) and is shown as dacite porphyry on a map by Lynch (1966). It is an intrusive body approximately 1,000 feet wide and 1,800 feet long which is emplaced in quartz monzonite porphyry and granodiorite. It crops out half a mile north of the Esperanza mine, and also forms very small bodies closer to the mine. The quartz monzonite phases are not separately distinguished on figure 2.

The quartz monzonite porphyry (table 3, analysis 3) is light gray to pinkish gray on fresh exposures. Pheno-

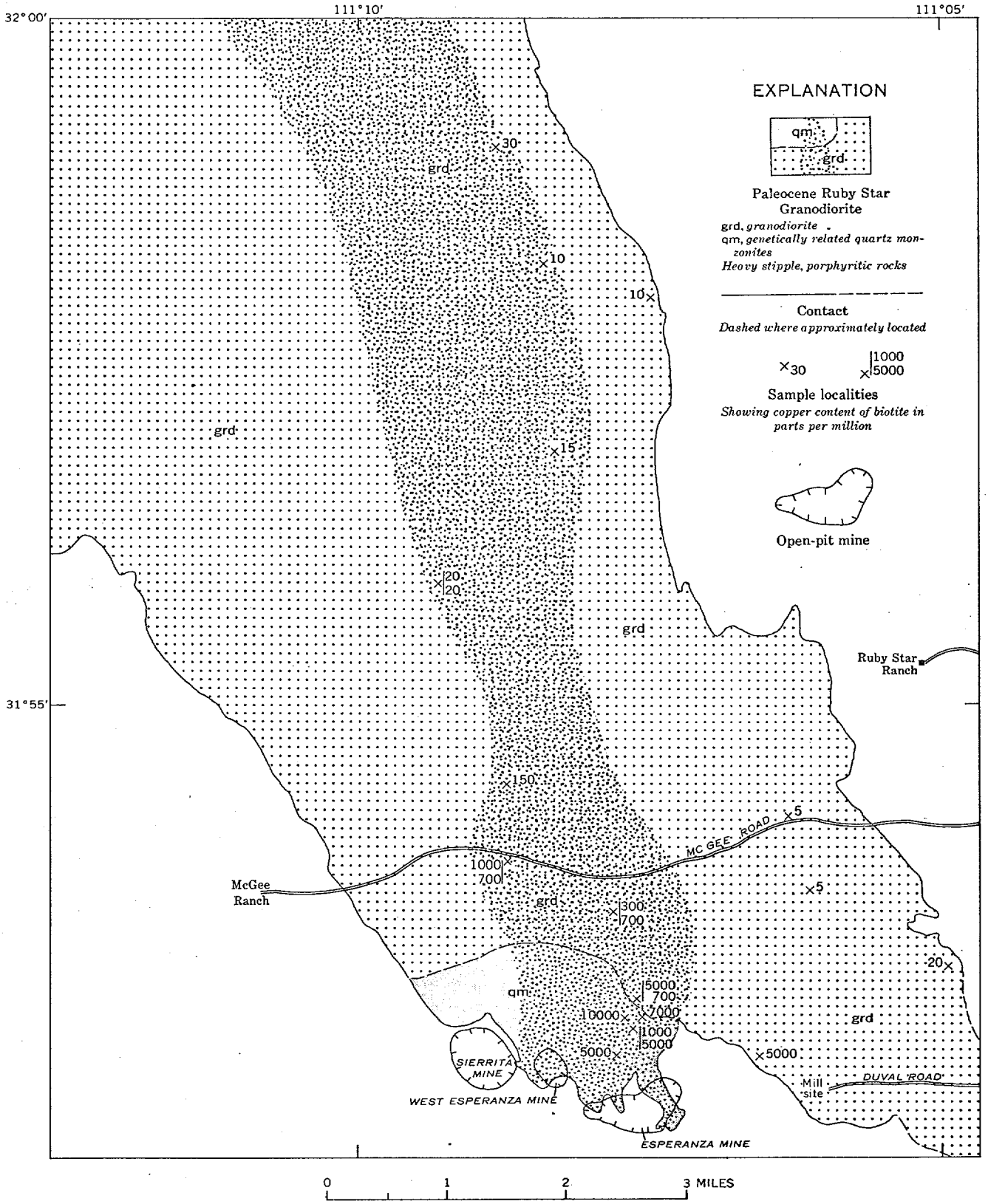

FIGURE 2.—Generalized map of composite stock and associated ore deposits in the southwestern part of the Pima mining district, east of the Sierrita Mountains, showing sample localities and copper content of biotite.

crysts of white plagioclase, gray quartz, pink potassium feldspar, and biotite make up about half the rock. The remainder is a fine-grained granular ground-mass of quartz, potassium feldspar, and a little plagioclase. Primary accessory minerals include magnetite, apatite, and zircon.

The aplitic quartz monzonite (table 3, analysis 4) is a light-gray aplitic rock whose groundmass consists largely of quartz, orthoclase, oligoclase, and biotite in grains less than half a millimeter in diameter. Zoned oligoclase phenocrysts as much as 5 mm long and biotite books 1–3 mm in diameter are fairly common, and quartz "eyes" as much as 3 mm in diameter have been observed but are much less abundant than in the adjacent quartz monzonite porphyry. The accessory minerals include magnetite, apatite, zircon, and sphene.

The quartz monzonite porphyry has been dated by Creasey and Kistler (1962) by the potassium-argon method as 56 m.y. This age may be too young, as the rock is mineralized in the Esperanza mine, and muscovite from a muscovite-quartz-sulfide veinlet in this mine has a potassium-argon age of 61 m.y. (Damon and Mauger, 1966)—very nearly the same age as the granodiorite.

Biotite concentrates and their copper content

The sample localities of the rocks from which the 22 biotite separates were made and the copper contents of these separates are shown in figure 2. Two copper values shown for a single locality represent separate samples collected tens of feet apart to test the possibility of sporadic local variation in trace-element content.

The biotite concentrates contain some mineral impurities, both as discrete grains of foreign minerals and as poikilitic inclusions of other minerals within the biotite flakes. The total content of such impurities in the various mineral concentrates ranges from less than 5 percent to nearly 20 percent; however, none of the concentrates contain any visible copper minerals.

The five samples from the equigranular border facies of the granodiorite stock show no consistent features that distinguish them from the 12 samples of porphyritic granodiorite from the central part of the stock. Hornblende is present as an accessory mineral in two of the five concentrates from the border facies but does not appear in any of those from the porphyritic facies. Zircon forms inclusions in biotite in 5 of the 12 concentrates from the porphyritic facies but not in any of the biotite from the equigranular facies.

There is a suggestion of a color change in the biotite of both rock types from north to south in this stock. Most samples near the southern end of the pluton are moderate brown to dark brown; those from about a mile to about 3 miles north of the southern end tend to be somewhat lighter brown, and those from localities more than 3 miles to the north are olive brown or mixed olive brown and shades of light brown.

Biotite from the porphyritic granodiorite contains a maximum of about 5 percent apatite, rutile, ilmenite, hematite, sphene, and zircon as inclusions. Chlorite, the most common accessory mineral in the concentrates, ranges from 0 to about 10 percent of the sample. Minor amounts of feldspar, hornblende, and sphene are also present as accessory minerals in a few of the concentrates.

Biotite from the quartz monzonite porphyry and aplitic quartz monzonite is moderate brown to dark brown and contains as much as 10 percent of inclusions of apatite, ilmenite, hematite, rutile, and zircon. Chlorite constitutes as much as 10 percent of the mineral concentrate, and minor amounts of sphene occur in two of the samples.

As shown in figure 2, the copper content of the biotites displays a zonal pattern around the copper deposits. The highest copper concentrations are in the biotite nearest the deposits, and anomalous concentrations extend outward for as much as 2½ miles. These very cupriferous biotites are mostly from quartz monzonite porphyry and aplitic quartz monzonite, but they include biotites from both the porphyritic and the equigranular granodiorite. The lithologic diversity of the samples high in copper content suggests that part or all of this copper may have been introduced by hydrothermal solutions at the time of mineralization, or conceivably could have been introduced by later circulating ground water. However, coarse hydrothermal biotite from veinlets in diorite above the Sierrita ore body contains only 30 ppm copper. This biotite has a potassium-argon age of 60 m.y. (S. S. Goldich, written commun., 1964), the same age as that of the hydrothermal mica from the Esperanza mine.

The zonal pattern of copper concentration in the biotite is also shown by the copper concentration in whole-rock samples, but it is less impressive (table 4). The copper content of whole-rock samples from which biotite was separated for this study is given in table 4.

CONCLUSIONS

The copper content of primary biotite in several rock types from southern Arizona ranges from a few parts per million to 1 percent. The concentration of copper in biotite from two different bodies of the same kind of rock differs by more than an order of magnitude, and it varies by three orders of magnitude within a single large ore-related stock of granodiorite in the

TABLE 4.—*Comparison of copper content of whole rock and biotite in selected samples from the Pima mining district*

Rock type and sample locality	Copper (ppm)		Percentage of copper in whole rock that is concentrated in biotite
	Whole rock [1]	Biotite [2]	
Equigranular granodiorite, 2.7 miles northeast of Esperanza mine.	7	5	<5
Porphyritic granodiorite, 2.9 miles northwest of Esperanza mine.	150	700	15
Quartz monzonite porphyry, 0.5 mile northwest of Esperanza mine.	300	5, 000	50

[1] N.M. Conklin, analyst.
[2] R. H. Heidel, analyst.

Pima mining district. Copper anomalies in the rock are magnified in the biotite from that rock, although rocks that are low in copper content contain biotite with equally low copper concentrations. Igneous-rock bodies in the Santa Rita Mountains that are genetically related to copper deposits contain primary biotite with copper concentrations at least an order of magnitude higher than those in biotite from rocks that are not related to copper deposits. The copper anomaly in biotite from the large stock in the Pima district is centered over the mineralized area and extends for more than a mile beyond it.

The copper content of biotite may be useful in recognizing plutons that are genetically related to copper mineralization and as a geochemical guide to copper ore deposits in such plutons.

Although all but one of the biotite samples analyzed are primary, it cannot be conclusively demonstrated that the copper in them is also primary. The lithologic diversity of rocks with high copper content suggests a hydrothermal source; however, a sample of hydrothermal biotite from the mineralized area of the Pima mining district contains only 30 ppm Cu. Putman and Burnham (1963, p. 72, 82) concluded that the copper, present in high concentrations in samples of biotite from their Boriana Granodiorite pluton, is a primary constituent and was not introduced by later hydrothermal activity.

Only the copper content of biotite in the igneous rocks of this area was investigated by the authors, since biotite is the only mafic mineral present in concentratable amounts in all these rocks. If other primary mafic minerals are present in an ore-related igneous rock, they may also concentrate copper. Two samples of hornblende from the Madera Canyon Granodiorite contain about the same amount of copper as the biotite samples from this rock.

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Memo from the desk of

JDS/FTG GEORGE J. STATHIS March 4-74

TO W. L. Kurtz,

Enclosed is results of biot sampling in the Aju Area.

Geochem results received this morning.

No evidence of zoning was noted while walking out the entire periphery of the biot grd (Menz?).

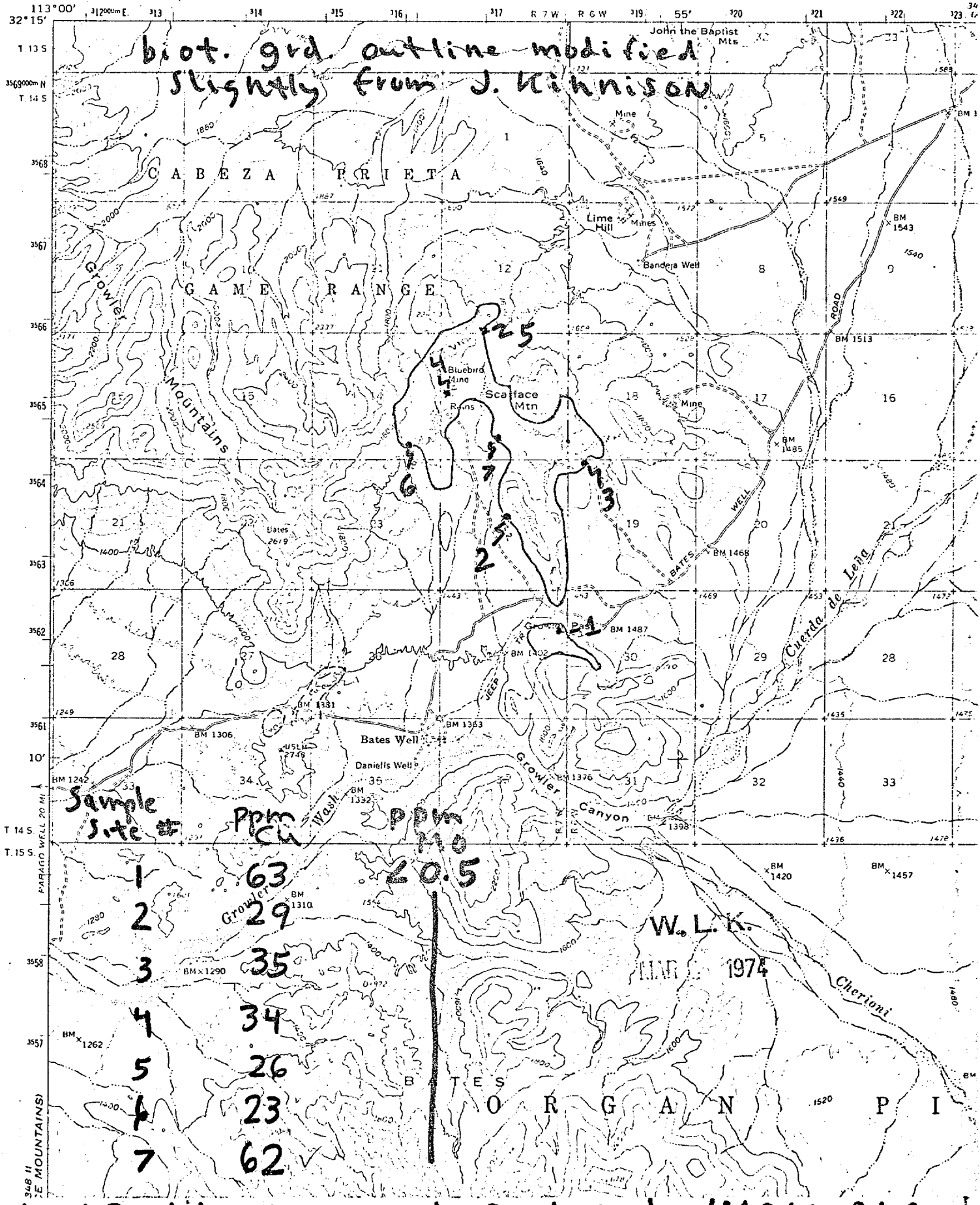
W. L. K.

MAR 4 1974

Overall, values are pretty low. FTG.

KINO PK Quad 15'
Ajo area

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY



Note: Biotite concentrate analysis by NARCO-S.L.C.

Biotite

AMERICAN SMELTING AND REFINING COMPANY
SOUTHWESTERN EXPLORATION DIVISION
P. O. BOX 5747, TUCSON, ARIZONA 85703

1150 NORTH 7TH AVENUE
TELEPHONE 602-792-3010

January 21, 1974

Mr. Bill Reed
Colorado School of Mines
Research Institute
P.O. Box 112
Golden, Colorado 80401

Dear Bill:

Seven rock samples (AJ1 thru 7) were sent to you today, prepaid, via Continental Trailways Bus. Shipment is in two separate burlap bags.

Please prepare biotite concentrates from these samples and forward the concentrates to our lab in Salt Lake, to the attention of Mr. Ernie Phillips. Also, save about a 200-gram split of each sample from the first grind and return these splits to me here in Tucson.

Thanks.

Sincerely,

George J. Stathis

George J. Stathis

GJS:lb

cc: WLKurtz
EHPhillips

Biotite

Bill,

High values of Cu in biotite as compared to Cu in whole rock samples are not unusual; they are typical of magmatic biotites associated with closely adjacent copper mineralization. Material in my report at the annual exploration meeting I had hoped had demonstrated this fact.

In addition secondary biotite often contains less Cu than the whole rock, although the behavior of these biotite types is variable.

Fred.

8/22

From: J. J. Collins

To: Mr Wm Kurtz

Some of your staff may care to comment

RECEIVED
AUG 25 1972
S. W. U. S. EXPL. DIV.

RECEIVED
AUG 11 1972
EXPLORATION DEPT.

8 Aug/72

Mr. J.H. Courtright,

Chief Geologist,
American Smelting & Refining Company,
P.O. Box 5747,
Tucson, Arizona 85703.

AUG 11 1972
J. V. D.

Yukon Territory
Whitehorse Mining Division 115-I
Minto Cu Prospect

Dear Mr. Courtright:

This will acknowledge receipt of your memo dated 4 Aug/72 re the title subject. Your summary of the geological aspects of the Minto Prospect is very good. Bob Gale and I have little to add, or comment upon, except to bring you up-to-date on a number of recent developments at the property.

Trenching to the west of the area that you and John Collins examined continues to encounter mineralization similar to that previously disclosed. Some of it is surprizing high grade, but as you have described, it is discontinuous. We do not as yet have the assay results from the two diamond drill holes drilled to the east of the better mineralization noted around Drill Holes 2 and 11. However, the mineralization is described as "spotty".

My primary reason for writing relates to the last sentence in the 3rd paragraph of your memorandum, wherein you refer to the sizeable area of geochemically anomalous copper exceeding 2000 ppm Cu. As you are aware, this is a surprizingly large geochem anomaly considering its strength, and it was assumed from data acquired at the Williams Creek Prospect, that the geochem anomaly generally reflected bedrock conditions. Much of the trenching in areas of + 2000 ppm Cu revealed rocks of granitic or granite gneiss composition with virtually no visible copper minerals. Nevertheless, many of these apparently barren trenches assayed approximately 0.20% Cu.

You may recall that during your visit, I collected a group of biotite-rich specimens in order to have the Salt Lake City laboratory test for a copper content of the secondary (?) biotite. I have just received the results of this test work(see attached), and it appears that the biotite does, in fact, contain a very high proportion of the copper noted in the granitic rocks. Salt Lake City reports that the

.....2

copper appears to be in the form of a "black shiny mineral" intimately associated with the biotite crystals. The total rock sample assayed 790 ppm Cu (0.079% Cu), while the biotite alone assayed 2300 ppm Cu (0.23% Cu). Salt Lake City reported that this high copper in the biotite versus copper in the whole rock is somewhat unusual.

not at Safford in the Sierrita andesite

The abundance of copper in the widespread biotite may partially explain the very large + 2000 ppm copper geochem anomaly that was picked up at the Minto Prospect. The breakdown of the biotite (mafics) and subsequent release of copper ion into the developing soils, may have contributed to the strong copper anomaly observed in the "B" horizon samples collected in the area. The underlying bedrock, while in many places assaying 0.20% Cu, did not appear to contain anywhere near that amount of copper visible either as oxides or sulfides.

I have given some thought to having an X-ray microprobe study conducted on some of this biotite to determine the true character of the "black shiny mineral". It would, however, be an academic exercise, and at this juncture may not be justified.

As soon as additional data is received from the Minto Prospect, a summary of these results will be forwarded to your office for your review.

Yours very truly,
Original Signed by
S. A. ANZALONE

S.A.Anzalone.

SAA:sm
Attach

CC: JJCollins, TCOsborne, w/encls.

Project 542

ASARCO
GEOCHEMICAL DATA

Page

Area MINTO PROSPECT, YUKON TERRITORY (BIOTITE)

Date August 3, 1972

Requested By R. E. Gale, Vancouver Office

No. Samples

SAMPLE NUMBER		Cu ppm								
Biotite										
Mineral		2300	[illegible]	[illegible]						
Pulp		790	[illegible]	[illegible]						

EXPLORATION SERVICES DIVISION
3422 SOUTH 700 WEST
SALT LAKE CITY, UTAH 84119

August 3, 1972

RECEIVED AUG 7 1972

Mr. R. E. Gale
American Smelting and Refining Company
504-535 Thurlow Street
Vancouver 5, B.C., Canada

Dear Mr. Gale

BIOTITE SAMPLE
MINTO PROSPECT, YUKON TERRITORY
GEOCHEMICAL LABORATORY #542

Transmitted herewith is the analytical report for the sample sent to the Laboratory for Biotite separation and analysis, reference your letter July 25, 1972.

The Biotite was separated and cleaned by the use of a magnetic separator and heavy liquid treatment. We were not able to remove all of the impurities but the Biotite was better than 95% pure.

The "Pulp" is a prepared sample from the material as received from you crushed and ground only. All fractions were saved in the separation of the Biotite for your inspection if you desire.

Molybdenum was checked but analysis showed less than one part per million.

Yours very truly,

E. H. PHILLIPS

EHP:db
Encl.

cc:S.A.Anzalone w/encl.
L.D.James w/encl.

Biotite

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

June 7, 1972

FILE MEMORANDUM

Variation of the Fe/Mg Ratio
In Chlorite as an Ore Guide

The association of chlorite with sulfide mineralization, particularly in the stratiform massive sulfide deposits in volcanic rocks, has been known for many years. However, the occurrence of chlorite in many different rocks, in many different chemical and structural forms, and as an ubiquituous constituent of greenstone, has apparently restricted use of this association as an ore guide.

The first attempt to understand the spatial distribution and chemistry of chlorite associated with sulfide ores and to apply this knowledge to ore finding was made by Price (1934). He noted that the Fe/Mg ratio changed in a regular way with distance from ore and was able to recognize these differences petrographically, thus determining both association with and direction toward ore. Recent work of a very similar nature has been reported by Miller (1961), Eckstrand (1963), and in a more general way in the book edited by Tatsumi (1970). Eckstrand's work indicated that ore-associated changes in the Fe/Mg ratio of chlorite in the Chibougamau district could be detected over 400 feet from the veins.

Differences in the Fe/Mg ratio of the chlorites exert a strong control on the birefringence, or difference between the high and low indices of refraction (n). Quantitative estimates of the birefringence can be made from immersion mounts of grains in oils of different n (Eckstrand, 1963) and from thin sections by using a Berek compensator. In addition, qualitative estimates of the Fe/Mg ratio can be made by measurement of the sign of elongation (Albee, 1962). These techniques can all be utilized with standard petrographic equipment. Other observations, including degree of crystallinity, grain size, and mixing of compositionally different types of chlorite, can also be shown to be related to distribution of ore.

My own experience with this technique is limited to examination of a few samples from the Bathurst-Newcastle district in New Brunswick, the Boliden district in Sweden, and the United Verde and several porphyry copper mines in Arizona. This work indicates that a reasonable finesse can be acquired in a short time. The relative simplicity and low cost of this technique suggest possible applications to the search for additions to the rapidly diminishing ore reserves at the Buchans Unit.

F. T. Graybeal

F. T. Graybeal

FTG:lad

cc: JHCourtright

References

1) Albee, A.L., 1962, Relationships between the mineral associations, chemical composition, and physical properties of the chlorite series: Amer. Mineral., 47, p. 851-870.

2) Eckstrand, O. R., 1963, Crystal chemistry of chlorite: Harvard Univ. Ph.D. thesis.
(This will soon be available at the Tucson office; it can't be purchased through University Microfilms.)

3) Miller, R. J. M., 1961, Wall rock alteration at the Cedar Bay mine, Chibougamau district, Quebec: Econ. Geol., 56, p. 321-330.

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5) Tatsumi, T. (ed), 1970, Volcanism and ore genesis: Tokyo, Univ. of Tokyo Press.

WLK → porph Geneset Geochem WES file

Economic Geology
Vol. 65, 1970, pp. 985–992

file

Copper Content of Biotites from the

WXIC ~~JHC~~ - file

Copy for Kurt

file ~~[illegible]~~ prop Copper Creek: J. H. C. BLK

GEOPHYSICAL DIVISION

3422 South 700 West
SALT LAKE CITY, UTAH 84119

FEB 2 1971

January 28, 1971

RECEIVED
FEB 1 1971
S. W. U. S. EXPL. DIV.

R. J. L.
JAN 29 1971

W.E.S.
FEB 1, 1971

MEMORANDUM to R. J. LACY:

not very good

file

BIOTITE PROJECT

We recently received the x-ray fluorescent analysis data for the biotite fractions separated by the Colorado School of Mines Research Institute from the rock samples collected by Mr. J. King in the general vicinity of the Esperanza Mine. The emission spectrograph data is due shortly, and our own atomic absorption analyses will be carried out as soon as we receive the samples back from Golden, Colorado.

I include plots of the Cu, Pb and Zn data. It would appear that the Cu data broadly substantiates that obtained by the U.S.G.S., but final conclusions had probably best await consideration of the emission spectrograph data and check analysis of the samples by the Geochemical Laboratory.

L. D. James.

L. D. JAMES

LDJ:db
Encl.

cc:J.R.King w/encl.
W.E.Saegart w/encl.

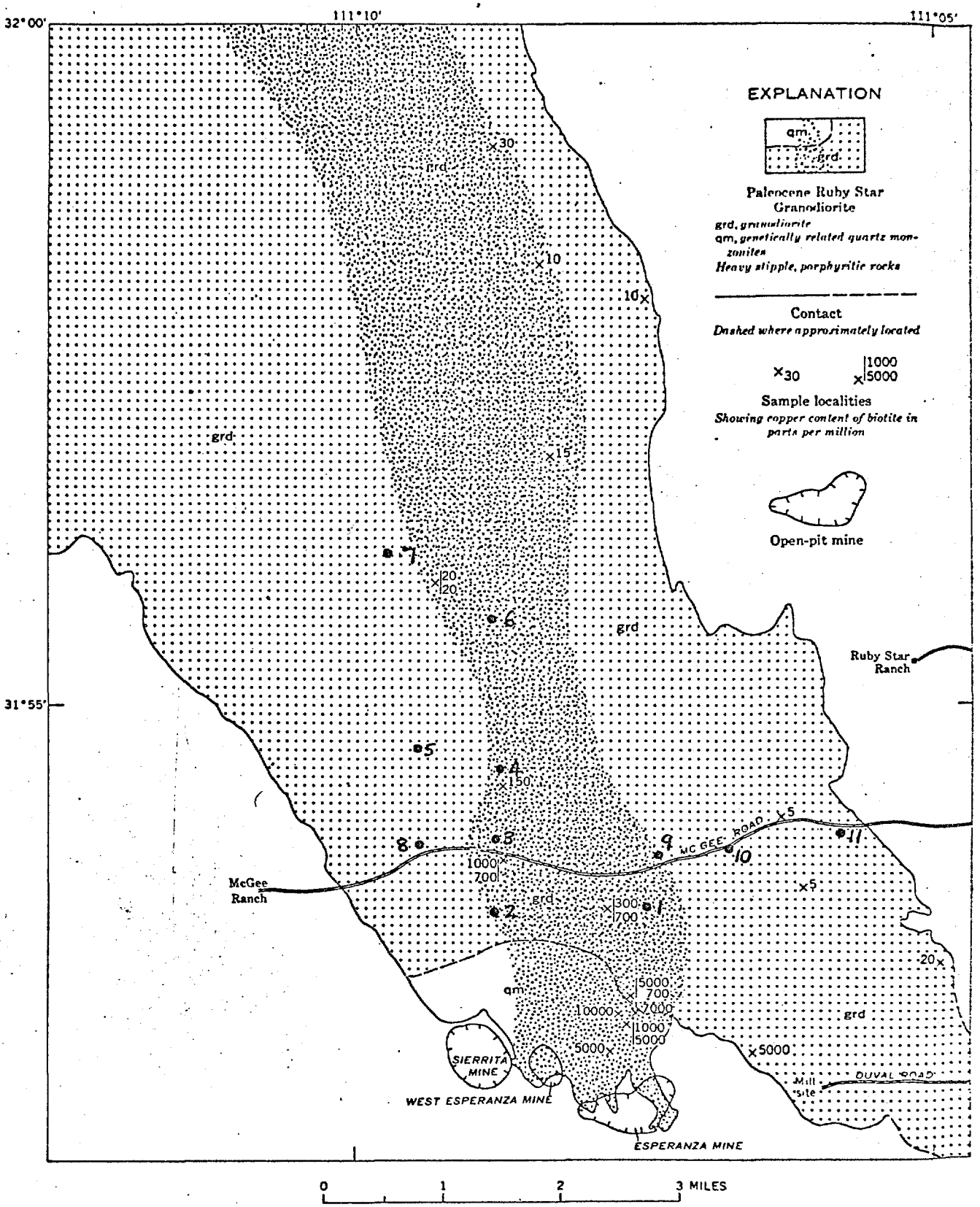


FIGURE 2.—Generalized map of composite stock and associated ore deposits in the southwestern part of the Pima mining district, east of the Sierrita Mountains, showing sample localities and copper content of biotite.

Location and numbers of Asarco rock samples.

Cu

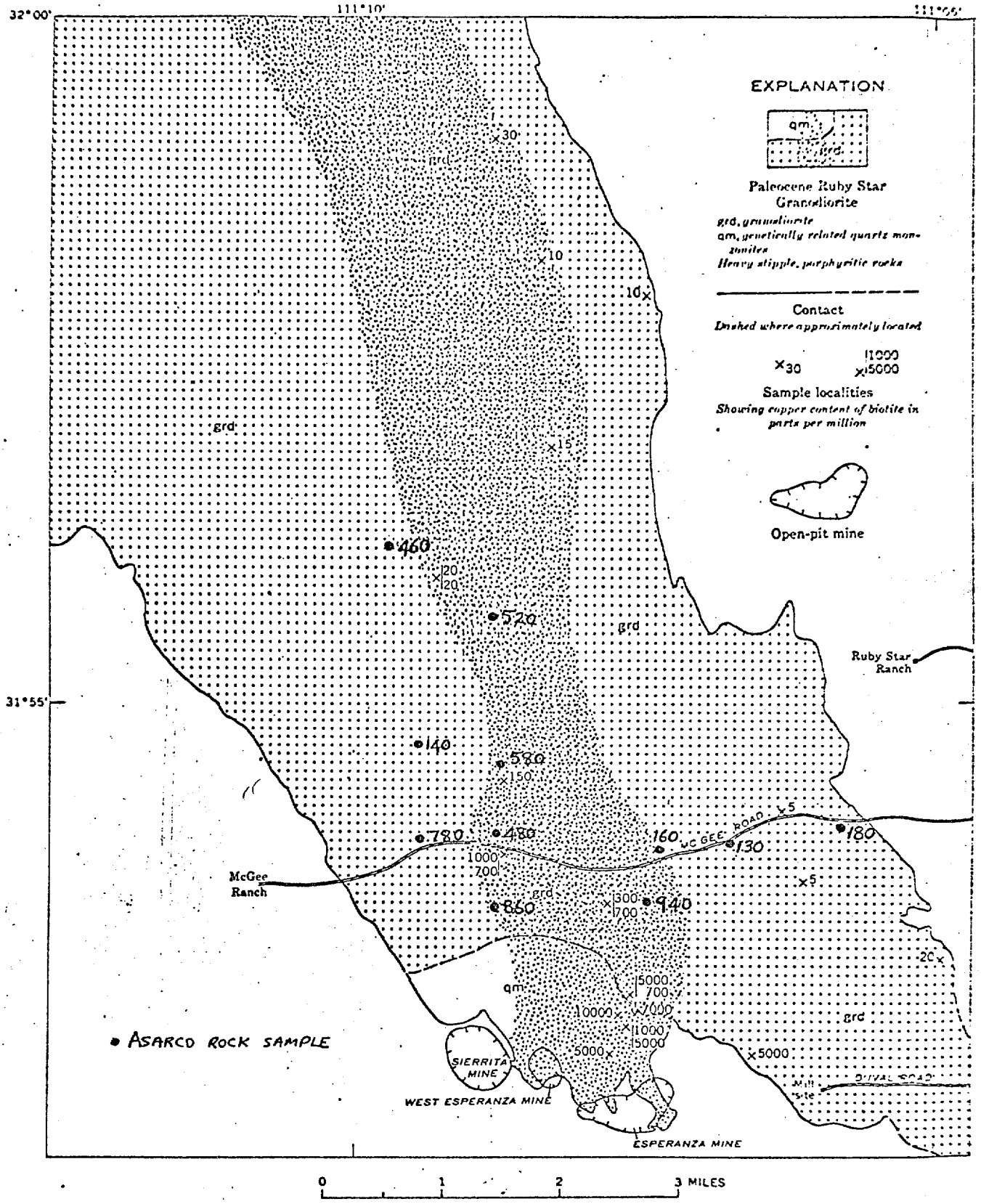


FIGURE 2.—Generalized map of composite stock and associated ore deposits in the southwestern part of the Pima mining district, east of the Sierrita Mountains, showing sample localities and copper content of biotite.

Location of Asarco rock samples and Cu content (ppm) of Biotite. (Analysis by Colorado School of Mines Research Institute using an X-ray fluorescence technique)

Pb.

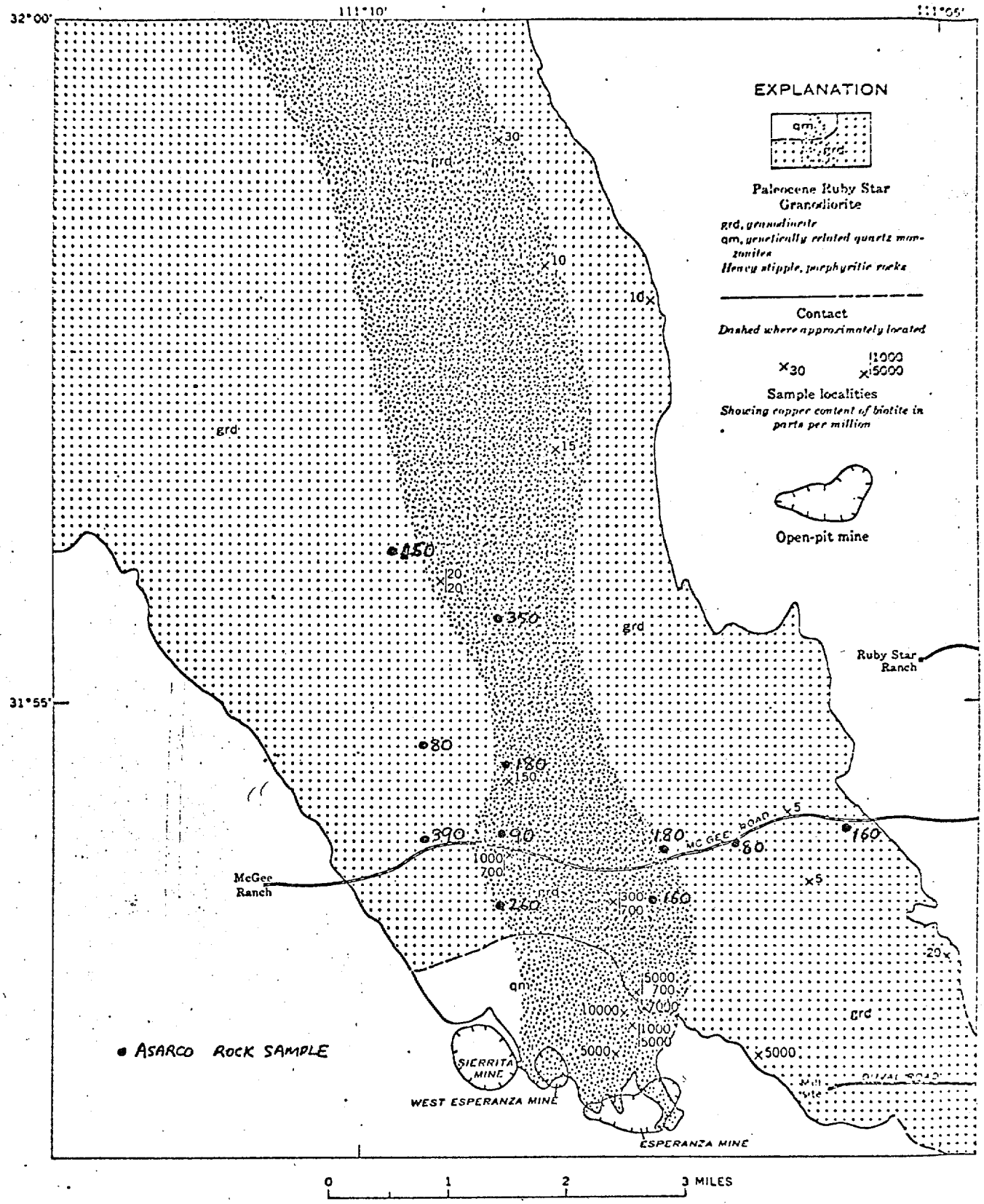


FIGURE 2.—Generalized map of composite stock and associated ore deposits in the southwestern part of the Pima mining district, east of the Sierrita Mountains, showing sample localities and copper content of biotite.

Location of Asarco rock samples and Pb content (ppm) of biotite. (Analyses by Colorado School of Mines Research Institute using an X-ray fluorescence technique.)

Zn

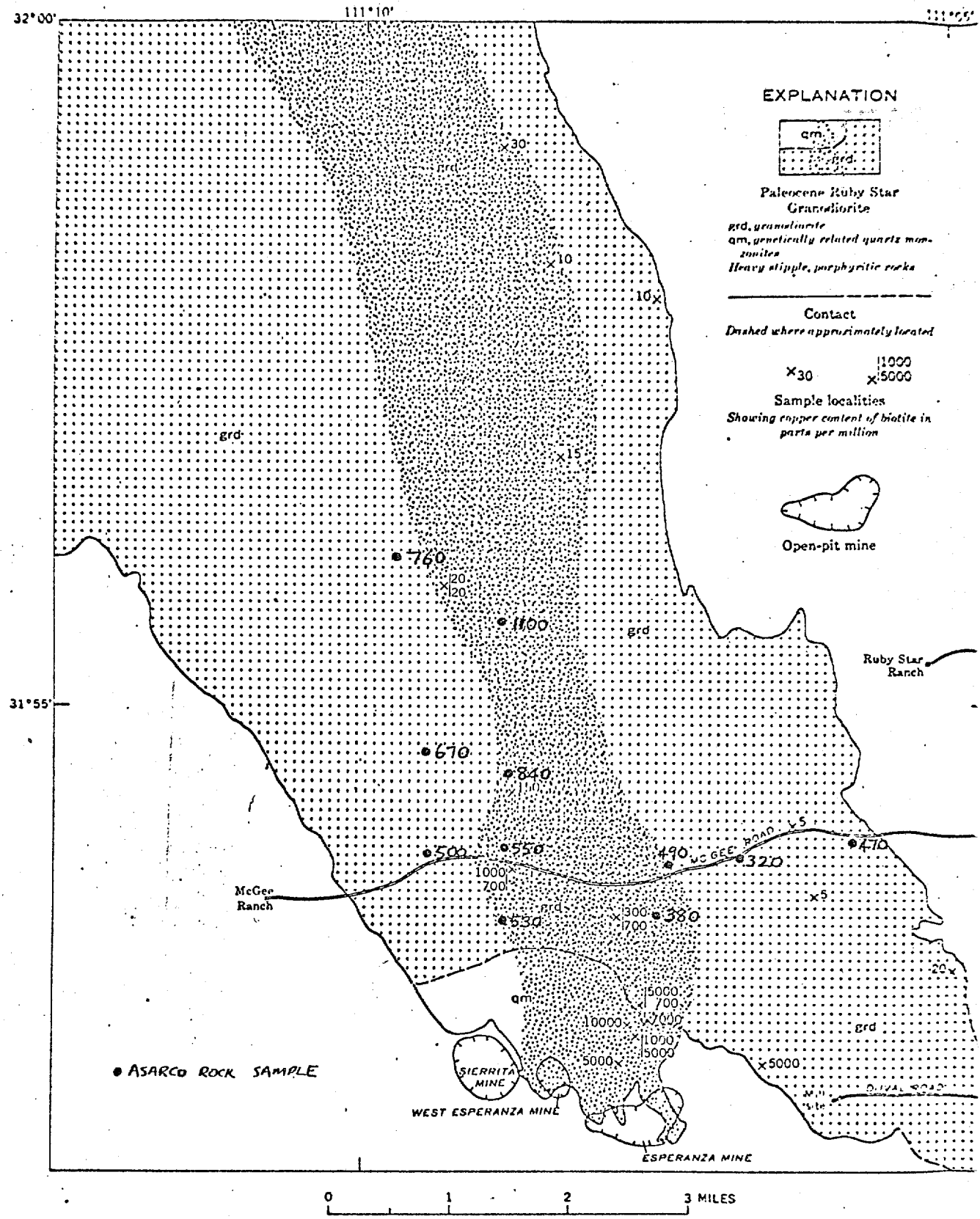


FIGURE 2.—Generalized map of composite stock and associated ore deposits in the southwestern part of the Pima mining district, east of the Sierrita Mountains, showing sample localities and copper content of biotite.

Location of Asarco rock samples and Zn content (ppm) of biotite. (Analyses by Colorado School of Mines Research Institute using an X-ray fluorescence technique.)

INTER OFFICE MEMO

Porph Copper ~~Copper~~ Biotite

To J J Collins w/ copy James letter **Date** 10/15/70

From W E S.

Subject USGS Research 1970 Chapter B (PP 700B) pages 1-8

MESSAGE Regarding your comments on L.D. James letter proposing sampling of biotites in Sierrita mtns to confirm USGS work —

USGS has tendancy to high grade their samples and then draw sweeping and generalized conclusions - For example, Drum mountain-Au (USGS Circ 623) and Monticello Box, Sierra Cuchillo (USGS Circ 600). Conclusions drawn in Cu bearing biotites in Sierrita mtns based on 8 anomalous and 1 threshold samples plus 8 background samples. This is not sufficient numbers of samples to be conclusive, considering the lithologic variations which undoubtedly occur and influence copper content of mafics. We will also try new areas such as Bagdad, Bisbee, Miami.

Signed

REPLY

cc: WLK

Date **Signed**

SEND COPIES 1 AND 3 WITH CARBON INTACT - RETURN COPY 3 WITH YOUR REPLY

Form 2644

RECEIVED
OCT - 3 1970
JOHN J. COLLINS

GEOPHYSICAL DIVISION
3422 SOUTH 700 WEST
SALT LAKE CITY, UTAH 84119

October 5, 1970

R. J. L.
OCT 6 1970

MEMORANDUM to R. J. LACY:

GEOCHEMISTRY OF IGNEOUS ROCKS
AS AN ORE INDICATOR

why not accept at face value?

Whilst in Tucson last week I discussed the recently published data on the relationship between the geochemistry of igneous intrusives and their ore potential with Mr. Saegart. He suggested, and I agreed, that a useful preliminary step would be to verify some of the U.S.G.S. data. To this end one of his field staff will carry out a limited rock sampling program in the Sierrita Mountains adjacent to the Esperanza and Sierrita Mines. At each sample location a composite composed of rock chips will be collected as well as a relatively large single speciman. The resultant analytical data will provide some indication of the homogeneity of Cu distribution and will enable an optimum sampling procedure to be developed.

Cost the USGS

The samples collected in the preliminary field study will be sent to the Geochemical Laboratory. A portion of each sample will be subjected to routine geochemical analysis whilst mineral (i.e. biotite) separation will be carried out on the remainder.

Why not try a new area, or at least another area?

L. D. James. Bagdad?

L. D. JAMES

LDJ:db

cc: J.J.Collins
J.H.Courtright
W.E.Saegart

~~JCB~~, ~~FWE~~, ~~JDS~~, ~~GJS~~, ~~AG~~, BEF, ~~AHW~~ ~~A.G.~~

Here is Kings Biotite Rpt with my notes & comments on the margin. Any comments & rebuttals are welcomed.

The biotite program which has been started may, hopefully, give positive results and add justification to the "geologic drift".

Kurt

W. L. K.

APR 10 1972

WLK —

your marginal notes are valid points —

JRK seems to be "carried away" with enthusiasm —

—

This (anomalous cu in brolite) is another reason to get the "geologic drill" going —

JRK

Return to WLK

Cell copy

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

J. H. C.

APR 11 1972

January 28, 1972

TO: W. L. Kurtz

FROM: J. R. King

COPPER IN BIOTITE

A New Approach to Porphyry Copper Exploration

SUMMARY AND RECOMMENDATIONS

This study establishes that analyses of copper in biotite can indicate favorable porphyry copper exploration targets at distances of one to over three miles beyond any other known method, be it geophysical, geochemical, or geologic. Furthermore, biotite analyses in conjunction with whole rock analyses delineate a pathway which points directly towards centers of hydrothermal mineralization. It is also shown that geologic control is extremely important in interpreting copper in biotite patterns.

Sufficient research into techniques and applications has been accomplished to warrant a controlled biotite sampling program. I, therefore, recommend an exploration program be established using biotite sampling in conjunction with geologic mapping. This program should concentrate on those Laramide stocks which disappear under post-mineral cover. Such a target would have a good chance of being secondarily enriched.

To my knowledge, ASARCO is the only company which understands and can utilize the biotite data; however, other companies are presently making inquiries into the feasibility of this program. It must be assumed that within two years ASARCO will no longer be the sole possessor of the biotite data and its exploration applications. Conoco is looking hard at possibilities, Cominco has been working with biotite for about 1 yr. in BC (FTG.

DISCUSSION

F. T. Graybeal established in his dissertation that magmatic biotite will have a copper content that is controlled by those magmatic conditions and processes which were operating at the time of crystallization. Lovering (1969) and Graybeal (1971) further proved that if a particular portion or phase of an intrusive is genetically associated with hydrothermal copper mineralization, the copper content of the biotites will reflect this association. For a detailed understanding of the behavior of copper (and selected other elements) one is referred to F. T. Graybeal's dissertation, "The Partition of Trace Elements Among Coexisting Minerals in Some Laramide Intrusive Rocks in Arizona".

ASARCO's work as presented in this report verifies that copper will be anomalously partitioned (either positively or negatively) in biotites with proximity to hydrothermal mineralization. It establishes that biotite analyses provide a better guide to porphyry copper deposits than whole rock analyses. The advantages of biotite analyses are:

1) Anomalous copper in biotite values extend from one to two miles beyond visible alteration and anomalous whole rock values. No Yes

2) The difference between background and anomalous values is greater for the copper content of biotite than the copper content of whole rock. However contrast is greater for biotite (FTG)

Since the ratios of copper in biotite concentrates versus copper content of whole rock samples can act as a guide to mineralization, whole rock analyses are also necessary.

The close correlation between changes in biotite values and geologic features emphasize that a clear understanding of the geology is necessary before the analytical data can be correctly interpreted. Petrographic work must be an integral part of a geologic examination for the proper interpretation of the varying igneous textures. This was clearly demonstrated in my thesis – this statement is a carry-over from it FTG.

An exploration program using copper in biotite analyses offers a relatively quick and inexpensive means by which a large number of intrusions can be examined and the ore potential under post-mineral cover determined. One or two qualified geologists could map and sample an intrusive in a week or two depending on accessibility. I predict that such a program in conjunction with the geologic drill would discover a porphyry copper ore zone in 12 to 18 months.

In this report I have drawn freely from Graybeal's memo, "Copper in Biotite as a Guide to Porphyry Copper Deposits" which is an abridged version of his presentation at the recent Annual Exploration Meeting. His memo, when compared to this report, illustrates the conciseness of the data which in turn eliminates any prejudicial interpretation either on his or my part. Although new data have been added at several sample sites and recontoured, the patterns and subsequent interpretation remain unchanged.

Preliminary data on lead and especially zinc partitioning indicate that these elements may also act as finger prints of distant hydrothermal mineralization. Analyses of other elements such as chlorine might also be fruitful and research along these lines should be continued.

It is important to note that this report is the result of the combined work of the geological staff. Special credit is due to F. T. Graybeal, John Balla and L. D. James.

SAMPLE PROCEDURE AND ANALYTICAL WORK

The Ruby Star, Tyrone, Three Peaks and Schultze stocks were sampled on a random, non-grid basis which depended heavily on road access. The field time involved in sampling varied between one and two days depending on the stock and accessibility. The emphasis in sampling was to obtain as fresh a composite sample as feasible. Sample density averaged between one-half and one mile centers; however, part of the Schultze granite was tested on slightly less than one-quarter mile centers. The sampling of the Three Peaks stock was roughly preplanned so that the different intrusive phases would have enough samples to permit statistical interpretations. On the average, 25 samples were taken per intrusive.

If it was done so quick why didn't we finish sampling Three Peaks and Schultz?

The samples consisted of five to ten pounds of rock chips collected over an area of roughly 200 square feet. Within this area, random boulders were broken with a sledge hammer and then only those chips which showed to be the freshest and without weathered surfaces were collected. Two hand specimens were taken at each location, one for Salt Lake analysis and the other for thin sectioning.

The Three Peaks rock samples were sent directly to Salt Lake for crushing and biotite separation. The composite rock samples from the Ruby Star, Tyrone and the Schultze stocks were shipped via commercial bus lines to the Colorado School of Mines Research Institute for crushing, screening and heavy liquid separation. The details of CSMRI separation techniques and procedures are attached in the appendix. The biotite concentrates and pulp splits were returned to Tucson for microscopic examination and then sent on to Salt Lake for analyses. CSMRI could normally perform the mineral separation within two weeks.

– have changed considerably. FTG

At Salt Lake, the concentrates were analyzed by total digestion atomic absorption methods with the exception of the molybdenum analyses which were done by a colorimetric procedure. The biotite concentrates were then recleaned by magnetic and heavy liquid separations and re-analyzed. The time involved in separation and analyses at Salt Lake was at best two weeks per batch of samples.

As reported by Salt Lake, "all of the elements analyzed with the exception of lead have a confidence level of 90% or better, with lead in low concentrations of 10 to 50 ppm about 60-85% confidence, 50 to 100 ppm about 85-90% confidence, and 100-500 ppm about 90-95% confidence".

Total time between sample collection and receipt of data is between four and six weeks depending mostly on Salt Lake's work load and staff availability. It is predicted that with a continuing program, the analytical results would be received in Tucson between three to four weeks after initial mailing.

Petrographic examination of representative hand samples collected at each biotite sample locality has not been accomplished. Such a study is absolutely necessary both to provide the petrologic understanding of the stock and to define if any visual changes are occuring within the biotites that may indicate internal chemical changes.

has not influenced your conclusions ↓ Thin section work still necessary – and you can't predict, a priori, when. FTG.

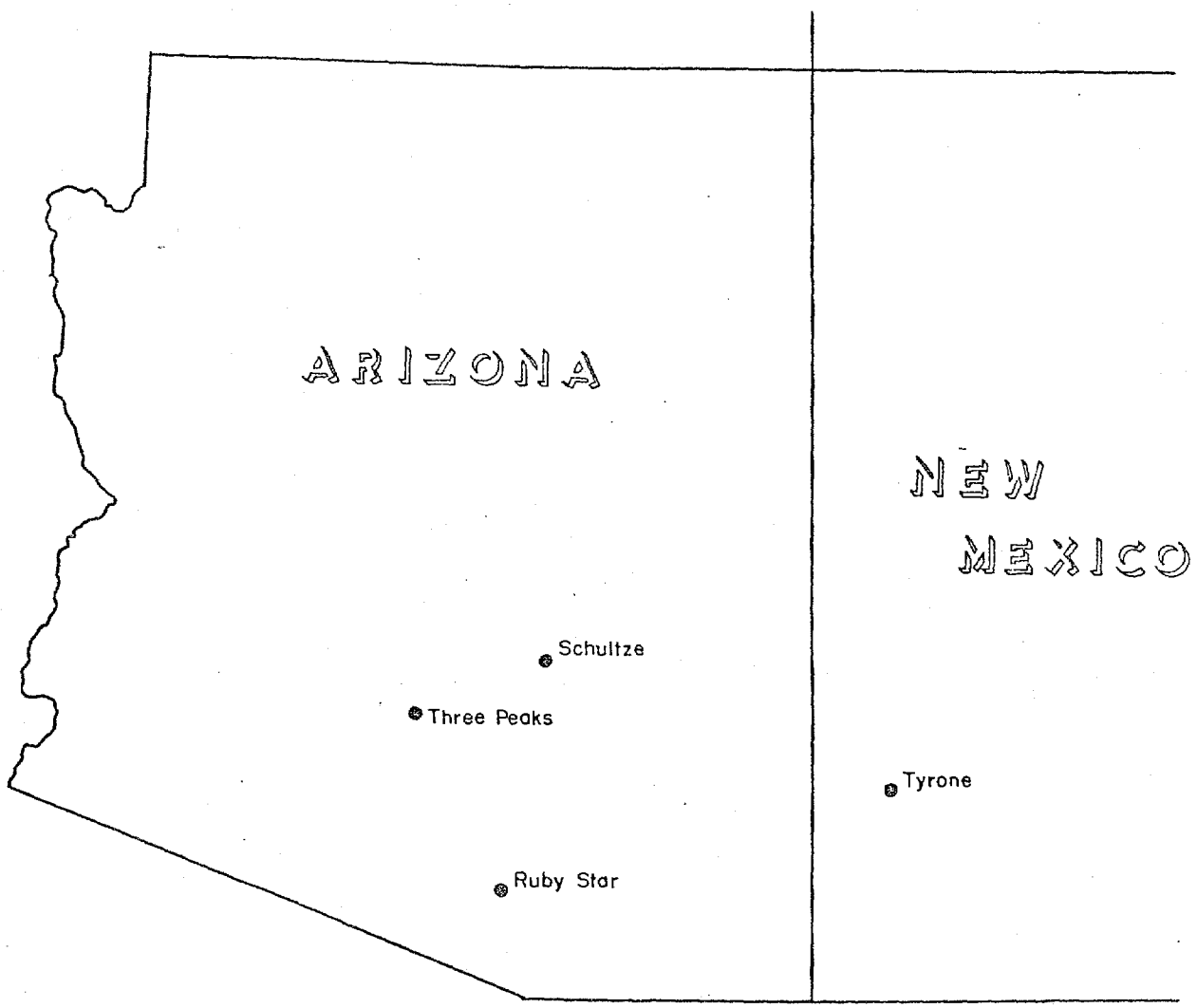
COST SUMMARY

The costs of separating and concentrating biotites at CSMRI are charged, for the most part, as direct salary payment of the persons who perform the work. In the past, a skilled scientist took an average of two hours to concentrate the biotites from a coarse rock chip sample. The cost of separating and concentrating, excluding other charges such as freight, averaged between 21 and 22 dollars per sample. Shipping charges (one way) to Denver via commercial bus lines averaged twenty cents per pound.

It is roughly estimated that costs incurred by an ASARCO geologist run at about 100 dollars per day in the field. Salt Lake analytical charges are guessed to be at about two and one-half dollars per sample.

Sounds like good expense account!

The total charges including field, freight, concentration and analytical costs average between 35 and 40 dollars per sample.



LOCATION MAP OF AREA INVESTIGATED

TAB

Ruby Star

W. L. Kurtz January 28, 1972

RUBY STAR GRANODIORITE

The Ruby Star granodiorite is a composite stock consisting of several granodiorite and quartz monzonite phases. The two main phases are a porphyritic granodiorite core and an equigranular granodiorite border. At the southern end of the Ruby Star stock is the Sierrita-Esperanza ore zone. The northern end of the Ruby Star stock disappears under post-mineral gravel cover.

At the request of L. D. James and W. E. Saegart (November 1970), eleven composite chip samples (RS-1 through RS-11) were collected by the author in an attempt to verify work by Lovering, et al., (1970). These samples were sent to the Colorado School of Mines Research Institute for biotite separation, x-ray fluorescence and emission spectrographic analyses, and limited electron microprobe studies. Atomic absorption analyses were conducted by the Salt Lake Services Division. The results of this work were presented in a report by L. D. James, March 1, 1971. The microprobe report is enclosed in the appendix of this report. Enough positive information was gained to warrant more sampling and further analytical studies. A total of 13 more samples (RS-12 through RS-24) were collected on two different occasions.

The initial Salt Lake atomic absorption analyses as well as CSMRI spectrographic and x-ray fluorescence analyses were made from biotite concentrates that averaged less than 95% pure (referred to as "unclean" in Table 1). Contaminants included magnetite, quartz, feldspar dust, sulfide grains and trap iron. All samples were cleaned up to over 98% purity (referred to as "clean" on Table 1) at Salt Lake by magnetic and heavy liquid separation and re-analyzed. Following this, samples RS-18 through RS-24 were resubjected to magnetic cleaning (referred to as "very clean" on Table 1) and re-analyzed. Sample RS-21 was taken from an unaltered outcrop of granodiorite, however, a small (100 sq. ft.) pod of alteration associated with a vein was found to be present less than 200 feet away from the sample site. Sample RS-24 was composited from several rocks taken while on tour at the Sierrita mine and probably contained hydrothermal biotites. – Maybe, but Lovering et al report one analysis of hydrothermal biotite at 30 ppm FTG

The copper content of biotite ("clean and very clean" on Table 1) of the samples taken from the Ruby Star granodiorite is shown on Figure 1-A. A well-defined copper in biotite anomaly extends for over 3 miles north from the Sierrita-Esperanza ore zone. This anomaly is developed from one to two miles beyond the limits of hydrothermal alteration. The anomaly appears to follow the prophyritic core and may be indicating a close genetic relation between the porphyry and ore.

Copper in whole rock is given on Figure 1-B. A well-defined 500 ppm anomaly extends outward from one to two miles from the Sierrita-Esperanza ore zone. The 500 ppm contour delineates the limits of identifiable alteration. but not Cu-in-rock anomaly

The copper content of the biotites gives an additional one to two miles of anomalous halo and provides guidance for exploration which would not be attainable through geologic mapping or whole rock geochemistry. Not true for whole rock but true for alteration

The ratios of copper in biotite versus copper in whole rock are shown on Figure 1-C. The values rise abruptly to over seven and then fall to

Biotite gives from 0 - 2 miles additional anomalous halo at threshold = 4x background (see 1A, 1B) FTG.

one or less as approaching the ore zone. This trend roughly defines the theorized curve F. T Graybeal predicts in his memorandum "Copper in Biotite as a Guide to Porphyry Copper Deposits". It should be noted that a slight increase in the ratios is indicated in the northern end of the pluton.

Figure 1-D summarily displays the percent difference between less than 95% pure biotite concentrates ("unclean") and greater than 98% pure biotite concentrates ("clean"). It is obvious that sample purity is extremely important. Background values were decreased on an average of 40% with increasing biotite purity. Anomalous copper in biotite values found beyond the limits of whole rock anomaly are increased on an average of 20%. It is important to note that the greater the purity of the biotite concentrates, the more pronounced will be the anomaly relative to background.

The zinc content of the biotites (Figure 1-E) apparently decreases as the ore zone is approached. Data on the zinc content is incomplete and samples that are "clean" are being contoured with "unclean" samples. Whole rock analyses for zinc (Figure 1-F) show a very slight increase in values as the ore zone is approached but again the data is incomplete. Further analyses on the samples are necessary in order to prove the validity of the zinc anomalies. The ratio of zinc in biotite to that of whole rock is not meaningful at this time.

The lead content of biotites and of whole rocks are shown on Figure 1-G and 1-H respectively. Again, the analyses are incomplete and the apparent trends are not interpretable. Figure 1-I shows the sample numbers.

Partial data on molybdenite might suggest a regional rock chip and biotite anomaly is associated with the Sierrita-Esperanza ore zone; however, the data is incomplete and samples of different purity are being compared. As can be seen on Table 1, all of the "unclean" biotite samples show a variable molybdenum content of greater than 1 ppm. On the other hand, all of the "clean" biotite samples show molybdenum content of less than 1 ppm. The most logical conclusion is that the variable molybdenum content of the "unclean" concentrates is reflecting contamination rather than true molybdenum content of biotite.

The mercury content (ppb) of single rock samples are listed on Table 1. L. D. James reports that these values are anomalously high. Whether the whole intrusion is high in mercury or the high values are related to the ore zone is unknown at this time.

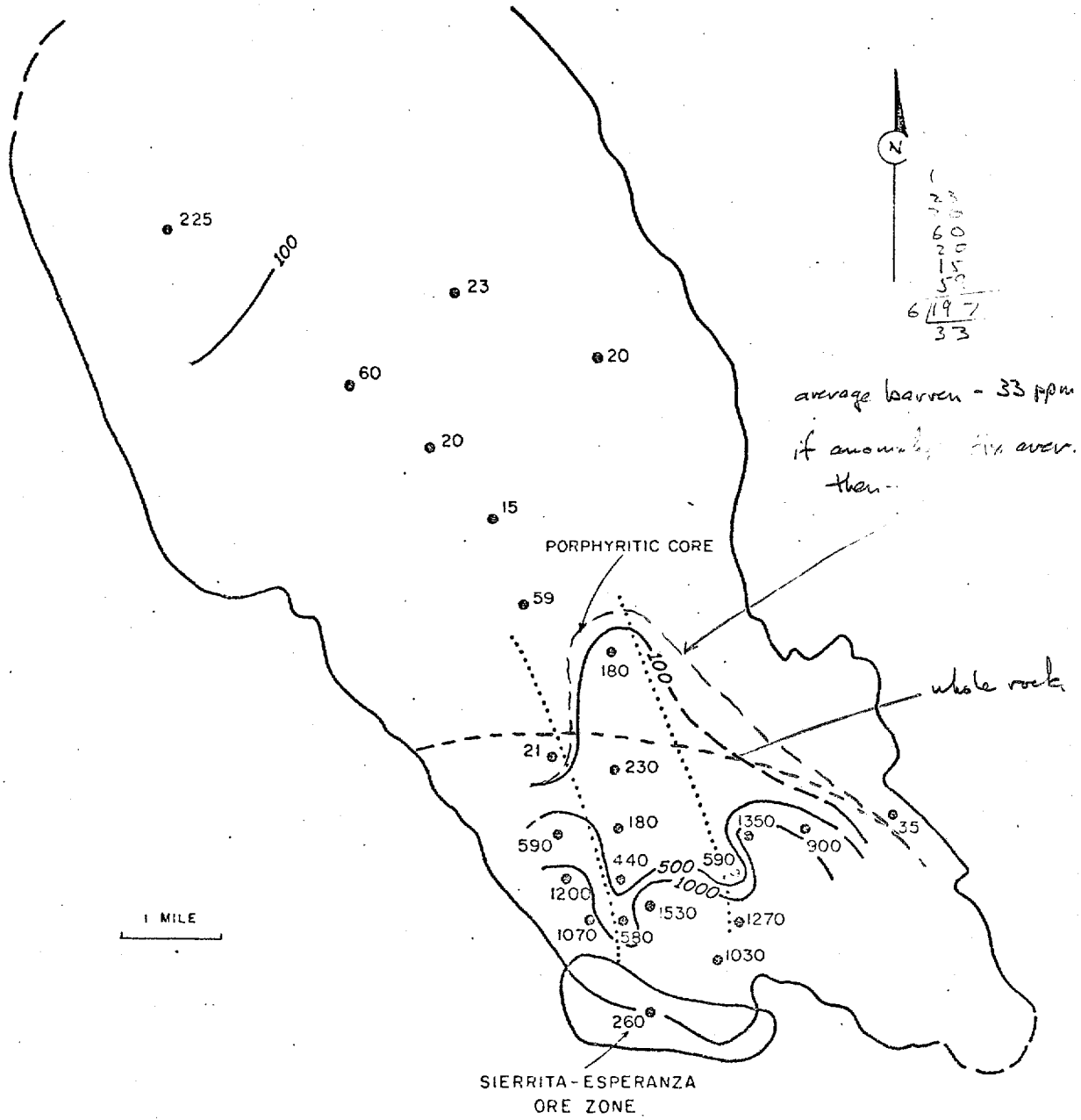
As reported by L. D. James, (1971), the spectrographic and x-ray fluorescence analyses were of little value and zirconium was the only element which may have displayed meaningful variations. It should be noted that these semi-quantitative analyses were made on unclean samples (RS-1 through RS-11) and any conclusions regarding the presence or absence of partitioning would, therefore, not be valid.

In summary, the ASARCO data verifies that:

1) Copper is anomalously concentrated in biotites with proximity to the Sierrita-Esperanza center of hydrothermal alteration-mineralization,
2) This halo extends on the order of one to two miles beyond the limits of alteration and whole rock anomaly,

3) The ratio of background to anomaly is much greater in the case of biotite than in whole rock, and
4) That biotite purity is extremely important in optimizing meaningful conclusions.

Figure 1A



RUBY STAR GRANODIORITE

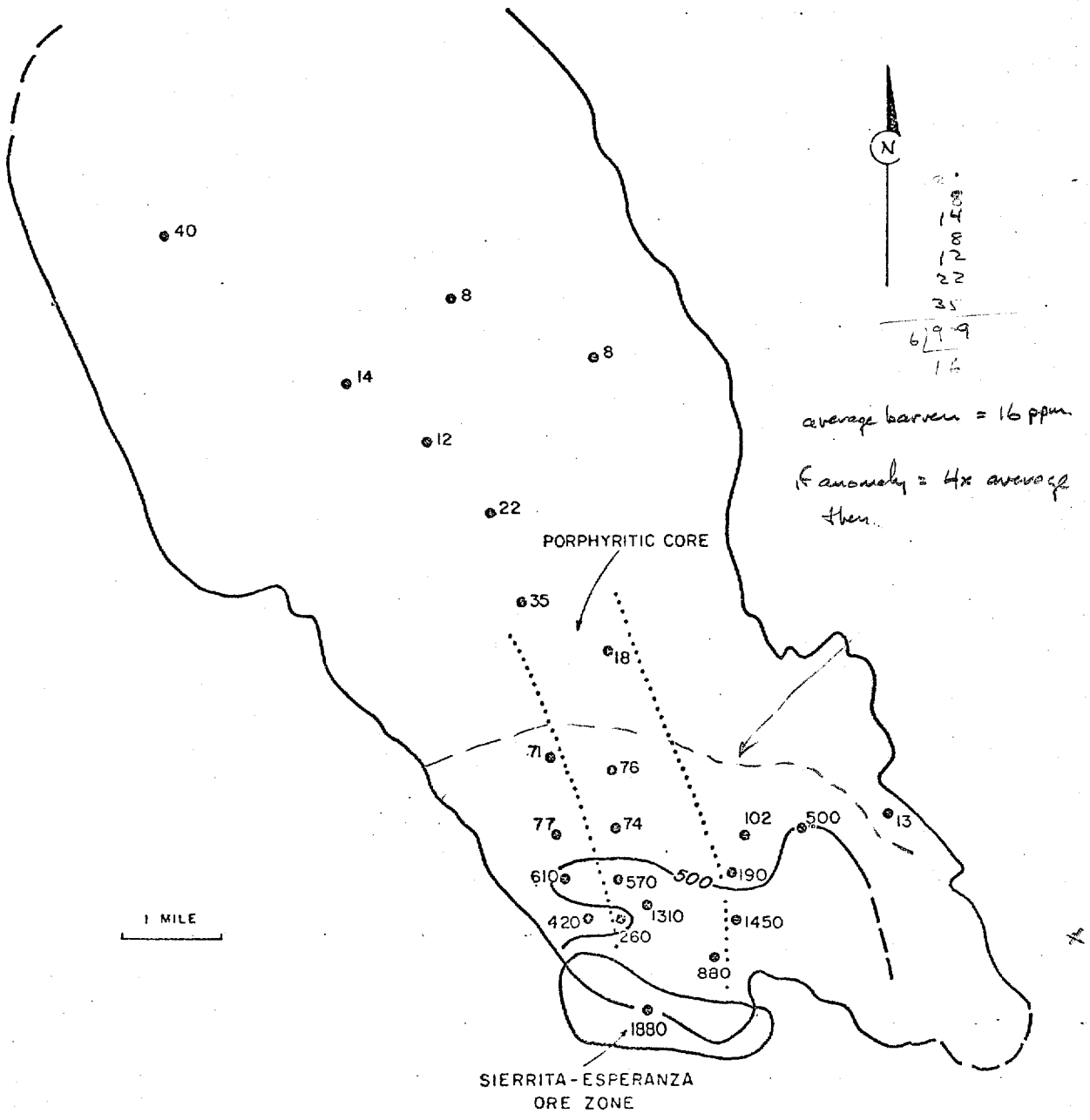
COPPER IN BIOTITE

ppm Values

(Clean)

2526-a

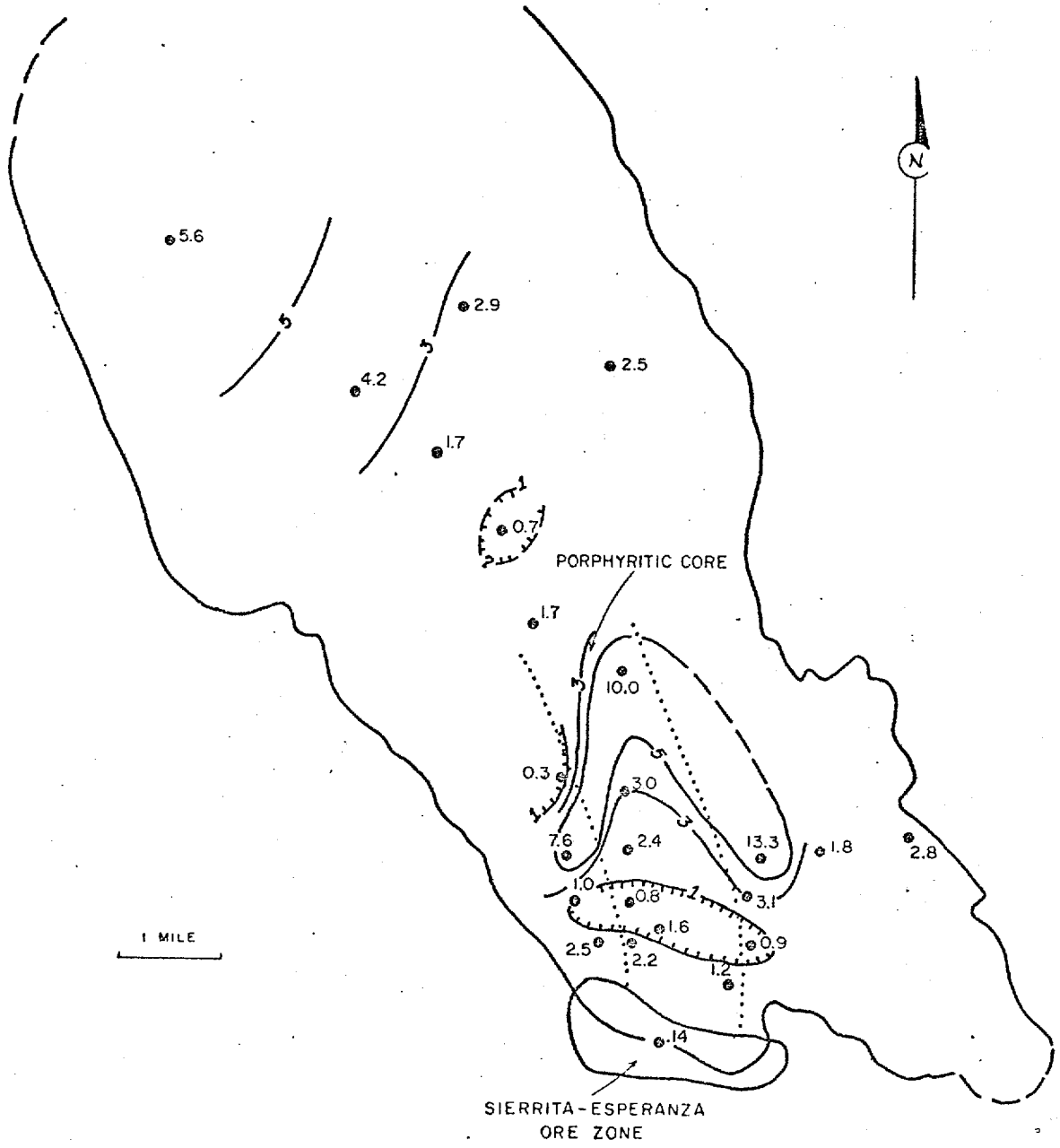
Figure 1-B



RUBY STAR GRANODIORITE
COPPER IN WHOLE ROCK
ppm Values

2526-b

Figure 1C



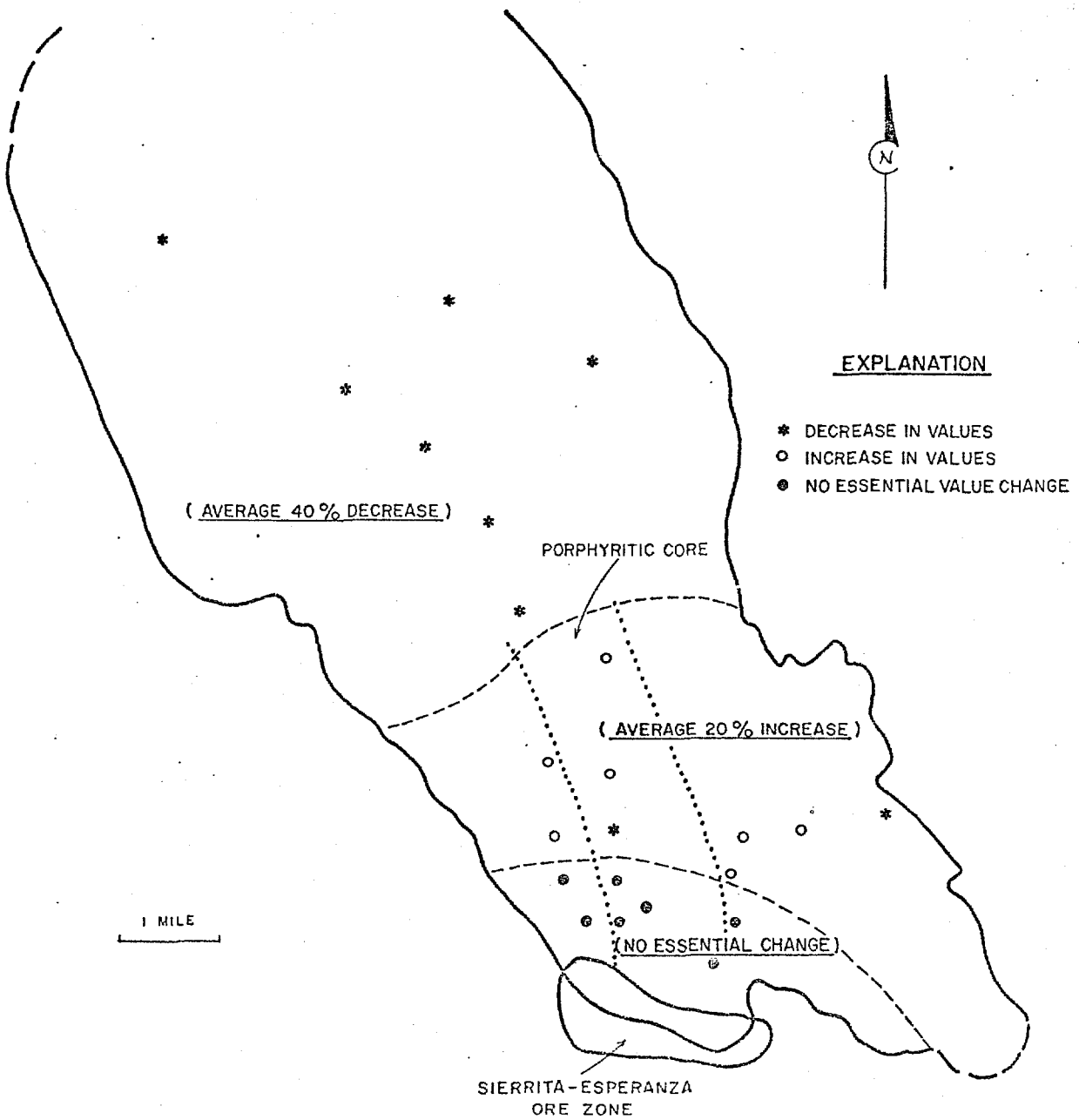
RUBY STAR GRANODIORITE

COPPER – $\frac{\text{biotite (clean)}}{\text{whole rock}}$

2526-c

FROM JKing

Figure 1-D



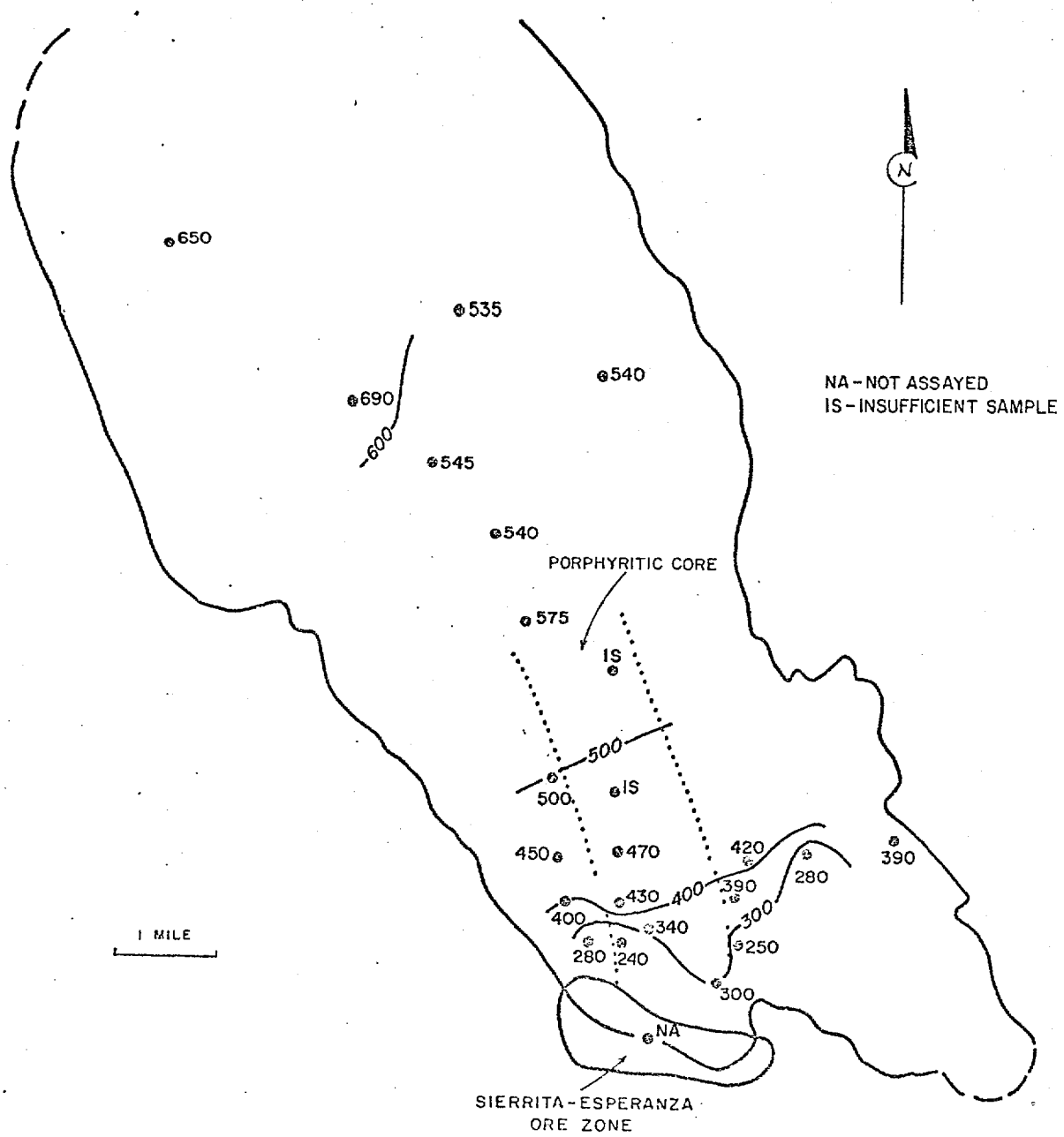
RUBY STAR GRANODIORITE

AVERAGE % CHANGE IN COPPER VALUES AS GREATER SAMPLE PURITY IS ACHIEVED

2526-d

From JKing

Figure I-E

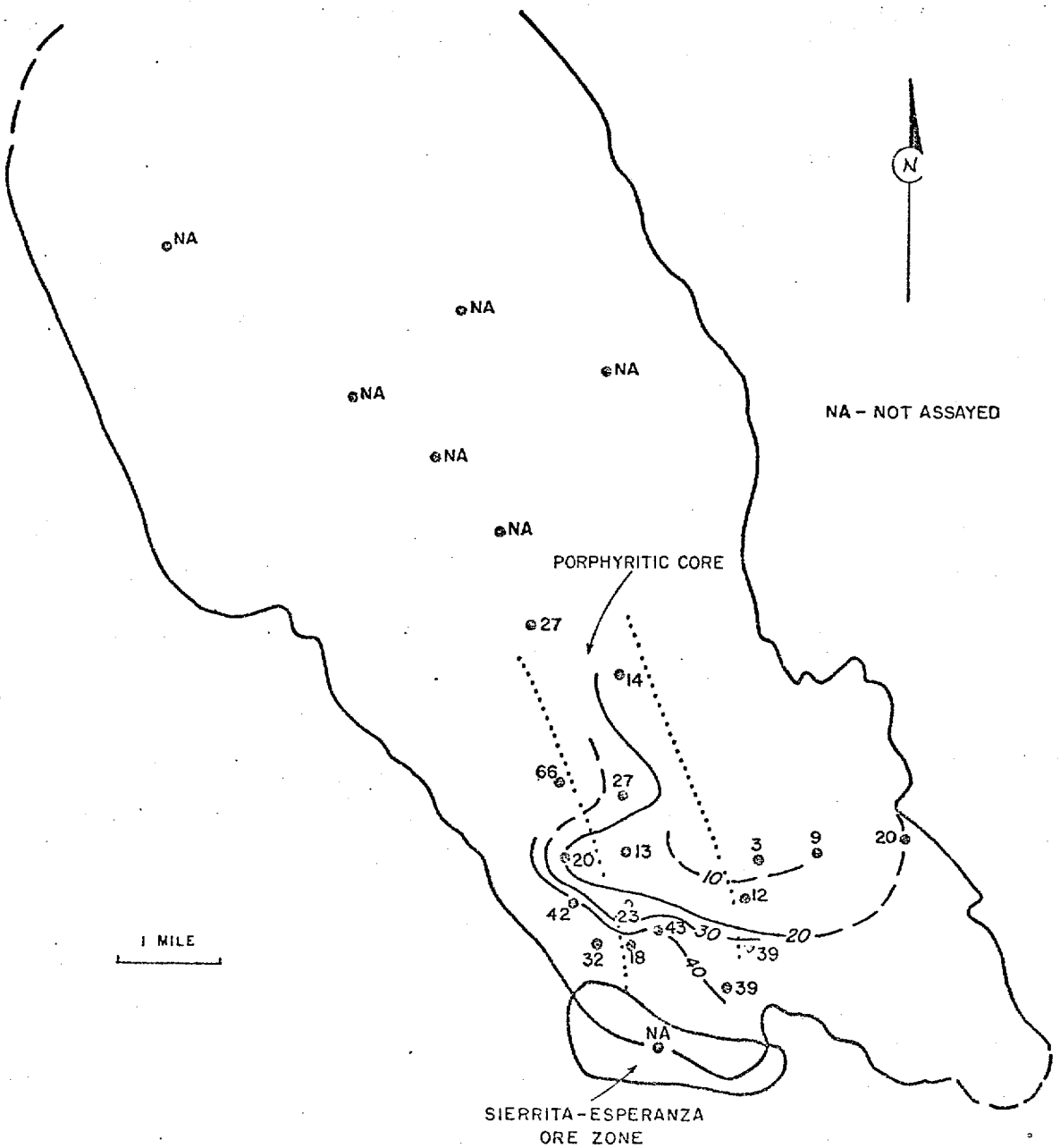


RUBY STAR GRANODIORITE
Zn IN BIOTITE
ppm Values
(Unclean)

2526-E

FROM J King

Figure I-F



RUBY STAR GRANODIORITE

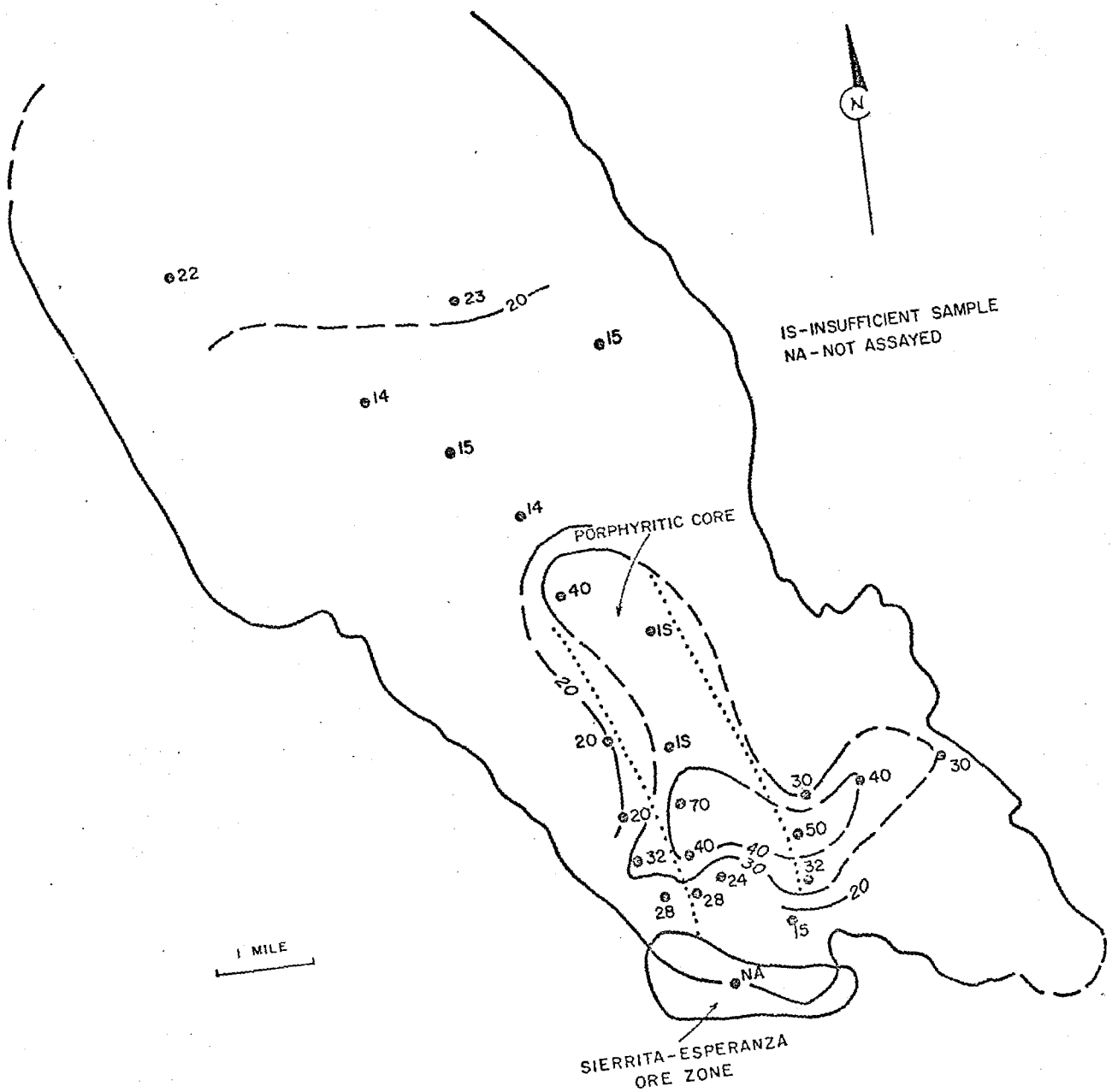
Zn IN WHOLE ROCK

ppm Values

(Unclean)

2526-f

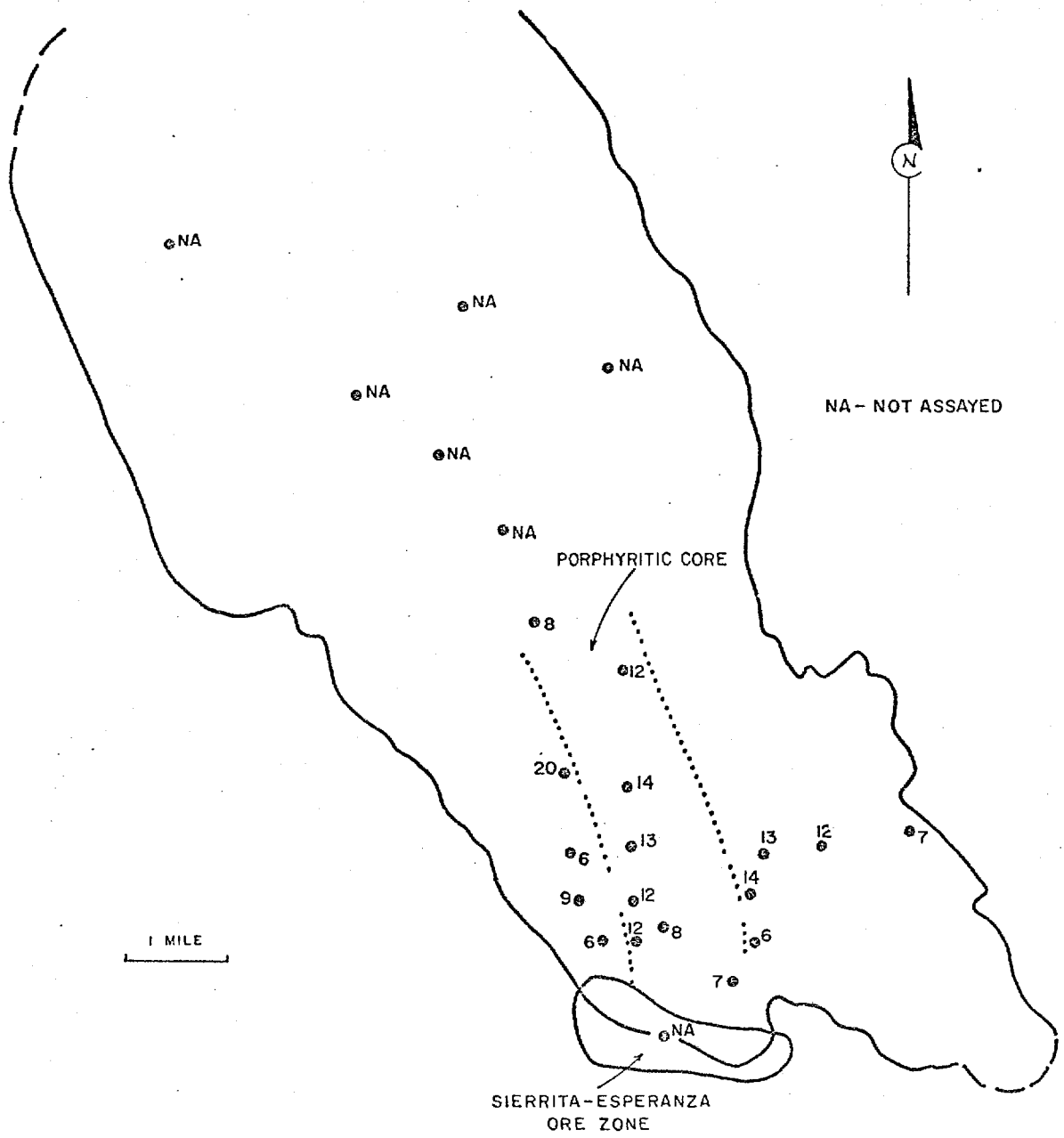
Figure 1-G



RUBY STAR GRANODIORITE
Pb IN BIOTITE
ppm Values
(Unclean)

FROM J Kuey

Figure I-H



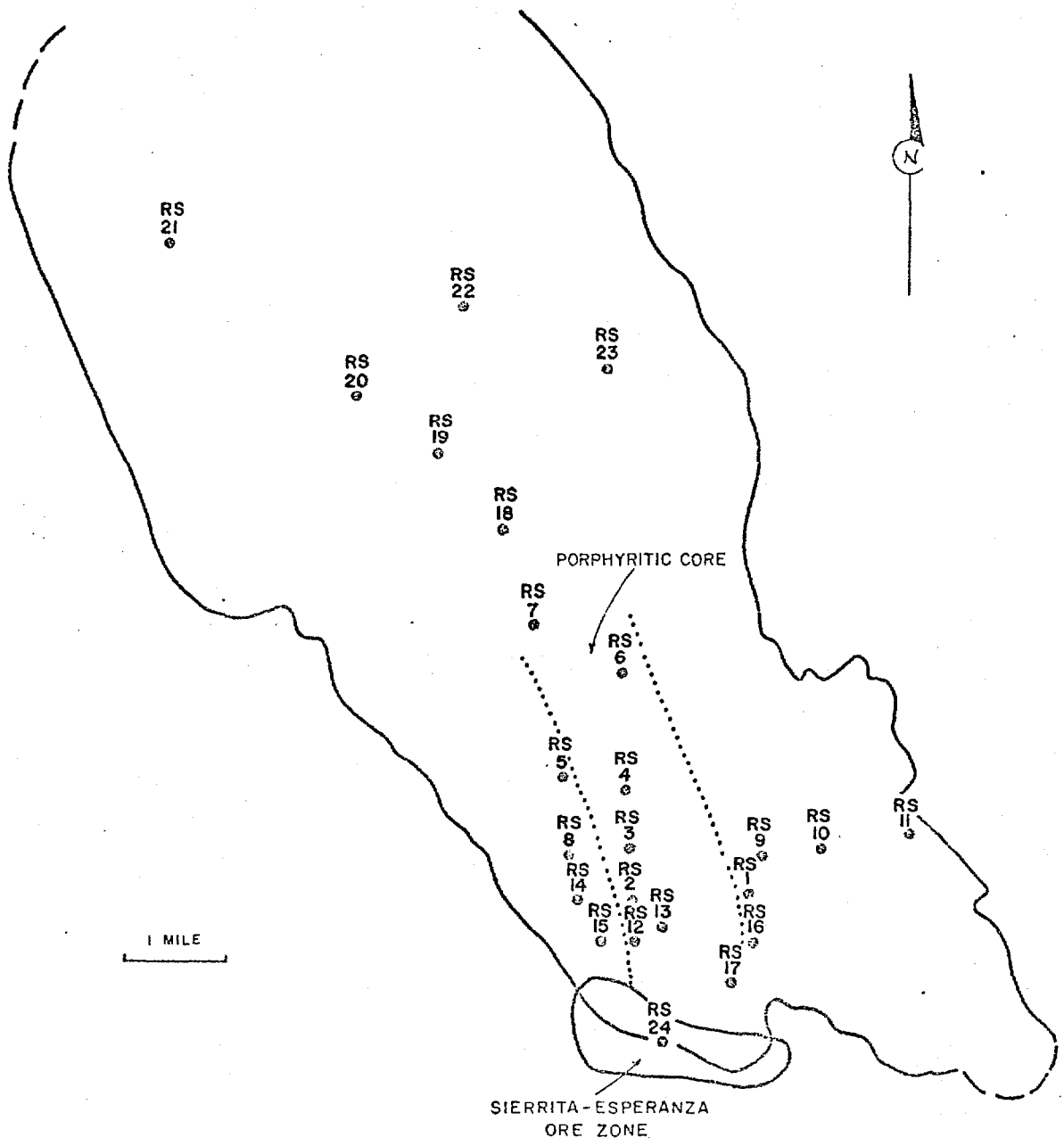
RUBY STAR GRANODIORITE

Pb IN WHOLE ROCK

ppm Values
(Unclean)

2526-h

Figure I-I



RUBY STAR GRANODIORITE

SAMPLE NUMBERS

2526-1

NOTE: UNCLEAN = less than 95% pure

TABLE 1 From JKing RUBY STAR GRANODIORITE

Sample Number	BIOTITE CONCENTRATE ppm									COMP. WHOLE ROCK ANALYSES					RATIOS Biotite / Whole rock		
	Cu			Zn		Pb		Mo		ppm				ppb		Cu / Cu	
	unclean	clean	v.clean	unclean	clean	unclean	clean	unclean	clean	Cu	Zn	Pb	Mo	Hg		unclean	clean
RS-1	530	590	NA	390	NA	50	NA	2	NA	190	12	14	6.0	158		2.8	3.1
2	450	440		430		40		5		570	23	12	9.7	130		.8	.8
3	200	180		470		70		6		74	13	12	2.4	120		2.6	2.4
4	135	230		IS		IS		IS		76	27	14	6.7	173		1.8	3.0
5	20	21		500		20		1		71	26	20	<1	182		.3	.3
6	70	180		IS		IS		IS		18	14	12	1.8	118		3.9	1.0
7	80	59		575		40		3		35	27	8	1.8	141		2.3	1.7
8	560	590		450		20		2		77	20	6	6.0	163		7.3	7.6
9	790	1350		420		30		IS		102	3	13	6.7	172		7.7	13.3
10	720	900		280		40		7		500	9	12	14.5	288		1.4	1.8
11	40	35		390		30		12		13	20	7	1.8	171		3.1	2.8
12	560	580		240		28		1.4		260	18	12	.6	NA		2.1	2.2
13	1460	1530		340		24		6		1310	43	8	38.0			1.1	1.6
14	1180	1200		400		32		2.8		610	42	9	10.0			1.0	1.0
15	1040	1070		280		28		1.8		420	32	6	1.2			2.5	2.5
16	1290	1270		250		32		8.8		1450	39	6	28.6			.9	.9
17	1000	1030		300		32		5.6		880	39	7	52.0			1.1	1.2

TABLE 1 RUBY STAR GRANODIORITE

Sample Number	BIOTITE CONCENTRATE ppm									COMP. WHOLE ROCK ANALYSES					RATIOS Biotite / Whole rock		
	Cu			Zn		Pb		Mo		ppm				ppb		Cu / Cu	
	unclean	clean	v.clean	unclean	clean	unclean	clean	unclean	clean	Cu	Zn	Pb	Mo	Hg		unclean	clean
RS-18	40	16	15	NA	540	NA	15	NA	<1	22	NA	NA	NA	NA		NS	.7
19	80	21	20		545		14		<1	12							1.7
20	120	60	60		670		15		<1	14							4.2
21	360	200	225		650		22		<1	40							5.6
22	40	24	23		535		23		<1	8							2.9
23	20	23	20		540		15		<1	8							2.5
24	NA	680	260		NA		NA		NA	1880							.14

TAB

Schultze

W. L. Kurtz January 28, 1972

SCHULTZE GRANITE

The Schultze granite is a homogeneous coarse-grained quartz monzonite. Small bodies of granite porphyry were intruded along the northern edge and are the only mappable exceptions to the homogeneity of the Schultze granite. Major ore bodies (Castle Dome and Miami-Inspiration) are located at or near the northern edge of the Schultze pluton.

The Schultze granite was chosen for biotite sampling following the preliminary analytical results on the Ruby Star stock. The original plans called for testing of other parameters such as sample density and ore potential of the western edge, in addition to verifying any copper in biotite anomaly associated with the already known porphyry copper deposits.

Initial results on the first ten samples along with Clarey's and Graybeal's thesis work were collectively interpreted to indicate that copper concentration in biotite increased towards the western and northern edges of the Schultze (L. D. James, May 19, 1971). Further sampling on closer spaced centers did not change the initial interpretation (L. D. James, July 14, 1971). It was then learned that all of the analyses were made on concentrates that were at best 95% pure biotite (shown as "unclean", Table 2). Contaminants were magnetite, quartz, feldspar dust, sulfides and trap iron. All samples were then recleaned by magnetic and heavy liquid separation to a greater than 98% purity and re-analyzed (shown as "clean", Table 2). The results showed that in over 80% of the samples, the Cu in biotite values decreased on an average of 40%.

Sample SG-DH-30 is from a porphyritic quartz monzonite block encountered in the Superior East drill hole M-1 at a depth of approximately 2930 feet. This sample was composited from split core over a distance of 20 feet.

with present drill data, this analyses indicates the potential of the geologic drill FTG

The copper values for "clean" biotite concentrates are shown on Figure 2-A, and, as can be seen, there are no interpretable patterns of copper distribution. Two possible areas of high values, one along the western edge and the other near the north edge of the Schultze granite, were detected; however, since contouring does not give meaningful patterns, the significance of the high values are not known. Current thought is that the lack of systematic variations of copper in biotite may be due to the present level of deep erosion of the Schultze granite. Although this assumption lacks proof, it requires only simple logic to postulate that deep erosion into a homogeneous coarse-grained intrusive far below any loci of ore deposition would give erratic, non-contourable results. The presence of numerous faults (flat and otherwise) emphasize the possibility that the Miami-Inspiration ore bodies may have moved to their present position.

it is now!! FTG

[illegible]

The copper content of the whole rock samples are given on Figure 2-B. Several high values are shown on the western edge of the Schultze granite, but again contouring does not give any interpretable patterns.

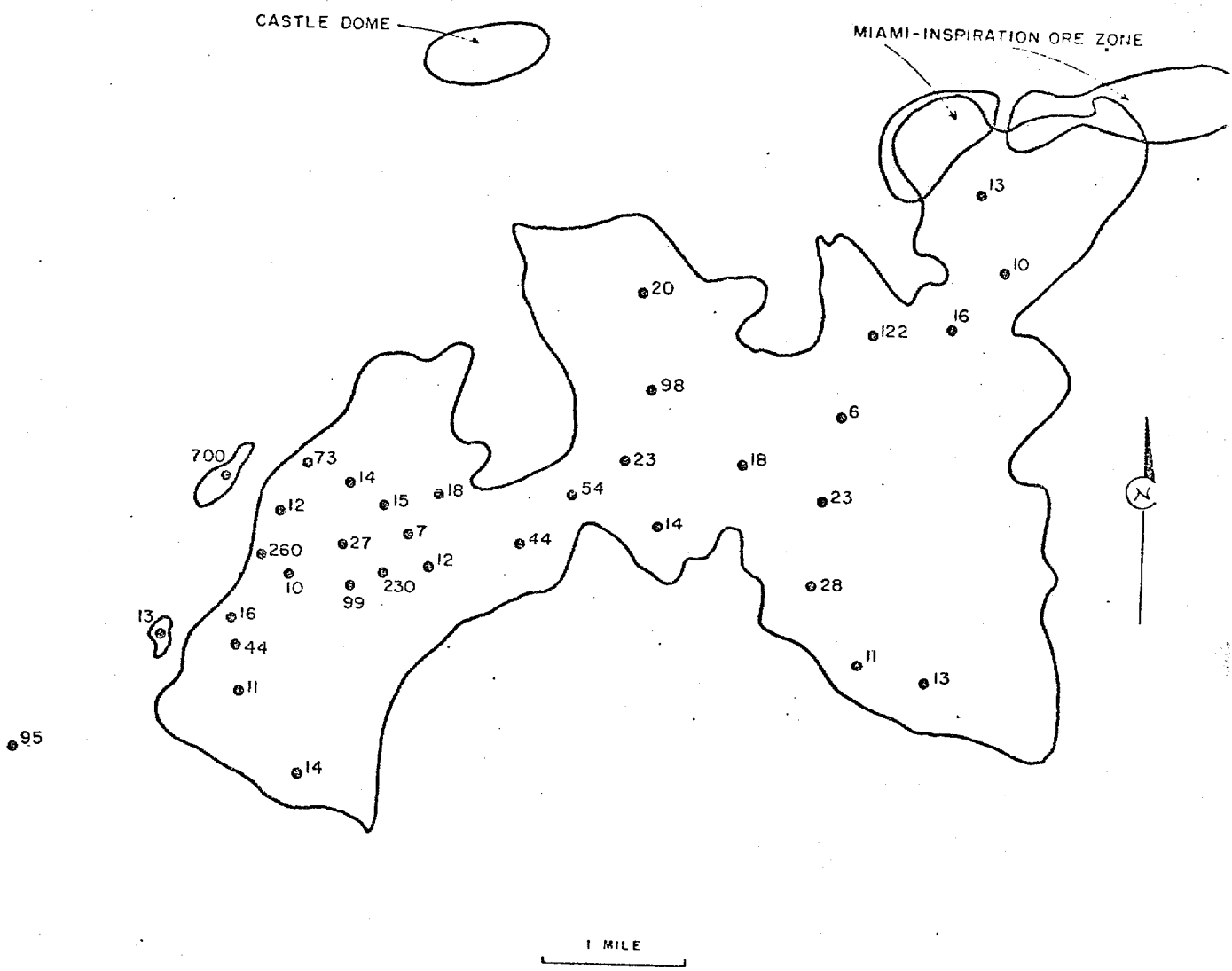
The ratios of copper in biotite versus copper in whole rock are shown on Figure 2-C. The ratios are erratic and do not demonstrate any systematic variation.

Lead, zinc, fluorine and molybdenum values for both biotites and whole rock samples are listed on Table 2, but are not shown on the figures. The results are incomplete, and the data presently available shows erratic distributional patterns that are uninterpretable. It should be noted that the lead, zinc, fluorine, and molybdenum analyses were made from samples that were less than 95% pure biotite. This lack of purity has been demonstrated both in the Ruby Star samples and in the Schultze granite samples to be extremely important for copper and molybdenum. It logically follows that lead, zinc and fluorine should also require a high degree of biotite purity if meaningful data is to be obtained. Further analyses are needed on the biotite and whole rock samples to complete the picture. Figure 2-D shows the sample numbers.

To summarize, the sampling of the Schultze granite indicates that greater than 98% biotite purity must be achieved before proper interpretation can be made and that detailed sampling is unnecessary. The Miami-Inspiration and Castle Dome ore bodies do not show a copper in biotite halo as does the Sierrita ore body in the Ruby Star granodiorite. The lack of anomaly is felt to be the result of deep erosion into the Schultze pluton and the presence of numerous flat faults.

From J King

Figure 2-A

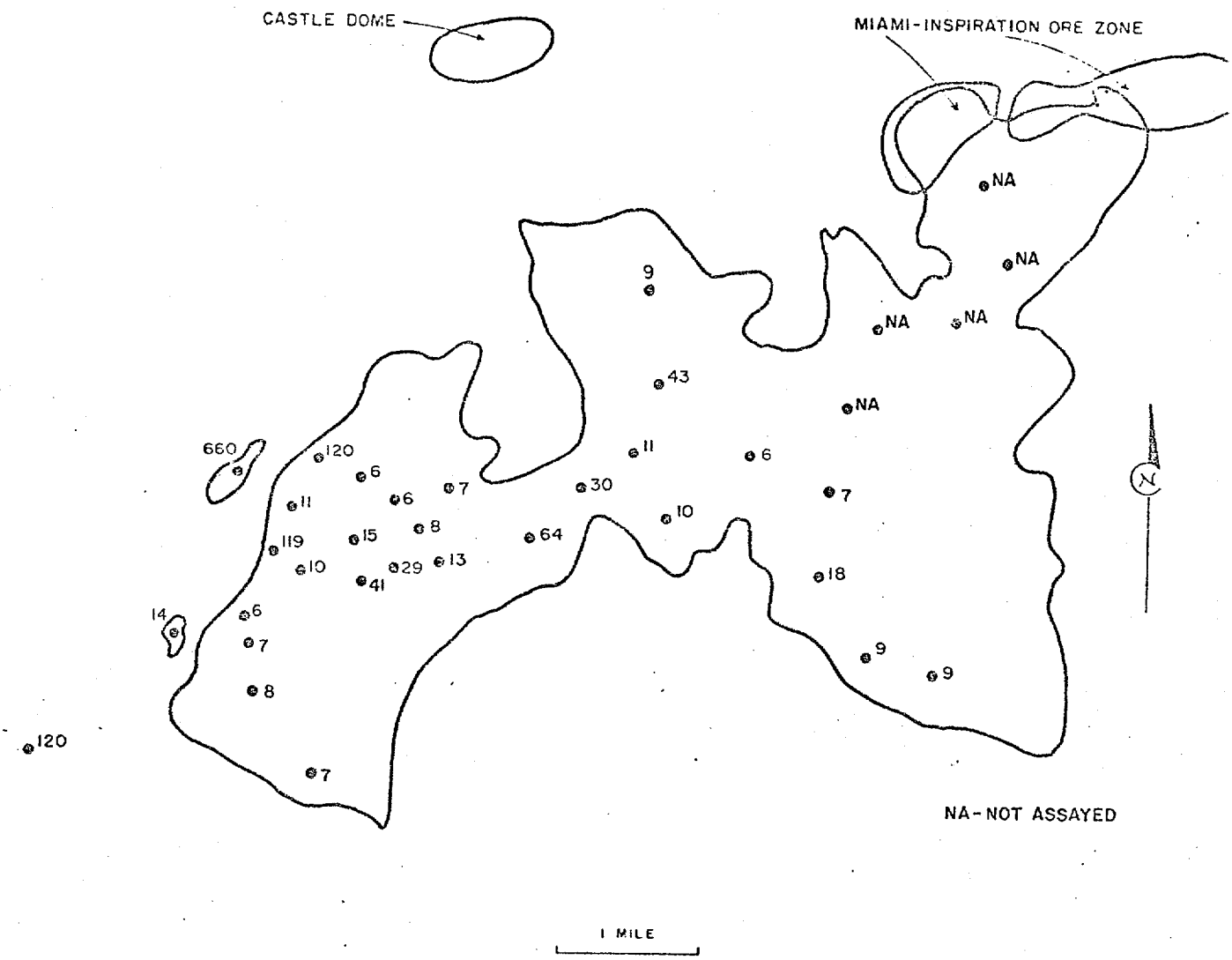


SCHULTZE GRANITE
COPPER IN BIOTITE
ppm Values
(Clean)

2527-a

From JKing

Figure 2-B

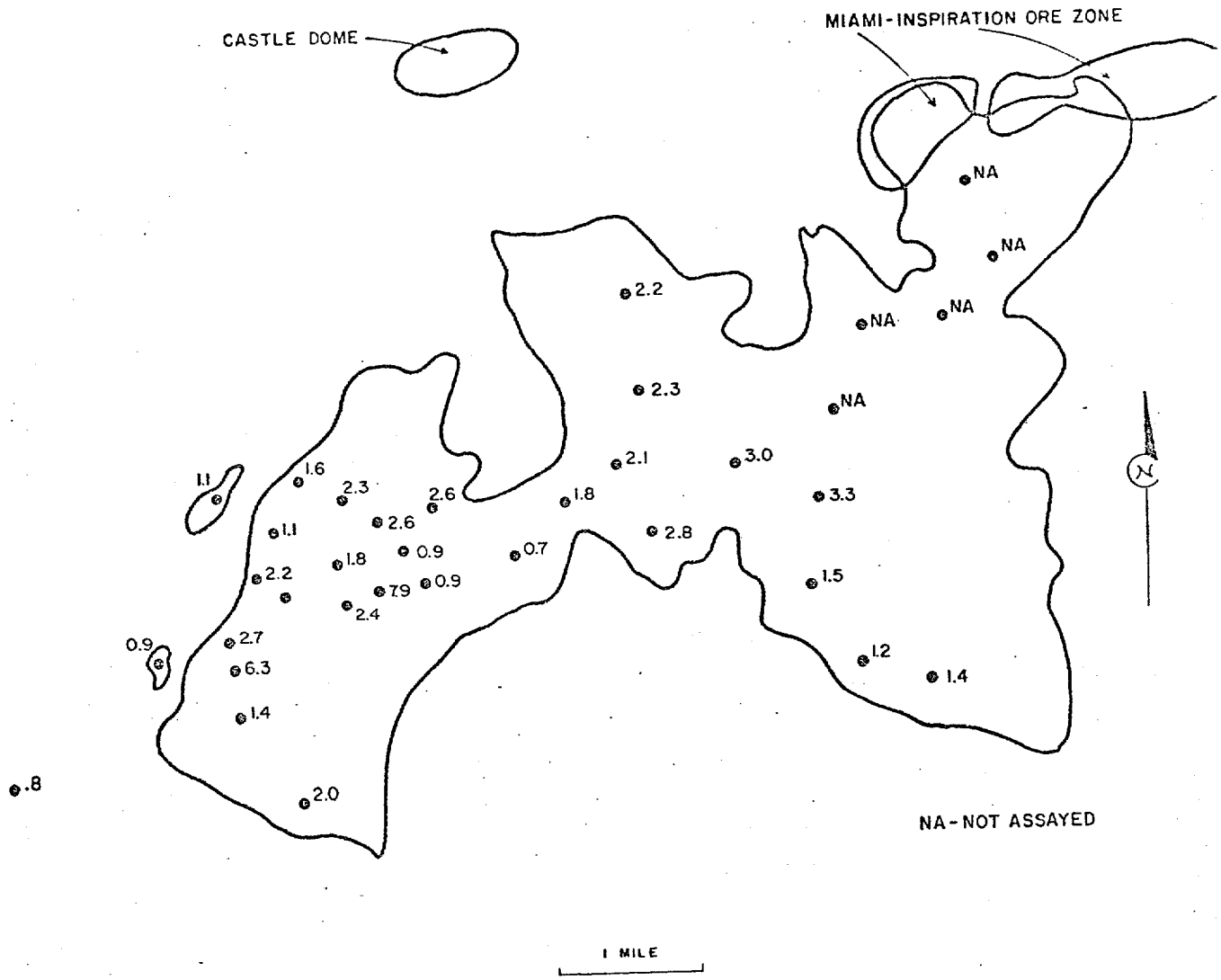


SCHULTZE GRANITE
COPPER IN WHOLE ROCK
ppm Values

2527-b

FROM J King

Figure 2-C



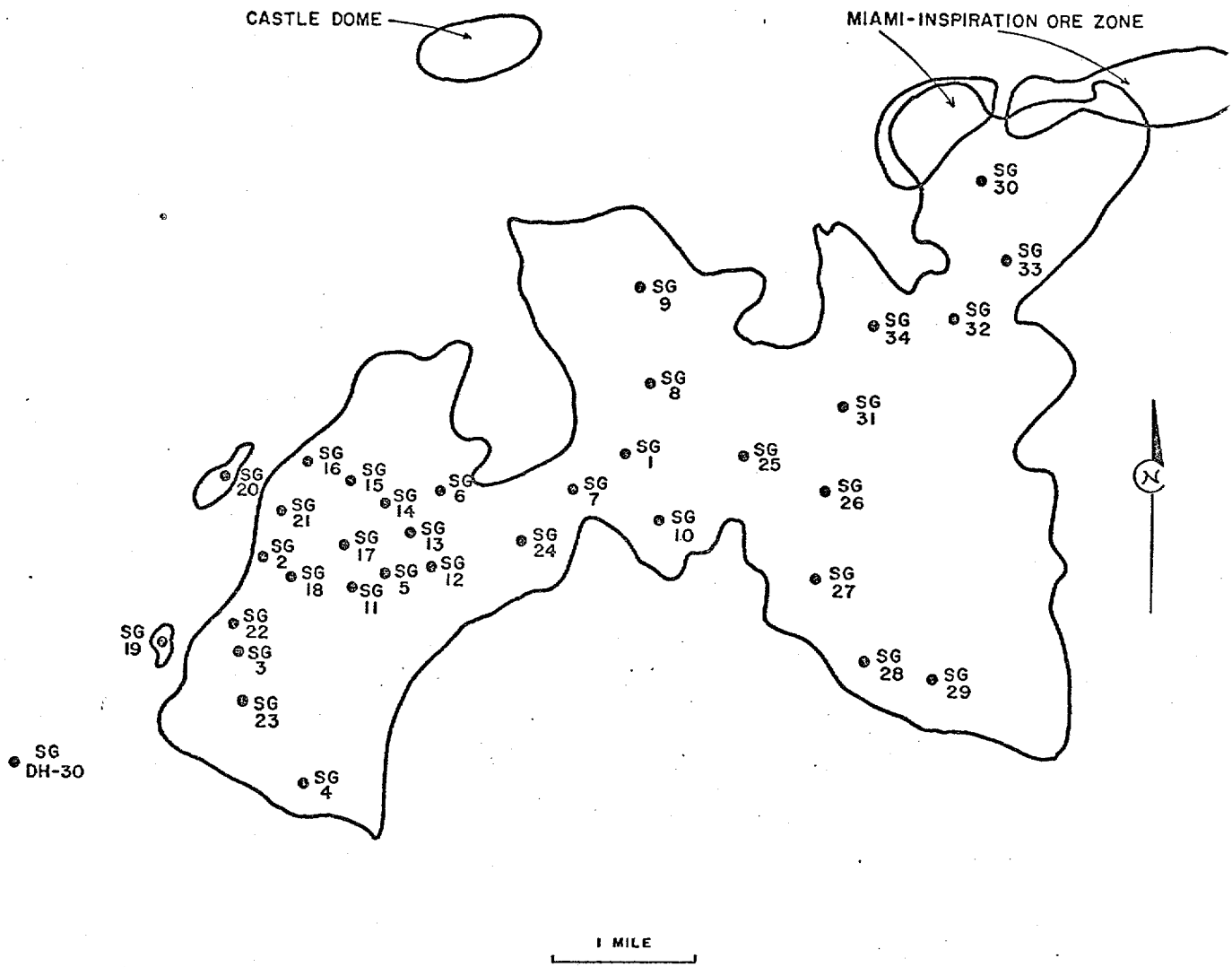
SCHULTZE GRANITE

COPPER – $\frac{\text{biotite (clean)}}{\text{whole rock}}$

2527-c

From J Kiney

Figure 2-D



SCHULTZE GRANITE

SAMPLE NUMBERS

2527-d

UNCLEAN = Less than 95% Pure

TABLE 2 FROM JKing SCHULTZE GRANITE

Sample Number	BIOTITE CONCENTRATE ppm										WHOLE ROCK ANALYSES ppm					RATIOS Biotite/Whole rock		
	Cu		Zn		Pb		Mo		Fl %		Cu	Zn	Pb	Mo	% Fl	Cu/Cu	Cu/Cu	
	unclean	clean	unclean	clean	unclean	clean	unclean	clean	unclean	clean						unclean	clean	
SG-1	30	23	480	NA	104	NA	.6	NA	NA	NA	11	23	7	.1	NA	2.7	2.1	
2	450	260	480		32		1.2				119	29	13	.1		3.8	2.2	
3	81	44	590		28		2.0				7	33	15	.1		11.6	6.3	
4	12	14	410		32		.1				7	26	10	<.1		1.7	2.0	
5	112	230	510		32		.1				29	27	11	.2		3.9	7.9	
6	18	18	620		292		.4				7	29	10	.1		2.6	2.6	
7	123	54	230		44		1.8				30	17	7	.2		4.1	1.8	
8	81	98	550		32		.8				43	47	16	.1		1.8	2.3	
9	82	20	550		16		3.2				9	25	11	.4		9.1	2.2	
10	21	14	570		32		.8				5	22	9	.2		4.2	2.8	
11	132	99	500		NA		2.2		2.14		41	28	NA	.4	.380	3.2	2.4	
12	41	12	440				3.4		1.98		13	44		.2	.480	3.1	.9	
13	23	7	500				1.6		2.14		8	28		.2	.400	2.9	.9	
14	34	15	500				3.6		1.70		6	30		.2	.480	5.6	2.6	
15	14	14	560				.8		1.84		6	28		.3	.510	2.3	2.3	
16	120	73	400				3.3		1.98		120	28		.2	.540	1.0	1.6	
17	27	27	820				.9		1.84		15	50		.2	.270	1.7	1.8	

TABLE 2 SCHULTZE GRANITE

Sample Number	BIOTITE CONCENTRATE ppm										WHOLE ROCK ANALYSES ppm					RATIOS Biotite/Whole rock		
	Cu		Zn		Pb		Mo		Fl %		Cu	Zn	Pb	Mo	% Fl	Cu/Cu	Cu/Cu	
	unclean	clean	unclean	clean	unclean	clean	unclean	clean	unclean	clean						unclean	clean	
SG-18	22	10	800	NA	NA	NA	1.4	NA	1.70	NA	10	44	NA	.3	.440	2.2	1.0	
19	28	13	680				1.4		2.14		14	92		.2	.380	2.0	.9	
20	700	700	240				1.4		2.48		660	26		.3	.400	1.1	1.1	
21	9	12	680				.6		2.48		11	26		.2	.460	.8	1.1	
22	12	16	600				.6		1.84		6	24		.4	.420	2.0	2.7	
23	32	11	540				2.4		1.98		8	32		.3	.400	4.0	1.4	
24	62	44	320				1.5		2.14		64	20		.2	.660	.9	.7	
25	16	18	400				.6		2.32		6	16		.2	.400	2.7	3.0	
26	17	23	740				1.3		1.59		7	24		.2	.360	2.4	3.3	
27	46	28	460				1.8		1.98		18	18		.2	.350	2.6	1.5	
28	20	11	266				1.4		1.98		9	16		.2	.380	2.2	1.2	
29	120	13	380				8.3		1.84		9	22		.2	.340	13.3	1.4	
SG-DH-30	620	95	180				13.3		1.84		120	24		1.0	.300	5.0	.8	
SG-30	NA	13	NA				NA		NA		NA	NA		NA	NA	NA	NA	
31		6					See following page				(			)				
32		16										-						
33		10																
34		122																

EXPLORATION SERVICES DIVISION
3422 SOUTH 700 WEST
SALT LAKE CITY, UTAH 84119

April 19, 1972

JRK
4 May

Mr. John R. King
Tucson Office

Project 517
Schultze Granite Samples

Dear Mr. King:

Transmitted herewith are the analytical determinations requested for the whole rock, Schultz granite samples submitted to the laboratory for analysis reference your letter dated March 8, 1972, on samples #SG31, 32, 33 and 34.

The samples were solubilized by first digesting the sample with hydroflouric acid for total solution and by routine atomic absorption methods for copper, lead, and zinc. Molybdenum was by a colorimetric procedure using thiocyanate on a Beckman DBG-T. All values are in ppm.

Sample No.	Elements Requested			
	Cu	Pb	Zn	Mo.
SG-31	16	18	20	1.6
32	22	16	25	1.5
33	30	16	30	2.4
34	150	18	9	2.7

Thank you.

Very truly yours,

E. H. PHILLIPS

EHP:am

TAB

THREE PEAKS

Important to state how far to Santa Cruz — approx 4 miles
I would also think sampling on N and necessary to interpret results

W. L. Kurtz January 28, 1972

Thus in this intrusion the biotite halo is less than 4 miles radius (if Santa Cruz is in place!)

THREE PEAKS STOCK

The Three Peaks stock is a multi-phase, composite intrusive that is elongated in a northeasterly direction. The three dominant phases, in order of decreasing age, are: diorite, monzonite and quartz monzonite. The southwesterly projection of the long axis of the stock extends through the Santa Cruz deposit.

The Three Peaks stock was chosen for biotite sampling in hopes of determining the importance of internal geology with respect to interpretation of analytical results. The geologic and petrographic knowledge was gained through work done by John Balla. The samples were sent to Salt Lake for crushing, biotite concentration and analyses. On the first run, the biotite concentrates were never greater than 80% pure. The concentrates were mailed back to Salt Lake for recleaning and analyses, but were lost in transit. Therefore, the analyses as listed on Table 3 are indications of approximate trends and do not qualify as fully quantitative measurements. Sample TP-19 was taken adjacent to a small altered and mineralized outcrop of quartz monzonite and is not considered to be a valid sample relative to the intrusive as a whole.

The content of the biotite, as given on Figure 3-A, shows that copper is highest in the border diorite and lowest in the central quartz monzonite. This variation may indicate a depletion of copper in the magma with progressive differentiation.

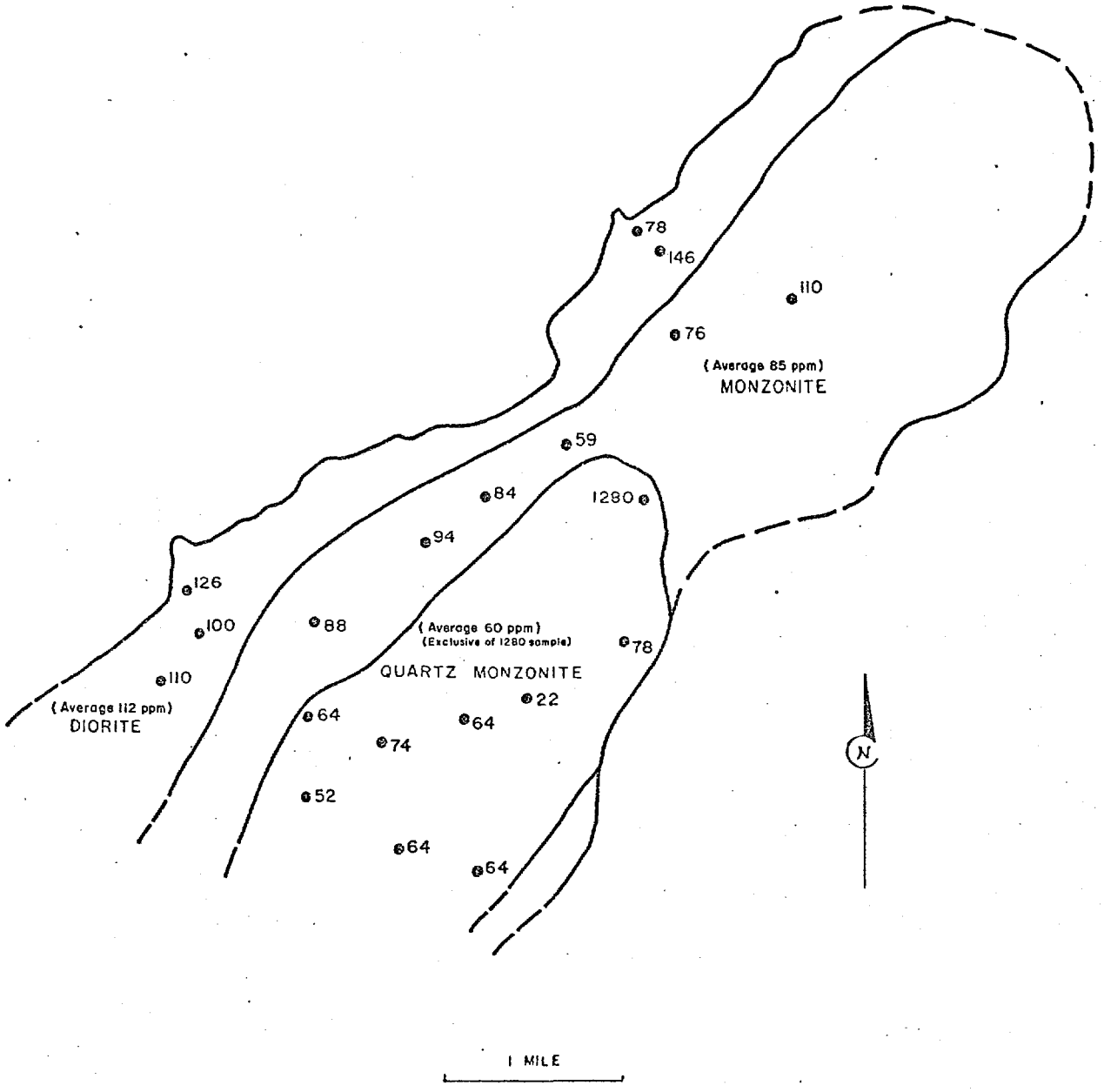
Figure 3-B shows the copper content of composite whole rock samples. Again, the quartz monzonite core is depleted in copper relative to the border diorite. This trend may in part be related to the higher biotite content of the diorite (10-15%) as compared to the quartz monzonite (2-8%). However, I suspect that the variation may also be reflecting the slight copper impoverishment of the core phase.

The ratios of copper in biotite versus copper in whole rock are plotted on Figure 3-C. The ratios are highest in the monzonitic phases. The interpretation of this trend is ambiguous; however, in the absence of any other information, the higher ratios of the core phases might be considered a favorable indication of ore association.

The zinc content of the biotite samples is shown on Figure 3-D. Zinc increases progressively into the core phase. The zinc content of whole rock samples (Figure 3-E) slightly decreases towards the center of the stock and this trend is felt to be reflecting the lower biotite content of the monzonitic phases. The ratios of zinc in biotite to zinc in whole rock (see Figure 3-E) show, as in the case of copper, higher ratios in the core phases. In the case of zinc, however, the greater values of zinc in biotite are associated with the larger ratios. It is this trend that, in case of copper, is known to be indicative of favorable mineralization. Lead and molybdenum do not show a meaningful or interpretable distribution and as such the analyses are only listed in Table 3. The sample numbers are plotted on Figure 3-G.

Even though the biotite analyses are not quantitatively applicable, the available data on the Three Peaks stock suggest that the copper and possibly the zinc content of biotite can be used as indicators of mineralization. Also emphasized by this work is the importance of understanding the internal geology of the stock before correct interpretation of the biotite analyses can be made. The correct interpretation is perhaps yet to be made!

Figure 3-A



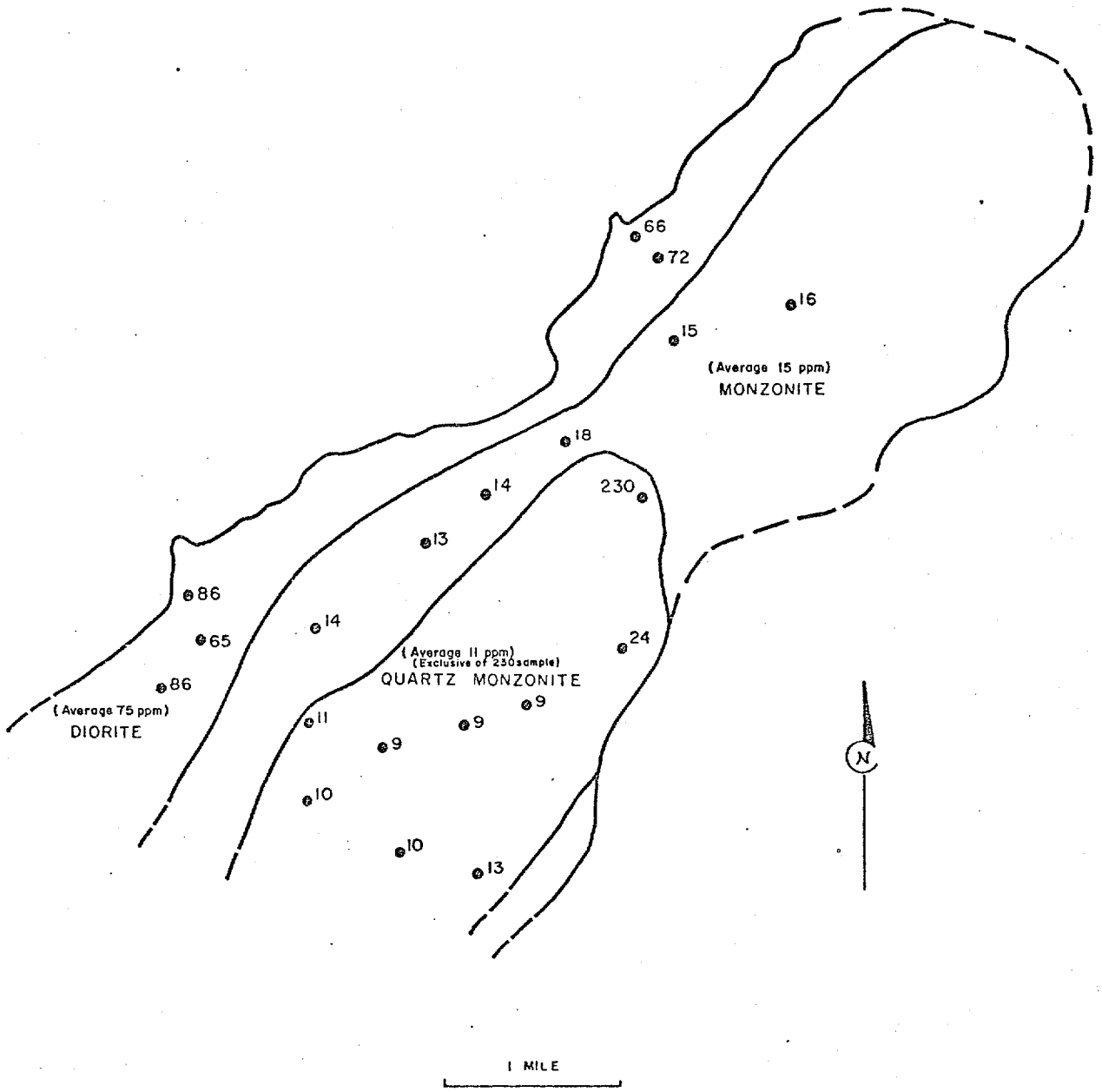
THREE PEAKS STOCK

Cu IN BIOTITE (COMPOSITE)

ppm VALUES

2528-a

Figure 3-B



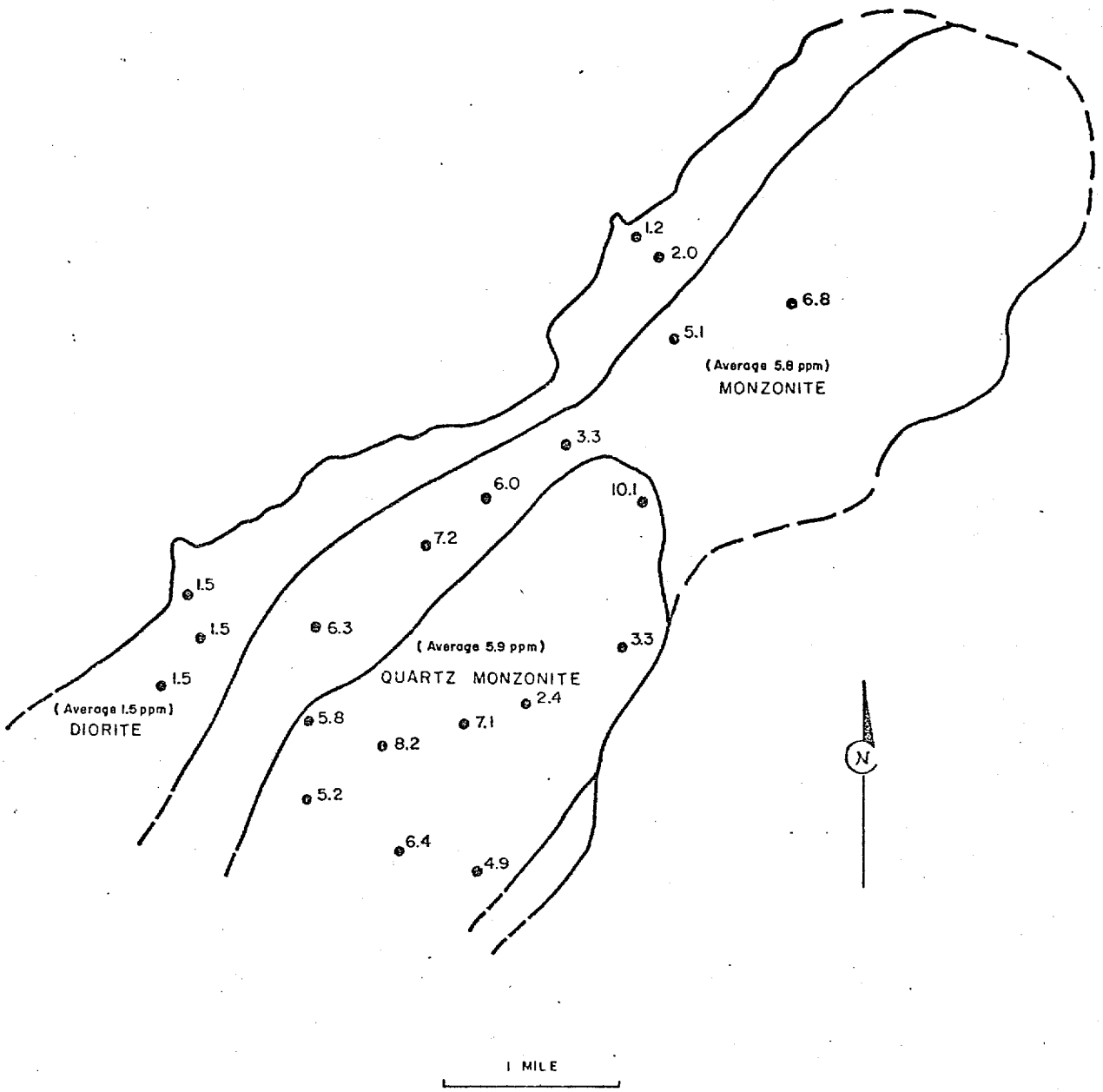
THREE PEAKS STOCK

Cu IN WHOLE ROCK (COMPOSITE)

ppm VALUES

2528-b

Figure 3-C



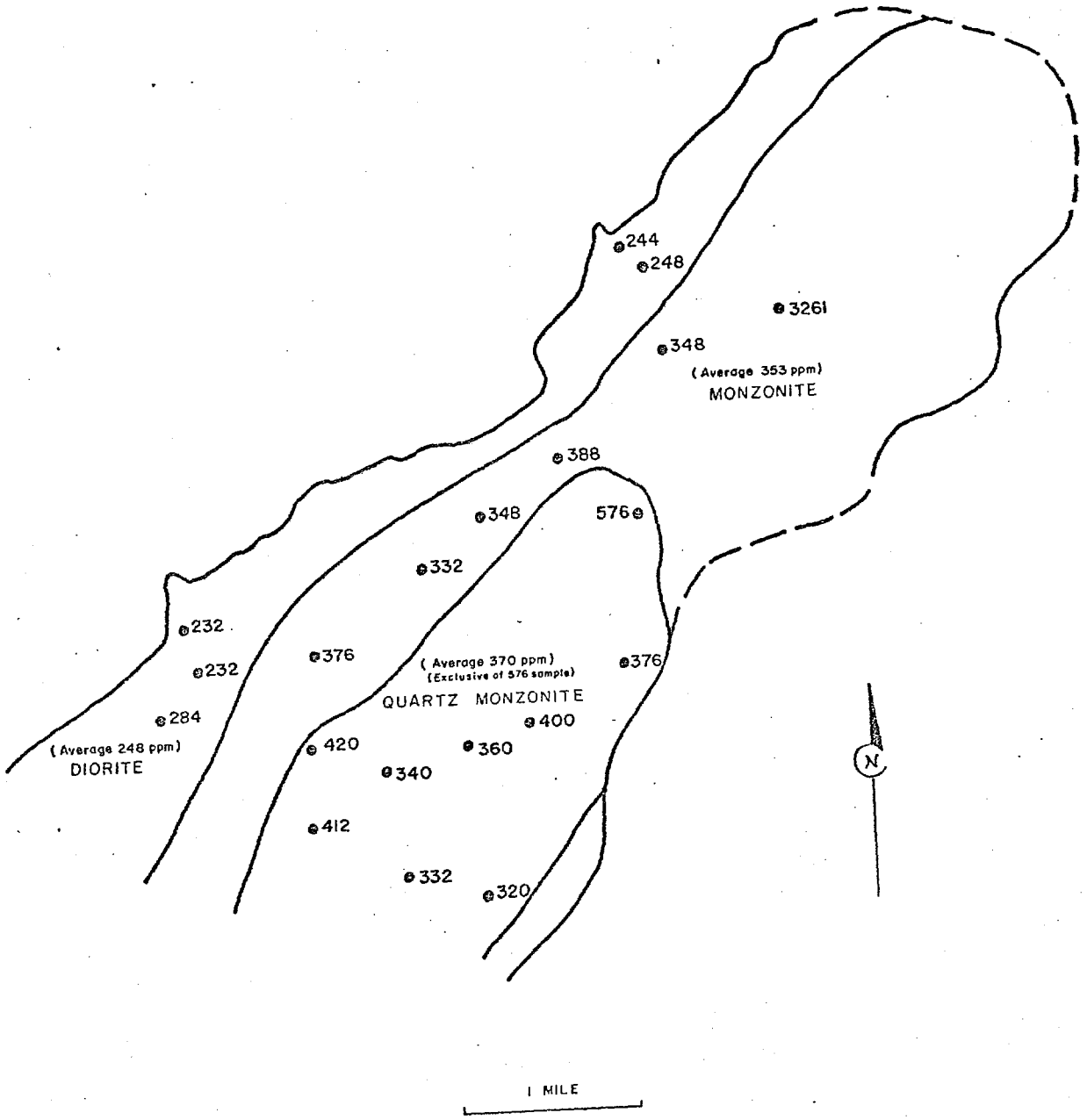
THREE PEAKS STOCK

$$Cu - \frac{\text{composite biotite}}{\text{composite whole rock}}$$

2528-c

FROM JKing

Figure 3-D

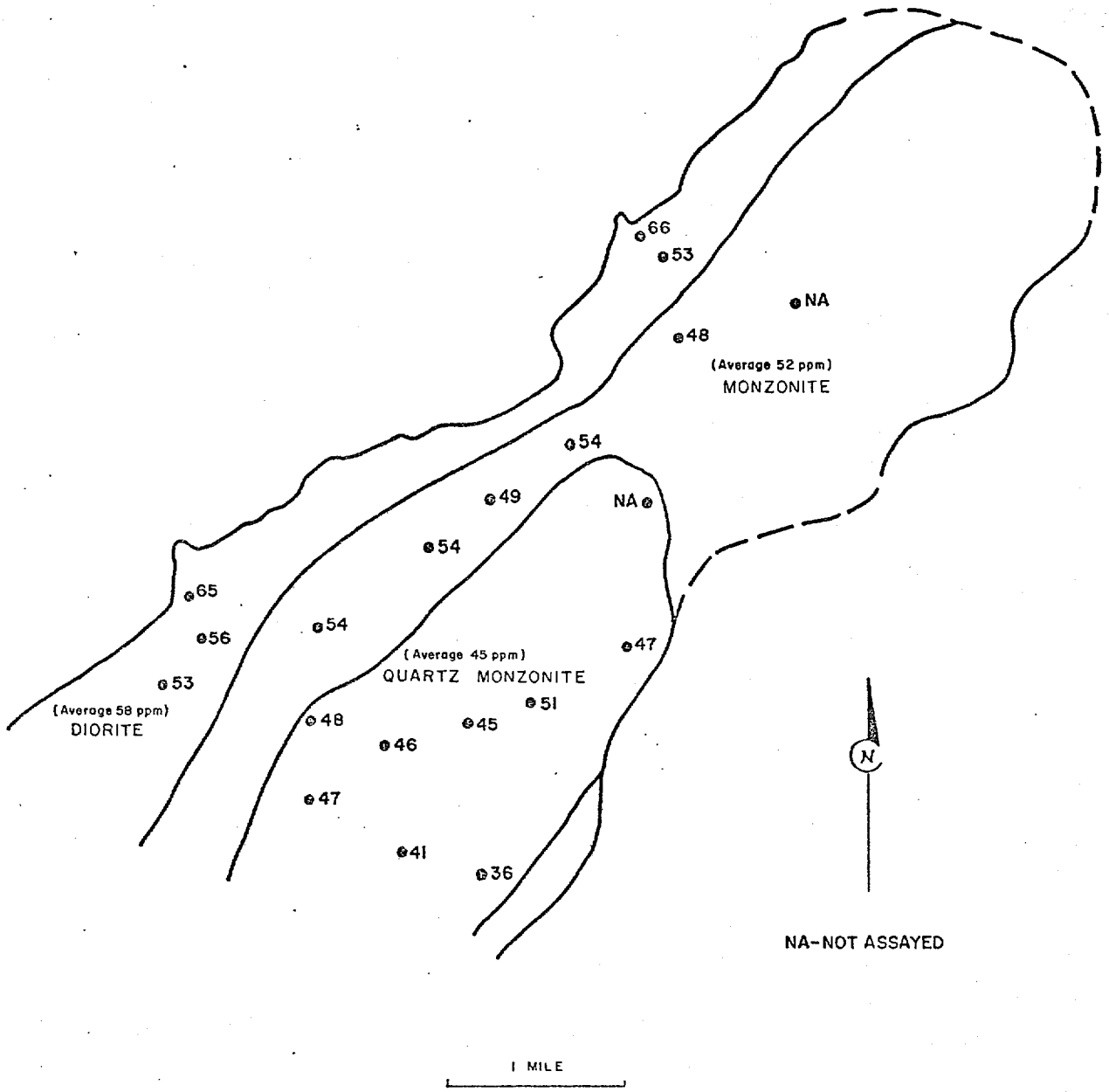


THREE PEAKS STOCK
Zn IN BIOTITE (COMPOSITE)
ppm VALUES

2528-d

FROM J King

Figure 3-E



THREE PEAKS STOCK

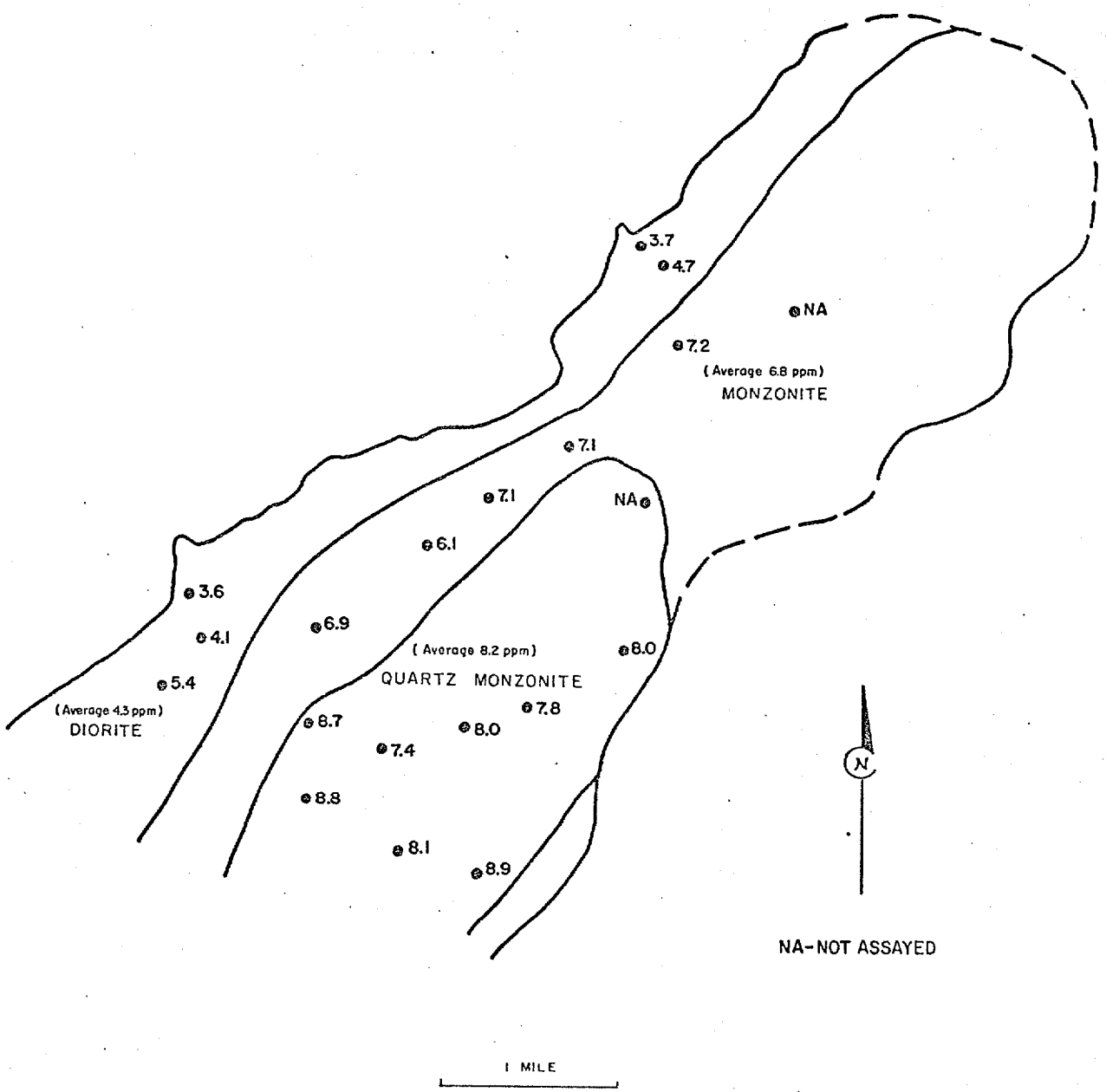
Zn IN WHOLE ROCK (COMPOSITE)

ppm VALUES

2528-e

FROM JKing

Figure 3-F



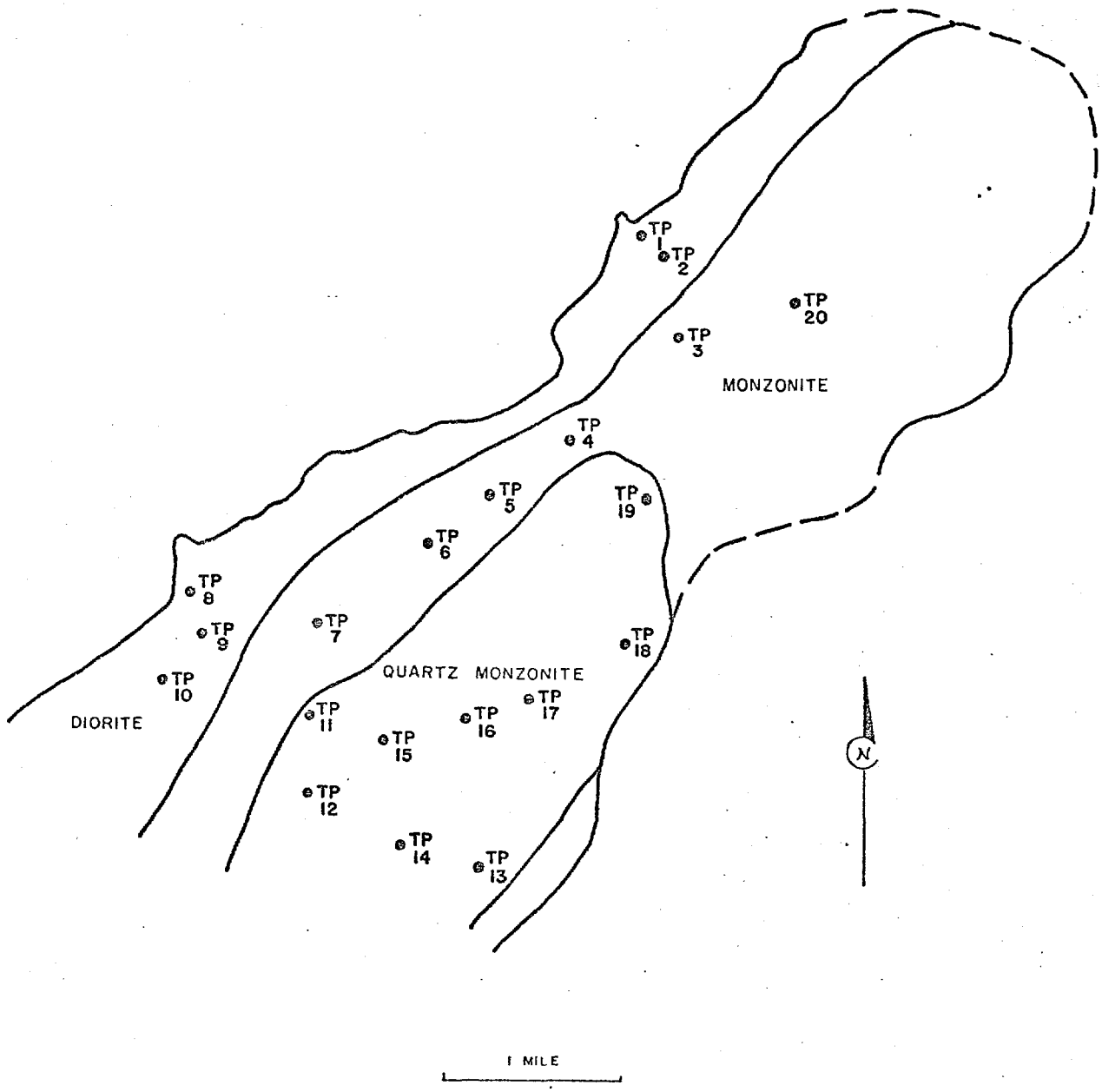
THREE PEAKS STOCK

$$Zn - \frac{\text{composite biotite}}{\text{composite whole rock}}$$

2528-h

From JKing

Figure 3-G



THREE PEAKS STOCK

SAMPLE NUMBERS

2528-g

~~UNCLEAN = less than 95% pure~~

TABLE 3 From J Kim **THREE PEAKS STOCK**

Sample Number	BIOTITE CONCENTRATES ppm						WHOLE ROCK ppm								RATIOS	
	From composite sample			One hand sample			Composite rock sample				Single rock sample				Biotite comp. / Whole rock	Biotite comp. / Whole rock
	Cu	Zn	Mo	Cu	Zn	Mo	Cu	Pb	Zn	Mo	Cu	Pb	Zn	Mo	Cu	Zn
TP- 1	78	244	2.4	44	244	3.2	66	5	66	.1	11	12	59	.4	1.2	3.7
2	146	248	1.6	170	252	2.4	72	4	53	.1	57	16	53	.5	2.0	4.7
3	76	348	2.4	94	352	2.4	15	5	48	.15	12	14	55	.5	5.1	7.2
4	59	388	1.6	50	364	2.4	18	5	54	.05	9	13	47	.4	3.3	7.1
5	84	348	1.6	74	360	2.4	14	7	49	.1	13	14	45	.3	6.0	7.1
6	94	332	1.6	82	360	1.6	13	5	54	.1	12	13	55	.3	7.2	6.1
7	88	376	2.4	74	392	2.4	14	4	54	.1	12	13	51	.3	6.3	6.9
8	126	232	2.4	82	252	2.4	86	6	65	.1	35	15	60	.3	1.5	3.6
9	100	232	2.4	84	256	2.4	65	13	56	.2	39	18	56	.4	1.5	4.1
10	110	284	1.6	120	280	2.4	86	12	53	.1	55	15	53	.3	1.3	5.4
11	64	420	2.4	20	508	3.2	11	7	48	.2	11	16	46	.2	5.8	8.7
12	52	412	2.4	112	368	2.4	10	7	47	.1	11	14	48	.2	5.2	8.8
13	64	320	1.6	56	352	1.6	13	3	36	.1	13	13	35	.2	4.9	8.9
14	64	332	2.4	50	364	1.6	10	3	41	.1	10	12	38	.2	6.4	8.1
15	74	340	1.6	72	368	1.6	9	9	46	.1	9	13	43	.2	8.2	7.4
16	64	360	1.2	80	352	2.4	9	5	45	.1	10	14	45	.2	7.1	8.0
17	22	400	2.4	36	380	2.4	9	14	51	.4	8	11	33	.3	2.4	7.8

TABLE 3 THREE PEAKS STOCK

Sample Number	BIOTITE CONCENTRATES ppm						WHOLE ROCK ppm								RATIOS	
	From composite sample			One hand sample			Composite rock sample				Single rock sample				Biotite comp. / Whole rock	Biotite comp. / Whole rock
	Cu	Zn	Mo	Cu	Zn	Mo	Cu	Pb	Zn	Mo	Cu	Pb	Zn	Mo	Cu	Zn
TP-18	78	376	1.6	32	424	2.4	24	22	47	.4	15	13	48	.2	3.3	8
19	1280	576	39.2	2100	456	43.6	230	NA	NA	NA	460	NA	NA	NA	10.1	NS
20	110	324	2.4	82	332	2.4	16	NA	NA	NA	16	NA	NA	NA	6.9	NS

TAB

Tyrone

W. L. Kurtz January 28, 1972

TYRONE QUARTZ MONZONITE

The Tyrone quartz monzonite is an elongate stock or laccolith that has a porphyritic core running parallel to the long axis of the intrusion. The Tyrone ore body is located near the northeastern end of the intrusion in a zone of strong shearing.

The Tyrone stock was chosen for biotite sampling in hopes of statistically establishing the applicability of "copper in biotite" to porphyry copper exploration. Twenty-three samples were collected and sent for biotite concentration at the CSMRI. Salt Lake analyzed, recleaned and re-analyzed the biotie concentrates. Sample number TY-17 did not have sufficient material left after initial analysis and recleaning for final analysis. From averaging the percent change in values of all the samples due to re-cleaning, I estimate that TY-17 would have a copper value of 1800 ppm and a ratio to whole rock copper value of 6.5. Sample TY-5 is from a premineral monzonite dike located within 100 feet of sample TY-6 and is not plotted on the figures.

The copper content of biotite from "clean" concentrates is shown on Figure 4-A. A strong, well-defined anomaly of greater than 100 ppm copper extends from two to over three miles from the Tyrone ore zone. This copper in biotite halo is developed from one to two miles beyond the limits of visible hydrothermal alteration. The anomaly tends to follow the porphyritic core ← determined by hand specimen study only FTG which may be an indication of a close genetic relation between the porphyry and Tyrone mineralization.

The composite whole rock copper content is given on Figure 4-B and a moderate anomaly is indicated near the southeast side of the pluton. This anomaly extends for only two miles beyond the Tyrone ore zone; however, it neither delineates the ore zone nor serves as an obvious pathfinder to the ore zone. Analyses on single rock samples (see Table 4) are significantly smaller than the composite samples by an average factor of 5.

The ratios of copper in biotite versus copper in whole rock are plotted on Figure 4-C. The ratios increase towards the ore zone and again are strongly associated with the porphyry core. As in the case of copper in biotite, the anomalous ratios extend from one to two miles beyond any visible hydrothermal alteration and provide an accurate guide pointing directly toward the ore zone.

The lead and zinc values of "unclean" biotite concentrates are given on Figures 4-D and 4-E respectively. Lead shows a weak but discernible increase ← not established in 4D-contouring is subjective FTG in value towards the ore zone. The 100 ppm lead contour delineates an anomaly that extends over 2.5 miles from the ore zone. Zinc shows a very rough depletion in ppm values as the ore zone is approached which is the same trend as seen in the Ruby Star. Molybdenite values for biotite are listed on Table 4 and do not show any distributional patterns. The whole rock samples were not analyzed for lead, zinc, and molybdenum. Figure 4-F shows the sample numbers.

"exists" not "extends"

To summarize, the data from the Tyrone quartz monzonite re-establishes and further delineates the positive application copper in biotite analyses may have in a successful porphyritic copper exploration program. The copper in biotite halo is developed at distances ranging from two to over three miles from the Tyrone ore zone and from one to two miles beyond the limits of alteration and/or whole rock anomaly.

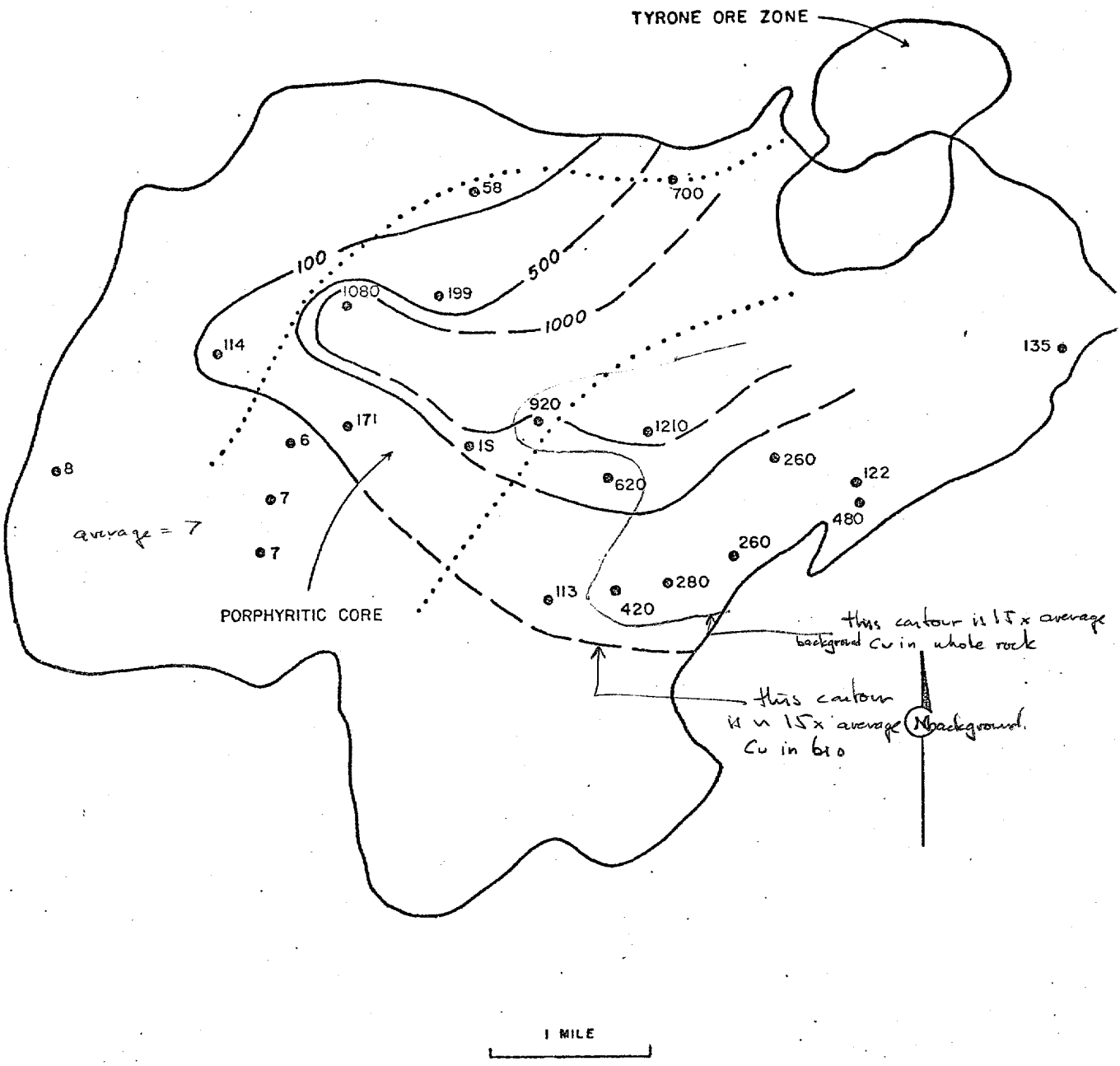
John R. King

John R. King

JRK:sg
attach.

cc: LDJames
FTGraybeal
FILE

Figure 4-A



TYRONE QUARTZ MONZONITE

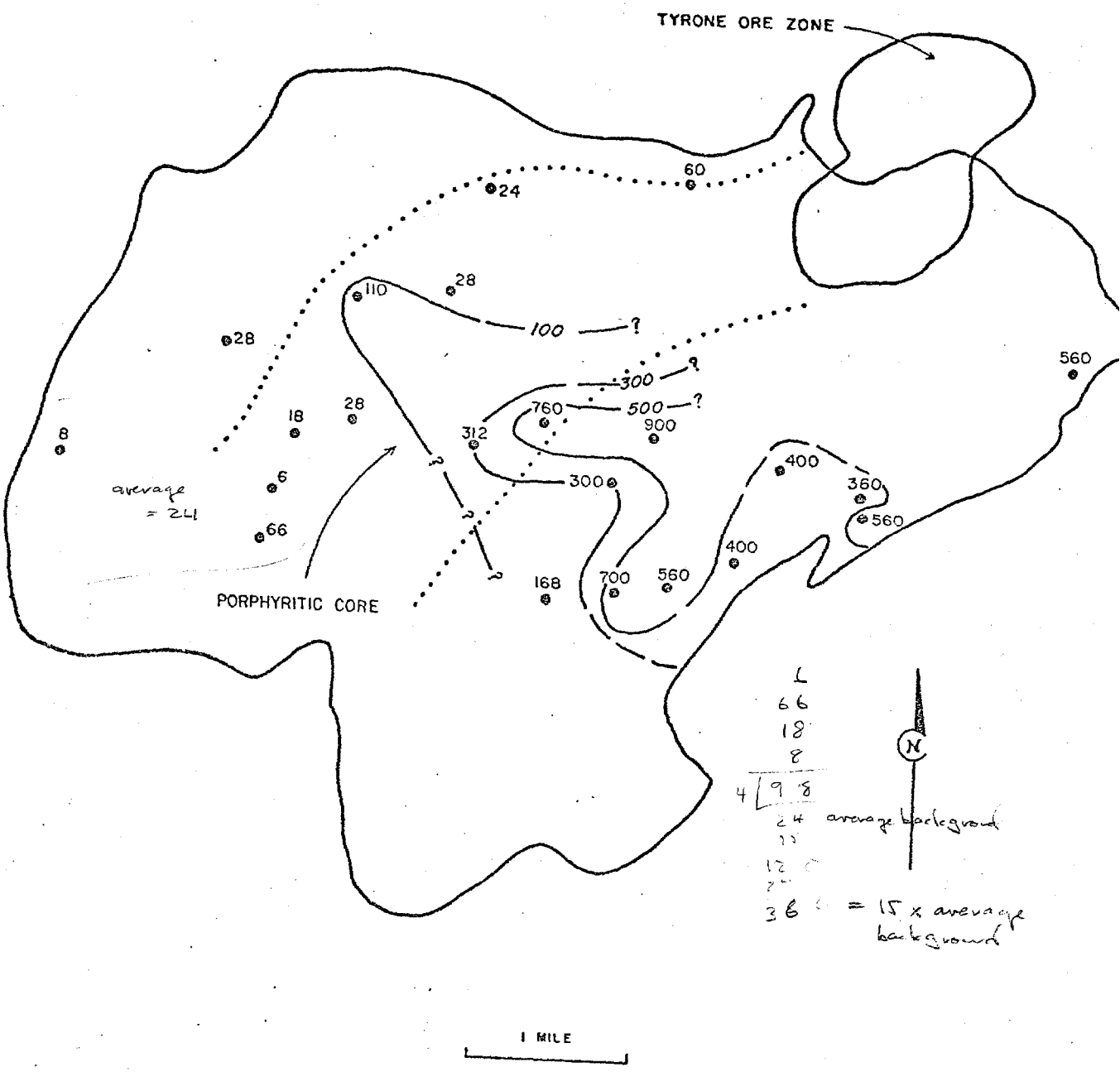
COPPER IN BIOTITE

(Clean)

ppm Values

2529-a

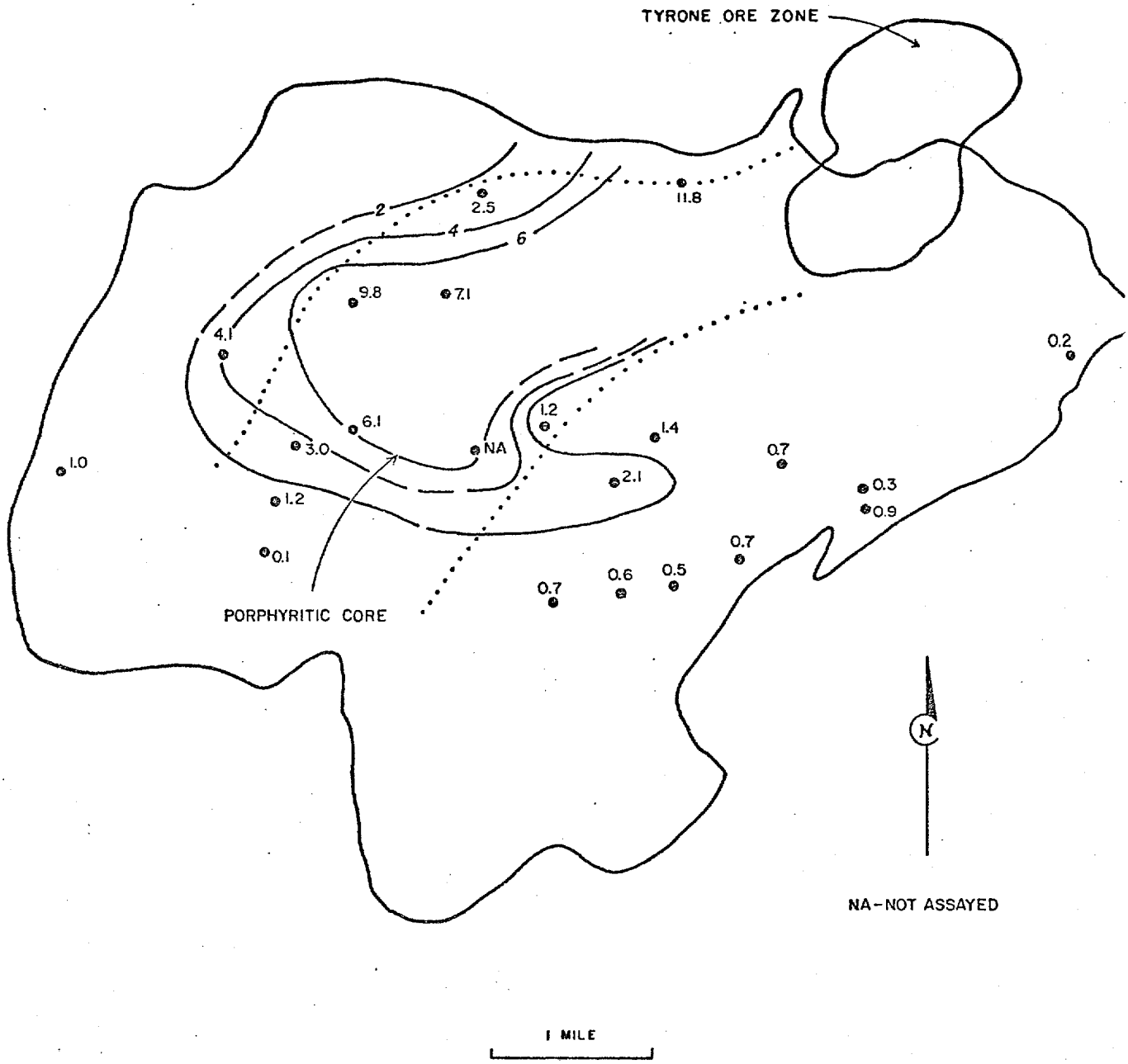
Figure 4-B



TYRONE QUARTZ MONZONITE
COPPER IN WHOLE ROCK
ppm Values

2529-b

Figure 4-C



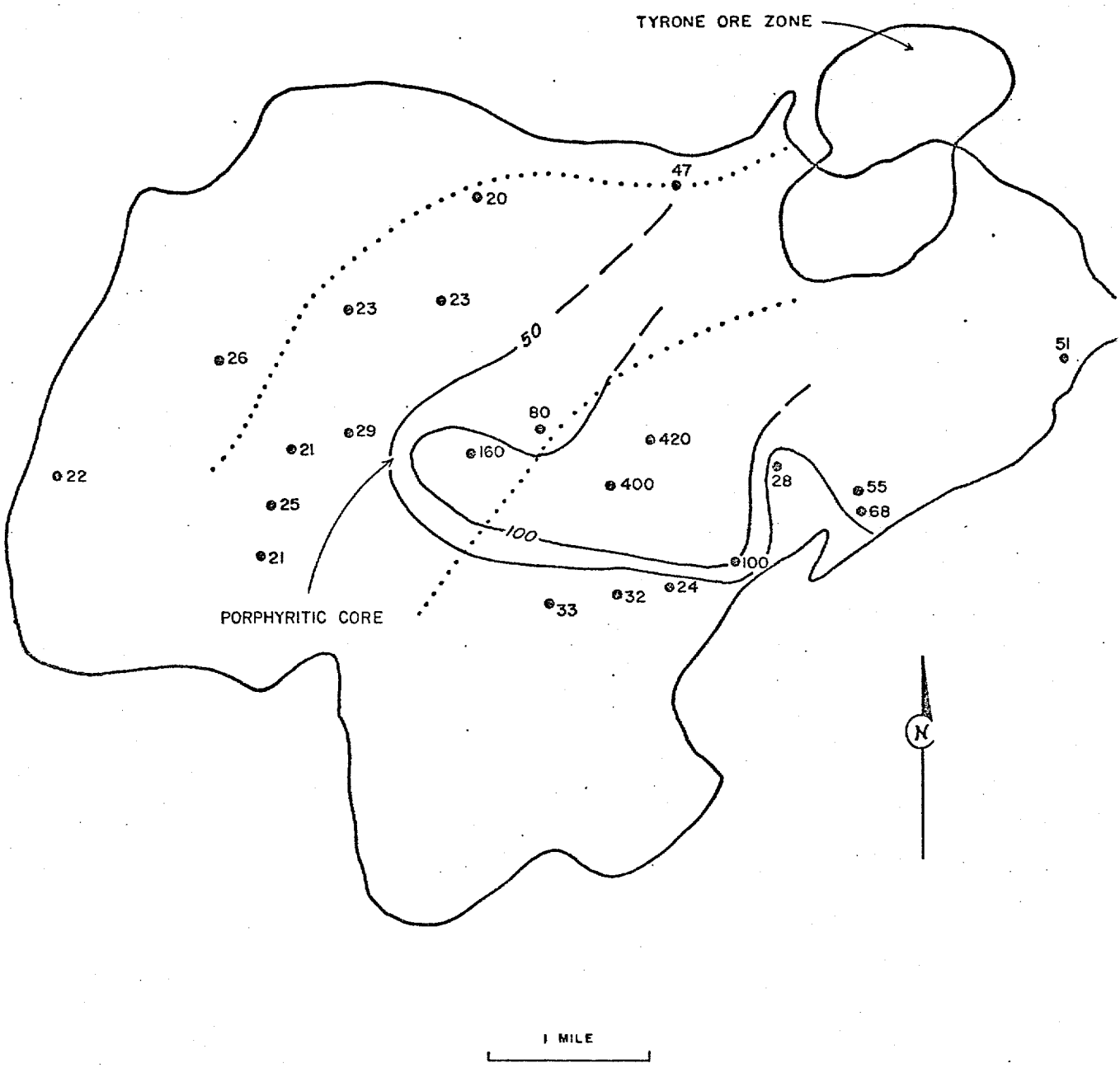
TYRONE QUARTZ MONZONITE

COPPER – $\frac{\text{biotite (clean)}}{\text{whole rock}}$

2529-c

FROM JKing

Figure 4-D



TYRONE QUARTZ MONZONITE

Pb IN BIOTITE

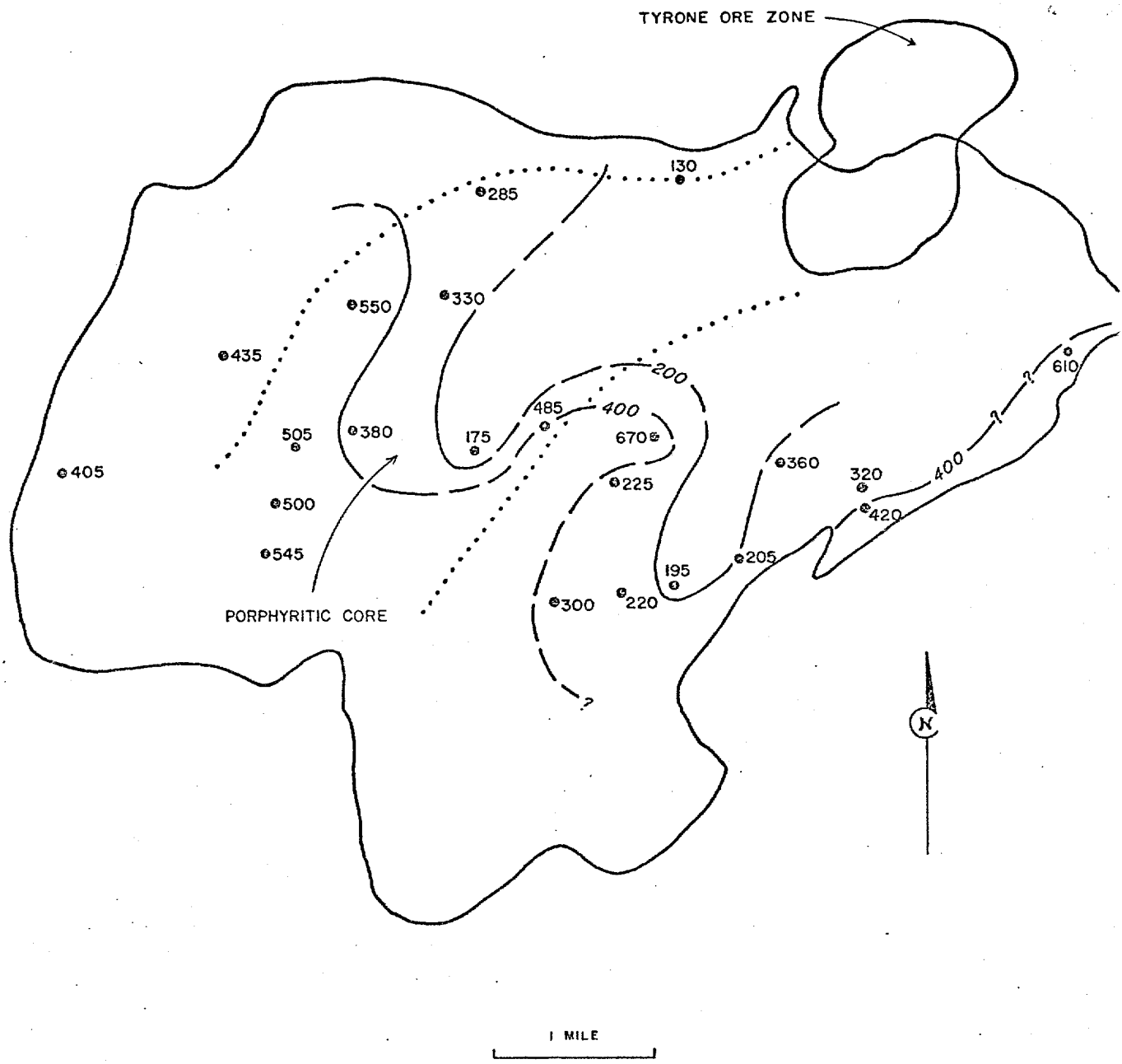
ppm Values

(Unclean)

2529-d

From J King

Figure 4-E



TYRONE QUARTZ MONZONITE

Zn IN BIOTITE

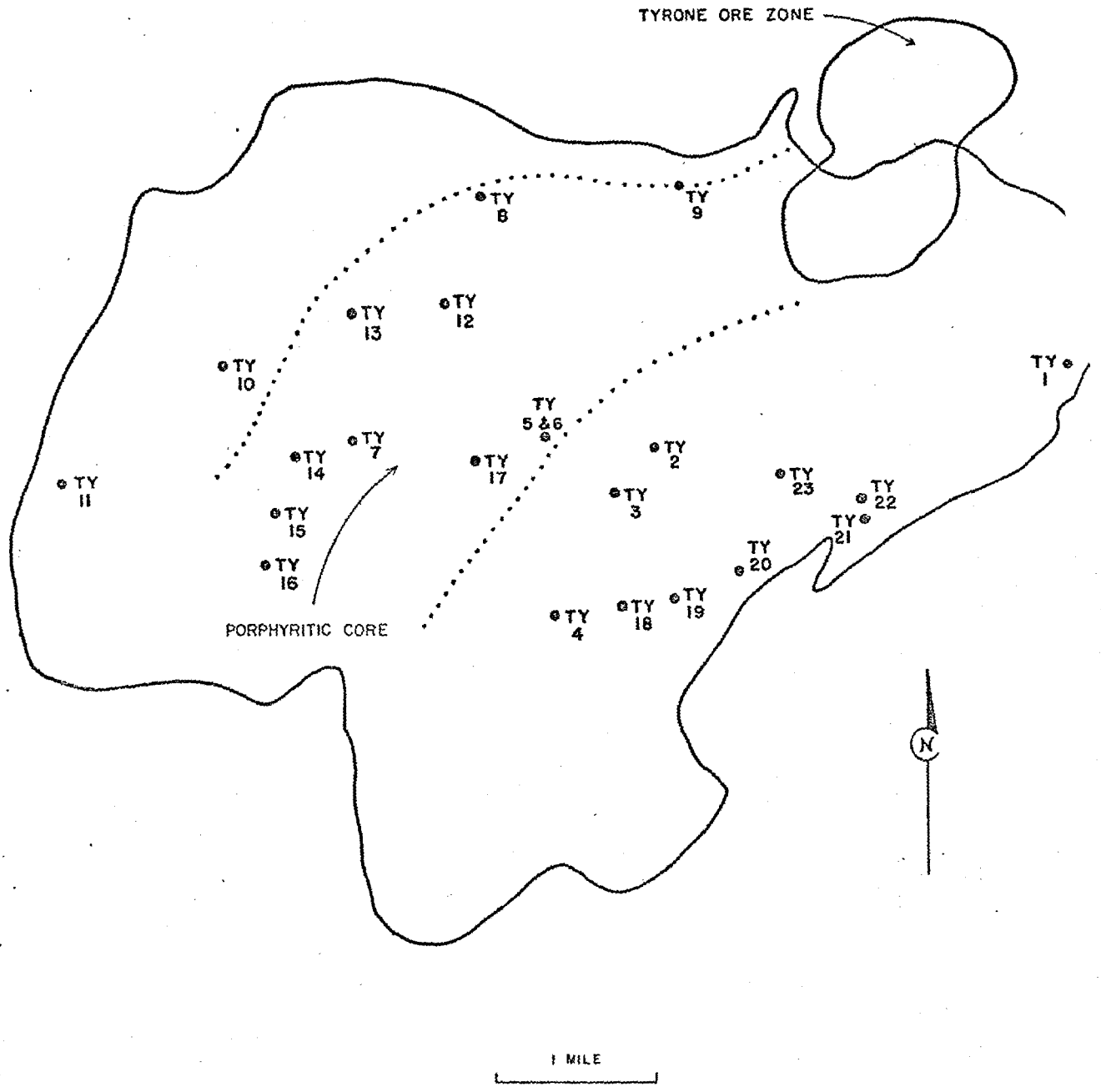
ppm Values

(Unclean)

2529-e

FROM JK

Figu



TYRONE QUARTZ MONZONITE

SAMPLE NUMBERS

2529-f

UNCLEAN = less Than 95% Pure

TABLE 4 From J King TYRONE QUARTZ MONZONITE

Sample Number	BIOTITE CONCENTRATE ppm								WHOLE ROCK COMP. ppm				ONE ROCK	RATIOS Biotite / Whole rock comp.	
	Cu		Pb		Zn		Mo		Cu	Pb	Zn	Mo	Analysis by R. M. G. C. Cu ppm	Cu / Cu	Cu / Cu
	unclean	clean	unclean	clean	unclean	clean	unclean	clean						clean	unclean
TY-1	260	135	51	NA	610	NA	<1	NA	560	NA	NA	NA	95	.2	.5
2	1500	1210	420		670		1		900				200	1.4	1.7
3	1160	620	400		225		<1		300				75	2.1	3.9
4	220	113	33		300		<1		168				-5	.7	1.3
5	840	480	104		485		1		404				85	1.2	2.1
6	1640	920	80		890		1		760				310	1.2	2.2
7	300	171	29		380		<1		28				10	6.1	10.7
8	100	58	20		285		<1		24				70	2.5	4.2
9	600	700	47		130		60		60				NS	11.8	10
10	240	114	26		435		<1		28				-5	4.1	8.6
11	20	8	22		405		<1		8				-5	1	2.5
12	380	199	23		330		<1		28				10	7.1	13.6
13	2000	1080	23		550		<1		110				85	9.8	18.2
14	40	6	21		505		<1		18				-5	3	2.2
15	40	7	25		500		<1		6				NS	1.2	6.7
16	40	7	21		545		<1		66				-5	.1	.6
17	2800	IS	160		175		1		312				NS	IS	8.9

TABLE 4 TYRONE QUARTZ MONZONITE

Sample Number	BIOTITE CONCENTRATE ppm								WHOLE ROCK COMP. ppm				ONE ROCK	RATIOS Biotite / Whole rock comp.	
	Cu		Pb		Zn		Mo		Cu	Pb	Zn	Mo	Analysis by R. M. G. C. Cu ppm	Cu / Cu	Cu / Cu
	unclean	clean	unclean	clean	unclean	clean	unclean	clean						clean	unclean
TY-18	800	420	32	NA	220	NA	< 1	NA	700	NA	NA	NA	45	.6	1.1
19	500	280	24		195		< 1		560				200	.5	.9
20	480	260	100		205		< 1		400				75	.7	1.2
21	600	480	68		420		< 1		560				120	.9	1.1
22	220	122	55		320		< 1		360				-5	.3	.6
23	500	260	28		360		< 1		400				45	.7	1.3

TAB

Appendix

TAB

COLORADO SCHOOL OF MINES RESEARCH INSTITUTE

J. R. K

OCT 21 1971

MEMORANDUM

To: John R. King
American Smelting and Refining Co.

Date: October 19, 1971

Project No. 311009

From: Norman Bennett NB

Subject: Biotite separation of 23 samples

Introduction

In compliance with your request, 23 rock samples labelled TY1-TY23 were crushed and biotite was concentrated from them by screening and two heavy liquid separations. The objective of this work was to obtain biotite concentrates from these samples for shipment to you.

Details of Investigation

Each sample was jaw crushed to minus 1/2 inch, roll crushed to minus 10 mesh, and Raymond milled to approximately minus 65 mesh. The Raymond Mill fraction was screened into plus 65 mesh, minus 65 plus 150 mesh, and minus 150 mesh fractions. The biotite was concentrated from the plus 65 mesh fraction by screening. The plus 65 mesh fraction was selected for screening since a binocular microscope examination indicated this to be an optimum grain size for biotite concentration.

The biotite in the plus 65 mesh fraction was then further concentrated by the use of heavy liquids. Each sample was separated into sink and float fractions using Certigrav (specific gravity 2.90). The fraction with a specific gravity greater than 2.90 was further separated using Methylene Iodide (specific gravity 3.3). The fraction with a specific gravity greater than 2.90 and less than 3.3 contained the biotite concentrate.

The biotite concentrates are being shipped to you under separate cover. If you have any questions, please contact me.

/laj

COLORADO SCHOOL OF MINES RESEARCH INSTITUTE
P.O. Box 112
GOLDEN, COLORADO 80401

J. R. K.

APR 9 1971

MEMORANDUM

To: Mr. Lloyd James
Geophysical Division
American Smelting & Refining Co.

March 30, 1971

From: W. T. Caneer

Project 301217

Subject: Electron Probe Studies of Copper in Biotite

In compliance with your request we have made electron probe studies on two rock samples (RS-5 and RS-10) submitted by you. The purpose of these studies was to determine the nature of copper which is contained in the biotite. In addition, similar studies were made on biotite concentrates from samples RS-1 and RS-8 which were previously obtained at the Research Institute. The authorization for work on the latter two samples was obtained from Mr. R. J. Lacy during a telephone conversation between Mr. Lacy and me on March 19, 1971.

Electron probe studies were initially made on rock samples RS-5 and RS-10. The results of these studies showed that the copper occurs in the biotite along planes parallel to the biotite cleavage. These planes vary up to only a few microns wide, but often extend across biotite grains which are a few millimeters in diameter. Figure 1 illustrates this occurrence. Photograph No. 1 is a backscattered electron image at 200x magnification across a biotite grain (in RS-10) which contains copper. Backscattered electron images are similar to optical photomicrographs. However, backscattered electron images give additional information inasmuch as areas which contain heavier elements appear as whiter areas on the photographs. Photograph No. 2 shows the copper distribution (white) across the same area as shown for the backscattered electron image. As may be seen, the copper occurs along two lines which extend diagonally across the photograph. The only other element detected with the copper was carbon. The copper and carbon were in approximately the proper proportions for the mineral malachite [$CuCO_3.Cu(OH)_2$] or possibly azurite [$2CuCO_3.Cu(OH)_2$]. Since the electron probe is capable of analysis for all elements except the first four in the periodic table plus oxygen, the oxygen and hydrogen contents cannot be determined.

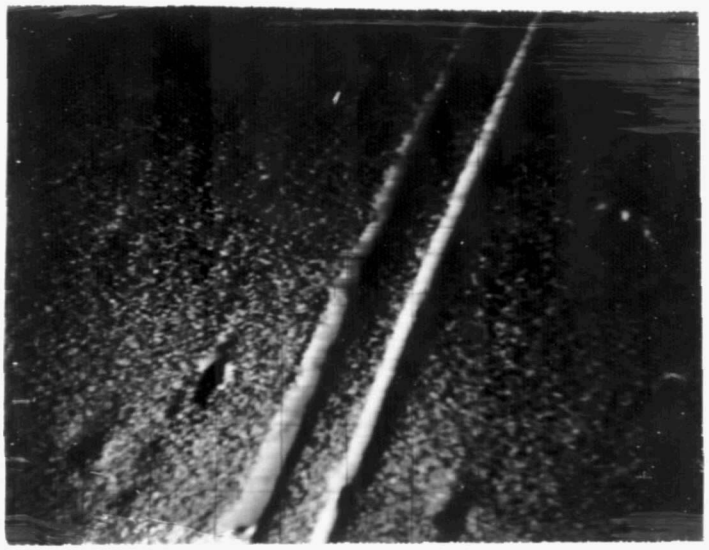
The copper occurrence in the biotite in rock samples RS-5 was similar to that described for sample RS-10, but to a lesser extent than in RS-10.

Except for a small amount of the malachite in the non-biotite portion of sample RS-10, all of the copper observed in RS-5 and RS-10 was associated with the biotite as described above.

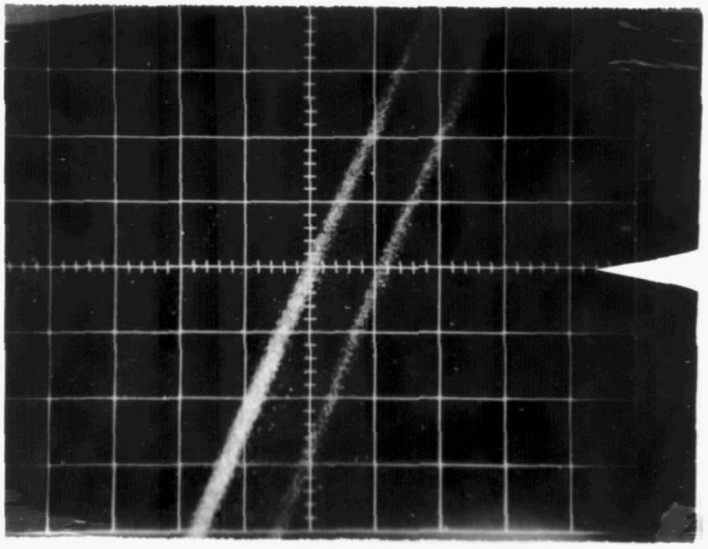
Electron probe examinations of biotite concentrates from samples RS-1 and RS-8 showed that the copper in these samples also occurs along very thin planes parallel to the biotite cleavage as described for rock samples RS-5 and RS-10.

If we can be of further service to you, or, if you have any questions regarding this project please contact me.

cc: Mr. R. J. Lacy



1. Backscattered Electron Image



2. Copper Distribution

Figure 1

Backscattered electron image plus copper distribution across a copper-bearing biotite grain in sample RS-10, 200x

INDEX OF FIGURES AND TABLES

RUBY STAR

Figure 1-A: Copper in Biotite

1-B: Copper in Whole Rock

1-C: Ratio of Copper in Biotites Versus Copper in Whole Rock

1-D: Average Percent Change in Copper Values as Greater Sample Purity is Achieved

1-E: Zinc in Biotite

1-F: Zinc in Whole Rock

1-G: Lead in Biotite

1-H: Lead in Whole Rock

1-I: Sample Numbers

Table 1: Analyses From Ruby Star Samples

SCHULTZE

Figure 2-A: Copper in Biotite

2-B: Copper in Whole Rock

2-C: Ratio of Copper in Biotite Versus Copper in Whole Rock

2-D: Sample Numbers

Table 2: Analyses From Schultze Samples

THREE PEAKS

Figure 3-A: Copper in Biotite

3-B: Copper in Whole Rock

3-C: Ratio of Copper in Biotite Versus Copper in Whole Rock

3-D: Zinc in Biotite

3-E: Zinc in Whole Rock

3-F: Ratio of Zinc in Biotite Versus Zinc in Whole Rock

Three Peaks (cont'd.)

Figure 3-G: Samples Numbers

Table 3: Analyses From Three Peaks Samples

TYRONE

Figure 4-A: Copper in Biotite

4-B: Copper in Whole Rock

4-C: Ratios of Copper in Biotite Versus Copper in Whole Rock

4-D: Lead in Biotite

4-E: Zinc in Biotite

4-F: Sample Numbers

Table 4: Analyses From Tyrone Samples

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COMPILED BY JOHN KING

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