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March 1, 1971

MEMORANDUM to R. J. LACY:

GEOCHEMISTRY OF IGNEOUS ROCKS
AS AN ORE INDICATOR -
RUBY STAR GRANODIORITE,
SIERRITA MOUNTAINS, ARIZONA

Introduction:

In accordance with an agreement reached with Mr. Saegart (my memorandum of October 5, 1970), Mr. J. King of the Tucson Office recently collected rock samples for the preliminary phase of an investigation of the value of the geochemistry of igneous rocks as an ore indicator. These samples, which were obtained from the Ruby Star Granodiorite, adjacent to the Esperanza and Sierrita Mines, Sierrita Mountains, Arizona, supplemented an earlier comparable program carried out by the U.S.G.S. The Asarco study was designed to enable verification of the encouraging U.S.G.S. data, relating to the distribution patterns of Cu in biotite, and, at the same time provide a preliminary opportunity for determining optimum sampling and analytical procedures.

Biotite concentrates from the rock samples were prepared and subsequently analyzed (by X-ray and emission spectrographic techniques) by the Colorado School of Mines Research Institute (CSMRI). The Geochemical Laboratory was unable to make the necessary mineral separations because of current building and remodelling activities. However, it did prove possible to carry out various analyses of the biotite concentrates and rock samples.

The CSMRI is currently making a limited study to determine whether it is both possible and economic to carry out the necessary chemical analyses of biotite with an electron probe and thereby enable avoidance of the mineral separation phase of this type of program. The results of this study should be forthcoming in the near future.

Conclusions and Recommendations:

1. The present limited study has successfully verified earlier U.S.G.S. data which demonstrated the presence of a well defined increase in the Cu content of biotite in the Ruby Star Granodiorite as genetically related Cu deposits are approached. This geochemical halo likely has a radius of some miles.

2. The presence of a poorly defined weak halo of Zn impoverishment is also indicated by the biotite data.

3. Chemical Studies indicate that the Cu (but not the Zn) content of the biotite is likely mainly in the form of small sulphide inclusions.

4. Analysis of composite rock samples indicates the presence of a broadly comparable pattern of Cu distribution to that in biotite but it is less consistent and of lower overall contrast. Of considerable interest are the Mo distribution patterns in the rock samples as they indicate the presence of a broad (i.e. some miles in radius) halo of Mo enrichment around the Cu deposits.

5. It is to be concluded that semi-quantitative spectrographic and x-ray fluorescence analytical data (or at least those obtainable from (CSMRI) have so far been of little value. It is advisable to place main emphasis on more precise A.A. and colorimetric analytical techniques.

6. Sufficient encouragement has been achieved in the present study to warrant additional orientation rock and mineral studies of other suitable areas--preferably in continued close cooperation with the Tucson office. Development of a viable ancillary exploration technique employing bedrock geochemistry to help recognize plutons genetically related to Cu mineralization and as a geochemical guide to deposits in such plutons would be of considerable potential value in certain situations.

7. Recent published data (in particular Putman & Alfors - Geochemistry and Petrology of the Rocky Hill Stock, Tulare County, California, by George W. Putman and John T. Alfors - G.S.A., Special Paper 120, 1970) indicate that sampling procedures are an extremely important factor in this type of study. Putman and Alfors in fact have reservations as to the value of mafic mineral analysis in exploration since their studies indicate that the variability of the Cu content of the ferromagnesium (and metallic oxide) phases of granitic rocks are relatively high and relatively steep gradients in the Cu content of these phases appear to exist on a very local scale. In our present study use of large composite samples has possibly helped minimize such problems--the forthcoming electron probe data will be of particular interest in this context.

8. It is essential that petrologic and mineralogic studies should be included in any continuance of the rock geochemistry program. Without the resultant data adequate interpretation of the geochemical data will not be possible.

9. If favorable results are achieved from additional orientation studies a general careful investigation of all available relevant published data should be undertaken before any large scale attempts to apply bedrock geochemical studies as an exploration tool. Copies of many of the recent relevant papers are attached to the Tucson office copy of the report (Attachment E).

Geology of the Study Area:

The geology of the study area is described in the paper "Copper in Biotite from Igneous Rocks in Southern Arizona as an Ore Indicator"--U.S.G.S. Professional Paper 700-B, B1-B8, 1970. (See Attachment C).

Sampling Procedure:

Rock samples were collected from eleven stations located at up to 5 miles distance from the Sierrita and Esperanza Mines. (Fig.1) Locations were influenced by the availability of relatively unweathered outcrop but it proved possible to obtain a reasonably satisfactory preliminary coverage of granodiorite (including the porphyritic "core".)

At each location a large (i.e. around 2 - 5 lbs.) single fresh sample was collected together with a large composite (around 10 lbs. weight) composed of fresh chips from a 50 - 100 ft. radius around the station. It was hoped that these samples would enable both the large and small scale homogenity of trace distribution element in rock and mineral separates to be determined.

Analytical Procedure:

In this preliminary phase of the study chemical analyses were confined to biotite separates and rock samples. The biotite separations were obtained by the procedure described in Mr. James M. Link's (CSMRI) letter of January 15, 1971 (see attachment A). This procedure probably provides an adequate concentrate for our present study.

In order to obtain a general indication of any major variations in geochemical distribution patterns (and also obtain some general indication of the quality of analytical service provided by CSMRI) the biotite samples were analyzed by both semi-quantitative emission spectrograph and x-ray fluorescence techniques by the Colorado School of Mines Research Institute. In addition the Geochemical Laboratory analyzed biotite and total rock samples for Cu, Pb, An and Mo using A.A. techniques following both total and partial digestions. The partial digestion, which involved application of hydrogen peroxide in the presence of excess ascorbic acid, enabled preferential leaching of any sulphide minerals present. The Geochemical Laboratory also analyzed the rock samples for Hg.

Geochemical Data - Biotite:

The emission spectrograph analyses generally provided (except in the case of Cu and Mo) "Ball-park" figures for Cu, Pb, Zn, Ba, Co, In, Mn, Mo, Ni, Sr, Ti, Zr and V concentrations (See Attachment B). Only Cu concentrations display distribution patterns which can be correlated to the presence of the known major mineralizations. (Fig. 8a).

Of the elements determined by x-ray fluorescence (Cu, Pb, Zn, Ba, Br, Cr, Fe, Mn, Ni, Ru, Sr, Ti, Zr, V and Y -- Figs. 8a through 8o) only Cu, Zn, and Zr display distribution patterns which can be related to the presence of the mineralization (Figs. 8a, 8c and 8o). Cu and Zr concentrations appear higher in proximity to the mineralization whilst Zn concentrations display a weak roughly inverse relationship.

Comparison of the emission spectrograph, x-ray fluorescent and our own A.A. data indicates that the two former sets of data are at best likely to be of relatively poor accuracy and precision. So for our present purposes, it is advisable to restrict attention to the A.A. data.

The A.A. data for the total digestions indicates the presence of a general increase in Cu and decrease in Zn concentrations in the biotite as the mineralizations are approached (Figs. 2a and 4a). These geochemical patterns show far more contrast in the case of Cu than of Zn. The Cu data broadly verifies that obtained previously by the U.S.G.S. Patterns of Pb and Mo (Figs. 3a and 5a) distribution display no apparent relationship to the presence of the Cu mineralization.

Partial extraction A.A. data gives broadly comparable geochemical patterns for Cu and Pb but not Zn, to those obtained by total digestion (Figs. 2b, 3b and 4b). Only the distribution pattern for partial Cu (Fig. 2b) shows any apparent relationship to the mineralization. Of potential significance is the fact than an appreciable proportion (50 - 100%) of the total Cu content of the biotites is extracted by the partial digestion (specific leaching for sulphide) process used (Figs. 2c). This indicates that much of the Cu in the biotites occurs in sulphide form -- a conclusion in agreement with recently published studies of the Boulder Batholith, Montana and Rocky Hill Stock, California. The Zn data does not provide evidence of comparable sulphide affinity.

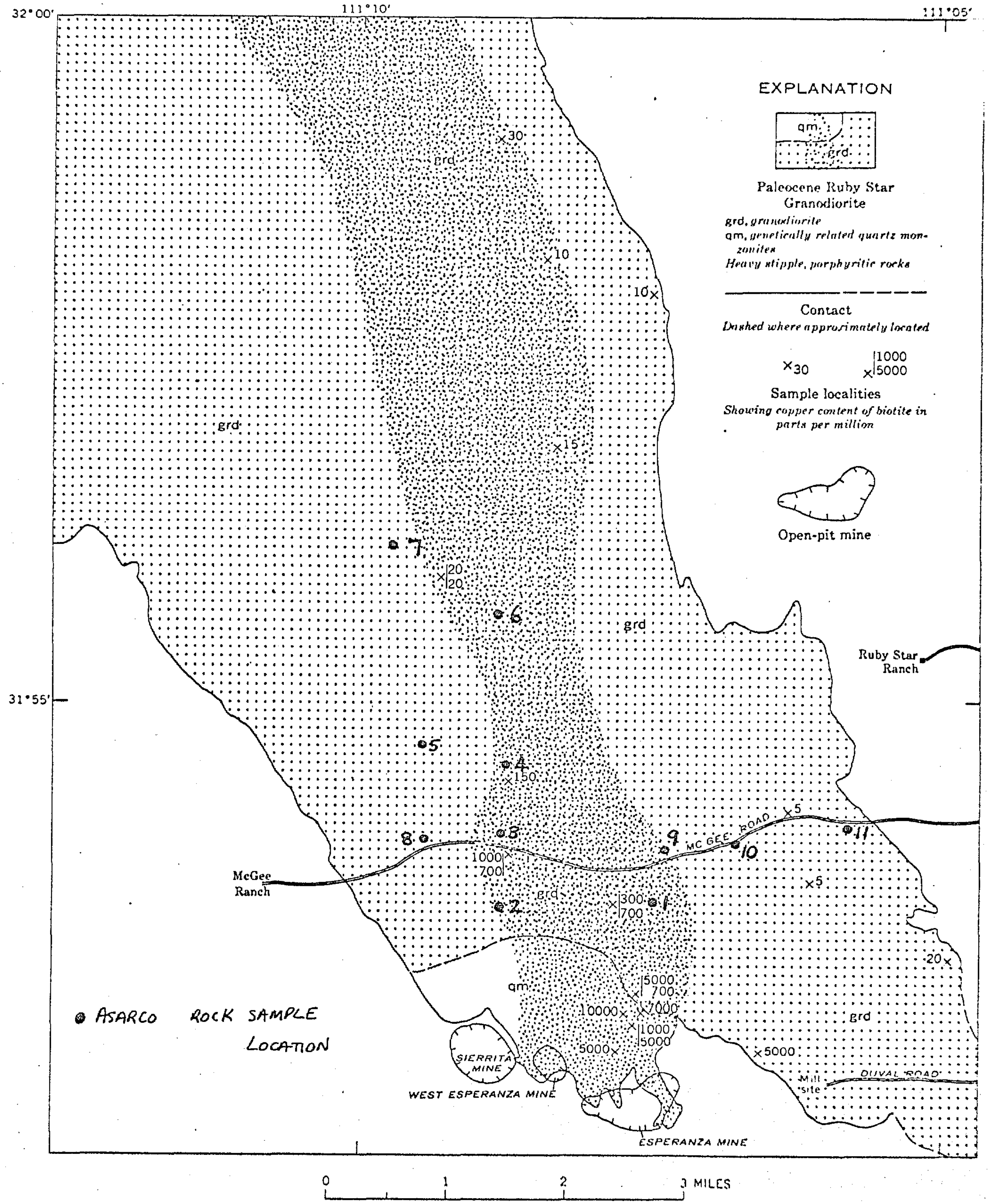
Geochemical Data - Rocks:

The composite rock samples have been analyzed for Cu, Pb and Zn by A.A. techniques following both total and partial digestion (sulphide specific leach) procedures. (Figs. 6a through 6e). Total Mo and Hg were also determined by colorimetric and A.A. procedures respectively. The distribution patterns of both Cu and Mo (Figs. 6a and 6d) show a distinct relationship to the presence of the known mineralization, both display a general increase in concentration as the mineralization is approached. However, the Cu distribution pattern is not so well defined as that of the biotite separates.

L. D. James

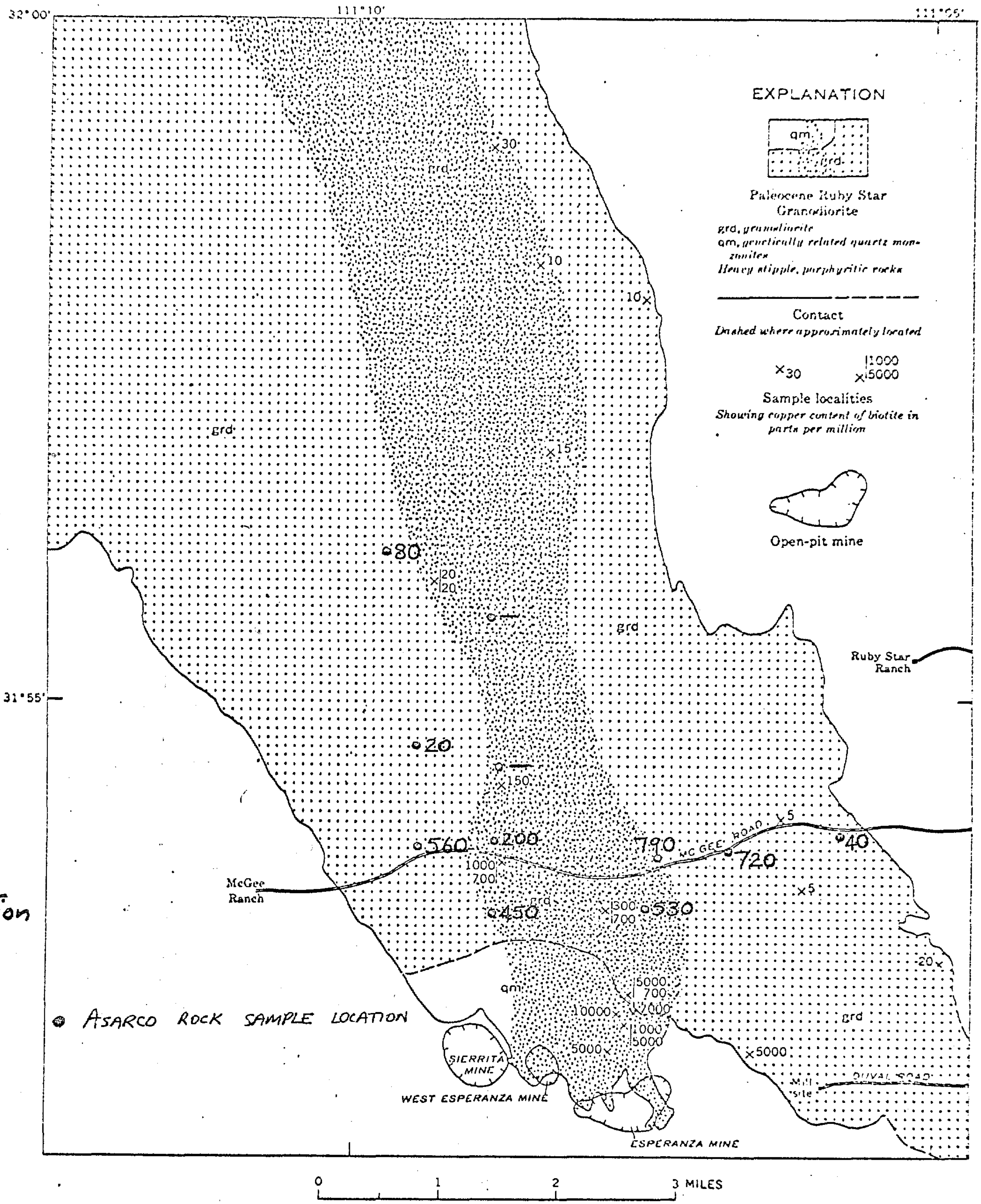
L. D. JAMES

LDJ:db
Encls.
cc: J.J.Collins w/encl.
J.H.Courtright "
J.King "
W.E.Saegart "



~~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.

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



Biotite

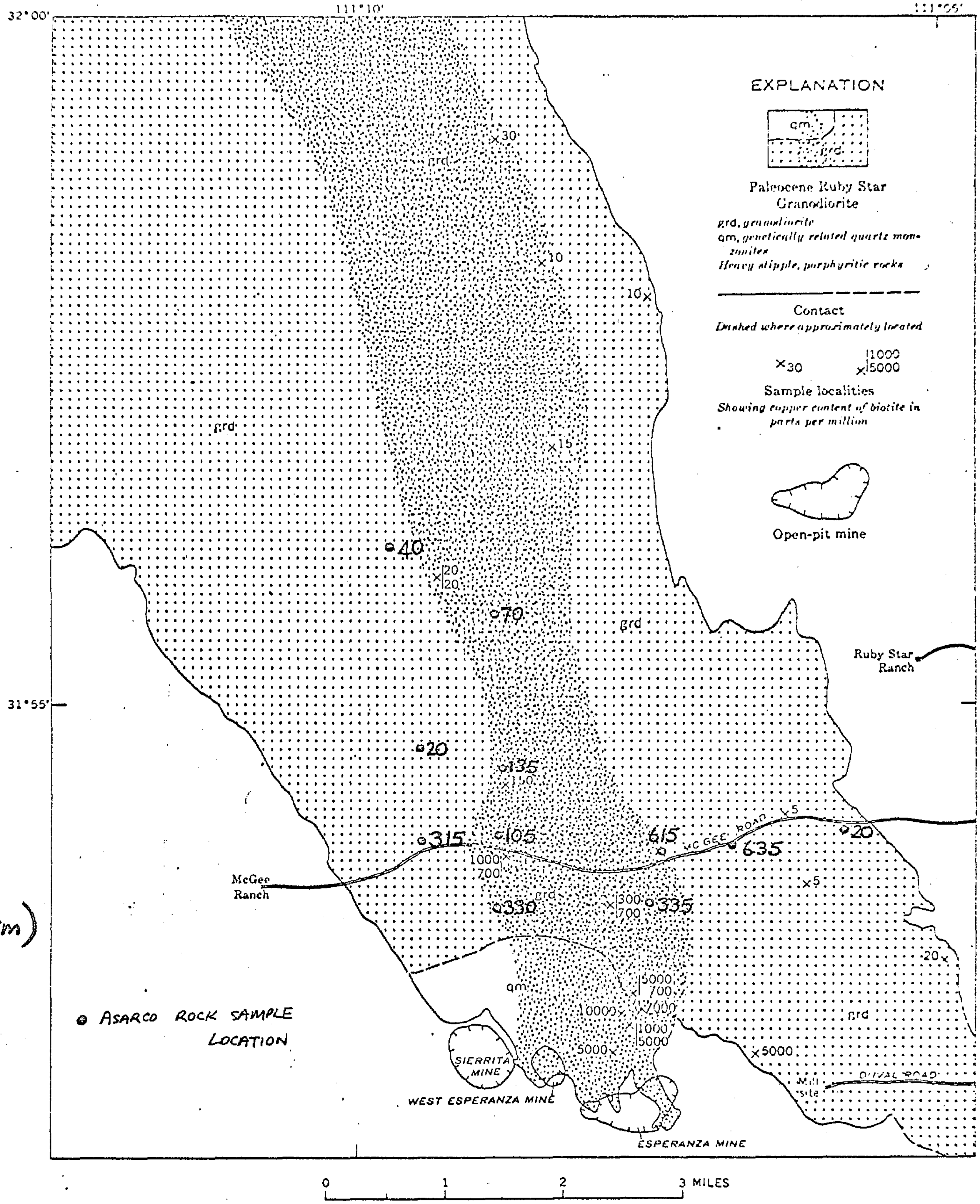
Cu

(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 Cu (sulphide form)

Fig. 2b

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

Biotite

Cu

(Ratio sulphide : total)

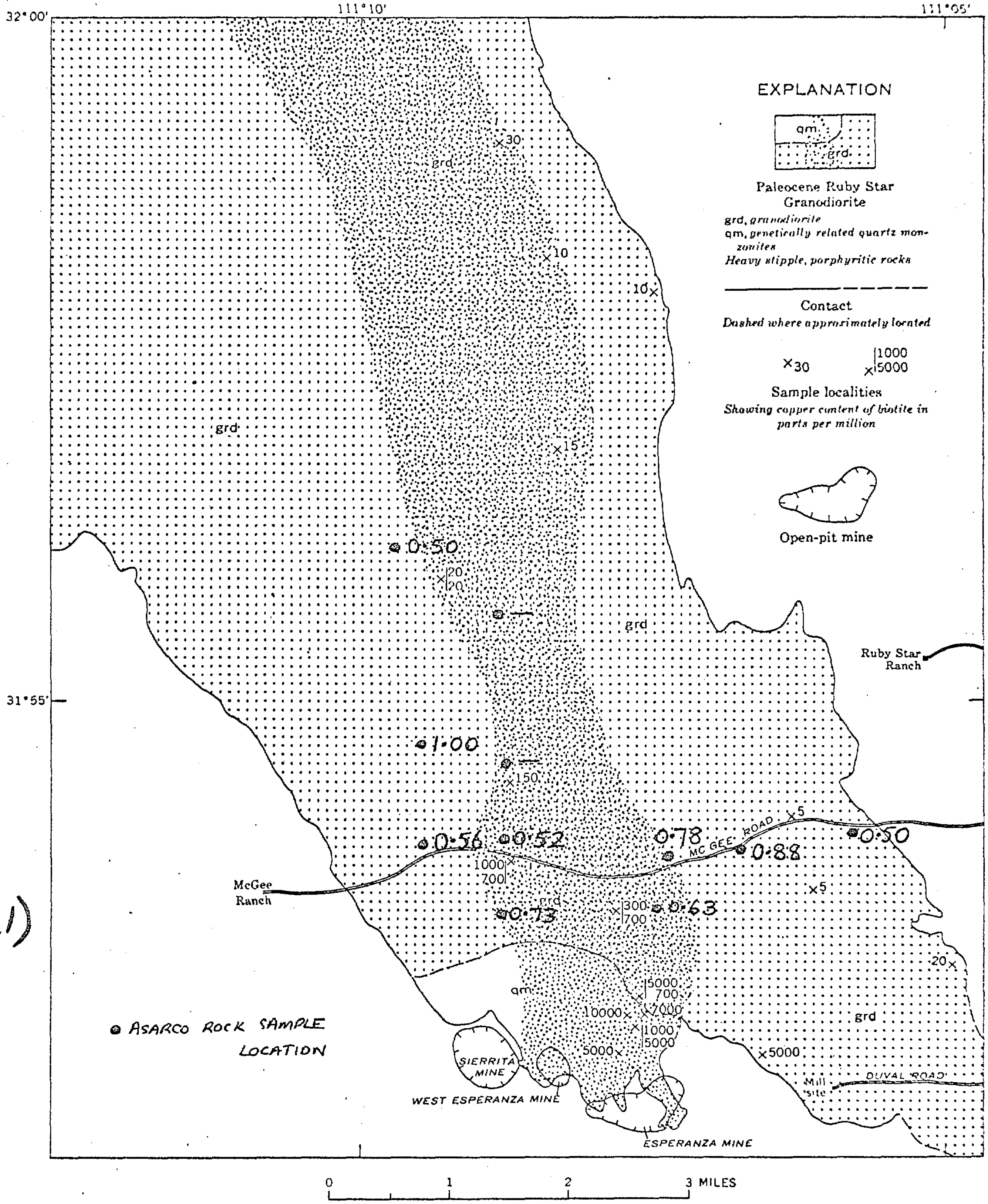


Fig. 2c

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.

Ratio Cu (sulphide form): Cu (total) in biotite from Asarco rock samples.

Biotite

Pb

(Total digestion & A.A.)

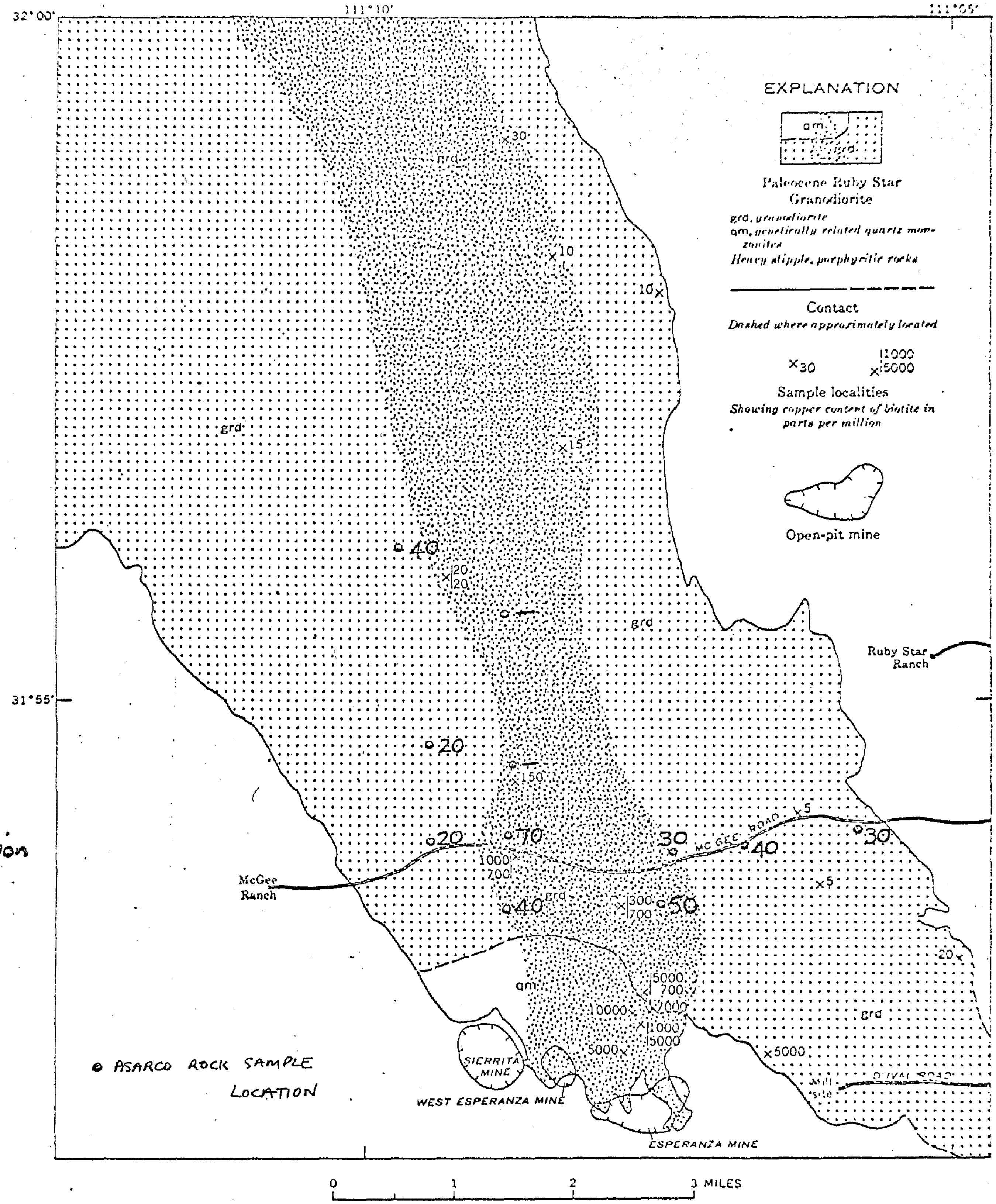


Fig. 3a

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

Pb

(sulphide form)

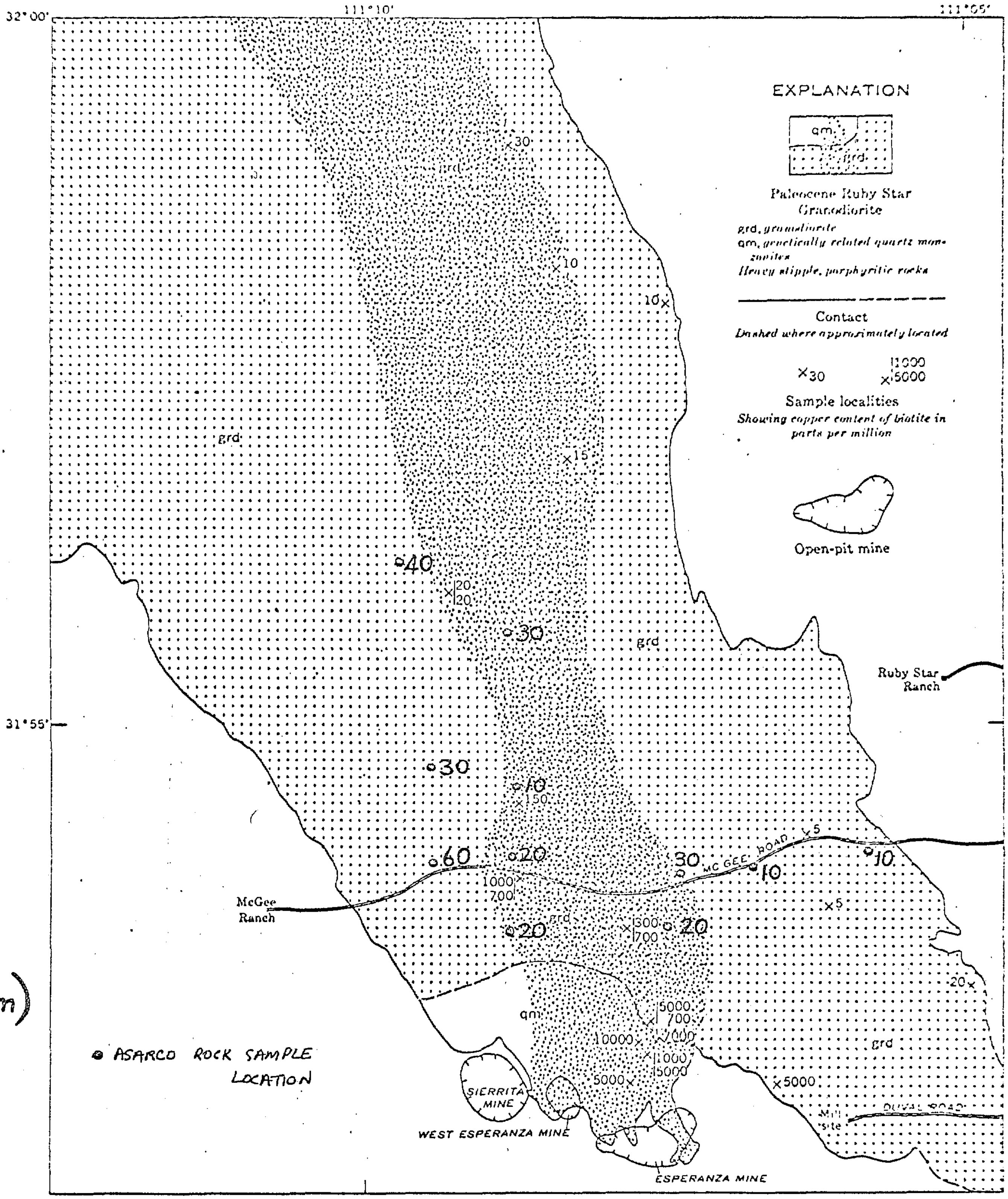


Fig. 3b

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 (sulphide form) ppm content of biotite in Asarco rock samples (analysis of leachate by Geochemical Laboratory using an A.A. technique)

Biotite

Zn

(Total digestion & A.A.)

Fig. 4a

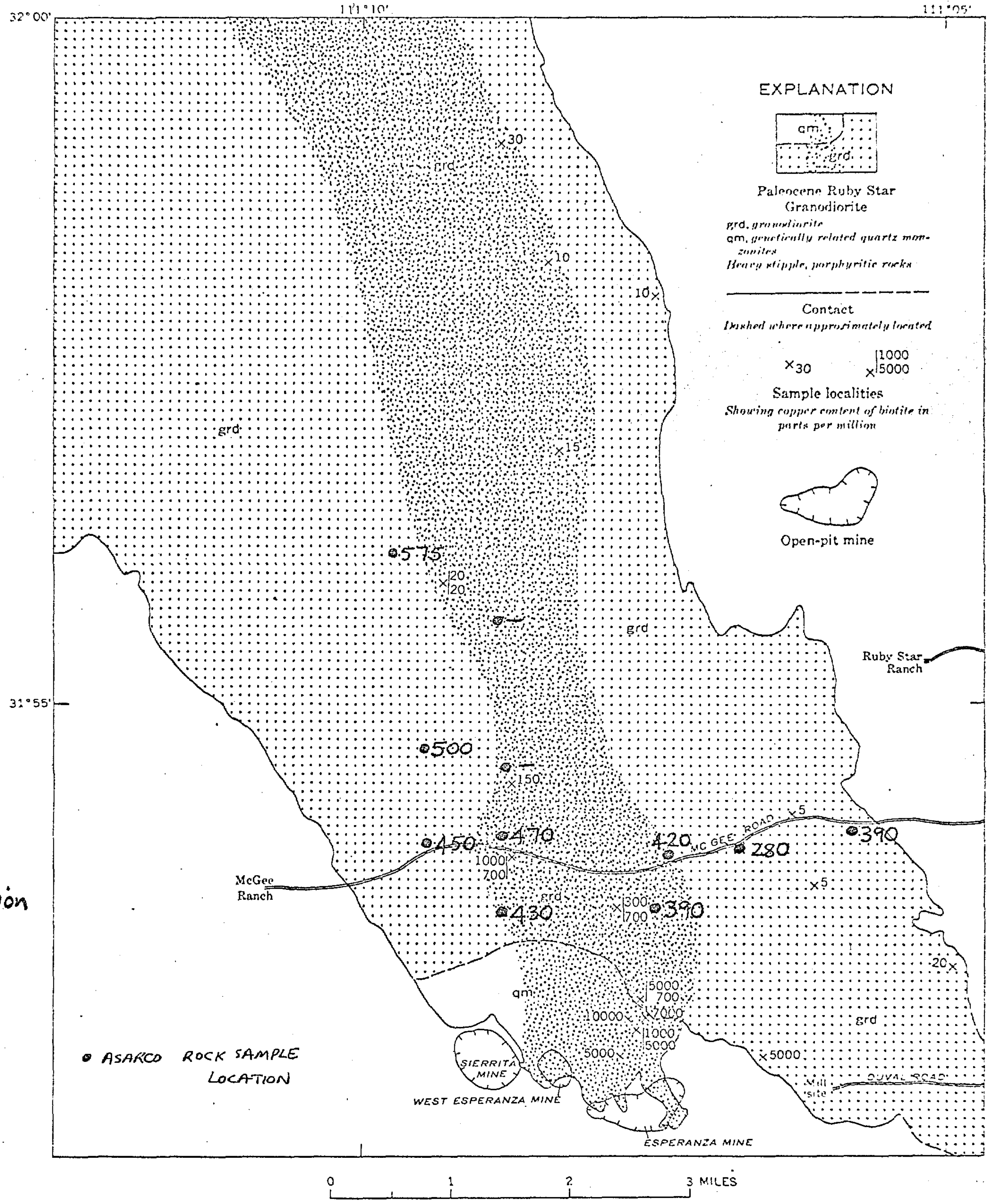
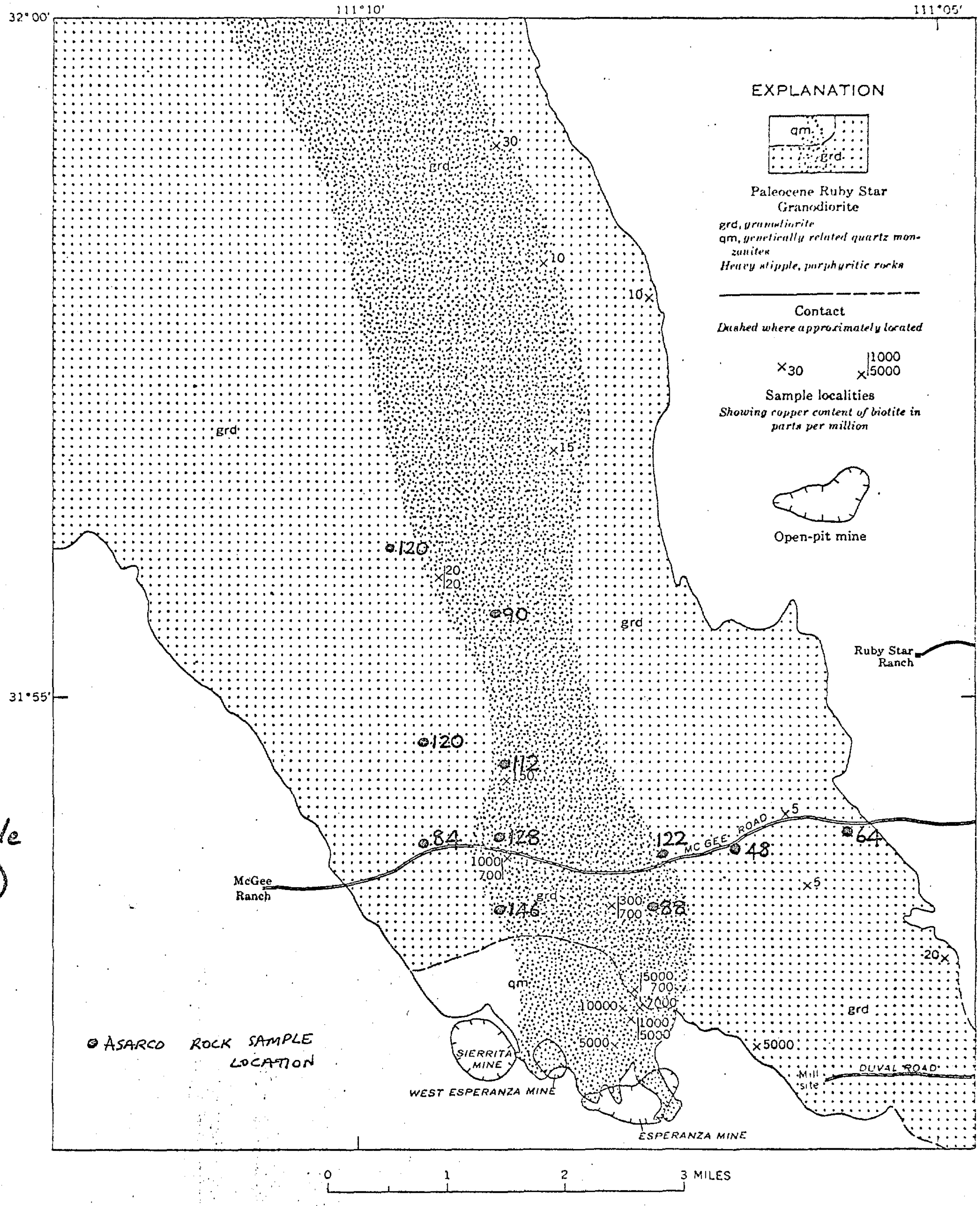


FIGURE 2.—Generalized map of composite stock and associated ore deposits in the southwestern part of the Pima mining district, east of the Sierrita Mountains, showing sample localities and copper content of biotite.

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



Biotite

Zn (sulphide form)

Fig. 4 b.

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 (sulphide form) ppm content of biotite in Asarco rock samples (analysis of leachate by Geochemical Laboratory using an A.A. technique)

BIOTITE

Mo

(Total digestion + colorimetric)

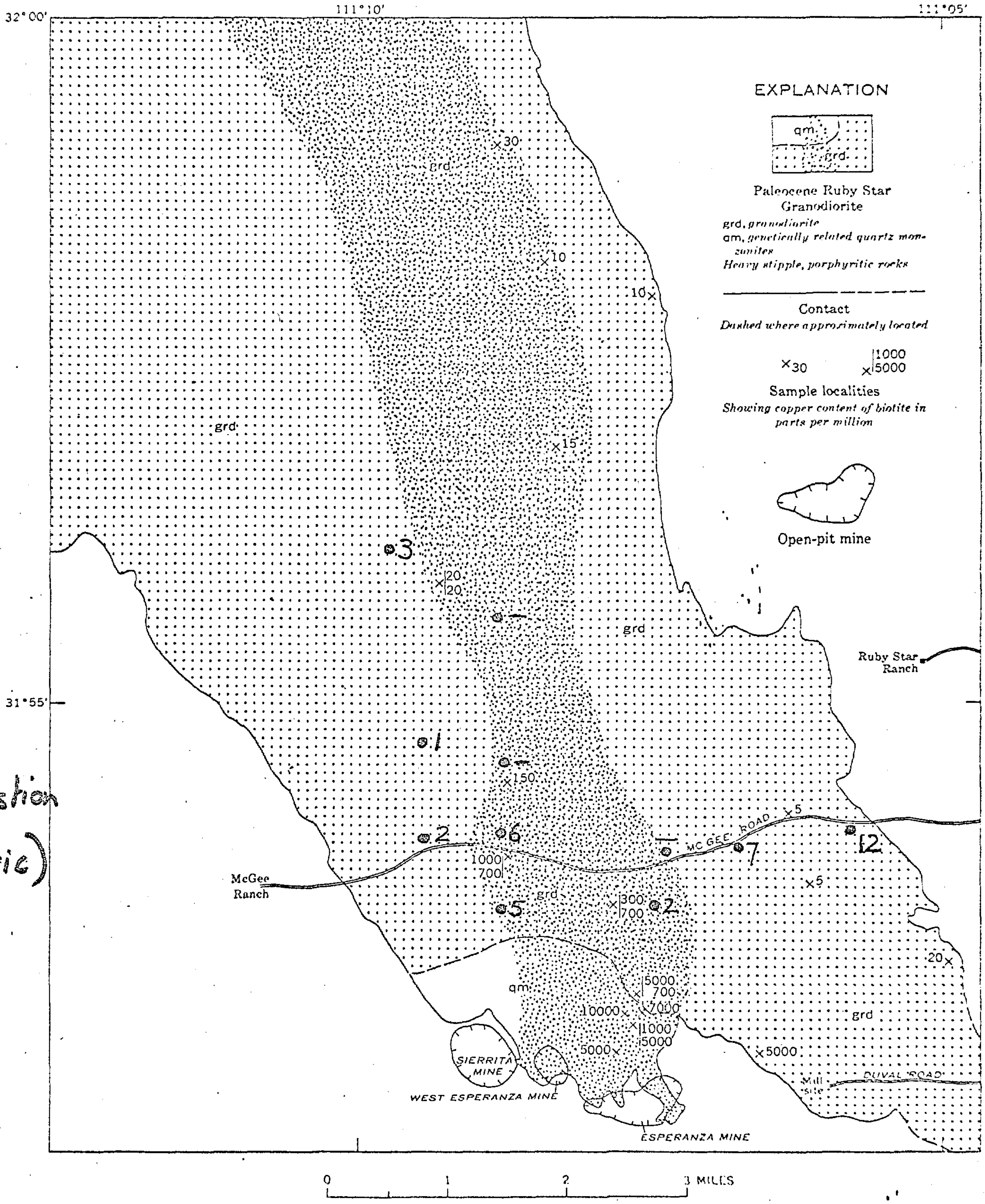


Fig. 5a —Generalized map of composite stock and associated ore deposits in the southwestern part of the Pima mining district, east of the Sierrita Mountains, showing sample localities and copper content of biotite.

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

Rock

Cu

(A.A. & Total Digestion)

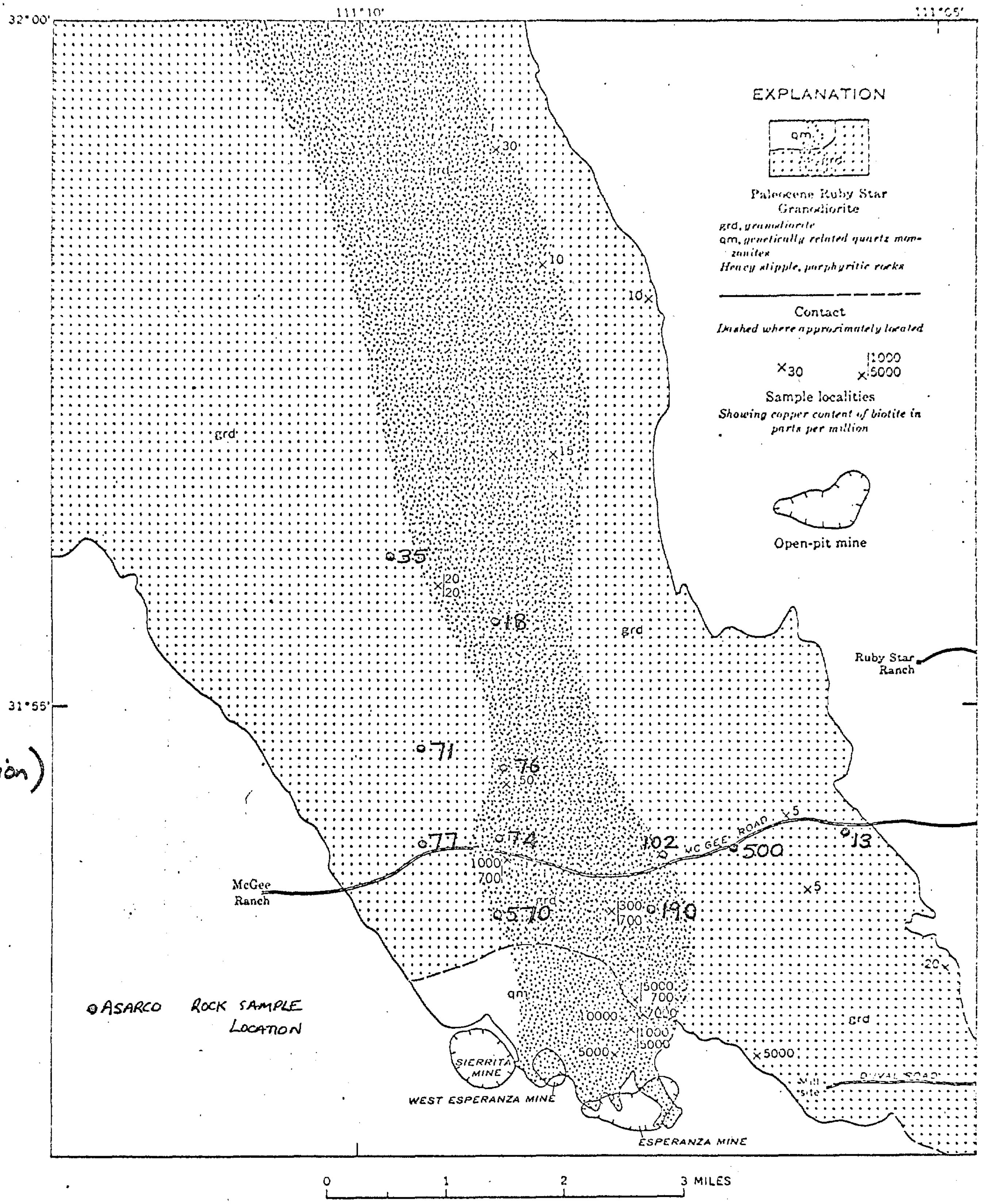


Fig. 6a

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) Asarco rock samples
(analysis by Geochemical Laboratory using an A.A. technique)

Rock

Pb

(A.A. & Total digestion)

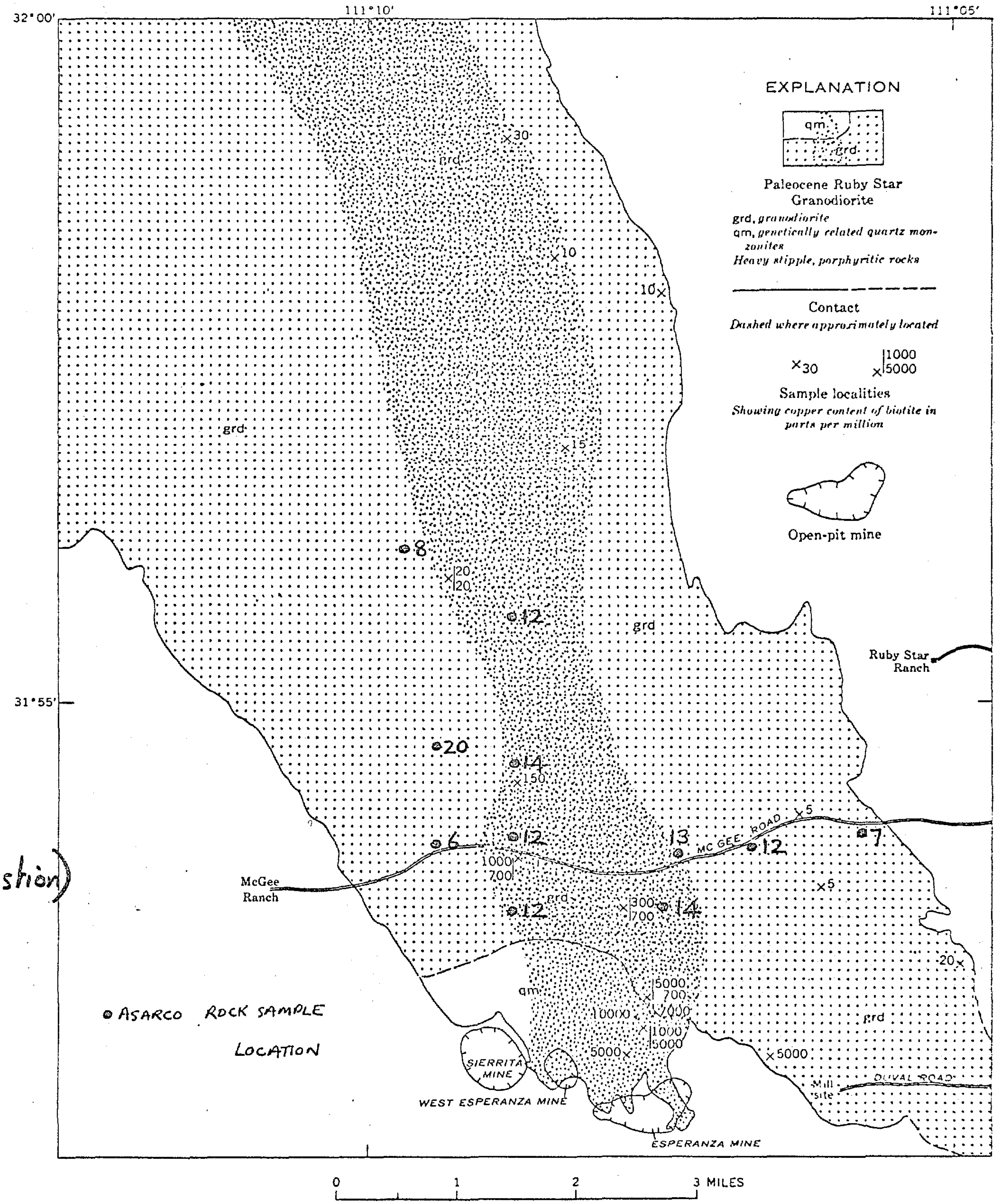


Fig. 6b

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) Asarco rock samples
(analysis by Geochemical Laboratory using an A.A.technique)

Rock

Zn

(A.A. + Total digestion)

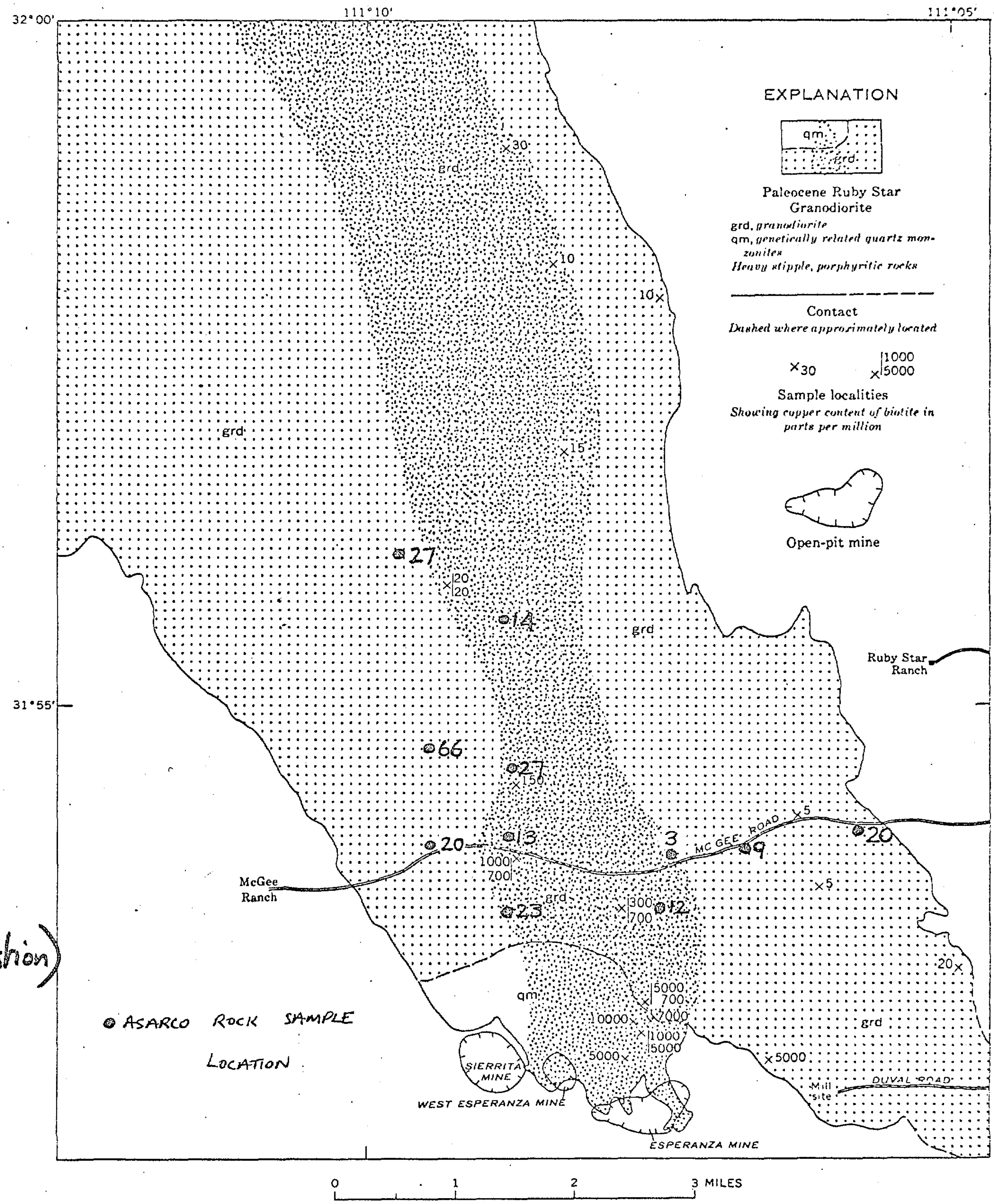


Fig. 6c

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) Asarco rock samples
(analysis by Geochemical Laboratory using an A.A.technique)

Rock

Mo

(Colorimetric
+
Total digestion

Fig. 6d

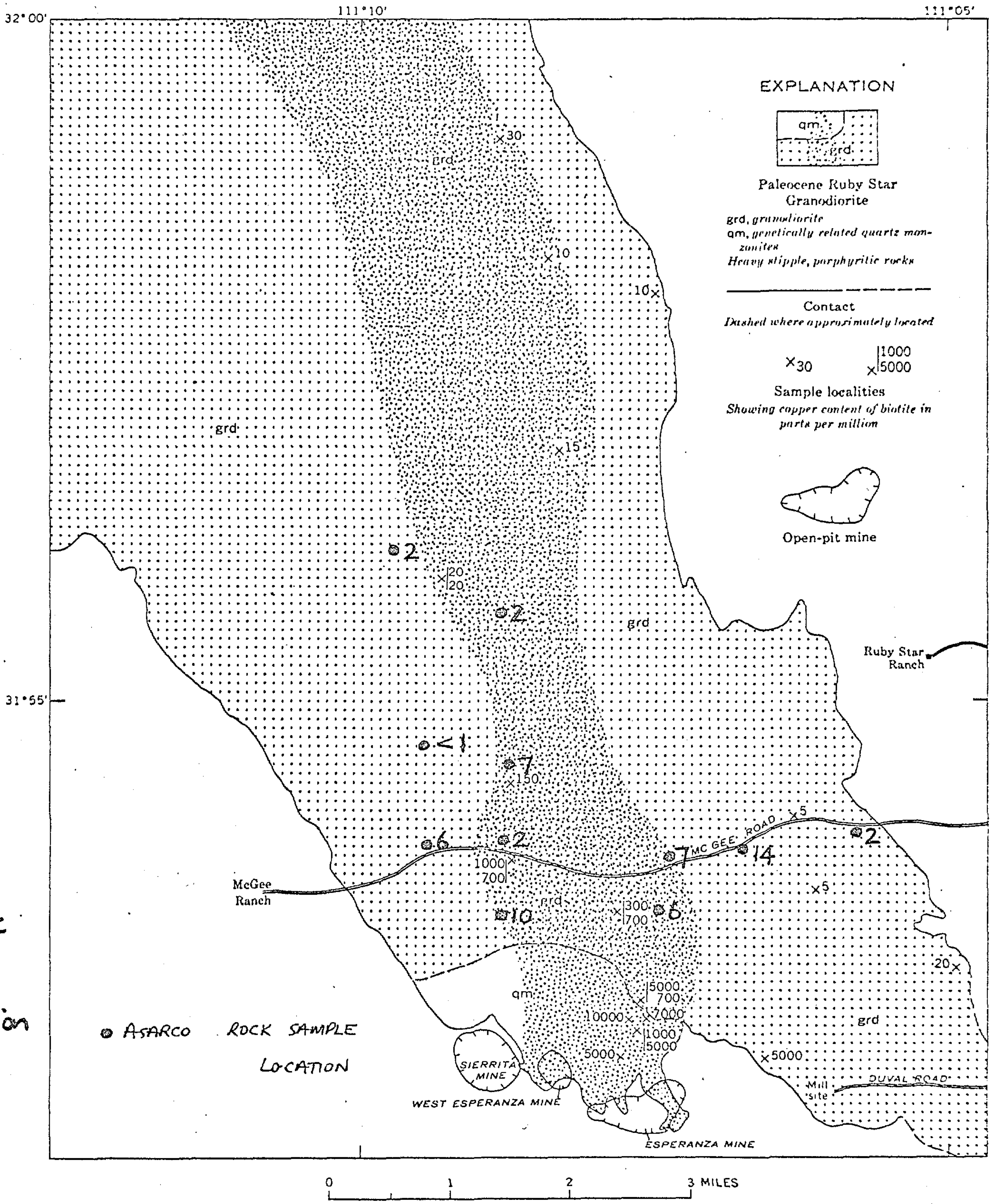


FIGURE 2.—Generalized map of composite stock and associated ore deposits in the southwestern part of the Pima mining district, east of the Sierrita Mountains, showing sample localities and copper content of biotite.

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

Rock Hg ("Total" digestion & A.A.)

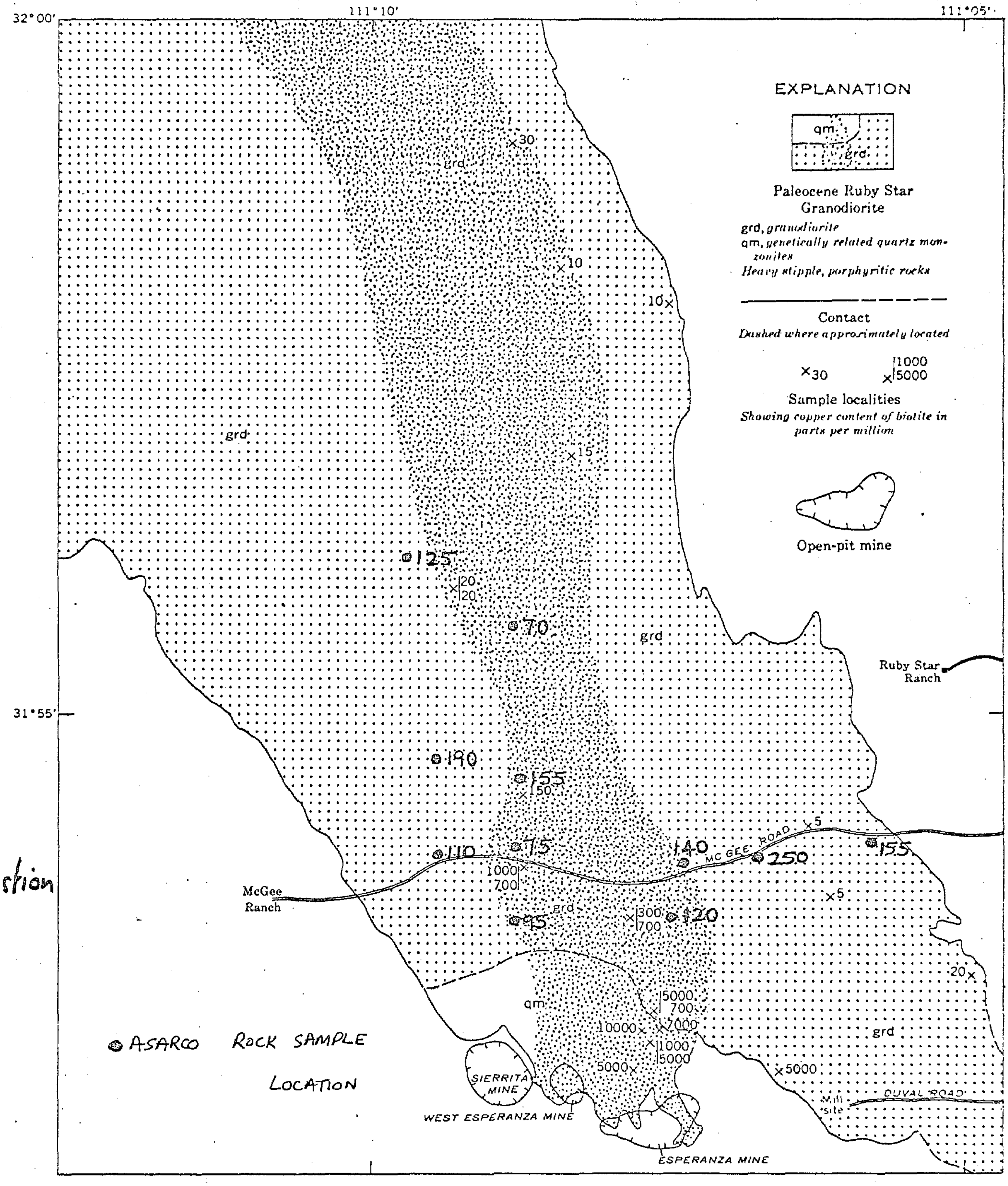


Fig. 6e

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.

Hg content (ppb) Asarco rock samples
(analysis by Geochemical Laboratory using an A.A. technique)

Biotite

Cu

(emission spec.)

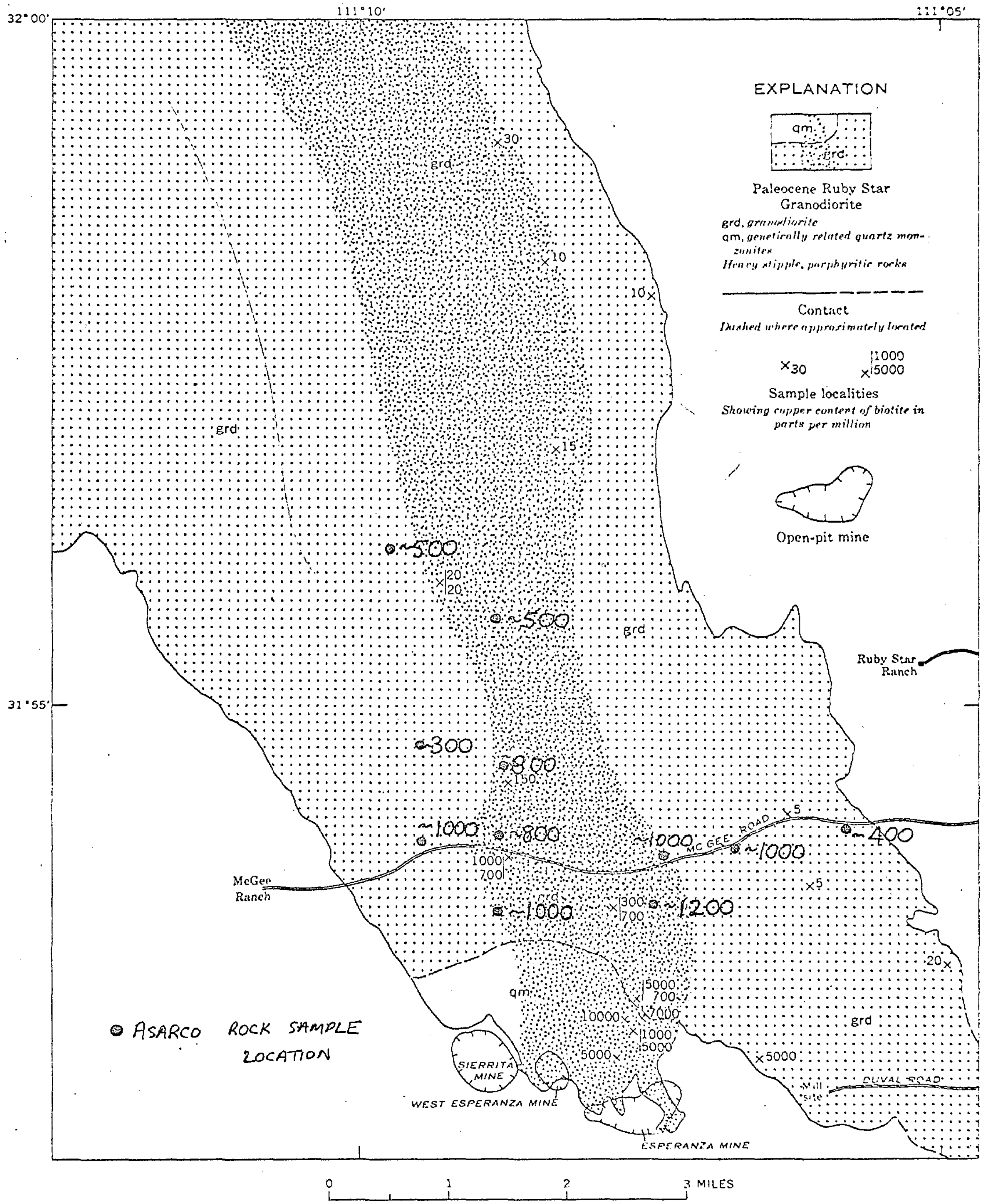


Fig. 7a

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 CSMRI using a semi-quantitative emission spectrographic technique.)

Biotite
Mo
(Emission spec.)

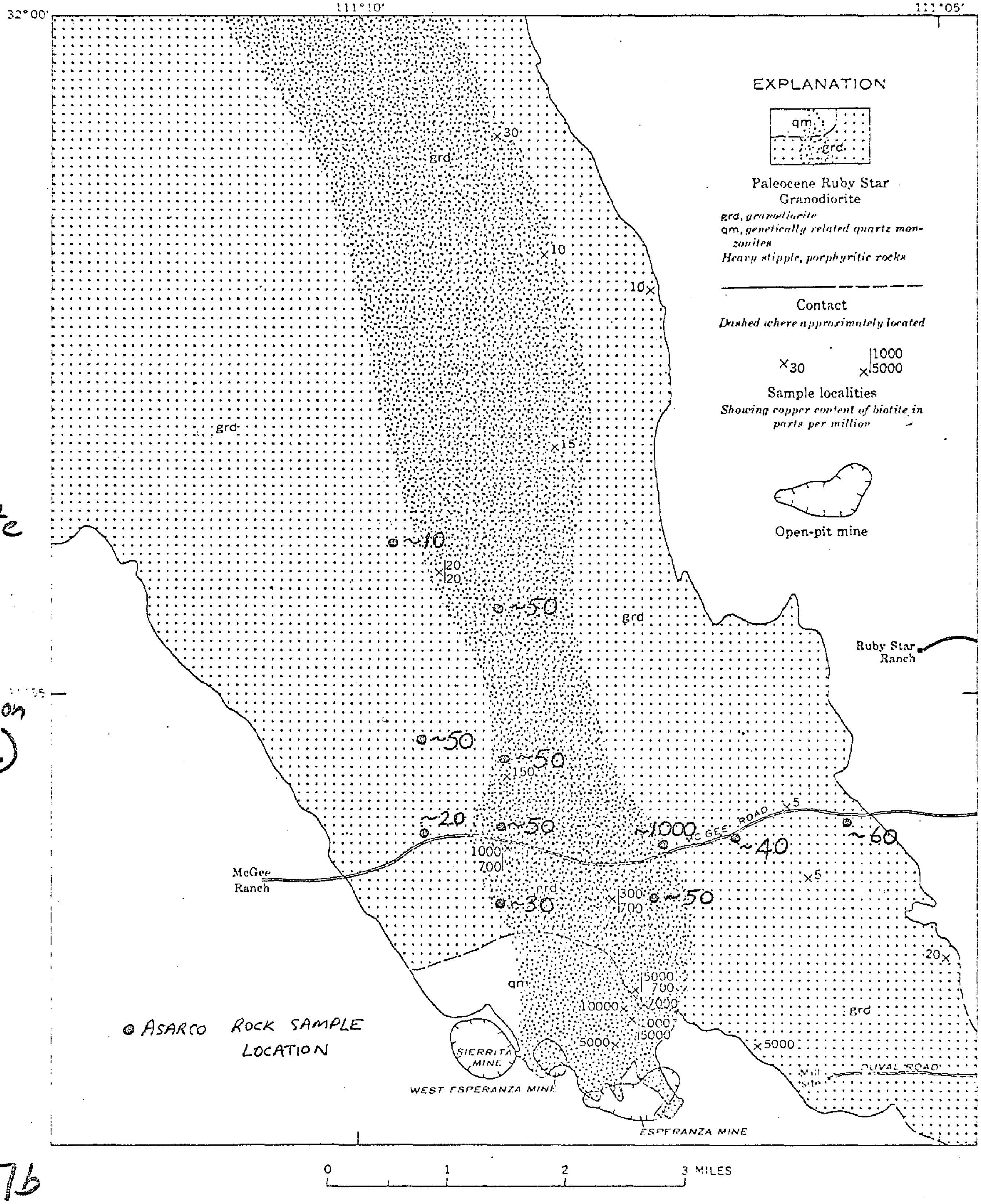


Fig 7b

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.

Mo content (ppm) of biotite in Asarco rock samples (analysis by CSMRI using a semi-quantitative emission spectrographic technique.)

Biotite

Cu

(x-ray fluorescence)

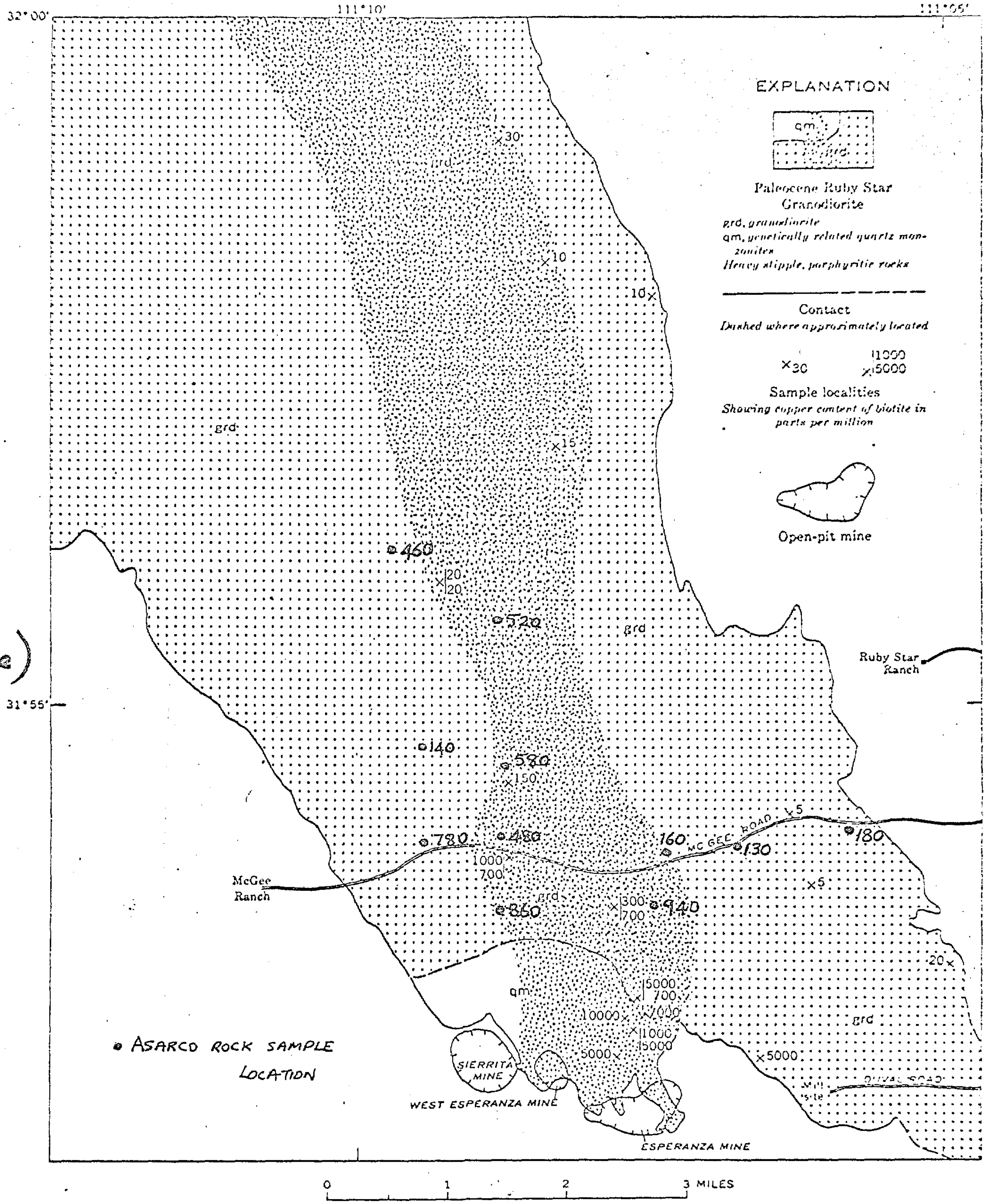


Fig. 8a

~~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)

Biotite

Pb

(x-ray fluorescence)

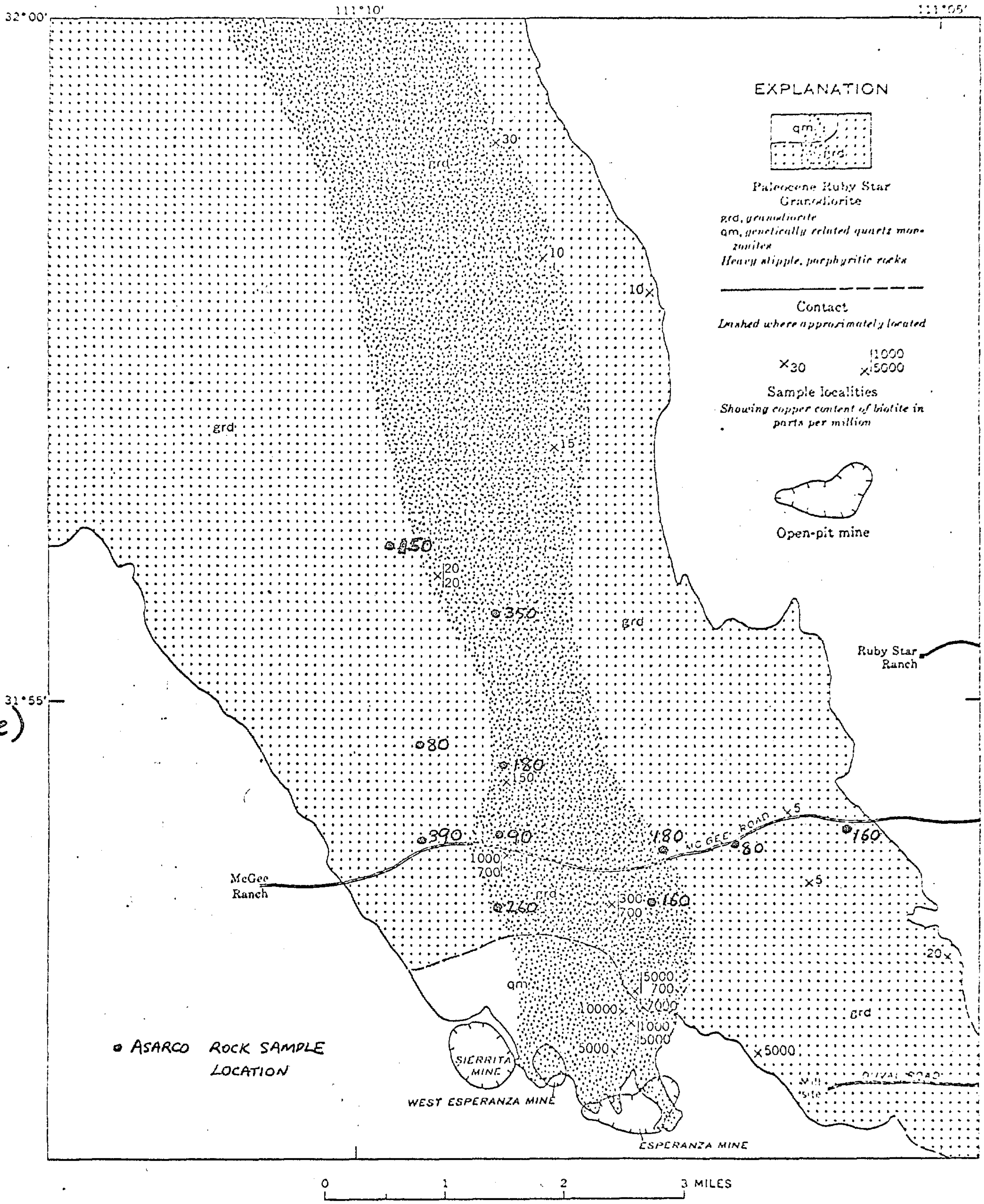


Fig. 8b

—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.)

Biotite

Zn (x-ray fluorescence)

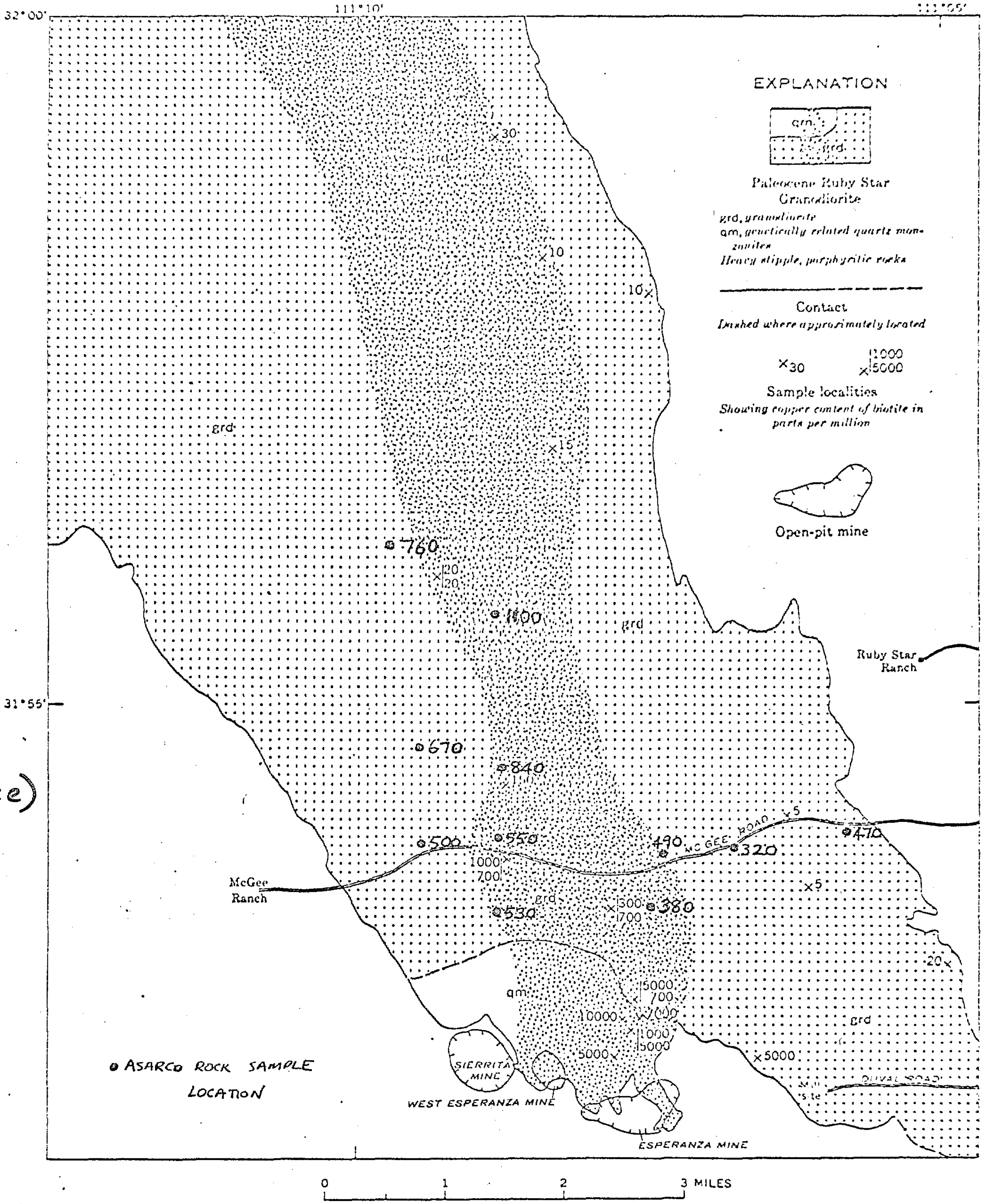


Fig. 8c

~~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.)

Biotite

Ba

(x-ray fluorescence)

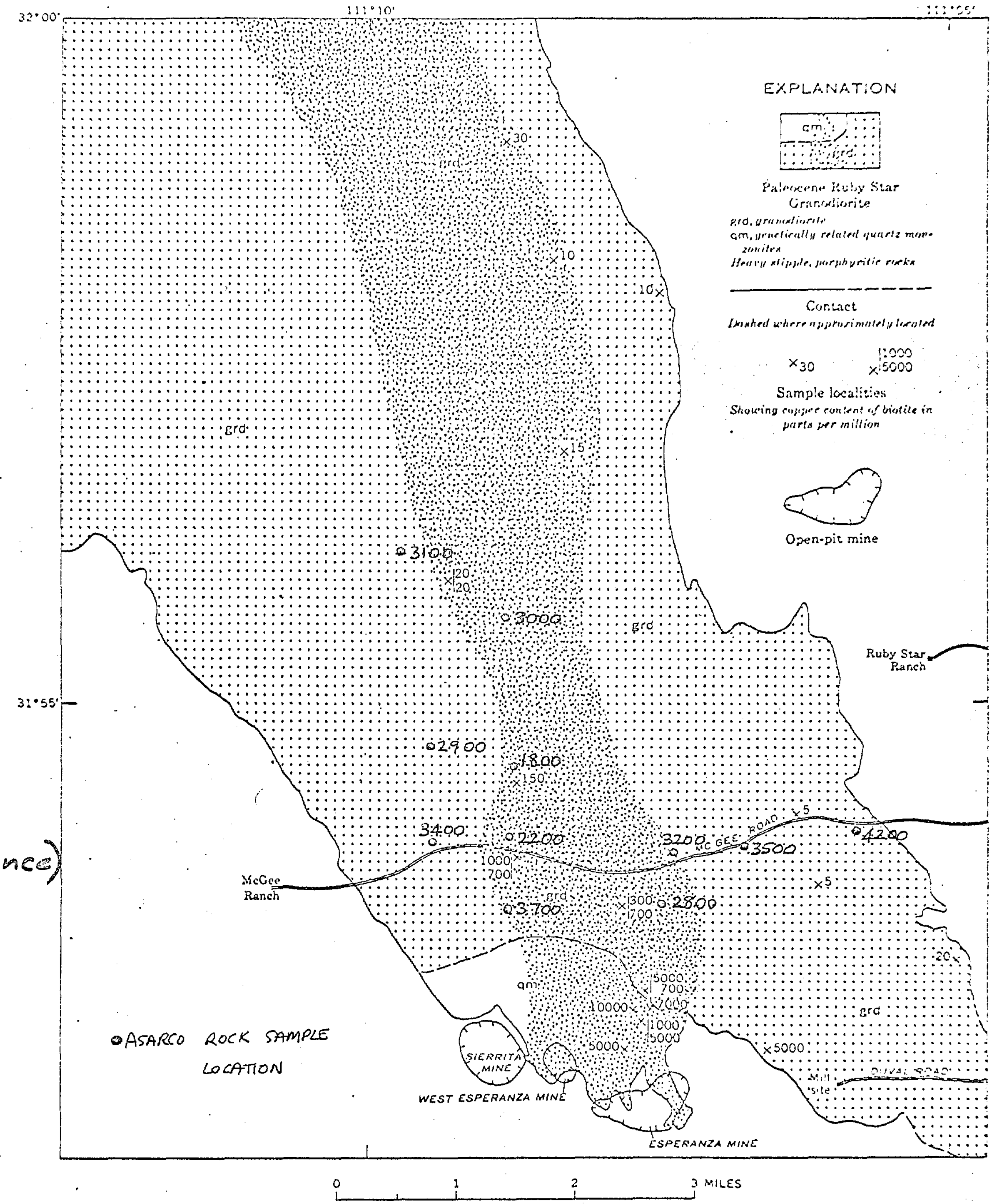


Fig. 8d

~~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.

Ba content (ppm) of biotite in Asarco rock samples (analysis by CSMRI using an x-ray fluorescence technique.)

Biotite

Br

(x-ray fluorescence)

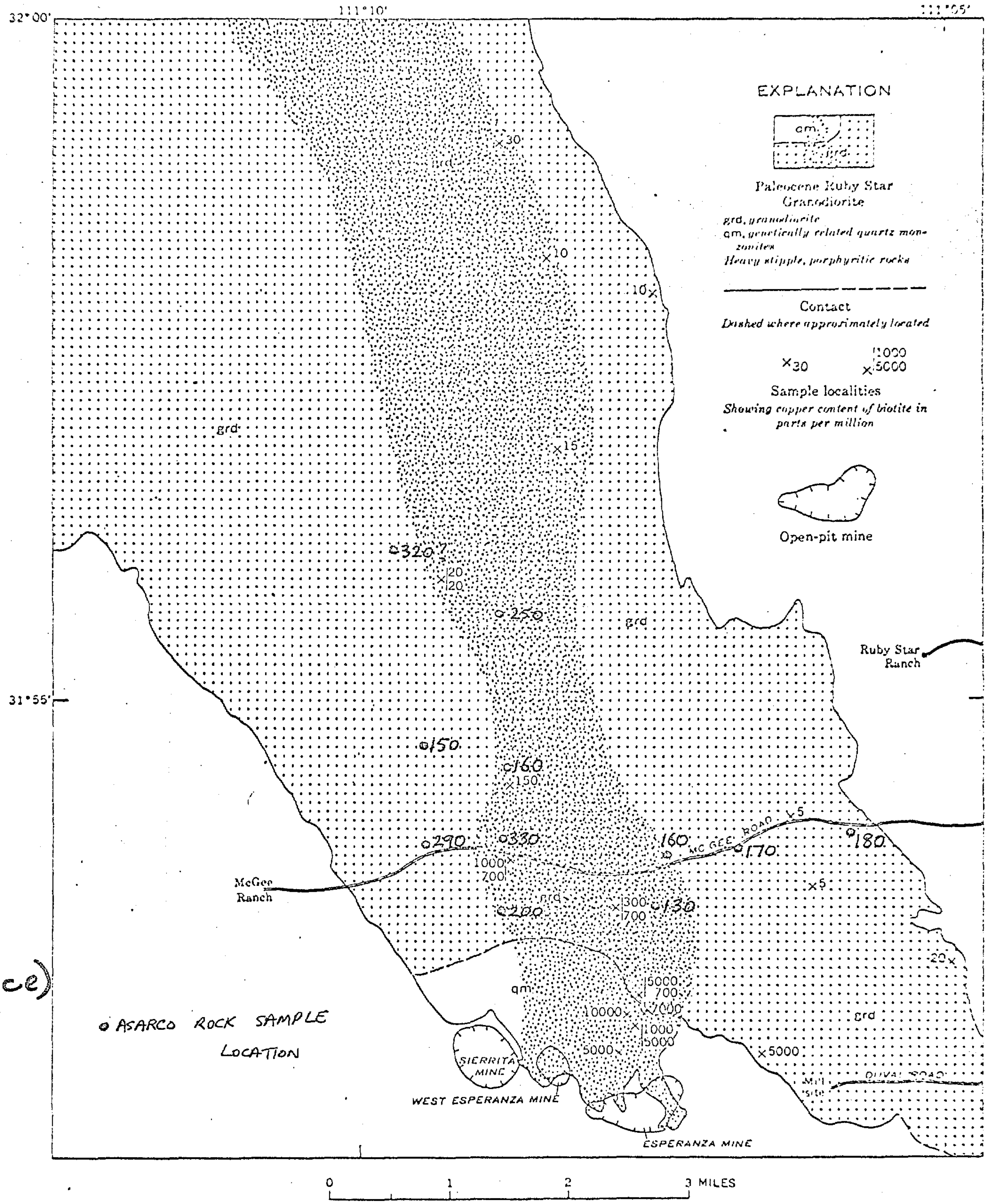
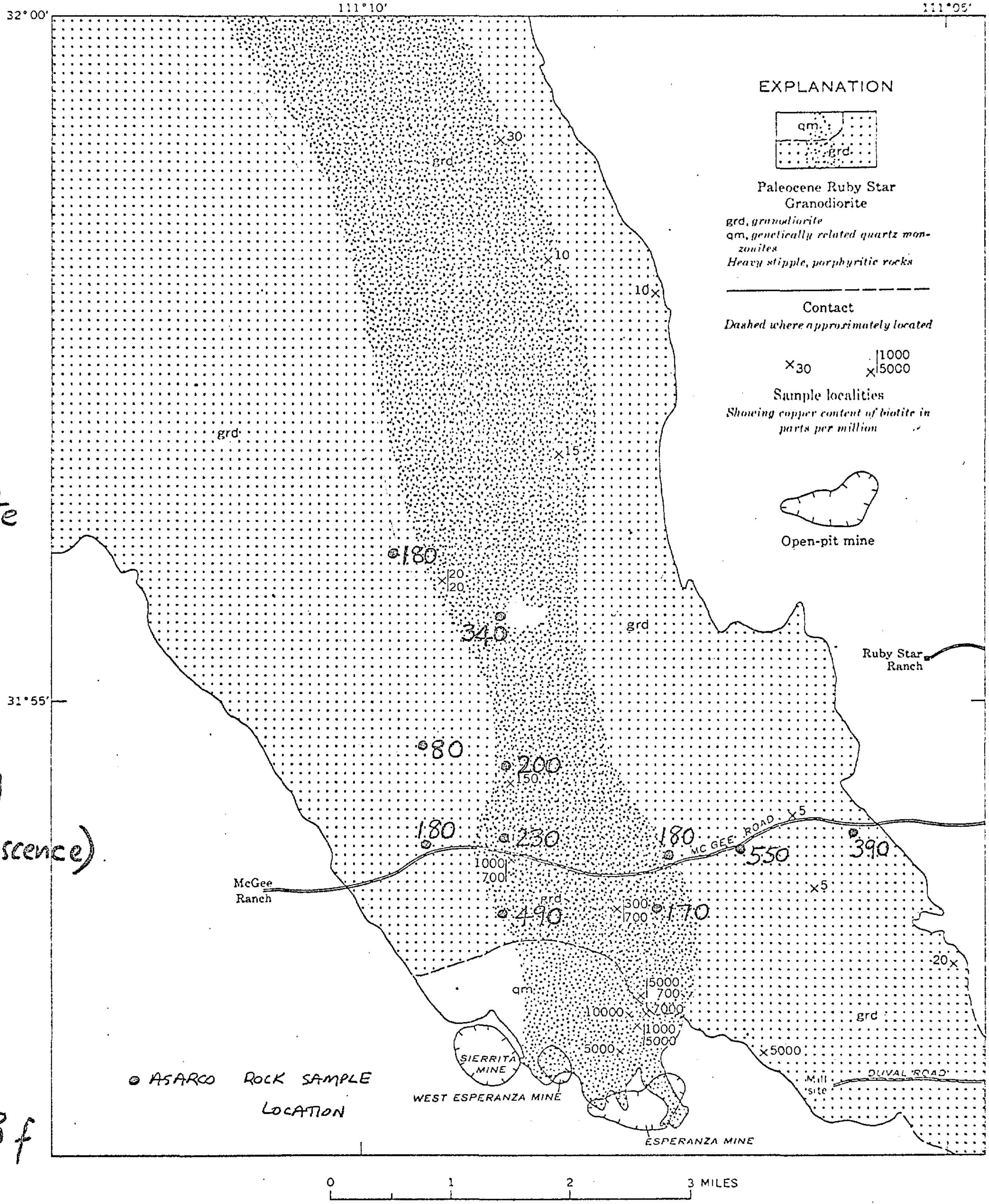


Fig. 8e

~~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.

Br content (ppm) of biotite in Asarco rock samples (analysis by CSMRI using an x-ray fluorescence technique)



Biotite

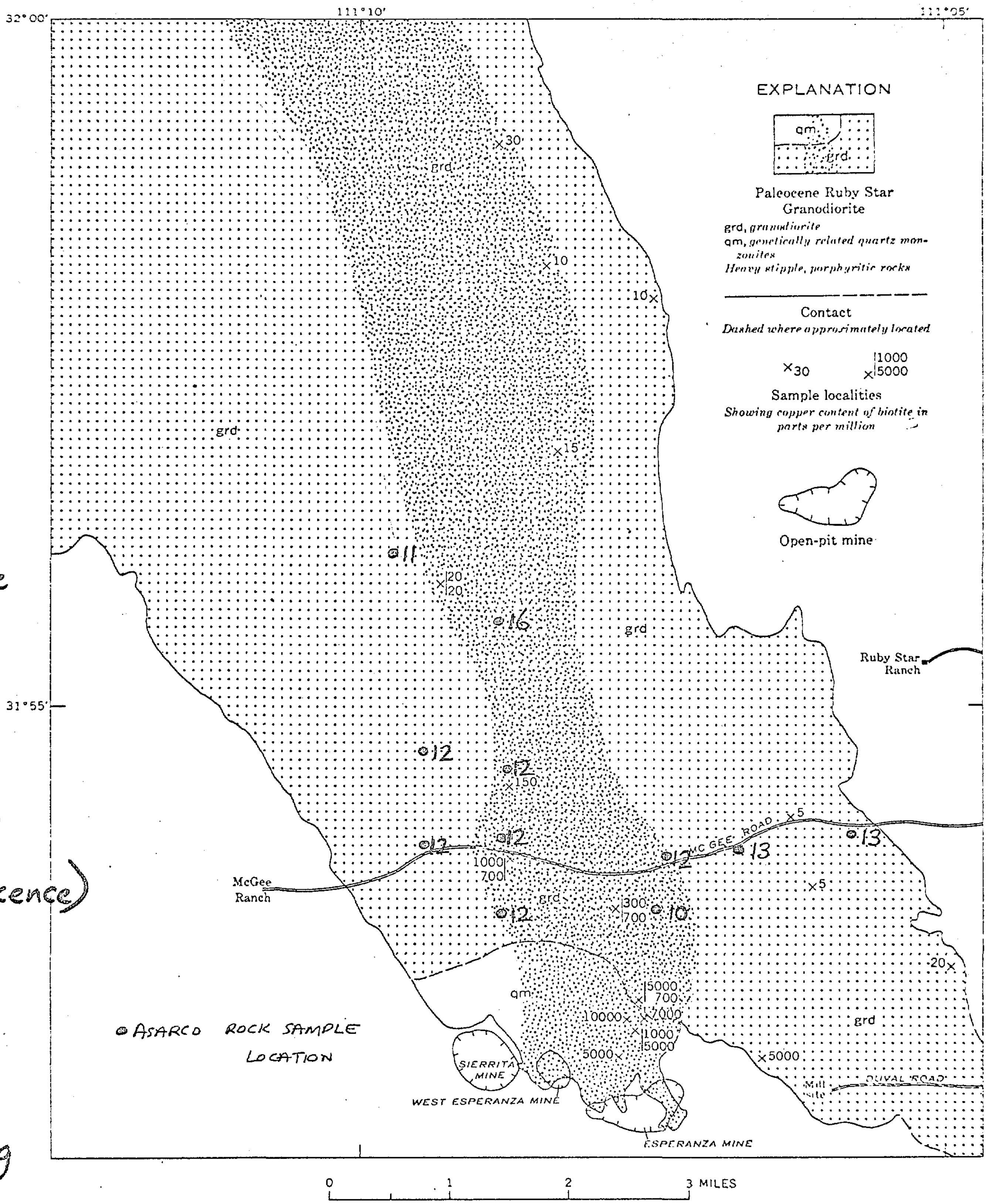
Cr

(x-ray fluorescence)

Fig. 8 f

~~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.

Cr content (ppm) of biotite in Asarco rock samples (analysis by CSMRI using an x-ray fluorescence technique)



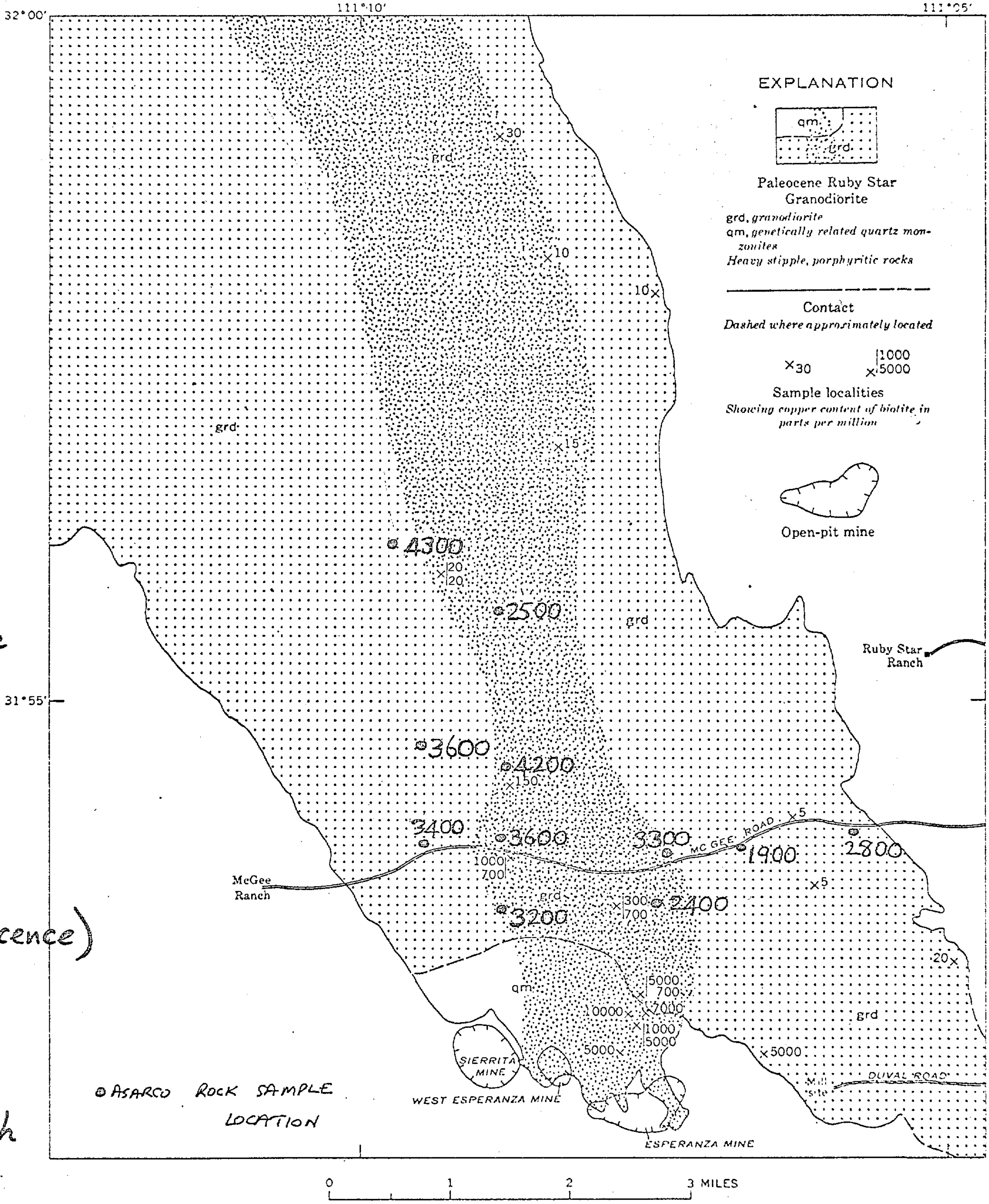
biotite

Fe (x-ray fluorescence)

Fig. 8 g

—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.

Fe content (%) of biotite in Asarco rock samples (analysis by CSMRI using an x-ray fluorescence technique)



Biotite

Mn

(x-ray fluorescence)

Fig. 8h

—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.

Mn content (ppm) of biotite in Asarco rock samples (analysis by CSMRI using an x-ray fluorescence technique)

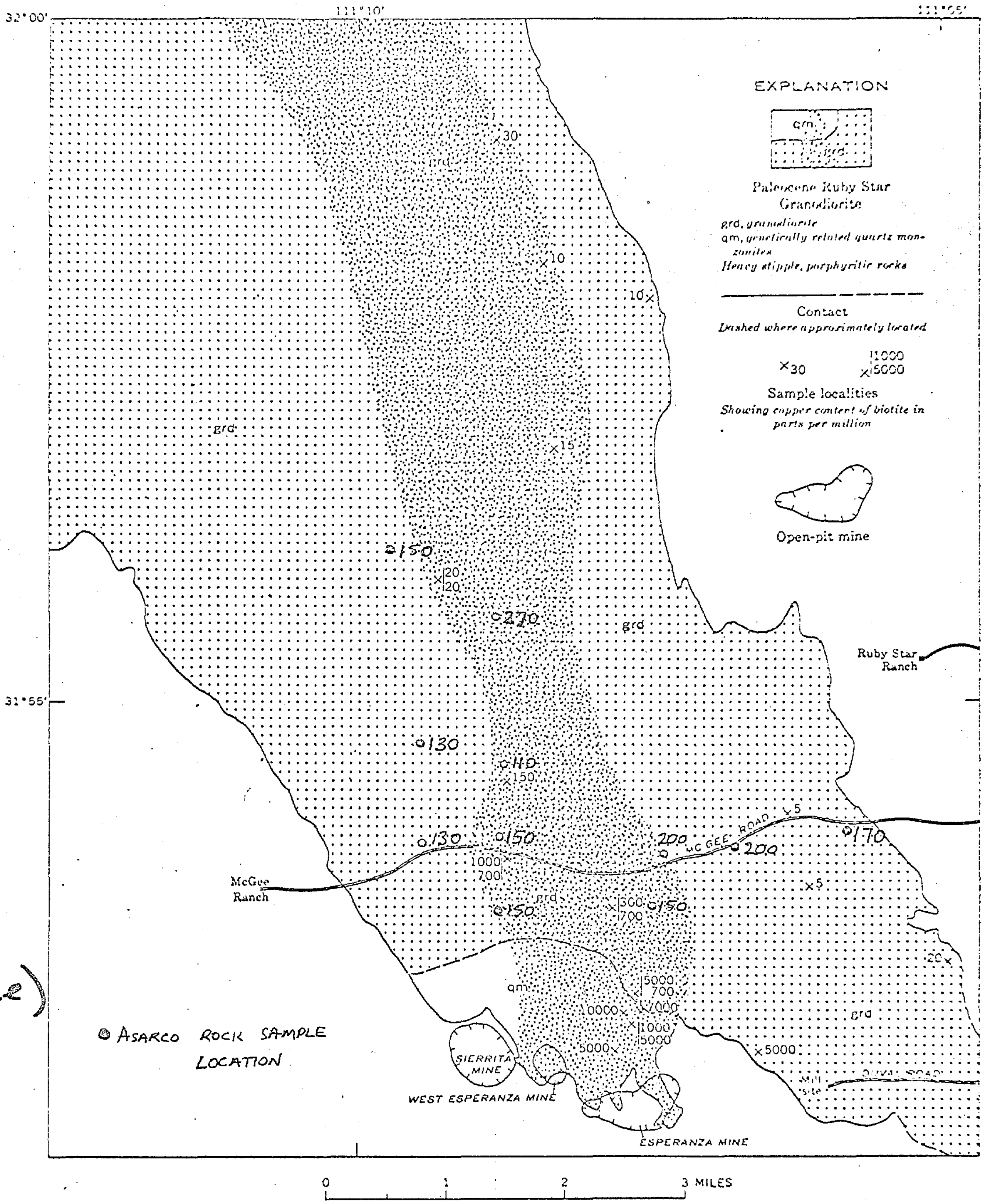
Ni

Biotite

Ni

(x-ray fluorescence)

Fig. 8 i



~~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.

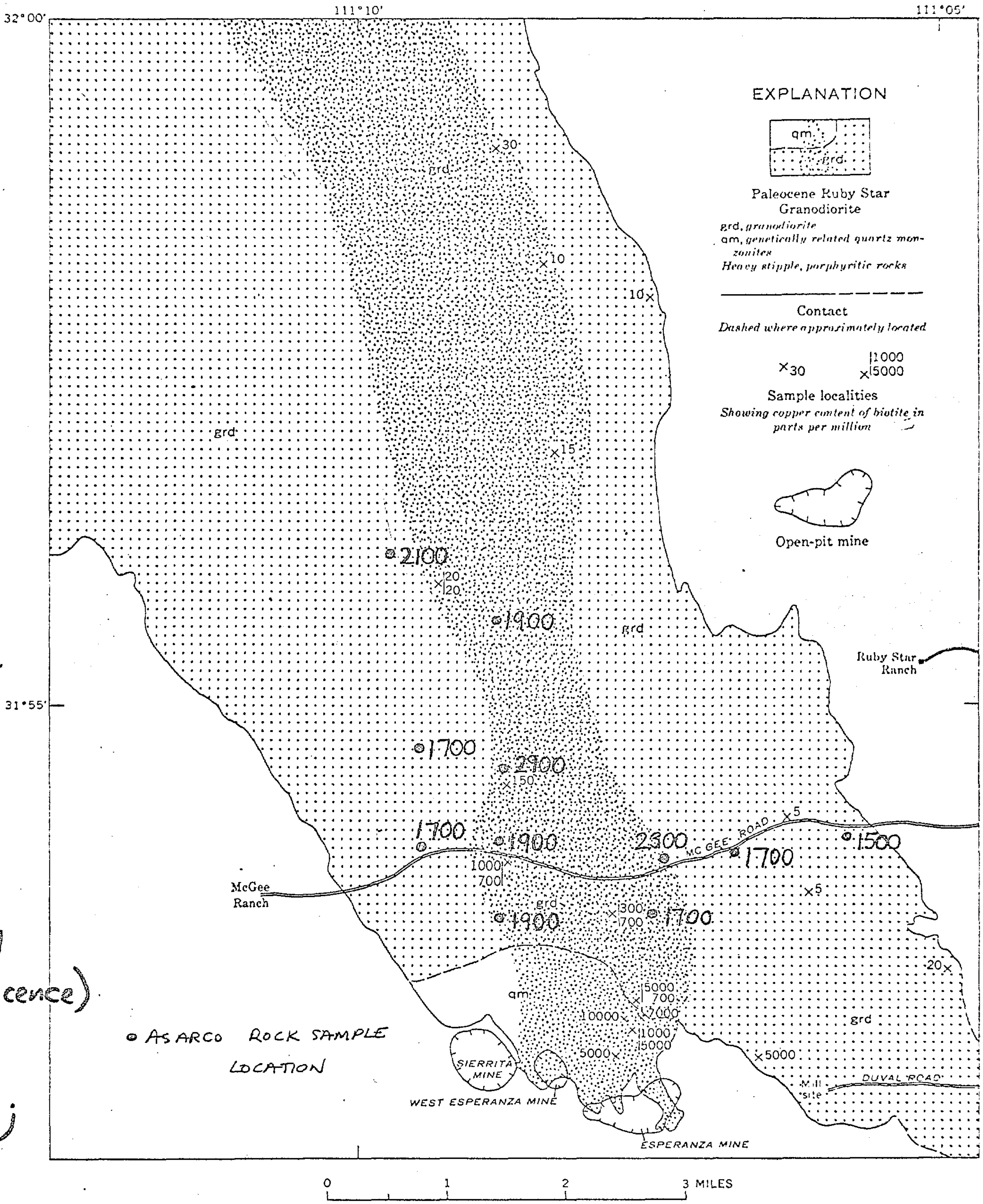
Ni content (ppm) of biotite in Asarco rock samples (analysis by CSMRI using an x-ray fluorescence technique)

Biotite

Ru

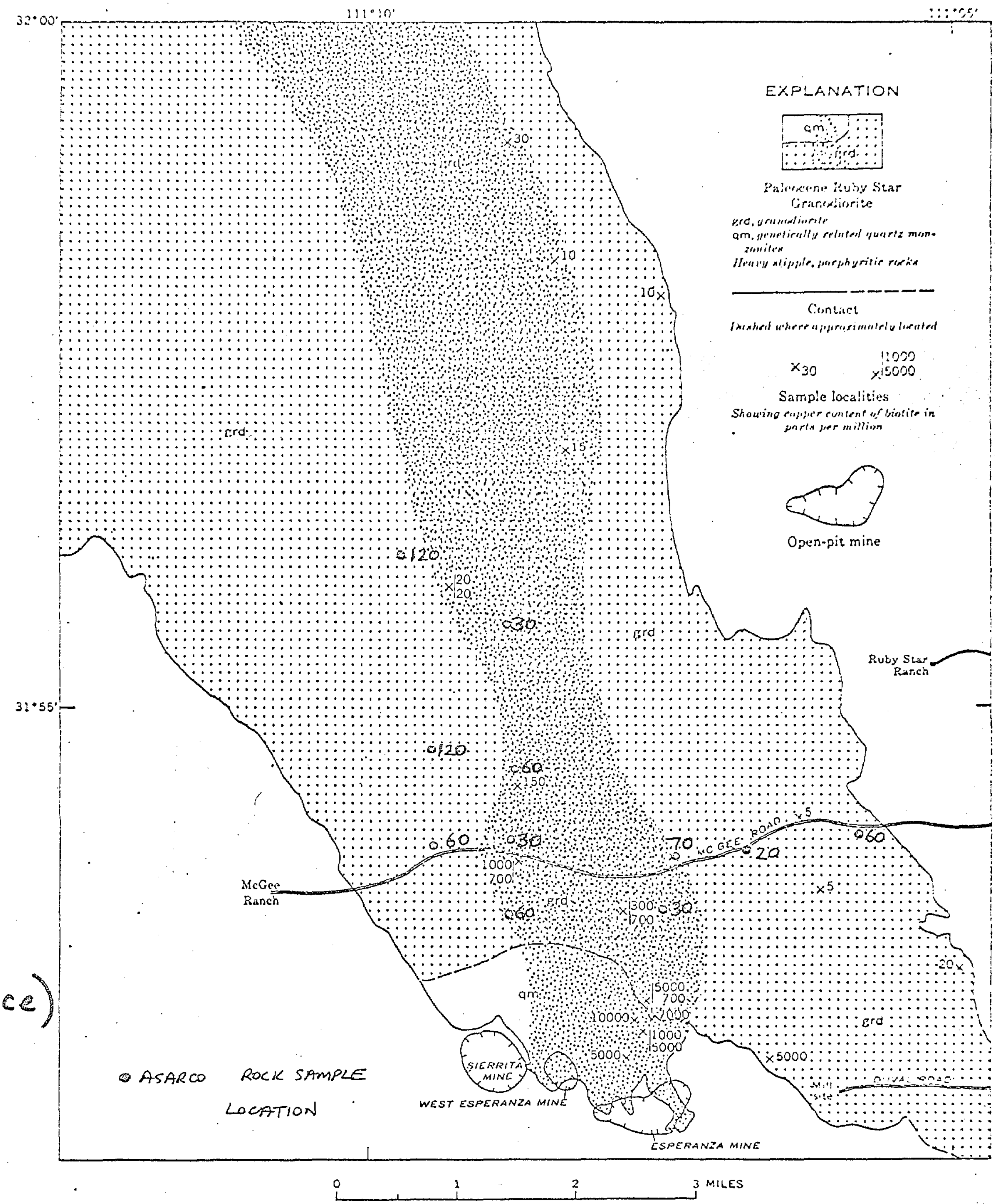
(x-ray fluorescence)

Fig. 8 j



~~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.

Ru content (ppm) of biotite in Asarco rock samples (analysis by CSMRI using an x-ray fluorescence technique)



Biotite

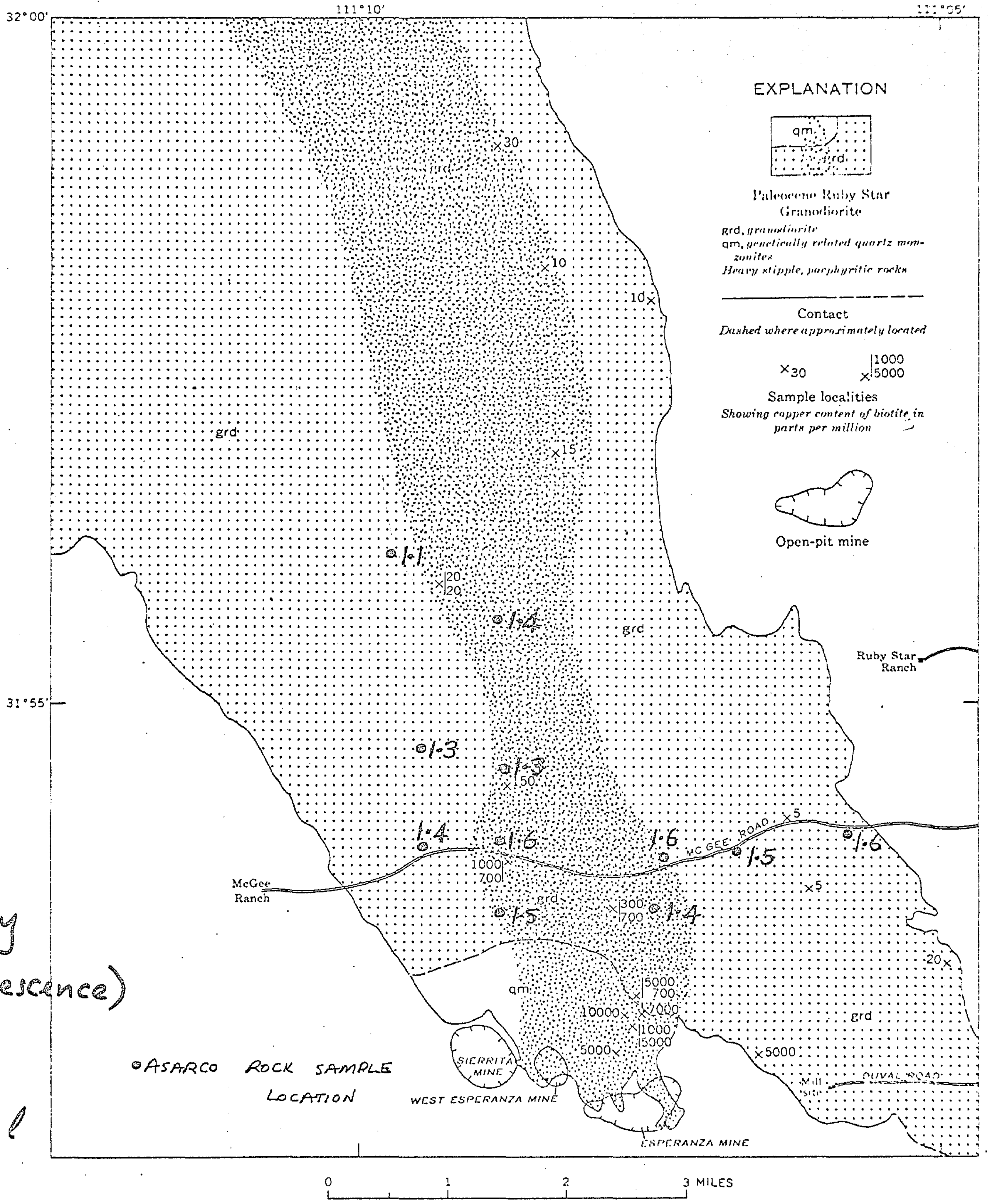
Sr

(x-ray fluorescence)

Fig. 8 k

—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.

Sr content (ppm) of biotite in Asarco rock samples (analysis by CSMRI using an x-ray fluorescence technique)



Biotite

Ti

(x-ray fluorescence)

Fig. 8 l

—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.

Ti content (%) of biotite in Asarco rock samples (analysis by CSMRI using an x-ray fluorescence technique)

Biotite

V

(x-ray fluorescence)

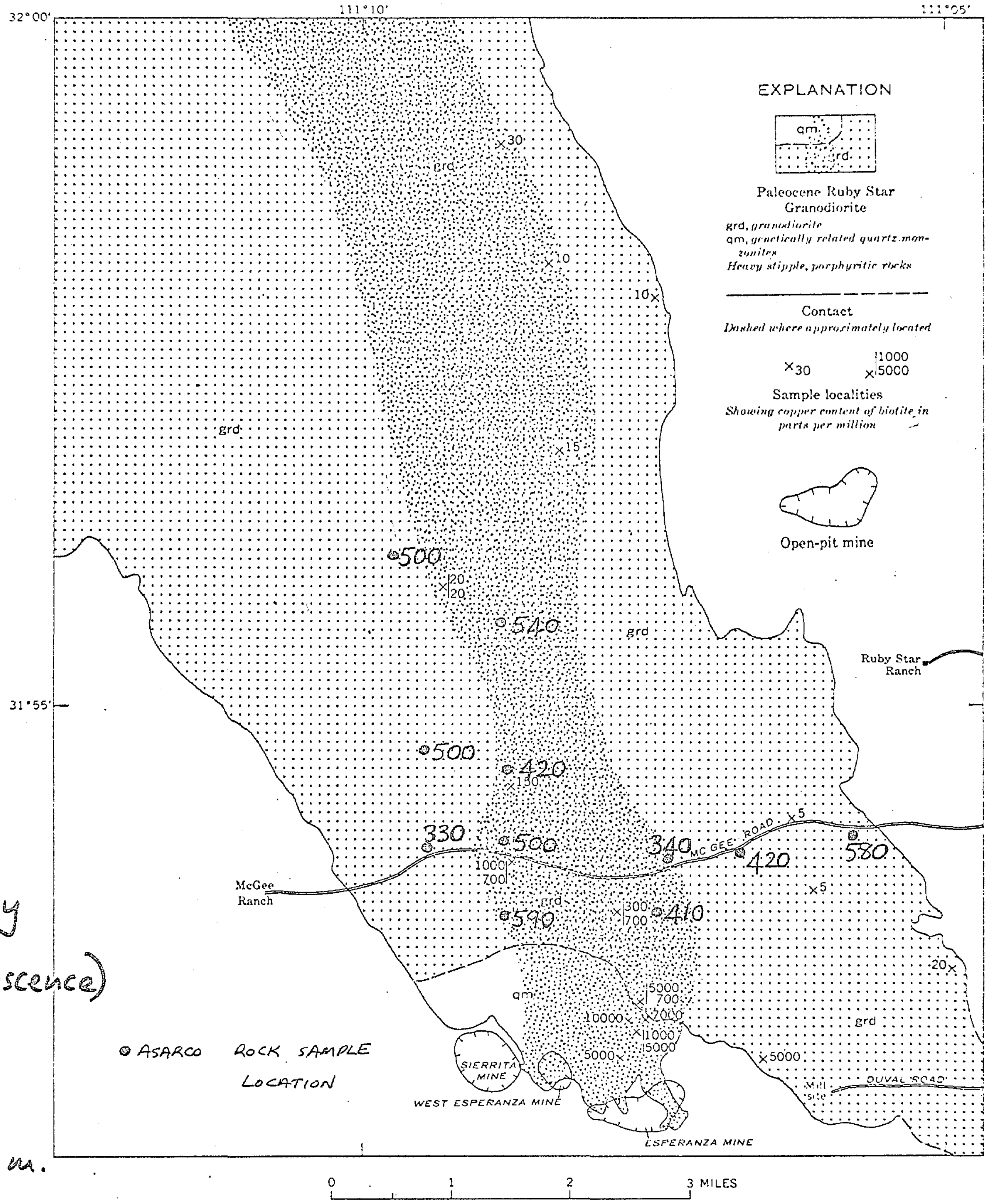


Fig. 8 m.

~~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.

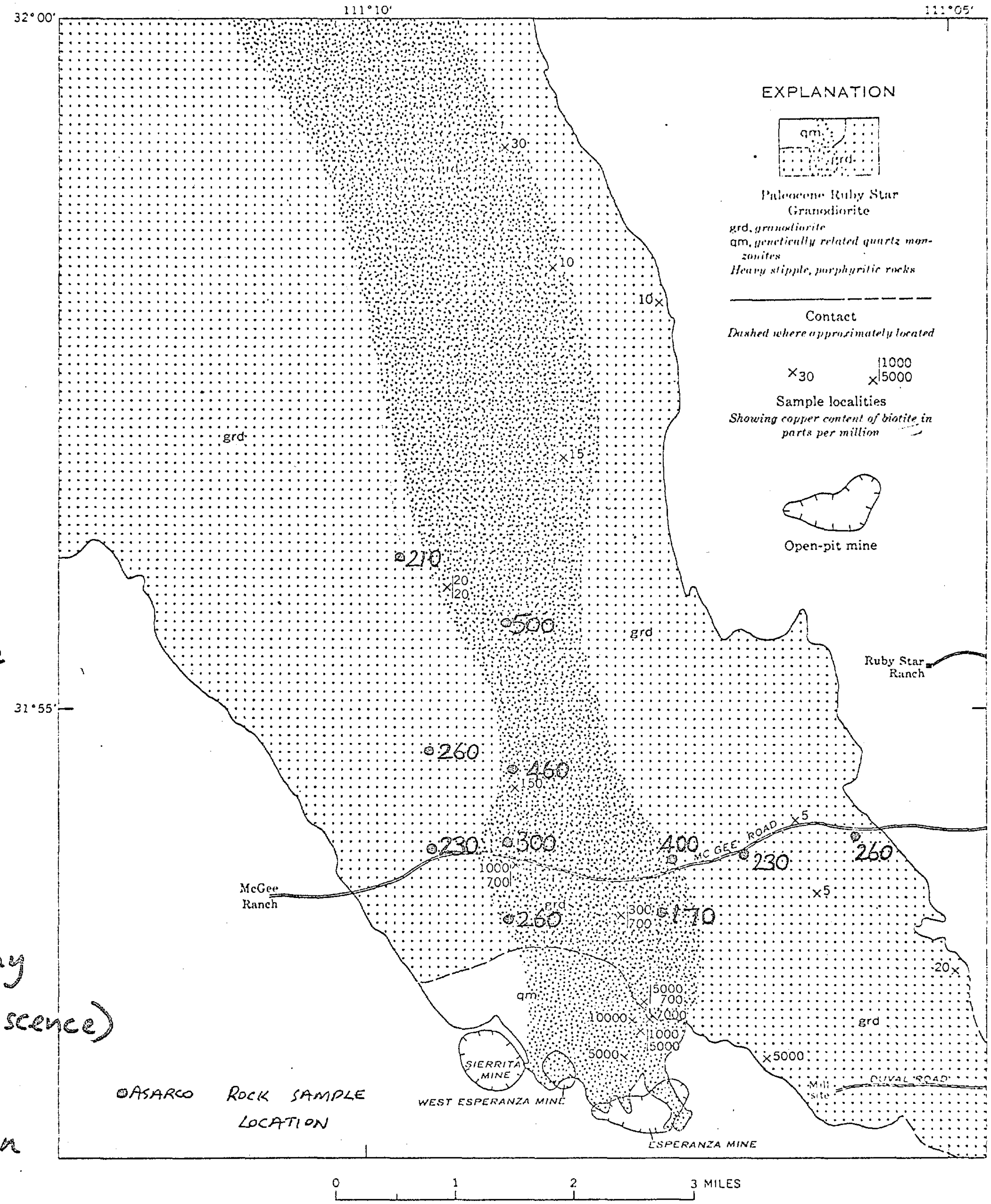
V content (ppm) of biotite in Asarco rock samples (analysis by CSMRI using an x-ray fluorescence technique)

Biotite

Y

(x-ray fluorescence)

Fig. 8n



~~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.

Y content (ppm) of biotite in Asarco rock samples (analysis by CSMRI using an x-ray fluorescence technique)

Biotite Zr (x-ray fluorescence)

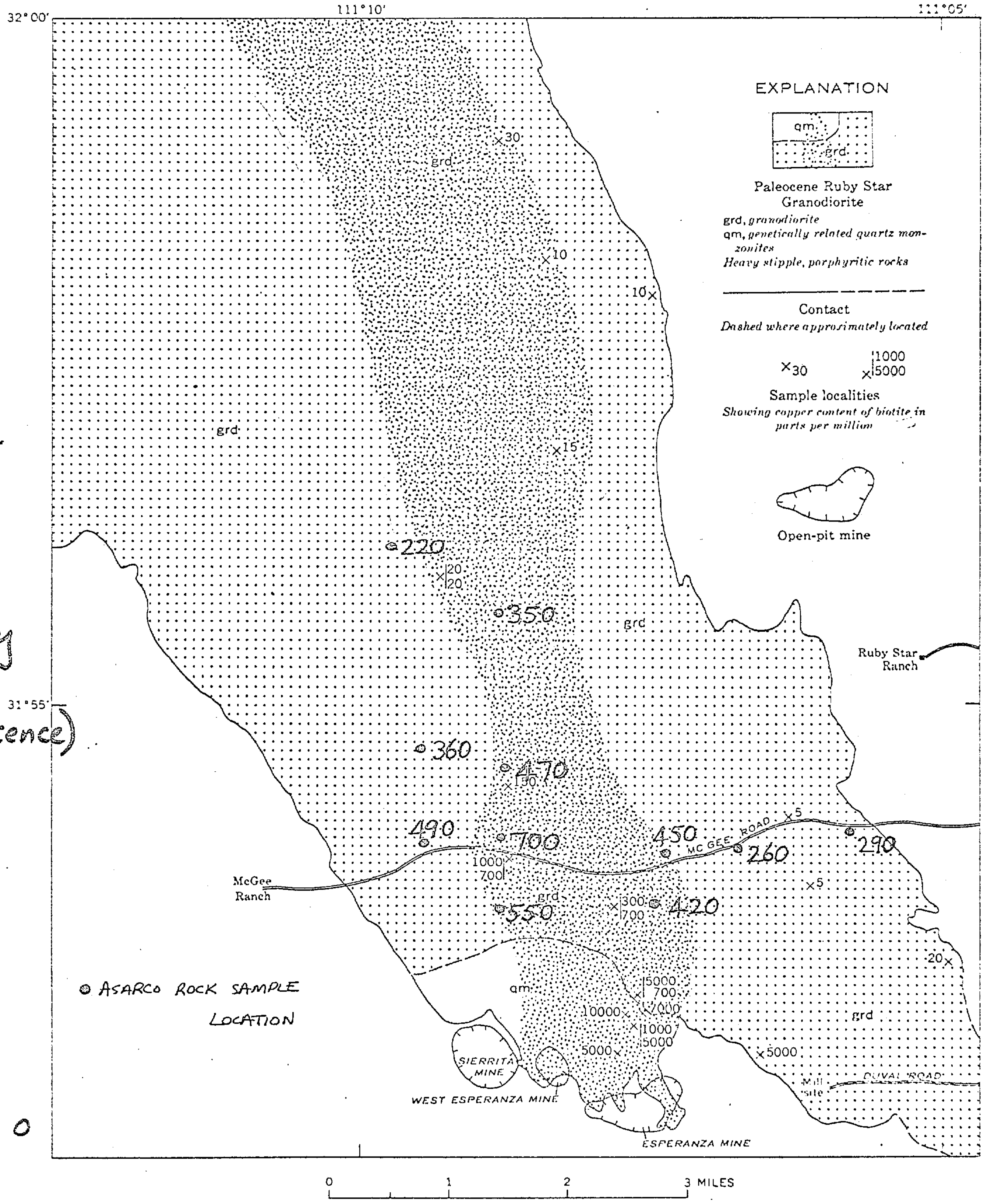


Fig. 8 o

~~FIGURE 4~~.—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.

Zr content (ppm) of biotite in Asarco rock samples (analysis by CSMRI using an x-ray fluorescence technique)

ATTACHMENT A

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

January 15, 1971

CSMRI Project No. 301217

RECEIVED
JAN 18 1971
GEOPHYSICAL DIVISION

REFER TO

Mr. Lloyd James
Geophysical Division
American Smelting and Refining Co.
3422 South 700 West
Salt Lake City UT 84104

Dear Lloyd:

Attached are Xerox copies of data sheets for the x-ray fluorescent analyses of the biotite from samples which you submitted to us. We are progressing with the emission spectrographic work and I hope to have the data for you late next week.

We short-cut the U.S.G.S. procedures shown in PP 700B. Our method for separating the biotite was as follows:

1. Jaw crush sample to -6 mesh.

2. Roll crush to -20 mesh.

3. Disc grind to nominal -65 mesh. Biotite flakes will not grind as easily as granular minerals and with a little effort a biotite concentration is made on the screen.

4. Sink-float biotite concentrate in TBE (S.G. 2.95).

5. Blend and split washed biotite.

6. Ring grind biotite for analysis.

I trust the foregoing description will be adequate for your purposes. If you have any questions, please contact me.

Sincerely,

James M. Link

James M. Link
Manager
Mining Division

JML:ebm
enclosures

SAMPLE: 301217 RS-1

NOTE: The values below are estimated percentages for the metal equivalent of the indicated elements. No check was made for elements with atomic numbers less than 22 (below titanium).

Copper	0.094	Iron	10.	Lanthanum	
Silver		Cobalt		Cerium	
Gold		Nickel	0.015	Praseodymium	
Zinc	0.038	Cesium		Neodymium	
Cadmium		Rubidium	0.17	Samarium	
Mercury		Barium	0.28	Europium	
Gallium		Strontium	0.003	Gadolinium	
Indium		Titanium	1.4	Terbium	
Thallium		Zirconium	0.042	Dysprosium	
Germanium		Hafnium		Holmium	
Tin		Thorium		Erbium	
Lead	0.016	Vanadium	0.041	Thulium	
Arsenic		Columbium		Ytterbium	
Antimony		Tantalum		Lutetium	
Bismuth		Chromium	0.017	Yttrium	0.017
Selenium		Molybdenum			
Tellurium		Tungsten			
Bromine	0.013	Uranium			
Iodine		Manganese	0.24		

SAMPLE: 301217 RS-2

NOTE: The values below are estimated percentages for the metal equivalent of the indicated elements. No check was made for elements with atomic numbers less than 22 (below titanium).

Copper	0.086	Iron	12.	Lanthanum	
Silver		Cobalt		Cerium	
Gold		Nickel	0.015	Praseodymium	
Zinc	0.053	Cesium		Neodymium	
Cadmium		Rubidium	0.19	Samarium	
Mercury		Barium	0.37	Europium	
Gallium		Strontium	0.006	Gadolinium	
Indium		Titanium	1.5	Terbium	
Thallium		Zirconium	0.055	Dysprosium	
Germanium		Hafnium		Holmium	
Tin		Thorium		Erbium	
Lead	0.026	Vanadium	0.059	Thulium	
Arsenic		Columbium		Ytterbium	
Antimony		Tantalum		Lutetium	
Bismuth		Chromium	0.049	Yttrium	0.026
Selenium		Molybdenum			
Tellurium		Tungsten			
Bromine	0.020	Uranium			
Iodine		Manganese	0.32		

SAMPLE: 301217 RS-5

... check was made for elements with atomic numbers less than 22 (below titanium).

Element	Value	Element	Value	Element	Value
Copper	0.048	Iron	12.	Lanthanum	0.020
Silver		Cobalt		Cerium	0.053
Gold		Nickel	0.015	Praseodymium	
Zinc	0.055	Cesium		Neodymium	
Cadmium		Rubidium	0.19	Samarium	
Mercury		Barium	0.22	Europium	
Gallium		Strontium	0.003	Gadolinium	
Indium		Titanium	1.6	Terbium	
Thallium		Zirconium	0.070	Dysprosium	
Germanium		Hafnium		Holmium	
Tin		Thorium		Erbium	
Lead	0.009	Vanadium	0.050	Thulium	
Arsenic		Columbium	0.009	Ytterbium	
Antimony		Tantalum		Lutetium	
Bismuth		Chromium	0.023	Yttrium	0.030
Selenium		Molybdenum			
Tellurium		Tungsten			
Bromine	0.033	Uranium			
Iodine		Manganese	0.36		

SAMPLE: 301217 RS-4

... elements. No check was made for elements with atomic numbers less than 22 (below titanium).

Element	Value	Element	Value	Element	Value
Copper	0.058	Iron	12.	Lanthanum	
Silver		Cobalt		Cerium	
Gold		Nickel	0.011	Praseodymium	
Zinc	0.084	Cesium		Neodymium	
Cadmium		Rubidium	0.29	Samarium	
Mercury		Barium	0.18	Europium	
Gallium		Strontium	0.006	Gadolinium	
Indium		Titanium	1.3	Terbium	
Thallium		Zirconium	0.047	Dysprosium	
Germanium		Hafnium		Holmium	
Tin		Thorium		Erbium	
Lead	0.018	Vanadium	0.042	Thulium	
Arsenic		Columbium	0.005	Ytterbium	
Antimony		Tantalum		Lutetium	
Bismuth		Chromium	0.020	Yttrium	0.046
Selenium		Molybdenum	0.002		
Tellurium		Tungsten			
Bromine	0.016	Uranium			
Iodine		Manganese	0.42		

SAMPLE: 301217 RS-5

[illegible] the metal equivalent of the indicated elements. No check was made for elements with atomic numbers less than 22 (below titanium).

Copper	0.014	Iron	12.	Lanthanum	
Silver		Cobalt	0.004	Cerium	
Gold		Nickel	0.013	Praseodymium	
Zinc	0.067	Cesium		Neodymium	
Cadmium		Rubidium	0.17	Samarium	
Mercury		Barium	0.29	Europium	
Gallium		Strontium	0.012	Gadolinium	
Indium		Titanium	1.3	Terbium	
Thallium		Zirconium	0.036	Dysprosium	
Germanium		Hafnium		Holmium	
Tin		Thorium		Erbium	
Lead	0.008	Vanadium	0.050	Thulium	
Arsenic		Columbium		Ytterbium	
Antimony		Tantalum		Lutetium	
Bismuth		Chromium	0.008	Yttrium	0.026
Selenium		Molybdenum			
Tellurium		Tungsten			
Bromine	0.015	Uranium			
Iodine		Manganese	0.36		

SAMPLE: 301217 RS-6

the metal equivalent of the indicated elements. No check was made for elements with atomic numbers less than 22 (below titanium).

Copper	0.052	Iron	16.	Lanthanum	
Silver		Cobalt	0.003	Cerium	
Gold		Nickel	0.027	Praseodymium	
Zinc	0.11	Cesium		Neodymium	
Cadmium		Rubidium	0.19	Samarium	
Mercury		Barium	0.30	Europium	
Gallium		Strontium	0.003	Gadolinium	
Indium		Titanium	1.4	Terbium	
Thallium		Zirconium	0.035	Dysprosium	
Germanium		Hafnium		Holmium	
Tin		Thorium		Erbium	
Lead	0.035	Vanadium	0.054	Thulium	
Arsenic		Columbium	0.007	Ytterbium	
Antimony		Tantalum		Lutetium	
Bismuth		Chromium	0.034	Yttrium	0.050
Selenium		Molybdenum			
Tellurium		Tungsten			
Bromine	0.025	Uranium			
Iodine		Manganese	0.25		

SAMPLE: 301217 RS-7

the metal equivalent of the indicated elements. No check was made for elements with atomic numbers less than 22 (below titanium).

Copper	0.046	Iron	11.	Lanthanum	
Silver		Cobalt	0.004	Cerium	
Gold		Nickel	0.015	Praseodymium	
Zinc	0.076	Cesium		Neodymium	
Cadmium		Rubidium	0.21	Samarium	
Mercury		Barium	0.31	Europium	
Gallium		Strontium	0.012	Gadolinium	
Indium		Titanium	1.1	Terbium	
Thallium		Zirconium	0.022	Dysprosium	
Germanium		Hafnium		Holmium	
Tin		Thorium		Erbium	
Lead	0.015	Vanadium	0.050	Thulium	
Arsenic		Columbium		Ytterbium	
Antimony		Tantalum		Lutetium	
Bismuth		Chromium	0.018	Yttrium	0.021
Selenium		Molybdenum			
Tellurium		Tungsten			
Bromine	0.32	Uranium			
Iodine		Manganese	0.43		

AMPLE: 301217 RS-8

NOTE: The values below are estimated percentages for the metal equivalent of the indicated elements. No check was made for elements with atomic numbers less than 22 (below titanium).

Copper	0.078	Iron	12.	Lanthanum	
Silver		Cobalt	0.004	Cerium	
Gold		Nickel	0.013	Praseodymium	
Zinc	0.050	Cesium		Neodymium	
Cadmium		Rubidium	0.17	Samarium	
Mercury		Barium	0.34	Europium	
Gallium		Strontium	0.006	Gadolinium	
Indium		Titanium	1.4	Terbium	
Thallium		Zirconium	0.049	Dysprosium	
Germanium		Hafnium		Holmium	
Tin		Thorium		Erbium	
Lead	0.039	Vanadium	0.033	Thulium	
Arsenic		Columbium		Ytterbium	
Antimony		Tantalum		Lutetium	
Bismuth		Chromium	0.018	Yttrium	0.023
Selenium		Molybdenum			
Tellurium		Tungsten			
Bromine	0.029	Uranium			
Iodine		Manganese	0.34		

SAMPLE: 301217 RS-9

check was made for elements with atomic numbers less than 22 (below titanium).

Copper	0.12	Iron	12.	Lanthanum	
Silver		Cobalt	0.004	Cerium	
Gold		Nickel	0.020	Praseodymium	
Zinc	0.049	Cesium		Neodymium	
Cadmium		Rubidium	0.23	Samarium	
Mercury		Barium	0.32	Europium	
Gallium		Strontium	0.007	Gadolinium	
Indium		Titanium	1.6	Terbium	
Thallium		Zirconium	0.045	Dysprosium	
Germanium		Hafnium		Holmium	
Tin		Thorium		Erbium	
Lead	0.018	Vanadium	0.034	Thulium	
Arsenic		Columbium	0.010	Ytterbium	
Antimony		Tantalum		Lutetium	
Bismuth		Chromium	0.018	Yttrium	0.040
Selenium		Molybdenum	0.15		
Tellurium		Tungsten			
Bromine	0.016	Uranium			
Iodine		Manganese	0.33		

The values below are estimated percentages for the metal equivalent of the indicated elements. No check was made for elements with atomic numbers less than 22 (below titanium).

SAMPLE: 301217 RS-10

Copper	0.13	Iron	13.	Lanthanum	
Silver		Cobalt	0.002	Cerium	
Gold		Nickel	0.020	Praseodymium	
Zinc	0.032	Cesium		Neodymium	
Cadmium		Rubidium	0.17	Samarium	
Mercury		Barium	0.35	Europium	
Gallium		Strontium	0.002	Gadolinium	
Indium		Titanium	1.5	Terbium	
Thallium		Zirconium	0.026	Dysprosium	
Germanium		Hafnium		Holmium	
Tin		Thorium		Erbium	
Lead	0.008	Vanadium	0.042	Thulium	
Arsenic		Columbium		Ytterbium	
Antimony		Tantalum		Lutetium	
Bismuth		Chromium	0.055	Yttrium	0.023
Selenium		Molybdenum			
Tellurium		Tungsten			
Bromine	0.017	Uranium			
Iodine		Manganese	0.19		

SAMPLE: 301217 RS-11

NOTE: The values below are estimated percentages for the metal equivalent of the indicated elements. No check was made for elements with atomic numbers less than 22 (below titanium).

Copper	0.011	Iron	13.	Lanthanum	
Silver		Cobalt		Cerium	
Gold		Nickel	0.017	Praseodymium	
Zinc	0.047	Cesium		Neodymium	
Cadmium		Rubidium	0.15	Samarium	
Mercury		Barium	0.42	Europium	
Gallium		Strontium	0.006	Gadolinium	
Indium		Titanium	1.6	Terbium	
Thallium		Zirconium	0.029	Dysprosium	
Germanium		Hafnium		Holmium	
Tin		Thorium		Erbium	
Lead	0.016	Vanadium	0.058	Thulium	
Arsenic		Columbium		Ytterbium	
Antimony		Tantalum		Lutetium	
Bismuth		Chromium	0.039	Yttrium	0.026
Selenium		Molybdenum			
Tellurium		Tungsten			
Bromine	0.018	Uranium	0.007		
Iodine		Manganese	0.28		

ATTACHMENT B

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

January 28, 1971

RECEIVED
FEB 1 1971
GEOPHYSICAL DIVISION

CSMRI Project No. 301217

Mr. Lloyd James
Geophysical Division
American Smelting and Refining Co.
3422 South 700 West
Salt Lake City UT 84119

Dear Lloyd:

Enclosed are Xerox copies of the emission spectrographic analyses of the biotite samples. If you have any questions regarding these analyses, please contact me.

We are returning the samples under separate cover. The biotite splits are being forwarded (air mail parcel post) and the bulk rejects are being sent air freight.

We have retained several grams of biotite from a few of the samples for our probe work. We would suggest that you allow us to examine these samples to determine the variation in copper content from grain to grain, as well as the variation or zonation within the grains. If copper content is uniform enough it might well be cheaper to perform the analyses on polished sections in the probe. I would estimate that this work would cost an additional $350 to $450. This should allow us to examine enough grains to determine whether or not the copper is actually uniformly distributed and also to estimate a cost per sample for routine analysis.

I realize that it will be several weeks before you are able to reach a decision regarding the probe work, but I will be looking forward to your authorization for the work to proceed.

Sincerely,

James M. Link
Manager
Mining Division

JML:ebm
enclosures

COLORADO SCHOOL OF MINES RESEARCH FOUNDATION, INC.

Golden, Colorado

ANALYTICAL LABORATORY REPORT

Figures are percentage estimates

Lab. No.: 711-807

Sample No.: R.S-1

Lab. Group No.: 97-71

Description:

Project No.: 301217

Sponsor: 301217

Project Engineer: Reid

Date Submitted: 1-20-71

1-10	Aluminum	5-Major	Iron	.001-.01	Strontium
	Antimony		Lanthanum		Sulfur
	Arsenic	<.01	Lead		Tantalum
.005-.05	Barium		Lithium		Tellurium
	Beryllium		Lutetium		Terbium
	Bismuth	1-10	Magnesium		Thallium
	Boron	.05-.5	Manganese		Thorium
	Bromine		Mercury		Thulium
	Cadmium	~.005	Molybdenum		Tin
.5-5	Calcium		Neodymium	.5-5	Titanium
	Cerium	.01-.10	Nickel		Tungsten
	Cesium		Osmium		Uranium
	Chromium		Palladium	.01-.1	Vanadium
.001-.01	Cobalt		Phosphorus		Ytterbium
	Columbium		Platinum (oz/ton)		Yttrium
~.12	Copper		Potassium	.05-.5	Zinc
	Dysprosium		Praseodymium	.005-.05	Zirconium
	Erbium		Radium		
	Europium		Rhenium		
	Gadolinium		Rhodium		
	Gallium		Rubidium		
	Germanium		Ruthenium		
	Gold (oz/ton)		Samarium		
	Hafnium		Scandium		
	Holmium		Selenium		
.001-.01	Indium	1-10	Silicon		
	Iridium	Trace	Silver (oz/ton)		

REMARKS

Signed: [signature]

Date: 1-27-71

COLORADO SCHOOL OF MINES RESEARCH FOUNDATION, INC.

Golden, Colorado

ANALYTICAL LABORATORY REPORT

Figures are percentage estimates

Lab. No.: 71- 808

Sample No.: R3 - 2

Lab. Group No.: 97-71

Description:

Project No.: 301217

Sponsor:

Project Engineer: Reid

Date Submitted: 1-20-71

Value	Element	Value	Element	Value	Element
.5 - 50	Aluminum	5 - Major	Iron	< .021	Strontium
	Antimony		Lanthanum		Sulfur
	Arsenic	< .01	Lead		Tantalum
.005 - .05	Barium		Lithium		Tellurium
	Beryllium		Lutetium		Terbium
	Bismuth	1 - 10	Magnesium		Thallium
	Boron	0.1 - 1.0	Manganese		Thorium
	Bromine		Mercury		Thulium
	Cadmium	~ .003	Molybdenum		Tin
.1 - 1	Calcium		Neodymium	.5 - 5	Titanium
	Cerium	.01 - .10	Nickel		Tungsten
	Cesium		Osmium		Uranium
	Chromium		Palladium	.01 - 0.1	Vanadium
.001 - .01	Cobalt		Phosphorus		Ytterbium
	Columbium		Platinum (oz/ton)		Yttrium
– .10	Copper		Potassium	.05 - .5	Zinc
	Dysprosium		Praseodymium	.005 - .05	Zirconium
	Erbium		Radium		
	Europium		Rhenium		
	Gadolinium		Rhodium		
	Gallium		Rubidium		
	Germanium		Ruthenium		
	Gold (oz/ton)		Samarium		
	Hafnium		Scandium		
	Holmium		Selenium		
.001 - .01	Indium	1 - 10	Silicon		
	Iridium	Trace	Silver (oz/ton)		

REMARKS

Signed: [signature]

Date: 1-22-71

COLORADO SCHOOL OF MINES RESEARCH FOUNDATION, INC.

Golden, Colorado

ANALYTICAL LABORATORY REPORT

Figures are percentage estimates

Lab. No.: 711-809

Project No.: 301217

Sample No.: RS-3

Sponsor:

Lab. Group No.: 97-71

Project Engineer: Reid

Description:

Date Submitted: 1-20-71

1-10	Aluminum	5-Major	Iron	.001-.01	Strontium
	Antimony		Lanthanum		Sulfur
	Arsenic	<.01	Lead		Tantalum
.005-.05	Barium		Lithium		Tellurium
	Beryllium		Lutetium		Terbium
	Bismuth	1-10	Magnesium		Thallium
	Boron	0.1-1.0	Manganese		Thorium
	Bromine		Mercury		Thulium
	Cadmium	~.005	Molybdenum		Tin
1-10	Calcium		Neodymium	.5-5	Titanium
	Cerium	.01-.10	Nickel		Tungsten
	Cesium		Osmium		Uranium
	Chromium		Palladium	.01-.1	Vanadium
.002-.01	Cobalt		Phosphorus		Ytterbium
	Columbium		Platinum (oz/ton)		Yttrium
~.02	Copper		Potassium	.05-.5	Zinc
	Dysprosium		Praseodymium	.005-.05	Zirconium
	Erbium		Radium		
	Europium		Rhenium		
	Gadolinium		Rhodium		
	Gallium		Rubidium		
	Germanium		Ruthenium		
	Gold (oz/ton)		Samarium		
	Hafnium		Scandium		
	Holmium		Selenium		
.001-.01	Indium	1-10	Silicon		
	Iridium	Trace	Silver (oz/ton)		

REMARKS

Signed: [signature]

Date: 1-22-71

COLORADO SCHOOL OF MINES RESEARCH FOUNDATION, INC.

Golden, Colorado

ANALYTICAL LABORATORY REPORT

Figures are percentage estimates

Lab. No.: 711-810

Project No.: 301217

Sample No.: RS-4

Sponsor:

Lab. Group No.: 97-71

Project Engineer: Reid

Description:

Date Submitted: 1-20-71

.5-5.0	Aluminum	5-Major	Iron	.001-.01	Strontium
	Antimony		Lanthanum		Sulfur
	Arsenic	<.01	Lead		Tantalum
.001-.01	Barium		Lithium		Tellurium
	Beryllium		Lutetium		Terbium
	Bismuth	1-10	Magnesium		Thallium
	Boron	0.1-1.0	Manganese		Thorium
	Bromine		Mercury		Thulium
	Cadmium	~.005	Molybdenum		Tin
.1-1	Calcium		Neodymium	.5-5	Titanium
	Cerium	.01-.10	Nickel		Tungsten
	Cesium		Osmium		Uranium
	Chromium		Palladium	.01-.1	Vanadium
.001-.01	Cobalt		Phosphorus		Ytterbium
Trace	Columbium		Platinum (oz/ton)		Yttrium
~.08	Copper		Potassium	.05-.5	Zinc
	Dysprosium		Praseodymium	.005-.05	Zirconium
	Erbium		Radium		
	Europium		Rhenium		
	Gadolinium		Rhodium		
	Gallium		Rubidium		
	Germanium		Ruthenium		
	Gold (oz/ton)		Samarium		
	Hafnium		Scandium		
	Holmium		Selenium		
.001-.01	Indium	1-10	Silicon		
	Iridium	Tr	Silver (oz/ton)		

REMARKS

Signed: [illegible]

Date: 1-22-71

COLORADO SCHOOL OF MINES RESEARCH FOUNDATION, INC.

Golden, Colorado

ANALYTICAL LABORATORY REPORT

Figures are percentage estimates

Lab. No.: 711-811 Project No.: 30217

Sample No.: RS-5 Sponsor:

Lab. Group No.: 97-71 Project Engineer: Reid

Description: Date Submitted: 1-20-71

1-10	Aluminum	5-Major	Iron	.001-.01	Strontium
	Antimony		Lanthanum		Sulfur
	Arsenic	<.01	Lead		Tantalum
.005-.05	Barium		Lithium		Tellurium
	Beryllium		Lutetium		Terbium
	Bismuth	1-10	Magnesium		Thallium
	Boron	0.1-1.0	Manganese		Thorium
	Bromine		Mercury		Thulium
	Cadmium	~.005	Molybdenum		Tin
.5-5	Calcium		Neodymium	.5-5	Titanium
	Cerium	.01-.10	Nickel		Tungsten
	Cesium		Osmium		Uranium
	Chromium		Palladium	.01-.1	Vanadium
.001-.01	Cobalt		Phosphorus		Ytterbium
	Columbium		Platinum (oz/ton)		Yttrium
~.03	Copper		Potassium	.05-.5	Zinc
	Dysprosium		Praseodymium	.005-.05	Zirconium
	Erbium		Radium		
	Europium		Rhenium		
	Gadolinium		Rhodium		
	Gallium		Rubidium		
	Germanium		Ruthenium		
	Gold (oz/ton)		Samarium		
	Hafnium		Scandium		
	Holmium		Selenium		
<.001	Indium	1-10	Silicon		
	Iridium	Tr	Silver (oz/ton)		

REMARKS

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COLORADO SCHOOL OF MINES RESEARCH FOUNDATION, INC.

Golden, Colorado

ANALYTICAL LABORATORY REPORT

Figures are percentage estimates

Lab. No.: 711-812

Sample No.: BS-6

Lab. Group No.: 97-71

Description:

Project No.: 301217

Sponsor:

Project Engineer: Reid

Date Submitted: 1-20-71

1-10	Aluminum	5-Major	Iron	.001-.01	Strontium
	Antimony		Lanthanum		Sulfur
	Arsenic	<.01	Lead		Tantalum
.005-.05	Barium		Lithium		Tellurium
	Beryllium		Lutetium		Terbium
	Bismuth	1-10	Magnesium		Thallium
	Boron	.1-1	Manganese		Thorium
	Bromine		Mercury		Thulium
	Cadmium	~.005	Molybdenum		Tin
.5-5	Calcium		Neodymium	.5-5	Titanium
	Cerium	.01-.1	Nickel		Tungsten
	Cesium		Osmium		Uranium
	Chromium		Palladium	.01-.1	Vanadium
.001-.01	Cobalt		Phosphorus		Ytterbium
	Columbium		Platinum (oz/ton)		Yttrium
~.05	Copper		Potassium	.05-.5	Zinc
	Dysprosium		Praseodymium	.005-.05	Zirconium
	Erbium		Radium		
	Europium		Rhenium		
	Gadolinium		Rhodium		
	Gallium		Rubidium		
	Germanium		Ruthenium		
	Gold (oz/ton)		Samarium		
	Hafnium		Scandium		
	Holmium		Selenium		
~.001	Indium	1-10	Silicon		
	Iridium	Tr	Silver (oz/ton)		

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Date: 1-22-71

COLORADO SCHOOL OF MINES RESEARCH FOUNDATION, INC.

Golden, Colorado

ANALYTICAL LABORATORY REPORT

Figures are percentage estimates

Lab. No.: 711-313　　Project No.: 301217

Sample No.: RS-7　　Sponsor:

Lab. Group No.: 97-71　　Project Engineer: Reid

Description:　　Date Submitted: 1-20-71

1-10	Aluminum	5-Major	Iron	.001-.01	Strontium
	Antimony		Lanthanum		Sulfur
	Arsenic	<.01	Lead		Tantalum
.001-.01	Barium		Lithium		Tellurium
	Beryllium		Lutetium		Terbium
	Bismuth	1-10	Magnesium		Thallium
	Boron	0.1-1.0	Manganese		Thorium
	Bromine		Mercury		Thulium
	Cadmium	~.001	Molybdenum		Tin
.5-5	Calcium		Neodymium	.5-5	Titanium
	Cerium	.01-.10	Nickel		Tungsten
	Cesium		Osmium		Uranium
	Chromium		Palladium	.01-.1	Vanadium
.001-.01	Cobalt		Phosphorus		Ytterbium
	Columbium		Platinum (oz/ton)		Yttrium
~.05	Copper		Potassium	.05-.5	Zinc
	Dysprosium		Praseodymium	.005-.05	Zirconium
	Erbium		Radium		
	Europium		Rhenium		
	Gadolinium		Rhodium		
	Gallium		Rubidium		
	Germanium		Ruthenium		
	Gold (oz/ton)		Samarium		
	Hafnium		Scandium		
	Holmium		Selenium		
.001-.01	Indium	1-10	Silicon		
	Iridium	Tr	Silver (oz/ton)		

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Golden, Colorado

ANALYTICAL LABORATORY REPORT

Figures are percentage estimates

Lab. No.: 711-814

Project No.: 301217

Sample No.: RS-8

Sponsor:

Lab. Group No.: 97-71

Project Engineer: Reid

Description:

Date Submitted: 1-20-71

1-10	Aluminum	5-Major	Iron	.001-.01	Strontium
	Antimony		Lanthanum		Sulfur
	Arsenic		Lead		Tantalum
.005-.05	Barium		Lithium		Tellurium
	Beryllium		Lutetium		Terbium
	Bismuth	1-10	Magnesium		Thallium
	Boron	.05-.5	Manganese		Thorium
	Bromine		Mercury		Thulium
	Cadmium	~.002	Molybdenum		Tin
.05 - .5	Calcium		Neodymium	.1-1	Titanium
	Cerium	.005-.05	Nickel		Tungsten
	Cesium		Osmium		Uranium
	Chromium		Palladium	.01-.1	Vanadium
.001-.01	Cobalt		Phosphorus		Ytterbium
	Columbium		Platinum (oz/ton)		Yttrium
~.10	Copper		Potassium	.05-.5	Zinc
	Dysprosium		Praseodymium	.005-.05	Zirconium
	Erbium		Radium		
	Europium		Rhenium		
	Gadolinium		Rhodium		
	Gallium		Rubidium		
	Germanium		Ruthenium		
	Gold (oz/ton)		Samarium		
	Hafnium		Scandium		
	Holmium		Selenium		
.001-.01	Indium	1-10	Silicon		
	Iridium		Silver (oz/ton)		

REMARKS

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Date: 1-27-71

COLORADO SCHOOL OF MINES RESEARCH FOUNDATION, INC.

Golden, Colorado

ANALYTICAL LABORATORY REPORT

Figures are percentage estimates

Lab. No.: 711-815 | Project No.: 30217

Sample No.: 135-9 | Sponsor:

Lab. Group No.: 97-71 | Project Engineer: Reid

Description: | Date Submitted: 1-20-71

Value	Element	Value	Element	Value	Element
1-10	Aluminum	5-Major	Iron	.001-.01	Strontium
	Antimony		Lanthanum		Sulfur
	Arsenic		Lead		Tantalum
.005-.05	Barium		Lithium		Tellurium
	Beryllium		Lutetium		Terbium
	Bismuth	1-10	Magnesium		Thallium
	Boron	.05-.5	Manganese		Thorium
	Bromine		Mercury		Thulium
	Cadmium	~.01	Molybdenum		Tin
.5-5	Calcium		Neodymium	.1-1	Titanium
	Cerium	.005-.05	Nickel		Tungsten
	Cesium		Osmium		Uranium
	Chromium		Palladium	.01-.1	Vanadium
.001-.01	Cobalt		Phosphorus		Ytterbium
	Columbium		Platinum (oz/ton)		Yttrium
~.1	Copper		Potassium	.05-.5	Zinc
	Dysprosium		Praseodymium	.005-.05	Zirconium
	Erbium		Radium		
	Europium		Rhenium		
	Gadolinium		Rhodium		
	Gallium		Rubidium		
	Germanium		Ruthenium		
	Gold (oz/ton)		Samarium		
	Hafnium		Scandium		
	Holmium		Selenium		
.001-.01	Indium	1-10	Silicon		
	Iridium		Silver (oz/ton)		

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COLORADO SCHOOL OF MINES RESEARCH FOUNDATION, INC.
Golden, Colorado

ANALYTICAL LABORATORY REPORT

Figures are percentage estimates

Lab. No.: 711-816
Project No.: 301217
Sample No.: RS-10
Sponsor:
Lab. Group No.: 97-71
Project Engineer: Reid
Description:
Date Submitted:

1-10	Aluminum	5-Major	Iron	.001-.01	Strontium
	Antimony		Lanthanum		Sulfur
	Arsenic		Lead		Tantalum
.005-.05	Barium		Lithium		Tellurium
	Beryllium		Lutetium		Terbium
	Bismuth	1-10	Magnesium		Thallium
	Boron	.05-.5	Manganese		Thorium
	Bromine		Mercury		Thulium
	Cadmium	~.004	Molybdenum		Tin
.1-1	Calcium		Neodymium	.5-5	Titanium
	Cerium	.005-.05	Nickel		Tungsten
	Cesium		Osmium		Uranium
	Chromium		Palladium	.01-.1	Vanadium
.001-.01	Cobalt		Phosphorus		Ytterbium
	Columbium		Platinum (oz/ton)		Yttrium
~.10	Copper		Potassium	.05-.5	Zinc
	Dysprosium		Praseodymium	.005-.05	Zirconium
	Erbium		Radium		
	Europium		Rhenium		
	Gadolinium		Rhodium		
	Gallium		Rubidium		
	Germanium		Ruthenium		
	Gold (oz/ton)		Samarium		
	Hafnium		Scandium		
	Holmium		Selenium		
<.001	Indium	1-10	Silicon		
	Iridium		Silver (oz/ton)		

REMARKS

Signed: [signature]
Date: 1-27-71

COLORADO SCHOOL OF MINES RESEARCH FOUNDATION, INC.

Golden, Colorado

ANALYTICAL LABORATORY REPORT

Figures are percentage estimates

Lab. No.: 711-817

Project No.: 301217

Sample No.: RS-11

Sponsor:

Lab. Group No.: 97-71

Project Engineer: Reid

Description:

Date Submitted: 1-20-71

1-10	Aluminum	5-Major	Iron	.001-.01	Strontium
	Antimony		Lanthanum		Sulfur
	Arsenic		Lead		Tantalum
.005-.05	Barium		Lithium		Tellurium
	Beryllium		Lutetium		Terbium
	Bismuth	1-10	Magnesium		Thallium
	Boron	.05-.5	Manganese		Thorium
	Bromine		Mercury		Thulium
	Cadmium	~.006	Molybdenum		Tin
.5-5	Calcium		Neodymium	.5-5	Titanium
	Cerium	.01-.10	Nickel		Tungsten
	Cesium		Osmium		Uranium
	Chromium		Palladium	.01-0.1	Vanadium
.001-.01	Cobalt		Phosphorus		Ytterbium
	Columbium		Platinum (oz/ton)		Yttrium
~.04	Copper		Potassium	.1-1	Zinc
	Dysprosium		Praseodymium	.005-.05	Zirconium
	Erbium		Radium		
	Europium		Rhenium		
	Gadolinium		Rhodium		
	Gallium		Rubidium		
	Germanium		Ruthenium		
	Gold (oz/ton)		Samarium		
	Hafnium		Scandium		
	Holmium		Selenium		
.001-.01	Indium	1-10	Silicon		
	Iridium		Silver (oz/ton)		

REMARKS

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Date: 1-27-71

Attachment C

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

By T. G. LOVERING, J. R. COOPER, HARALD DREWES, and G. C. CONE, Denver, Colo.

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 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).

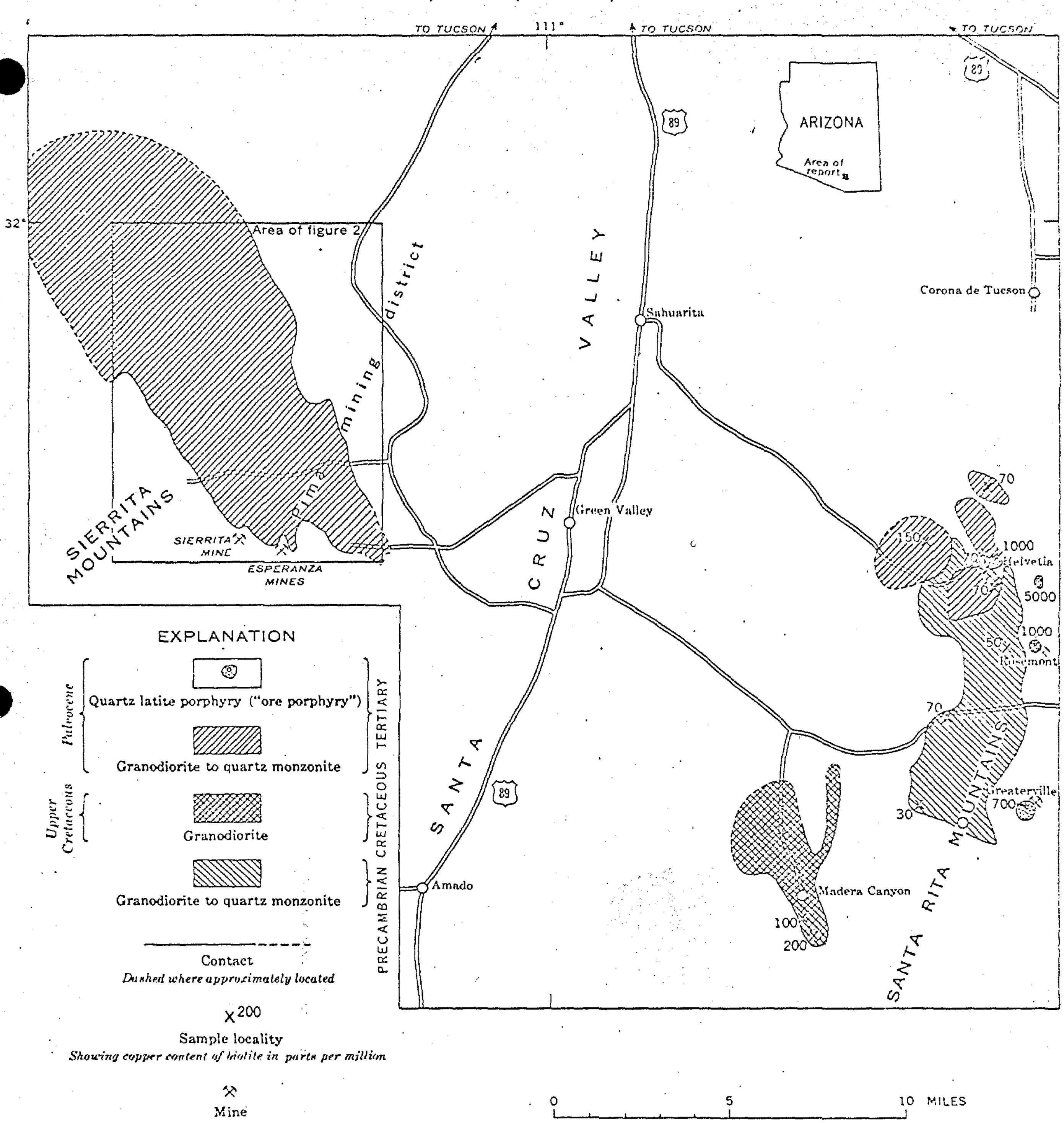

FIGURE 1.—Index map showing location of Sierrita and Santa Rita Mountains (light tone), plutons sampled, locality and copper content of biotite samples from the Santa Rita Mountains, and area of figure 2.

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	Copper content (ppm) 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-

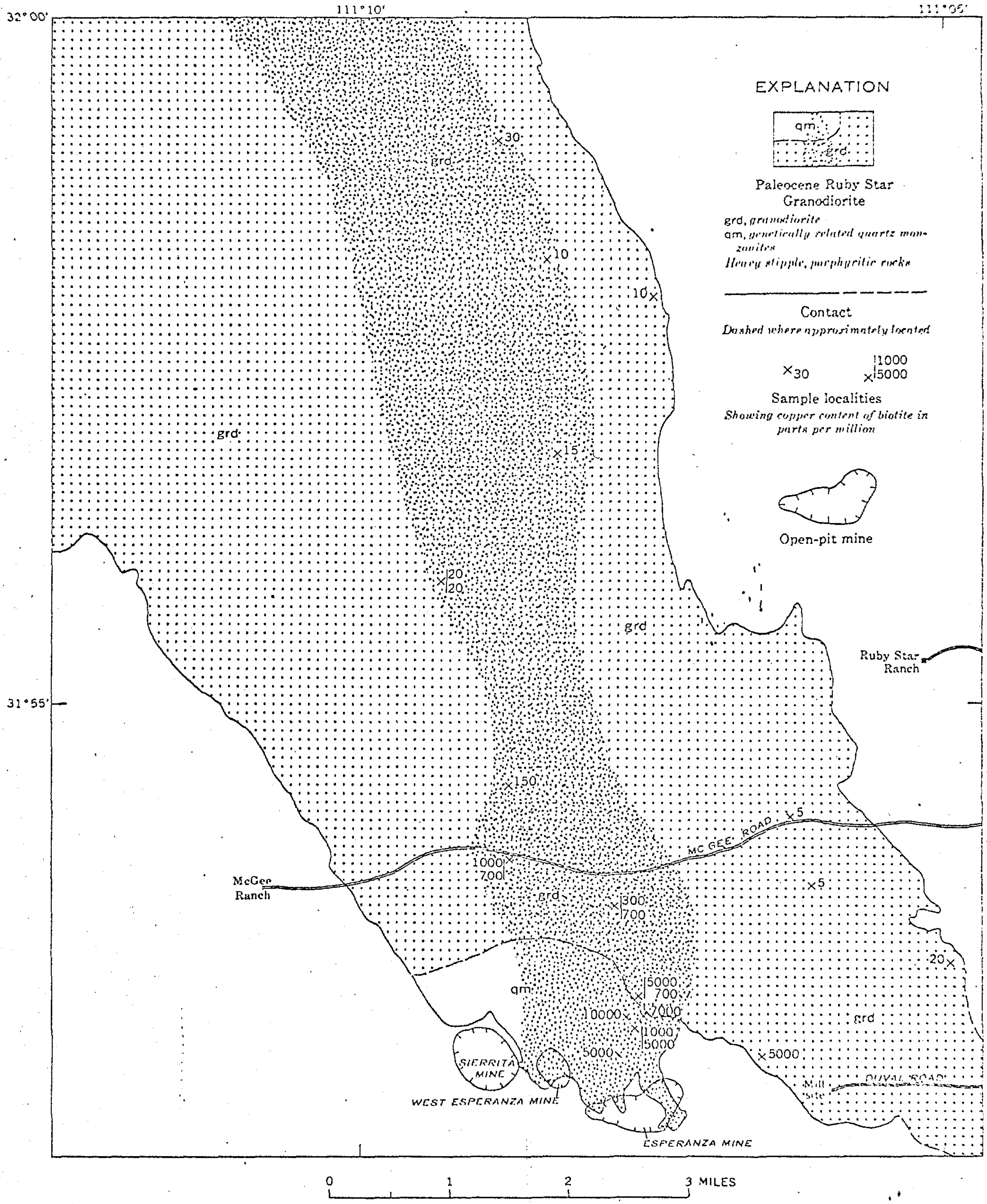

FIGURE 2.—Generalized map of composite stock and associated ore deposits in the southwestern part of the Pima mining district, east of the Sierrita Mountains, showing sample localities and copper content of biotite.

ATTACHMENT D

GEOCHEMISTRY OF IGENOUS ROCKS AS AN ORE INDICATOR - LIST OF SOME RECENT PAPERS

1. "Trace Lead in Potash Feldspars Associated with Ore Deposits" by William F. Slawson and M. P. Nackowski - Ec. Geol., Vol. 54, 1959, pp 1543 - 1555.

2. "Trace Element Distribution in the Searchlight, Nevada, Quartz Monzonite Stock" by Jai N. Shrivastava and Paul Dean Proctor - Ec.Geol., Vol. 57, 1962, pp 1062 - 1070.

3. "Trace Elements in Igneous Rocks, Northwestern and Central Arizona" by G. W. Putman and C. W. Burnham - Geochimica et Cosmochimica Acta, Vol. 27, 1963, pp 53 - 106.

4. "Copper, Lead and Zinc in Biotites from Basin and Range Quartz Monzonites" by William T. Parry and M. P. Nackowski, Ec. Geol., Vol. 58, 1963, pp 1126 - 1144.

5. "Frequency Distribution of Minor Metals in the Rocky Hill Stock, Tulare County, California" by G. W. Putman and J. T. Alfors - Geochimica et Cosmochimica Acta, Vol. 31, 1967, pp 431- 450.

6. "Distribution of Minor Elements in Samples of Biotite from Igenous Rocks" by Tom G. Lovering, U,S.G.S. Prof. Paper 650-B, B101 - B106, 1969.

7. "Copper in Biotite from Igneous Rocks in Southern Arizona as an ore Indicator" by T. G. Lovering, et al, U.S.G. Prof. Paper 700-b, B1 - B8, 1970.

8. "Geochemistry and Petrology of the Rocky Hill Stock, Tulare County, California" by George W. Putman and John T. Alfors - G.S.A., Special Paper 120, 1970.

9. "Copper Content of Biotites from the Boulder Batholith" by Abdul Razak K. Al-Hashimi and Arthur H. Brownlow - Ec. Geol., Vol. 65, 1970, pp 985 - 992.