CONTACT INFORMATION
Mining Records Curator
Arizona Geological Survey
3550 N. Central Ave, 2nd floor
Phoenix, AZ, 85012
602-771-1601
http://www.azgs.az.gov
inquiries@azgs.az.gov

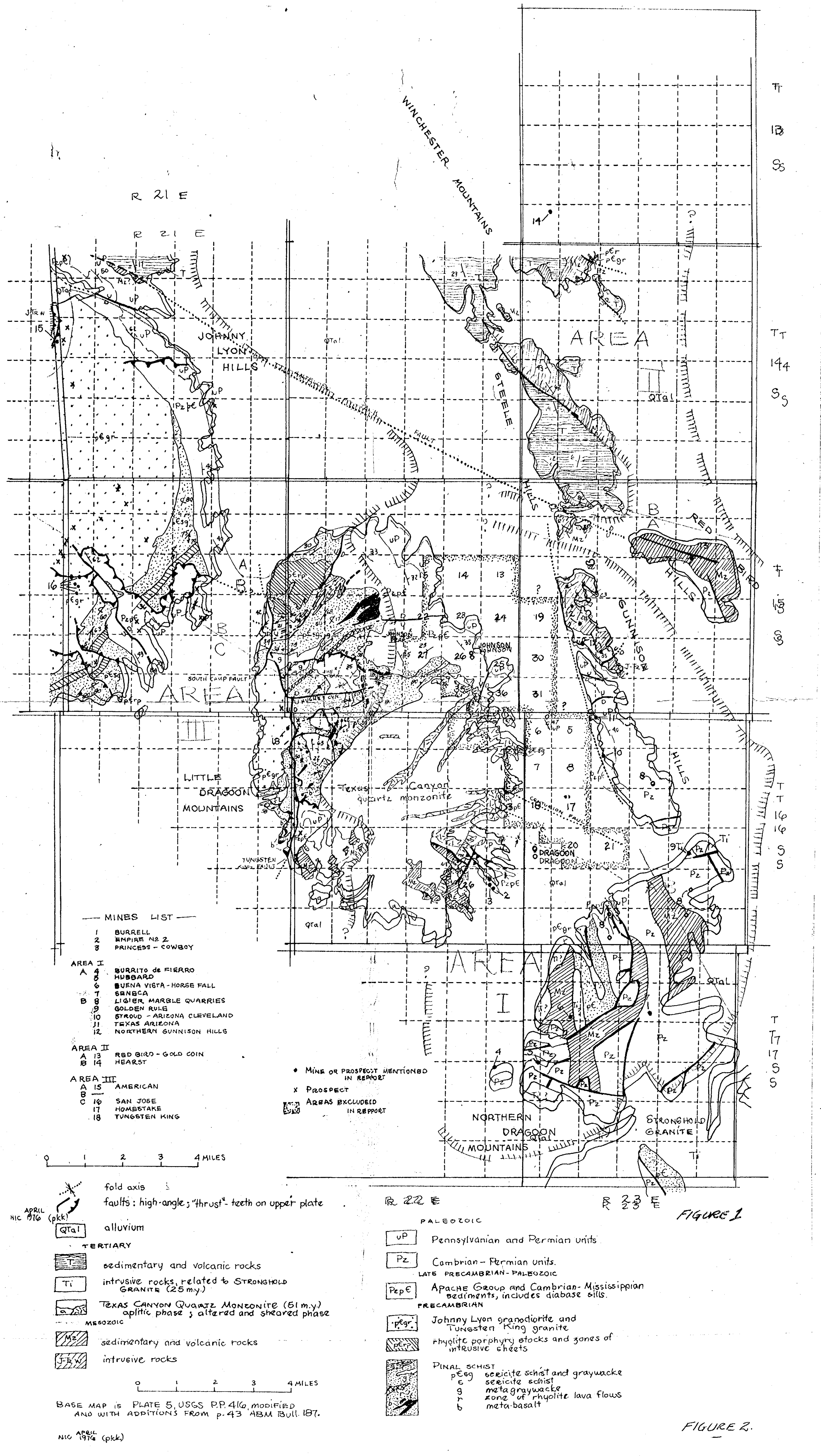
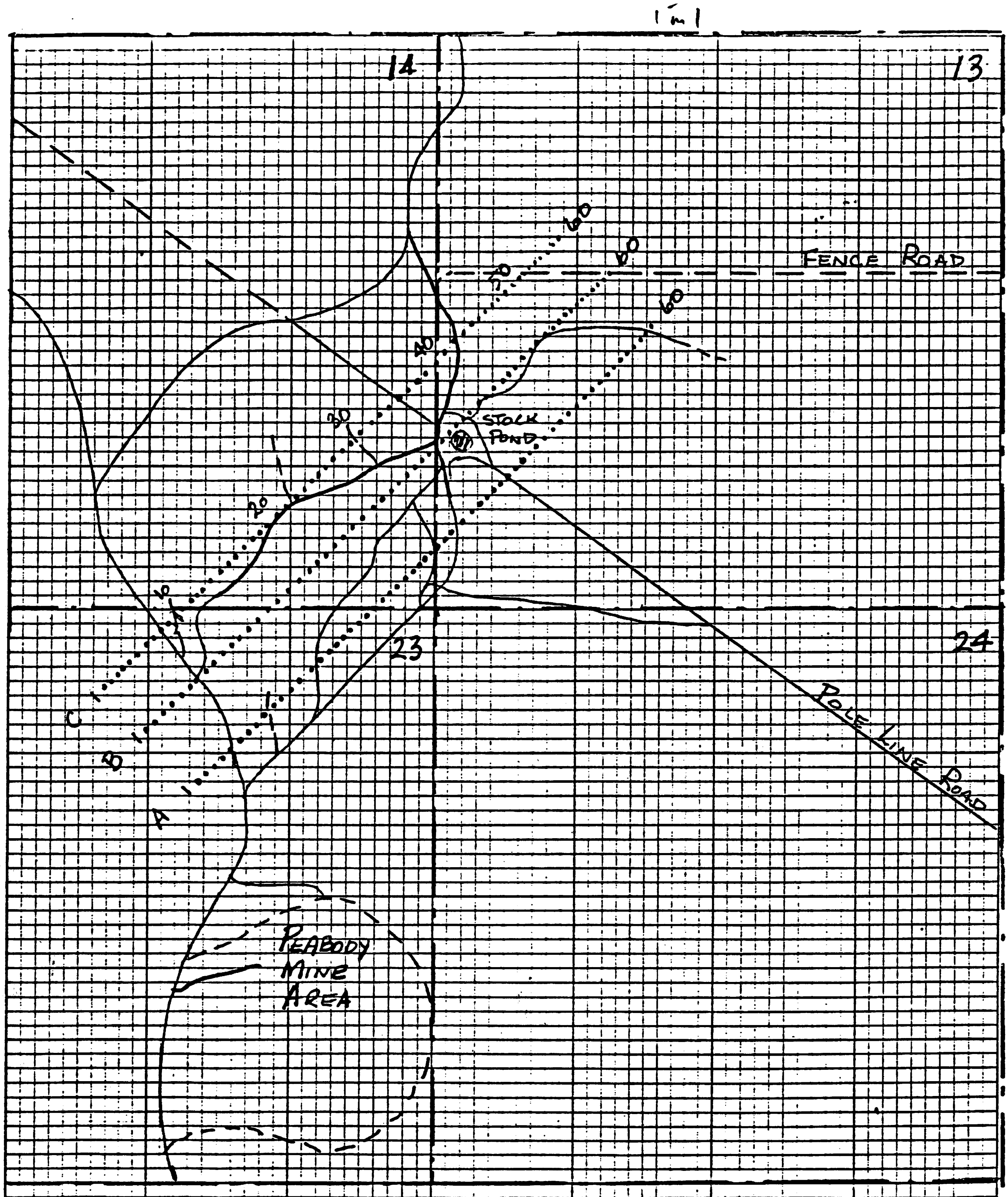


FIGURE 1

FIGURE 2.



T15S
R22E
DRAGOON, AZ. 2° SHT.

3/83

Hold until arrive
JBI
Haven't you
been talking
to Mann?

Cochise Co. Ariz
Gunnison Hills

INTER-OFFICE CORRESPONDENCE

COPIES TO:

MINING & EXPLORATION IMC

Referred.................Answered.........

RECEIVED MAY 11 1972

File - Adm. - Com. - Loc. - Opt. - Eqp. - Prac.

Subject..

TO D. H. Freas

FROM R. B. Kayser

DATE May 8, 1972

SUBJECT Donald Mann Copper Prospect Submittal

I have reviewed the enclosed submittal from Donald Mann on his property in the Gunnison Hills, Arizona. Although I do not recall visiting his property I have examined a number of skarn and copper occurrences in the Gunnison Hills. None of them are sufficiently interesting to stand alone as viable exploration targets. Taken as a group they are part of a very interesting regional pattern of mineralization around which a massive sulfide-porphyry copper exploration program could be built. This, of course, has already been done by Cyprus, Bear Creek, Superior, and C. F. & I. The alluvial plain between Johnson Camp, Dragoon, and the Gunnison Hills has received much prospecting interest, mainly through geophysics but also with some drilling. I do not believe that Mann's property would be of interest to our present exploration program.

The area in which I have been interested is about 10 miles west of Mann's property. It consists of an aeromag anomaly, similar but smaller than the one at Johnson Camp, which is associated with a tightly folded section of the Abrigo along the flank of the Texas Canyon Stock. One of these days I will write that up and send it to you.

Bob

R. B. Kayser

Enclosures
RBK:jk

Form O-100 Rev. 3-61

from the desk of

Donald H. Freas

RBK

I recall you worked in the Johnson Camp area. Is this anything worthwhile?

DONALD M. MANN
MINERALS GEOLOGIST
SUITE 626, PATTERSON BLDG.
555 17TH STREET
DENVER, COLORADO 80202
303-893-8692

March 30, 1972

Mr. Donald F. Freas
Manager of Exploration - U.S.
International Minerals & Chemical Corporation
Administrative Center
Skokie, Illinois 60076

Dear Mr. Freas:

Re: Copper Prospect, Gunnison Hills
Cochise County, Arizona

Secondary copper minerals are present in two propsect pits near intersection of East-West and Northeast trending structures in Cretaceous Glance conglomerate. A pyritized and sericitized (?) Tertiary dike is present in the same area (Fig. 1).

The East-West trend is dominant; it extends the width of the Gunnison Hills, and may be a mile wide. Two strong faults in the South-Central part of Section 20, T 15 S, R 23 E are silicified and contain the copper prospects. The pyritized and sericitized (?) dike lies along the Southerly fault. Northeast of these structures, the East-West trend is manifested by numerous calcite-pyrite veinlets. Disseminated pyrite is present in the intervening limestone. Tremolite is present about 600 feet Northeast of the copper prospects. Calcite-pyrite veinlets were traced Northeast of the copper prospects for about 700 feet; the actual width of this alteration is not known.

The dike, tremolite, calcite-pyrite veinlets, and copper suggest the presence of an unexposed intrusive at some depth in the thick Paleozoic limestone section.

High grade copper replacement ores are the target. The middle Abrigo, which i s the main producer at Johnson Camp (Figure 1), three miles West, may be quite deep. No significant aeromagnetic patterns are present in Section 20 (Fig. 2); which may be due to the masking effect of the Northwest trend, and to the fact that magnetite is rare in the Johnson ore. The unexposed intrusive, if mineralized, is another possibility.

Bedrock in the vicinity of the copper prospects has been trenched and pitted. A short, vertical hole is reported 300 feet West of the shaft in Section 20.

Five Hundred and Forty acres of Section 20, T 15 S, R 23 E is State land, and I own a five year prospecting permit, No. 21473. I will assign the permit for $5,000.00, a 1% N.S.R. royalty, and assumption of the $2,000.00 bond.

Feel free to visit the property. For reference see U.S.G.S. Prof Paper 416, and G.P. 412. If you have any questions, please contact me.

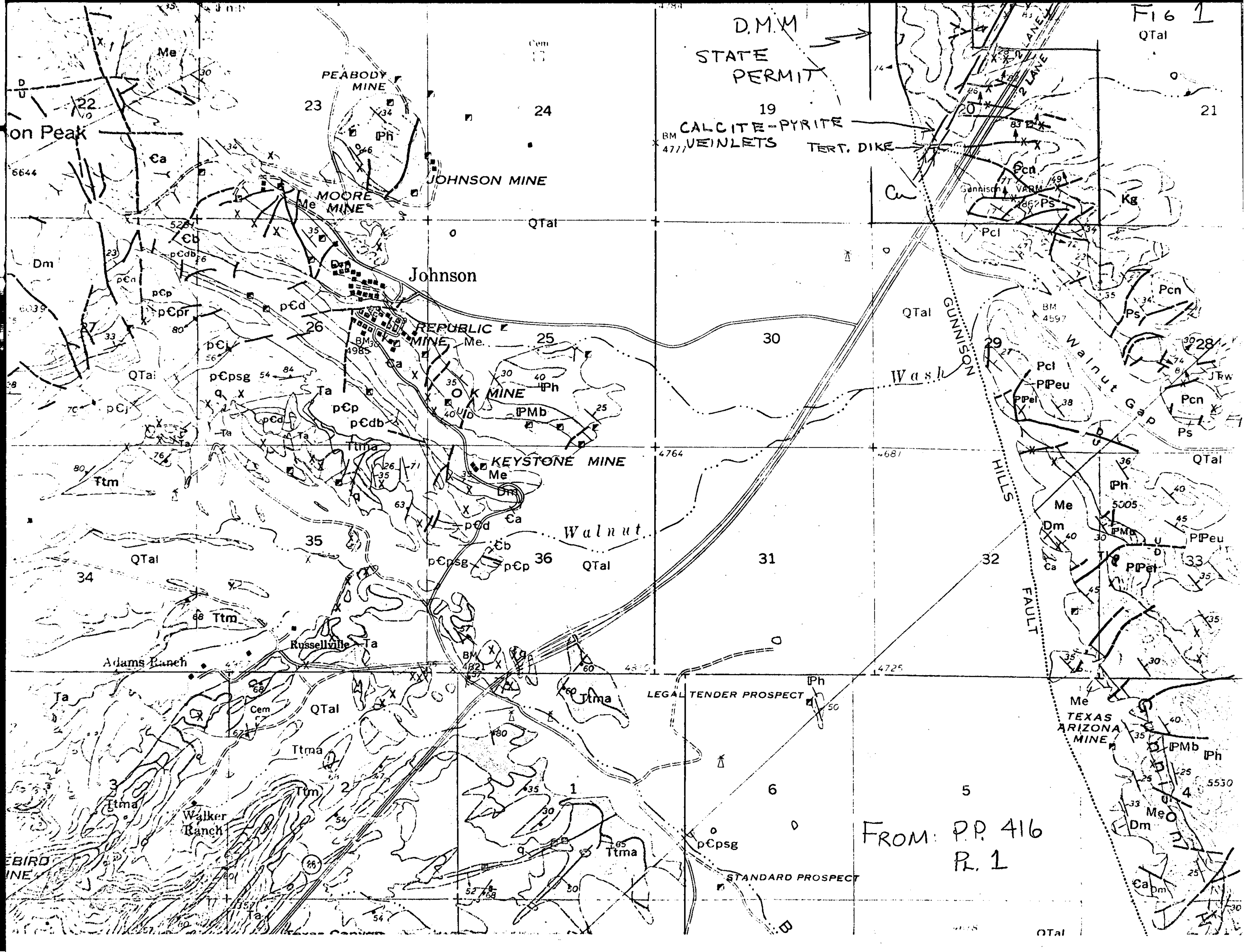
Very truly yours,

Donald M. Mann

Donald M. Mann

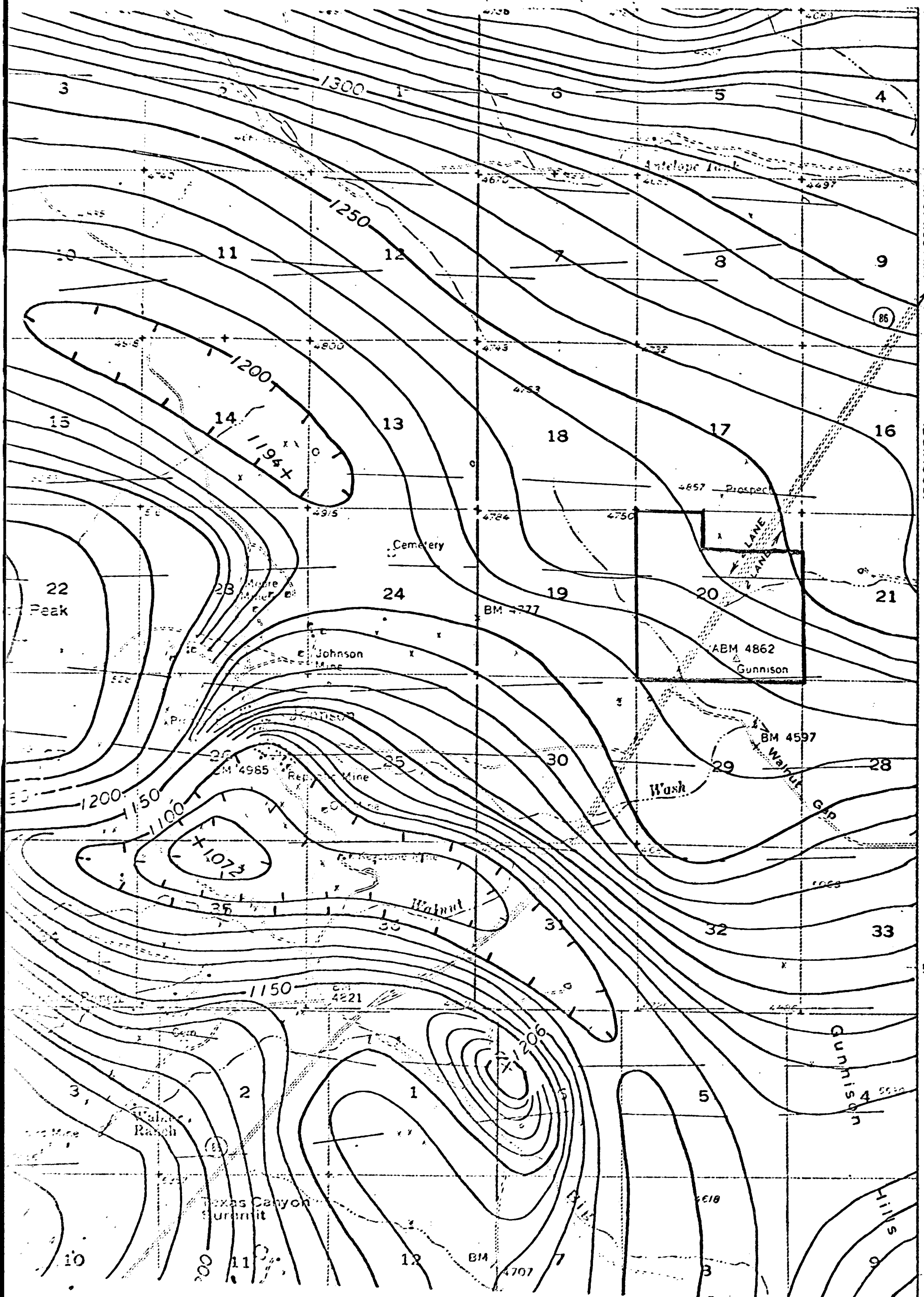
DMM/kg

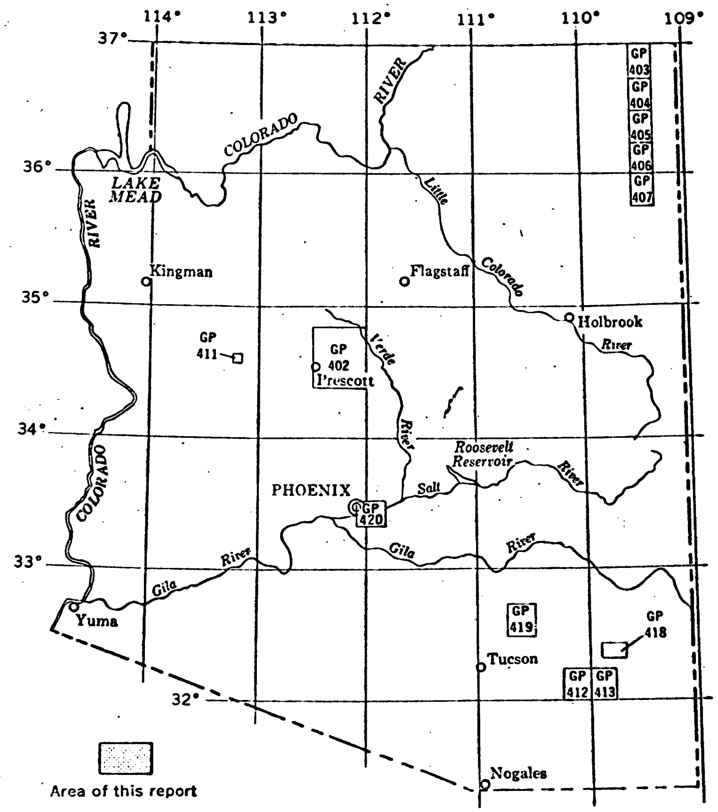
Fig 1



FROM: P.P. 416
Pl. 1

Fig. 2





INDEX MAP OF ARIZONA SHOWING AEROMAGNETIC MAPS
PUBLISHED BY THE U.S. GEOLOGICAL SURVEY

From G.P. 412

January 6, 1972

TUNGSTEN OCCURRENCES
DRAGOON - CHIRICAHUA MOUNTAINS
COCHISE COUNTY, ARIZONA

Tactite zones containing scheelite are known to occur adjacent to some Laramide quartz monzonite intrusives in the Little Dragoon Mountains near Johnson Camp, the Dragoon Mountains east of Benson, and the Chiricahua Mountains near Galeyville in southeastern Cochise County.

Some of the tactite zones are quite large, such as the one at Johnson Camp. The most important minerals in the deposits are those of copper, lead, and zinc, and scheelite is merely reported as being present.

The association of quartz monzonite rather than a more basic rock such as granodiorite with the tactite zones, and the presence of large amounts of copper, lead, and zinc minerals indicates that mineralization may be of a lower temperature phase than is favorable for the formation of tungsten deposits.
Therefore, it is felt that the southern Arizona deposits do not present favorable exploration targets.

Joseph V. Tingley
1/6/72

OFFICES:

TUCSON, ARIZONA (BUSINESS)
5055 E. BROADWAY, SUITE 206-B
P. O. BOX 12754, ZIP 85732
TELEPHONE (602) 790-1175

PERRY, KNOX, KAUFMAN, INC.

MINERAL EXPLORATION AND DEVELOPMENT

SPOKANE, WASHINGTON
NORTH 20 PINES ROAD, SUITE 21
P. O. BOX 14336, ZIP 99214
TELEPHONE (509) - WA 4-0878

Tucson, Arizona
May 14, 1976

Mr. J.B. Imswiler
Manager of Exploration
Western USA
IMC
390 Freeport Boulevard
Suite 12
Sparks, Nevada 89431

Attached are the views of PKK with respect to potential at Johnson, excluding the I-10 orebody of Cyprus-Sullivan and the Strong-Harris, now being re-evaluated by Cyprus.

The areas which warrant our immediate consideration are:
1) N. extension of S-H onto Ellsworth's Section 11, and
2) Sullivan's Section 7. Several other areas should be reconnoitered.

S-H ores may or may not extend onto Ellsworth, but well mineralized holes #69 and #129 are located only ±1000' (on strike) from SE 11.

Sullivan may not want to break out Section 7 from his total Johnson parcel, but that is yet to be determined.

IMC should consider that any exploration at Johnson will likely entail a fairly substantial effort involving the use of ground and possibly aerial magnetics, detailed geologic work and blind drilling. Ores located, particularly on Ellsworth, will probably be deeply buried (+700'-1000'). Exploration at Johnson-Dragoon may possibly yield more ores of the mixed oxide-sulfide type.

Please study our reports and recommendations and advise as to how we should proceed.

A.J. Perry

AJP/sc

attach

from the desk of

Donald H. Freas

4-24-72

JBI

Will you call Mann & see what he has. Looks like he's promoting consulting work to me. I'm not much interested in his copper projects, but the tungsten thing could be interesting if he'll talk.

TO: Dr. D. Freas
IMC, Skokie

FROM: M. Goldenberg
COC, New York

MINING & EXPLORATION

Referred.................Answered.................

RECEIVED APR 19 1972

File - Adm. - Com. - Loc. - Opt. - Eqp. - Prac.

Subject.................

April 18, 1972

Mr. Donald M. Mann
Suite 626, Patterson Building
555 17th Street
Denver, Colorado 80202

Dear Mr. Mann:

We have your letter of March 30 advising of the various properties you have. We at Continental Ore are not particularly interested in base metal mining in the U.S. I am, however, passing a copy of your letter on to the IMC Geoligical Division in Skokie. If there is an interest within IMC, I would imagine that you will be hearing from them.

Very truly yours,

CONTINENTAL ORE CORPORATION

Marcel Goldenberg

MG:ls

cc: D. Freas - IMC, Skokie

DONALD M. MANN
MINERALS GEOLOGIST
SUITE 626, PATTERSON BLDG.
555 17TH STREET
DENVER, COLORADO 80202
303-893-8692

[illegible], 19[illegible]

Mr. Marcel Goldenberg
Director, New Product Development
Continental [illegible]
45 Park Avenue
New York, New York [illegible]

Dear Mr. Goldenberg:

I am a mineral exploration geologist with experience in the United States and Canada. In addition to part time consulting, I have been attempting to interest companies in joint exploration ventures for large base metal deposits in either country. I own copper prospects in Arizona and [illegible]. Would you be interested in reviewing the data on my joint venture proposals, or my copper properties?

A major oil company is drilling out a large copper deposit in Cochise County, Arizona. This property contains significant tungsten as a by-product. The owner is looking for a party that will develop the tungsten potential. Would you be interested in this situation?

Yours truly,

Donald M. Mann

Donald M. Mann

DMM/ma

Donald M. Mann

Re:

Letter to ~~Merrill~~ Goldenberg COC

Tungsten in Copper Deposit in Cochise Co. Arizona.

Size Potential:
Tungsten grade:

Angle: i.e.: ~~do~~ they plan to recover conc? etc.

Near Johnson Camp - out in ~3 mi
Gunnison Hills

Sect 20 T15S R23E
P.P. 416 + GP 412 auberner geology

Tertiary Dike in lo inglance cgl

possible

In Johnson camp - Superior Oil.

Tungsten credits in ore.
J-V for marketing
Not ~~cap~~

Tactite Cu - Tailings 240,000 @ 0.1 WO_3

Johnson Camp Tungsten.

Charlie Goddard advising Superior

Superior black lamping ore. Have some good tungsten intercepts

Probably important source —

Twin Buttes possib

Summary

Superior Oil is drilling a large copper body in Johnson Camp Arizona that contains tungsten credits. They were interested in someone to put up capital for tungsten recovery circuit and market product. Tailings contain 0.1 % WO_3, but recent drilling indicates a possibly better overall WO_3 content. They have backed off actively seeking outside participation until they have a chance to further evaluate their drilling data. Mann is to get further information including Superior's present feature and forward same to me.

Mann also mentioned the possibility of a similar situation at Twin Buttes and other Arizona porphyry copper deposits.

OFFICES:

TUCSON, ARIZONA (BUSINESS)
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NORTH 20 PINES ROAD, SUITE 21
P. O. BOX 14336, ZIP 99214
TELEPHONE (509) - WA 4-0878

PERRY, KNOX, KAUFMAN, INC.

MINERAL EXPLORATION AND DEVELOPMENT

Tucson, Arizona
May 14, 1976

Mr. J.B. Imswiler
Manager of Exploration
Western USA
IMC
390 Freeport Boulevard
Suite 12
Sparks, Nevada 89431

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Please study our reports and recommendations and advise as to how we should proceed.

A.J. Perry

AJP/sc

attach

Tucson, Arizona
May 14, 1976

To: Mr. J.B. Imswiler
IMC

From: A.J. Perry
Perry, Knox, Kaufman, Inc.

Subject: OPPORTUNITIES FOR EXPLORATION FOR COPPER IN THE VICINITY OF JOHNSON-DRAGOON, EXCLUSIVE OF SULLIVAN AND CYPRUS' (I-10)

BACKGROUND

On March 17, 1976, PKK submitted a revised copy of our evaluation of the properties of James Sullivan at Johnson, Arizona, with the recommendation that negotiations be entered into with Sullivan to obtain exploration rights to his properties -- with the added suggestion that IMC management contact Cyprus to determine their possible interest in additional exploration and metallurgical testing of I-10 ores on a joint basis. IMC determined that the problems at Johnson-Sullivan were too complex -- too costly to overcome to be of interest to IMC.

IMC thought it wise for PKK to consider other exploration possibilities within the Johnson-Dragoon area. We have examined those opportunities. The attached report of Colburn and this report with its comments on Colburn's analysis reflect PKK's views as to additional Johnson-Dragoon potential.

EVENTS IN THE DISTRICT SUBSEQUENT TO 3/17/76

There has been activity - change of status in the District subsequent to our March 17 report some of which affect IMC-PKK's opportunities in the area.

Strong-Harris

PKK evaluated the Strong-Harris property in a report dated November 13, 1975, recommending that attention be given the +55 million tons of mixed oxide-sulfide ores declared by Superior Oil (grade 0.68% Cu, 0.79% Zn and 0.22 oz Ag) -- subject to assurances by Weiss that metallurgical difficulties could be overcome. Such assurances were not given and interest by IMC-PKK was dropped. We have learned subsequently that Cyprus is encouraged with more recent testing of the oxides, using a hot alkaline leach.

A portion of the declared S-H reserve consisted of a small tonnage of very high grade oxide/sulfide - most of which occurred beneath the Colina ls. Recent laboratory scale metallurgical tests conducted by Superior using cores of the higher grade sections and separating oxide and sulfide, have indicated good recoveries are possible. Cyprus, with its low grade reserve in the Cyprus-Johnson pit -- (20-40 million tons 0.85% total Cu -- but only 0.24% Cu recoverable) is now investigating the possibility of "sweetening" their leach piles with higher grade S-H oxide material. For this reason, S-H is not currently available for reconsideration by IMC-PKK.

CFI (Dragoon)

CFI has performed their annual assessment work with additional drilling in Sec. 25-T16S-R22E. CFI reportedly holds portions of Secs. 23, 24, 25 and 26. This is the area where Superior once performed insitu leach tests. The CFI property is said to be available. The reserves are estimated at 27 million tons - 0.40% Cu.

Sullivan

Sullivan maintains the same land position in the I-10 area as reported March 17, except that portions of the State lands in Sec. 36 are now held on a lease rather than a prospecting permit basis. Some other lands (refer to Fig. 2 - March 17 report) held by prospecting permit application have been relinquished; notably NE/SE Sec. 13, W2-Sec. 5, all of 8 and portions of the E2 of 18.

To the best of our knowledge, there is no other current activity in the District.

COMMENTS ON N.I. COLBURN'S PROSPECTS

Prospects developed by N.I. Colburn are described in the attached review. Colburn's recommendations result from her scrutiny of the available literature and her personal knowledge of the Johnson area. The recommendations have been reviewed and discussed with our Johnson consultant, Joe Kantor. The comments of Kantor and Perry are combined below.

S. Little Dragoon Mtns. (Area I) - vicinity of NIC's prospects 1-2 and 3 (See Fig. 1).

This area of CFI holdings contains an estimated reserve of 27 million tons of 0.40% Cu.

In SW-25 CFI reportedly drilled one or two holes to test an aeromagnetic anomaly. This anomaly does not show well on the published Dragoon Quad Magnetic map. There is some dispute as to whether or not the anomalism was explained by the results of their drilling, leaving open the possibility that a skarn zone high in magnetite might remain untested at depth. The intrusive at Dragoon is known to be at least in part tabular with some past drilling penetrating first sediments then intrusive and finally a secondary sedimentary section.

Discussions with CFI and examination of their data should clarify the possibility of additional significant potential in and near Sec. 25. We will approach CFI.

<u>N. Edge N. Dragoon Mountains</u> (Area I)

Sulfides, including minor chalcocite, are reported near a windmill in SE/Sec. 32, T16S, R23E (mouth of Jordan Canyon). Minerals Exploration once occupied the area and is said to have moved to the south after drilling a series of holes. Minex abandoned Sec. 29 (State) in March, 1976. We will reconnoiter to determine the extent of Minex's activities.

<u>Colburn's Area II</u>

NIC's recognition of possible Safford type deposits (mineralized pre-Tertiary rocks covered by post-mineral volcanics) cannot be disputed but exploration for such deposits would require deep and often blind drilling, at great expense; generally after a period of detailed geologic work. This type of exploration is not within the scope of the current IMC-PKK project. However, the specific prospects set out on page 7 by NIC - <u>Red Bird</u> and <u>Hearst</u> - will be briefly examined and sampled.

<u>Area III</u>

The <u>Johnny Lyon Hills</u> would have to rank low as an exploration target area. The American Mine is a specular hematite-copper oxide occurrence, typical of many in S. Arizona which appear to have no particular regional significance. There is a general paucity of mineralization as noted by NIC (page 7) as compared with the numerous minor occurrences associated with S-H, the main Johnson District (Republic-Moore) and I-10 -- with its bordering Keystone-St. George mineral. We are not discounting the possibility of hidden ores at Johnny Lyon -- we are simply stating that pediment or outcrop exploration extending from unmineralized exposures without magnetic or other geophysical backup is likely to be unproductive relative to starting from a better "lead".

The West Side of the Little Dragoons has been reconnoitered in detail by Kantor as has the mountain's schist core (thought by NIC to have possibilities for massive-sulfide deposits of volcanogenic origin). Kantor found a general absence of mineralization.

SUMMARY -- of NIC judged to be worthy of followup.

1. S. Little Dragoons - evaluate CFI data, holdings, reserve, possible ore extensions and the thoroughness of their exploration of the magnetic anomaly in SW 25.

2. N. Edge of Dragoons - briefly reconnoiter - check on results of Minex's exploration, if possible.

3. Red Hills - S. Winchester's - examine the Red Bird and Hearst areas.

OTHER AREAS WARRANTING MORE DETAILED EXAMINATION

Northern Extension of the Strong-Harris ore trend on to the patented lands of Rex Ellsworth - Sec. 11, T15S, R22E. Reference to Figure 3 on the Strong-Harris Report of November 13, 1975, will show the location of exploration holes at the north end of S-H North. Hole 69 had 80' - 0.45% Cu at 780' in the Colina and 70' of 0.74% in the upper Earp @ 980'.

Further SW, Hole 129 had 22' - 0.98% Cu @ 696 and 81' - 0.47% directly below. The North orebody trend is open to the NW and may extend onto Ellsworth land. Kantor reports no drilling there.

Depths, as the S-H work indicates, are +700' to ±1000' and the ores are mixed oxide-sulfide providing us with some of the same problems recognized in our initial S-H evaluation.

The main economic difficulty, assuming ore on Ellsworth, is that of developing a reserve separate from S-H that is substantial enough to be economic and to be of interest to IMC. There is no predicting opportunities for such a reserve.

Sec. 7 of Sullivan, T16S - R23E

Kantor reports, "previous drilling (by Superior) encountered low grade copper sulfide mineralization in the lower Abrigo at moderate depths and at a considerable distance from the Texas Canyon stock within this section. At an equal distance from the stock in Section 31 (I-10 orebody area) much lower values were found in the Lower Abrigo". Kantor's remarks suggest that drilling to the west of Superior's two holes is in order. The E/2 of Sec. 13 may be included in the exploration area.

The vein fault copper mineralization of the Centurion Mine, SE/SE - 12, projects into SW7.

The principal non-geologic complication of Sec. 7 is that of Sullivan's possibly being unwilling to break up his land holdings to allow exploration of this small tract.

GENERAL

The surface expression of the copper-zinc ores in the Johnson-Dragoon area is relatively limited even at the sites of the earliest mining -- (eg) the Moore Mine was discovered in 1947 by diamond drilling from the surface; the Main Manto of the Republic was not exposed, and Cyprus' I-10 is completely buried. Only intense thermal metamorphism and scattered copper-zinc oxide occurrences mark the general vicinity of future mining in the Main District. Less intense metamorphism and more sparse copper exposures delineate the general area of CFI's mineralization at Dragoon.

Minor clusters of copper occurrences are far more abundant in the Johnson-Dragoon area than are orebodies. The relationship of ore to magnetic anomalism is well documented by the experience of Superior-Cyprus at I-10 (see Fig. 10 - March 17 report). It is the careful application of geology in combination with quality magnetics and at least a limited amount of blind (stratigraphic) drilling in the District that is likely to lead to new discoveries.

JOHNSON CAMP, COCHISE COUNTY, ARIZONA

CYPRUS MINES BURRO PIT

(JOHNSON PIT)

Field Trip 3.20.76

. Leach Operations

.. Ore: 0.80-0.85% total Cu | ~0.3% acid soluble Cu (Essentially all chrysocalla)

.. Recovery: 60% of acid soluble Cu hoped for, i.e. 0.18%/T or 3.6 lbs Cu/T

.. Production: Presently producing 22-25,000 lbs of electrowin Cu per day

.. Process:

... Heap leach → solvent extraction → electrowin

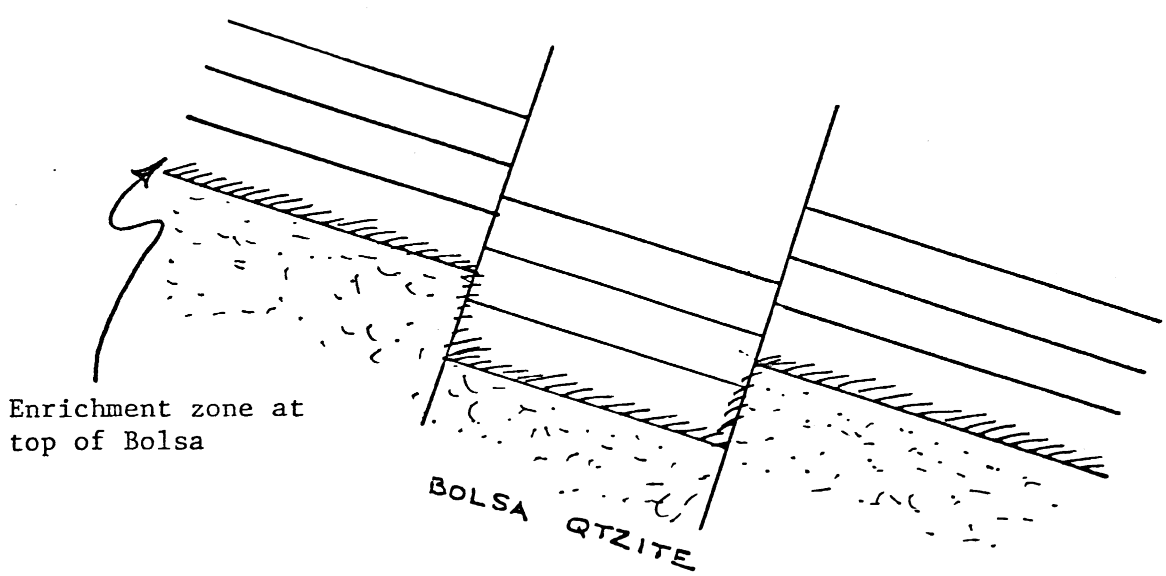
... No pads are presently used under the leach piles. The underlying pioneer shale is impervious and acts as a natural pad.

... Use 75 lbs of acid/ton of ore & maintain a pH of 1.5. Acid is obtained from San Manuel

.. Mining: Open pit - cats, loaders & trucks

... Present stripping ratio is less than 1:1 but will increase as pit is worked down dip.

.. Geology



LITTLE DRAGOON MTNS
JOHNSON CAMP FIELD TRIP

Stop 1 Highway I-10 Dragoon turnoff - Texas Canyon Quartz Monzonite-porphyritic stage with K-spar phenocrysts in quartz, plagioclase, K-spar, biotite groundmass.

Stop 2 Highway I-10 .8 mile south on Johnson Road - Altered phase of Texas Canyon Quartz Monzonite. Quartz veining, muscovite, weak argillic alteration. Copper-tungsten.

Stop 3 Johnson Camp - Moore Shaft stratigraphic section.

3A - Mississippian Escabrosa fm. cherty limestone and basal dolomite
3B - Devonian Martin fm - hornstone marker (Unit 7)
3C - Copper Chief fault
3D - Devonian Martin fm. - granular dolomite (Unit 6)
3E - Devonian Martin fm. - upper serpentine marker (Unit 5)
3F - Devonian Martin fm. - white tactite-diopside rich (Unit 4)
3G - Devonian Martin fm. - dolomitic marble (Unit 1)
3H - Cambrian Abrigo fm. - upper unit - lower serpentine marker
3I - Cambrian Abrigo fm. - upper unit - white tactite
3J - Cambrian Abrigo fm. - middle unit - garnetite - ore horizon
3K - Cambrian Abrigo fm. - middle unit - crenulated limestone

ll old mine workings assive sulfides etc. n upper part of iddle Abrigo % Cu 6% Zn

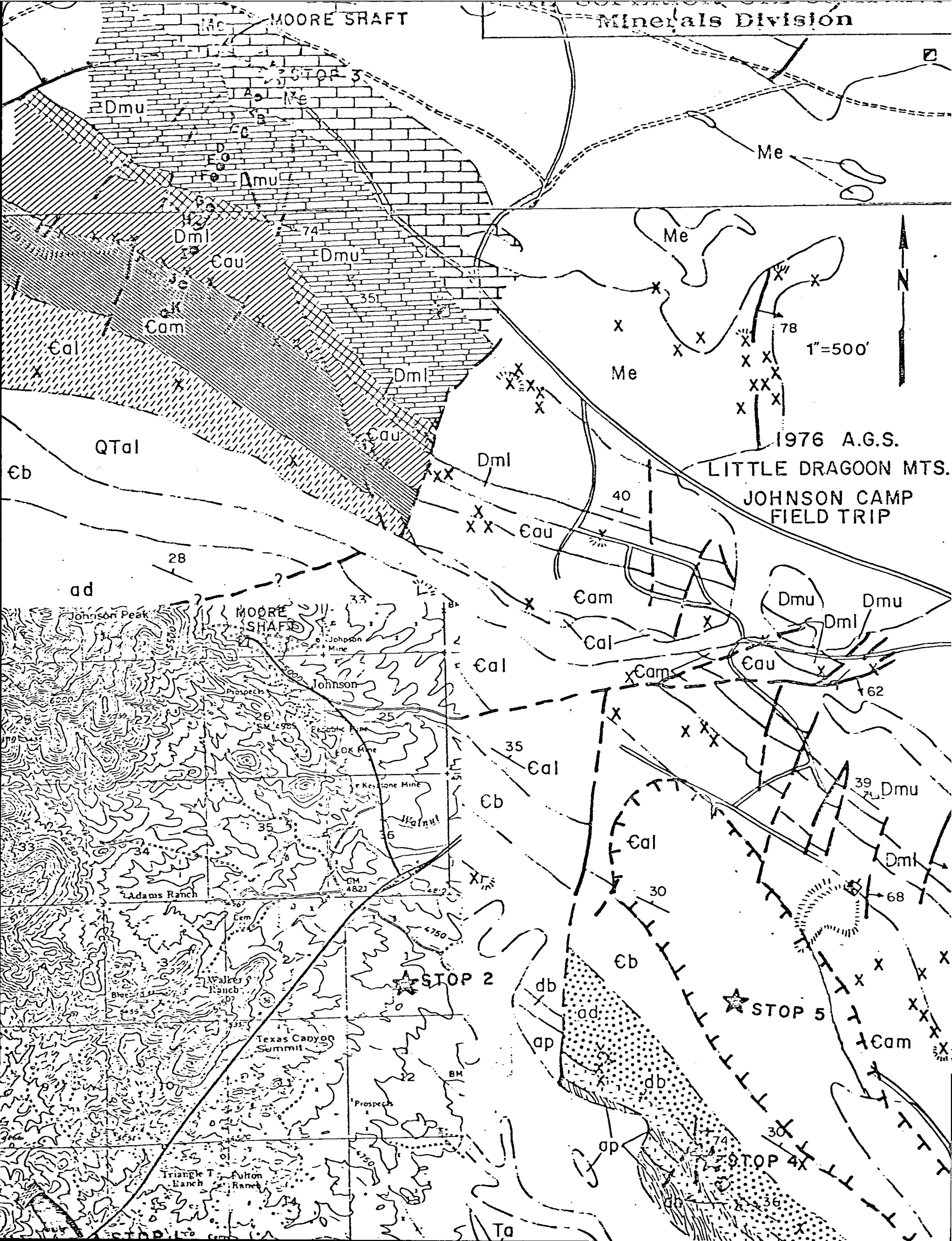
Stop 4A Precambrian Apache Group - Dripping Spring quartzite, Barnes conglomerate, Diabase, Pioneer shale

4B Leach Pads

Stop 5 Johnson Pit - Middle Abrigo garnetite, Lower Abrigo hornfels, Bolsa quartzite - mineralization and alteration.

Geologic Legend

Me	Escabrosa fm.
Dmu	Martin fm. - upper unit
Dml	Martin fm. - lower unit
Cau	Abrigo fm. - upper unit
Cam	Abrigo fm. - middle unit
Cal	Abrigo fm. - lower unit
Cb	Bolsa
ad	Dripping Spring with Barnes conglomerate at base
db	Diabase
ap	Pioneer fm.



Minerals Division
MOORE SHAFT
STOP 3
Me
Dmu
Dml
Cau
Cam
Cal
Cb
QTal
ad
1"=500'
N
1976 A.G.S.
LITTLE DRAGOON MTS.
JOHNSON CAMP
FIELD TRIP
Johnson Peak
MOORE SHAFT
Johnson Mine
Johnson
Prospects
Republic Mine
OK Mine
Keystone Mine
Walnut
Adams Ranch
Walker Ranch
Texas Canyon Summit
Prospects
Triangle T Ranch
Fulton Ranch
STOP 2
STOP 5
STOP 4
db
ap
Ta

JOHNSON CAMP, COCHISE COUNTY, ARIZONA

CYPRUS MINES BURRO PIT

(JOHNSON PIT)

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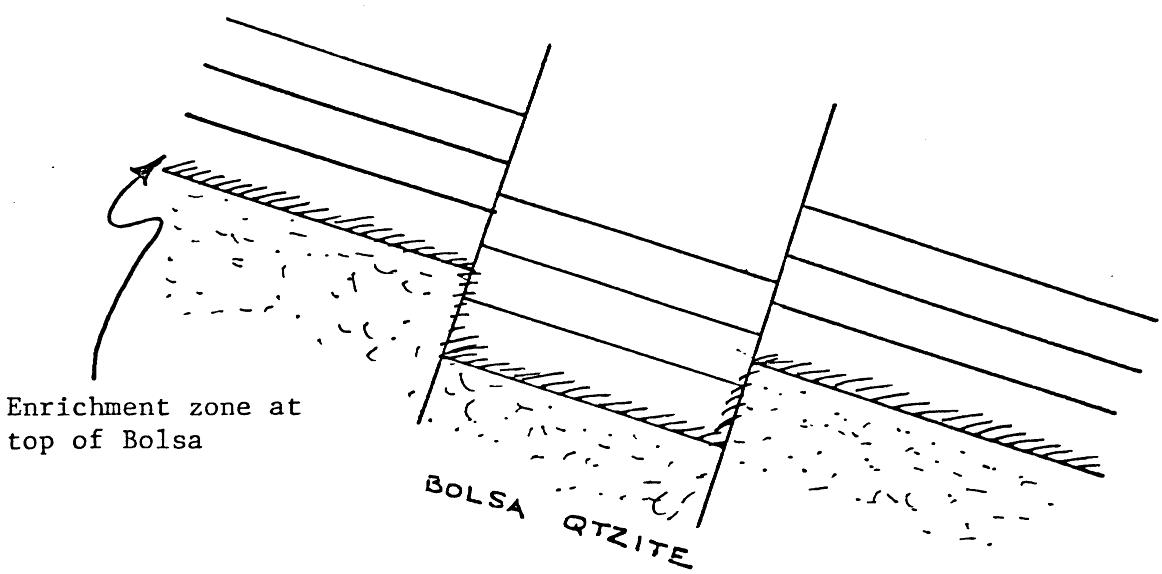

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3E - Devonian Martin fm. - upper serpentine marker (Unit 5)
3F - Devonian Martin fm. - white tactite-diopside rich (Unit 4)
3G - Devonian Martin fm. - dolomitic marble (Unit 1)
3H - Cambrian Abrigo fm. - upper unit - lower serpentine marker
3I - Cambrian Abrigo fm. - upper unit - white tactite
3J - Cambrian Abrigo fm. - middle unit - garnetite - ore horizon
3K - Cambrian Abrigo fm. - middle unit - crenulated limestone

ll old mine workings
assive sulfides etc.
n upper part of
iddle Abrigo
% Cu 6% Zn

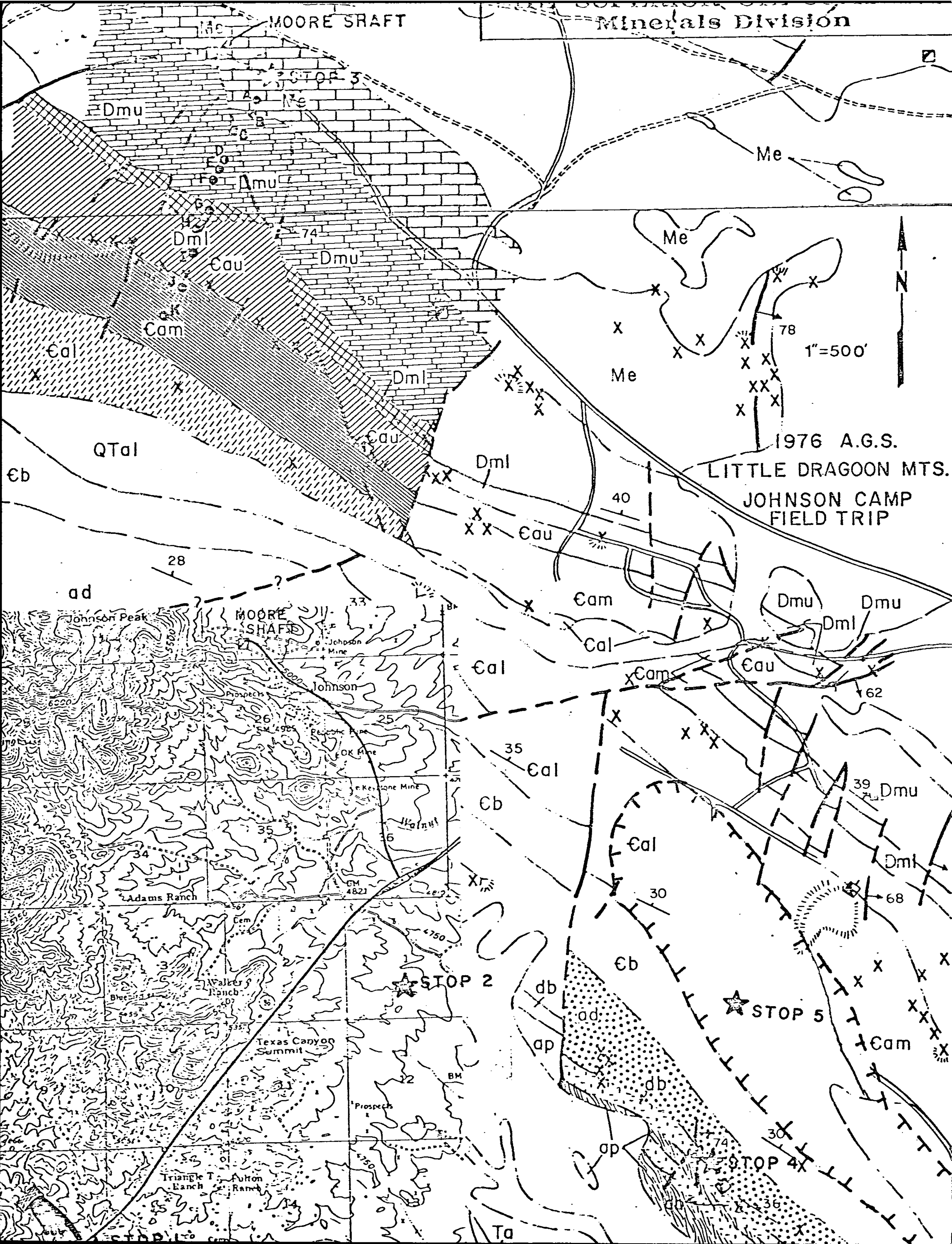
Stop 4A — Precambrian Apache Group - Dripping Spring quartzite, Barnes conglomerate, Diabase, Pioneer shale

4B — Leach Pads

Stop 5 — Johnson Pit - Middle Abrigo garnetite, Lower Abrigo hornfels, Bolsa quartzite - mineralization and alteration.

Geologic Legend

Me	Escabrosa fm.
Dmu	Martin fm. - upper unit
Dml	Martin fm. - lower unit
Cau	Abrigo fm. - upper unit
Cam	Abrigo fm. - middle unit
Cal	Abrigo fm. - lower unit
Cb	Bolsa
ad	Dripping Spring with Barnes conglomerate at base
db	Diabase
ap	Pioneer fm.



Minerals Division
MOORE SHAFT
STOP 3
1976 A.G.S.
LITTLE DRAGOON MTS.
JOHNSON CAMP
FIELD TRIP
1"=500'
N
Dmu
Dml
Me
Cau
Cam
Cal
Cb
QTal
ad
db
ap
Ta
Johnson Peak
MOORE
SHAFT
Johnson Mine
Johnson
Prospects
Peacock Mine
OK Mine
Keystone Mine
Walnut
Adams Ranch
Walker Ranch
Texas Canyon Summit
Triangle T Ranch
Fulton Ranch
STOP 2
STOP 5
STOP 4

GEOLOGICAL INVESTIGATIONS AND GEOCHEMICAL PROSPECTING EXPERIMENT AT JOHNSON, ARIZONA.[1]

JOHN R. COOPER AND LYMAN C. HUFF.

CONTENTS.

ABSTRACT.

Deposits of copper and zinc at Johnson, Arizona, occur in metamorphosed Paleozoic limestone near a quartz monzonite stock probably of late Cretaceous or early Tertiary age. The metallic mineralization was preceded by a stage of thermal metamorphism during which pure carbonate beds were recrystallized and impure carbonate beds were altered to garnet, diopside, and other contact-metamorphic silicates. Silicate formation, which involved loss of carbon dioxide, was accompanied by shrinkage that reached a maximum of 30 percent. In the following metallic mineralization, the metamorphic rock was replaced by copper and zinc sulfides associated with some chlorite and other relatively low temperature gangue minerals. Nearly all the ore occurs as tabular masses and chimneys in particular beds in the Abrigo formation of Cambrian age.

The recently discovered Moore ore body is a lenticular mass in the Abrigo formation about 400 feet below the present surface. Faulted and fractured limestone and dolomite beds of the Escabrosa limestone (Mississippian) crop out above the ore body. Local copper stains, which are abundant in the district, and a greater-than-average amount of faulting are somewhat meager geological evidence for the presence of ore.

To determine if there was any geochemical evidence for the proximity of ore, outcrops of the Escabrosa limestone and part of the underlying

[1] [Pu]blished by permission of the Director, U. S. Geological Survey.

Martin formation (Devonian), the fault zones, and soils were sampled both over the ore and in the adjoining area, and the samples were analyzed for traces of the ore metals.

The ore-metal content varies widely and is determined in part by stratigraphy and structure. Large areas abnormally high in ore metal are indicated by samples from the fault zones. Composite chip samples of the rock between the faults show small high areas within the high areas indicated by the fault-zone samples. One of the chip-sample anomalies is over the Moore ore body but displaced somewhat to one side of the center of the body. Two other anomalies are over unexplored ground some distance from the ore body. Soil samples collected on low ridges, where contamination is unlikely, show the same general anomalies as the rock samples.

A genetic relationship between the Moore ore body and the nearby geochemical anomaly is suggested by its proximity and by the presence in the anomaly area of fault zones which carry concentrations of ore metal and project toward the ore. Diamond drilling and further geochemical studies are suggested as possible means of checking the inferred relationship. At present, geochemical studies give promise of becoming a valuable adjunct of geology in prospecting the Johnson district and similar areas elsewhere.

INTRODUCTION.

THE time-honored profession of prospecting has undergone many changes through the years. At one time an individual with no more than primitive equipment, a smattering of knowledge concerning ore deposits, and fortitude had a good chance of finding valuable ore deposits. Many of the deposits found were easily recognizable from the surface outcrop and were profitable from the grass roots down.

Unfortunately, most of the deposits of this kind have been found and many have been exhausted. Although the needs of industry continue to increase, ore deposits have become more and more difficult to discover. At present, prospecting commonly consists of detailed geological study, expensive drilling or other exploratory development, and possibly geophysical studies, all integrated so that every pertinent scrap of knowledge can be utilized. New discoveries continue but with ever-increasing cost in time and trouble; continual improvement of prospecting methods is a vital necessity.

The use of trace analysis to detect and map natural materials with a higher-than-average content of the ore metals, i.e., geochemical prospecting, offers possibilities of facilitating the discovery of new ore bodies. Most geochemical prospecting in the past has been confined to the analysis of vegetation, soil or other weathering products; i.e., investigations of the supergene dispersal of the ore metal (2, 3, 7).[2] Recently, however, chemical prospecting studies in the mining district at Tintic, Utah, have discovered evidence indicating a hypogene or primary dispersion of ore metals in volcanic rocks overlying the ore bodies (6). It seems highly desirable to investigate primary dispersion in other environments.

This paper presents the results of such an investigation in the Johnson mining district. This district seemed favorable for geochemical study because the geology has been studied in considerable detail; and surface showings of copper

[2] Numbers in parentheses refer to Bibliography at end of paper.

minerals have been found above several deep-lying ore bodies in the district, suggesting that partially spent ore solutions may have leaked almost straight upward.

The Johnson district is in southeastern Arizona, about 55 miles east of Tucson, 45 miles north of Bisbee, and 55 miles southeast of San Manuel. Mining in the district has been carried on intermittently since 1881 and has resulted in a total production of about $10,000,000 in copper and zinc ores. Economically, the deposits are marginal; most of the ore contains from 1½ to 4 percent copper and 2 to 15 percent zinc. The most productive periods were 1914–20 and 1944–49. All mines in the district were inactive between July 1, 1949, and July 1, 1950, because of low metal prices. The largest property owner at present is the Coronado Copper and Zinc Company, which is controlled by the Harvey S. Mudd interests of Los Angeles. This company purchased the most productive mines in 1942 and has subsequently purchased some of the surrounding claims.

A detailed study of the geology of the Johnson area was begun in 1944 by J. R. Cooper of the U. S. Geological Survey. L. C. Huff of the Survey's geochemical prospecting section visited the area on February 4, 1948, and March 23, 1949. Samples of soil and bed rock collected on these occasions and additional samples collected by Mr. Cooper in April 1949 were analyzed for traces of ore metal, with encouraging results. Field work for the systematic geochemical study described in this report was conducted jointly by Messrs. Cooper and Huff between October 12 and November 6, 1949. Mr. Cooper is responsible for the geologic mapping and geologic interpretations and Mr. Huff for the chemical analyses; they are jointly responsible for the sampling and geochemical interpretations.

Acknowledgments are gratefully extended to the Coronado Copper and Zinc Company for permission to make the investigation, for information concerning the ore body obtained by core drilling, and for the use of a house that served as a field laboratory.

PHYSIOGRAPHIC AND GEOLOGIC SETTING.

The Johnson mining district is in the Little Dragoon Mountains, a range about 10 miles long and 6 miles wide in the Basin and Range physiographic province. The deposits are at the base of the main mountain mass. The area of geochemical study, shown in Figures 1 and 2, is a rock pediment of low relief and fairly abundant rock outcrops. It is bounded on the west by foothills and on the east by a typical desert-type alluvial fan.

Within the areas mapped as bedrock in Figure 2, the soil is thin and rocky; it is obviously a product of immature weathering, as it contains many fragments of fresh rock. The Quaternary alluvium and slope wash shown on Figure 2 are poorly stratified and sorted mixtures of silt, sand, and angular pebbles. This surficial material is less than 10 feet thick in most of the area but thickens rapidly along the northeastern margin.

The regional geologic setting is described only briefly here as a detailed description of the area is planned for later publication by the Geological Survey. The area of interest is within a belt of sedimentary and metamorphic rocks that

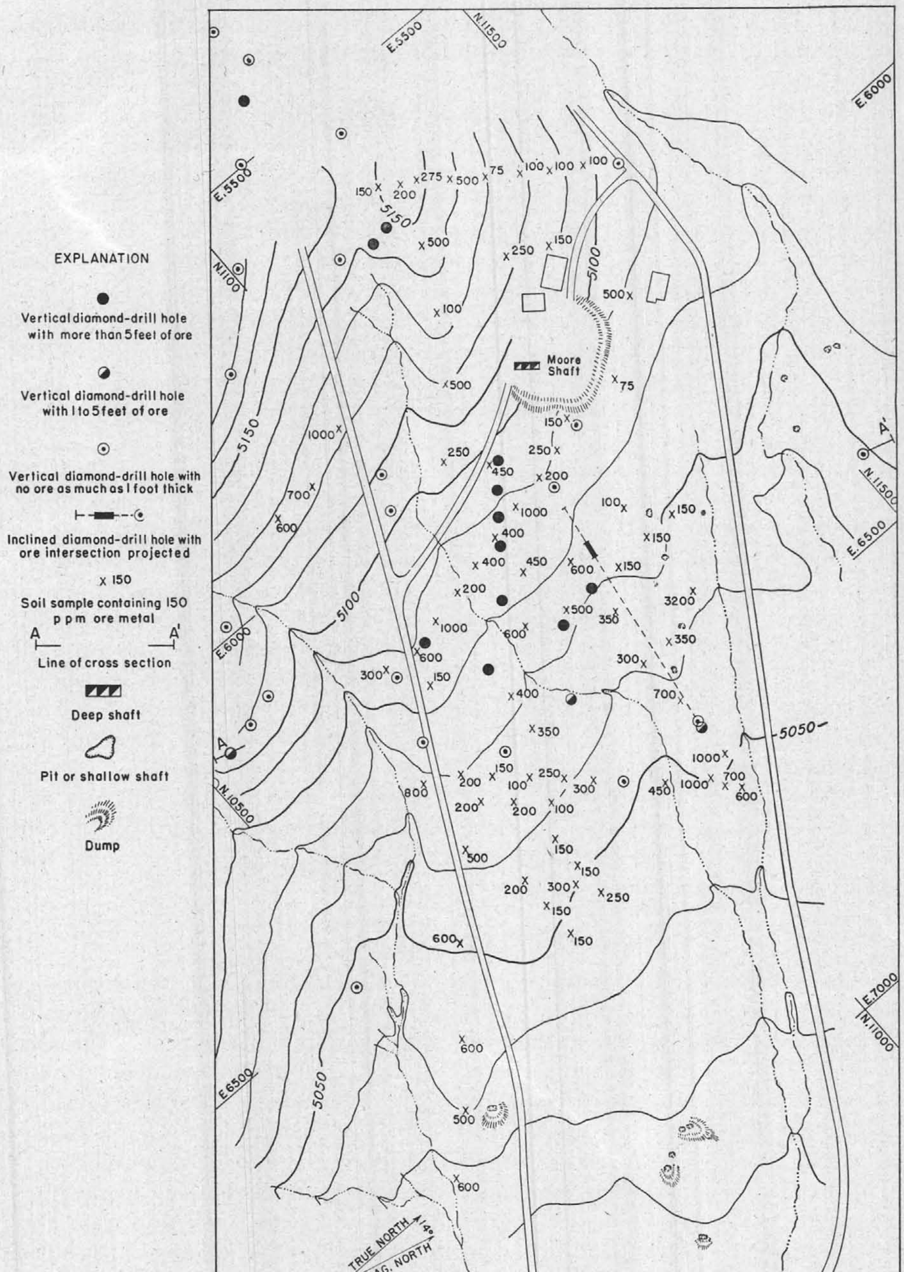


FIG. 1. Topographic map of the Moore ore body area showing diamond-drill holes and geochemical data on soils.

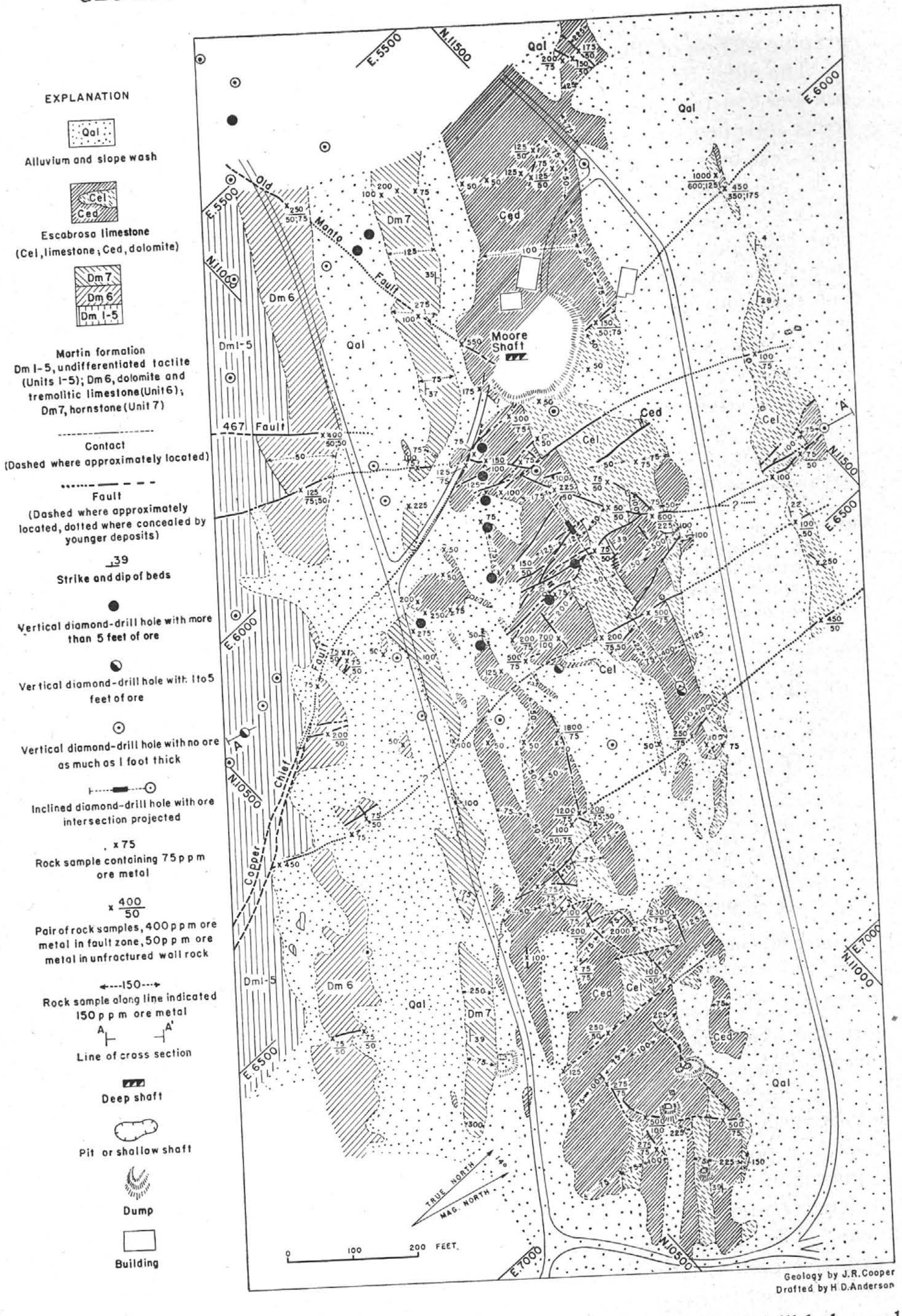


FIG. 2. Geologic map of the Moore ore body area showing diamond-drill holes and geochemical data on bedrock.

was mined a short distance south of the area shown in Figure 2, along the intersection of the 467 fault (Northeaster) with the favorable beds at the top of the middle member of the Abrigo formation. Elsewhere in the district, narrow ore veins cross the beds along both the Easters and Northwesters. The Easters also appear to have been important in localizing mantos, for the two known mantos in the district were both in the favorable beds at the top of the middle member of the Abrigo near and parallel to a major Easter. This relationship can hardly be fortuitous and is thought to indicate that the ore was localized by obscure minor structures associated with the large Easters. At least two periods of fault movement, each followed by the introduction of quartz, are indicated for some Northeasters by brecciated early quartz fillings cut by later unbrecciated fillings. Alternating movement on the various fault sets is indicated at one place in the Republic mine. There, a conspicuous Northeaster that was lined with a 3-foot band of quartz was cut and offset a few feet by an Easter; but later movements reopened the Northeaster across the Easter and this fracture also was filled with quartz. Post-ore faulting is indicated by fragments of ore in the gouge of some of the faults. The "offset" of ore bodies along faults is not a reliable criterion of post-ore faulting in the district because the stratigraphic control of ore deposition was so strong that after the fault movement ceased, the same beds may have been mineralized on the two sides.

The primary ore consists of various proportions of chalcopyrite, sphalerite, bornite and pyrite, a little scheelite, and traces of molybdenite in a gangue of lime-silicates, potash feldspar, calcite, and quartz. The most abundant lime-silicates are garnet, diopside, and epidote; vesuvianite and wollastonite are abundant locally. Within the zone of oxidation, which generally extends to a maximum depth of 50 feet, the ore minerals are chrysocolla, malachite, tenorite, native copper, hemimorphite, and aurichalcite. There is little evidence that copper was leached from the oxidized zone, and almost no evidence that it was redeposited in a zone of secondary enrichment below. Oxidized ores were mined in the early history of the district, but nearly all the ore mined in recent years has been primary ore.

The primary mineralization is divisible into two stages, an earlier metamorphic stage and a later metasomatic stage. The metamorphic stage, which might also be called the thermal or non-additive stage, affected a large area near Johnson presumed to be the roof of the Texas Canyon stock. The metamorphism resulted from increase in temperature and involved the loss of carbon dioxide and the chemical rearrangements of the other constituents of the rock. In general, the mono-mineralic rocks like quartzite, pure limestone, and pure dolomite were recrystallized without the formation of new minerals; whereas rocks like shale and mixed calcareous or dolomitic sediments were profoundly altered mineralogically and texturally. The shales were converted to aphanitic hornstone, the mixed calcareous sediments to granular lime silicate rocks, and the mixed dolomitic sediments to granular lime-magnesia silicate rocks.

The geochemical prospecting study, described later in this report, indicated that the ore-metal content is related to the composition of the host rock, which, therefore, must be considered in interpreting the geochemical results. A stratigraphic section describing the lithology in the vicinity of the deposits is given in Table 2 and can be used as a basis for interpreting geochemical data and as an aid in deciphering structure. The names of distinctive units are given in parentheses. Some of the units, like the "hornstone marker" at the top of the Martin formation, are everywhere present; others, like the quartzite beds in the Abrigo formation, are only distinguishable locally; a few, like the "lower serpentine marker," are conspicuous concentrations of a rock type that locally appears in small quantities in other parts of the section.

TABLE 2.

PARTIAL SECTION IN JOHNSON METAMORPHIC AREA (COMPOSITE).

	Thickness (feet)
Escabrosa limestone, in part:	
Alternating limestone and dolomite units, some with metachert nodules	300+
Dolomite	150
Martin formation:	
Hornstone, light gray, with disseminated pyrite; consists largely of diopside, tremolite, and orthoclase (Dm7 or "hornstone marker")	30
Dolomite, showing some stylolites (Dm6 or "stylolitic dolomite")	85
Limestone, containing some tremolite and serpentine; metageodes are conspicuous on weathered surface (Dm5 or "upper serpentine marker")	10
White tactite, granular; about 75 percent diopside (Dm4)	50
Quartzite containing some diopside (Dm3 or "quartzite marker")	5
Hornstone, light gray; consists largely of diopside, chlorite, and othoclase (Dm2)	8
More or less limy dolomite, generally containing a little chlorite and other silicates (Dm1)	25
Total thickness of Martin formation	213
Abrigo formation:	
Upper member:	
Quartzite containing some diopside (Abrigo unit 10)	3
White tactite, granular, rich in diopside (Abrigo unit 9 in part)	12
Limestone; contains scattered half-inch masses of forsterite or serpentine ("lower serpentine marker") (Abrigo unit 9 in part)	12
White tactite, granular, rich in diopside and orthoclase (Abrigo unit 8 and Abrigo unit 9 in part)	63
Quartzite containing some diopside (Abrigo unit 7)	4
White tactite, granular, rich in diopside and orthoclase (Abrigo unit 6)	24
Middle member:	
Interbedded limestone and hornstone, commonly garnetized and locally containing ore (Abrigo unit 5 or "ore beds")	50
Calcareous sandstone, commonly garnetized (Abrigo unit 4)	26
Limestone with abundant irregular partings of dark hornstone, locally garnetized in part (Abrigo unit 2 and Abrigo unit 3, "crenulated beds")	172
Lower member: Shaly hornstone; includes occasional bands of limestone or garnet tactite (Abrigo unit 1 or "shale marker"), thickness measured outside metamorphic area	300
Total thickness of Abrigo formation	666

As shown in the section above, the thicknesses of the Abrigo and Martin formations are somewhat less than the corresponding thicknesses measured outside the metamorphosed area and presented in Table 1. The difference is thought to signify a decrease in volume of the rock through loss of carbon dioxide and through the formation of relatively dense silicates during metamorphism. The thicknesses in the metamorphic area vary directly with the amount of carbonate remaining in the rock. For some individual members, the thickness of the silicated facies is nearly 30 percent less than the thickness of the corresponding impure carbonate facies. Shrinkage of such magnitude must have been accompanied by structural adjustments and may be related to some of the faults. Though it is not yet possible to reconstruct the structural history in detail, some of the faulting must have been later than the metamorphism because early metamorphic silicates were sheared before the ore was emplaced. Several large ore bodies occur near the edges of silicate masses where slumping due to shrinkage would have been most intense and most likely to yield broken ground.

The metasomatic or ore-forming stage that followed the metamorphic stage was probably a time of decreasing temperature. The ore minerals are generally accompanied by the relatively low temperature gangue minerals—chlorite, ferriferous tremolite, calcite, and quartz—which have replaced the earlier-formed diopside, garnet, and other relatively high temperature silicates. The silicated rocks far from ore bodies also show some retrograde alteration products that commonly, but not invariably, are associated with traces of ore minerals. These alteration products include serpentine derived from forsterite, tremolite and calcite derived from diopside, and quartz and calcite derived from wollastonite. The breakdown of diopside and wollastonite are clearly reversals of reactions that took place during the metamorphic stage.

Moore Ore Body Area.

The Moore ore body, which lies below the area of the geochemical study, was discovered by the Coronado Copper and Zinc Company in 1947 by core drilling. The company started to develop the body for mining by means of a new vertical shaft, the Moore shaft, and by an inclined winze from the Mammoth mine, which is southwest of the new ore body. Neither of the development workings had reached the ore when the Company suspended all operations in the district in 1949.

As indicated by drilling, the ore body is a lenticular mass near the top of the middle member of the Abrigo formation east of the Copper Chief fault and between 400 and 500 feet below the surface. Figure 2 is a detailed geologic map of the surface showing the location of ore holes and blank holes, and Figure 3 is a generalized cross section with nearby drill holes and ore intersections projected.

Several smaller ore bodies, also near the top of the middle member of the Abrigo formation, have been mined a short distance south of the mapped area. One of these, at the Copper Chief mine, about 1,500 feet south of the Moore ore body, was similar to the Moore ore body in shape and in location with respect to the Copper Chief fault. Others were west of the Copper Chief fault and included several tabular masses of the bedded type that were mined many years ago by extensive underhand stopes below the outcrop, and also two blind ore chimneys, both in the Mammoth mine. One chimney, mined during World War I, was a manto below the Old Manto fault. The other chimney, mined in very recent years, was almost parallel to the dip of the beds along the 467 fault.

Both these faults appear on the geologic map. The 467 ore chimney ended near the edge of the mapped area, the Old Manto ore body about 150 feet beyond the edge of the area. The ore shown by drill holes north of the Old Manto fault appears to be part of another very small unmined manto.

On the geologic map, Figure 2, the formations are subdivided on a lithologic basis in those areas where samples for geochemical analysis were collected. Most of the lithologic units correspond to stratigraphic units, but some limestone areas were formed by local alteration of dolomite beds, dedolomitization resulting from the reaction of silica with dolomite to form calcite and a magnesia-rich silicate, generally tremolite and less commonly forsterite or its alteration product serpentine. No evidence has been found anywhere in the Johnson district for the opposite process, dolomitization, which is common in some mining districts.

The beds in the Moore ore body area strike northwest and dip 30°–40° NE except in the arroyo along the northeast edge of the mapped area, where the dips are flatter and the strike shows local variations. The Copper Chief fault, a Northwester with east side down, is the largest of many faults in the area. East of it in the vicinity of the ore body the rock is broken by faults and fractures with several trends. Fractures are especially abundant in a triangular area between the Copper Chief fault and a north-trending fault that joins the Copper Chief fault about 850 feet south of the Moore shaft. Another intensely faulted and fractured area, separated from the first by a relatively unfractured band about 200 feet wide, is found in the Escabrosa limestone near the eastern edge of the mapped area. Considerable shifting of fault blocks is suggested by the pattern of limestone bands in the Escabrosa in this area, but no comparable offsets are apparent in the units of the Martin formation. This puzzling relation may be due to dying out of the faults or to their termination against a strike fault as suggested on the map. A third area containing many fractures is found several hundred feet west of the Copper Chief fault in the vicinity of coordinates N 11,600, E 5,700, where half a dozen small faults have been omitted from the map so that the geochemical data could be shown.

In the area of geochemical study east of the Copper Chief fault the oldest faults strike approximately east and dip south, generally at 30° to 60°. These Easters are commonly mineralized by narrow veins of quartz carrying iron oxides and occasional traces of copper minerals. Many faults that cut and offset the Easters range in strike from N 45° E to N 20° W and thus bridge the gap generally present in the district between Northeasters and Northwesters. These are normal faults, which dip more than 60° E or W and are represented by zones of breccia (Fig. 4) or sheared rock. Although some are locally silicified and rusty they are generally less silicified than the Easters.

The typical Northeasters of the district are commonly marked by small fissure veins of quartz, orthoclase, fluorite, calcite, and the ore minerals chalcopyrite, bornite, sphalerite, and locally tetrahedrite and galena. No veins of this type were found in the area of the geochemical study.

The geologic map (Fig. 2) shows the larger faults but does not show small fractures in the intervening fault blocks. The small fractures vary notably in abundance from place to place. They are much more common in dolomite than in limestone, perhaps because dolomite acted as a brittle material, whereas limestone may have yielded by recrystallization or plastic flow. There seems to be a complete gradation from areas with no visible fractures other than wide-spaced joints to other areas where fractured ground merges imperceptibly into intensely sheared fault material. A fault that is a well-defined structure at one place may pass into a broad ill-defined zone of fractured rock in another part of its course. Much of the displacement in such areas took place through considerable widths of shattered rock and not along well-defined fault planes. Many of the approximately located faults shown on the geologic map are more or less arbitrarily located in zones of intense fracturing. In general, the density of faults shown on the map is a rough measure of the relative abundance of the smaller fractures.

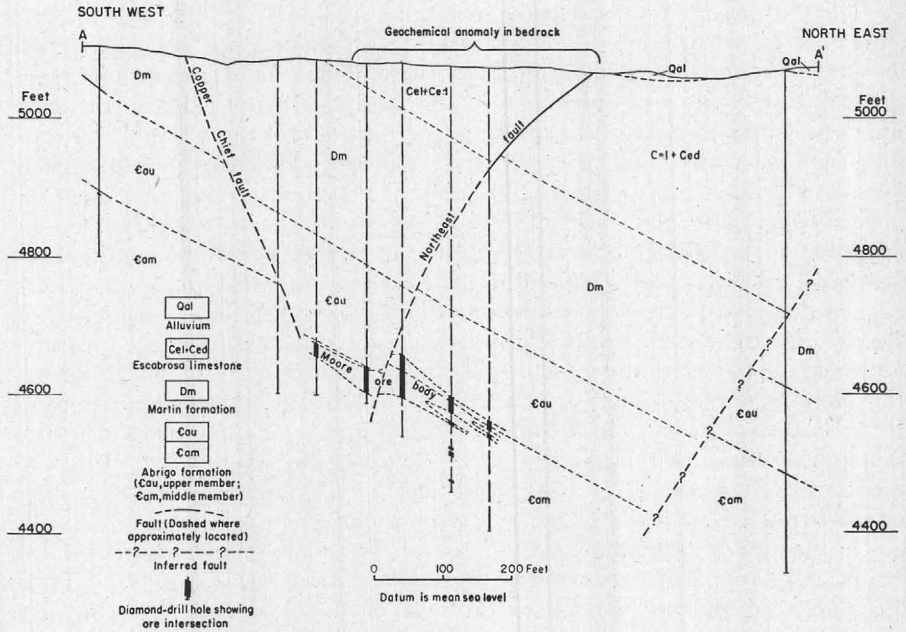


FIG. 3. Generalized cross section along the line indicated on Figures 1 and 2.

The cross section, Figure 3, is generalized as the diamond-drill holes do not provide enough data to work out the structure in detail. The large fault at the north end of the section is inferred from the apparent absence of upper units of the Martin formation in the drill hole in this area. The fault may be the extension of the east-trending fault zone exposed near coordinates N 11,640, E 5,750, which has about the same displacement, judging from evidence provided by the drill hole 300 feet northwest of the Moore shaft.

GEOCHEMICAL INVESTIGATIONS.

The Moore ore body area was selected for detailed geochemical study because much information on underground conditions there was available through core drilling and yet the land surface is not much disturbed nor covered by mine dumps and buildings. Moreover, the Escabrosa limestone is well exposed above the ore; and as this formation is the most uniform lithologically of any formation in the area, geochemical data obtained on it should be relatively easy to interpret.

Sampling Procedure.

The first rock samples were collected in order to determine whether the metal content of the weathered surface of the rock was different from that of the unweathered rock. At each of 11 localities, two separate samples were collected, one composed of 5 to 10 chips from the weathered surface of the outcrop and the other composed of chips from the unweathered interior. The analyses of these samples, given in Table 3, show differences little or no larger than the

TABLE 3.

COMPARISON OF ORE-METAL CONTENT OF WEATHERED AND UNWEATHERED ROCK.

Location		Rock type	Total ore metal in parts per million	
N	E		Unweathered sample	Weathered sample
10,850	6,190	Hornstone	250	250 300
10,885	6,160	Dolomite	75 125	200 200
10,940	6,160	Dolomite	50	50
10,965	6,130	Dolomite	50	50
11,040	6,140	Dolomite	50	75
11,090	6,130	Dolomite	100 100	100
11,105	6,055	Dolomite	75	50 100
11,145	6,115	Dolomite	75	50 75
11,190	6,105	Limestone	50	50
11,230	6,065	Limestone	50	50
11,315	6,080	Limestone	50	50

Note: Braces indicate two separate analyses of a single sample.

error of analysis and indicate that surficial weathering has little effect upon the ore-metal content. To save sampling time all subsequent samples were taken with no regard to the amount of weathered surface in the sample; and subsquent analyses showed that this practice did not veil the systematic variations in the metal content of the samples.

Composite samples of about a dozen chips each were collected at intervals of about 50 feet along three traverse lines across the area. The analyses of these samples, shown in Figure 2, suggested that highly fractured rock had a higher-than-average metal content, presumably because metal-bearing fluids that penetrated the rock tended to follow the faults and fractures.

To test further the effect of fractures the next set of rock samples was taken by pairs, one sample of highly fractured or brecciated rock marking a fault and another of the least fractured wall rock procurable within 6 feet of the fault. Thus each pair of samples represents extremes—the most fractured and the least fractured rock from essentially the same locality. The analyses of these samples shown in Figure 2, proved beyond any possibility of doubt that the abundance of fractures strongly affected the metal content of the rock; which in turn indicated that, unless samples contained fractured and unfractured rock in the same proportion as in the outcrop, a large "sampling error" would result and might obscure systematic areal variations of the ore metal.

The final set of rock samples was taken in a manner designed to make the samples representative of the area and at the same time to test the fault blocks for ore-metal anomalies. Small chips were collected every few feet along traverses that crossed the fault blocks. No chips were taken from the faults themselves but otherwise the samples include representative portions of the rock and whatever fractures it contained. Most of the samples consisted of 20 to 30 chips collected over a traverse of about 50 feet. The analytical results for these samples are also shown on Figure 2.

Soil samples were collected after a 1- to 2-inch layer of pebbles, plant material, and soil from the land surface was scraped off. The soil to be sampled was put through a 2-mm mesh stainless steel and aluminum sieve. Sampling was confined largely to low ridges where the soil was definitely derived from the local rock.

Sample Analysis.

Usually samples were collected in the morning and analyzed the same afternoon so that results would be available for guidance of more sampling the following morning. The rock samples, which averaged about 10 grams in weight, were ground to a fine powder with an iron mortar and pestle before analysis. The soil samples required no grinding. It was found that 25 to 30 rock samples could be collected, ground, and analyzed in an 8-hour day. Soil samples required less time in collection and preparation.

The analytical method used in the field was a primitive version of the general "heavy metal" test (4). Approximately ⅓ gram of the sample was measured with a volumetric scoop and digested in 4 ml of 1 : 3 nitric acid by keeping the solution at or near the boiling point for 10 minutes. The nature of effervescence, amount of residue, and presence of discoloration caused by iron were noted in the case of the rock samples, so that a rough estimate could be made of the relative amounts of calcite, dolomite, insoluble silicates, and iron in each sample. The determination was made as described in the reference given except that the buffer contained no fluoride and oxidation of the dithizone by iron gave some trouble in analyzing the soil samples. To eliminate any possible subjective influence in the colorimetric determinations, the procedure was arranged so that the source of the sample was unknown to the analyst at the time he made the analyses.

The reliability of the field analyses was checked in the Denver laboratory of the U. S. Geological Survey in two different ways: 1) by repeating the field analyses of all samples, using an improved procedure; and 2) by accurate determinations of copper, lead, and zinc in 37 selected samples. The field analyses were repeated by Mr. J. J. Schuch, using weighed portions of the sample and digesting them in aqua regia. Determinations were made in the presence of fluoride to avoid interference by iron. The accurate laboratory determinations were made by Mr. Harold Bloom. As described in the reference given, the field test gives a positive reaction with any copper, lead, or zinc present in the sample. The results of the field test are expressed as parts per million of "zinc equivalents," which should correspond to zinc plus 1/2 of the copper plus 1/4 of the lead. A comparison of the results obtained by the different analytical methods for the 37 samples analyzed by laboratory methods is presented in Table 4. The data from analyses based on the aqua regia extraction have been used in all the illustrations and interpretations; where two determinations were available for the same sample, an intermediate rounded-off value was used. As indicated by Table 4, the agreement of results from the various analytical methods used is fairly good, and even the original analyses made in the field were adequate to reveal significant differences among the samples.

TABLE 4.

COMPARISON OF RESULTS BY DIFFERENT ANALYTICAL METHODS, CONCENTRATIONS GIVEN IN PARTS PER MILLION.

Sample location		Description	Laboratory method			Zinc + ½Cu + ¼Pb	Field method	
N	E		Copper	Lead	Zinc		1:3 HNO	Aqua regia
Unmetamorphosed area		Limestone (Escabrosa)	10	10	10	17	50	50
Unmetamorphosed area		Dolomite (Escabrosa)	10	10	20	27	75	50
Unmetamorphosed area		Dolomite (Escabrosa)	10	10	15	22	75	75
Unmetamorphosed area		Dolomite (Martin, Dm6)	10	10	25	32	75	75
Unmetamorphosed area		Shale (Martin, Dm7)	10	10	20	27	50	50
Unmetamorphosed area		Sandy shale (Martin, Dm7)	15	20	25	37	50	75
12,325	4,950	Hornstone (Dm7)	140	10	35	107	150	75
11,880	5,325	Hornstone (Dm7)	40	10	20	42	100	75
11,515	5,550	Hornstone (Dm7)	115	10	110	170	100	{250, 150
11,240	5,760	Hornstone (Dm7)	115	10	40	100	200	{100, 125
10,850	6,190	Hornstone (Dm7)	410	10	35	242	400	{300, 250
10,840	6,235	Hornstone (Dm7)	100	10	25	77	50	100
11,310	5,700	Hornstone (Dm7)	20	10	24	36	75	75
11,005	6,570	Limestone (Escabrosa)	20	10	10	22	25	50
11,145	6,115	Dolomite (Escabrosa)	10	10	20	27	150	{50, 75
10,850	6,430	Dolomite (Escabrosa)	10	10	20	27	50	50
11,050	6,600	Fault zone in dolomite	190	10	165	262	400	250
11,050	6,600	Unfractured dolomite	15	10	40	50	125	{50, 75
11,400	5,760	Dolomite (Escabrosa)	10	10	10	17	50	50
11,110	6,075	Fault zone in dolomite	35	110	120	165	400	{125, 150

TABLE 4—*Continued.*

Sample location		Description	Laboratory method			Zinc + $\frac{1}{2}$Cu + $\frac{1}{4}$Pb	Field method	
N	E		Copper	Lead	Zinc		1:3 HNO	Aqua regia
11,195	6,255	Fault zone in limestone	15	10	15	25	50	50
10,600	6,350	Fault zone in limestone	40	10	20	42	75	75
10,840	6,780	Fault zone in limestone	1,280	1,500	1,760	2,775	{800 1,000	{2,200 2,400
10,905	6,455	Fault zone in limestone	1,100	1,190	1,060	1,907	1,000	{2,000 1,600
10,840	6,570	Fault zone in limestone	680	8,000	1,550	3,890	1,200	—
10,375	6,580	Fault zone in dolomite	15	10	20	30	75	75
11,205	6,345	Dolomite (Escabrosa)	150	10	490	567	700	500
10,855	6,495	Dolomite (Escabrosa)	10	10	25	32	75	50
11,425	5,960	Dolomite (Escabrosa)	15	10	40	50	75	50
11,595	5,745	Dolomite (Escabrosa)	40	10	85	107	200	{100 125
11,665	6,895	Dolomite (Escabrosa)	220	10	60	172	250	{100 75
10,790	6,785	Dolomite (Escabrosa)	20	10	50	62	150	{75 75
11,050	6,600	Soil near fault	640	30	1,080	1,407	1,000	1,000
11,410	5,770	Soil on dolomite	105	15	80	136	100	{75 150
11,290	5,680	Soil on hornstone	380	20	140	335	150	275
11,055	6,010	Soil on hornstone	350	20	225	405	300	250
10,840	6,010	Soil on hornstone	460	25	170	406	400	{100 200

Note: Braces indicate two separate analyses of a single sample.

Ore Metals in Bedrock.

Background Values.—Some ore metal is incorporated in sediment at the time it is deposited, and the amount of metal may be increased or decreased in the normal course of diagenesis and groundwater circulation. The resulting ore-metal content of the sedimentary rock is the background value. The background may vary from bed to bed and from place to place within a particular bed, without any relationship to hydrothermal processes of ore deposition.

The background values for the stratigraphic units sampled near the Moore ore body were obtained by sampling the same units on the northeast slope of Johnson Peak, about a mile west of the Moore ore body, in an area where the rocks are apparently unaltered. Each sample was a composite of chips taken every foot or so across the unit. Laboratory analyses of these samples, presented in Table 4, show 10 to 15 ppm of copper, 10 to 20 ppm of lead and 10 to 25 ppm of zinc; with a total "zinc equivalent" of less than 40 ppm in all samples. The corresponding field analyses show a 50 or 75 ppm "zinc equivalent."

Effects of Stratigraphy in the Mineralized Area.—It is obvious that ore bodies in the Johnson district have selectively replaced particular beds. Available geochemical evidence indicates that traces of ore metals were similarly concentrated in particular beds and rock types. In the metamorphosed area, 175 bedrock samples, excluding fault-zone samples, were analyzed for total ore metal (Fig. 2). Of these, the limestone samples average 67 ppm in metal; the dolomite samples average 100 ppm; the hornstone samples average 150 ppm. Selective deposition in dolomite and hornstone is indicated. At five localities samples were taken on opposite sides of faults that separate limestone from dolomite, with the following results:

Location		Limestone	Dolomite
N 11,660	E 6,022	{125 {225	350
N 11,660	E 6,002	125	600
N 11,375	E 6,035	50	75
N 10,823	E 6,573	50	75
N 10,850	E 6,595	50	75

Note: Brace indicates two separate analyses of a single sample.

The metal content at the first two localities is definitely above the background content and shows preferential deposition in the dolomite. The selective concentration in particular rock types may be due to differences in permeability or some unknown chemical effects. For the purpose of geochemical prospecting, at least in the Johnson area, the explanation is not so important as the empirical facts that the percentage of ore metal in one rock type is not directly comparable with that in another and that some rock types are more sensitive indicators of areas with introduced metals. The facts suggest that the heart of a geochemical anomaly may be located by examining progressively less susceptible beds.

The importance of stratigraphy goes beyond broad lithologic distinctions like limestone and dolomite. A dolomite bed that contains small masses of silicates derived from chert nodules is particularly rich in ore metals. The once cherty bed is about 10 feet thick and may be traced from the northeast-trending fault near N 11,225, E 6,300 to the north trending fault near N 11,060, E 6,600. The three prospect pits in this area are all in this bed, which shows some copper stain, particularly in the metachert nodules. Chip samples across the bed, taken where no copper minerals were apparent, yielded 500, 400 and 300 ppm respectively, the maximum values obtained in any of the chip samples taken along traverses. Some metachert nodules, which may indicate the same bed, were noted for about 150 feet northwest of the prospect at N 10,645, E 6,985. This area is also one of the very few places within the map limits where ore minerals are visible.

The stratigraphy must be borne in mind in any future geochemical studies that may be undertaken in the district. This study provides a basis for interpreting results in the small part of the stratigraphic section studied. It is expected that higher beds, at least those of the Escabrosa limestone, will yield results that are comparable with those obtained from dolomite and limestone units already studied, for these beds are similar in lithology and in type of alteration. The lower beds constitute a different and far more difficult problem because the rocks below the stylolitic dolomite unit (Dm6) are very diverse lithologically. They are much altered mineralogically in a large area surrounding the mines and contain small quantities of visible ore minerals in many parts of the altered area.

Concentration in Fault Zones.—The concentration of ore metals in certain fault zones is an incontrovertible fact revealed by this geochemical investigation. The data, presented in Figure 2, show that fault zones contain up to 2,300 ppm ore metal even though unfractured dolomite several feet away may contain only 75 ppm, the background value. Metal is concentrated in every type of fault material sampled. The fault material sampled included breccia (Fig. 4) and intensely sheared or sheeted rock both with and without introduced silica and iron; soft fault gouge, found in some of the mine workings of the district, is nowhere exposed in the area studied geochemically and therefore was not sampled. Quantitative estimates made in the course of chemical anal-

FIG. 4. Fault zone marked by breccia.

ysis and presented in Table 5 show that, on the average, faults rich in insoluble matter, iron and secondary calcite are higher in ore metal than the rest, but that each kind of fault material contains both high and low values. Field observations lead to the same conclusion, for experience has shown repeatedly that faults, which appear to be similar in every way, may range in richness from a very high metal content to a background metal content.

The concentrations are not confined to any particular set of faults; they may be different in two parallel faults and in one part of a particular fault as contrasted with another part. The Copper Chief fault contains from 75 to 600 ppm ore metal, and other faults show comparable variations along their course. The greatest concentrations were found in thin, silicified and rusty Easters;

and the Easters average somewhat higher in metal than the rest. In general, the introduced metals are copper and zinc, but several faults are surprisingly high in lead (Table 4). The metals are the same as those contained in visible minerals found in quartz veins along some Northeasters in the district. The commonest ore minerals in such veins contain copper and zinc, but lead minerals are present locally.

It is not surprising that fault zones contain abnormally large quantities of heavy metals. Fault fissures were evidently channels for mineralizing solu-

TABLE 5.

RELATION BETWEEN ORE-METAL CONTENT AND MAJOR CONSTITUENTS OF SAMPLES OF CARBONATE ROCKS.

		Pure or nearly pure carbonate				High insoluble residue, little or no iron				High insoluble residue and iron			
		Number of samples	ppm of ore metal			Number of samples	ppm of ore metal			Number of samples	ppm of ore metal		
			Min.	Max.	Average		Min.	Max.	Average		Min.	Max.	Average
Fault-zone samples	Carbonate dominantly calcite	7	100	500	211	3	50	100	75	13	100	2,300	698
	Carbonate dominantly dolomite	11	75	275	125	10	75	600	252	16	75	1,800	361
Wall-rock samples	Carbonate dominantly calcite	12	50	175	69	0				1	50	50	50
	Carbonate dominantly dolomite	43	50	600	86	3	50	225	117	1	50	50	50
Traverse samples	Carbonate dominantly calcite	15	50	150	77	0				0			
	Carbonate dominantly dolomite	56	50	500	106	9	50	400	164	0			

tions in the district because ore bodies are found along them and because ore minerals are visible in them at some places. The chief problem in prospecting for new ore is to tell which fissure or which part of a fissure was a channelway for mineralizing solutions and, therefore, where ore may be localized in the favorable beds. A concentration of ore metals in and near a fissure is certainly a good indication of a channelway at the ore-forming stage. Exposures of the 467 fault above the 467 ore chimney in the Mammoth mine contain visible copper minerals, and fissures in the Escabrosa limestone above the large ore bodies of the Republic mine also contain visible copper minerals. Chemical tests for ore metals are much more sensitive and accurate than visual examination in measuring the concentrations. The samples in the Copper Chief fault zone at N 11,660 are the only ones taken where any ore minerals were visible. This is the only place on all the faults sampled that would be noted visually as favorable for prospecting. The chemical data, however, permit all the faults to be evaluated quantitatively in terms of contained ore metal. They reveal that several faults with no visible ore minerals have an even higher metal content than the fault with visible ore minerals.

Other criteria used to recognize fractures that have been channelways for ore solutions and may have localized ore bodies in the favorable beds are the presence of quartz and of iron stain. Neither of these criteria is reliable, as indicated by the geochemical data. Although silicified and rusty faults showed the highest concentrations of ore metal, some equally silicified and rusty faults yielded only background values.

Concentrations in Fractured Rock.—The blocks between the faults shown on the geologic map are cut by minute fractures, some of which have seams of quartz or calcite. These small fractures and seams, like the larger faults, are places where ore metals are concentrated, as shown by a comparison of the analyses of unsheared rock next to faults with the analyses of nearby chip samples collected along traverses (Fig. 2). In general the geochemical highs in bedrock, indicated by the traverse samples, are in much-fractured areas, but some equally fractured areas yield only background values and some areas without evident fractures are notably mineralized. The highs are not marked by visible peculiarities, but are revealed only by chemical analysis. As in the faults, the principal ore metals involved are copper and zinc.

Pattern of Distribution.—Figure 5, a and b, shows the general relation of known ore in depth to ore-metal determinations in fault zones and intervening fault blocks at the surface. To facilitate the graphic presentation, the analyses are simply classified as + or −, depending upon whether they show values higher or lower than an arbitrary value. The pattern given by the fault-zone samples is somewhat erratic and does not correlate with underlying ore in detail. It seems clear that at the horizon of the present land surface, metal-depositing solutions leaked along faults over a larger area than the one investigated. Fault-zone studies of this kind may prove most useful in outlining broad areas favorable for prospecting.

Geologic relations not shown in Figure 5 must be considered in interpreting the fault-zone data. For example, the three background values over the northern edge of the Moore ore body, though in an area where leaks from the ore body would be expected, were obtained from faults in limestone, a rock that tends to be "tight" and to have a low metal content. The seven background values south of the ore body all came from faults in dolomite, a better host rock, and thus give a sounder basis for concluding that they indicate a truly unfavorable area for prospecting. The abundance of high values in the area east of the Moore ore body is noteworthy; the geologic structure would permit leaks from the Moore ore body in this direction but it is unlikely that the whole anomaly is related to that ore body as now known, for this would mean that the metal-bearing solutions had crossed several late and persistent fault channels

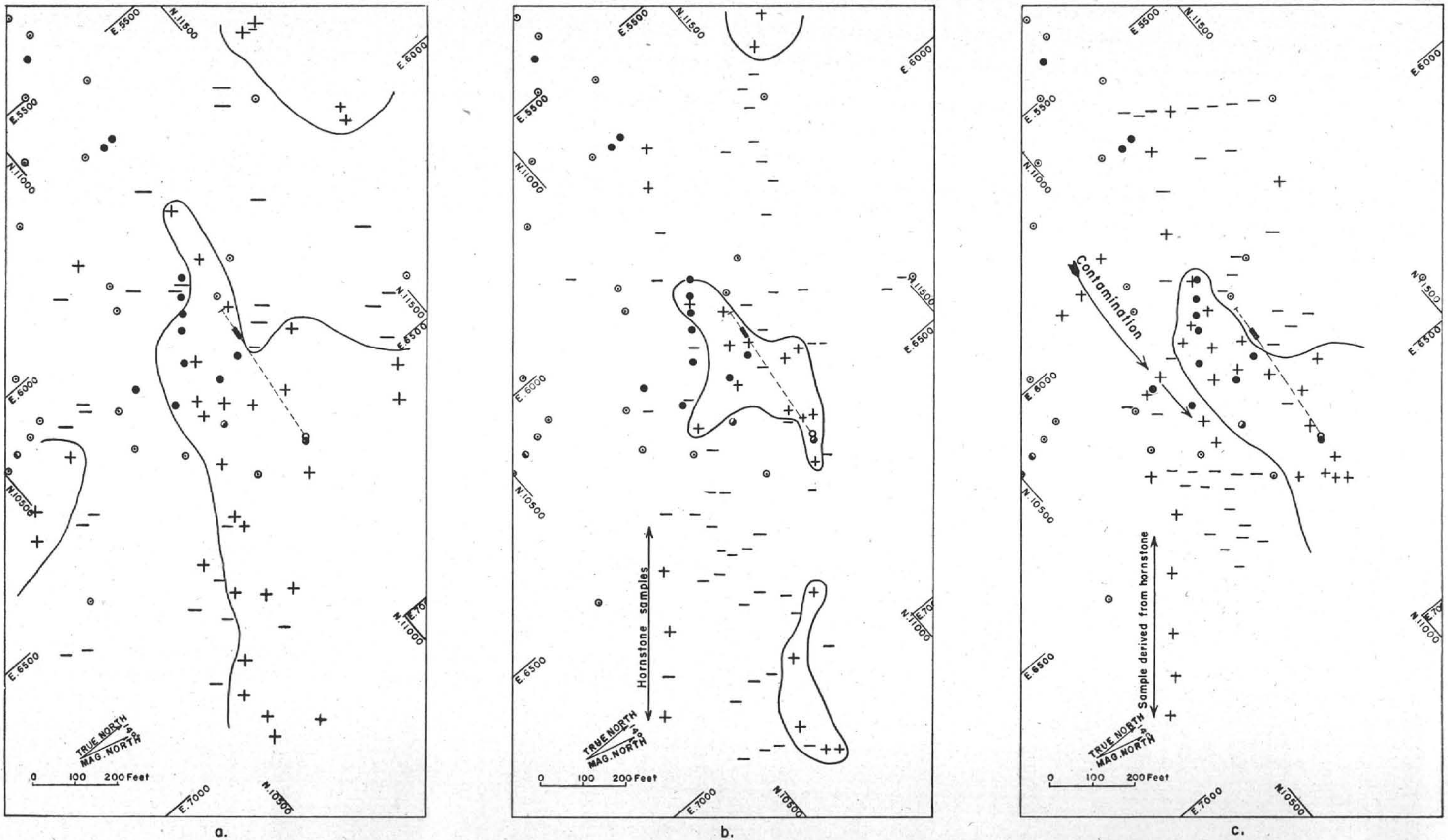


FIG. 5. Sketch maps showing relation of geochemical anomalies to known ore in depth. Diamond-drill hole symbols same as in Figures 1 and 2. (a) anomaly based on analyses of fault samples; + indicates metal concentration of 175 ppm or more and – indicates 174 ppm or less; (b) anomaly based on analyses of chip samples collected along traverses; + indicates a metal concentration of 125 ppm or more and – indicates 124 ppm or less; and (c) anomaly based on analyses of soil samples; + indicates a metal concentration of 350 ppm or more and – indicates 349 ppm or less.

across the trend of the anomaly. Some of the high values in the area west of the Moore ore body may be related to other ore bodies. For example, high values were obtained from the 467 fault and Old Manto fault, both of which are associated with ore bodies a short distance outside the map area. High values were also obtained in the northern part of the mapped area; there is no reason to suppose that these are related to any ore body now known.

The ore-metal content of the rock between the faults, indicated by the analyses of chip samples taken across the fault blocks, provides a basis for locating areas particularly promising for prospecting (Fig. 5b). As with the fault-zone data, the stratigraphy and structure, which are not shown on Figure 5, must be considered in interpreting the results. For example, the hornstone, which tended to collect ore metal, is expressed by a band of predominantly high values along the southwestern side of the mapped area. Ignoring this band of high values, which seems to be simply an expression of the stratigraphy, two conspicuous anomalies remain. The larger one of these overlaps the Moore ore body and extends east of it to the overlapping alluvium. A spatial and genetic connection between the ore body and the geochemical anomaly seems probable. Another anomaly centers about 700 feet southeast of the first and also extends eastward to the overlapping alluvium. Each of these anomalies contains a small area with visible copper minerals, and these visibly mineralized portions mark areas in which samples of apparently unmineralized rock are very high in ore metals. The high values seem to be related in part to the presence of cherty dolomite, as previously pointed out, but cannot be explained wholly in this way for they are in several beds, including limestone and noncherty dolomite. In the southeastern anomaly, the very high values may be related to an east-trending fault that dips 54° to 60° S and contains chrysocolla and malachite in the prospect at N 10,700, E 6,960. There may be an analogy in the northwestern high, where the best showing of copper at the surface is also in an Easter exposed in the prospect at N 11,205, E 6,320. Though this Easter cannot be traced at the surface and may not be a through-going structure, its projection points toward the Moore ore body.

Another anomaly is indicated in the northern part of the mapped area by high values in faults and unsheared wall rock near the Copper Chief fault, and in the fractured outcrop several hundred feet farther west (Fig. 2). It was impossible to investigate this anomaly fully in the time available.

Desirable Future Investigations.—This study shows that geochemistry may be a valuable tool in prospecting for concealed ore bodies in the district. The geochemical method certainly merits additional investigation. Additional work could follow either or both of two approaches; both are desirable and the two might be followed simultaneously. One approach is to explore beneath the surface geochemical anomalies by diamond drilling or some other means to see if anomalies are always or generally associated with ore in depth; the other is to investigate the vertical extent of the geochemical anomalies to see if there is a continuous connection between the surface anomaly and the ore.

The best prospect for exploration in the area studied is the anomaly about 750 feet southeast of the Moore ore body (Fig. 5b). This area is similar to the Moore ore body area both in geologic structure and in ore-metal distribution. The most promising place to start exploration is probably several hundred feet southwest of the center of the anomaly. This suggestion is made because of the direction and amount of offset between the Moore ore body and the geochemical anomaly apparently related to it, and because of the apparent importance of a south-dipping Easter in localizing maximum deposition of ore metal in the project area. It should be emphasized, however, that the course of mineralizing solutions in any particular area must have been controlled by the local geologic structure. All parts of the much-fractured area east of the large fault running approximately along E 6,600 must be considered favorable ground until more is known about the geologic structure and its effects on movements of solutions.

On the geochemical side, it would be desirable to study the drill cores from the Moore ore body area to get all possible information on the location and behavior of the geochemical anomaly in depth. Geochemical anomalies should be sought and mapped in the vicinity of other ore bodies in the district by studies of both surface samples and underground samples procured from mine workings and drill cores. In some limited area, say the Moore ore body area, the fault zones should be sampled every 5 or 10 feet and the beds at somewhat greater intervals to determine whether variations in ore-metal content are uniform or erratic, and thus whether close-spaced sampling is required to give a reliable picture.

Soil Studies.

If it can be assumed that the ore-metal content of the soil is related to the ore-metal content of the rock from which the soil is derived, then soil analysis offers a means of detecting higher-than-average metal content in the bedrock. Soil studies involve several problems not present in rock studies; however, the problem of obtaining representative samples is somewhat simplified.

Typically, a soil is derived not only from parent rock immediately underneath but also from material that has migrated downhill under the influence of gravity during the process of weathering and erosion. Consequently, the ore-metal content of the soil may be related more closely to the metal content of rock on the hillside above than to the metal content of the underlying rock. In the process of soil formation considerable mixing is involved so that it would be futile to try to distinguish soils derived from unfissured rock, fissured rock, and fault or vein rock because these rock types are so closely associated areally. However, the mixing during soil formation is advantageous in some respects; for a small sample of soil is a naturally mixed sample representing a considerable mass of parent rock.

Soil samples collected on the hillside southwest of the Moore shaft at coordinates 10,970 N, 5,870 E; 10,890 N, 5,910 E; and 10,820 N, 5,920 E, have total metal contents of 1,000, 700, and 600 ppm, respectively. These soils rest on dolomite with a relatively low metal content. Ore-bearing Abrigo formation crops out and is exposed in old surface workings near the crest of the hill to the southwest of the mapped area. From the distribution of float containing ore minerals around these old workings it is obvious that copper- and zinc-rich soil materials are migrating downhill toward the sites sampled and explain their high metal content. Similarly, all soils downhill from known ore deposits or workings may be expected to be contaminated to a greater or lesser extent by slope wash from these ore deposits. To avoid such contamination soil sampling was restricted largely to areas so situated topographically that such contamination is very unlikely. Sludge from diamond-drill rigs and ore dropped along roads are other possible sources of contamination. Sample sites were selected where contamination of this type is unlikely.

A tailings pond at the Republic Mill, about 1.5 miles south of the area shown in Figure 1, is still another possible source of contamination. On windy days dry tailings are blown about and are undoubtedly incorporated in neighboring soils. The extent to which this aeolian contamination has affected the soils is unknown. However, if the contamination is widespread it must be comparatively low in magnitude because many of the soil samples have a low metal content.

Samples of soil that could not be contaminated by slope wash correlate crudely in metal content with the rock nearby. In general the metal content of the soil is several times that of the corresponding rock. Most of the soils sampled were derived from limestones and dolomites of varying purity. They weather largely by solution of their carbonate constituent and the resulting soils are relatively carbonate-poor. In general the soil seems to represent the insoluble residue of the limestone or dolomite, and the ore metal appears to remain in the residue. Apparently even the small trace of the ore metal present is insoluble enough under the prevailing climatic conditions so that it is not leached away by ground water. This conclusion substantiates observations of the behavior of copper upon weathering at San Manuel (5).

The correlation between the metal content of the soil and of the bedrock is poorest for soils from the non-carbonate hornstone bed in the Martin formation. Possibly the poor correlation is due to the manner of weathering of the hornstone, which breaks up into resistant blocks with few small fragments.

The correlation between the metal content of the soil and that of the bedrock is best for soils derived from the carbonate rocks. In Figure 5c an ore-metal anomaly above the Moore ore body shows some of the characteristics of both fault-zone and traverse-sample anomalies. The correspondence between these anomalies not only indicates that there is a relationship between metal content in soil and bedrock but also confirms the existence of an anomaly in the vicinity of the hidden ore body.

It seems likely that in many places chemical prospecting for anomalies of this type can be accomplished by either soil or rock analysis. Soil study offers advantages in ease of sampling and preparation but the disadvantage of soil contamination. Soil studies may prove especially valuable in reconnaissance work and in areas where outcrops are scarce. It seems obvious that both rock and soil should be studied until more is known about geochemical prospecting, so that the results obtained by one approach can be checked against the results obtained by the other.

CONCLUSIONS.

In the area investigated, the copper, zinc, and lead content of the rock varies markedly because of inherent differences in the original rock and differences in the amount of metal subsequently introduced. The factors determining the amount of introduced metal include lithology and kind of alteration of the original bed, amount of fracturing, and geographic position. After discounting the factors that can be evaluated by careful geologic study—lithology, kind of alteration, and amount of fracturing—anomalies remain. One of these anomalies seems to be related to the Moore ore body, which is about 400 feet beneath the surface. Therefore, geochemistry is regarded as a promising tool in exploring for other concealed ore bodies in this and similar districts.

The beds investigated include relatively pure limestones and dolomites of the Escabrosa and Martin formations and a shale bed in the Martin. The carbonate beds both outside the mining district and at many places within the district average out 20 ppm zinc, 10 ppm copper, and 10 ppm lead. This small background metal content seems to be syngenetic and thus unrelated to the ore deposits of the district. The background metal content of the shale bed is about the same as that of the carbonate rocks.

In the area of special study near the Moore ore body, the ore-metal content correlates to some extent with particular beds or particular rock types. For example, limestone generally contains less metal than dolomite, both where the values are very low and apparently due to slight differences in the background and where the values are higher and indicate introduction of metal from mineralizing solutions. The introduction into dolomite in preference to limestone may have been due to differences in permeability resulting from differences in behavior of the two rocks under stress; dolomite seems to have been brittle, for it is much fractured and hence relatively permeable; whereas limestone seems to have yielded partly by recrystallization or plastic flow, for it is less fractured and hence presumably less permeable. Particularly high concentrations of metal, up to 490 ppm zinc (24 times background) and 150 ppm copper (15 times background, were found in a once-cherty dolomite bed in which the chert nodules are now represented by aggregates of contact-metamorphic silicates. This bed is one of the few in the area investigated where any ore minerals are visible. The visible ore minerals are chrysocolla and malachite, but the bed is not particularly high in copper. Samples from areas where no ore minerals are visible contain up to 1,280 ppm copper (128 times background). It is concluded that the ore-metal content of these rocks cannot be determined by visual examination; it can be determined only by chemical analysis.

Fault zones carry the highest concentrations of ore metal, concentrations much higher than the background. Accurate laboratory analyses have shown concentrations up to 1,760 ppm zinc (88 times background) and 1,280 ppm copper (128 times background). Anomalously high lead values are present in a few samples. The metal content varies markedly; it ranges from 75 to 600 ppm along one fault. On the average, the east-trending faults and faults high in insoluble material, iron, and secondary calcite are somewhat higher in ore metal than the rest; but there is no clear-cut correlation between the amount of ore metal and either the attitude of the fault or the character of the fault material. Chemical analyses have shown repeatedly that faults of identical appearance may have a very high or only a background metal content, or any metal content between those two extremes. The data available indicate broad anomalies in which all the fault zones are high in metal. The Moore ore body is beneath such an anomaly, which is considerably larger than the ore body.

In general, there was little impregnation of ore metal into unfractured rock near the faults. A fault zone with as much as 2,300 ppm ore metal may be only a few feet from unfractured wall rock that contains no more than 75 ppm ore metal, the background value. However, the rock between the faults locally contains concentrations of metal along minute fractures. The mere presence of fractures does not necessarily entail concentration of metal. Some highly fractured areas have the background content of metal, whereas some little-fractured areas contain notable concentrations.

The analyses of chip samples taken at short intervals along traverses show the average metal concentration of large fault blocks. One of the anomalies determined by chip sampling is above the Moore ore body but displaced somewhat to one side. A genetic relation is suggested by proximity and by the occurrence within the anomaly of metal-bearing fault zones that project toward the ore. Other chemical anomalies are present in areas which have not been explored and below which the presence or absence of ore is unknown. Underground exploration of these areas and further geochemical work are suggested as means of proving or disproving genetic relationships between ore bodies and geochemical anomalies of this type.

The sampling and analysis of soil also can be used to locate geochemical anomalies. The ore-metal content of the soil is higher than that of the limestone or dolomite from which it is derived; this probably is the result of residual concentration of copper and zinc with other insoluble rock constituents when the carbonates are dissolved and leached away by ground water. The mixing of soil during weathering and erosion makes soil samples more representative than bedrock samples. However, the soil samples may be contaminated by soil-forming materials from higher on the hillside. The analysis of apparently uncontaminated soil samples confirms the presence of a geochemical high over the Moore ore body.

The sampling and field analytical methods used during this investigation are simple and rapid. Two men can easily collect and analyze, in a field laboratory, from 25 to 30 samples a day.

U. S. Geological Survey,
Denver, Colorado,
April 22, 1951.

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Tucson, Arizona
April 28, 1976

To: A.J. Perry

From: N.I. Colburn

Subject: PROSPECTS IN THE VICINITY OF LITTLE AND NORTHERN DRAGOON MOUNTAINS, COCHISE COUNTY, ARIZONA

Purpose and Location

This report is a review of further possible mineralized zones in or near the Cochise (Johnson) - Dragoon (Golden Rule) mining districts, excluding the known ore occurrences previously evaluated - which extend from the Strong and Harris property on the north to the "I-10 orebody" and adjacent areas on the south. (See Figures 1 and 2).

Also excluded, as being of no interest, are a number of small prospects along primarily tungsten-bearing, NE-trending quartz veins, which occur within the mass of the Texas Canyon Quartz Monzonite (50-52 m.y.). Otherwise the area reviewed extends northward from the Stronghold Granite intrusive (22-26 m.y.) in the northern Dragoon Mountains into the Southern Winchester Mountains. East-west dimensions include the Johnny Lyon Hills on the west to the bajada slopes into the Sulphur Spring Valley on the east.

Summary and Recommendations

In addition to general geologic reconnaissance, possibly ground or further aeromagnetic coverage is needed for a complete evaluation of areas I A, B and III A (listed below and see Fig. 2). A secondary target would be area II. The remaining two areas III B, C are not of major interest, but should be at least cursorily examined. In all areas the alluvium-covered pediments are important exploration zones. (See Figure 1).

Possible Target Areas

Area I -- the best exploration zones for Texas Canyon stock related mineralization

A: Northern Dragoon Mountains
B: East edge of northern Dragoons and Gunnison Hills

Area II -- minor precious-metal mineralization in Paleozoic-Mesozoic rocks; much of the Tertiary volcanics (generally similar to the Safford area volcanics) have not been completely explored.

A. Red Bird Hills
B. Winchester Mining District-Southern Galiuro Mountains

Area III -- possibly both Tertiary-skarn and Precambrian volcanogenetic types could exist.

A. NW edge of Little Dragoon Mountains and apron of Paleozoic rocks bordering the Johnny Lyon Hills -- mineralization associated with Tertiary "thrusts", quartz veins and other dikes with a small possibility of "skarn" similar to String & Harris occurrence

B. W. half of Little Dragoon Mountains and outcrops rimming the grano diorite core of the Johnny Lyon Hills - no known prospects, but Precambrian massive-sulfide bodies could exist, based on the presence of rhyolite flows and intrusives within a gray-wacke environment

C. Johnny Lyon Hills and W and SW edges of Texas Canyon stock - Precambrian, Mesozoic-Paleozoic units as "fault-plate" remnants intruded by Tertiary aplites, rhyolites and lamprophyres

Description and General Geologic Setting

Following are brief geologic summaries of the principal areas defined for prospecting. Specific descriptions of mines and prospects are verbatim from Stanton B. Keith, 1973, ABM Bull 187.

The proven extent of mineralization (Johnson pit, Republic and Moore mines, plus Strong & Harris and "I-10" zones) occurs in tactitized Paleozoic rocks away and down-dip from outcrops of the Tertiary Texas Canyon intrusive. These ore-skarn zones more or less form an extension of the northeastward long-axis trend of the stock. The outer rim of the quartz monzonite is an obvious exploration area, and most of the land is controlled by Cyprus Mines Corp., Strong & Harris or James Sullivan.

The E-SE edge of the Texas Canyon Quartz Monzonite has similar features to the NE edge of the intrusive, leading into the "I-10" ore zone. On the SE side, located west of Dragoon, are three prospects which constitute the area explored by The Superior Oil Company and experimentally tested by in-situ leaching. Descriptions of these are included for comparison to prospects in the northern Dragoon Mountains, located south and east of Dragoon. (See Figure 2)

Cochise Mining District

1. Burrel claim group 16S 22W NW/4 25
   Cu, Pb-, Zn-, Ag-, W
   Bornite and chalcopyrite with spotty galena, sphalerite, and scheelite in a small quartz-calcite vein cutting partly silicified Pennsylvanian Horquilla Limestone. Cuprotungsite noted.
   Pit and shaft workings.
   Produced a small tonnage of copper-silver ore and some tungsten concentrates around 1917-1918.

2. Empire No. 2 mine (Empire Gold & Copper Mng. Co.)
   16S 22E NE/4 25
   Cu, Pb, Ag, W
   Bornite, chalcopyrite, spotty galena, and some scheelite in small quartz veins cutting partly silicified Pennsylvanian Horquilla Limestone.
   Shaft and open cut workings.
   A total of about 65 tons of base metal ore produced in 1909-1913 and 1946-1947.

3. Princes(s) and Cowboy working. (Empire No. 2 Shaft, Old Bridge Shaft; Empire Gold and Copper Mng. Co.)
   16S 22E NW/4 25
   Cu, Ag, W, Pb-, Au-
   Copper carbonates, bornite, chalcopyrite, scheelite, and local galena in replacement bodies in partly silicified Pennsylvanian Horquilla Limestone cut by small quartz veins.
   Shafts and surface workings. A total of some 185 tons of base metal ore produced intermittently from 1913 to 1954 and a few hundred tons of tungsten concentrates in the early 1900's.

<u>AREA I</u>

This is the prime exploration area. Varying mineralization (Pb-Zn-Cu-Au) occurs as sulfide-replacements in Paleozoic lime units. In several cases, ore also occurs as smeared concentrations along fault zones and isolated fault slivers. Pre-stock folding has occurred. Both post-52 m.y. faulting and rhyolite to lamprophyre diking exist. There is a good chance that "blind" tactized-ore blocks could be present.

A: Northern Dragoon Mountains - Dragoon (Golden Rule) Mining District

Four small mines occur as bedded replacements in

Paleozoic limestones. From southwest to northeast, they are the Hubbard, Burrito de Fierro, Buena Vista-Horse Fall, and Seneca. The area is well faulted. Further mineralization could exist under the alluvial cover along WSW and NE extrapolations of this "zone".

Dragoon Mining District

4. Burrito de Fierro Mine (Ligier, Perevill & Danvers)
17S 22E NW/4 24
Pb, Zn, Cu-, Ag
Bedded replacement deposits of oxidized base metal sulfides in Paleozoic limestone close to strong thrust faulting and Tertiary igneous intrusions.
Tunnel and surface workings. Over 200 tons of ore shipped intermittently from 1956 to 1964.

5. Hubbard Mine (Democrat & Sherman, Dragoon Zinc)
17S 23E Cor. 17, 19 & 20
Zn, Pb-, Cu-, Ag-, Au-
Zinc mineralization with minor lead and copper in tabular replacement bodies in complexly folded and faulted Paleozoic limestone.
Shaft workings. About 330 tons of zinc ore produced intermittently during 1944, 1949 and 1952.

6. Buena Vista and Horse Fall Mines (Fourr)
17S 23E SE/4 8
Pb, Ag, Cu-
Bedded replacement deposits of oxidized lead and zinc mineralization in Paleozoic limestone.

7. Senecia Mine (Lewis group, Senika; Le Roy Mines Co.)
17S 23E SE/4 10
Zn, Pb, Ag, (Cd)
Sphalerite, pyrite, and minor galena in small irregular masses in brecciated wall rock in a generally thin, weakly mineralized vein structure in metamorphosed Naco limestone.
Shaft and adit workings. About 248 tons of ore shipped in 1942-1943.

Between the Buena Vista-Horse Fall and Burrell-Empire claim groups, the area is also covered by alluvium. Here the aeromagnetic map (USGS GP-412) shows a N-S trending "blip" (non-closed high in the gamma-contours), which marks on the north the Burrell-Empire mineralization. This coverage does not extend as far south as the Hubbard Mine.

B: East Edge of northern Dragoon Mountains and Gunnison Hills - Cochise and Dragoon Mining Districts.

The various Ligier marble quarries are included to show a minimum extend of obvious marmolization. These marbelized units, plus a band of Cretaceous rocks, appear to separate the main mass of the northern Dragoon Mountains from the NNW-trending Gunnison Hills. A major buried fault borders the west edge of the Gunnison Hills.

The Golden Rule Mine occurs at the southern end of the NNW-trending structure. On the aeromagnetic map (USGS GP-413), there is an anomaly (high) centered over the mine area. A twin magnetic high adjoins the first, just to the NE, $4\frac{1}{2}$ miles SW of the rail-town of Cochise. It is said that this second high was tested by drilling, with negative results. The depth and position of these holes is unknown.

The major portion of the Dragoon Mining District production came from one mine (Golden Rule). Between 1873-1902 some 6000 to 8000 tons of Au-Pb ore was mined. For the whole mining district through 1970, production totalled $340,000 from 19,000 tons of ore, yielding 9 tons Cu, 178 tons Pb, 124 tons Zn, 72,000 oz. Ag and 9700 oz Au.

This is in comparison to the Cochise Mining District with a total production from the early 1880's through 1970 equalling $32 million; mainly from the Johnson Area about 1.64 million tons of ore mined with yields of 37,000 tons Cu, 300 tons Pb, 47 thousand tons Zn, 734,000 oz. Ag and 300 oz. Au. (Keith, 1973, p.7,9).

Dragoon Mining District

8. Ligier Marble quarries

16S 23E SE/4 10
No. Cen. 27
No. Cen. 35
marble products

Marmolized, fractured, and folded, white and colored Mississippian, Pennsylvanian and Permian limestones.

Quarries. A relatively small production of dimension stone and crushed marble.

9. Golden Rule Mine area (Old Terrible, Golden Eagle, Santa Lucia; Golden Queen Consolidated Gold Mng. Co., Old Terrible Mng. Co., Manzoro Mng. Co., G.S. & L. Leasing Co.)

16S 23E Cen. 23
Pb, Zn, Ag, Au, Cu-

Cerrusite, anglesite, galena, pyrite and oxidized zinc minerals in coarsely crystalling quartz, calcite and iron oxides in vuggy fissure veins in Cambrian Abrigo Limestone intruded by small Tertiary rhyolite and

and rhyolitic porphyry intrusives.

Shaft workings. Over 6,000 tons of ore produced intermittently from 1883 to 1957.

Cochise Mining District

10. Stroud Bros. Mine (Arizona Cleveland Mng. Co.)

16S 23E No. Cen. 9

Pb, Ag, Cu, Zn, Au

Oxidized lead and copper sulfides along shear zones in Paleozoic limestone.

Pit and adit workings. A few tons of picked, high-grade ore produced in 1911.

11. Texas Arizona Mine (Texas Arizona Mng. Co.)

16S 23E NW/4 4

Pb, Ag, Cu, Zn, Au

Cerrusite, anglesite; minor galena, malachite, and oxidized iron and zinc sulfides in tabular pyrometasomatic replacement bodies, streaks, bunches, and lenses in faulted Paleozoic limestones.

Shaft workings. A total of over 700 tons of lead-silver ore produced intermittently from 1910 to 1928.

12. Northern Gunnison Hills Mines and prospects

15S 23E 17, 20, 28, 29

Cu, Pb, Ag

Argentiferous copper and lead sulfides and oxidation products in narrow, quartz fissure veins cutting silicified Paleozoic limestone and Cretaceous formations.

Pit and shaft workings. A total of about 100 tons of hand-sorted ore produced intermittently since 1910.

AREA II

Minor Ag-Au prospects exist here, indicating mineralization extends northward into the southern Galiuro (Winchester) Mountains. In this same range copper prospects are found farther north as near Cascabel (12 mi. N) and the Copper Creek breccia pipes (36 mi. N). The mineralized pre-Tertiary rocks are covered throughout the area by post-mineral volcanics, with only scattered erosion windows. This setting is very similar to the Safford area, where erosion of post-ore volcanics has exposed in part the mineralized zone. The Safford area is located on the lower west slopes of the Graham Mountains, the nearest range to the east of the Winchesters. An exploration approach using as a model the Safford deposit would be most useful, especially along the east side of the Winchesters where detailed mapping has not been done.

A: The Red Bird prospect area appears to be localized by and/or separated from the Steele Hills-Galiuro Mountains by the WNW-trending Antelope Tank fault or parallel structure.

B: The Winchester Mining District extends NW along a zone of Precambrian, Paleozoic and Mesozoic rocks in fault slivers. The prospects seem limited to Ag-bearing jasperoid replacement lenses in the Paleozoics, but some base metals are present.

Cochise Mining District

13. Red Bird Mine (Gold Coin)
15S 23E So. Cen. 11
No. Cen. 14
Au, Ag
Relatively weak gold and silver mineralization in fault breccia cutting Cretaceous Bisbee Formation.
Shaft workings. Some 75 tons of ore produced during 1930-1932.

Winchester District

14. Hearst Mine 13S 23E NE/4 31
Silica, Ag-, Au
Large jasperoid mass, carrying erratic silver and gold values, in Paleozoic limestone.
Developed rather extensively underground in 1890's. About 260 tons of argentiferous silica flux shipped from the dump in 1924.

AREA III

This is a mixed zone of two, perhaps three geologic settings. Covering the western half of the Little Dragoon Mountains, the zone also includes a number of scattered prospects in the Johnny Lyon Hills. As in Areas I and II geophysical work (magnetics) would pinpoint possible targets under the gravels.

A: Essentially unmineralized Paleozoic units wrap around the northern ends of the Little Dragoons and Johnny Lyon Hills. These are cut by lamprophyre dikes, which are unmineralized in outcrop as the one near the Strong & Harris area. "Thrust" type faulting is common.

At the northwest end of the Johnny Lyon Hills a few prospects exist. One, the American Mine has had some production.

Yellowstone District

15. American Mine (War Eagle, La Vantia; La Vantia Mng. Co.)
14S 20E E. Cen. 13
Pb-, Cu-, Ag, Au (F, Ba)
Sparse pyrite, galena, chalcopyrite and oxidized sulfides, with fluorite and barite, in narrow quartz-carbonate veins deposited in a thrust plane in Precambrian granodiorite. Local concentrations of specularite.
Shaft workings. About 125 tons produced in 1906-1907.

Based on the known association of a magnetic low over the Strong & Harris ore zone, there could possibly be an unexplained magnetic high-low pair in Sections 12, 11, 3, 27, T15S, R21E. However, most of the enclosed magnetic lows in this area can be correlated with low-response from gravels, overlapping Paleozoic slices and faults rather than possible skarn.

Evaluation should be done on the American Mine and vicinity prospects because further mineralization could exist to the NW, again extending under alluvium. To the NE the Antelope Tank fault may separate Paleozoics from Tertiary volcanics. This could explain the WNW-trending moderately steep magnetic gradient. Alluvial cover in Allen Flats does not seem to be overly deep. The general characteristics apparently make the mineralization related more to the type described under Area III C than to the "typical" Texas Canyon stock association.

B: The Older Precambrian rocks exposed in the cores of the Little Dragoon Mountains and Johnny Lyon Hills

The older Precambrian rocks exposed in the cores of the Little Dragoon Mountains and Johnny Lyon Hills constitute a possible volcanogenetic massive-sulfide type environment. The Pinal schist complex (mainly graywacke) would be the host sequence, expecially in association with the rhyolite porphyry intrusives and flows. Chloritized meta-basalts are present. These well-metamorphosed, folded and overturned units are intruded by two separate stocks, the Johnny Lyon granodiorite and Tungsten King granite. The relationship with the Tungsten King granite is not clear but the Johnny Lyon granodiorite acted as the late-stage doming stock, so common in the Canadian Shield.

No recorded prospects exist in this zone. However because the major production was from Tertiary skarns, this deposit type may have been initially overlooked. Cyprus Mines is or has within the last two years briefly looked at this sequence.

The subtility of indications leading to this massive-sulfide type make a reconnaissance a necessity before this zone can be completely ignored.

C: In the southern half of the Johnny Lyon Hills and the SW part of the Little Dragoons, are several clusters of base metal-W prospects. These are situated along some of the many faults and associated with good-sized lamprophyre dikes and pods or large quartz veins or aplite masses and perhaps rhyolite dikes. All these intrusives are Tertiary in age and spatially and probably genetically related to the Texas Canyon stock. Depending on whether the stock was intruded as a lopolith or tilted after intrusion, these late-stage rocks could initially have been positioned respectively marginal-near surface or at depth within the intrusive system. The mineralization would be accordingly classified.

Tertiary tilting of stocks is fairly common. Keith and Barrett, 1976, report such tilting in the Central Dragoon Mtns. Some evidence for a shallow "..sill" form for the NE end of the Texas Canyon stock was summarized by J. Kantor, 1975.

Yellowstone District

16. San Jose Prospects (Gold Mine Ridge)
15S 20E SE/4 12
21E 18
Cu-, Pb-, Zn-, Ag-, Au-
Narrow, iron oxide and quartz veins, with weak and spotty copper oxides and carbonates, and minor chalcopyrite, galena, sphalerite, and pyrite, cutting Precambrian granodiorite and a thrust plane zone.
Prospects. Some scattered test lots produced in the late 1920's and early 1930's.

Cochise Mining District

17. Homestake claim group 16S 22E W 5
W, Cu-, Au-, F-
Disseminated scheelite with minor copper, gold and fluorite mineralization associated with quartz fissure veins cutting amphibolite unit of Precambrian Pinal Schist.
Mostly surface workings. Little or no production noted.

18. Tungsten King Mine (Black Rock group; Gold, Silver, and Tungsten, Inc., Kramer Mng. & Milling Co., Standard Tungsten Corp.)
16S 22E NW/4 6
W, Cu-, Pb-, Mo-, (Bi, Be)
Pockets of calcite containing disseminated scheelite, pyrite, and galena with exsolved tetra-

dymite, beryl, chalcopyrite, iron oxides, jarosite and wulfenite in a fault zone between Precambrian Pinal Schist and granite.

Pit, adit, and shaft workings. About 12 tons of tungsten concentrates produced intermittently from 1913 to 1954.

Summary Regional Tectonic Setting

The area covered in the report is tectonically complex and is critical for regional structural interpretation. It is a junction area for 2 or 3 E and NE moving "thrust plates" according to Drewes, 1976. Northwest structures are prominent, and one of the major reactivated pre-Mesozoic stepped-graben faults (Titley, 1976) cuts directly across the area. These NW structures are differently interpreted by Keith and Barrett 1976, as they extrapolate their detailed work for Kennecott, northward along strike from the Middlemarch and Central Dragoon Mining Districts. (See Appendix). These districts are contiguous to the south boundary of the Dragoon Mining District. Basically they consider that at least the Paleozoic and older rocks are involved in vertical motive resulting in a majorfold (NW trending axis slightly overturned to the west); later intruded by Tertiary magma systems and modified by faulting and by bedding plane and gravity sliding. This may be only a short segment of a larger crystal structure reaching at least to Ray in the Dripping Spring Mountains, with a mechanics similar to the monoclines crossing the Colorado Plateau (Keith & Barrett, 1976; oral communication Stanley Keith & Douglas Shakel, U of A). Northeast structures are locally important as elongate trends of the stocks, which also may be aligned on major NE-trend of intrusive centers which may extend into New Mexico.

This is mentioned to indicate the variety of opinion about the various geologic features. Because of the range of features, several interpretations may need to be applied to possible geophysical and mineralization trends delineated locally in this area.

TECTONICS OF THE CENTRAL DRAGOON MOUNTAINS: A NEW LOOK

Stanley B. Keith (Kennecott Exploration, Inc., Salt Lake City, Utah) and
Larry F. Barrett (Bear Creek Mining Company, Tucson, Arizona)

in Arizona Geological Society Digest, Volume X, March 1976, p. 169-204.

p. 199 -" 2. Similar eastward rotation of Paleozoic and Lower Cretaceous strata is found to the north in the adjoining Dragoon quadrangle. It may be conjectured that tectonics responsible for the Silver Cloud fold can be extended at least 15 miles to the north to include the east-dipping Apache Group and Paleozoic sections in the Johnny Lyon Hills, the Little Dragoon Mountains, and the Gunnison Hills where the rotation predates the emplacement of the Texas Canyon Quartz Monzonite. Some post-Texas Canyon Quartz Monzonite tilting is also possible, particularly if the Stronghold Granite-related, northwest-striking dike swarm has in fact been rotated about 15 degrees to the northeast. Bryant and Metz (1966) also report 15 degrees of mid-Tertiary rotation of the Mule Mountains. Possibly the monoclinal tectonics recurred in the mid-Tertiary. Well-documented northeastward rotation of Miocene age has occurred in the Tortilla Mountains (Krieger, 1974), which are 55 miles northwest of and on trend with the Dragoon Mountains. Krieger has interpreted this northeast rotation as monoclinal. "

p. 200 -" 4. The extensive thrusting shown by Gilluly (1956, sections II-VI, plate 6) around the Stronghold Granite is seen now from a different perspective. Rather than a more imbricated area along strike of the Dragoon fault system (which now has no basis for support southeast of Cochise Stronghold), the low-angle faults of which the principal element is the Mount Glen fault are alternatively viewed as low-angle faults induced by gravity tectonics associated with the emplacement of the 24 m.y. Stronghold Granite. Proximity of the low-angle faulting to the Stronghold Granite, general dip of the Mount Glen and other similar faults away from the Stronghold Granite to the north and south, and generally younger upper-plate rocks, which suggest low-angle <u>normal</u> faulting, are consistent with gravity-induced gliding of roof rocks away from the top of the Stronghold Granite intrusion. If folds are present in these rocks, a fold analysis would verify either alternative. Fold geometries for the Gilluly thrust model would have consistent northwest trends and northwest vergence, while in the gravity model they should show a general vergence away from the Stronghold pluton. It is, of course, possible that a combination of thrust and gravity models could be the case."

TECTONICS OF THE CENTRAL DRAGOON MOUNTAINS: A NEW LOOK
Keith and Barrett
AGS Digest, Vol. X, March 1976, p. 169-204.

p. 201 "Drewes states that the Silver Cloud fold nowhere involves the Precambrian crystalline rocks, is therefore disharmonic, and is therefore separated from the crystalline rocks by a fault (the "structural ungluing" concept of Gilluly, 1956). He then states that the principal difference between our models concerns the amount of movement on this fault. ...wavelength and amplitude of the Silver Cloud fold is disproportionately large and therefore disharmonic in the <u>geometric</u> sense of the term. We do not intend any mechanical overtones, such as separation of the layered rocks from the crystalline basement by a (thrust?) fault. ...there is no surface evidence for such a fault at the key contact - namely, the contact of the Bolsa Quartzite with the Precambrian granite (see Figure 3 of text). Exposures of the contact in the southwestern portion of the mapped area are also clearly depositional and show no evidence of movement. ...Any bedding plane movements in such a zone could, however, be readily interpreted as bedding plane slippage during flexural slip folding (see analogous arguments for the Glance-Paleozoic contact at p. 193).

p. 202 "The question of whether the isotropic Precambrian granitic rocks are involved in the folding is necessarily problematic as there are no layer markers in the granite to indicate the presence or absence of folding. It is interesting that where there are such markers — the presence of folding has been confirmed. For example, Krieger (1974) mentions folded diabase sills below the monoclinally folded Apache Group rocks which rest depositionally on the "Ruin" granite west of Kearny, Pinal County, Arizona.

... "Drewes asks why, if the Silver Cloud fold buckled against the buttress of an uplifted block, was the fold overturned rather than upright or erratically crumpled. In our view, the Silver Cloud fold is part of a regional compressive tectonic framework and retains the systematics of the framework. That is, the northeast vergence and the northwest-trending fold axes suggest that a regional east-northeast-directed compression was at work between 72 m.y. and 52 m.y. ago. The location, disproportionate size, and disharmonic nature of the fold are the results of a local, pre-compressional basement uplift with a northwest-striking, southwest-dipping edge. ...As the case was, the basement discontinuity acted as a steep ramp against which the Silver Cloud fold initially buckled and in its later stages attempted to override (see Figure 6 in text)."

TECTONICS OF THE CENTRAL DRAGOON MOUNTAINS: A NEW LOOK
Keith and Barrett
AGS Digest, Vol. X, March 1976, p. 169-204.

p.202 - 203 "...field evidence overwhelmingly favors a high crustal level, solid-state system in which deformation proceeded predominantly by brittle fold and fracture mechanics, not flow mechanics.

... "The lack of any stratigraphic record of the uplift of the Black Diamond structural block is somewhat perplexing. But then, so also is the lack of any similar record for other well-documented faults with pre-Cretaceous, post-Paleozoic movement histories (for example, the Dividend fault at Bisbee). ...The paper by Titley (this Digest) is a good summary of that part of the geologic record and also indicates how little we know about the Jurassic with respect to other events, such as the "Laramide."...

"...As we have attempted to show, there is simply no field evidence to support the concept of a thrust fault geometry along which large-magnitude tectonic transport has taken place. The available evidence, on the other hand, strongly supports a pre-Cretaceous uplift along the Black Diamond fault and the existence of a large, northeast-vergent fold pair."

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