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416 W. Congress St., Suite 100
Tucson, Arizona 85701
520-770-3500
http://www.azgs.az.gov
inquiries@azgs.az.gov

2-1-79 Mining costs — Tom S.

Sacaton dir .45 in dir 50% = $.68

Sil Bell dir .53 " " = $.80

JH

NEW YORK OFFICE

JHC.

ASARCO

TELECOPIER COVER SHEET

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LOCATION: Tucson Office

DEPARTMENT: Mining - Exploration

FROM: F.T. Graybeal

DEPARTMENT: Expl.

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5/31/83

HISTORY OF EXPLORATION AT SILVER BELL, ARIZONA

by Fred Graybeal

Silver Bell is located about 35 miles northwest of Tucson, Arizona. It is a classic porphyry copper deposit containing enriched disseminated chalcocite ore in altered porphyritic rocks with chalcopyrite ore in ~~porphyry and~~ adjacent skarn zones. The discovery of Silver Bell was an evolutionary process which occurred over a 75 year period.

Recorded mining activity began about 1865 on Boot Hill just east of El Tiro pit where outcropping altered limestones were found to contain 15-17 oz. Ag mixed with copper oxides. By 1874 the Young America Copper Company was mining shallow occurrences of 30% Cu along the north side of the present Oxide Pit. The ore was shipped by wagon to Yuma, Arizona and then by boat to San Francisco for smelting. By 1881 the area supported several mining companies and two small smelters and the district was being favorably compared to Bisbee in local newspapers.

Most of the ore mined in the period 1865-1903 came from pods of massive sulfide or their oxidized products which were distributed in an unpredictable fashion through a large skarn zone in Paleozoic limestone east of El Tiro pit. Ore grades varied from 5-10% Cu.

In 1903 most of the properties were incorporated into or purchased by the Imperial Copper Company and the district had a population in excess of 1000. With the formation of Imperial, mining at Silver Bell became more organized, production increased, and by 1910 over 21 miles of workings existed in the district. During the period 1900-1909 the El Tiro Copper Company had mined oxidized products of supergene enriched ore in a zone of brecciation along the alaskite-dacite contact west of the skarn ores. The significance of ~~small zones~~ exposures of disseminated chalcocite in alaskite in the El Tiro mine workings was apparently recognized by the Imperial Copper Co. which in 1909 acquired control of 240 acres owned by the El Tiro Copper Co. and in 1910 completed 44 churn drill holes in alaskite and quartz monzonite porphyry just southwest of the El Tiro mine. This drilling covered an area about 1000 ft. by 2500 ft. and discovered enriched disseminated chalcocite under leached capping at depths of about 100 ft. The geologic reports which were presumably written to recommend this drilling cannot be found. At the same time a similar drilling program was started by Oxide Copper Company in the area adjacent to the Young America mine workings. This program completed 72 churn drill holes and also encountered disseminated chalcocite. Finally, in 1909, the Seeley Mudd interests in Los Angeles drilled 10 churn drill holes in an altered area east of the present Oxide Pit with mostly negative results.

From 1907-1910 Imperial increased production sixfold which caused ore grades to decline to 2.4% Cu. During the same period copper prices fell from \$.20 to \$.13 and, despite the opening of a smelter in August 1909, the Imperial Copper Company closed operations in August 1910 and was declared bankrupt in July 1911. However, the importance of the previous churn drill results had not been overlooked and Meade Goodeloe, the general manager, wrote in an operating report of November 8, 1910:

"A further element of great promise had appeared in the finding ...... of workable values in the granitic porphyry. The mining of porphyry deposits of this character ...... with no waste vein matter to be mined and discarded, can be accomplished at much less cost per ton than the mining of our contact orebodies, and ...... places the undertaking on a manufacturing basis."

By 1914 copper prices had increased to $.17/lb. and several companies investigated the district, including the American Smelting and Refining Company (ASARCO). On April 12, 1915, H. A. Guess, a mining engineer (who would later become Vice President of the Mining Department and a Director of Asarco), submitted a detailed report of his investigations at Silver Bell which stated:

"I would not recommend spending money that would be necessary for a thorough sampling and examination of the Imperial mines, were it not for the possibilities of the disseminated area."

Guess sent an additional letter two days later which stated:

"We cannot let this thing go by without looking fully into it and I therefore recommend, first, we acquire control of the Imperial Company's property, or the disseminated portion of it, and similarly of the El Tiro property on the same basis."

In September 1915 Asarco obtained an option on the Imperial and, probably, the El Tiro properties. Five holes were drilled under the supervision of Julius Kruttschnitt (who would later become Chairman of the Board of Mt. Isa Mining Co.) to check previous work by Imperial. The results were disappointing, but on December 16, 1916 Asarco purchased the Imperial properties which were operated until 1921. During 1916 Guess, Kruttschnitt, and J. Gordon Hardy examined the holdings of the Oxide Copper Co. which were eventually rejected as too small and of marginal grade. The recommendations were influenced by metallurgical tests which indicated 78% recovery of copper into a 14% Cu concentrate and perhaps by the purchase price of $1 million.

Geological activity was generally low from 1920-1940. In 1923 Roland Blanchard made a study of Silver Bell outcrops in which he indicated that variations in the color of limonite on the weathered surface did not bear an obvious relationship to ore-bearing rock. In his book (1968) Blanchard amended his earlier observations and noted that maroon-colored limonite was a reliable guide to chalcocite in the quartz monzonite porphyry (he called it alaskite porphyry), but not in adjoining alaskite. Later studies by Kenyon Richard and Harold Courtright were to find that the color of powdered limonite (produced by scratch) was a fairly reliable guide to chalcocite enrichment regardless of rock type or strength of alteration.

In 1929 the Oxide property was submitted to Asarco a second time. Blanchard, Kruttschnitt, and H. P. Hill restudied the area in 1930 and, after a $25,000 program of mapping, underground sampling, and drifting, estimated a reserve of 10,047,000 tons averaging 1.46% Cu in a blanket 85 ft. thick. However, due to (1) the inferred spotty distribution of mineralization interpreted from surface outcrops, (2) the fact that much of the area was estimated to contain roughly 1% Cu which was then submarginal, (3) indications that the churn drill samples were at least 0.3% Cu too high (presumably due to contamination from uncased holes), and (4) unfavorable projections of future copper prices, the property was again rejected.

Following closure of the mine in 1921, the area became a ghost town and in 1938 Asarco stopped making property tax payments on the Imperial properties. In 1939 the Pima County Treasurer advertised the Imperial claims for sale, but (because certain legal procedures had not been followed) no sale had occurred by

April 17, 1940 when H. A. Kursell wrote a brief, but thorough summary of the disseminated mineralization in the Silver Bell district. He noted that:

> "... a strong shear zone, or zone of brecciation ... through the El Tiro mine .... heads for the Mammoth Mine ... and beyond that towards the Oxide Copper orebody. This fracture zone was quite evidently a channel from which copper mineralization spread, and the fact that apparently no comprehensive mapping was ever done of this copper belt three miles in length, suggests to me that this problem has never been approached in a sufficiently broad way."

Kursell suggested that the disappointing results obtained in the 1915 check drilling at El Tiro were partly due to poor placement of holes and that a potential existed for 4.5 million tons averaging 1.2% Cu in a blanket 95 ft. thick. He noted that since Kruttschnitt's report in 1930 technological advances in bulk mining, mill construction, and flotation methods permitted new costs to be used and estimated that copper could be produced for about $.09/lb. He concluded by recommending purchase of the Oxide Copper and El Tiro properties.

Two weeks after Kursell wrote his report the Oxide Copper Company property was again offered to Asarco, this time for $40,000. On May 6, 1940, H. A. Guess, now Vice President of Mining, [redacted] wrote W. H. Loerpabel, Manager of the Southwestern Mining Department, that purchase of the Oxide Copper property had been approved, that an immediate attempt be made to acquire the El Tiro Copper Company properties, that all delinquent taxes on the Imperial properties be paid, and that all open ground be staked. On May 8 an expenditure of $75,000 was approved to consolidate properties at Silver Bell. Loerpabel sent a coded telegram on May 17 indicating competition from Inspiration and from Calumet and Hecla for the El Tiro properties, but on May 21 wrote that verbal agreement had been reached to purchase the properties for $10,000. The sale of Oxide Copper properties was approved by Oxide's Directors on June 3, 1940 and the payment of $40,000 made on June 5. Purchase of the El Tiro properties was consummated June 14 by payment of $10,000. By July 24, land acquisition strategies appeared firmly established, options on small claim blocks were being acquired, and a recommendation was made to begin compilation of a surface geological map of the district.

In 1941 Harrison Schmitt supervised a ~~detailed mapping~~ program by Lawson Entwistle and H. M. Kingsbury which established a topographic base between the El Tiro and Oxide areas and mapped all rock types. Their report did not consider the extent of surface alteration and Kingsbury concluded that in the El Tiro area there were no reliable indications in outcrop which could predict the continuity of secondary enrichment.

It had been recognized in 1914 that the Oxide area was clearly the larger of the two disseminated deposits and Kruttschnitt's suggestions made in 1930 regarding inaccurate drill results were of considerable concern. Further work was deferred until after World War II and in 1948 a churn drill program was begun in the Oxide area to check the previous results and to locate extensions of known mineralization. It was also recognized that reliable guides to chalcocite enrichment which could be interpreted from outcrop studies and then used to guide drilling more efficiently had yet to be established. In 1947 Prof. Paul F. Kerr of Columbia University was retained to study the distribution of alteration, which he had previously found to be a useful ore guide at Santa Rita. In

November 1947, Harold Courtright was sent to Tucson by W. R. Landwehr, Chief Geologist for the Western Mining Department, to set up and supervise the churn drill program and to make a study independent from Kerr's of the geology of the area as it related to the interpretation of the drill results.

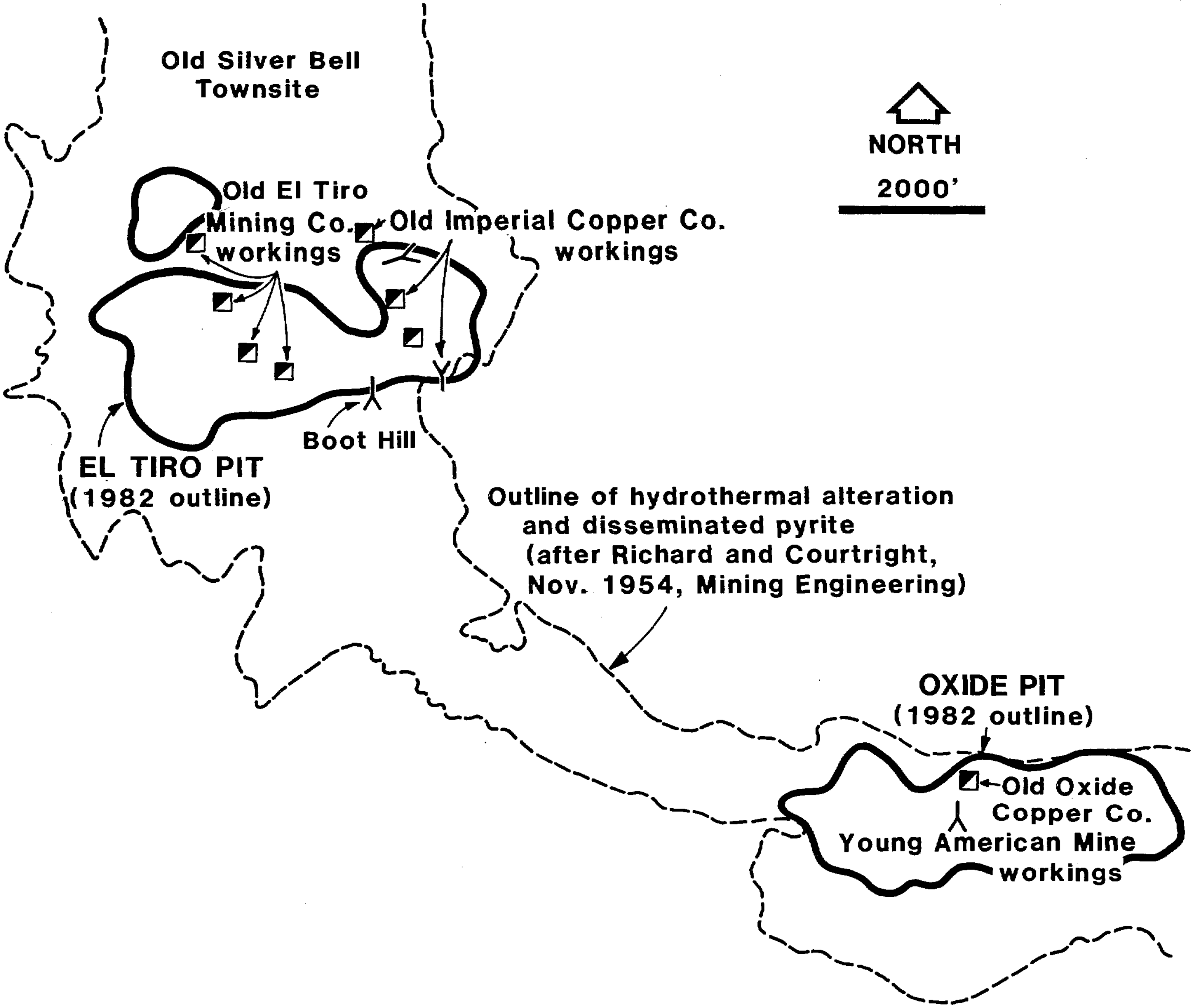
Kerr [redacted] concluded [redacted] ~~were~~ that surface alteration could be used as an ore guide [redacted] regardless of whether ~~additional~~ surface indications of mineralization were present. Later drilling suggested that surface alteration was not the principal guide to supergene ore and, in addition, that some of the alteration was itself of supergene origin. In July 17, 1948, Courtright reported that:

> "A study of the outcrops over the Oxide orebody and adjacent areas disclosed the fact that notable variations in both the color and intensity of residual limonite were present. The attached 200-scale map was prepared to depict the distribution and relative intensity of copper mineralization as evidenced by characteristic limonite visible in the bedrock exposures. The characteristic limonite, apparently derived from pyritic chalcocite, possesses a color varying from purple tinged dark red to chocolate brown. In contrast, the outcrops over essentially pyritic bodies exhibit yellow and brick red colors."
>
> "Blue-green stains and veinlets, representing chrysocolla for the most part, are prominent in some of the alaskite outcrops in the area. .... Such areas, classed as weakly mineralized, are not considered to hold potentialities in respect to disseminated copper ore, regardless of their spectacular appearance."

Utilizing the above guides an eventual mining reserve of ________ million tons averaging ________ % Cu was defined in the Oxide area. Also in July [redacted] 1948, Kenyon Richard and J. C. Playter reported on [redacted] the area of previously indicated disseminated mineralization in the El Tiro area. Interpreting zones of strong sheeting in alaskite and a characteristic "live" limonite as ore guides they recommended 20 holes which eventually led to the definition of a mining reserve of ________ million tons averaging _______ % Cu. The essential aspects of the geological [redacted] work by Richard and Courtright were published in the November 1954 issue [redacted] of Mining Engineering. [redacted] In 1951 the Defense Material Procurement Agency guaranteed to purchase 177 million pounds of copper from the first 197 million pounds produced at $.245/lb. (Milling of open pit ore at 7000 tpd began) in March 1954.

In 1959 Stephen Von Fay began a field study under the direction of Richard and Courtright of the exploration possibilities for small high grade copper deposits in the skarns east of El Tiro pit. He also reviewed old file data previously acquired from the Imperial Copper Company and found numerous comments regarding "low grade ..... cupriferous pyrite", "imperceptible grading of ore in stopes into non-ore grade material", and core intercepts containing 0.4-1.0% Cu being described as "barren rock." Von Fay's work led to recognition of the potential for disseminated mineralization in the altered sediments, and subsequent drilling in this area defined a zone containing roughly 10 million tons averaging 0.8% Cu as chalcopyrite overlain by an additional 10 million tons of oxidized material averaging 1% Cu as chrysocolla and malachite. Open pit Production to date at Silver Bell has been 89 million tons averaging .78 % Cu.

The importance of Silver Bell to Asarco transends its mere profitability. It was the Company's first open pit and large-scale mining operation and was a major step toward greater integration of mining operations into what had previously been largely a smelting and refining business. In addition, the success of Silver Bell and the emerging importance of Arizona as a major porphyry copper province led to the organization of a porphyry copper program by Kenyon Richard and Harold Courtright which resulted in discoveries at Mission, Sacaton and elsewhere.



LOCATION OF MINING AREAS
SILVER BELL DISTRICT
PIMA COUNTY, ARIZONA

ASARCO

Exploration Department
Frederick T. Graybeal
Chief Geologist

J. H C.
SEP 26 1983

July 27, 1983

Mr. J. D. Sell, Manager
Southwestern U.S. Division
Tucson Office

Regional Structural Control of
Mineralization at Silver Bell

Dear Mr. Sell:

I have your note of July 13 which resurrects the hypothetical caldera setting at Silver Bell. I have wondered about this for the past 20 years or so and am not the first one as you note. Control of the alteration at Silver Bell by a ring structure is certainly a possibility particularly in view of the vast volumes of volcanic rock which must have generated some type of collapse phenomenon subsequent to eruption. In addition, because Silver Bell is eroded to moderate depth, it is likely that the perfectly circular symmetry common in high level calderas might become distorted by basement structures and one could therefore argue that the lack of perfect symmetry at Silver Bell is merely a function of depth.

The major structural feature between Oxide and El Tiro pits is a healed fault structure which separates alaskite and Mesozoic sedimentary rocks on the southwest from Paleozoic sedimentary rocks to the northeast. This line can be seen on the hydrothermal alteration map prepared by Richard and Courtright as it follows the southwestern limit of silicated limestone. It is interesting that this very fundamental structure actually cuts across the alteration zone in the El Tiro area rather than running parallel to it even though the structure is of pre-mineral age. It is likely that the near north-south orientation of the alteration zone between El Tiro and north Silver Bell follows a swarm of high level quartz monzonite porphyry stocks which, in this area, have a nearly north-south elongation. On a larger scale, however, when the alteration zone is traced farther to the north beyond the limits of the Richard and Courtright map it actually bends back to the west again taking the shape of a giant cymoid loop with the El Tiro area in the bend of the loop.

I want to emphasize very strongly that the northeast-striking veins at Silver Bell do not follow pre-existing structures. They <u>are</u> the structures and probably formed by a phenomenon similar to hydraulic fracturing. The same also applies to the quartz monzonite porphyry and monzonite porphyry dikes extending northeast from El Tiro pit. It is important to recognize that the El Tiro area does not owe its location to pre-ore northeast-striking structures, but rather to an intersection of a northwest structure and a north-south structure. The northeast structures in the El Tiro area and elsewhere within the alteration zone at Silver Bell are all syn-ore.

Very truly yours,

F. T. Graybeal

cc: WLKurtz
JHCourtright

ASARCO

SILVER BELL UNIT

S-10.10

May 18, 1984

J. H. C.

MAY 22 1984

Memo To: B.K. Malone

From: David Sawyer

Subject: Exploration Possibilities Around The Oxide And El Tiro Mineralized Centers, Silver Bell District

At the end of my two year period of field work in the Silver Bell District, I felt it might be useful to write my impressions on areas of exploration potential that remain to be fully examined. These conclusions are based in part on my own work, having geologically mapped around the Oxide and El Tiro areas at 1:24,000 scale, and in part come from having reflected upon previous geologic work on the district written in articles, reports, theses, maps and cross-sections; supplemented by my own examination of drill core and drill logs while collecting samples for my own study. The conclusions are certainly preliminary, and would need further geologic work to evaluate. Perhaps some of them can be laid to rest based on more detailed knowledge of other workers who are more familiar with Silver Bell than I. The discussion following will be broken down into areas of potential high-grade reserves, and potential low-grade reserves.

POTENTIAL HIGH GRADE RESERVES

Supergene Enrichment Blanket Mineralization

After studying the geology of the Silver Bell District in detail for two years, I am confident that Kenyon Richard, Harold Courtright and other early workers have identified all areas of significant leached capping and potential high-grade chalcocite blanket-type mineralization. All potential targets in the alteration/mineralization zone extending from North Silver Bell to El Tiro to Oxide (which my studies indicate is a ring fracture margin of a caldera) have been carefully identified and evaluated. Some potential for low-grade mineralization of this type exists and will be discussed in a subsequent section.

Skarn or Tactite Mineralization

I believe that the best possibilities for additional high-grade copper reserves in the Silver Bell district are associated with skarn mineralization in areas adjoining the El Tiro and Oxide pits. The caldera model has significant implications for the search for skarn ore, because of the perspective it will provide on the distribution of favorable Paleozoic sedimentary host rocks for replacement. In contrast to previous interpretations of the Paleozoic sequence at Silver Bell as being a complete section tilted homoclinally to the east (Merz, 1967), my work has shown the Paleozoic rocks to be affected by significant omission of strata caused by bedding plane thrust faults (Laramide, precaldera), as well as large scale structural juxtapositions of internally coherent caldera collapse megabreccia blocks. These structural complexities will take detailed geologic mapping to resolve, in order to have predictive understanding for locating exploration drill holes.

W El Tiro: (W of Daisy pit) Several exploration holes have been collared in the alaskite (biotite granite) and then crossed into strongly mineralized skarn, interspersed with minor dacite porphyry (Confidence Peak lithic tuff). Grades have ranged up to 0.8 - 2%, though generally for not more than a couple of benches (except in hole D219 where 368' of 1.09% Cu was intercepted; hole 241 also has higher-grade ore). Some of this mineralization is moderatly deep, occurring between 2300' and 1800' elevation. The contact between the biotite granite and lithic tuff (and enclosed sedimentary rocks),is an expression of the ring fault zone and appears to dip steeply west. Significant areas in the footwall of this contact zone remain to be tested for the distribution and grade of high-grade Cu skarn ore.

N W Oxide: (area from just E of N Butte to NE side of Copper Butte, N of Dump #3, W of the dike). Strong skarn alteration exists at the surface in this area, but the downward extension of it has not been thoroughly tested. Unfortunately, some areas at the surface have been covered by waste dumps. Moderate grade Cu skarn mineralization (0.5 - 1.0% Cu) has been drilled in this area, but the vertical and lateral extent of this mineralized zone and its overall grade has not been determined. High-grade potential would seem to be strongest toward the SW, adjacent to the contact between the lithic tuff and the biotite granite or quartz monzonite porphyry.

Nightingale Mine area: (basin midway between Oxide and El Tiro). Skarn alteration in this area, particularly to the W as the contact between the lithic tuff and biotite granite is approached, is locally strong but to my knowledge potential mineralization has never been tested by the drill. An orthoclase quartz porphyry pluton occurs in this vicinity, and is very similar to one associated with ore in deep drill holes in the E Extension area. The pluton is relatively unaltered but the possibility exists of deeper mineralization associated with its contact margins.

POTENTIAL LOW GRADE RESERVES

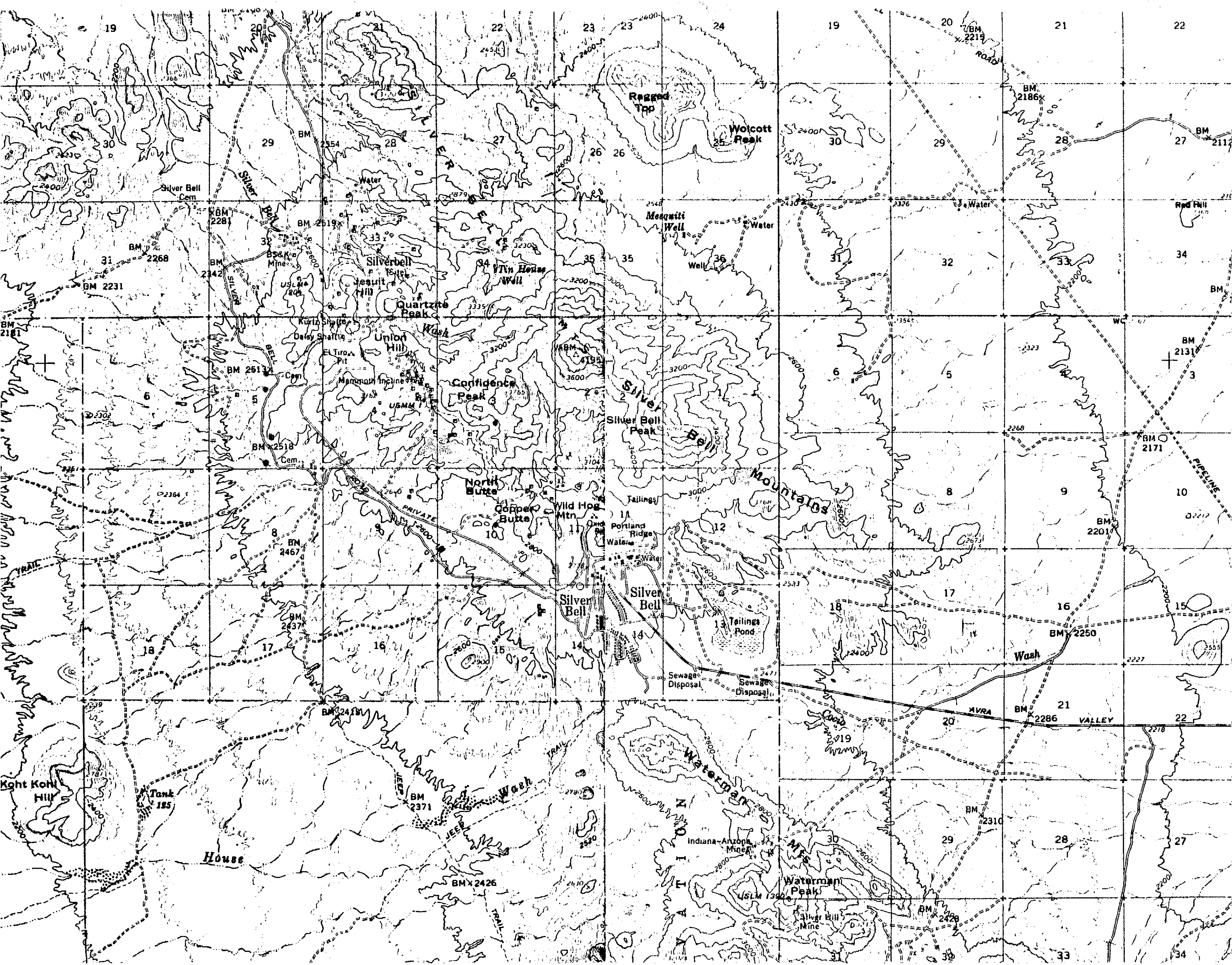
By this I generally mean areas of hypogene or low-grade supergene mineralization in silicate igneous rocks, at Silver Bell ranging in grade from .2 - .5% Cu. Two main areas strike me as having poorly constrained potential reserves in this range of cutoffs, though undoubtedly more remain. In fact, most of the area beneath the present exploration drill coverage in El Tiro and Oxide pits (which bottoms out close to the present mining surface) could be considered as potentially containing low-grade reserves.

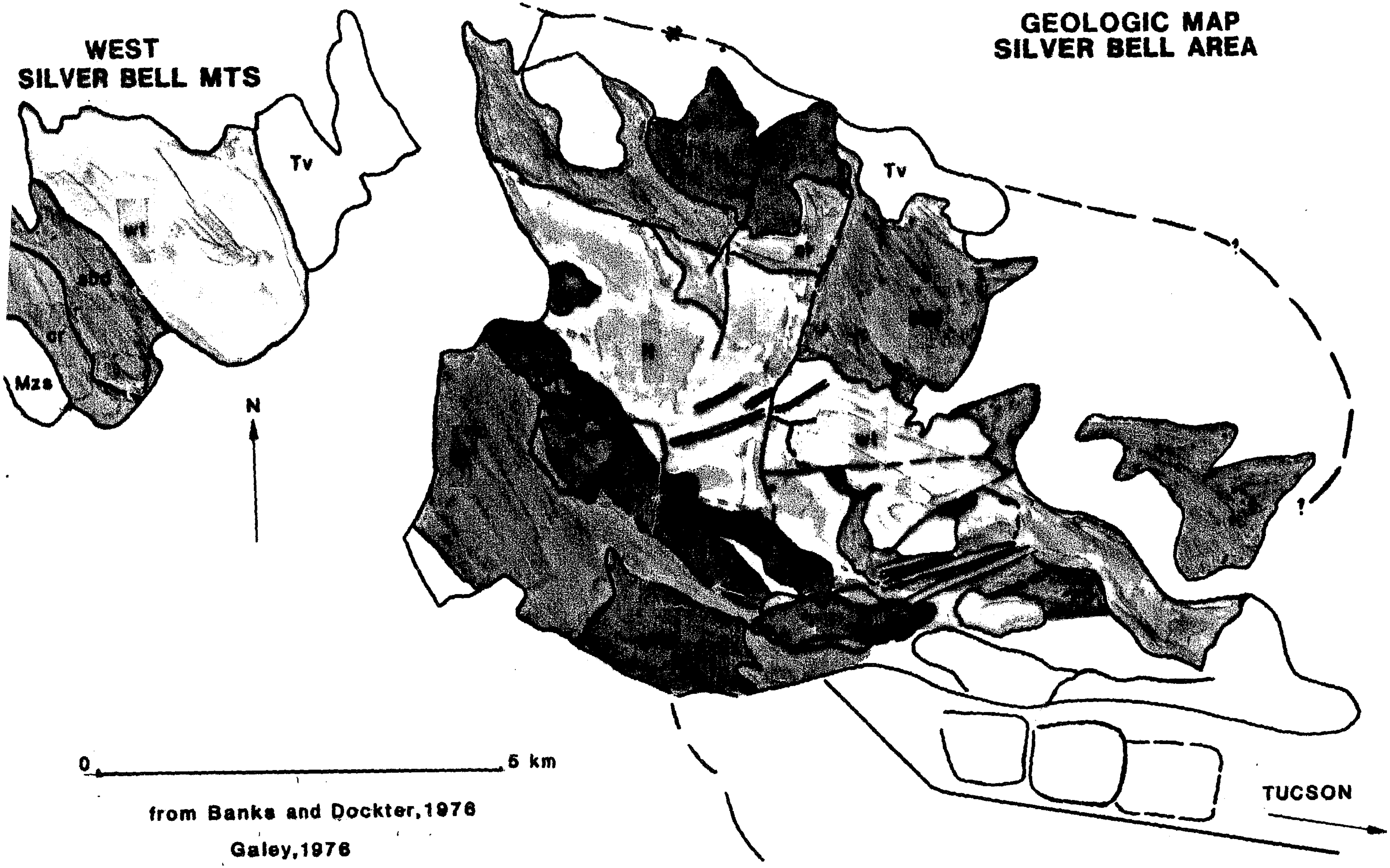
Imperial Stock: This is the pluton which occurs between the main El Tiro and E extension pits, and is well exposed on the W side of the E extension pit. In previous works, it is often referred to as the "barren pluton". However, my interpretation of the drill logs from the very few holes drilled into its margins indicate that no holes have been drilled much below the leached oxidized zone, or evaluated the grade of hypogene copper mineralization below through most of its area of outcrop. The observed "barren" quality of the pluton may in part be a function of surface leaching. Inspection of leached capping in outcrops shows no evidence that would indicate a high-grade chalcocite enrichment blanket at depth. However, there may have been weak enrichment of a hypogene protore which would constitute a potential low-grade Cu resource. At least a few exploration drill holes should be drilled to evalute hypogene Cu grades in the Imperial stock and potential low-grade enrichment.

E of Oxide: In the area between Oxide pit and the deep drilling associated with the E Silver Bell exploration project in the mid 70s, there exists an area of moderately strong to strong alteration tested by only a low density of drill holes. The potential exists in this area for weak enrichment forming low-grade chalcocite bodies, as well as deeper hypogene Cu mineralization. In this area the question of whether the ore bodies were tilted ENE along with the Laramide volcanic rocks in the central Silver Bell Mts. assumes importance. If the ore bodies are tilted, then hypogene mineralized horizons would occur at progressively greater depths to the E of the main Silver Bell ore zone. A test to evaluate tilting of the ore bodies would be a paleomagnetic study of the Silver Bell district. Such studies in the Yerington, Questa, and Red Mt. (Henderson, CO.) mining districts have documented the extent and timing of tilting and their effect on ore distribution.

DS/me

cc: SAAnzalone
WLKurtz
JDSell
FTGraybeal
RCummings
LJohnson

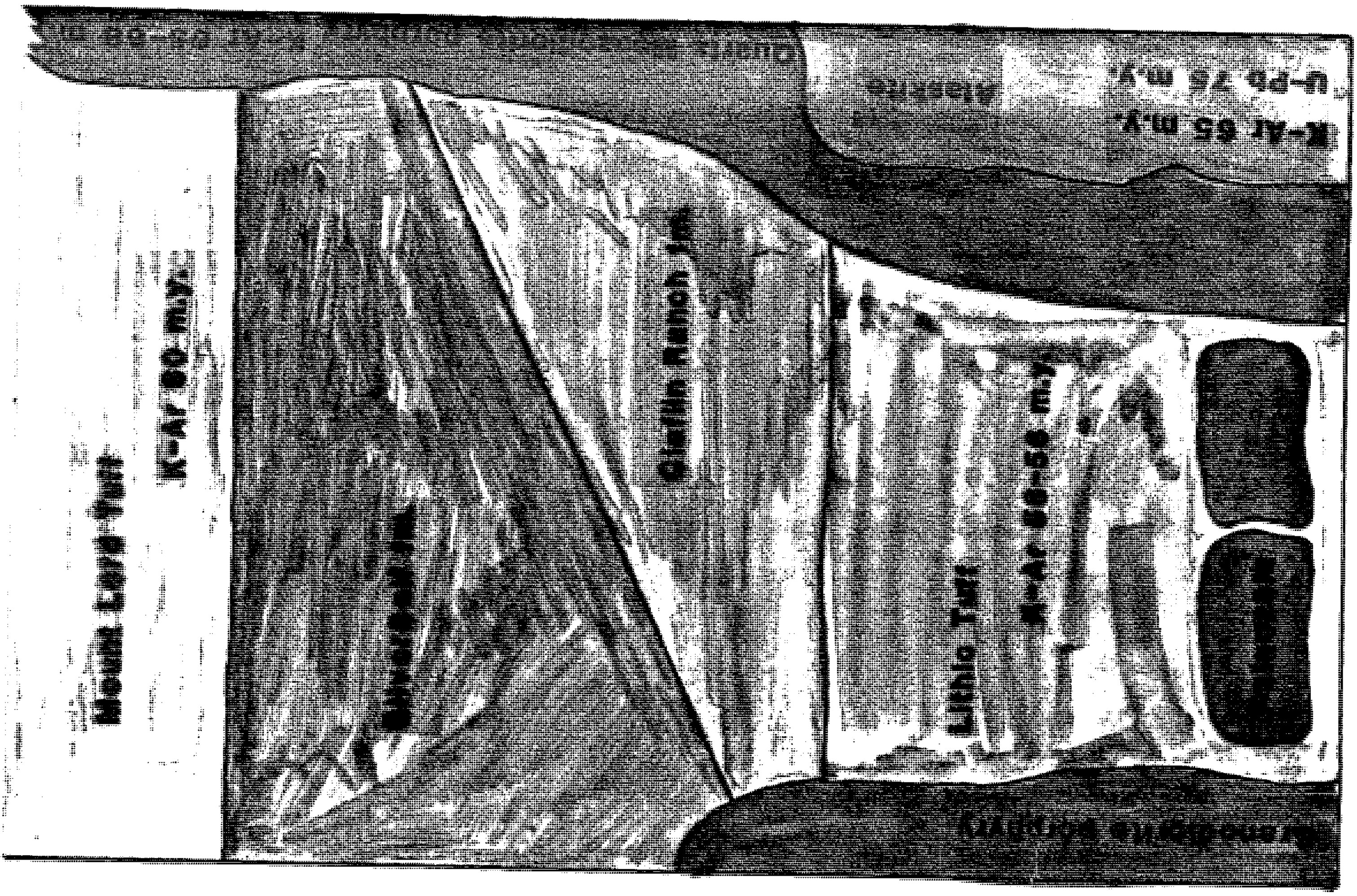

Ragged Top
Wolcott Peak
Mesquite Well
Silverbell
Jesuit Hill
Quartzite Peak
Union Hill
Confidence Peak
Silver Bell Peak
Silver Bell Mountains
North Butte
Copper Butte
Wild Hog Mtn
Portland Ridge
Silver Bell
Tailings Pond
Sewage Disposal
Waterman Mts
Waterman Peak
Indiana-Arizona Mine
Silver Hill Mine
Koht Kohl Hill
House
Wash
Avra Valley
Pipeline
Silver Bell Cem
Mammoth Incline
El Tiro Pit
Daisy Shaft
Kurtz Shaft
Red Hill
Tin House Well



from Banks and Dockter, 1976

Galey, 1976

Sawyer, unpubl.



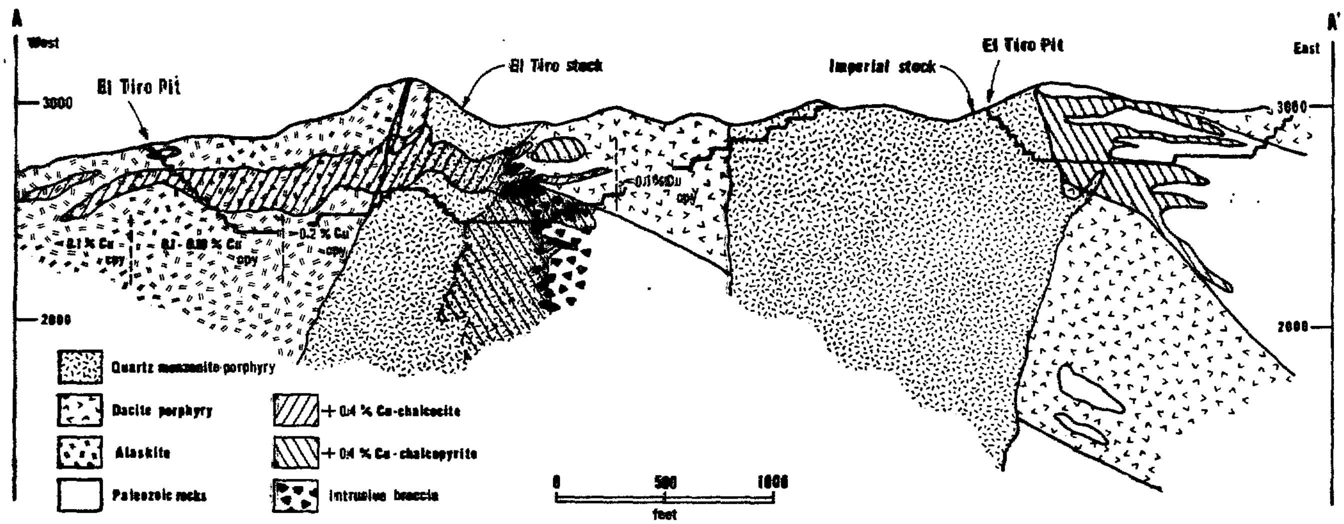
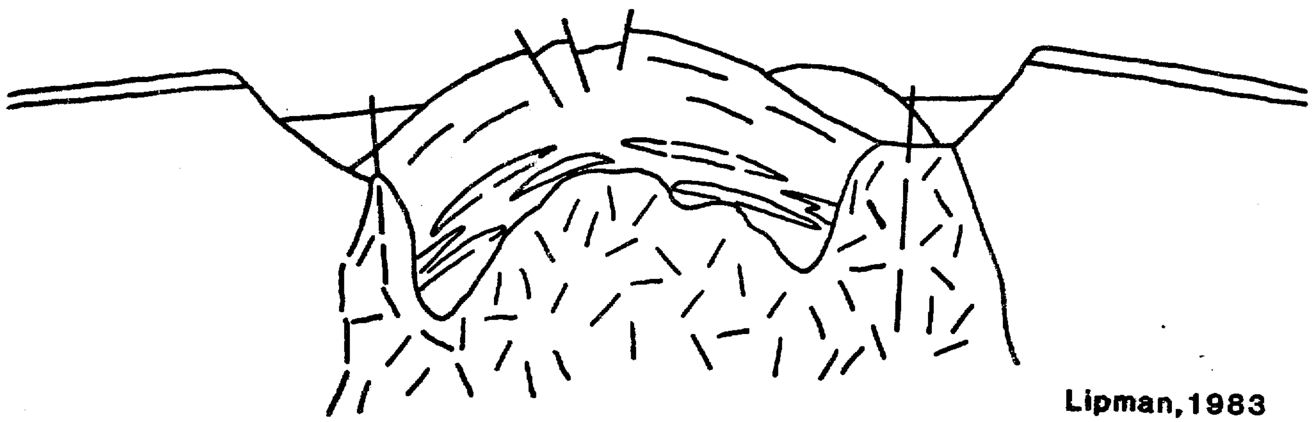


Figure 24.3. East-west cross section through the central portion of the El Tiro area, looking north (see Fig. 24.2 for location)

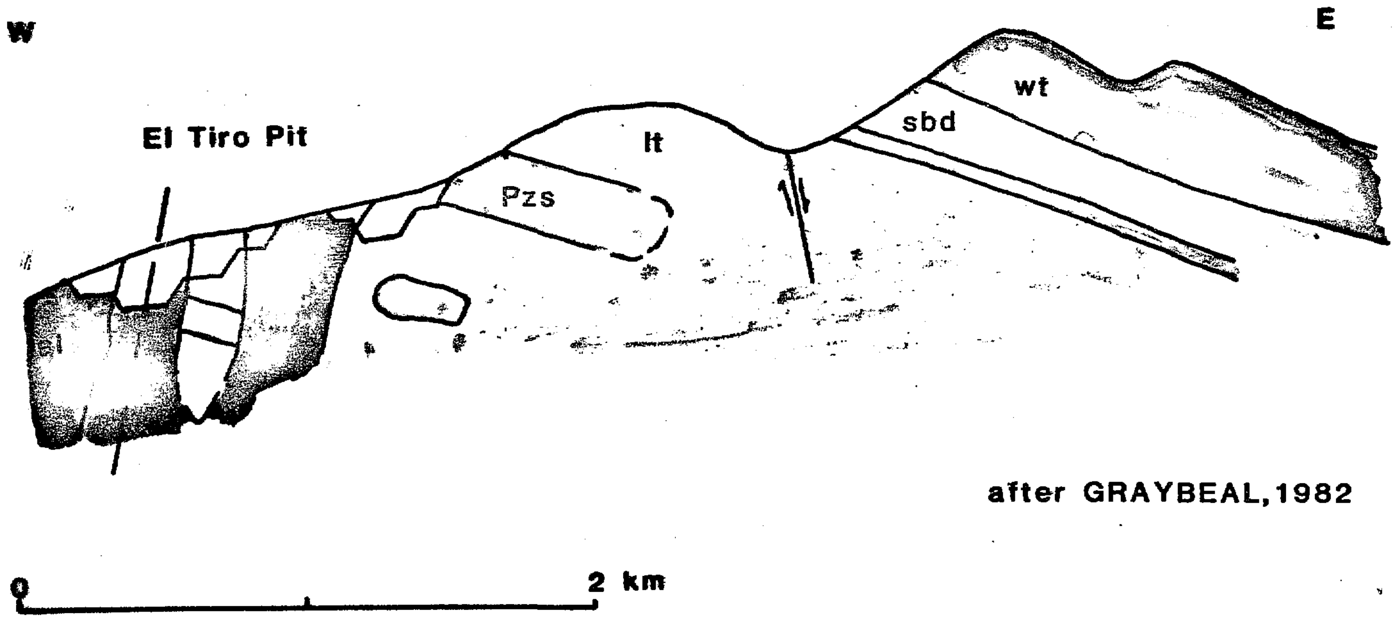
and opaques. The biotite and feldspar contents are locally variable, but within the mapped area the alaskite does not

liest members of the Laramide intrusive porphyry suite, cut dacite porphyry and Paleozoic carbonate rocks in the eastern



Lipman, 1983

GEOLOGIC CROSS-SECTION SILVER BELL



after GRAYBEAL, 1982

ASARCO

Southwestern Exploration Division

J. H. C.

July 13, 1983

JUL 15 1983

File Memorandum

Comparison of Silver Bell, AZ
Fault Pattern with
Goldfields, NV

Mr. David Sawyer, University of California, Santa Barbara, doing a Ph.D. dissertation in the Silver Bell region, remarked in his visit to this office in June that perhaps a caldera setting was possible at Silver Bell. Such a feature has been suggested in the past but I cannot recall any serious writings on the problem.

It is interesting to compare the Ashley Figure 1 (attached) of the fault pattern of the Goldfield, NV District, with that of Richard and Courtright (Figure 1 attached) of the mineralized zone at Silver Bell, AZ. I have sketched on the equivalent portion of the Silver Bell zone onto the Goldfield map.

Note the curving sweep of the El Tiro-oxide zone tailing eastward with the intense northeast fracture zones controlling the location of the orebodies, with that portion of the Goldfield zone. The Goldfield ore zone is also essentially where the northeast faulting intercepts the sweep of the curving fault pattern on the west to southeast.

Also attached is Figure 8, Ashley, showing the hydrothermal altered and ore-bearing areas at Goldfield.

In both cases--Goldfield and Silver Bell--the major deposit(s) found to date are at the northeast fracture junction with the inflection portion of the sweeping curve; equivalent to the southwest portion of a caldera root system.

James D. Sell

James D. Sell

JDS/cg

cc: JHCourtright

Reference

Richard, Kenyon, and Courtright, James H., 1966. Structure and Mineralization at Silver Bell, Arizona, <u>in</u> Geology of the Porphyry Copper Deposits, Southwestern North America, Titley and Hicks, Editors, Univ. of Arizona Press, p. 157-163.

Ashley, Roger P., 1979. Relation Between Volcanism and Ore Deposition at Goldfield, Nevada, <u>in</u> Papers on Mineral Deposits of Western North America: Nevada Bureau of Mines Report 33, p. 77-86.

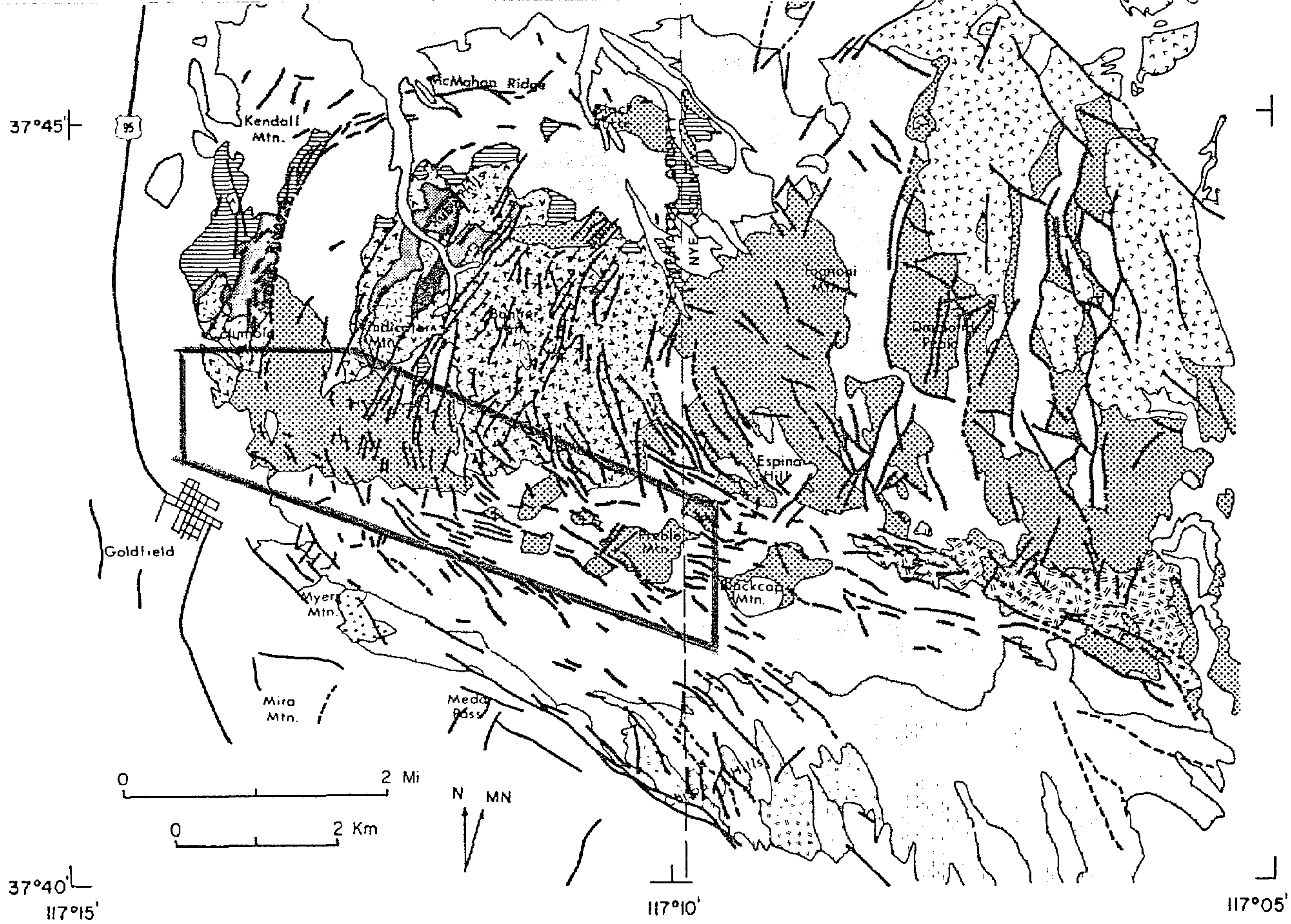


Figure 1. Generalized geologic map of the Goldfield mining district.

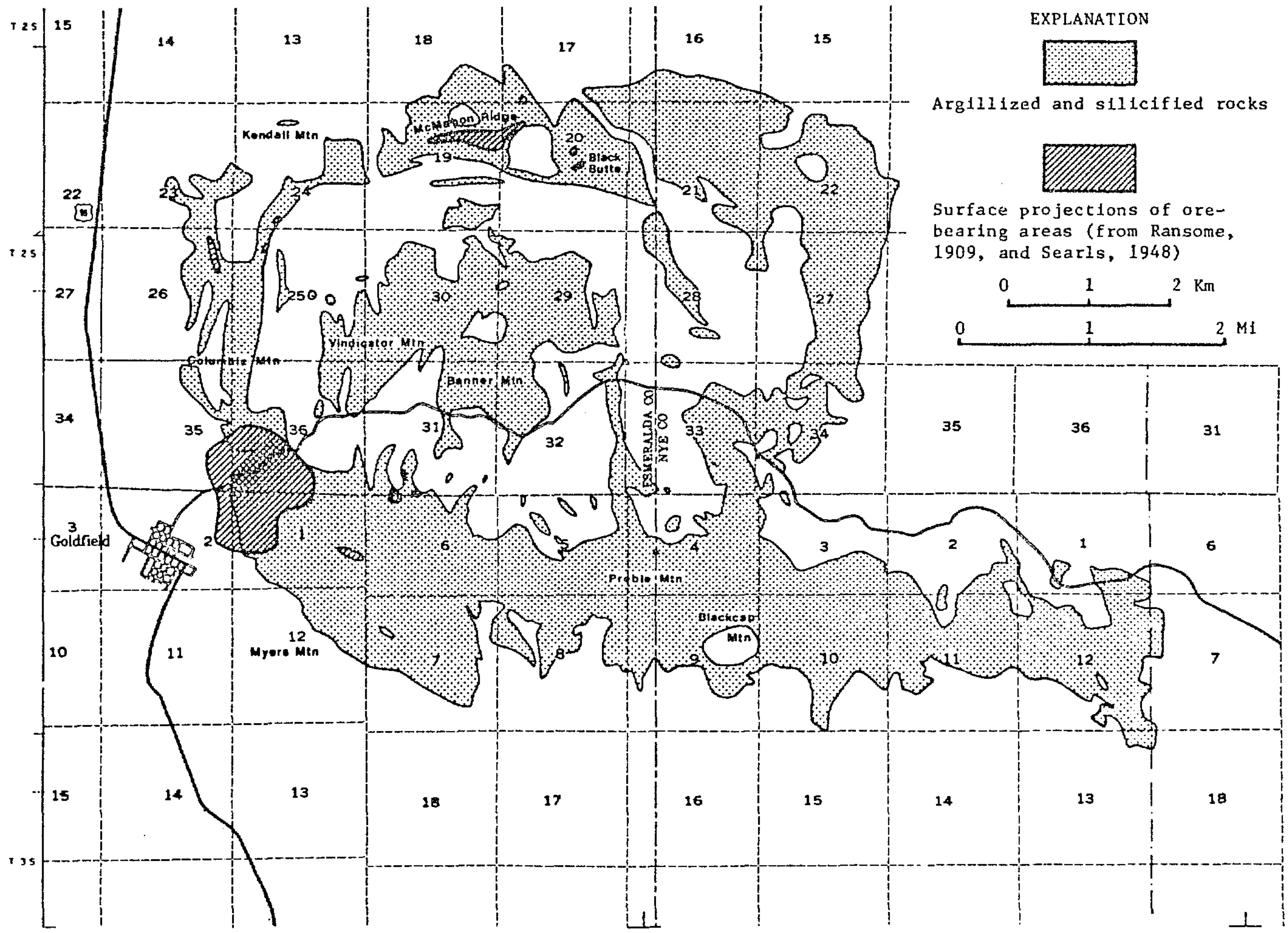
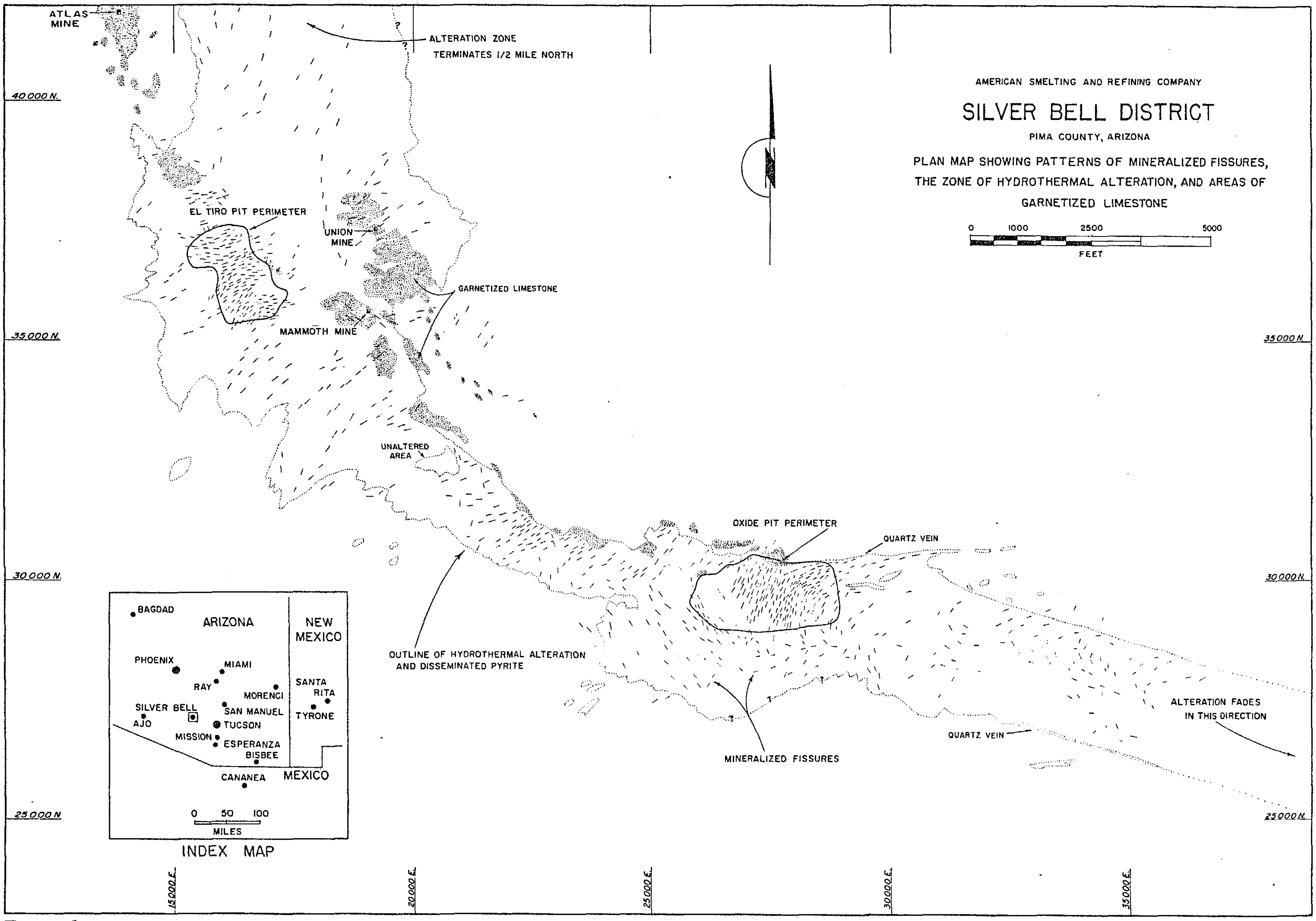
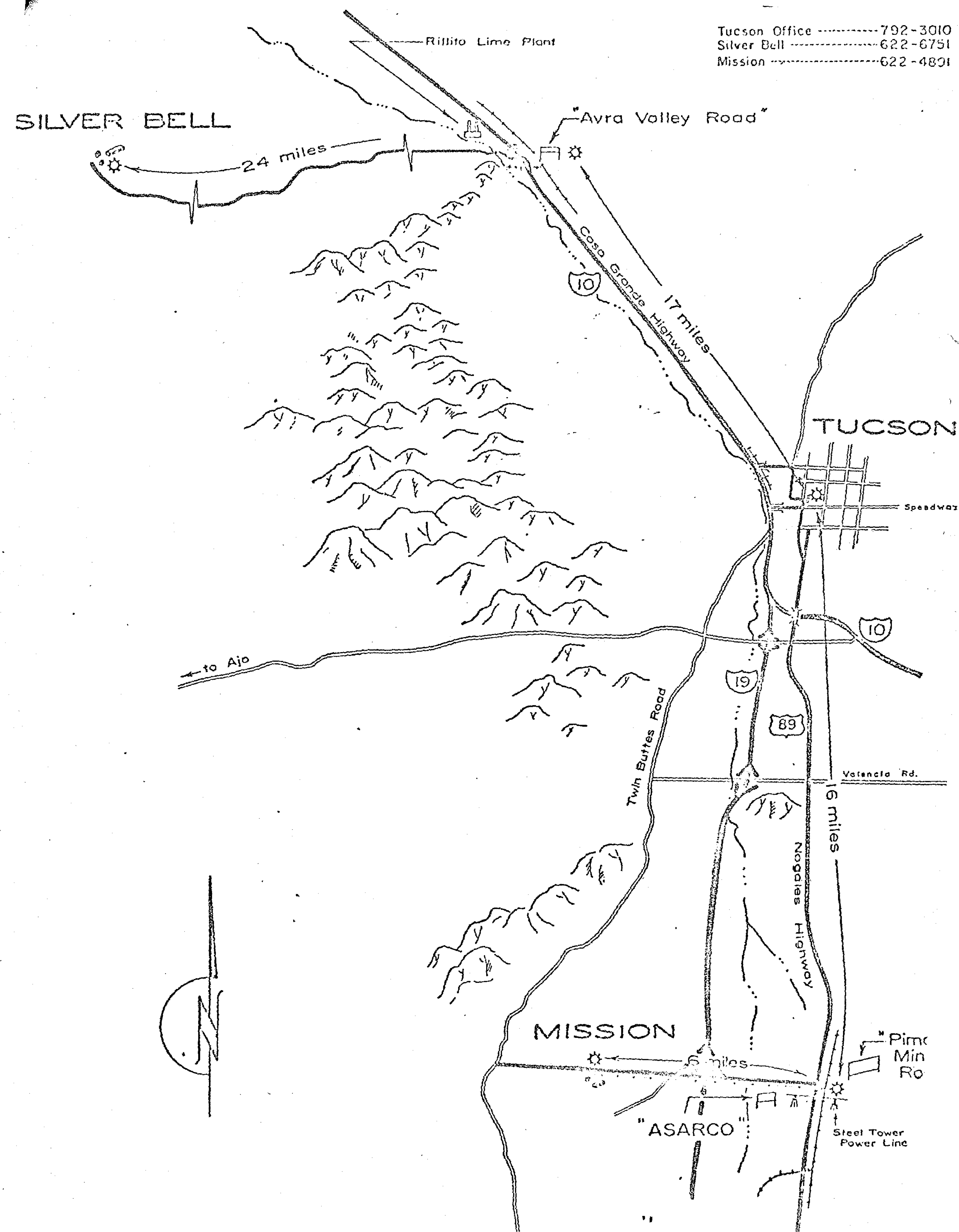


Figure 8. Hydrothermally altered and ore-bearing areas

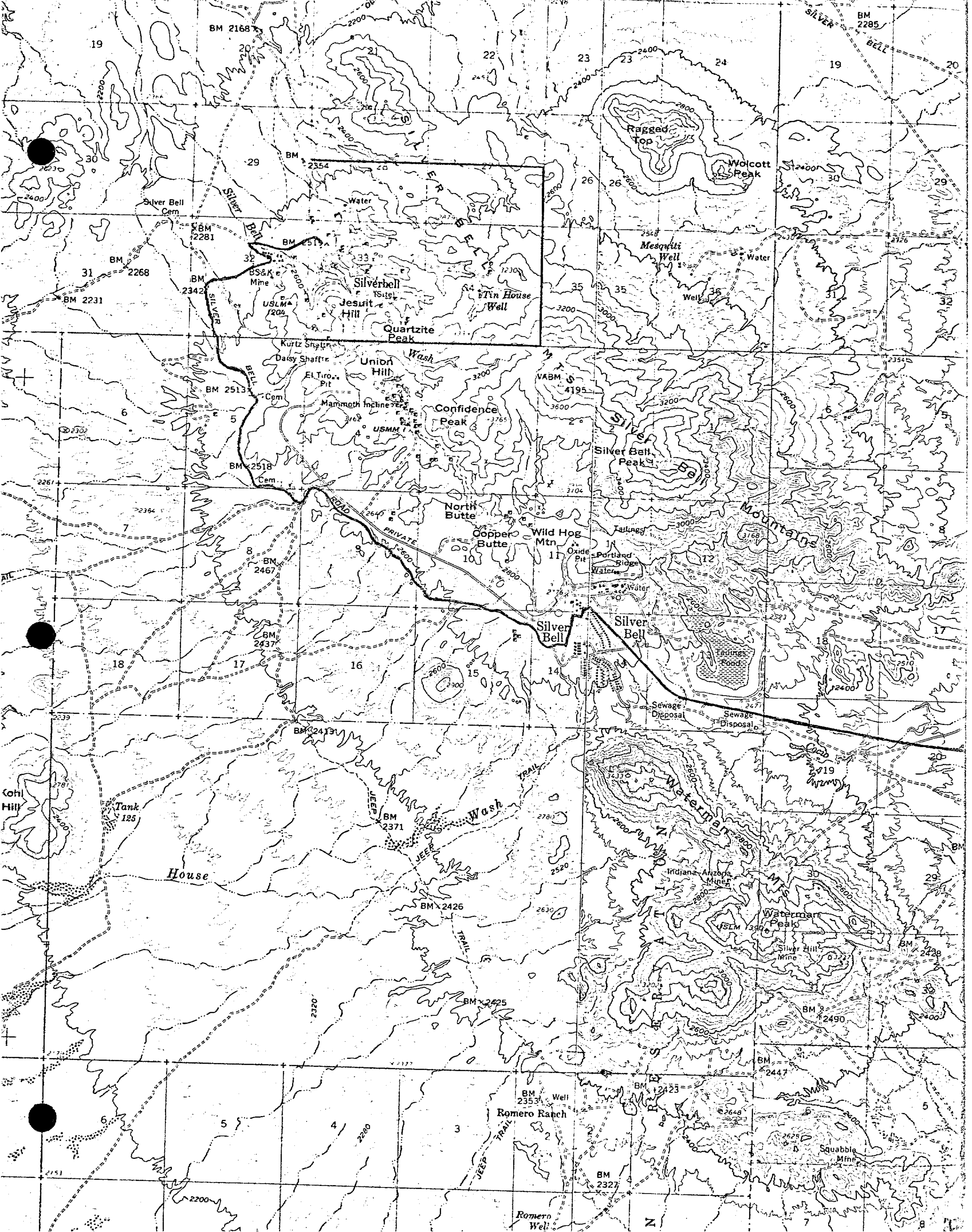


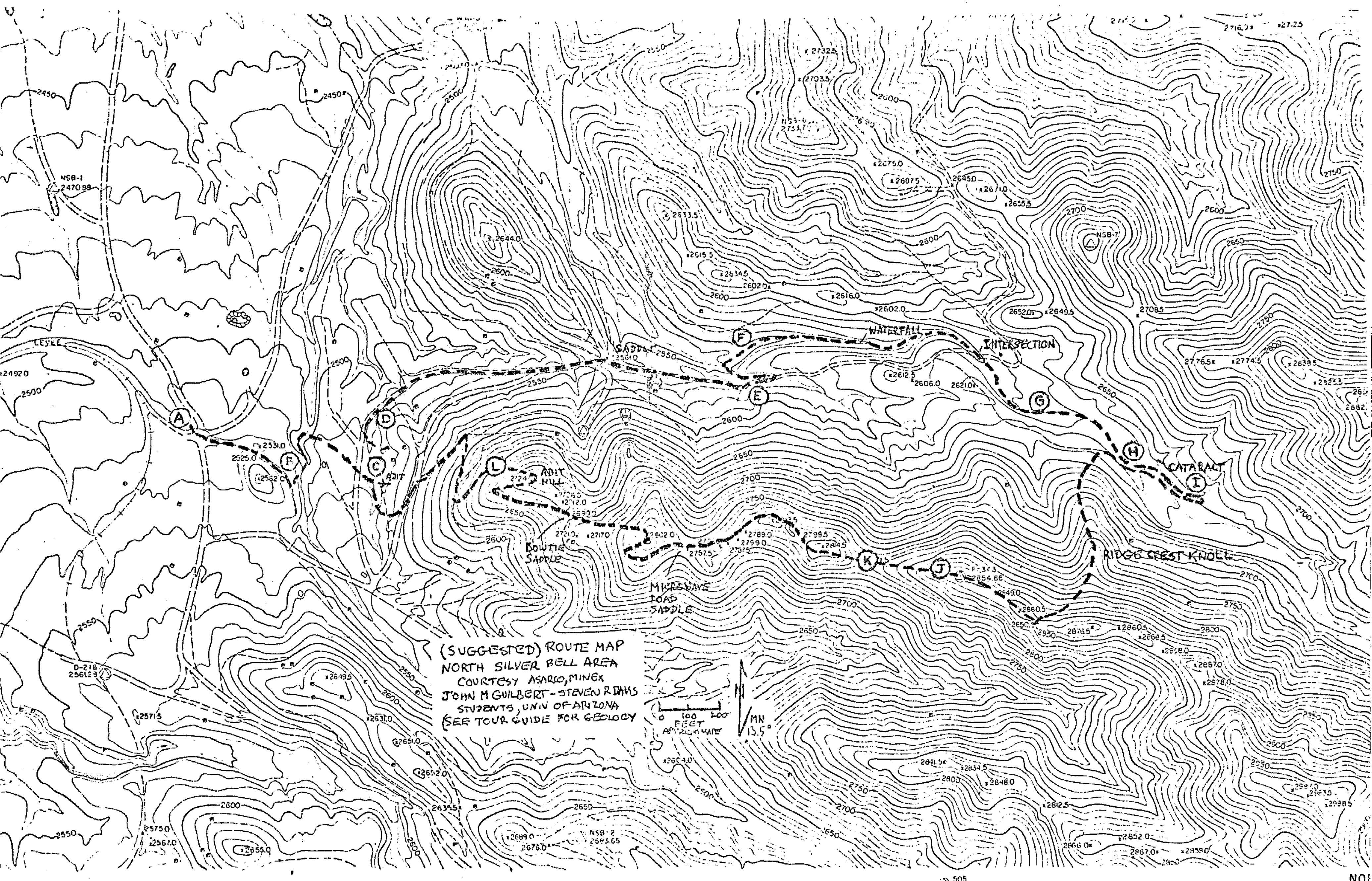
ATLAS MINE
ALTERATION ZONE TERMINATES 1/2 MILE NORTH
AMERICAN SMELTING AND REFINING COMPANY
SILVER BELL DISTRICT
PIMA COUNTY, ARIZONA
PLAN MAP SHOWING PATTERNS OF MINERALIZED FISSURES, THE ZONE OF HYDROTHERMAL ALTERATION, AND AREAS OF GARNETIZED LIMESTONE
0 1000 2500 5000
FEET
40 000 N.
35 000 N.
30 000 N.
25 000 N.
EL TIRO PIT PERIMETER
UNION MINE
GARNETIZED LIMESTONE
MAMMOTH MINE
UNALTERED AREA
OXIDE PIT PERIMETER
QUARTZ VEIN
OUTLINE OF HYDROTHERMAL ALTERATION AND DISSEMINATED PYRITE
MINERALIZED FISSURES
ALTERATION FADES IN THIS DIRECTION
QUARTZ VEIN
15 000 E.
20 000 E.
25 000 E.
30 000 E.
35 000 E.
BAGDAD
ARIZONA
NEW MEXICO
PHOENIX
MIAMI
RAY
MORENCI
SANTA RITA
SILVER BELL
SAN MANUEL
TYRONE
AJO
TUCSON
MISSION
ESPERANZA
BISBEE
CANANEA
MEXICO
0 50 100
MILES
INDEX MAP

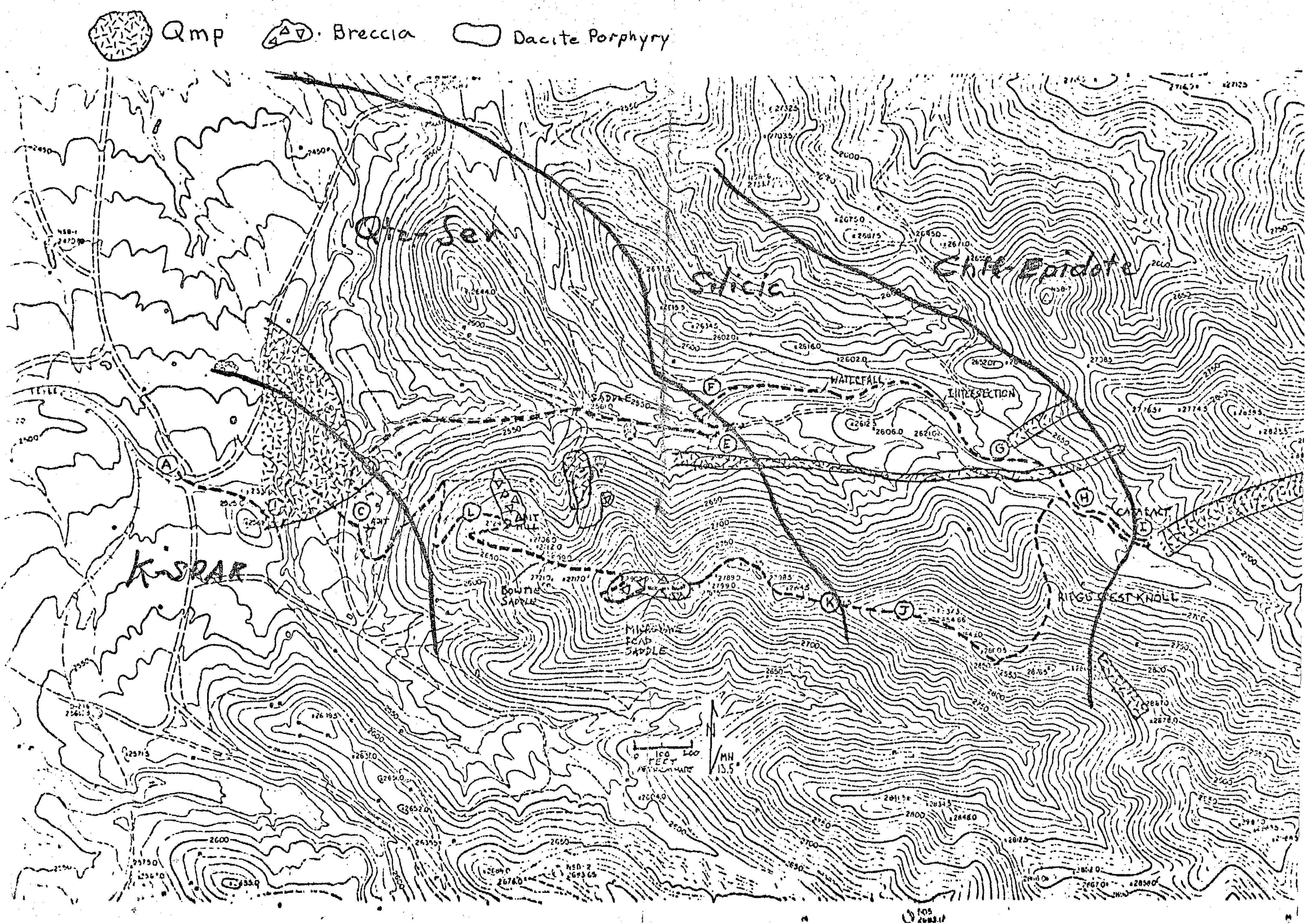
FIGURE 1.



Tucson Office ------------ 792-3010
Silver Bell --------------- 622-6751
Mission ------------------- 622-4801
Rillito Lime Plant
SILVER BELL
24 miles
"Avra Valley Road"
Casa Grande Highway
10
17 miles
TUCSON
Speedway
to Ajo
10
19
89
Twin Buttes Road
Valencia Rd.
16 miles
Nogales Highway
MISSION
6 miles
"Pim
Min
Ro
"ASARCO"
Steel Tower
Power Line
N


BM 2168
BM 2285
SILVER BELL
Ragged Top
Wolcott Peak
BM 2354
Silver Bell Cem
BM 2281
BM 2513
BM 2268
BM 2231
BM 2342
BS&K Mine
USLM 1204
Silverbell (Site)
Jesuit Hill
Quartzite Peak
Tin House Well
Mesquite Well
Water
Well
Kurtz Shaft
Daisy Shaft
Union Hill
El Tiro Pit
Wash
VABM 4195
Mammoth Incline
Confidence Peak
USMM
Silver Bell Peak
Silver Bell Mountains
BM 2518
Cem.
North Butte
Copper Butte
Wild Hog Mtn
Tailings
Oxide Pit
Portland Ridge
PRIVATE ROAD
BM 2467
BM 2437
Silver Bell
Tailings Pond
Sewage Disposal
BM 2413
Cocio
Waterman Mts
Kohl Hill
Tank 125
JEEP TRAIL
BM 2371
Wash
House
Indiana-Arizona Mine
BM 2426
Waterman Peak
USLM 3900
Silver Hill Mine
BM 2428
BM 2425
BM 2490
BM 2447
BM 2423
BM 2353
Well
Romero Ranch
Squabble Mine
BM 2327
Romero Well


(SUGGESTED) ROUTE MAP
NORTH SILVER BELL AREA
COURTESY ASARCO, MINEX
JOHN M GUILBERT - STEVEN R DAMS
STUDENTS, UNIV OF ARIZONA
(SEE TOUR GUIDE FOR GEOLOGY
SADDLE
WATERFALL
INTERSECTION
CATARACT
RIDGE CREST KNOLL
ADIT HILL
ADIT
BOWTIE SADDLE
MICROWAVE ROAD SADDLE
LEVEE
A
B
C
D
E
F
G
H
I
J
K
L
FEET
MN
13.5°



Qmp
Breccia
Dacite Porphyry
Qtz-Ser
Silicic
Chl-Epidote
K-SPAR
SADDLE
WATERFALL
INTERSECTION
RIDGE CREST KNOLL
A
C
E
F
G
H
I
J
K
L

ASARCO Incorporated
Silver Bell Unit
Silver Bell, Arizona

160 M .75 ±
(15% skarn

March 1976

J. H. C.

FEB 7 - 1978

LOCATION: Silver Bell, Arizona, 40 miles northwest of Tucson, Arizona.

PLANT: 2 Pits - Known as Oxide and El Tiro - Approximately 2½ airline miles apart or 3½ miles by haul road.

Crushing Plant - 600 Tons per hour capacity - Ore crushed from maximum size of 48 inches to 1/2 inch for mill feed.

Mill - 11,400 Tons per day capacity or 4,000,000 Tons/Year. Concentrate shipped to Hayden for smelting.

HOUSING: 175 two and three bedroom houses - 24 two and three bedroom apartments. One trailer court for private trailers.

300 Employees, living in Silver Bell, Avra Valley and Tucson.

Recreation Facilities:	Other Facilities:
Recreation Hall	Post Office
Swimming Pool	Grocery Store
Ball Park	Barber Shop

WATER: Wells drilled on ASARCO land in Avra Valley. 18 inch pipe line from wells to mill - 8 miles. Static Head 950 feet from water level to receiving tank. Estimated percent consumption 2000 gals/min.

POWER: Electrical power purchased from The Tucson Gas & Electric Company. Consumption: Six million kilowatt hours per month. Natural Gas used for heating.

Reserve 26 M .72 1-1-78

MINE PRODUCTION TO JANUARY 1, 1976

Oxide Pit:	33,689,000	Tons Ore
	17,817,000	Tons Leach
	30,825,000	Tons Waste
	82,331,000	TOTAL TONS
El Tiro Pit:	36,584,000	Tons Ore
	38,023,000	Tons Leach
	84,587,000	Tons Waste
	159,194,000	TOTAL TONS
	241,525,000	Total Tons moved to date.

PRODUCT PRODUCED:

Copper Concentrates	64,000	Tons/Year
Cement Copper	5,600	Tons/Year

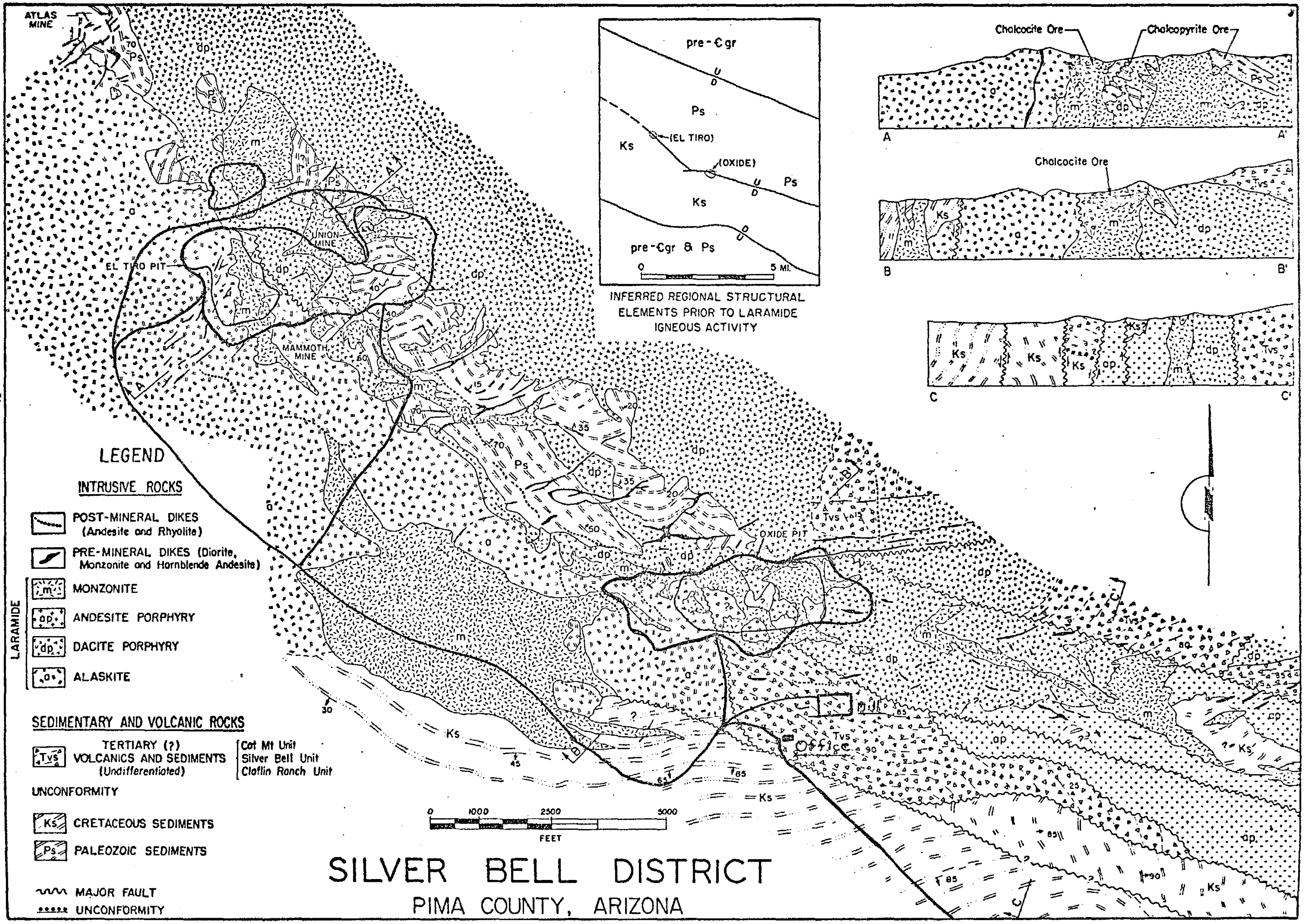

ATLAS MINE
UNION MINE
EL TIRO PIT
MAMMOTH MINE
OXIDE PIT
Office
pre-€ gr
Ps
Ks
(EL TIRO)
(OXIDE)
pre-€gr & Ps
0
5 MI.
INFERRED REGIONAL STRUCTURAL ELEMENTS PRIOR TO LARAMIDE IGNEOUS ACTIVITY
Chalcocite Ore
Chalcopyrite Ore
A
A'
Chalcocite Ore
B
B'
C
C'
LEGEND
INTRUSIVE ROCKS
POST-MINERAL DIKES (Andesite and Rhyolite)
PRE-MINERAL DIKES (Diorite, Monzonite and Hornblende Andesite)
LARAMIDE
MONZONITE
ANDESITE PORPHYRY
DACITE PORPHYRY
ALASKITE
SEDIMENTARY AND VOLCANIC ROCKS
TERTIARY (?) VOLCANICS AND SEDIMENTS (Undifferentiated)
Cat Mt Unit
Silver Bell Unit
Claflin Ranch Unit
UNCONFORMITY
CRETACEOUS SEDIMENTS
PALEOZOIC SEDIMENTS
MAJOR FAULT
UNCONFORMITY
0
1000
2500
5000
FEET
SILVER BELL DISTRICT
PIMA COUNTY, ARIZONA

FIGURE 2.

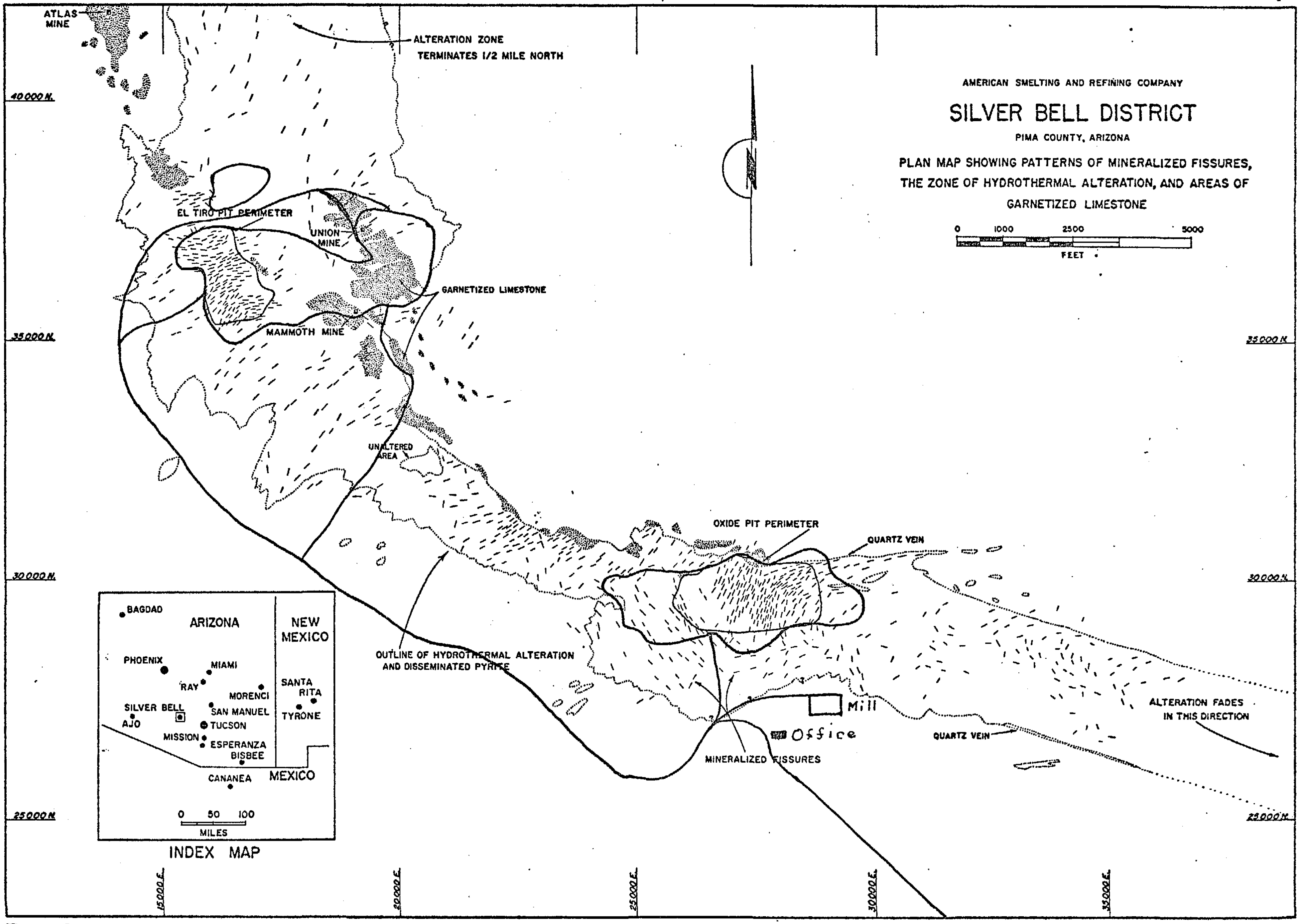
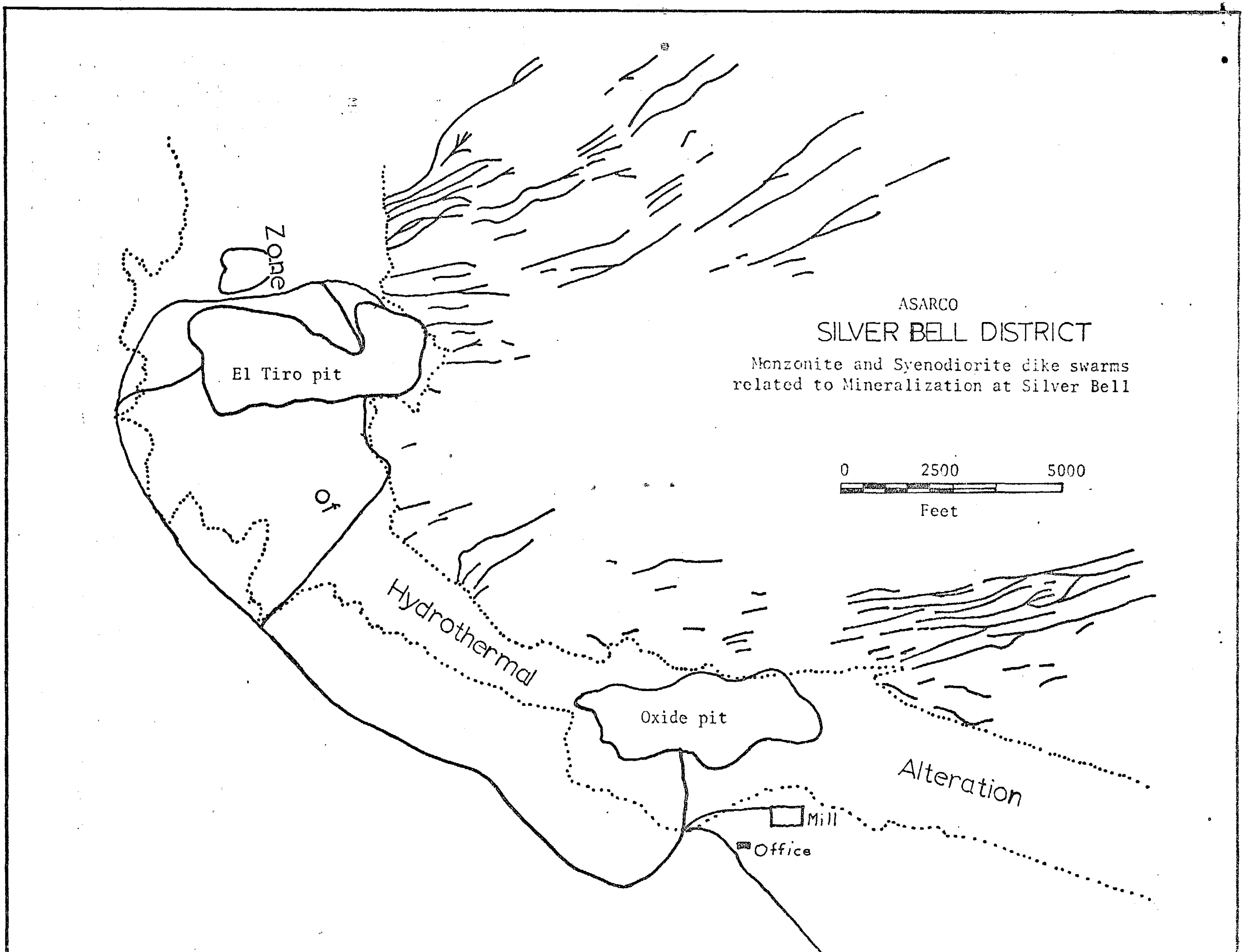

AMERICAN SMELTING AND REFINING COMPANY
SILVER BELL DISTRICT
PIMA COUNTY, ARIZONA
PLAN MAP SHOWING PATTERNS OF MINERALIZED FISSURES, THE ZONE OF HYDROTHERMAL ALTERATION, AND AREAS OF GARNETIZED LIMESTONE
0 1000 2500 5000
FEET
ATLAS MINE
ALTERATION ZONE TERMINATES 1/2 MILE NORTH
EL TIRO PIT PERIMETER
UNION MINE
GARNETIZED LIMESTONE
MAMMOTH MINE
UNALTERED AREA
OXIDE PIT PERIMETER
QUARTZ VEIN
OUTLINE OF HYDROTHERMAL ALTERATION AND DISSEMINATED PYRITE
Mill
Office
MINERALIZED FISSURES
QUARTZ VEIN
ALTERATION FADES IN THIS DIRECTION
40000 N.
35000 N.
30000 N.
25000 N.
15000 E.
20000 E.
25000 E.
30000 E.
35000 E.
BAGDAD
ARIZONA
NEW MEXICO
PHOENIX
MIAMI
RAY
MORENCI
SANTA RITA
SILVER BELL
AJO
SAN MANUEL
TUCSON
TYRONE
MISSION
ESPERANZA
BISBEE
CANANEA
MEXICO
0 50 100
MILES
INDEX MAP

FIGURE 1.



ASARCO
SILVER BELL DISTRICT
Monzonite and Syenodiorite dike swarms related to Mineralization at Silver Bell
0
2500
5000
Feet
El Tiro pit
Oxide pit
Zone of Hydrothermal Alteration
Mill
Office

CLARKE, FIGURE 6

GEOLOGIC MAP OF THE EL TIRO HILLS, WEST SILVER BELL MOUNTAINS, PIMA COUNTY, ARIZONA

ROAD LOG
WEST SILVER BELL MOUNTAINS
1969 AGS Spring Field Trip

Meeting begins at ASARCO parking lot, 1150 N. 7th Avenue. Caravan will take Speedway west to the freeway (Casa Grande Highway) and travel north. Log begins at the Ruthrauff Rd. overpass. Truck stop complex on the right.

Road Log

Total Miles	Interval	
0	0	Ruthrauff road overpass.
1.1	1.1	Orange Grove Rd. Amole Peak at 9 o'clock is the high point in the Tucson Mountains.
5.8	4.7	Cortaro Rd. overpass. Safford Peak at 9 o'clock, is a dacite neck. The low ridges on the left are mid-Tertiary volcanics. Picacho Peak is dead ahead on the skyline (visible unless smog is unusually heavy)
8.1	2.3	Prepare to take right hand ramp off freeway at Avra Valley Rd., exit 1 mile. Move to right hand lane.
9.1	1.0	Exit.
9.3	0.2	STOP. Turn left, Rd. sign points to RILLITO.
9.4	0.1	DO NOT turn right at sign RILLITO. Continue
9.5	0.1	Small sign on the left directs to ASARCO, SILVER BELL--23 miles. Follow this paved road.
9.8	0.3	Crossing north tip of the Tucson Mountains. Bridge crosses Santa Cruz River.
10.5	0.7	Road cut in mid-Tertiary andesite.
10.6	0.1	TRUCK CROSSING, CAUTION. Arizona Cement Company plant at 3 o'clock; limestone quarry at 9 o'clock is an outlier of Paleozoic strata, known as Twin Peaks or (older ref.) Picacho de Calera.
10.8	0.2	At 9 o'clock: Looking south into Safford Peak, a volcanic neck intrusive into gently dipping mid-Tertiary volcanics. The horizontal strip of white visible ahead just below the skyline is the Silver Bell tailing pond.
12.6	1.8	At 9 o'clock, Twin Peaks and a low hill to the north, both Paleozoic limestone outliers. Ahead on the skyline, the Silver Bell tailings pond is in a narrow valley basin between the Silver Bell Mountains on the north and the Waterman Mountains on the south. The high peaks in the Central Silver Bell Mountains are formed of Laramide ignimbrite; the jagged peak to the north is Ragged Top, an eroded mid-Tertiary plug. To the southwest, about 10 o'clock, Kitt Peak on the skyline, as is Baboquivari Peak about 9 o'clock. The low range in view on the southwest is the Roskruge Mountains, of Laramide volcanics.

ROAD LOG

Total miles	Interval	
14.8	2.2	Crossing Avra Valley--good farm land.
19.3	4.5	Your car is pointed at the Silver Bell tailings pond. Ragged Top on the skyline at 1 o'clock. The Sasco Hills at 2 o'clock form the low skyline. Picacho Peak and Picacho Mountains are at 3 o'clock.
23.8	4.5	Low hills nearby on the right are post-mineral, mid-Tertiary andesites. A conglomerate beneath the flows contains altered porphyry fragments with cavities derived from leached sulphides.
27.6	3.8	Enter a slightly trenched pediment carved on tilted Cretaceous (?) Clastic sediments.
28.5	0.9	Tin Buildings in a little saddle at 10 o'clock, with the narrow road leading up to them, mark the Indiana Mine, a lead-zinc replacement in Paleozoic limestone. The limestone bluffs on the left form the north edge of the Waterman Mountains.
29.0	0.5	Titan Missle site at 9 o'clock.
30.2	1.2	Tailings pond on the right.
30.8	0.6	Road swings northerly toward Silver Bell camp. Brown colors in the foreground hills indicate a pervasively mineralized zone of igneous rocks. The hump-back hill at 1 o'clock is Portland Ridge--possibly an intrusive ignimbrite; Silver Bell Mill is at its base.
31.6	0.8	Residence area on the left. Mine offices are ahead.
31.7	0.1	Slow, 15 mph. Turn left at the speed limit sign.
31.8	0.1	Swing around the loop and enter the paved road going south.
31.85	0.05	Cattle guard. You have gone too far. Back up 100 feet and turn right on a graded dirt road, a part of the old Silver Bell road maintained by Pima County. Please do not get lost here.
31.9	0.05	Turn sharp left and follow the graded road.
32.2	0.3	Cretaceous red beds.
32.3	0.1	Corrals and ranch house.
32.6	0.3	Leaching plant at 3 o'clock. Altered igneous hills at 1-2 o'clock.
32.8	0.2	Weak alteration of K? sediments.
34.4	1.6	From the last point the road has run parallel and slightly west of the limits of pervasively mineralized zone.
34.9	0.5	From last point road is on weakly altered and mineralized igneous rock.
35.1	0.2	Old smelter slag dump.
36.0	0.9	Point of dump by road. From last point road has crossed streaks of very weak mineralization. The main zone of pervasive mineralization is to the east.

ROAD LOG

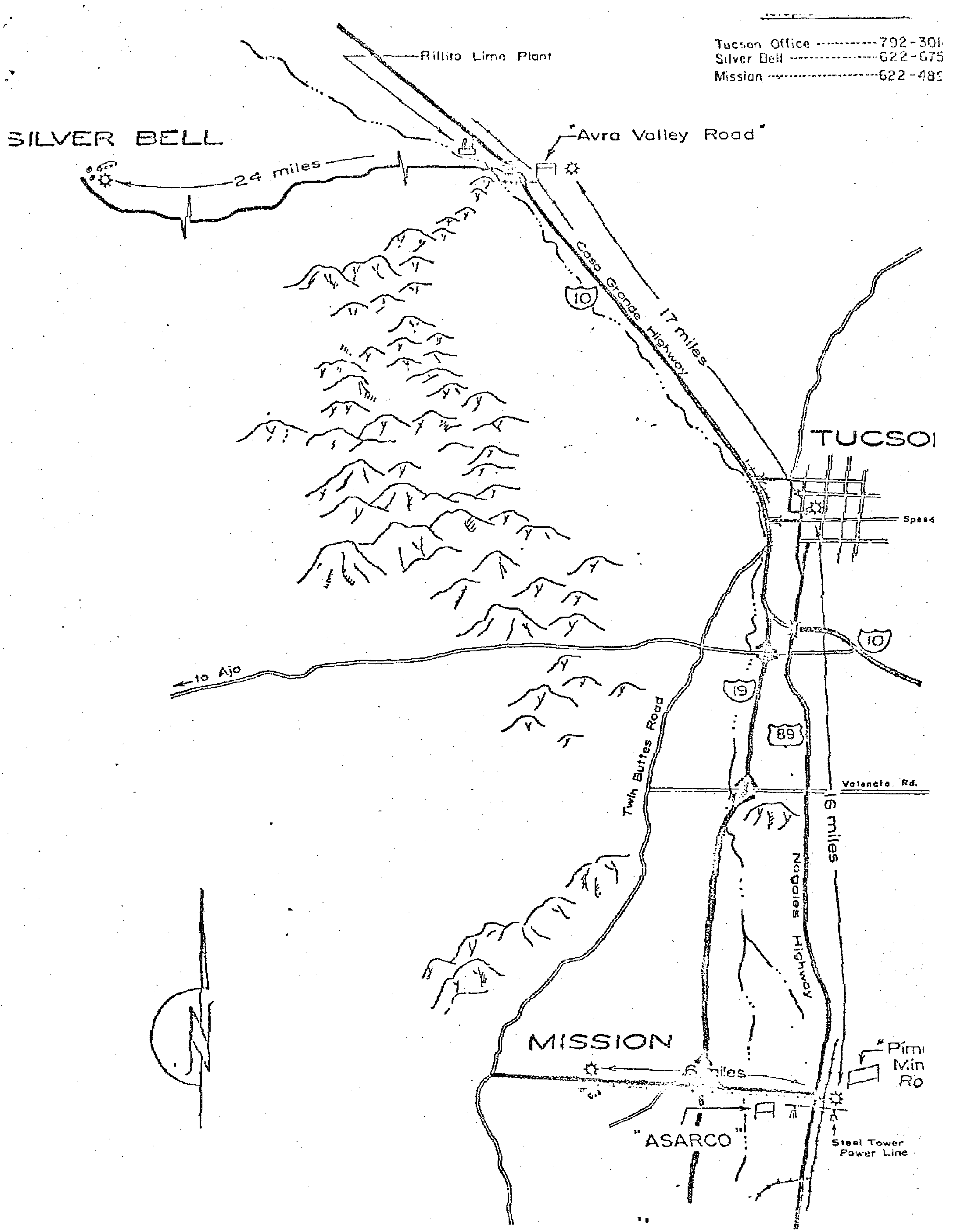
Total Miles	Interval	
36.3	0.3	Road enters unaltered igneous rock.
36.8	0.5	Cattle guard, Atlas Mine (lead-zinc replacement) at 2 o'clock.
37.2	0.4	County road curves right. Take left fork.
37.8	0.6	Cross road, turn left.
37.9	0.1	Graveyard.
38.0	0.1	Take left fork.
38.8	0.8	Road leading north. Continue straight.
40.0	1.2	Fence and gate. Continue ahead.
40.3	0.3	Fence and gate. Enter Papago Indian Reservation (SW Cor.Sec 31, T11S,R8E).
41.0	0.7	Sharp ridge of Claflin Ranch formation, at 3 o'clock, dips 30°E.
41.7	0.7	Low hilss of andesite and Cretaceous sediments.
42.1	0.4	Road leads north to Gato Peak. Continue ahead.
42.3	0.2	Take right fork.
42.5	0.2	Cretaceous sediments on the right. Paleozoic limestone makes sharp gray ridges ahead.
42.6	0.1	Take left fork, along power line.
42.8	0.2	Paleozoic limestone, dips east, on ridges ahead.
43.2	0.4	Take road leading north (to the right).
43.5	0.3	Take right fork.
43.7	0.2	Stop 1. Hike about 400 yards up to Cretaceous-Paleozoic contact. A basal conglomerate is present, overlain by arkoses and siltstone of presumed Cretaceous age. The lithology is similar to that of the Amole Arkose in the Tucson Mountains. From Stop 1 drive northerly following bulldozer road and tire tracks overland as required.
44.9	1.2	Desert Auto road crosses bulldozer trail. Turn right.
45.5	0.6	Gato Peak at 1 o'clock, Claflin Ranch fm, dips NE. Sharp peak of K sediments, at 3 o'clock, dips steeply NE. Ahead, Ridges and Peaks formed from Silver Bell and Claflin Ranch formations. Begin detour to stops 2, 3, and 4. Take bulldozer road south (turn right).
45.8	0.3	Stop 2. Claflin Ranch formation. Isolated outcrop of grits and siltstone, dipping 40°NNE. Ignimbrite at this stop might be intrusive.
46.1	0.3	Stop 3 (brief) Small exposure isolated in alluvium. Ledge of typical limy grit and conglomerate of the Cretaceous section. Dips 70°NE.

ROAD LOG

Total Miles	Interval	
46.5	0.4	Stop 4. Hike east, down slope and cross small wash onto next ridge, about 300 yards. Cross steeply inclined strata typical of the Cretaceous section. Thin beds of argillite and sandstone, and some thin silty limestone. All slightly metamorphosed. Return to beginning of detour. Turn right, and continue on desert auto road.
48.0	1.5	Begin detour to Stop 5. Take cross road right 0.8 miles to southern base of Gato Peak. Do not take any left hand forks.
48.8	0.8	Stop 5. Claflin Ranch formation forms the resistant ledges of Gato Peak, overlying the andesite conglomerate and/or flows, and/or intrusive andesite. The attitude which can be seen in a few places is parallel to the Cretaceous strata on each side of this andesitic complex, and is markedly divergent from the attitude of the overlying conglomerates of the Claflin Ranch. We interpret the contact as an unconformity possibly equivalent to the Tucson surface in the Tucson Mountains. Refer to the geologic sketch map for better visualization of structural relationships.
49.6	0.8	Return to beginning of detour, turn right and continue on desert auto road.
49.7	0.1	Abandoned windmill.
50.0	0.3	Large wash. Drive or walk south toward stops 6, 7, 8, and 9.
50.1	0.1	Stop 6. Cat Mountain rhyolite; Dips 15° NE. Laramide welded ignimbrite.
50.2	0.1	Stop 7. Arkose with a few pebbles. This could mark the erosion surface present in some localities at the base of the Cat Mountain (as in the Roskruge Mountains).
50.3	0.1	Stop 8. Andesite. This does not display the typical laharic breccia texture of the Silver Bell formation, but is probably more or less equivalent to that formation (Note: if Caravan drives down the wash, turn around at stop 8).
50.5	0.2	Stop 9. Sandstone and andesite-conglomerate of the Claflin Ranch formation underlie andesite breccia of the Silver Bell formation. The length of time at this stop will depend partly on the temperature and general state of decay of the dead cow in the pothole at the contact above described.
51.0	0.5	Return to detour point and continue.
51.1	0.1	Stop 10. Walk east up slope for outcrops of Cat Mountain rhyolite. Begin return route, crossing the northern part of the Silver Bell Mts.
51.6	0.5	Cattle guard.
52.2	0.6	Take road leading east (right). Before turning, pre-Cambrian granite ridge forms skyline at 10 o'clock.
52.3	0.1	The black mesa ahead is Mid-Tertiary basalt.
53.3	1.0	Crossing the point of a ridge of mid-Tertiary basalt.

ROAD LOG

Total Miles	Interval	
53.4	0.1	Connection with desert road, turn left.
53.9	0.5	Turn right on road, along fence.
54.1	0.2	Take right fork.
54.9	0.8	Turn right, then left and pass through gate on a road crossing easterly.
56.2	1.3	Light tan rock on lower slope of Mesa, at 10 o'clock, is pre-Cambrian granite which lies beneath the basalt flow.
57.6	1.4	Cattle guard. Turn left on the old Silver Bell road. Before turning, Ragged Top is at 1 o'clock. The mid-Tertiary volcanic-textured plug intrudes along a fault, striking WNW, which brings pre-Cambrian granite on the north against Laramide volcanics on the south.
59.9	2.3	Left bend in road. The straight, even line of the road ahead is because the road is built on the old railroad grade which connected the Sasco Smelter with the Imperial Copper Company mines at Silver Bell.
60.0	0.1	Turn right and return on the Cocio Ranch road. Note: This turn off is easily passed up as the road is shielded from view by brush.
61.5	1.5	Ragged Top at 3 o'clock.
63.1	1.6	Pediment cut on crumbly pre-Cambrian granite.
63.6	0.5	El Paso gas line.
66.5	2.9	Entering alluvial slope to the Santa Cruz drainage. Post-mineral volcanic hills (Sasco Hills) are to the north; an isolated volcanic knob is to the south.
72.2	5.7	Connection with road crossing. Turn right.
74.6	2.4	Trico Compressor Plant.
79.2	4.6	Connection with cross road. Turn right.
79.7	0.5	Connection with Avra Valley road. Turn left.
85.9	6.2	Casa Grande Highway (freeway). Turn right and return to Tucson.
		NOTE: Alternate route through Red Rock to Tucson. Continue past 60.0 mileage at Cocio Ranch road.
62.1	2.1	Pre-Cambrian granite on the right. Sasco Hills immediately ahead, made of mid-Tertiary volcanics and conglomerate.
65.4	3.3	Ruins of Sasco camp on the right.
65.7	0.3	Ruins of Sasco Smelter on the left.
67.6	1.9	Santa Cruz River (with water, too!)
72.7	5.1	Red Rock. Turn right to connect with Casa Grande Highway to Tucson.



Tucson Office -------------- 792-30
Silver Bell ---------------- 622-675
Mission ------------------- 622-48
Rillito Lime Plant
SILVER BELL
"Avra Valley Road"
24 miles
Casa Grande Highway
10
17 miles
TUCSO
Speed
10
to Ajo
19
89
Twin Buttes Road
Valencia Rd.
16 miles
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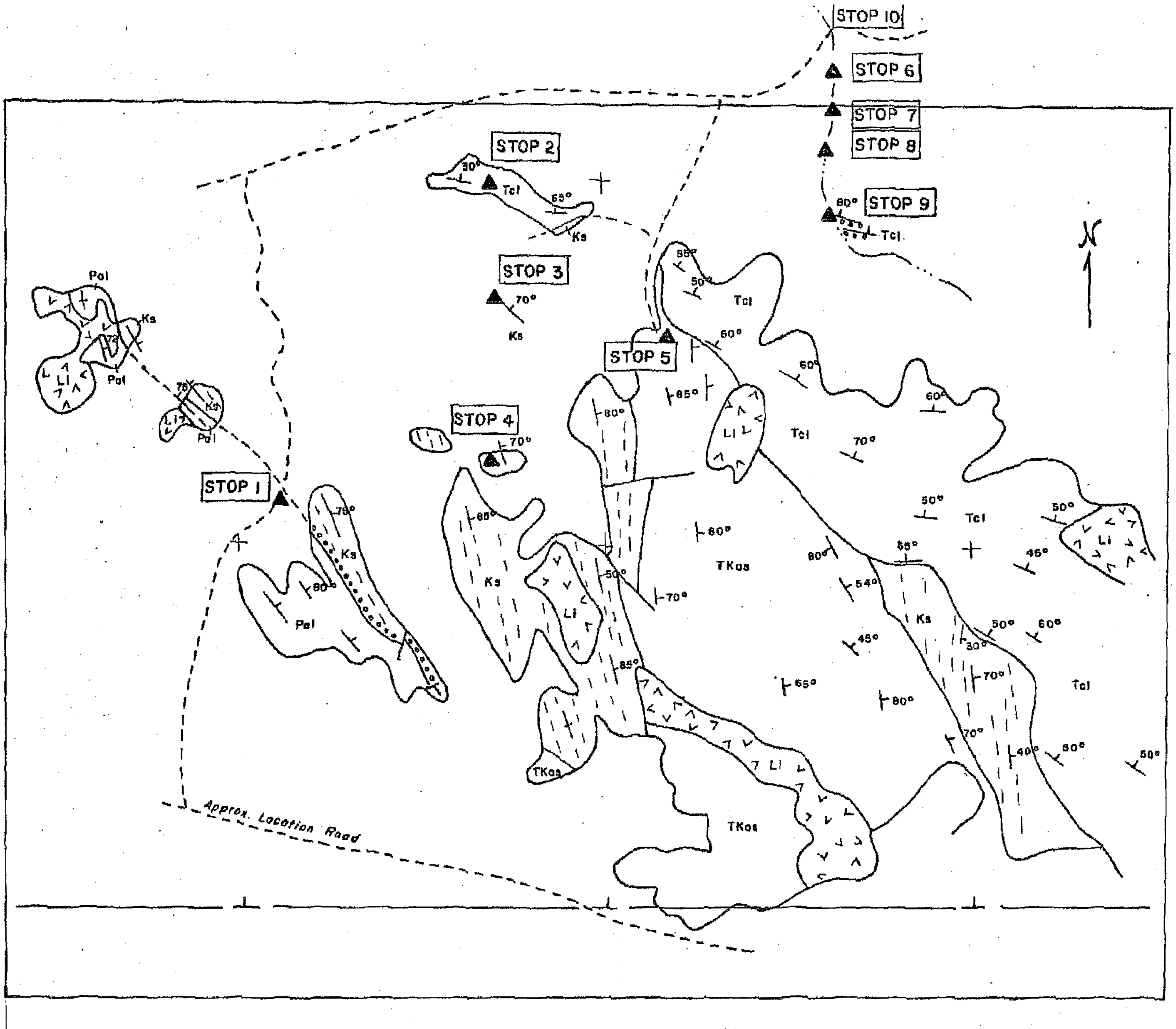
MISSION
miles
"ASARCO"
Steel Tower
Power Line



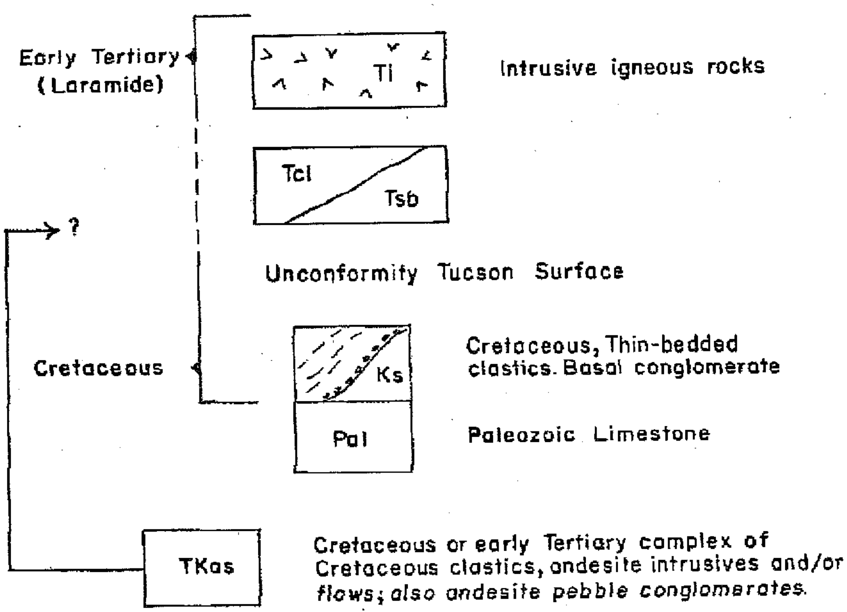
GEOLOGIC MAP

WEST SILVER BELL MTS.

Mod. from Craig W. Clarke, 1965. Pl. 6. Univ Ariz Thesis

Generalized Columnar Section

West Silver Bell Mountains



for A.G.S. Spring Field Trip
1969

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

January 12, 1972

Mr. R. B. Meen
Building

Silver Bell District
Pima County, Arizona

Dear Sir:

Enclosed is a copy of my letter to Mr. Collins recommending a thorough study of the "greater" Silver Bell district. Both Mr. Collins and Mr. Snedden have given their approval for this work. Mr. Snedden requires that the Silver Bell geologist not neglect his normal duties to help the Southwestern Exploration Division and, further, that the Exploration Division will inform Mr. Jameson whenever they will be working on the Silver Bell Unit's ground.

I am assigning Mr. Graybeal to conduct this study and I am sure you, Mr. Jameson and Mr. Cameron will help him in any way you can. Because of the need to find outlets for the acid produced at Hayden, Mr. Graybeal's immediate attention will be placed on the search for and development of oxide copper reserves.

Mr. Graybeal will plan to start work in the Silver Bell District immediately.

Very truly yours,

W. L. Kurtz

W. L. Kurtz

WLK:lad
Enc.

cc: JJCollins - w/o enc.
TASnedden - w/o enc.
JHCourtright - w/o enc.
DRJameson - w/enc.
FTGraybeal - w/enc.
JWCameron - w/enc.

bc: RBCrist - w/o enc.
JDSell - w/enc.

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

December 20, 1971

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

Silver Bell District
Pima County, Arizona

Dear Sir:

For sometime now I have considered that a thorough geological study of the Silver Bell District should be conducted by the Southwestern Exploration Division. For this study I would consider the Silver Bell District to mean a large area surrounding Silver Bell and not just the known, exposed alteration zone.

The purpose of this study is to locate copper targets both within and outside of Asarco's ground. The work within the main district would be coordinated with the Silver Bell Unit and, hopefully, the Silver Bell geologist will have time to aid in this study.

This work would utilize all existing information (geology, drilling, assays, geochemistry, geophysics) coupled with the appropriate field and laboratory work. This in-depth study will point up not only residual targets within the main district, but also new possibilities outside of the main district. The study will be concerned not only with near-surface targets, but also possibilities at depth. Though testing of the deeper targets may not be undertaken at this time, it is an integral part of any thorough study of a major mining district. An important part of this study will be the endeavor to locate oxide copper reserves. As you recall, in our discussion of oxide copper deposits earlier this month, the Silver Bell District was thought to hold one of the best potentials available to Asarco.

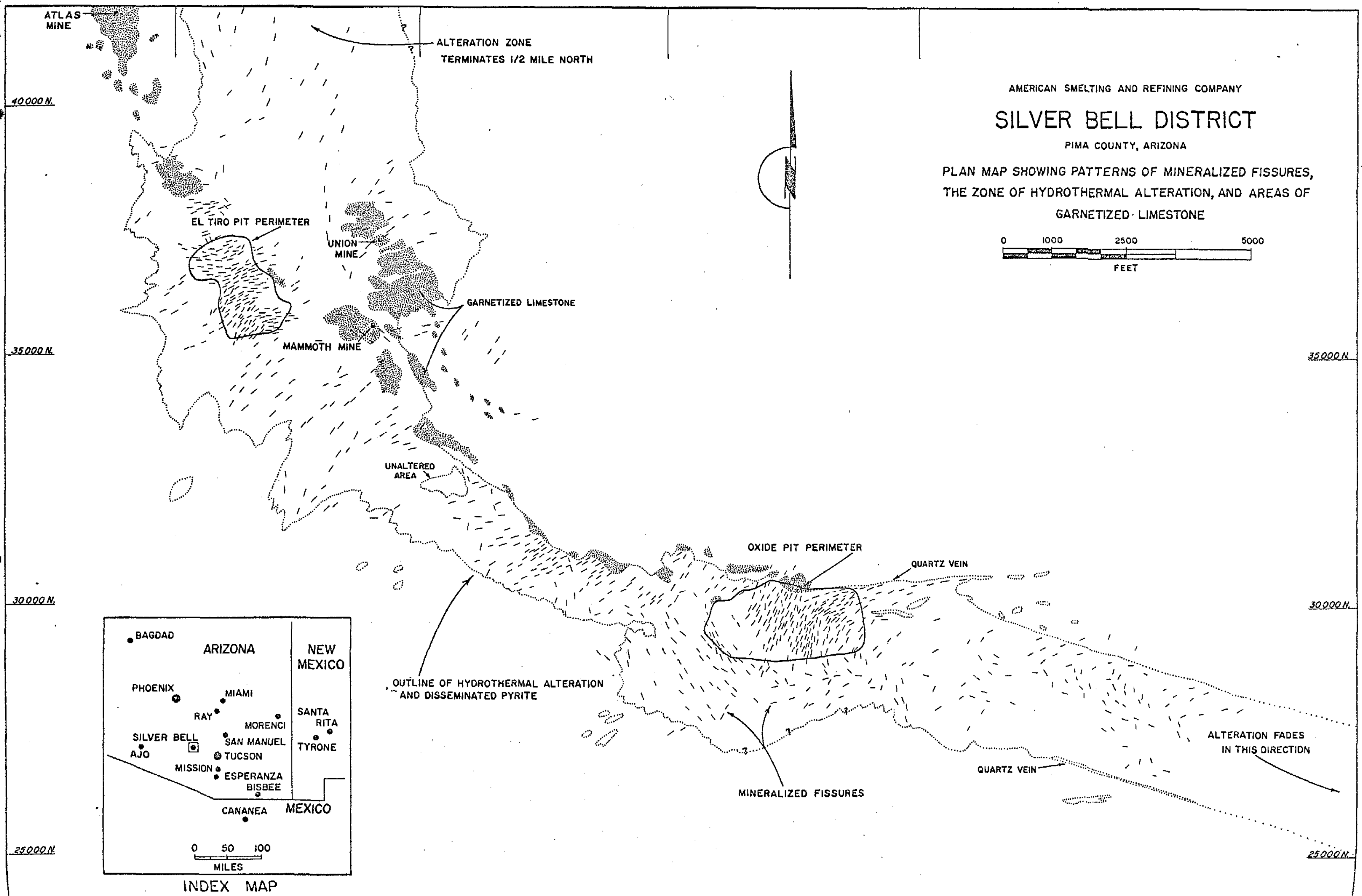
An important outgrowth of this study should be a better understanding of the copper mineralization at Silver Bell, its regional setting, and its similarities and dissimilarities to the Lowell-Guilbert model. The information gained in this study should greatly aid in our continued exploration for porphyry coppers in the southwest.

With your approval, I should like to appoint one of the Division's geologists to this interesting and difficult assignment of a thorough, intensive study of the "greater" Silver Bell District. Since the work will involve a study of the records of the Silver Bell Unit, will you please obtain Mr. Snedden's permission for us to have access to the property and pertinent records.

W. L. Kurtz

W. L. Kurtz

WLK:lad


AMERICAN SMELTING AND REFINING COMPANY
SILVER BELL DISTRICT
PIMA COUNTY, ARIZONA
PLAN MAP SHOWING PATTERNS OF MINERALIZED FISSURES, THE ZONE OF HYDROTHERMAL ALTERATION, AND AREAS OF GARNETIZED LIMESTONE
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ALTERATION ZONE TERMINATES 1/2 MILE NORTH
40000 N.
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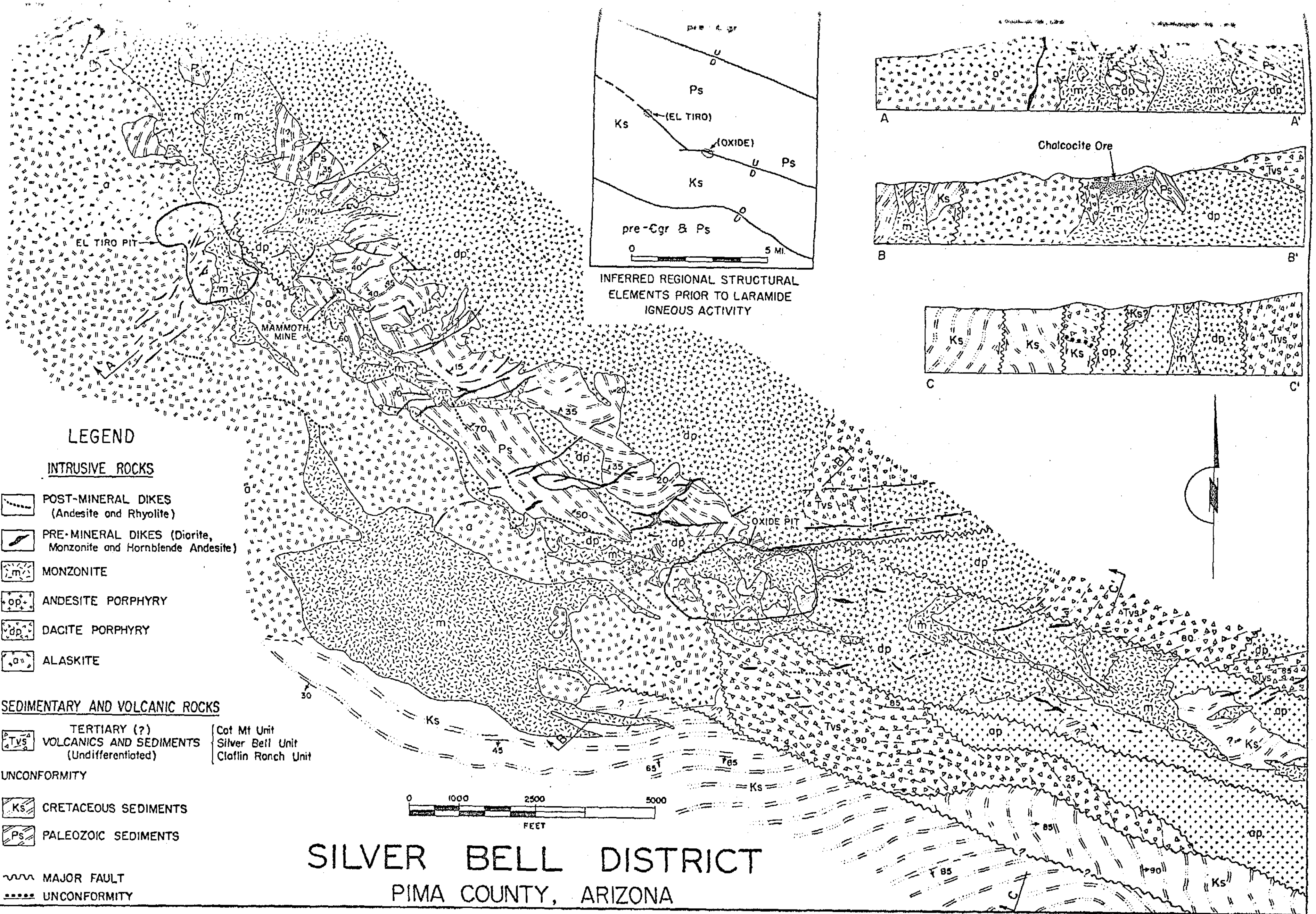
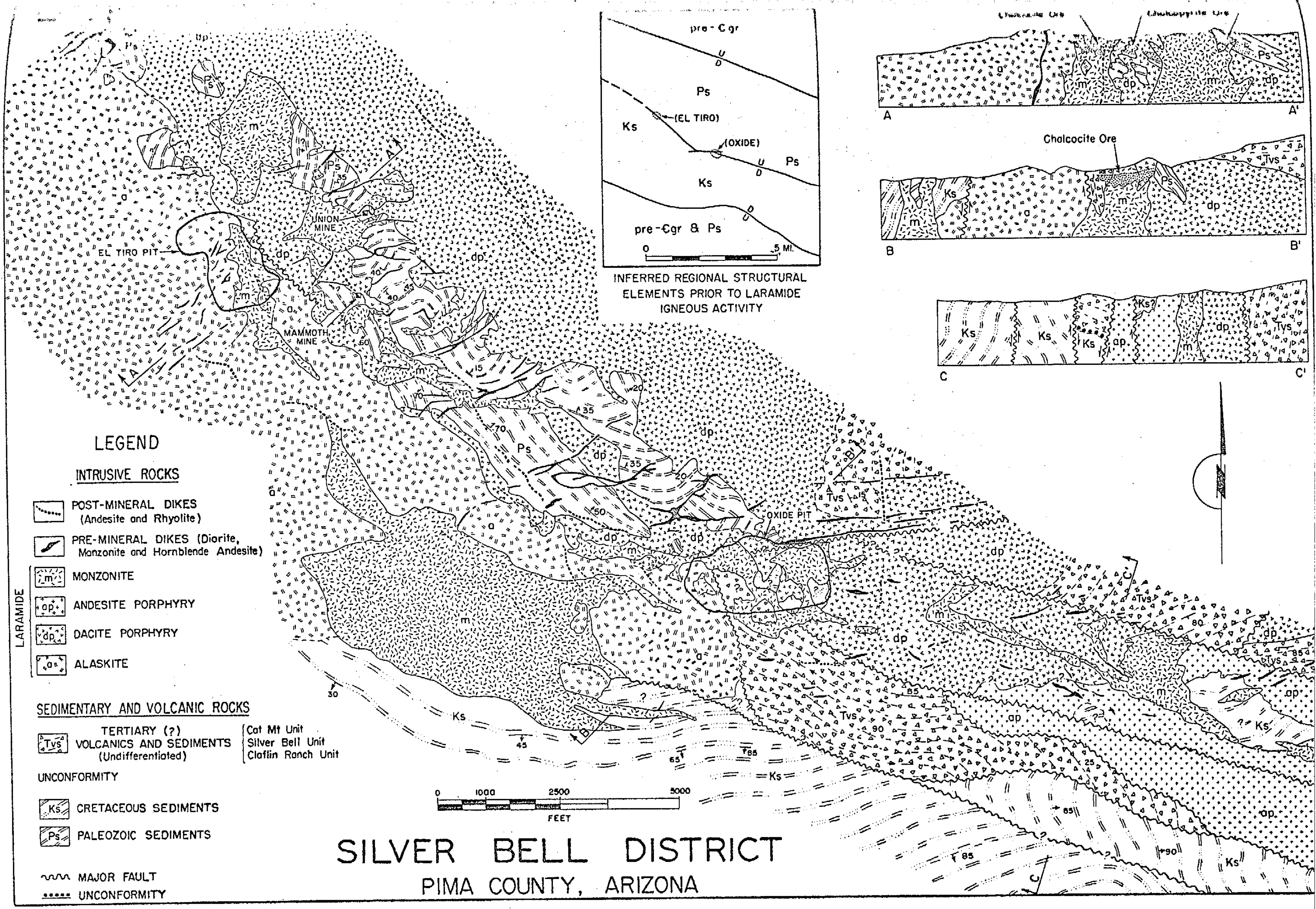
GARNETIZED LIMESTONE
MAMMOTH MINE
UNALTERED AREA
OXIDE PIT PERIMETER
QUARTZ VEIN
OUTLINE OF HYDROTHERMAL ALTERATION AND DISSEMINATED PYRITE
MINERALIZED FISSURES
QUARTZ VEIN
ALTERATION FADES IN THIS DIRECTION
BAGDAD
ARIZONA
NEW MEXICO
PHOENIX
MIAMI
RAY
MORENCI
SANTA RITA
SILVER BELL
SAN MANUEL
TYRONE
AJO
TUCSON
MISSION
ESPERANZA
BISBEE
CANANEA
MEXICO
0 50 100
MILES
INDEX MAP


SILVER BELL DISTRICT
PIMA COUNTY, ARIZONA
LEGEND
INTRUSIVE ROCKS
POST-MINERAL DIKES (Andesite and Rhyolite)
PRE-MINERAL DIKES (Diorite, Monzonite and Hornblende Andesite)
MONZONITE
ANDESITE PORPHYRY
DACITE PORPHYRY
ALASKITE
SEDIMENTARY AND VOLCANIC ROCKS
TERTIARY (?) VOLCANICS AND SEDIMENTS (Undifferentiated)
Cat Mt Unit
Silver Bell Unit
Claflin Ranch Unit
UNCONFORMITY
CRETACEOUS SEDIMENTS
PALEOZOIC SEDIMENTS
MAJOR FAULT
UNCONFORMITY
EL TIRO PIT
MAMMOTH MINE
UNION MINE
OXIDE PIT
0 1000 2500 5000
FEET
INFERRED REGIONAL STRUCTURAL ELEMENTS PRIOR TO LARAMIDE IGNEOUS ACTIVITY
(EL TIRO)
(OXIDE)
pre-Єgr & Ps
0 5 MI.
Chalcocite Ore
A A'
B B'
C C'

URE 2.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(OXIDE)
pre-Cgr & Ps
0 5 MI.
Chalcocite Ore
A
A'
B
B'
C
C'

FIGURE 2.

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

December 4, 1969

TO: J. H. Courtright

FROM: W. G. Farley

Geophysical Surveys
East Silver Bell Area
Pima County, Arizona

On September 5, 1969, a report was submitted to you covering geophysical surveys in the East Silver Bell Area. Attached to that report was a Silver Bell Peak Quadrangle base map with geology after the Arizona Bureau of Mines Pima County Geological Map. Following a review of the East Silver Bell geophysical report, Mr. W. E. Saegart suggested several revisions in the geological base map. Attached to this memo is an updated geological base map of the Silver Bell Area which is to be substituted for the earlier base map. Also attached to this memo is an expanded ASARCO Aeromagnetic Map of the Silver Bell Area.

On the Aeromagnetic Map are also Afmag crossovers from a 1968 McPhar survey which suggest fault locations. Of particular interest are the fault type Afmag anomalies near the Ragged Mt. Fault and the fault type Afmag anomalies over the aeromagnetic low lobe southeast of the Ragged Mt. Fault. These coincident features would tend to confirm the author's earlier interpretation in the September 5, 1969, report suggesting that the aeromagnetic low east of Silver Bell was caused by a southeast extension of the Ragged Mt. Fault Zone having hydrothermal alteration and possibly base metal mineralization.

Another bit of favorable information recently brought forward is an exploration note file by J. D. Sell reporting a shear zone in precambrian granite containing weak alteration and spotty mineralization in the vicinity of the coincident aeromagnetic low lobe and the Afmag crossover. (See attached note file by J. D. Sell.)

At this time additional I.P.-resistivity depth probes are planned for the center of the East Silver Bell Aeromagnetic Low to try and detect sulfides at depth. Also, I.P.-resistivity traverses will be run over the aeromagnetic low lobe in the area reported by Mr. Sell for the detection of possible shallower sulfides. Revision of the author's earlier recommended deep drilling program may follow the additional I.P.-resistivity surveys.

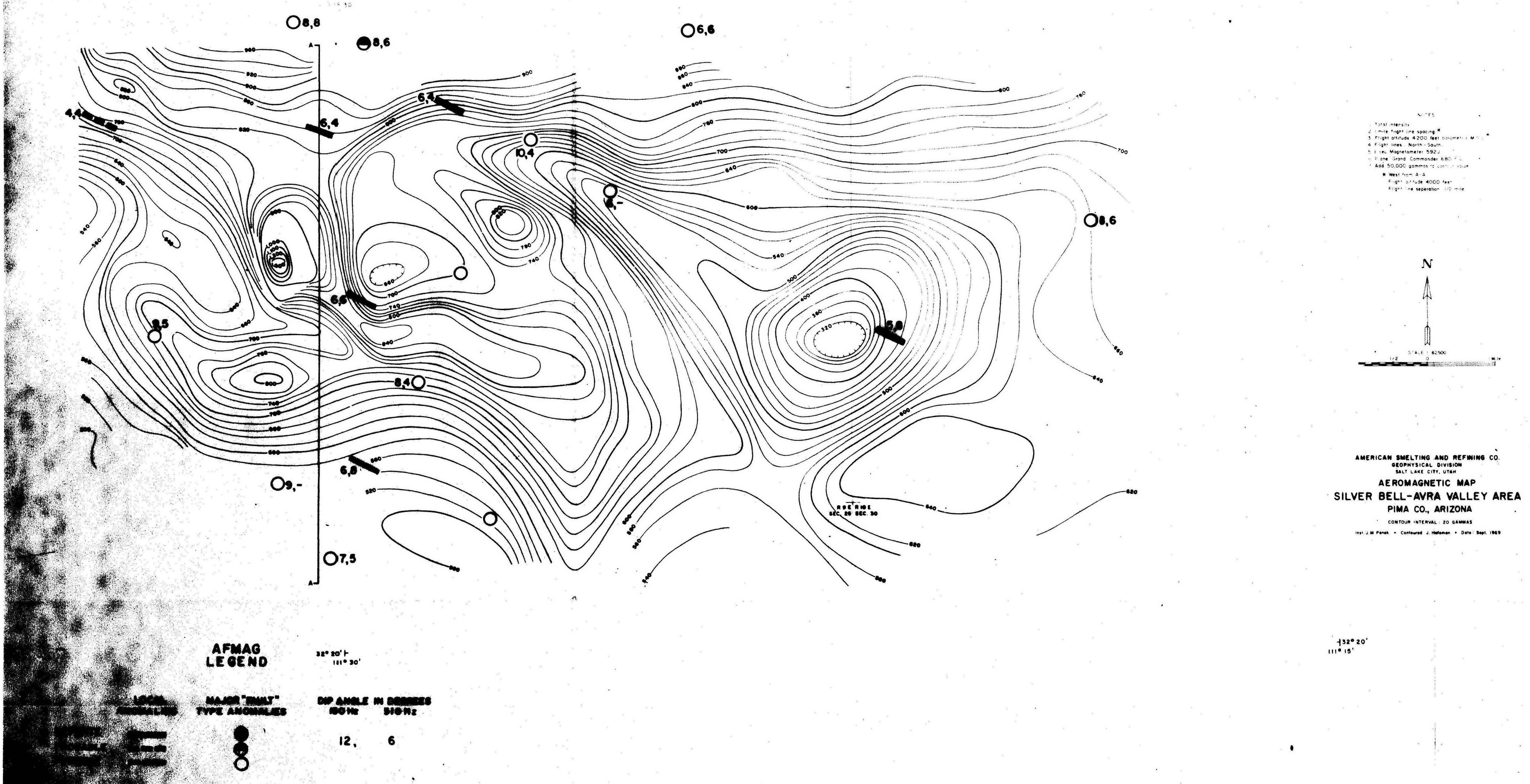
Wayne G. Farley

Wayne G. Farley

WGF/kvs

cc: RJLacy
WESaegart
JDSell


EXPLANATION
QUATERNARY
Qal Valley fill – Sand, silt, gravel
Qb Basalt
TERTIARY
Ts Sandstone, Shale, Conglomerate
Tl-a Latite, andesite
Tl, Tr Latitic, Rhyolitic Intrusives
Post mineralic
Pre mineralic
TKcr Cat Mountain Rhyolite
TKi-al,-d,-gp,-m Intrusives – alaskite (-al), dacite (-d), granodiorite porphyry (-gp), monzanite (-m)
TKa Silver Bell Formation
TKs Claflin Ranch Formation
CRETACEOUS
Ks Amole and Red Beds
CARBONIFEROUS and DEVONIAN
CDl Sandstone, shale, limestone, quartzite
CAMBRIAN
€t Limestone, quartzite
YOUNGER PRECAMBRIAN to TERTIARY
db Diabase
YOUNGER PRECAMBRIAN
p€a Apache group
OLDER PRECAMBRIAN
p€gr Granite, may include some post-p€ intrusives
p€p Pinal schist
Contact (Dashed where approximately located)
Concealed Contact
Fault (Dashed where approximately located)
Concealed Fault
Doubtful or probable Fault
Reverse Fault
Alteration and/or Mineralization
Taken from A.G.S. Southern Arizona Guidebook II
April, 1959 Fig. 45, pg 212
N
PAPAGO
INDIAN RESERVATION
VALLEY
AGUIRRE
R 6E.
R 7E
R 8E.
R 9E
T 11S
T 12S
SILVER BELL AREA
GEOLOGY and TOPOGRAPHY
of
VACA HILLS and SILVER BELL
QUADRANGLES
SCALE : 1 inch = 1 mile
OCTOBER, 1969
W. G. FARLEY
MKB
22-5-A


AMERICAN SMELTING AND REFINING CO.
GEOPHYSICAL DIVISION
SALT LAKE CITY, UTAH
AEROMAGNETIC MAP
SILVER BELL-AVRA VALLEY AREA
PIMA CO., ARIZONA
CONTOUR INTERVAL: 20 GAMMAS
Inst. J.M Panek • Contoured J. Hafeman • Date: Sept. 1969
Flight lines . North - South.
Magnetometer 592J
Add 50,000 gammas
* West from A-A
Flight altitude 4000 feet
N
AFMAG
LEGEND
DIP ANGLE IN DEGREES
12, 6
32° 20'
111° 30'
32° 20'
111° 15'

EXPLORATION NOTE FILE - RECONNAISANCE WES J.H.C.

W.E.S. JAN 8 1969

JAN 7 1969

Location: N ½, Sec. 34
T 11S, R9E
Pima, County

Property Red Hill
Area Silver Bell Peak Quadrangle
District NE Silver Bell
Mt. Range
State Arizona

Field Check by: James D. Sell

Date January 6, 1969

Recommended Company Interest Classification:
- [ ] First Order
- [ ] Second Order
- [ ] Inactive
- [X] None
- [ ] Technical

Conclusion: The coloration is fresh Precambrian granite with only minor aplite zones. No alteration or mineralization was noted, all other rocks surrounding the hill is either volcanic tuffs and flows or alluvium.

Notes on Recconnaissance: Red Hill is fresh Precambrian granite with only minor aplite zones. The granite covers the main hill and extends outward to the west, north, east and goes under the alluvial cover. On the south contour bulge an andesite feeder system and flows cover the granite and dip off to the south. The andesite also covers eastward. Reconnaissance was continued along the roads and float checked at each wash crossing. Specific hill outcrops were visited in the center of Sec. 3 (T 12S, R9E) and the NW ¼, Sec. 4 (T 12S, R9E). All outcrops and float checks showed various volcanic flow rocks with some tuff. The reconn continued northwest along the pipeline road and then cut over to the old Silver Bell Road completing the traverse around Red Hill. Some weakly altered and mineralized granite was found near the center of Sec. 29 (T 11S, R9E) and is reported on a seperate note file.

- [ ] Map Attached

Date January 6, 1969 By James D. Sell

UPDATING THE GEOLOGY AND STRUCTURAL ORE CONTROLS AT SILVER BELL, ARIZONA

by Barry N. Watson
ASARCO Geologist

A talk to be presented to the Mining Geology Division of the Arizona Section of A.I.M.E. on May 20, 1968.

One of the more complete stratigraphic sections in southern Arizona can be pieced together in the Silver Bell area. Much of the geology has been worked out by ASARCO geologists, while a few important areas have been mapped by students as thesis problems. Other portions of the Silver Bell area have yet to be mapped in any kind of detail, and some of this yet-uncharted geology could well be critical to a better understanding of the complex Mesozoic and Cenozoic stratigraphy.

It is my strong belief that a knowledge of certain of the stratigraphic units in the Silver Bell area--their lithologic characters and structural settings--would be of considerable help to field geologists dealing with similar phenomena elsewhere in southern Arizona. Parts of the Silver Bell stratigraphic section are accessible only by washes or somewhat obscure truck trails, and other portions of the section are on, or readily reachable only by passage through, private property owned by ASARCO.

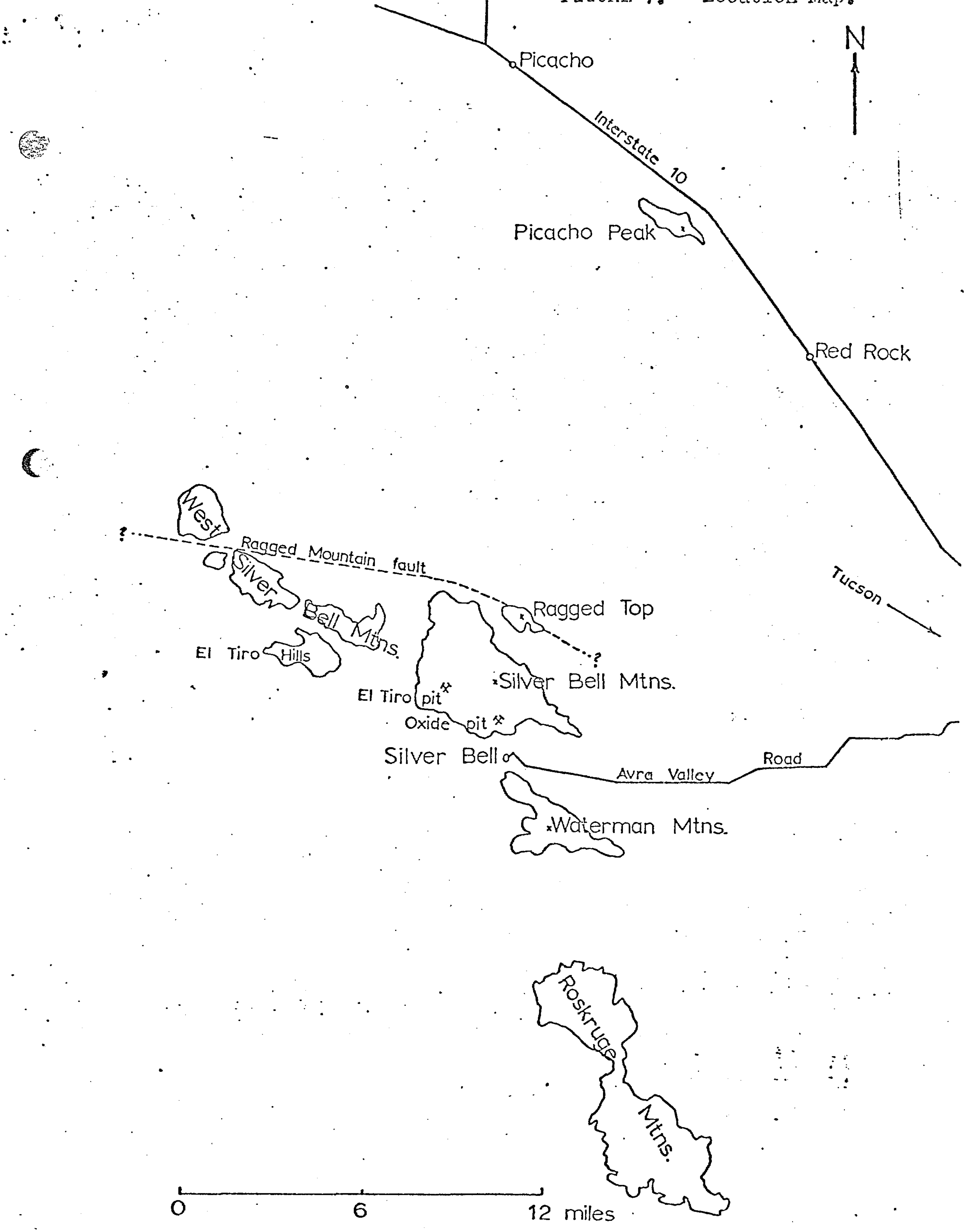
In the following, I will attempt to briefly describe the geologic history of the Silver Bell area, with particular emphasis on the Mesozoic Era. My knowledge of the area has been greatly enhanced through field excursions and conversations with Harold Courtright, Kenyon Richard, Jim Briscoe, Craig Clarke, Chuck Haynes, Nick Nuttycombe, Joy Merz, Fred Graybeal and Dr. Willard Lacy. I must take, however, the responsibility for the interpretations drawn herein.

Figure 1 is a location map showing the principal topographic features mentioned below. Figure 2 is my diagrammatic representation of the Silver Bell stratigraphic column.

PRECAMBRIAN

Pinal Schist

The only outcrop of the basement Pinal Schist known to the author in the Silver Bell vicinity straddles the El Paso Natural Gas pipeline road about two miles east of Ragged Top. Relationships with other rock units are obscured by cover, except on the south where the schist is bounded by a mid-Tertiary dike filling the major WNW-trending Ragged Mountain fault.


N
Picacho
Interstate 10
Picacho Peak
Red Rock
Tucson
West
Ragged Mountain fault
Silver Bell Mtns.
Ragged Top
El Tiro Hills
Silver Bell Mtns.
El Tiro pit
Oxide pit
Silver Bell
Avra Valley Road
Waterman Mtns.
Roskruge Mtns.
0
6
12 miles

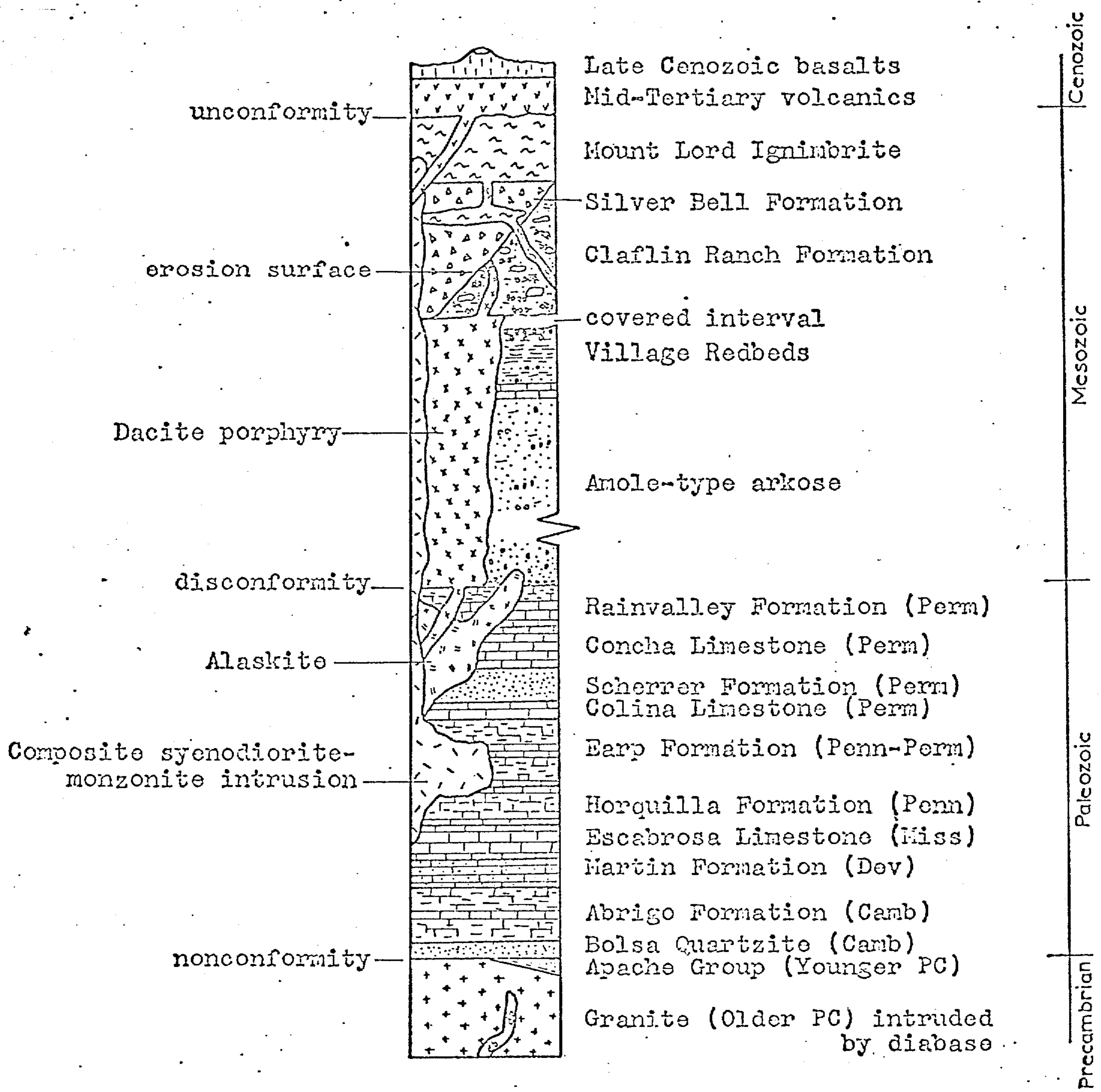


FIGURE 2. Diagrammatic geologic column of the Silver Bell area. Maximum known thicknesses for Paleozoic and Mesozoic rocks are shown. Scale of column: 1"=2000'.

Many fragments (ranging up to boulder size) of Pinal-like schist are seen in Cretaceous sediments just south of Ragged Top, indicating the presence of a considerable area of that schist at the surface in the near vicinity during the Laramide igneous activity.

Granite

A coarse-grained granite is found extensively to the north of the Ragged Mountain fault. Large and numerous quartz grains--frequently.25 inch in diameter--are set among pinkish crystals of feldspar and clumps and books of biotite. In many places orthoclase porphyroblasts up to an inch in length are common. This granite megascopically resembles the Precambrian Oracle granite seen near the town of Oracle.

Paleozoic sediments in the Waterman Mountains southeast of Silver Bell are also underlain by porphyroblastic granite.

Apache Group

Younger Precambrian Apache Group metasediments lie on granite just northeast of Ragged Top. Locally more than 200 feet thick, these south-dipping beds are sharply cut off to the south by the Ragged Top intrusive which wells up along the Ragged Mountain fault. The Apache Group stratigraphy here is not well worked out, but it appears as if a few tens of feet of probable Pioneer Formation (mixed sandy and shaly beds) are overlain by 2-3 feet of Barnes Conglomerate, which is in turn overlain by thin-to moderately thick-bedded quartzites of the Dripping Springs Quartzite.

Apache Group metasediments are missing in the Waterman Mountains where McClymonds (1957) notes Cambrian Bolsa Quartzite to conformably overlie basement granite.

Diabase

Well-altered diabase of possible Precambrian age irregularly intrudes the granite on the northern slopes of Ragged Top. As it is found only within granite, it's relative age cannot be stated with certainty. The principal period of Precambrian diabase intrusion in southern and central Arizona is post-Apache Group.

PALEOZOIC ERA

The Paleozoic stratigraphy of the Waterman Mountains has been deciphered by McClymonds (1957) and Ruff (1951) who mapped a well-faulted pile of limestones, quartzites, siltstones, and shales amounting to a thickness of 4,400+ feet. In the Silver Bell Mountains, Paleozoic stratigraphy was unravelled by Kingsbury, Entwistle and Schmitt in 1941 in a private report to the American Smelting and Refining Co. Merz (1967) undertook the difficult study of the altered and mineralized Paleozoic sediments on Union Ridge east of ASARCO's El Tiro pit. The alteration and mineralization of these Union Ridge sediments will be described in the next paper this morning.

The Paleozoic section in the Silver Bell Mountains is well faulted, locally intensely altered, and generally inundated by various Laramide intrusive units. Although each of the Paleozoic periods represented in the Waterman Mountains also show in the Silver Bell range, the section in the latter is obviously incomplete. A brief tabulation of units with thickness estimates is presented below:

Permian quartzites, limestones, shales	550 ft. approx.
Pennsylvanian Horquilla Limestone	220 ft. max.
Mississippian Escabrosa Limestone	275 ft. max.
Devonian Martin Formation	300 ft. max.
Cambrian Abrigo Formation	430 ft. max.
Cambrian Bolsa Quartzite	230 ft. min.
Total	2,005± ft.

In the El Tiro Hills section of the West Silver Bell Mountains, Clarke (1965) mapped 1,200+ feet of uppermost Permian sediments. Approximately 300 feet of quartzites and dolomitic limestones belonging to the Scherrer Formation are overlain by ±420 feet of Concha Formation Limestone and ±550 feet of Rainvalley Formation limestone and argillite. These Permian rocks protrude from alluvial cover and are overlain by Mesozoic sediments.

MESOZOIC ERA

Amole-type arkose

A clearly exposed contact between Mesozoic and Paleozoic sediments is found in the El Tiro Hills where Clarke (1965) has mapped an estimated 5,000+ feet of probable Cretaceous Amole-type sediments overlying Permian Rainvalley rocks. The basal Amole-type units, lying on a disconformity, is a massive arkosic conglomerate containing rounded quartzite cobbles up to several inches in diameter. This unit of the Cretaceous (?) is several feet thick; the remainder is generally more thinly bedded.

Hayes and Drewes (1968) consider the Amole Arkose of the Tucson Mountains to be more or less a time-equivalent of the lower Middle Cretaceous Bisbee Group sediments. If the Amole-type materials in the El Tiro Hills can be considered correlative with the Amole Arkose, then Clarke's basal quartzite pebble conglomerate qualifies as a far-western equivalent of the basal Bisbee Glance Conglomerate. The presence of Cretaceous (?) beds lying disconformably on the uppermost Permian Rainvalley certainly suggests that the Silver Bell area did not experience, at least locally, the degree of structural unrest manifested farther to the east.

Another interpretation suggested by the near-conformable nature of the Paleozoic-Mesozoic contact related to recent U.S. Geological Survey recognition of Triassic sediments in southern Arizona. Possibly the hiatus between Permian and Mesozoic deposition is not as great as might be thought, and the lowermost Amole-type sediments are of Triassic age?

A few tuffaceous beds are scattered through the Amole-type arkoses, indicating periodic volcanic activity in the general region. Red-colored shales and conglomerates are found here and there through the sequence and are most prevalent in the upper portions. A 20-30-foot thick sandy limestone occurs near the top of the exposed older Cretaceous beds.

The Amole-type sediments are overlain in angular unconformity by interbedded tuffs and coarse clastic sediments of the Claflin Ranch-type. A similar mid-to late Cretaceous unconformity has been noted elsewhere across southeastern Arizona. It is felt that this unconformity reflects initial upheaval related to Laramide deformation.

Amole-type arkoses, conglomerates and sandstones also crop out in the valley between the Waterman and Silver Bell Mountains. Immediately overlying the arkoses near the southeast corner of the older Silver Bell tailings dam is a limestone unit probably exceeding 200 feet in thickness. Donald Bryant of the University of Arizona was able to identify recrystalized pelecypods here as of definite Cretaceous age. Outside of the Bisbee Group Mural Limestone, this localized unit is probably the thickest Cretaceous limestone known in southcentral Arizona.

Village Redbeds and red conglomerates

A sequence of red-colored clastics is found overlying the limestone unit and Amole-type arkoses south of the Silver Bell tailings dams. These clastics, which also underlie Silver Bell village, are locally several hundreds of feet thick, but faulting and alluvial cover prevent thickness determinations. The author originally considered this unit to be an equivalent of the Recreation Redbeds of the Tucson Mountains. However, detailed mapping plus radiometric age-dating have recently proven the Recreation Redbeds to be of pre-Amole age, and evidence is now overwhelming that red coloration represents restricted environmental conditions that could, and do, appear at various times throughout the Mesozoic. Consequently, I am here designating the Cretaceous redbeds and red conglomerates near the Silver Bell townsite the "Village Redbeds".

In places redbeds and light-colored Amole-type arkoses are found interbedded, suggesting a somewhat gradual transition from the Amole to the Village environment. Several hundred feet of red silts, sands and arkoses occur in the lower portions of the Village Redbeds and are seen to grade upward to red conglomerates. At first these conglomerates contain only sedimentary detritus. Higher in the sequence igneous materials begin to appear, however, and in the uppermost known portions the red conglomerate consists almost entirely of purple andesitic fragments set in a detrital matrix. Deformation of an ancient Silver Bell landscape and a gradual increase in volcanic activity is readily evidenced in the continuing deposition of the redbeds and red conglomerates. Thus the transition from normal Cretaceous subaerial sedimentation to coarse and rapid Laramide accumulation is not always marked by an obvious stratigraphic break.

The Village red conglomerates are cut off by a major WNW-trending fault in the tailing pond area, and their relation to overlying units is not presently known.

Claflin Ranch Formation

The Claflin Ranch Formation is something of a catch-all term, and the rocks it represents are not limited to any one specific time of deposition. The formation represents a type of sedimentation associated with a terrane undergoing volcanic upheaval and rapid erosional deformation. Thus, in the Silver Bell Mountains where Richard and Courtright first used the name (1960), the conglomerates, mudflows, landslide blocks, aeolian tuffs, water-lain tuffs and pyroclastic layers included within the Claflin Ranch Formation have ambiguous relationships with associated volcanic units. They are pre-dacite and post-dacite, pre-Silver Bell andesite and post-Silver Bell andesite. In the West Silver Bell Mountains Claflin-like conglomerates are interbedded with pyroclastics and overlie earlier Cretaceous sediments by angular unconformity.

The thickest continuous Claflin Ranch sequence in the Silver Bell Mountains--approximately 1800 feet--occurs southwest of Ragged Top. This accumulation is, at least in good part, pre-dacite porphyry (the earliest of the Laramide volcanic and sub-volcanic rocks in the Silver Bell range). Coarse, greenish clastic materials megascopically identical with parts of the Claflin Ranch Formation are found as a matrix of the Tucson Mountain Chaos in the Tucson Mountains. Claflin Ranch-type rocks also are seen in roadcuts north of Sonoita along Arizona State Highway 83.

It seems reasonable to expect that the Claflin Ranch-type of surface accumulation of detrital and volcanic debris might be found throughout southern Arizona wherever Laramide volcanic piles exist. Such depositional sequences--seemingly thickest in earlier Laramide time--would run the gamut from fairly thin-bedded sands to chaotic masses of landslide-block accumulations.

Alaskite

Richard and Courtright (1966), in accounting for the WNW-striking zone of alteration at Silver Bell, conclude that "indirect evidence suggests a fault representing a line of profound structural weakness existed in this position prior to the advent of Laramide intrusive activity." This line is referred to as the "major structure." They go on to note that this major structure "was largely obliterated by the Laramide intrusive bodies, but it effected a degree of control on their emplacement, as evidenced by their shapes and positions."

The first indication of activity along the Silver Bell fault zone came in early Laramide time with the intrusion of a coarsely granitoid alaskite along the southwest side of the major structure. This alaskite, which contains a very low ferromagnesian mineral content, intrudes Paleozoic sediments and Cretaceous Amole-type arkoses in the El Tiro area. Aplite dikes are found through the alaskite, and, locally, fine-grained border phases of alaskite are found in contact with other rock units.

The alaskite is one of the principal hosts for the later porphyry copper mineralization. This coarse-grained felsic rock locally shows high chalcopyrite-to-pyrite ratios.

Dacite porphyry

The dacite porphyry is a sub-volcanic rock characterized by numerous rounded or triangular quartz "eyes" set in a very fine-grained matrix. Orthoclase and sanidine phenocrysts, vague but consistent flow structure, and up to 20% of xenoliths are also commonly seen. Chemically, the dacite porphyry is more accurately a quartz latite porphyry.

The dacite occurs extensively northeast of the major structure in the form of sills and dikes within Paleozoic and Mesozoic sediments. The largest body of the porphyry--a sill + 3,400 feet thick--occupies the stratigraphic interval in the Silver Bell range proper where Amole-type arkose should occur. This sill is floored by Paleozoic sediments and roofed by an 1800-foot sequence of Claflin Ranch materials. The dacite-Claflin Ranch contact is gradational over several feet, but dikes of dacite porphyry are found locally in the overlying Claflin Ranch beds.

An explosive history for the dacite porphyry is strongly suggested by the numerous xenoliths, the large fragments of quartz, and the shards of former glass in the matrix. The nature of the rock is believed to reflect an emplacement by fluidization in the following manner:

The gas-and fragment-charged dacite porphyry magma (actually quartz latite in composition, suggesting greater viscosity and more explosive potential) rose along the Silver Bell fault zone into Paleozoic strata. The higher the porphyry magma ascended, the more the confining pressure decreased, causing exsolution of gases and thus lending an explosive and dilative nature to the intrusive material.

Its extension to the southwest blocked by the large body of alaskite, the dacite porphyry welled up, sending small dikes and sills northeastward into the Paleozoic beds. Damp Amole-type Cretaceous (?) sediments were reached and more gas evolved. The magmatic material, expanding constantly, spread laterally to the northeast in the weak Cretaceous (?) sediments. Dilation occurred, as did the incorporation of fragments broken by churning gas action.

The dacite porphyry probably surfaced in one or more places, venting gases as it did. Gas also escaped laterally through the just-formed sill and vertically into overlying Claflin Ranch sediments. The heat and vapor action altered the immediately overlying quartzo-felspathic clastic sediments, giving rise to the gradational contact seen today.

The dacite porphyry was a poor host rock for porphyry copper mineralization because of its flinty, "tight" nature.

Silver Bell Formation

The Silver Bell Formation (Richard and Courtright, 1960) consists of laharic, autobrecciated, and intrusive andesitic to dacitic breccias, andesitic to dacitic flows, and andesitic intrusions. These materials overlie Claflin Ranch sediments and dacite porphyry in the Silver Bell Mountains. The rugged nature of the basal Silver Bell contact and the fact that it locally lies on unroofed dacite porphyry points to a period of rapid uplift and erosion following intrusion of the dacite porphyry sills.

Purplish Silver Bell-type breccias are seen to be interlayered in places with overlying Mount Lord Ignimbrite. Such a transition from andesitic activity to more felsic and explosive volcanism is seen throughout the world and is commonplace in the Laramide rocks of southern Arizona and southwestern New Mexico.

It is believed that the Silver Bell Formation is roughly correlative with the Demetrie Formation of the Sierrita Mountains, the Picacho Peak volcanics (Briscoe, 1967), the Owl Head volcanics, and that portion of the Cloudburst Formation north and east of the San Manuel mine.

Mount Lord Ignimbrite

A welded ignimbrite lithologically similar to, and stratigraphically a time-equivalent of, the Cat Mountain Rhyolite of the Tucson Mountains overlies the Silver Bell Formation in the Silver Bell Mountains. This quartz latitic ignimbrite is up to 800 feet thick, including an 80-foot thick cap of lithic vitric tuff. As Silver Bell Peak was formerly known to residents of the area as "Mount Lord" and since the peak is composed of the pyroclastic unit, the name "Mount Lord Ignimbrite" has been given to this Cat Mountain-type unit.

Intrusive ignimbrites--genetically related to the Mount Lord Ignimbrite, and megascopically and petrographically identical with it--occur as dikes and sills in the underlying Silver Bell Formation and dacite porphyry. These feeder materials once en route to the surface spread along bedding and formational contacts, apparently when vents became choked.

The Cat Mountain Rhyolite of the Tucson Mountains evinces an average age of 68 million years (Damon, 1968), and it is felt that the Mount Lord Ignimbrite is of similar age.

Syenodiorite porphyry

The syenodiorite porphyry is an early and somewhat extensive pyroxene-bearing phase of the composite intrusive thought to be related to the copper mineralization at Silver Bell. Later phases of this composite intrusive are monzonitic and quartz monzonitic. The syenodiorite porphyry is found principally in the southeastern portion of the Silver Bell Mountains. It occurs as massive bodies in Oxide pit (where it was previously called both "andesite" and "dacite") and east of Oxide pit along the major structure, and is found as east-trending dikes north of Oxide pit in the mountain range.

The syenodiorite porphyry is the best host rock in Oxide pit. It shows the highest primary copper sulfide content of any of the igenous rocks at Silver Bell and has allowed precipitation of a substantial chalcocite blanket.

Only occasional dikes of syenodiorite porphyry are seen in El Tiro pit.

Monzonite porphyry

The later monzonitic and quartz monzonitic phases of the composite intrusion are found as massive bodies scattered along the major structure. They occur also as generally east-trending dikes in the mountain range to the northeast of the major structure.

The principal porphyry copper mineralization followed emplacement of the monzonite porphyry, and a zone of alteration was superimposed on the major structure. K-Ar age-dating (Mauger, Damon and Giletti, 1965) has shown that the solidification of the monzonite porphyry and the subsequent hydrothermal alteration occurred at approximately 65 million years and within a short enough time span so that, considering the limits of error of the age-dates, the two events are radiometrically indistinguishable. I do not mean to imply here that the Silver Bell deposits are to any great extent syngenetic as has been suggested recently (Mauger, 1966). It may be that a small amount of chalcopyrite became trapped as discrete grains in the monzonite magma at the time of solidification. The great preponderance of copper mineralization, however, was emplaced in the various host rocks through veins, veinlets, and hairline fractures with values diffusing into wallrocks, possibly with the aid of a certain amount of igneous rock recrystallization.

It is interesting to note that both the Oxide and El Tiro orebodies occur at structural intersections (see Figure 3). Oxide pit is located at the junction of the WNW-trending major structure with an ENE-trending swarm of syenodiorite and monzonite porphyry dikes. Similarly, El Tiro pit exists at the junction of the major structure with a northeast-trending swarm of monzonite porphyry dikes.

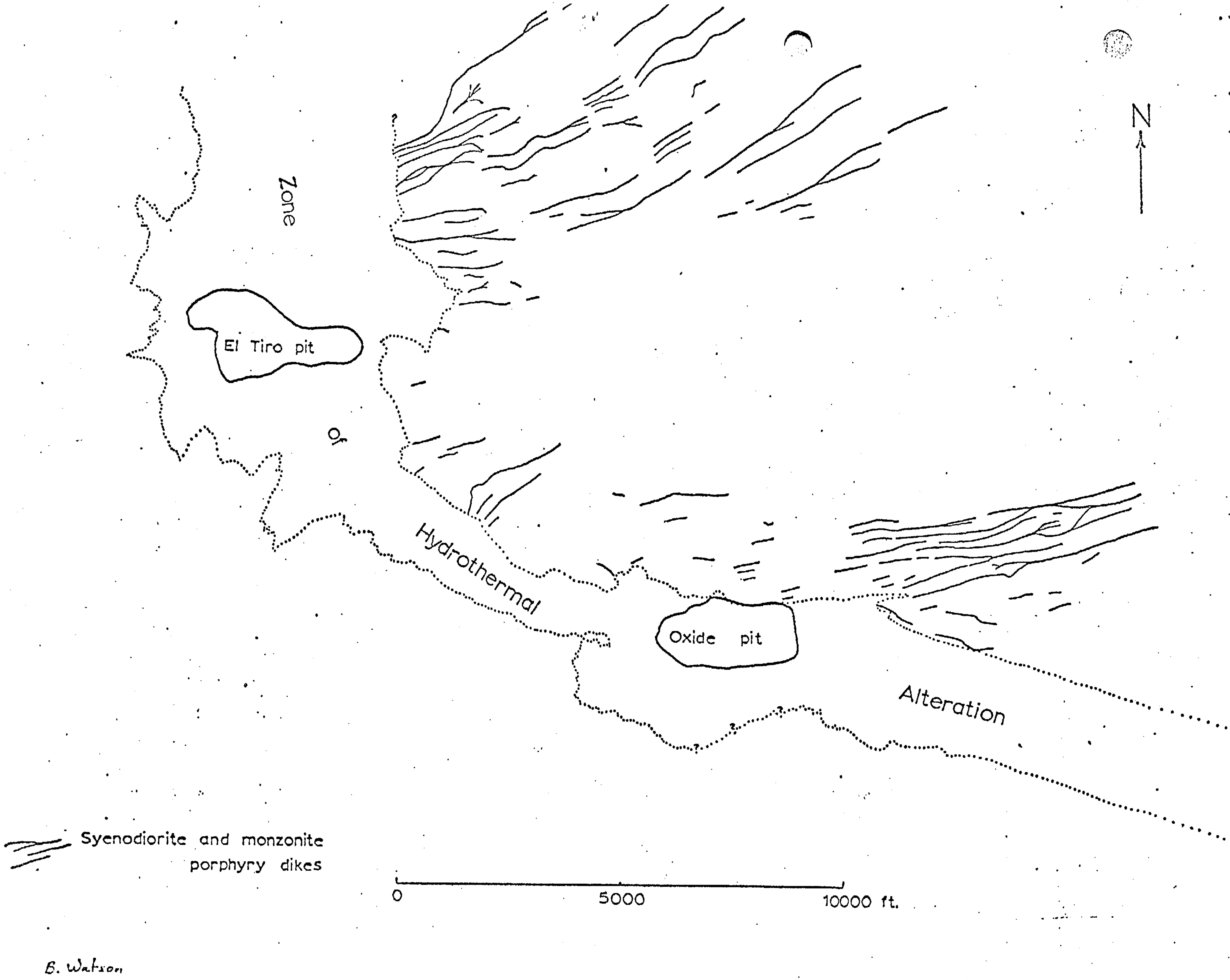


FIGURE 3. Dike swarms related to mineralization at Silver Bell

CENOZOIC ERA

It is preferred here to set the Mesozoic-Cenozoic time boundary at 63 million years as defined by Folinsbee, Baadsgaard, and Lipson (1961). This allows the Silver Bell mineralization to fall at the end of the Cretaceous Period.

Regional northeasterly tilting of 20°-30° occurred sometime between the emplacement of the composite Laramide intrusion and the mid-Tertiary volcanism. It probably was a result of late Laramide upheaval. This tilting, shown by the present orientation of Laramide depositional units, appears to have taken place by rotation of WNW-elongate, fault-bounded blocks in the Silver Bell area.

The mineralized rocks at Silver Bell were exposed to weathering and probably supergene enrichment in early Tertiary time. This is strongly suggested 3 miles east of Oxide pit where pieces of leached capping were found in a conglomerate immediately underlying an andesite flow dated at 28 million years (Damon and Mauger, 1966). A mid-Tertiary period of rhyolitic to andesitic volcanism evinced widely over southern Arizona probably covered and thus preserved the Silver Bell mineralization. This mineralization has been exhumed in more recent times and is presently undergoing destruction through weathering processes.

North-northwest-trending quartz latite porphyry and andesite porphyry dikes of the mid-Tertiary volcanic epoch cut all earlier rock units in the Silver Bell Mountains. The quartz latite dikes have a strangely discontinuous line of outcrop which is caused not by faulting, as has been previously suggested by Schmitt (1941), but by intrusion into a very broken and faulted terrane. A few of the andesite porphyry dikes are conspicuous in El Tiro pit where they are locally collectors of green copper oxide.

The Ragged Top Latite Porphyry dated at 25±1.0 million years (Mauger, Damon and Giletti, 1965) intruded the prominent Ragged Mountain fault which had dropped Laramide rocks on the south some 5,000-7,000 feet against Precambrian granite. Andesitic and rhyolitic flows of probably similar age are seen several miles west of Ragged Top in the northeastern part of the West Silver Bell Mountains.

A late and minor lead-silver-copper mineralization is found in the Silver Bell range. North-trending epithermal veins carrying galena, native silver and cerargyrite with a barite-quartz-calcite-fluorite gangue were mined in the early days. Copper stain is seen on the old dumps. This later period of mineralization has been superimposed very locally on the porphyry copper deposits to the south. On the other hand, a mid-Tertiary quartz latite porphyry dike cuts one of the epithermal veins, thus establishing a general minimum date to this mineralization.

Quaternary-Tertiary basalt cones and flows are found north of the Ragged Mountain fault.

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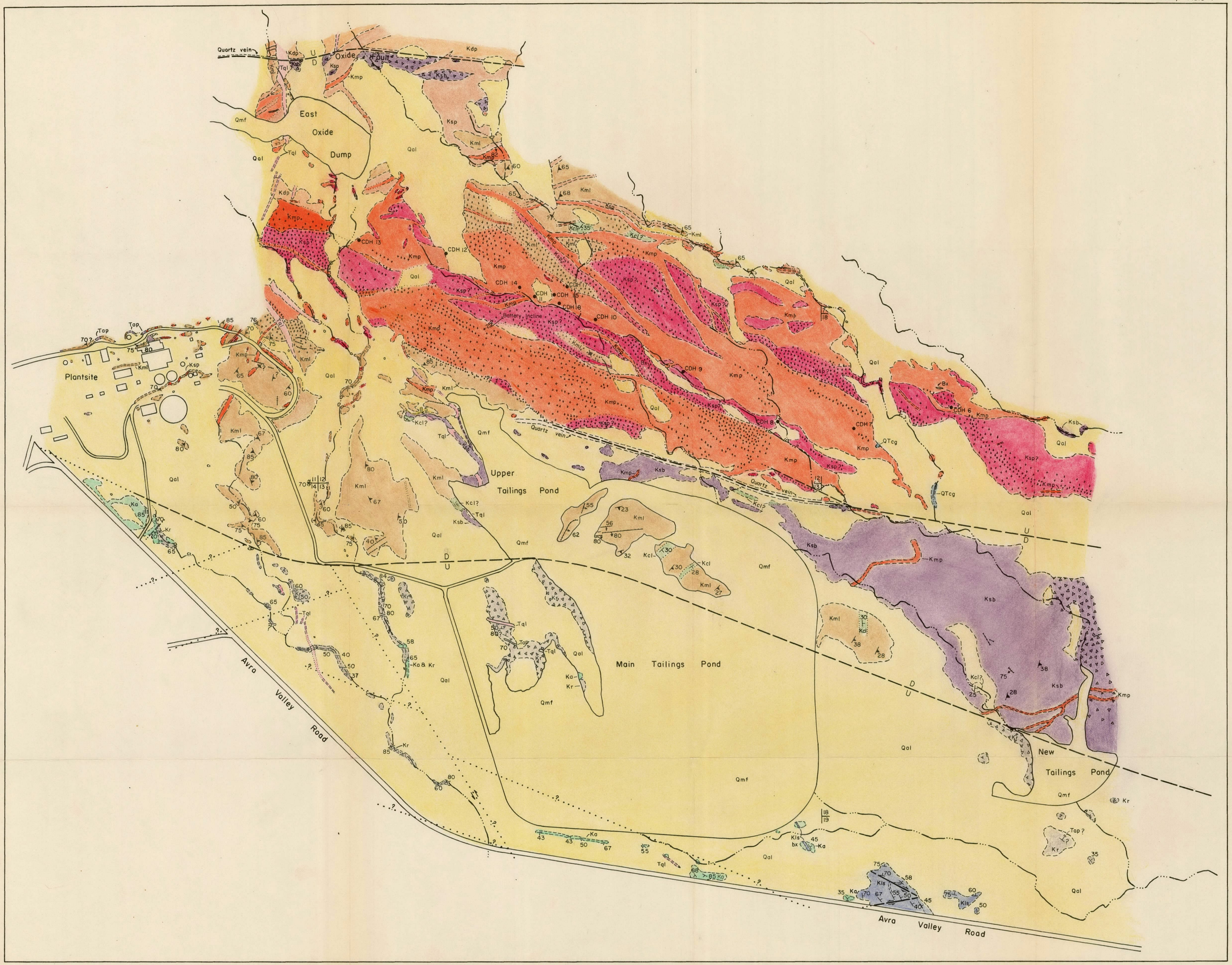

EXPLANATION

Sedimentary rocks

QUATERNARY
- Qmf — Man-made fill
- Qal — Alluvium
- QTcg — Stream conglomerates

TERTIARY

CRETACEOUS
- Kcl — Claflin Ranch formation
- UNCONFORMITY
- Kr — Recreation-type redbeds, red conglomerates
- Kls — Limestone
- Ka — Amole-type arkoses, conglomerates

Igneous rocks

- Tql — Quartz latite porphyry dikes
- Tap — Andesite porphyry dikes
- Kmp — Monzonite porphyry stocks, dikes
- Ksp — Syenodiorite porphyry stocks, dikes
- Ksp? — Probable Ksp, but alteration makes indistinguishable from earlier andesite porphyries
- Kml — Mount Lord ignimbrite
- Ksb — Silver Bell complex — breccias, flows, intrusions
- Kdp — Dacite porphyry

Contact — dashed where approximate, dotted where concealed

High-angle fault — dashed where approximate, dotted where concealed (U / D)

57 — Strike and dip of beds

73 — Strike and dip of overturned beds

23 — Strike and dip of foliation

Mineralized structure (quartz and or calcite)

Silicification

CDH — Old 'Mudd' churn drill holes

11|12 / 14|13 — Section corner

True North

AREAL GEOLOGY

of Area East of Oxide Pit

Silver Bell, Ariz. A. S. & R. Co.

Scale 1" = 500' May, 1965

B. N. Watson

1757

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

March 7, 1973

FILE MEMORANDUM

AMAX Drilling
Silver Bell East Area
Pima County, Arizona

Mr. Bud Himes of Himes Drilling Company, Grand Junction, Colorado, was in yesterday to relate that he had a Gardner Denver 1500W with air package and two Longyear 44's available for work.

He stated that he had recently completed three rotary holes, some to 2000 feet, for AMAX east of Silver Bell on the gas line road. After setting 3-1/2" pipe, his core rigs are now coring below the rotary hole bottom. He did not relate at what depths he is presently drilling, but said he had cored to 4000-4700 feet NX with the rigs.

Himes Drilling Company was involved in some of the Monticello, Utah uranium work of ASARCO.

James D. Sell

James D.Sell

JDS:lb

cc: HLCrittendon

AMERICAN SMELTING AND REFINING COMPANY
TUCSON ARIZONA

July 26, 1974

FILE MEMORANDUM

Silver Bell District
Pima County, Arizona

Freeport Minerals hired Kenyon Richards to review with them and Jim Briscoe Briscoe's ideas of the extension of the Silver Bell alteration zone (offset to the south along the "cemetary fault"). Apparently Kenyon is more intrigued with the idea now than he was a number of years ago.

When they discovered our NWS claims, Briscoe couldn't believe anyone would stake that ground for mineral potential. Kenyon was non-committal.

W. L. Kurtz

WLK:lb

cc: JHCourtright
FTGraybeal
JDSell

West Silver Bell Mtns

Aug. 13, 1974

WLK.

Yes, NJ Zinc drilled one 500 foot vertical hole via down-the-hole hammer in ± 1965.

Bolmer said it was low down on the edge of the hill below the shaft (pits)? on edge of outcrop. Drilled in the intrusive (for most part). Drilled on magnetic anomaly – not enough magnetite in hole to satisfy anomaly.

Bolmer thinks NJZ would trade data.

He also thinks Humble came in several years ago (on Briscoes claims?) and did abundant IP, large block, numerous validation holes – some probably fairly deep.

JDS

AMERICAN SMELTING AND REFINING COMPANY
TUCSON ARIZONA

August 14, 1974

FILE MEMORANDUM

West Silver Bell
Sec. 34

Bob Radabaug in a telephone conversation stated that the NJ2 hole is located about 1500 feet due west of the shaft. They no longer have any cuttings. An abbreviated log is:

0-20	Qal
20-195	Dacite porphyry, quite fresh, no min. mod. magnetite
195-505	Rhyodacite flow, fresh, no min. mod. magnetite

Water encountered at 430'. Sufficient magnetite to account for the anomaly.

He has a more detailed log if we want to see it. There is mention of epidote, and some zones being more siliceous.

W.L.K
W. L. Kurtz

WLK:lb

cc: JHCourtright
JDSell ✓
FTGraybeal

Happy Jack Mines, Inc.
Waterman Mtns., Ariz.
(old Indiana - Ariz)

owned by:
H. L. Jones
Leonard Beitgen

They will be in mid-week of
Dec. 5.
Want ASARCO to review the
property - our last chance
Doing some cat work - will
do diamond drilling in Jan.

To FTG

Date 12/13 Time 10:15

WHILE YOU WERE OUT

M Harlow Jones HL

of prob. Tho 21st

Phone 505-265-2994

Area Code Number Extension

TELEPHONED	✓	PLEASE CALL	✓
CALLED TO SEE YOU		WILL CALL AGAIN	
WANTS TO SEE YOU		URGENT	

RETURNED YOUR CALL

Message Take Selig Bell Peak Quad See Spirit Hat, notebook etc.

Operator Lois

No. 2725 S Clark Office Products Phone 298-2374

Waterman Mtns

Leonard Bestgen
(303) 471-3966

ASARCO

Exploration Department
Frederick T. Graybeal
Chief Geologist

July 27, 1983

Mr. J. D. Sell, Manager
Southwestern U.S. Division
Tucson Office

Regional Structural Control of
Mineralization at Silver Bell

Dear Mr. Sell:

I have your note of July 13 which resurrects the hypothetical caldera setting at Silver Bell. I have wondered about this for the past 20 years or so and am not the first one as you note. Control of the alteration at Silver Bell by a ring structure is certainly a possibility particularly in view of the vast volumes of volcanic rock which must have generated some type of collapse phenomenon subsequent to eruption. In addition, because Silver Bell is eroded to moderate depth, it is likely that the perfectly circular symmetry common in high level calderas might become distorted by basement structures and one could therefore argue that the lack of perfect symmetry at Silver Bell is merely a function of depth.

The major structural feature between Oxide and El Tiro pits is a healed fault structure which separates alaskite and Mesozoic sedimentary rocks on the southwest from Paleozoic sedimentary rocks to the northeast. This line can be seen on the hydrothermal alteration map prepared by Richard and Courtright as it follows the southwestern limit of silicated limestone. It is interesting that this very fundamental structure actually cuts across the alteration zone in the El Tiro area rather than running parallel to it even though the structure is of pre-mineral age. It is likely that the near north-south orientation of the alteration zone between El Tiro and north Silver Bell follows a swarm of high level quartz monzonite porphyry stocks which, in this area, have a nearly north-south elongation. On a larger scale, however, when the alteration zone is traced farther to the north beyond the limits of the Richard and Courtright map it actually bends back to the west again taking the shape of a giant cymoid loop with the El Tiro area in the bend of the loop.

I want to emphasize very strongly that the northeast-striking veins at Silver Bell do not follow pre-existing structures. They are the structures and probably formed by a phenomenon similar to hydraulic fracturing. The same also applies to the quartz monzonite porphyry and monzonite porphyry dikes extending northeast from El Tiro pit. It is important to recognize that the El Tiro area does not owe its location to pre-ore northeast-striking structures, but rather to an intersection of a northwest structure and a north-south structure. The northeast structures in the El Tiro area and elsewhere within the alteration zone at Silver Bell are all syn-ore.

Very truly yours,

F. T. Graybeal

F. T. Graybeal

cc: WLKurtz
JHCourtright

ASARCO

Southwestern Exploration Division

JDS

July 13, 1983

File Memorandum

Comparison of Silver Bell, AZ
Fault Pattern with
Goldfields, NV

Mr. David Sawyer, University of California, Santa Barbara, doing a Ph.D. dissertation in the Silver Bell region, remarked in his visit to this office in June that perhaps a caldera setting was possible at Silver Bell. Such a feature has been suggested in the past but I cannot recall any serious writings on the problem.

It is interesting to compare the Ashley Figure 1 (attached) of the fault pattern of the Goldfield, NV District, with that of Richard and Courtright (Figure 1 attached) of the mineralized zone at Silver Bell, AZ. I have sketched on the equivalent portion of the Silver Bell zone onto the Goldfield map.

Note the curving sweep of the El Tiro-oxide zone tailing eastward with the intense northeast fracture zones controlling the location of the orebodies, with that portion of the Goldfield zone. The Goldfield ore zone is also essentially where the northeast faulting intercepts the sweep of the curving fault pattern on the west to southeast.

Also attached is Figure 8, Ashley, showing the hydrothermal altered and ore-bearing areas at Goldfield.

In both cases--Goldfield and Silver Bell--the major deposit(s) found to date are at the northeast fracture junction with the inflection portion of the sweeping curve; equivalent to the southwest portion of a caldera root system.

James D. Sell

James D. Sell

JDS/cg

cc: JHCourtright

bxc: FTG, WLK, DSawyer

Reference

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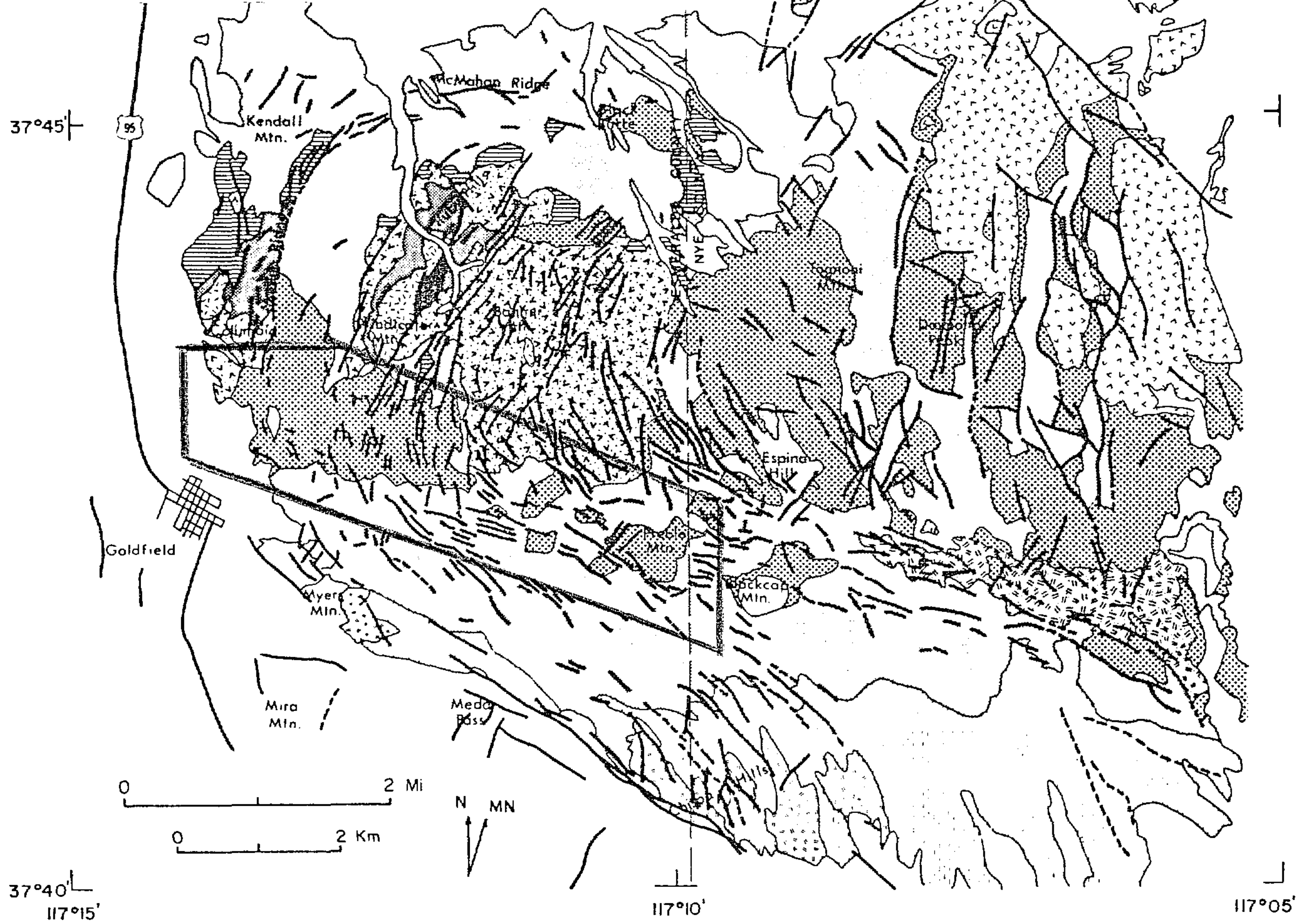


Figure 1. Generalized geologic map of the Goldfield mining district.

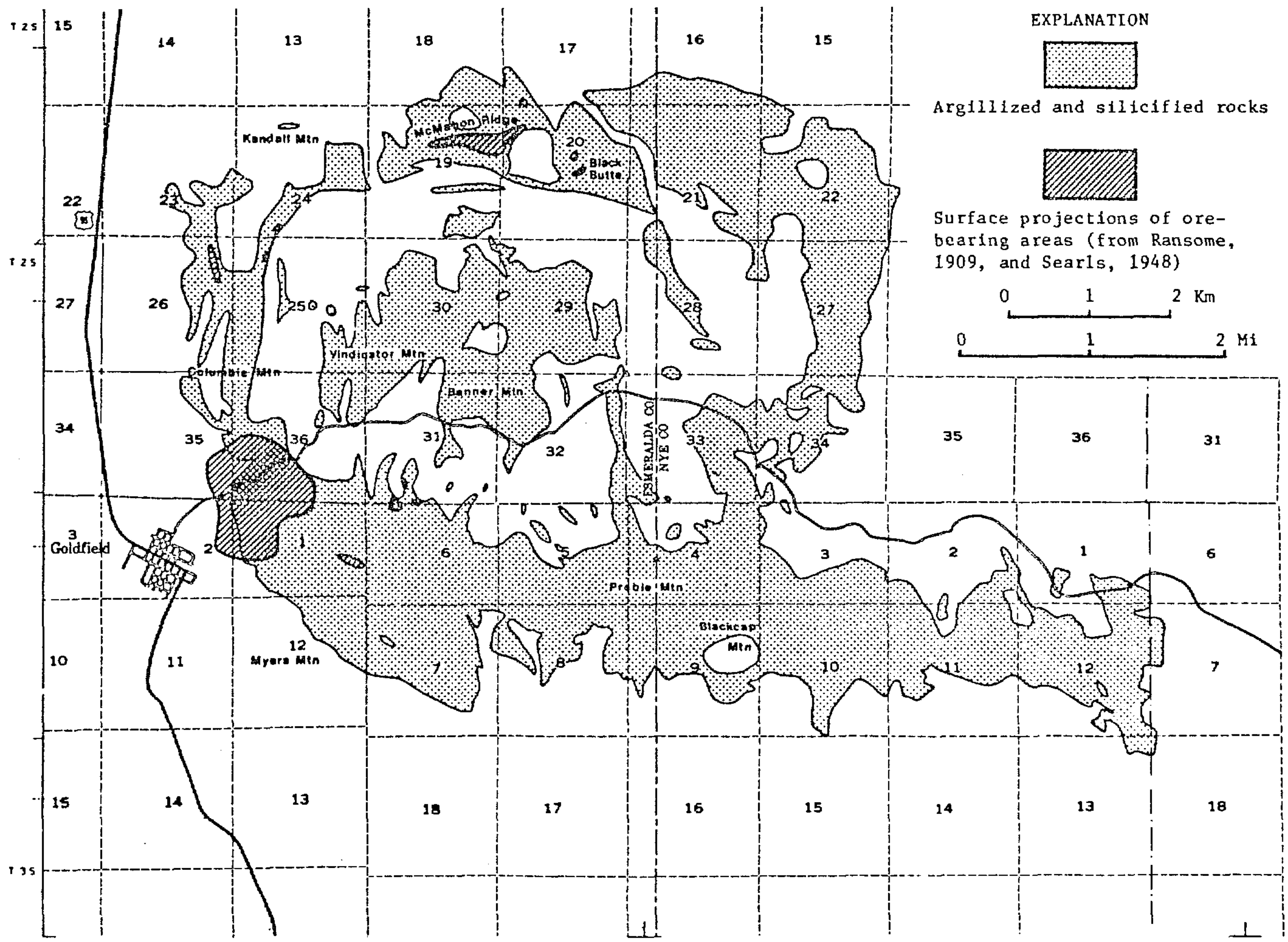
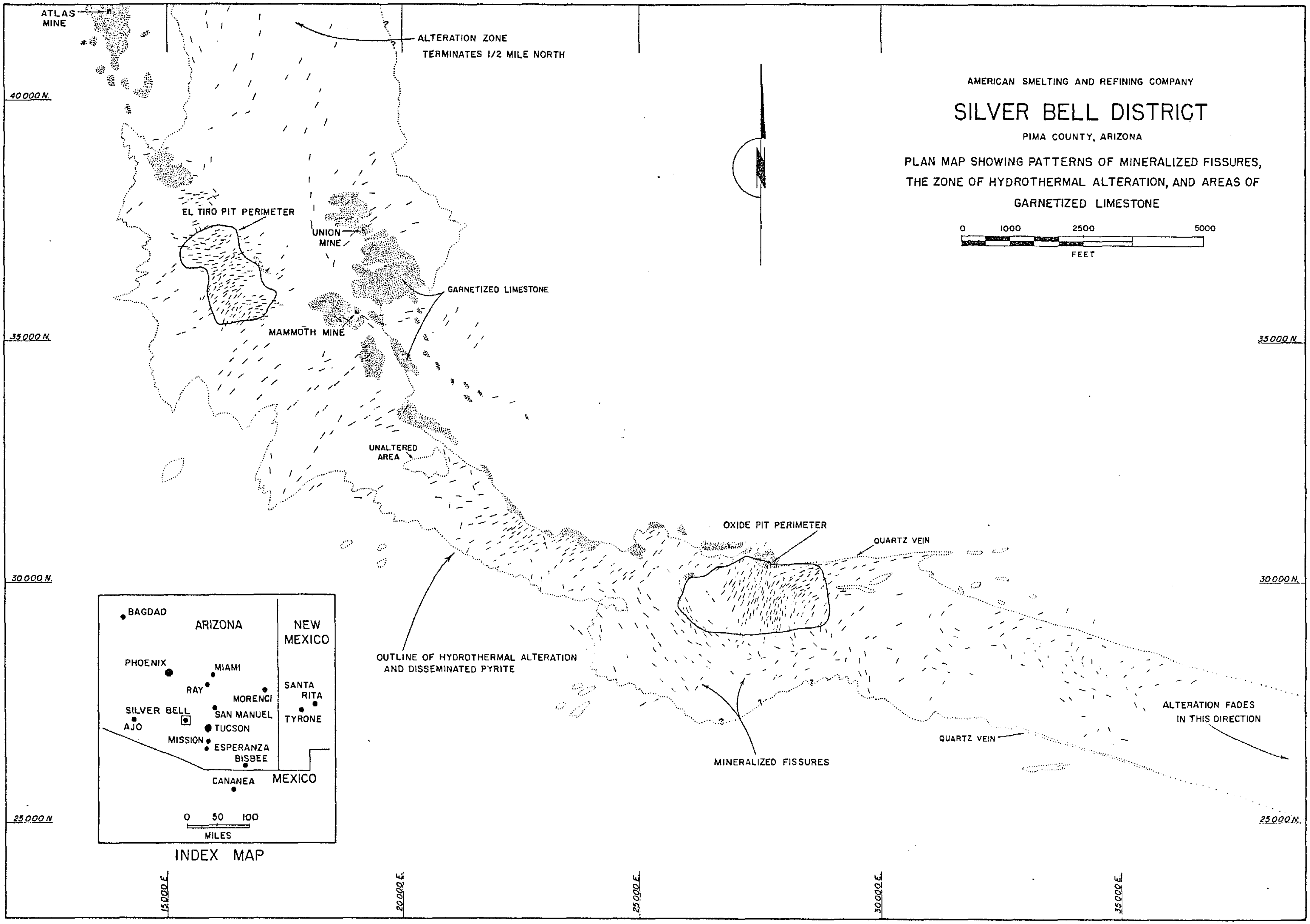


Figure 8. Hydrothermally altered and ore-bearing areas



AMERICAN SMELTING AND REFINING COMPANY
SILVER BELL DISTRICT
PIMA COUNTY, ARIZONA
PLAN MAP SHOWING PATTERNS OF MINERALIZED FISSURES, THE ZONE OF HYDROTHERMAL ALTERATION, AND AREAS OF GARNETIZED LIMESTONE
0 1000 2500 5000
FEET
ATLAS MINE
ALTERATION ZONE TERMINATES 1/2 MILE NORTH
EL TIRO PIT PERIMETER
UNION MINE
GARNETIZED LIMESTONE
MAMMOTH MINE
UNALTERED AREA
OXIDE PIT PERIMETER
QUARTZ VEIN
OUTLINE OF HYDROTHERMAL ALTERATION AND DISSEMINATED PYRITE
MINERALIZED FISSURES
ALTERATION FADES IN THIS DIRECTION
QUARTZ VEIN
40 000 N.
35 000 N.
30 000 N.
25 000 N
15 000 E.
20 000 E.
25 000 E.
30 000 E.
35 000 E.
BAGDAD
ARIZONA
NEW MEXICO
PHOENIX
MIAMI
RAY
MORENCI
SANTA RITA
SILVER BELL
SAN MANUEL
TYRONE
AJO
TUCSON
MISSION
ESPERANZA
BISBEE
CANANEA
MEXICO
0 50 100
MILES
INDEX MAP

Figure 1.

ASARCO

Southwestern Exploration Division

JDS Copy

December 13, 1983

To: SAAnzalone
RBCummings
FRKoutz
HGKreis
WLKurtz
GJStathis
JRStringham

From: JDSell

Dave Sawyer will present a talk on his dissertation work - "Volcanic Geology of the Silver Bell Mountains" - in the 3rd floor Conference Room at 9:30 a.m. on Wednesday, December 21, 1983. I hope you can attend.

J. D. Sell

JDS/cg

SOME CRETACEOUS-TERTIARY RELATIONSHIPS IN SOUTHEASTERN ARIZONA AND NEW MEXICO

By

Kenyon Richard and J. H. Courtright

American Smelting and Refining Company

In Courtright's (1) report on this subject it was pointed out that the presumed age of certain volcanic rocks described in the literature as Cretaceous was subject to question. It was concluded that the field evidence in the Silver Bell, Stanley, Winkleman-Christmas and other areas indicated that the rocks which frequently have been mapped as Cretaceous volcanics are distinctive in character, being composed predominantly of andesite breccia of probable volcanic-mud-flow origin, and are not interbedded with sediments of certain or probable Cretaceous age. Instead, they are resting on an erosion surface cut in deformed Cretaceous and older sediments, and are probably early Tertiary in age. These andesitic rocks are locally termed the "Silver Bell" formation. Field information accumulated since the first report expands and lends further support to these concepts.

The accompanying chart which covers nine localities, including five of those previously reported, shows postulated age relationships and correlations based on lithology and stratigraphic position. We are aware of the great distances between some of the observation points, and admit a deficiency of supporting detail. Nevertheless, we believe these correlations merit consideration.

The presence of igneous pebbles (most andesitic porphyries) in some Cretaceous beds in southern Arizona suggests contemporaneous or earlier igneous activity somewhere in the region. However, we contend that volcanism on a widespread scale did not begin until after the destruction of Cretaceous sedimentary basins had started, and that the age of these eruptions is most probably early Tertiary.

The principal purpose of this paper is to call further attention to the problem and to encourage the undertaking of critical field studies.

DESCRIPTION OF PRINCIPAL OCCURRENCES

Silver Bell

Recent field studies have determined that the "Silver Bell" formation is underlain by a thick series of clastic beds termed the "Claflin Ranch" formation. From their composition it may be judged that the arkoses of this formation were derived in part from erosion of underlying dacite agglomerate; some beds are conglomerates which contain abundant arkosic fragments derived from probable Cretaceous rocks, while others contain much schist and andesite. Enclosed within these thin- to thick-bedded clastics are a few angular blocks of "Cretaceous-type" arkose as much as 10' in length, and a few blocks of andesite-schist conglomerate over 50' in length and 25' in thickness. Except for the absence of large limestone blocks, this formation resembles Kinnison's (2) Tucson Mountain chaos as it is exposed 1/2 mile south of Gates Pass.

The "Silver Bell" formation consists largely of angular to sub-rounded fragments of andesite in a mud-like andesitic matrix. It unconformably overlies the "Claflin Ranch" formation and in turn is overlain by welded pyroclastics which are lithologically identical to the Cat Mountain rhyolite in the Tucson Mountains.

South Tucson Mountains

Except for the absence of the "Silver Bell" formation, the sequence here is similar to that in the Silver Bell district.

AGS Digest III, March 1960

As described by Kinnison, the Tucson Mountain chaos is a giant breccia --unusually large rock blocks in a clastic matrix--that was deposited on an early Tertiary(?) erosion surface (the Tucson surface). Parts of this formation, and also a series of andesite-pebble conglomerate beds in the Piedmontite Hills, had previously been mapped by Brown (3) as Cretaceous volcanics. A recent study of the Piedmontite Hills was made by Colby (4) who reported the occurrence of a rhyolite tuff in these clastics. The field evidence indicates to us that this rhyolite is an intrusive rather than a pyroclastic.

At this time none of the volcanics of the Tucson Mountains can be demonstrated to be Cretaceous. Locally, andesite underlies the Tucson Mountain chaos; the relationship to older rocks is not definitely known, but we believe that it is most probably post-Cretaceous.

South Twin Buttes District

A considerable thickness of the Silver Bell-type formation is well exposed southeast of the Esperanza mill. From west to east, massive andesite flows and "clastic" breccias pass into unsorted, coarse conglomerates made up of angular to sub-rounded andesite fragments and well rounded boulders of granite, quartzite, and other rock types. A few thin, pebbly beds are present. The formation is overlain unconformably by rocks of the Cat Mountain rhyolite type. Its basal relations in this area are not known.

Southwest Sierrita Mountains

Massive andesite breccias of the Silver Bell type are underlain by Precambrian (?) granite and overlain by a fragment-bearing rhyolitic formation which may correlate with the Cat Mountain rhyolite of the Tucson Mountains. Both contacts appear to be erosional unconformities.

Southwest Empire Mountains

Galbraith (5) recognizes two major units (northern and southern) in the Cretaceous(?) beds below the thrust fault on the west side of the Empire Mountains. Of the southern series, he states: "Their relationship to the other Cretaceous(?) strata is not known, but they are presumably younger than the arkosic sandstone and shale, because they contain numerous fragments of arkosic rocks which appear to be identical with those exposed to the north. This series may in part be as young as Tertiary in age." This implies that an unconformity may exist between these two series.

This unconformity is exposed in a south fork of Barrel Canyon, three quarters of a mile S60E from Barrel Springs. There, steep-dipping arkose and shale beds terminate against a thin arkosic bed containing scattered pebbles and boulders of arkose, andesite and other rock types. This sharply angular unconformity, near vertical in dip, is visible on both sides of the canyon. The thin arkose bed passes stratigraphically upward into a coarse, unsorted conglomerate 100 feet or more in thickness, and then into andesite breccia of the Silver Bell type. The contact with the latter is not well exposed; but on the north slope of a ridge about a mile and a quarter N75W of the Martinez Ranch, the andesite breccia can be seen unconformably overlying arkose boulder conglomerates similar to those near Barrel Springs. These conglomerates contain occasional andesite blocks over 20 feet in diameter, and a few 5- to 10-foot blocks of arkose and limestone.

A younger boulder-conglomerate which may overlie an erosion surface cutting the Silver Bell-type andesite, the Cretaceous beds, and the intervening conglomerate crops out about one mile south of Barrel Springs.

Tombstone

Gilluly (6) describes the lower half of the Bronco volcanics as being made up largely of clastic andesite breccias--andesite fragments in an andesitic mud matrix--which probably originated as volcanic mud flows. As these rocks unconformably overlie the Cretaceous Bisbee formation, he regards their age as late Cretaceous or early Tertiary.

This lower unit of the Bronco volcanics is megascopically identical to the "Silver Bell" formation. In an outcrop about 2 miles due east of Bronco Hill, or 7 miles S60W of Tombstone, red sandstone and mudstone beds of the Bisbee formation are overlain unconformably by 60 feet of conglomerate made up of well rounded cobbles of arkose, chert, quartzite, and limestone in a friable matrix of andesitic debris. Between the conglomerate and the overlying andesite breccias is a 50-foot thickness of greenish, gritty siltstone containing a few large (± 8 feet in dia.) angular boulders of limestone conglomerate and massive andesite or felsite. This bed and the underlying conglomerate together are considered a probable correlative of the "Claflin Ranch" formation.

Hatchita Mountains (New Mexico)

Perhaps the most detailed study of volcanic rocks of designated Cretaceous age in the region was made by Lasky (7) in the Hatchita Mountains, New Mexico. The principal unit, the Hidalgo volcanics, is described to be unconformably overlain by the Howell's Ridge formation which is assigned to the lower Cretaceous on fossil evidence. Other volcanics reportedly are interbedded in the Ringbone shale and Skunk Ranch conglomerate. The volcanics are confined to the northern part of the Hatchita Mountains, but the associated sedimentary formations, excepting the Ringbone shale which underlies the Hidalgo volcanics, continue several miles into the southern part. This lack of continuity, which in the case of Hidalgo volcanics involves a decrease in thickness from 5000 feet to zero in 4 miles along strike, is regarded by Lasky as being due to deep erosion both before and after extrusion of the volcanics.

We suggest certain alternative interpretations. These are summarized on the accompanying chart which shows proposed correlation of the "Claflin Ranch" and "Silver Bell" formations with the Ringbone shale and Hidalgo volcanics respectively.

As mapped by Lasky, the Hidalgo volcanics along the northeast slope of Howell's Ridge dip under the Howell's Ridge formation. The contact is mapped as depositional. Close inspection of all good exposures revealed that the two formations are separated by a fine-grained diorite intrusive. Elsewhere, the Miss Pickle fault forms the contact. Thus, evidence for Lasky's postulated age relationship between the Howell's Ridge formation and the Hidalgo volcanics appears lacking. In some outcrops, strong shearing in the volcanics was observed along the diorite contact, suggesting that the diorite may have intruded a fault plane--possible a thrust. According to Zeller (8) "... Lasky's section may include at least one duplication. If this contention is true, the section in the Little Hatchet Mountains will be virtually the same in lithology, fauna, and in thickness as that of the Big Hatchet Mountains." Zeller's Lower Cretaceous section in the Big Hatchet Mountains contains no volcanic units.

The only other occurrence of Hidalgo volcanics crops out as an irregular area surrounded by the Howell's Ridge formation, immediately south of Howell's Wells. Lasky interprets this exposure of the volcanics to be formed by erosion of overlying sediments along the axis of an anticline; however, the postulated anticline in this area is not evidenced by the attitudes recorded on the map. During our field check, an intrusive was found to occupy the western end of the area mapped as volcanics; and elsewhere the limits of the volcanics were either concealed or obscured by alluvium. The areal pattern of these volcanics in relationship to the topography suggests that they were deposited on an erosion surface cut in the sediments.

The Ringbone shale is distinctive because of the abundance of andesitic material in many of its beds, which range in composition from fine silts to coarse conglomerates. Also, it contains unusually large blocks (over 50 feet in diameter) of andesitic rock. Lasky describes a basalt porphyry flow, interbedded in the Ringbone shale and repeated in the outcrops by faulting. These outcrops were investigated and the basalt occurrences appear to be sills. It is notable that the few fossils collected in this formation are not among those listed by

Lasky as diagnostic of the Lower Cretaceous. His assignment of the Ringbone shale to the Lower Cretaceous, therefore, rests entirely on his structural and stratigraphic interpretations. There appears to be no question that the Ringbone shale is stratigraphically lower than the Hidalgo volcanics; but there is reasonable doubt that the Hidalgo volcanics are stratigraphically lower than the Cretaceous Howell's Ridge and overlying formations.

The Hidalgo volcanics are lithologically similar to other localities of Silver Bell-type andesite breccia. In view of this and of the possibility that they overlie a post-Howell's Ridge erosion surface, we tentatively suggest a correlation with the "Silver Bell" formation.

Stanley and Winkleman-Christmas Areas

As pointed out by Courtright (1), the andesite breccias and flows are not interbedded with, but overlie, Upper Cretaceous sandstones and shales in the Stanley area; in the Winkleman-Christmas area they overlie Paleozoic limestones. The surface of deposition is marked by a few feet of greenish silt and grit.

GENERAL

Volcanics and clastics of the Silver Bell-Claflin Ranch types have been observed in several other localities, including the Silver City district of New Mexico. There, they have been mapped (9) as Cretaceous-Tertiary extrusives unconformably overlying the Upper Cretaceous Colorado formation. In the Chiricahua Mountains they have been mapped by Sabins (10) as the Nipper formation which unconformably overlies Lower Cretaceous and older rocks. As mapped by Guillerman (11) in the Peloncillo Mountains, they likewise overlie a post-Lower Cretaceous erosion surface.

In the foregoing paragraphs we have described the interval between the Tucson surface (2) and the overlying acid pyroclastics of the Cat Mountain rhyolite type as being occupied principally by two formations: the older clastics of the "Claflin Ranch" or chaos type and the younger andesites of the "Silver Bell" type. This may be an over-simplification of the inter-relation of these two rock types. Actually, there may have been repeated episodes of deposition of clastics and volcanics, with local intervals of erosion. Thus, the sequences may be found to differ in order and number of units from place to place. The important points are that these rocks as a group are lithogically similar over wide areas; they lie on an erosion surface cut in Cretaceous and older rocks; and this surface usually marks a pronounced change in the environment of sedimentation.

Thanks are due to the American Smelting and Refining Company for permission to publish this paper, and to Mr. John Kinnison for his critical reading and useful suggestions.

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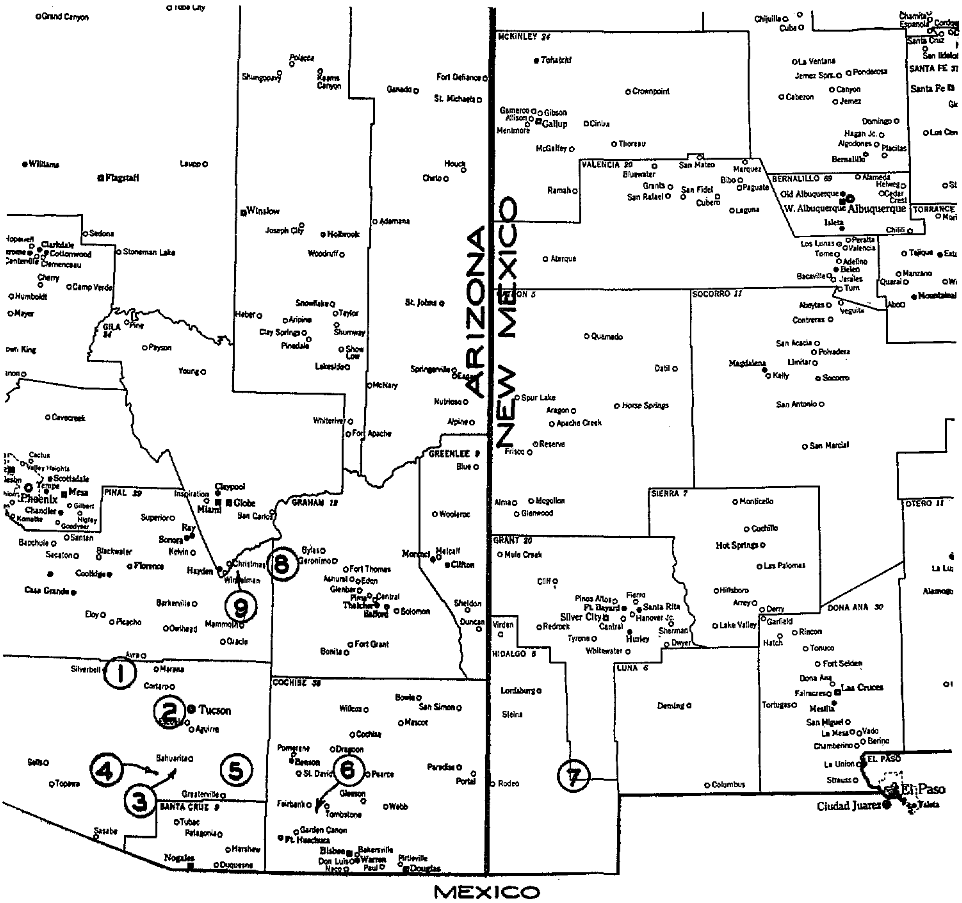

INDEX MAP OF LOCALITIES

1 Silver Bell
2 South Tucson Mountains
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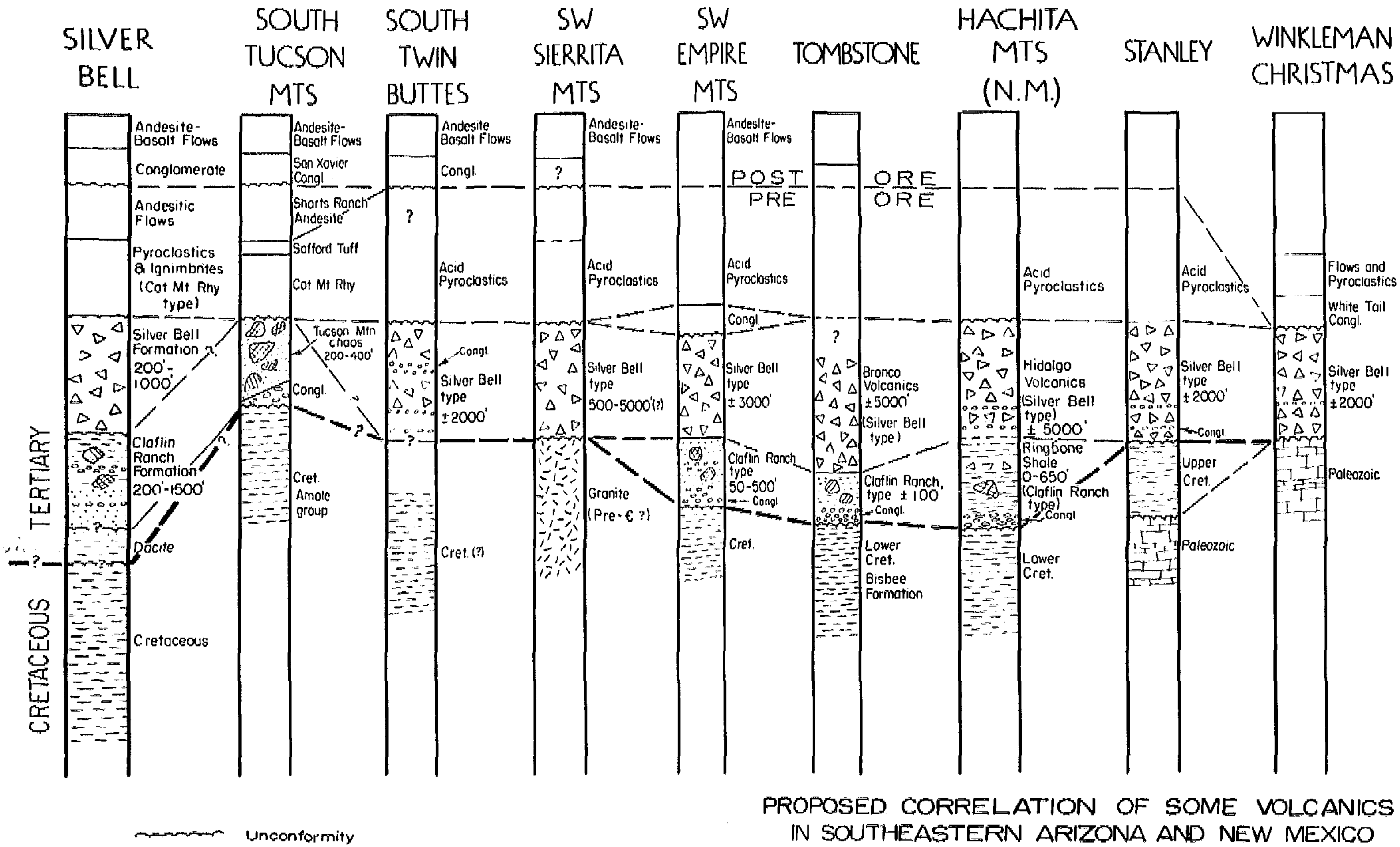
8 Stanley Area
9 Winkleman - Christmas Area



PROPOSED CORRELATION OF SOME VOLCANICS IN SOUTHEASTERN ARIZONA AND NEW MEXICO

NOT TO SCALE

K.R. and J.H.C.

Sept. '59

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ASARCO Southwestern Exploration Division

JDS

April 10, 1984

F. T. Graybeal
New York Office

Dissertation by
G. H. Ballantyne

Attached is a copy of G. H. Ballantyne's letter, the Cover, Abstract, Table of Contents, List of Figures, List of Tables, and Acknowledgments of his dissertation "Chemical and Mineralogical Variations in Propylitic Zones Surrounding Porphyry Copper Deposits."

As Geoffrey requested your address I suspect he will be sending you a copy. He is expected to send two bound copies to the Tucson office, so I'm sure we can supply you with a volume in the event he does not send one to you.

Please advise as time progresses.

James D. Sell
James D. Sell

JDS/cg

Attachments

cc: WLKurtz (w/o attach)

JDS

ASARCO

Exploration Department
Southwestern United States Division
James D. Sell
Manager

April 10, 1984

Dr. G. H. Ballantyne
Kennecott Exploration Group
P. O. Box 11248
Salt Lake City, UT 84147

in library

Dear Dr. Ballantyne:

Thank you very much for your note and the soft-bound copy of your dissertation. I look forward to the two bound copies in the near future.

The address you seek is:

Dr. F. T. Graybeal, Chief Geologist
Exploration Department
ASARCO Incorporated
120 Broadway, Room 3422
New York, NY 10271

Phone: 212-669-1267

Sincerely,

James D. Sell

James D. Sell

JDS/cg

cc: WLKurtz
FTGraybeal

JDS

S-10.10

ASARCO

SILVER BELL UNIT

May 18, 1984

Memo To: B.K. Malone

From: David Sawyer

Subject: Exploration Possibilities Around The Oxide And El Tiro Mineralized Centers, Silver Bell District

At the end of my two year period of field work in the Silver Bell District, I felt it might be useful to write my impressions on areas of exploration potential that remain to be fully examined. These conclusions are based in part on my own work, having geologically mapped around the Oxide and El Tiro areas at 1:24,000 scale, and in part come from having reflected upon previous geologic work on the district written in articles, reports, theses, maps and cross-sections; supplemented by my own examination of drill core and drill logs while collecting samples for my own study. The conclusions are certainly preliminary, and would need further geologic work to evaluate. Perhaps some of them can be laid to rest based on more detailed knowledge of other workers who are more familiar with Silver Bell than I. The discussion following will be broken down into areas of potential high-grade reserves, and potential low-grade reserves.

POTENTIAL HIGH GRADE RESERVES

Supergene Enrichment Blanket Mineralization

After studying the geology of the Silver Bell District in detail for two years, I am confident that Kenyon Richard, Harold Courtright and other early workers have identified all areas of significant leached capping and potential high-grade chalcocite blanket-type mineralization. All potential targets in the alteration/mineralization zone extending from North Silver Bell to El Tiro to Oxide (which my studies indicate is a ring fracture margin of a caldera) have been carefully identified and evaluated. Some potential for low-grade mineralization of this type exists and will be discussed in a subsequent section.

Skarn or Tactite Mineralization

I believe that the best possibilities for additional high-grade copper reserves in the Silver Bell district are associated with skarn mineralization in areas adjoining the El Tiro and Oxide pits. The caldera model has significant implications for the search for skarn ore, because of

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EXPLORATION DEPARTMENT

the perspective it will provide on the distribution of favorable Paleozoic sedimentary host rocks for replacement. In contrast to previous interpretations of the Paleozoic sequence at Silver Bell as being a complete section tilted homoclinally to the east (Merz, 1967), my work has shown the Paleozoic rocks to be affected by significant omission of strata caused by bedding plane thrust faults (Laramide, precaldera), as well as large scale structural juxtapositions of internally coherent caldera collapse megabreccia blocks. These structural complexities will take detailed geologic mapping to resolve, in order to have predictive understanding for locating exploration drill holes.

W El Tiro: (W of Daisy pit) Several exploration holes have been collared in the alaskite (biotite granite) and then crossed into strongly mineralized skarn, interspersed with minor dacite porphyry (Confidence Peak lithic tuff). Grades have ranged up to 0.8 - 2%, though generally for not more than a couple of benches (except in hole D219 where 368' of 1.09% Cu was intercepted; hole 241 also has higher-grade ore). Some of this mineralization is moderatly deep, occurring between 2300' and 1800' elevation. The contact between the biotite granite and lithic tuff (and enclosed sedimentary rocks), is an expression of the ring fault zone and appears to dip steeply west. Significant areas in the footwall of this contact zone remain to be tested for the distribution and grade of high-grade Cu skarn ore.

N W Oxide: (area from just E of N Butte to NE side of Copper Butte, N of Dump #3, W of the dike). Strong skarn alteration exists at the surface in this area, but the downward extension of it has not been thoroughly tested. Unfortunately, some areas at the surface have been covered by waste dumps. Moderate grade Cu skarn mineralization (0.5 - 1.0% Cu) has been drilled in this area, but the vertical and lateral extent of this mineralized zone and its overall grade has not been determined. High-grade potential would seem to be strongest toward the SW, adjacent to the contact between the lithic tuff and the biotite granite or quartz monzonite porphyry.

Nightingale Mine area: (basin midway between Oxide and El Tiro). Skarn alteration in this area, particularly to the W as the contact between the lithic tuff and biotite granite is approached, is locally strong but to my knowledge potential mineralization has never been tested by the drill. An orthoclase quartz porphyry pluton occurs in this vicinity, and is very similar to one associated with ore in deep drill holes in the E Extension area. The pluton is relatively unaltered but the possibility exists of deeper mineralization associated with its contact margins.

POTENTIAL LOW GRADE RESERVES

By this I generally mean areas of hypogene or low-grade supergene mineralization in silicate igneous rocks, at Silver Bell ranging in grade from .2 - .5% Cu. Two main areas strike me as having poorly constrained potential reserves in this range of cutoffs, though undoubtedly more remain. In fact, most of the area beneath the present exploration drill coverage in El Tiro and Oxide pits (which bottoms out close to the present mining surface) could be considered as potentially containing low-grade reserves.

Imperial Stock: This is the pluton which occurs between the main El Tiro and E extension pits, and is well exposed on the W side of the E extension pit. In previous works, it is often referred to as the "barren pluton". However, my interpretation of the drill logs from the very few holes drilled into its margins indicate that no holes have been drilled much below the leached oxidized zone, or evaluated the grade of hypogene copper mineralization below through most of its area of outcrop. The observed "barren" quality of the pluton may in part be a function of surface leaching. Inspection of leached capping in outcrops shows no evidence that would indicate a high-grade chalcocite enrichment blanket at depth. However, there may have been weak enrichment of a hypogene protore which would constitute a potential low-grade Cu resource. At least a few exploration drill holes should be drilled to evalute hypogene Cu grades in the Imperial stock and potential low-grade enrichment.

E of Oxide: In the area between Oxide pit and the deep drilling associated with the E Silver Bell exploration project in the mid 70s, there exists an area of moderately strong to strong alteration tested by only a low density of drill holes. The potential exists in this area for weak enrichment forming low-grade chalcocite bodies, as well as deeper hypogene Cu mineralization. In this area the question of whether the ore bodies were tilted ENE along with the Laramide volcanic rocks in the central Silver Bell Mts. assumes importance. If the ore bodies are tilted, then hypogene mineralized horizons would occur at progressively greater depths to the E of the main Silver Bell ore zone. A test to evaluate tilting of the ore bodies would be a paleomagnetic study of the Silver Bell district. Such studies in the Yerington, Questa, and Red Mt. (Henderson, CO.) mining districts have documented the extent and timing of tilting and their effect on ore distribution.

DS/me

cc: SAAnzalone
WLKurtz
JDSell
FTGraybeal
RCummings
LJohnson

JDS

ASARCO

Exploration Department
Southwestern United States Division

James D. Sell
Manager

May 6, 1985

Dr. Peter W. Lipman
U.S. Geological Survey
MS913, Box 25046
Denver, Colorado 80225

Dear Pete:

Dave Sawyer dropped off the two recent papers you two have out on the Silver Bell, AZ area.

I note several references which are in publications which our library does not receive. Is there any chance of receiving a copy of these? (Xerox or otherwise?)

Lipman, P.W., 1984, The Roots of Ash-Flow Calderas in Western North America: Jour. Geophys. Res., vol. 89, p. 8801-8841.

Kluth, C.F., 1983, Geology of the Northern Canelo Hills and Implications for the Mesozoic Tectonics of Southeastern Arizona, in Mesozoic Paleogeography of West-Central United States: Rocky Mtns. Sect. Soc. Econ. Paleont. Miss., p. 159-171

Sawyer, D.A. and Lipman, P.W., 1983, Silver Bell Mountains, Arizona: Porphyry Copper Mineralization in a Late Cretaceous Caldera: EOS, vol. 64, p. 874.

Thank you very much.

Sincerely,

James D. Sell

James D. Sell

JDS:mek

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

JDS

coarsen and thicken dramatically toward the incipient ring fracture, along which 225 m of normal displacement took place. This precursory volcanotectonism was followed by eruption of about 20 km³ of rhyolite ash-flow tuff and simultaneous subsidence of the Vandever Mountain caldera, as shown by: (1) the great thickness (>0.5 km) of compositionally zoned ash-flow tuff, which accumulated very rapidly; (2) high-angle normal faults which pond the ash-flow tuff and offset underlying but not overlying stratigraphy; and (3) slide blocks up to 0.5 km long that were shed from the caldera wall and incorporated into the ash-flow tuff as it filled the caldera. Disruption of the caldera floor was intense near the caldera margins but negligible along most of its length, due to piston-like subsidence of an intact cylinder of crust. Suppression of a vertical eruptive column by the pressure of an overlying water column may be indicated by the restricted dispersal of extra-caldera ash-flow tuffs and the unusually small volume of associated fall-out tuff. A topographic depression was not created by caldera collapse because relatively little pyroclastic material exited the caldera. The Vandever Mountain caldera was not affected by resurgent doming or late-stage rhyolite magmatism in the cross-sectional view afforded by the Mineral King roof pendant.

V11A-13

Silver Bell Mts., Arizona: porphyry copper mineralization in a late Cretaceous caldera.

D.A. SAWYER USGS,
P.W. LIPMAN Denver, CO 80225

Two porphyry copper deposits in the Silver Bell mining district, NW of Tucson, AZ, are spatially associated with a thick sequence of late Cretaceous volcanic rocks related to an ash-flow caldera. A >1-km-thick lithic-rich rhyolite welded tuff (72-73% SiO_2) forms the base of the volcanic sequence and is overlain by volcaniclastic sediments incorporating clasts of lithic tuff. Extrusion of dacitic (63-65% SiO_2) breccias and flows followed; these and other volcanic rocks are high-K varieties, low in Ca and Mg with little Fe enrichment. Capping the sequence is a eutaxitic rhyolite welded tuff ranging from 71% to 77% SiO_2. The volcanic sequence is intruded by monzodiorite and quartz monzodiorite dikes and plutons. The plutons have yielded K-Ar biotite ages of 65-68 m.y.

Several lines of evidence suggest that the entire volcano/plutonic complex is a deeply eroded and faulted caldera. The >1 km thickness of the lithic tuff suggests ponding during caldera collapse. Lithic and phenocryst enrichment of the groundmass relative to cognate pumice is consistent with sorting effects observed in other intracaldera tuff accumulations. Paleozoic sediments that are enclosed by lithic tuff may represent caldera-collapse breccias or disrupted caldera floor. The locus of mineralized and unmineralized intrusions forms a 150° arc on the west side of the range, probably along a ring-fracture zone. Alteration mapping by remote sensing suggests closure of the arc on the pediment to the east of the range (R. Lyon, pers.comm.). Porphyry copper mineralization associated with caldera-related silicic volcanism at Silver Bell illustrates the diversity of magmatic processes leading to copper mineralization; not all porphyry copper deposits form beneath andesitic stratovolcanoes.

Phase Equilibria
CH, Presidio Mon AM
Presider, C. M. Scarfe, Univ of Alberta

V11B-01 ~~POSTER~~

Viscosity-temperature relationships of melts at one atmosphere in the system diopside-albite

C. M. SCARFE (Experimental Petrology Laboratory, Department of Geology, University of Alberta, Edmonton, Alberta, T6G 2E3)
D. J. CRONIN (Center for Materials Science, National Bureau of Standards, Washington, D.C. 20234)

The viscosities of six melt compositions have been measured along the join diopside-albite with a concentric-cylinder viscometer. Measurements were made between 1600 and 1150°C and viscosities were independent of shear rate, indicating Newtonian viscous behavior. Viscosities decreased with increasing temperature and, at constant temperature, they decreased with increasing amounts of diopside component in the mixtures. The temperature dependence of the viscosity above the liquidus was fitted to an Arrhenius relationship from which activation energies for viscous flow, ranging from 88 kcal/mole for a melt of albite composition to 38 kcal/mole for a melt of diopside composition, were derived. Viscosities over the entire range of the melt and supercooled liquid temperatures were fitted to the Fulcher equation. Viscosity is strongly dependent upon the mole fraction of silica and alumina in the melt and on temperature. Addition of diopside to albite melt probably causes a reorganization of the three-dimensional network in favor of a more depolymerized structure. Furthermore, activation energies indicate significant differences in the flow properties of diopside versus alumina-bearing melts across the join.

V11B-02 ~~POSTER~~

The Effect of Fluorine on Viscosities in the System Na2O-Al2O3-SiO2: A Model for Phonolites, Trachytes and Rhyolites.

D. B. DINGWELL and C. M. SCARFE, Experimental Petrology Laboratory, Department of Geology, University of Alberta, Edmonton, Alberta, T6G 2E3
D. J. CRONIN, Center for Materials Science, National Bureau of Standards, Washington D. C., 20234

Viscosities were measured to test the effect of fluorine on aluminum-saturated, peralkaline and peraluminous melts in the system Na_2O-Al_2O_3-SiO_2. Fluorine was added to albite, jadeite and nepheline melts on the SiO_2-$NaAlO_2$ join and to peralkaline and peraluminous compositions off the join. Viscosities were determined by concentric-cylinder viscometry over the temperature range 1000°C-1600°C.

The viscosities (logη) of all compositions were fitted within error to Arrhenian functions of temperature, and activation energies (Eη) were obtained. Melts of albite, jadeite and nepheline with 5-6% F added show large reductions in logη (e.g. at 1400°C: 1.60, 1.18 and 0.86) and Eη (40, 32 and 16 kcal/mole). The peralkaline melt (3.6% F) shows a 1.0 logη drop and only a 5 kcal/mole reduction in Eη; whereas the peraluminous melt (5.4% F) shows a 0.94 logη drop and a 16 kcal/mole reduction in Eη. These results, combined with unpublished data on fluorine-doped SiO_2, indicate that reductions in logη and Eη are positive linear functions of $XSiO_2$ on the join $NaAlO_2$-SiO_2 between nepheline and SiO_2.

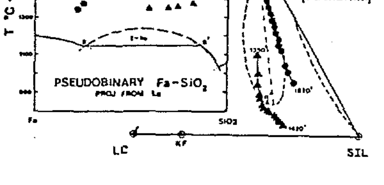
According to published data on hydrous rhyolite melt (≈albite), the viscosity-reducing effect of fluorine on albite is one half that of water and the reduction in Eη is very similar (40 vs. 37 kcal/mole). Thus, the viscous flow of highly-polymerized melts is similarly altered by the addition of F^- or OH^-. These results are applicable to the flow of rhyolites, trachytes and phonolites.

V11B-03 POSTER

SORET SEPARATION NEAR A SILICATE SOLVUS

D. WALKER[1] and C.E. Lesher[2]
([1]Lamont-Doherty Geol. Obs. and Dept. of Geol. Sci., Columbia U. Palisades, N. Y. 10964, [2]Dept. of Geol. Sci., Harvard U. Cambridge, MA. 02138)

Thermal diffusion in the single-phase liquid field in the system $KAlSi_2O_6$-Fe_2SiO_4-SiO_2(LcFaS) is strongly affected by the chemical potential "abnormalities" which lead to the development of silicate liquid immiscibility (SLI) at lower temperatures. Soret compositional arrays, normally sub-radial to S in other systems, follow the SLI tie lines in the composition region of stable SLI but deflect towards S outside this field. Remarkable temperature-composition deflections of the Soret array are also observed in the SLI compositional range. These results suggest that the shape of thermal diffusion arrays may be used to determine the solution properties of silicate liquids. The analysis, which can also be applied to solids, gives an excess energy of mixing of SiO_2 in many silicate solutions of 5-10 kcal and a heat of transport, $Q^*(SiO_2)$, generally less than 2 kcal.



V11B-04 POSTER

Solubility of Sulfur in Silicate Liquids at High fO_2

J.F. STEBBINS (Earth Sciences Division, Lawrence Berkeley Laboratory, Berkeley CA 94720)
F.C. BISHOP (Department of Geological Sciences, Northwestern University, Evanston IL 60201)
I.S.E. Carmichael (Department of Geology and Geophysics, University of California, Berkeley CA 94720)

The occurrence of $CaSO_4$ phenocrysts in the 1982 pumice eruption of El Chichon has stimulated an experimental study of sulfur-oxygen gas solubilities in silicate liquids. The $CaSO_4$ phenocrysts have the following composition (in ppm) in contrast to the residual glass:

	La	Ce	Nd	Yb	Th	U	Ta	Hf	Ba	S
pheno.	159	258	77	2.0	2.4	1.1	.1%	<0.5	8	-
glass	34	59	21	1.9	19.1	5.8	1.2	5.4	1320	2800

and are taken to represent equilibrium. Thus, in high fO_2 magmas (>NNO), the reaction:

$$Na_8Al_6Si_6O_{24}SO_4 + CaAl_2Si_2O_8 + 16SiO_2 = 8NaAlSi_3O_8 + CaSO_4$$

demonstrates that anhydrite plays a role in siliceous magmas that is similar to that of nosean in mafic melts. The presence of pyrrhotite phenocrysts in the Chichon samples suggests that some of the sulfur in the glass is sulfide and the balance more oxidized species.

Results of others indicate that high sulfur contents (S_{tot}) can be produced in synthetic melts at high fSO_3. We have made experiments in evacuated silica tubes using the SiO_2-$CaSiO_3$-$CaSO_4$ buffer at 1250°C and fSO_3= 0.029 b. Preliminary results indicate that S_{tot} is greater in $Li_2Si_2O_5$ and $K_2Si_2O_5$ than in a 58% SiO_2 andesite in 24 hr runs. No S_{tot} (<100ppm) was detected in an albite melt under the same conditions. Longer experiments have produced up to 1.5 wt% S_{tot} in $Li_2Si_2O_5$. Higher S_{tot} contents after longer run times and concentration gradients indicate that these samples have not reached equilibrium. Further experiments in gas mixing apparatus are underway, and sulfur speciation determinations by wet chemical techniques are being made.

V11B-05 ~~POSTER~~

The Magmatic - Hydrothermal Transition in Rare-Metal Pegmatites: Fluid Inclusion Evidence from the Tanco Mine, Manitoba

D. LONDON (School of Geology & Geophysics, University of Oklahoma, Norman, Okla. 73019)

Fluid inclusions in lithium aluminosilicates from the Tanco pegmatite, Bernic Lake, Manitoba, contain a complex assemblage of daughter minerals that includes albite, cookeite, Cs-analcime or pollucite, quartz, and lithium tetraborate ($Li_2B_4O_7$). This assemblage appears to represent crystallization products from a dense, silicate-rich aqueous fluid, or from a dense two-phase suspension of aqueous fluid + silicate melt. The $Li_2B_4O_7$ component acts as a flux to increase miscibility of H_2O and silicate components and to depress the solidus (?) of this system to 450°-480°C at approximately 3 kbar. The system $LiAlSiO_4$-$NaAlSi_3O_8$-SiO_2-$Li_2B_4O_7$-H_2O has been investigated experimentally as an analogue to the natural fluids at Tanco. The solidus of this model system lies at 500°C at 2 kbar (fluid). Crystallization of albite, lithium aluminosilicates, and quartz drives the melt composition toward the middle of the albite-$Li_2B_4O_7$ sideline; addition of Cs should further reduce the solidus temperature and lead to the crystallization of Cs-aluminosilicates. As in the Tanco inclusions, the aqueous fluid and silicate melt of the model system exhibit extensive miscibility over a large range of bulk compositions. Evidence from the fluid inclusions and these preliminary experiments indicate that (1) late-stage fluids at Tanco (and similar pegmatites?) were dense borosilicate aqueous gels or melts; (2) the B content of solution/melt phases may have reached 7 wt % B_2O_3 or greater; and (3) the transition from magmatic to hydrothermal crystallization may have been essentially continuous (i.e., supercritical).

V11B-06 ~~POSTER~~

Prediction of free energies of silicates and trace element distribution during hydrothermal alteration

D. A. SVERJENSKY (Department of Earth and Space Sciences, SUNY at Stony Brook, NY 11794)

The standard Gibbs free energies of formation at 25°C and 1 bar of compositional end-members of silicate structures (MX) exhibit linear correlations with the corresponding free energies of formation of the aqueous cations (M^{z+}) to within ±700 cal. mole^{-1} according to

$$\Delta G^\circ_{MX} = a_{MX}(\Delta G^\circ_{M^{z+}}) + b_{MX}$$

where M is Mg, Mn, Fe, Co, or Ni, and MX refers to olivines, orthopyroxenes or clinopyroxenes (data from Navrotsky, 1978 and Robie et al., 1982), or where M is Na, K, Rb or Cs in dioctahedral or trioctahedral micas (using free energies retrieved from experiments summarized by Volfinger and Robert, 1980 with thermodynamic data from Helgeson et al., 1978, 1981). These linear correlations enable prediction of the free energies of end-member silicates with accuracies comparable to that measurable.

Assuming that other major silicate families, for which the free energies of only the Mg or Fe end-members are known, exhibit analogous linear correlations, free energies from Helgeson et al., (1978) were used to predict a_{MX} and b_{MX} and the free energies of amphibole, biotite, and chlorite structures containing Mn, Co, Ni, Cu and Zn by taking advantage of the temperature independence of the ratios (a_{MX}/a_{MY}) for different silicate structures MX and MY. Together with thermodynamic data for aqueous species at elevated temperatures and pressures, the above free energies enable prediction of the equilibrium distribution of trace elements during hydrothermal alteration.

V

Jim –
With best regards
Pete

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 89, NO. B10, PAGES 8801–8841, SEPTEMBER 30, 1984

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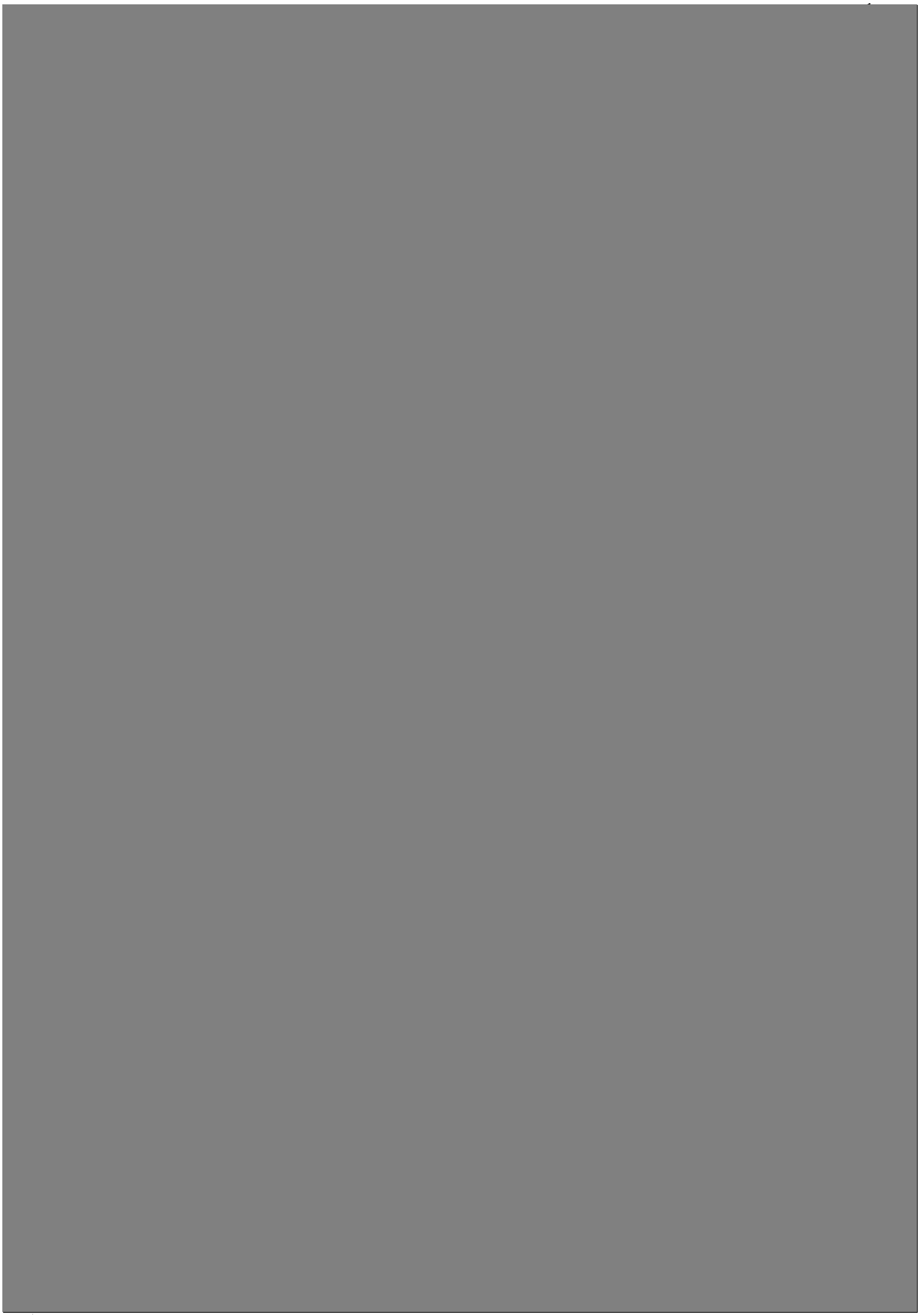

ABSTRACTS with PROGRAMS 1985

81st Annual Meeting

CORDILLERAN SECTION

The Geological Society of America

with the
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JDS

ASARCO

Exploration Department
Southwestern United States Division

James D. Sell
Manager

September 30, 1985

Ms. Margaret E. Hinkle
U.S. Geological Survey
P.O. Box 25046
Denver Federal Center
Denver, CO 80225

Dear Ms. Hinkle:

In the September issue of the "Journal of Geochemical Exploration," I note that you co-authored with C.A. Dilbert, the 1984 article "Gases and trace elements in soils at the North Silver Bell deposit, Pima County, Arizona" J-G.E., 20; 323-336 (1984).

Would it be possible to secure a copy (or Xerox) of this paper?

Thank you for your consideration.

Sincerely,

James D. Sell
James D. Sell

JDS:mek

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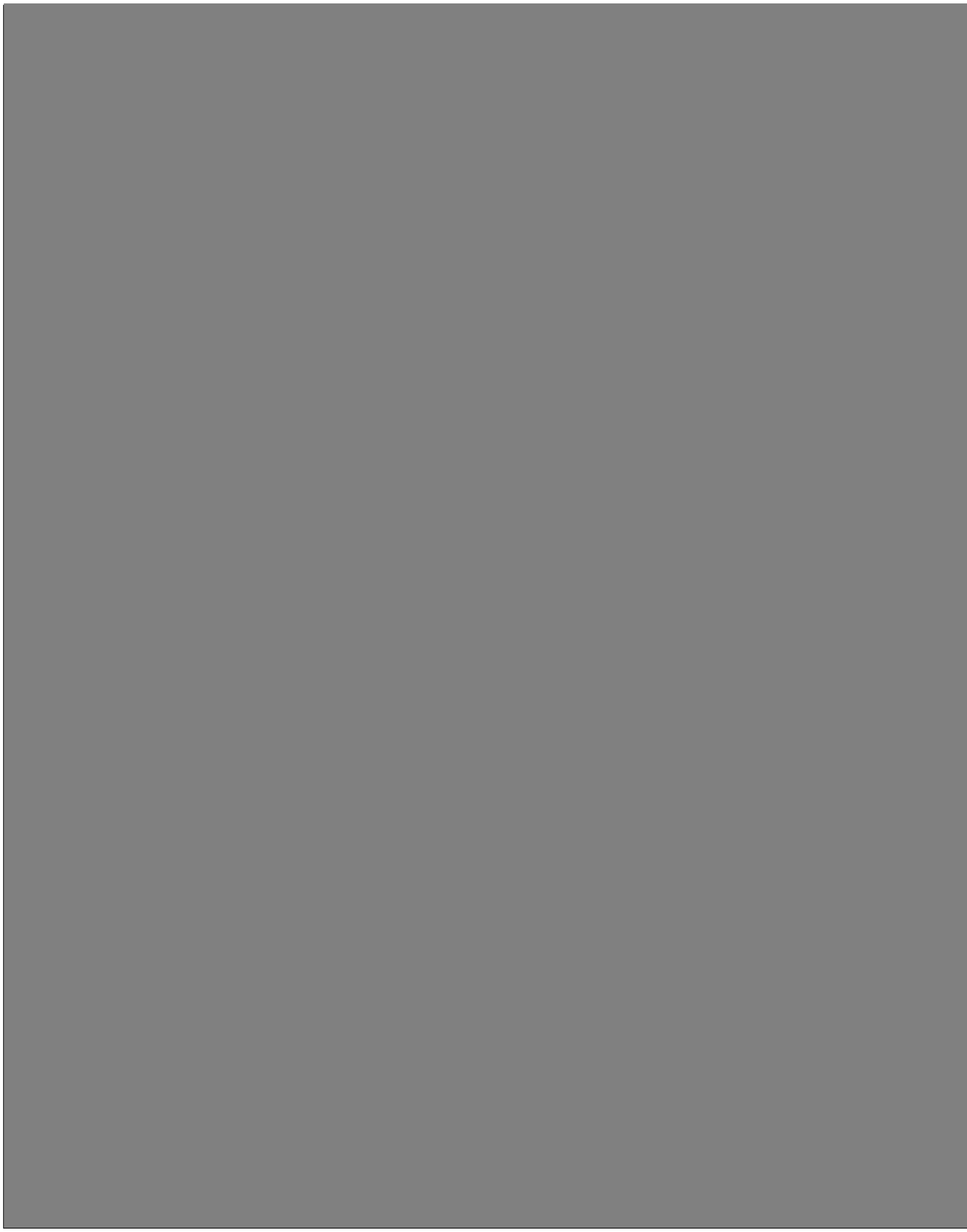
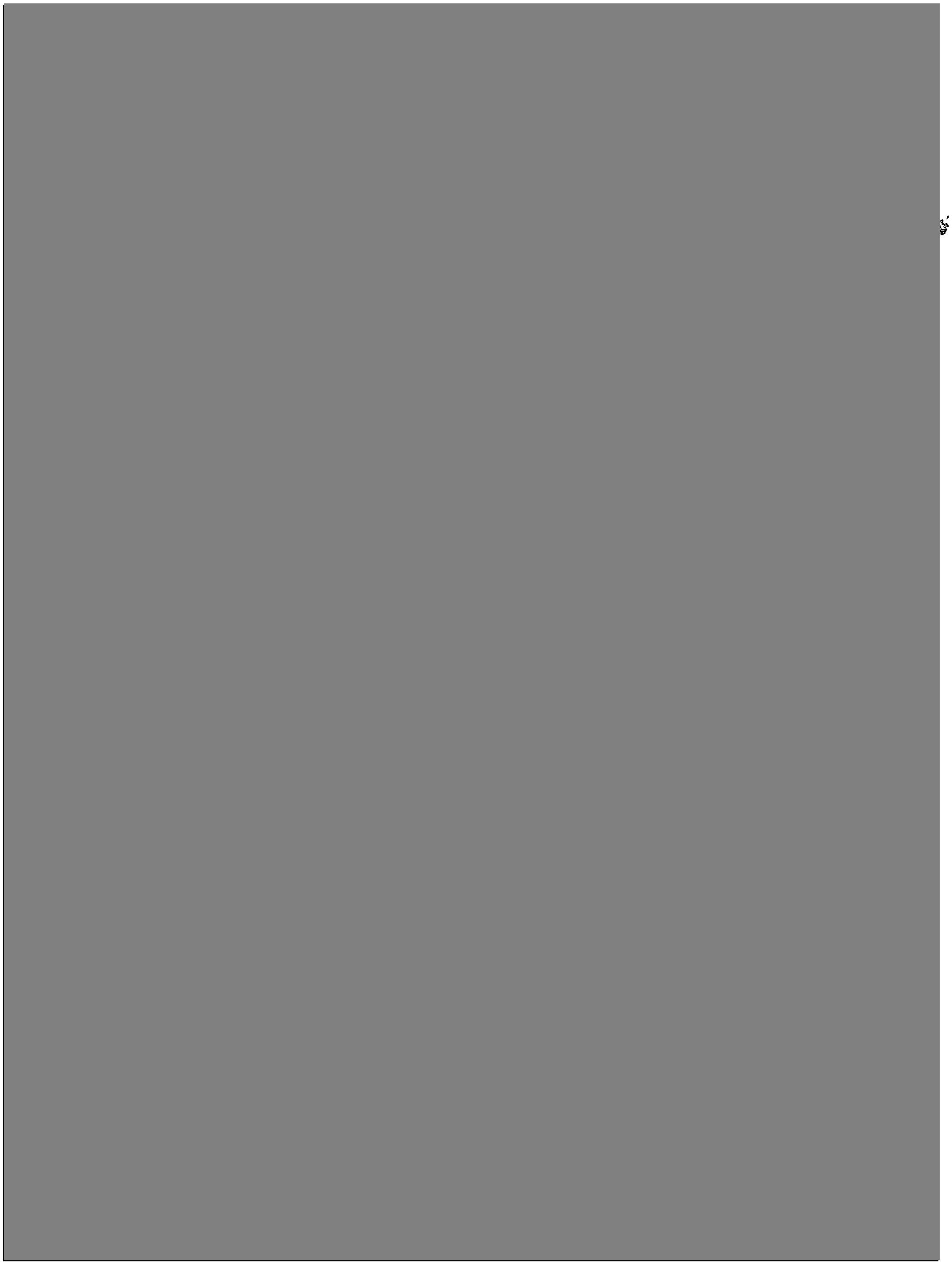
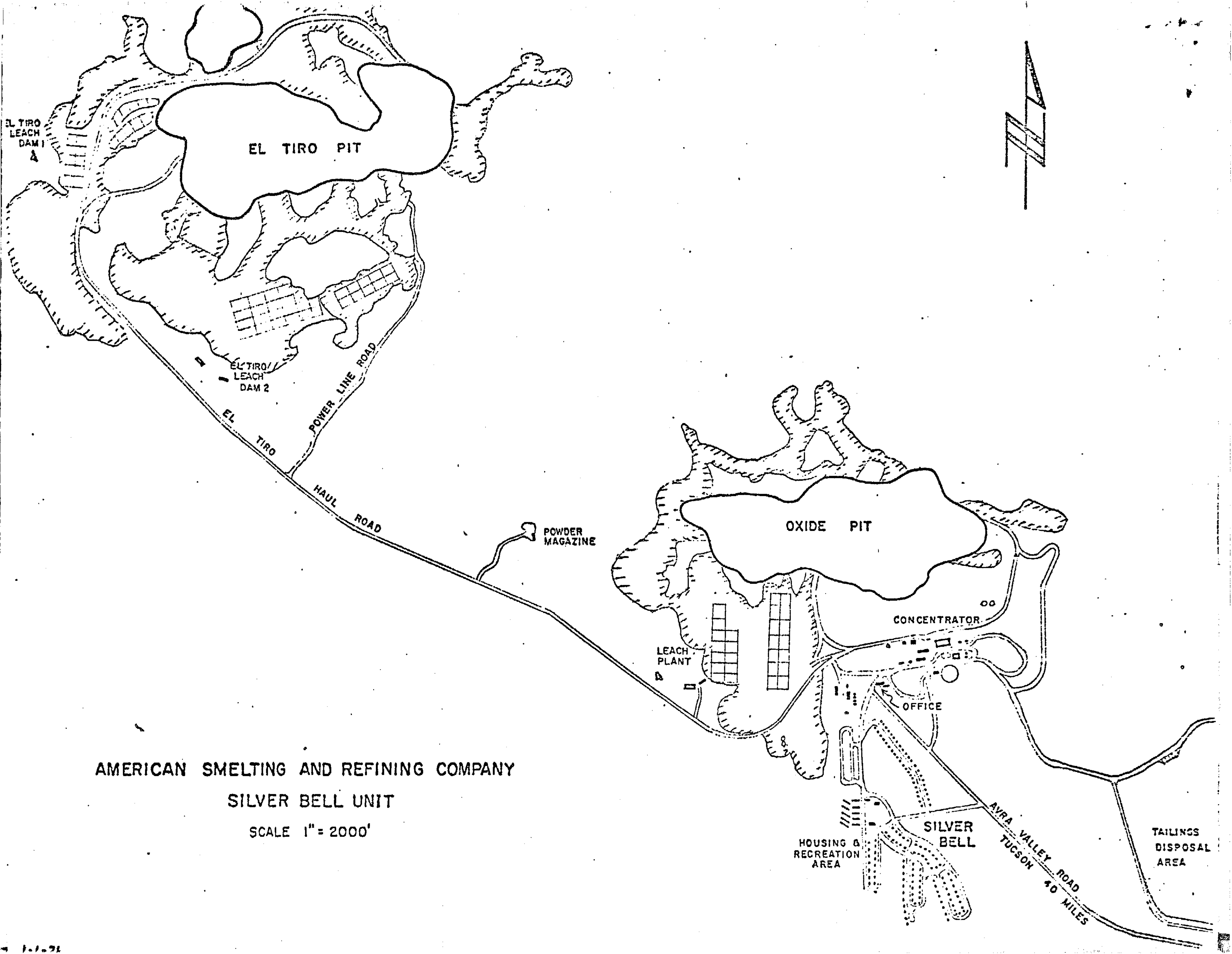




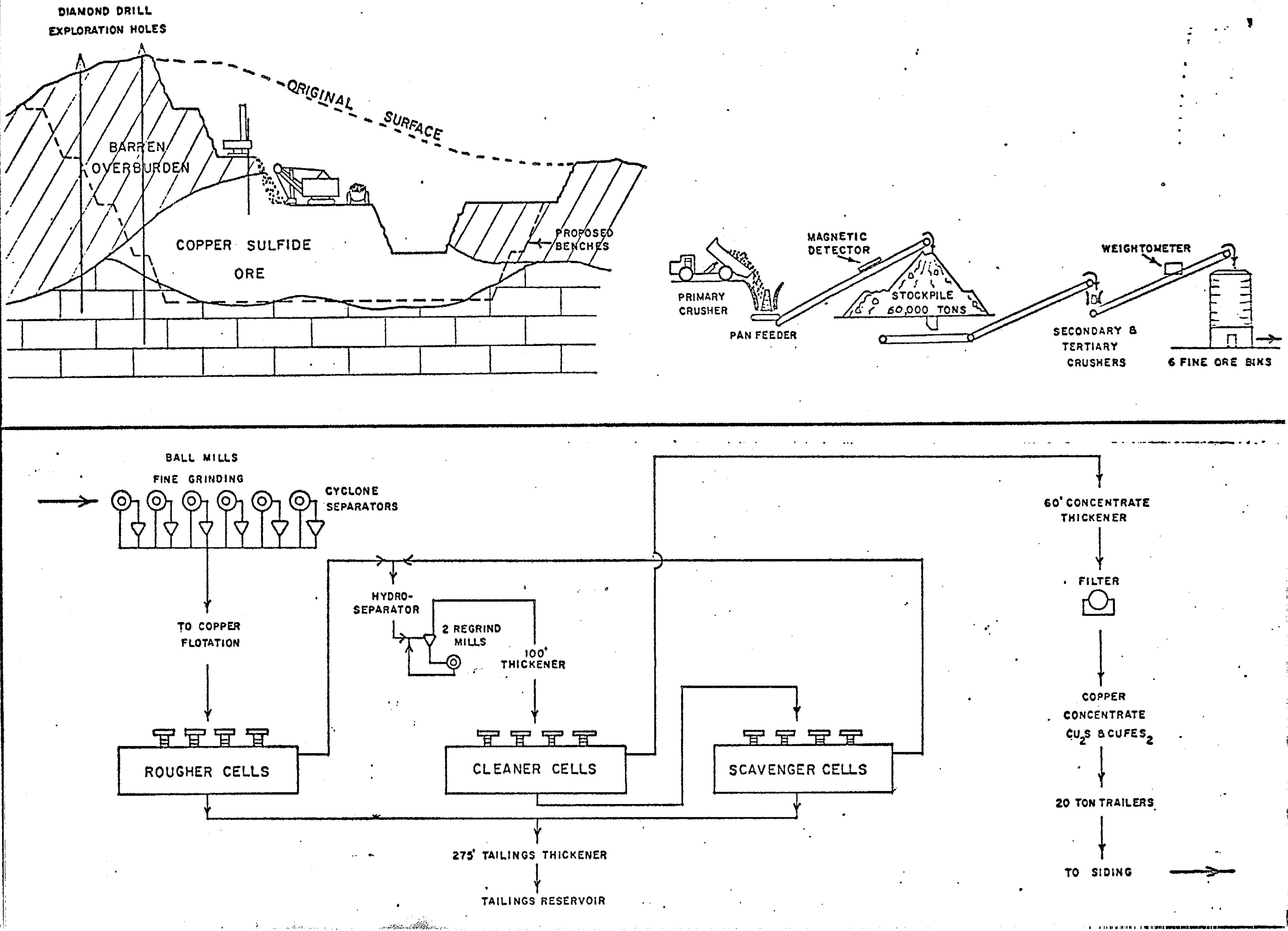


AMERICAN SMELTING AND REFINING COMPANY

SILVER BELL UNIT

SCALE 1" = 2000'

AMERICAN SMELTING AND REFINING COMPANY
SILVER BELL UNIT MINING & MILLING FLOW SHEET



ASARCO

Southwestern Exploration Division

JDS

January 30, 1987

FILE NOTE

USBM Wilderness Appraisal
Ragged Top Mountain WSA
Silver Bell Mountains
Pima County, AZ

A Terry J. Kreidler, USBM, Denver, Colorado (phone: 303/236-3400) is one of the Wilderness Appraisal people and is with the Ragged Top WSA group.

He will be down this Spring to complete the work. I have asked him to come in and chat when he is in town.

James D. Sell
James D. Sell

JDS:mek

cc: W.L. Kurtz
W.D. Gay

90 S

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Analytical results and sample locality map for stream-sediment, panned-concentrate, and rock samples from the Ragged Top Wilderness Study Area, Pima County, Arizona

By

John B. McHugh*, Gary A. Nowlan*,
David A. Sawyer**, and John H. Bullock, Jr.*

Open-File Report 88-587

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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94-579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine their mineral values, if any. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a geochemical survey of the Ragged Top Wilderness Study Area (AZ-020-197), Pima County, Arizona.

INTRODUCTION

In March 1987, the U.S. Geological Survey conducted a reconnaissance geochemical survey of the Ragged Top Wilderness Study Area, Pima County, Arizona. Additional samples were collected in December 1987. The wilderness study area and nearby sampled terrain are termed the "study area."

The Ragged Top Wilderness Study Area comprises 4,460 acres (about 7 mi^2) in the north central part of Pima County, Arizona, and lies about 35 mi northwest of Tucson, Arizona (see fig. 1). Access to the study area is provided by the Silver Bell, Avra Valley, and Red Rock roads.

Topography of the study area is dominated by the rugged mass of Ragged Top Peak, elevation 3,907 ft, and a shorter subsidiary peak called Wolcott Peak which rise abruptly to a maximum of 1,700 ft above the surrounding bajada. The two peaks, which are collectively known as Ragged Top, are the northeastern peaks of the Silver Bell Mountains. Ragged Top is separated from the main mass of the Silver Bell Mountains by a mile-wide valley.

Vegetation is characteristic of the Sonoran Desert. Common species include saguaro and other cacti, paloverde, acacia, ironwood, mesquite, and creosote bush.

The southwest part of the study area lies within the Silver Bell mining district (Richard and Courtright, 1966; Graybeal, 1982). The first recorded mining activity in the district was in 1865 about 2 miles south-southwest of the wilderness study area; silver and copper were recovered from skarn. Exploitation of porphyry copper deposits at the El Tiro and Oxide pits began in 1954 and continued until 1985. The El Tiro pit is about 2 miles southwest of the wilderness study area and the Oxide pit is about 3 miles south. A third, unexploited, porphyry copper deposit, the North Silver Bell deposit, lies about 1 mile from the southwest corner of the wilderness study area. Production from the El Tiro and Oxide deposits from 1954 to 1977 totaled 75,655,000 tons averaging 0.80 percent copper, 0.07 oz/ton silver, and 0.022 percent molybdenum sulfide (Graybeal, 1982). Copper has been the predominant commodity produced in the Silver Bell district but two mines about 2 miles southwest of the wilderness study area produced about 150,000 tons of ore averaging 16 percent zinc, 1.3 percent copper, 0.6 oz/ton silver, and minor lead and gold (Keith, 1974). Total production of base and precious metals in the Silver Bell district from 1885 to 1981 amounted to 90,351,000 tons (Keith and others, 1983).

Geology of the study area is included in reports by Sawyer (1986, 1987). A major structural feature in the study area is the Ragged Top fault, a probable strike-slip fault that runs from near the southeast tip of the wilderness study area west-northwest across the wilderness study area. Precambrian Oracle-type granite predominates on the north side of the fault

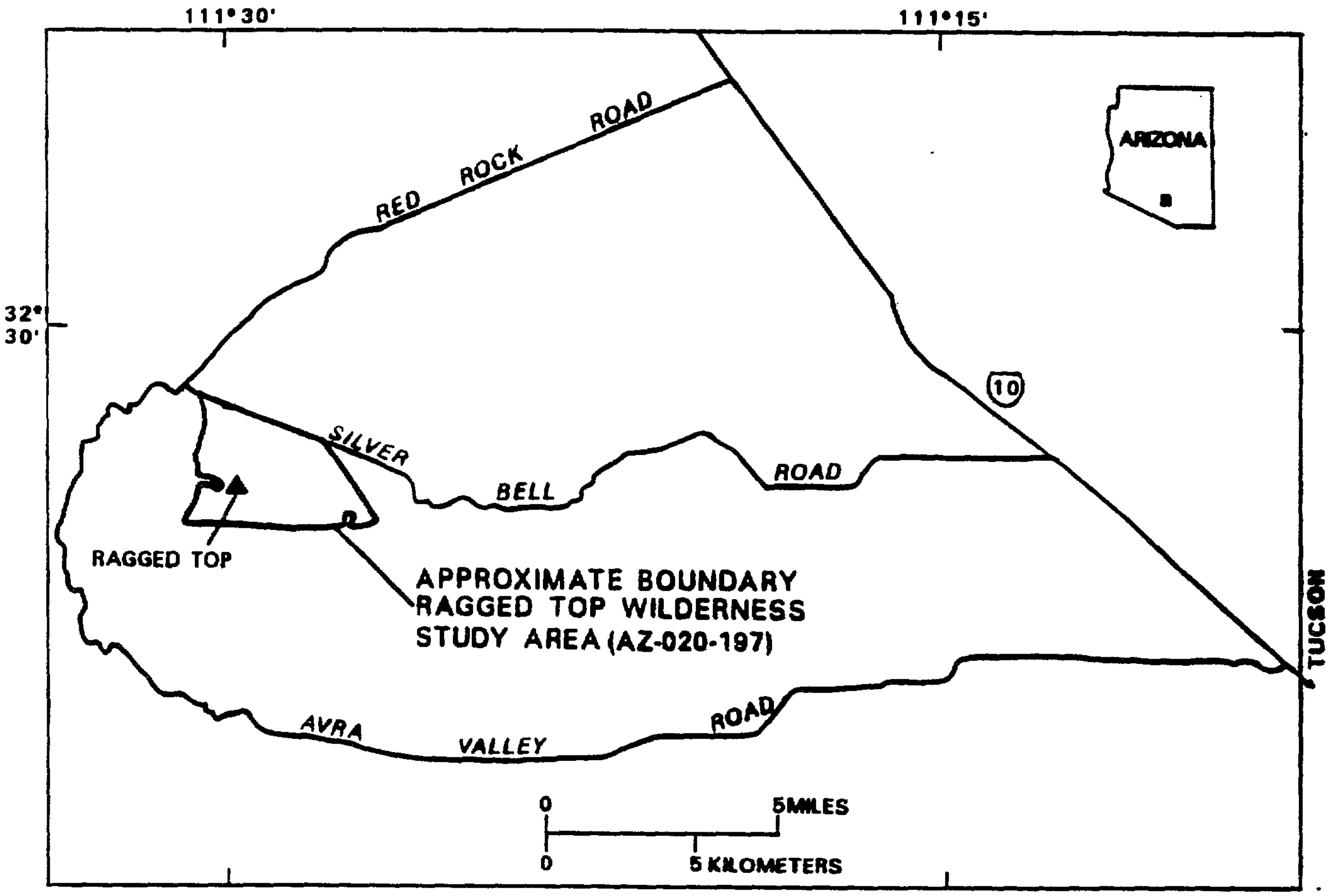

Figure 1. Index map, Ragged Top Wilderness Study Area, Pima County, Arizona.

although Middle Proterozoic Apache Group sedimentary rocks crop out east of Ragged Top. Upper Cretaceous volcanic rocks predominate south of the Ragged Top fault. The volcanic rocks consist of andesite-to-dacite extrusive rocks and rhyolite tuffs. Upper Cretaceous sedimentary rocks southwest of Ragged Top contain clasts that include Precambrian schist, Paleozoic sedimentary rocks, probable Lower Cretaceous sandstone, Cretaceous algal limestone, and volcanic rocks. An Upper Cretaceous granodiorite porphyry laccolith underlies part of the southwestern section of the wilderness study area. Ragged Top is an Oligocene rhyolite dome that was extruded along the trace of the Ragged Top fault. Quaternary sediments that are mostly unconsolidated cover the flatter sections of the study area.

Sawyer (1986, 1987) and Lipman and Sawyer (1985) present evidence to support the concept that the Upper Cretaceous sedimentary rocks, the Upper Cretaceous andesite-to-dacite extrusive rocks, and certain of the Upper Cretaceous rhyolite tuffs are the results of the formation and later collapse of a caldera during Late Cretaceous time.

METHODS OF STUDY

Sample Media

Analyses of stream-sediment samples represent the chemistry of the rock material eroded from the drainage basin upstream from each sample site. Such information is useful in identifying those basins which contain concentrations of elements that may be related to mineral deposits. Panned-concentrate samples derived from stream sediment provide information about the chemistry of certain minerals in rock material eroded from the drainage basin upstream from each sample site. The selective concentration of minerals in panned-concentrate samples, many of which may be ore related, permits determination of some elements that are not easily detected in stream-sediment samples. Analyses of unmineralized or unaltered rock samples provide background geochemical data for individual rock units. Analyses of mineralized or altered rocks may provide useful geochemical information about the major- and trace-element assemblages associated with a mineralizing system.

Sample Collection and Preparation

Sampling sites are represented on plate 1. During the initial reconnaissance sampling in March 1987, a stream-sediment sample and two panned-concentrate samples derived from stream sediment were collected at each of the 11 sites (numbers 105-108, 113-118, 126). The two panned-concentrate samples from each site were treated differently, as described below, and after preparation were respectively termed a "nonmagnetic heavy-mineral-concentrate sample" and a "raw panned-concentrate sample." Average sampling density during the reconnaissance sampling was about one sample site per 0.7 mi^2 and the drainage basins ranged from 0.2 mi^2 to 1.5 mi^2 in area. During the follow-up sampling in December 1987, nonmagnetic heavy-mineral-concentrate and raw panned-concentrate samples were collected at 15 localities (numbers 7301-7305, 7312-7314, 7317-7323) except that no nonmagnetic heavy-mineral-concentrate sample was collected at site 7321. Samples were collected by Gary A. Nowlan and David A. Sawyer.

Stream-sediment samples

The stream-sediment samples consisted of active alluvium collected primarily from first-order (unbranched) and second-order (below the junction of two first-order) streams as shown on U.S. Geological Survey topographic maps (scale = 1:24,000). The stream-sediment samples were dried, then sieved using 30-mesh (0.595-mm) stainless-steel sieves. The portion of the sediment passing through the sieve was pulverized to approximately minus-100 mesh (minus-0.15 mm) for analysis.

Nonmagnetic heavy-mineral-concentrate samples

Ten to twenty pounds of stream sediment were collected from the active alluvium. Most of the samples were panned without screening. However, samples from sites 105-108 and 113-114 were screened with a 2.0-mm (10-mesh) screen to obtain about 20 lb after removal of the coarse material. The samples were panned to remove most of the quartz, feldspar, organic matter, and clay-sized material. The resulting concentrates were estimated to weigh between 1 and 4 oz.

After drying, bromoform (specific gravity 2.8) was used to remove the remaining quartz and feldspar from the samples that had been panned. Each heavy-mineral sample was then separated into three fractions using a large electromagnet (in this case a modified Frantz Isodynamic Separator). The most magnetic material, primarily magnetite, was not analyzed. The second fraction, largely ferromagnesian silicates and iron oxides, was saved for archival storage. The third fraction (the least magnetic material which may include the nonmagnetic ore minerals, zircon, sphene, etc.) was split using a Jones splitter. One split was hand ground for spectrographic analysis; the other split was saved for mineralogical analysis. These magnetic separates are approximately the same separates that would be produced by using a Frantz Isodynamic Separator set at a slope of 15° and a tilt of 10° with a current of 0.2 ampere to remove the magnetite and ilmenite, and a current of 0.6 ampere to split the remainder of the sample into paramagnetic and nonmagnetic fractions.

Raw panned-concentrate samples

Raw panned-concentrate samples were collected and panned in the same manner as the heavy-mineral-concentrate samples except that the samples were panned to a smaller amount. The raw panned-concentrate samples were dried and then were analyzed for gold without further preparation.

Rock samples

Sixty-four samples of bedrock were collected (table 1). The 28 samples from the RTR130 series were collected from outcrops at generally 100-ft intervals along a traverse crossing an area of altered bedrock along the west side of the wilderness study area. Sample RTR106A is from a shear zone. The seven samples from the 82S series were collected in 1982 and are representative of bedrock units where mineralization is absent and alteration is slight. The 28 samples from the RT7300 series are samples of mineralized rock, altered rock, and vein material. Descriptions of the rock samples are in table 1. Rock samples were crushed and then pulverized to approximately minus-100 mesh (minus-0.15 mm) with ceramic plates.

Sample Analysis

Spectrographic method

The stream-sediment samples were analyzed for 31 elements and the nonmagnetic heavy-mineral-concentrate and rock samples for 35-37 elements using a semiquantitative, direct-current arc emission spectrographic method (Grimes and Marranzino, 1968). The elements analyzed and their lower limits of determination are listed in tables 2 and 3. Spectrographic results were obtained by visual comparison of spectra derived from the sample against spectra obtained from standards made from pure oxides and carbonates. Standard concentrations are geometrically spaced over any given order of magnitude of concentration as follows: 100, 50, 20, 10, and so forth. Samples whose concentrations are estimated to fall between those values are assigned values of 70, 30, 15, and so forth. The precision of the analytical method is approximately plus or minus one reporting interval at the 83 percent confidence level and plus or minus two reporting intervals at the 96 percent confidence level (Motooka and Grimes, 1976). Values determined for the major elements (iron, magnesium, calcium, titanium, sodium, and phosphorus) are given in weight percent; all others are given in parts per million (ppm). Emission spectrographic analyses were performed by John H. Bullock, Jr.

Other methods

Table 4 lists other methods of analysis used on samples from the Ragged Top Wilderness Study Area and lists limits of determination, precision, and references for the methods. Rock and stream-sediment samples were analyzed for gold by graphite furnace atomic absorption spectroscopy and for antimony, arsenic, bismuth, cadmium, and zinc by inductively coupled plasma emission spectrometry. Rock samples were analyzed for mercury by cold vapor atomic absorption spectroscopy, for tellurium and thallium by flame atomic absorption spectroscopy, for fluorine by ion selective electrode, and for tungsten by visible spectrophotometry. Stream-sediment samples were analyzed for uranium by ultraviolet fluorimetry. Raw panned-concentrate samples were analyzed for gold by flame atomic absorption spectroscopy. Analysts were Paul H. Briggs, Alonza H. Love, John B. McHugh, Richard M. O'Leary, Theodore A. Roemer, John D. Sharkey, and Eric P. Welsch.

Analytical results for stream-sediment, nonmagnetic heavy-mineral-concentrate, raw panned-concentrate, and rock samples are listed in tables 5, 6, 7, and 8, respectively.

DATA STORAGE SYSTEM

Upon completion of analytical work, the results were entered into a U.S. Geological Survey computer data base called PLUTO. This data base contains both descriptive geological information and analytical data. Any or all of this information may be retrieved and converted to a binary form (STATPAC) for computerized statistical analysis or publication (VanTrump and Miesch, 1977).

DESCRIPTION OF DATA TABLES

The numeric portion of each sample identification in tables 5-7 and of RT7300-series rock samples and sample RTR106A in table 8 corresponds to the site number on plate 1. However, only the last three numbers in sample identifications for 82S-series rock samples in table 8 correspond to site numbers on plate 1. Sites A-Z on plate 1 show the sampling sites of RTR130-series rocks and correspond to the letter immediately following 130 in each sample identification in table 8.

A letter "N" in the tables indicates that a given element was looked for but not detected at the lower limit of determination. If an element determined by emission spectrography was observed but was below the lowest reporting value, a "less than" symbol (<) was entered in the tables in front of the lower limit of determination. No distinction was made between "not detected" and "less than" for samples analyzed by methods other than emission spectrography. If an element was above the highest reporting value, a "greater than" symbol (>) was entered in the tables in front of the upper limit of determination. The lower limit of determination for gold in raw panned-concentrate samples by atomic absorption spectroscopy is 0.05 ppm, based on a 10-g sample. Because the sample weight for raw panned-concentrate samples was variable, the lower limits of determination varied from 0.02 to 0.07 ppm. The weights of the raw panned-concentrate samples (table 7) are given in grams and are in the column headed by "weight".

Because of the formatting used in the computer program that produced tables 5-8, some of the elements listed in these tables (Ca, Fe, Mg, Na, P, Ti, Ag, Be, Cd-i, Au-a, Hg-a, Te-a, and Tl-a) carry one or more nonsignificant digits to the right of the significant digits. The spectrographic determinations for As, Au, Bi, Cd, Mo, Sb, Th, and W in stream-sediment samples; for As, Co, Ge, Nb, Pd, Pt, Sb, and Th in nonmagnetic heavy-mineral-concentrate samples; and for As, Au, Ge, Sb, Sn, and Th in rock samples were all below the lower limits of determinations shown in tables 2 and 3; consequently, the columns for these elements were omitted from tables 5, 6, and 8, respectively. The spectrographic determinations for Zr in nonmagnetic heavy-mineral-concentrate samples were all greater than the upper limit of determination and so that element was omitted from table 6.

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Table 1.--Descriptions of analyzed rock samples from the Ragged Top Wilderness Study Area, Pima County, Arizona.

Sample	Description
RTR130AA	Granodiorite porphyry
RTR130BA	Granodiorite porphyry
RTR130CA	Granodiorite porphyry, slightly altered
RTR130DA	Granodiorite porphyry, slightly altered
RTR130DB	Granodiorite porphyry, altered
RTR130EA	Granodiorite porphyry, altered
RTR130EB	Granodiorite porphyry, altered
RTR130FA	Granodiorite porphyry, altered
RTR130GA	Granodiorite porphyry, highly altered, brecciated
RTR130HA	Granodiorite porphyry, highly altered, brecciated
RTR130IA	Granodiorite porphyry, highly altered, brecciated
RTR130JA	Granodiorite porphyry, highly altered, brecciated
RTR130KA	Granodiorite porphyry, highly altered,
RTR130LA	Fine grained rock, highly altered
RTR130MA	Granodiorite porphyry, altered
RTR130NA	Potassium-rich rock
RTR130OA	Potassium-rich rock
RTR130PA	Granodiorite porphyry, slightly altered
RTR130QA	Granodiorite porphyry, slightly altered
RTR130RA	Granodiorite porphyry, slightly altered
RTR130SA	Granodiorite porphyry
RTR130TA	Granodiorite porphyry, slightly altered
RTR130UA	Granodiorite porphyry, slightly altered
RTR130VA	Granodiorite porphyry
RTR130WA	Diabase
RTR130XA	Oracle-type granite
RTR130YA	Diabase
RTR130ZA	Oracle-type granite
RTR106A	Oracle-type granite from shear zone
82S-023	Granodiorite porphyry
82S-044	Granodiorite porphyry
82S-122	Lithic tuff
82S-133	Rhyolite welded tuff
82S-135	Rhyodacite porphyry
82S-150	Rhyodacite porphyry
82S-382	Rhyolite
RT7306A	Barite-fluorite vein
RT7306BA	Barite vein
RT7306BB	Altered wall rock by barite vein
RT7307A	Granodiorite porphyry, altered
RT7308A	Granodiorite porphyry, altered
RT7309A	Sulfide minerals and calcite
RT7309B	Granodiorite porphyry with sulfide minerals
RT7309C	Granodiorite porphyry with sulfide minerals

Table 1.--Descriptions of analyzed rock samples from the Ragged Top Wilderness Study Area, Pima County, Arizona--Continued.

Sample	Description
RT7309D	Dolomite (?) vein with sulfide minerals
RT7309EA	Rhodochrosite (?) vein with sulfide minerals
RT7309EB	Granodiorite porphyry with rhodochrosite (?) and sulfide minerals
RT7309F	Granodiorite porphyry with sulfide minerals
RT7309G	Granodiorite porphyry with sulfide minerals
RT7310A	Granodiorite porphyry
RT7310B	Granodiorite porphyry with calcite and sulfide minerals
RT7311AA	Quartz vein
RT7311AB	Quartz vein
RT7315A	Quartz vein
RT7315B	Quartz vein
RT7315CA	Quartz vein
RT7315CB	Altered granite
RT7316A	Diabase
RT7324A	Barite vein
RT7324B	Barite vein
RT7324CA	Quartz vein
RT7324CB	Quartz vein
RT7325A	Quartz vein
RT7326A	Quartz vein with sulfide minerals

TABLE 2.--Limits of determination for the spectrographic analysis of stream-sediment samples, based on a 10-mg sample

Elements	Lower determination limit	Upper determination limit
	Percent	
Iron (Fe)	0.05	20
Magnesium (Mg)	.02	10
Calcium (Ca)	.05	20
Titanium (Ti)	.002	1
	Parts per million	
Manganese (Mn)	10	5,000
Silver (Ag)	0.5	5,000
Arsenic (As)	200	10,000
Gold (Au)	10	500
Boron (B)	10	2,000
Barium (Ba)	20	5,000
Beryllium (Be)	1	1,000
Bismuth (Bi)	10	1,000
Cadmium (Cd)	20	500
Cobalt (Co)	5	2,000
Chromium (Cr)	10	5,000
Copper (Cu)	5	20,000
Lanthanum (La)	20	1,000
Molybdenum (Mo)	5	2,000
Niobium (Nb)	20	2,000
Nickel (Ni)	5	5,000
Lead (Pb)	10	20,000
Antimony (Sb)	100	10,000
Scandium (Sc)	5	100
Tin (Sn)	10	1,000
Strontium (Sr)	100	5,000
Vanadium (V)	10	10,000
Tungsten (W)	50	10,000
Yttrium (Y)	10	2,000
Zinc (Zn)	200	10,000
Zirconium (Zr)	10	1,000
Thorium (Th)	100	2,000

TABLE 3.--Limits of determination for the spectrographic analysis of heavy-mineral-concentrate samples based on a 5-mg sample

[The spectrographic limits of determination for rock samples are based on a 10-mg sample and are therefore two reporting intervals lower than the limits listed in this table]

Elements	Lower determination limit	Upper determination limit
	Percent	
Iron (Fe)	0.1	50
Magnesium (Mg)	.05	20
Calcium (Ca)	.1	50
Titanium (Ti)	.005	2
Sodium (Na)	.5	10
Phosphorus (P)	.5	20
	Parts per million	
Manganese (Mn)	20	10,000
Silver (Ag)	1	10,000
Arsenic (As)	500	20,000
Gold (Au)	20	1,000
Boron (B)	20	5,000
Barium (Ba)	50	10,000
Beryllium (Be)	2	2,000
Bismuth (Bi)	20	2,000
Cadmium (Cd)	50	1,000
Cobalt (Co)	20	5,000
Chromium (Cr)	20	10,000
Copper (Cu)	10	50,000
Lanthanum (La)	100	2,000
Molybdenum (Mo)	10	5,000
Niobium (Nb)	50	5,000
Nickel (Ni)	10	10,000
Lead (Pb)	20	50,000
Antimony (Sb)	200	20,000
Scandium (Sc)	10	2,000
Tin (Sn)	20	2,000
Strontium (Sr)	200	10,000
Vanadium (V)	20	20,000
Tungsten (W)	50	20,000
Yttrium (Y)	20	5,000
Zinc (Zn)	500	20,000
Zirconium (Zr)	20	2,000
Thorium (Th)	200	5,000
Gallium (Ga)	10	1,000
Germanium (Ge)	20	200
Platinum (Pt)	20	1,000
Palladium (Pd)	5	1,000

TABLE 4.--Analytical methods used other than emission spectrography

[AAC, cold vapor atomic absorption; AAF, flame atomic absorption; AAG, graphite furnace atomic absorption; F, ultraviolet fluorimetry; ICP, inductively coupled plasma spectrometry; ISE, ion selective electrode; VS, visible spectrophotometry; <, less than value shown]

Element determined	Sample type	Method	Lower limit of determination, ppm	Precision, percent relative standard deviation	References
Mercury (Hg)	rocks	AAC	0.02	<5	Crock and others, 1987.
Tellurium (Te)	rocks	AAF	0.1	4.5-7.3	Hubert and Chao, 1985.
Thallium (Tl)	rocks	AAF	0.05	1.6-12.5	Hubert and Chao, 1985.
Gold (Au)	raw panned concentrates	AAF	0.05[a]	9.3-42.5	Thompson and others, 1968; O'Leary and Meier, 1986.
Gold (Au)	rocks, stream sediments	AAG	0.001	3.7-21.1	Meier, 1980; O'Leary, and Meier, 1986.
Uranium (U)	stream sediments	F	0.1	6.9-14.2	Centanni and others, 1956; O'Leary and Meier, 1986.
Antimony (Sb)	rocks, stream sediments	ICP	2	6.4-11	Crock and others, 1987.
Arsenic (As)	rocks, stream sediments	ICP	5	3.5-20	Crock and others, 1987.
Bismuth (Bi)	rocks, stream sediments	ICP	2	2.2-11.9	Crock and others, 1987.
Cadmium (Cd)	rocks, stream sediments	ICP	0.1	2.8-8.8	Crock and others, 1987.
Zinc (Zn)	rocks, stream sediments	ICP	2	1.4-11.9	Crock and others, 1987.
Fluorine (F)	rocks	ISE[b]	100	0.98-5.51	Hopkins, 1977; O'Leary and Meier, 1986.
Tungsten (W)	rocks	VS	1	2.9-6.9	Welsch, 1983; O'Leary and Meier, 1986.

[a]Based on 10-g sample

[b]Hot nitric acid digestion

Table 5.--Results of analyses of stream-sediment samples collected from the Ragged Top Wilderness Study Area, Pima County, Arizona

[N, not detected; <, detected below limit of determination shown for emission spectrographic analyses, less than value shown for other methods; >, greater than value shown; ---, not determined. Methods: Au-a, atomic absorption; As-i, Bi-i, Cd-i, Sb-i, Zn-i, inductively coupled plasma spectroscopy; U-f, ultraviolet fluorimetry; others, emission spectrography. Element values in ppm except Ca, Fe, Mg, and Ti, which are weight percent]

Sample	Latitude	Longitude	Ca	Fe	Mg	Ti	Ag	Au-a	As-i	B	Ba	Be	Bi-i	Cd-i	Co
RTA105	32 26 34	111 27 28	1.5	5	1.5	.7	N	---	7	50	700	3.0	<2	.8	30
RTA106	32 27 5	111 27 18	1.0	10	1.5	.7	N	.001	6	20	300	2.0	<2	2.3	70
RTA107	32 27 16	111 27 29	1.0	7	1.0	1.0	N	<.001	<5	30	500	3.0	<2	1.4	30
RTA108	32 27 46	111 27 54	.3	15	.3	.5	N	---	7	70	300	3.0	<2	2.5	70
RTA113	32 27 2	111 27 17	.5	7	.7	1.0	N	<.001	9	70	300	2.0	<2	1.9	30
RTA114	32 28 8	111 28 50	.7	7	1.0	1.0	N	---	6	15	500	3.0	<2	1.3	15
RTA115	32 28 31	111 30 4	.7	10	1.5	.7	N	<.001	<5	30	500	3.0	<2	1.3	20
RTA116	32 28 19	111 30 30	.7	10	.7	.7	N	.002	9	50	1,500	3.0	2	1.4	30
RTA117	32 27 43	111 30 39	1.0	5	1.5	.5	.5	.005	8	50	1,000	2.0	<2	1.3	15
RTA118	32 26 57	111 30 35	.5	5	1.0	.3	N	.010	<5	10	500	1.0	<2	.7	5
RTA126	32 26 14	111 29 4	.7	7	1.0	.5	N	.001	7	10	300	1.5	<2	.8	10

Sample	Cr	Cu	La	Mn	Nb	Ni	Pb	Sb-i	Sc	Sn	Sr	U-f	V	Y	Zn	Zn-i	Zr
RTA105	30	30	30	500	<20	30	50	2	15	N	200	1.1	150	20	N	68	500
RTA106	50	70	<20	1,000	N	50	50	11	15	<10	<100	2.2	200	50	200	88	200
RTA107	30	50	20	1,500	N	20	50	<2	20	N	<100	3.0	200	70	200	71	300
RTA108	200	30	N	700	<20	50	30	<2	10	N	N	7.5	500	500	N	31	300
RTA113	30	50	<20	300	<20	30	30	14	15	<10	N	1.9	200	50	N	89	300
RTA114	20	50	70	700	<20	15	30	<2	20	<10	<100	3.7	150	100	N	75	1,000
RTA115	30	30	50	2,000	<20	15	50	<2	15	N	100	2.8	200	100	N	81	500
RTA116	50	50	50	1,000	<20	30	150	<2	20	<10	100	2.9	300	70	N	77	1,000
RTA117	30	70	30	2,000	N	20	300	<2	15	N	150	1.1	100	20	200	150	200
RTA118	20	30	<20	500	N	7	70	<2	<5	N	100	1.2	70	<10	<200	68	70
RTA126	20	20	<20	500	N	15	50	<2	5	N	100	1.1	100	10	N	80	100

Table 6.--Results of analyses of nonmagnetic heavy-mineral-concentrate samples from the Ragged Top Wilderness Study Area, Pima County, Arizona

[N, not detected; <, detected below limit of determination shown; >, greater than value shown. Analyses by emission spectrography. Element values are ppm except Ca, Fe, Mg, Na, P, and Ti, which are weight percent]

Sample	Latitude	Longitude	Ca	Fe	Mg	Na	P	Ti	Ag	Au	B	Ba	Be	Bi	Cd
RTH105	32 26 34	111 27 28	5	1.00	.30	1.5	2.0	2.0	N	N	20	>10,000	3	N	N
RTH106	32 27 5	111 27 18	3	1.50	.30	.7	2.0	2.0	N	N	20	5,000	7	50	N
RTH107	32 27 16	111 27 29	5	.70	.20	.5	5.0	1.0	N	N	30	3,000	10	70	N
RTH108	32 27 46	111 27 54	5	1.00	.20	5.0	1.5	.2	N	N	20	1,000	5	N	N
RTH113	32 27 2	111 27 17	5	1.00	.50	2.0	1.5	1.5	N	N	30	>10,000	5	N	N
RTH114	32 28 8	111 28 50	10	.50	.20	1.5	10.0	.7	N	N	<20	700	5	N	N
RTH115	32 28 31	111 30 4	10	1.00	.30	2.0	5.0	1.5	N	N	20	3,000	7	N	N
RTH116	32 28 19	111 30 30	5	.70	.30	1.0	1.0	.7	N	N	<20	>10,000	7	N	N
RTH117	32 27 43	111 30 39	10	1.50	.50	3.0	2.0	1.5	<1	N	30	>10,000	2	N	N
RTH118	32 26 57	111 30 35	2	.30	.10	1.0	1.0	.5	1,000	>1,000	N	>10,000	N	30	N
RTH126	32 26 14	111 29 4	7	.70	.15	2.0	1.5	1.5	2	N	<20	10,000	3	N	<50
RTH7301B	32 26 56	111 30 34	7	.10	.10	N	2.0	.3	2	N	N	>10,000	N	N	N
RTH7302	32 26 53	111 30 31	20	.20	.10	N	7.0	.7	2	N	N	>10,000	N	N	N
RTH7303	32 26 55	111 30 27	30	.30	.10	N	7.0	.5	<1	N	N	>10,000	N	N	N
RTH7304B	32 26 50	111 30 16	20	.20	.15	N	1.5	.5	300	N	N	>10,000	N	300	70
RTH7305B	32 27 1	111 30 43	10	.10	.07	N	.5	.1	30	N	N	>10,000	N	N	N
RTH7312	32 27 9	111 27 44	15	.70	.15	.5	2.0	1.5	N	N	20	3,000	5	30	N
RTH7313	32 27 8	111 27 43	15	.70	.30	1.0	.7	1.0	N	N	20	>10,000	3	N	N
RTH7314	32 27 5	111 27 21	20	1.50	1.00	2.0	1.0	2.0	N	N	30	10,000	2	30	N
RTH7317	32 26 31	111 29 57	20	1.00	.15	N	7.0	1.5	N	N	N	>10,000	<2	N	N
RTH7318	32 26 39	111 30 3	5	.20	.10	<.5	.7	.3	N	N	N	>10,000	<2	N	N
RTH7319B	32 26 42	111 30 13	10	.20	.10	<.5	2.0	1.0	15	70	<20	>10,000	N	N	N
RTH7320B	32 26 40	111 30 14	2	.10	.07	N	<.5	.2	N	N	N	>10,000	N	N	N
RTH7322	32 26 9	111 30 16	3	<.10	.07	N	<.5	.2	N	N	N	>10,000	N	N	N
RTH7323	32 26 15	111 30 18	3	.15	.10	N	.5	.2	1	N	N	>10,000	N	N	N

Sample	Cr	Cu	Ga	La	Mn	Mo	Ni	Pb	Sc	Sn	Sr	V	W	Y	Zn
RTH105	<20	70	20	N	300	N	<10	70	50	N	700	50	N	500	N
RTH106	20	20	15	<100	500	N	<10	1,000	200	N	N	200	N	1,500	N
RTH107	N	15	10	<100	700	N	<10	70	200	N	N	100	N	1,500	N
RTH108	N	<10	30	N	700	N	<10	50	70	N	N	50	50	1,000	N
RTH113	<20	50	70	N	700	N	<10	2,000	100	N	200	100	N	1,500	N
RTH114	N	N	15	100	1,000	N	N	70	150	N	N	50	N	1,500	N
RTH115	N	10	30	100	700	N	N	100	100	N	N	50	N	1,000	N
RTH116	N	<10	15	N	700	N	N	200	150	N	700	30	N	1,000	N
RTH117	20	50	50	150	700	<10	<10	3,000	50	N	700	100	N	500	N
RTH118	N	150	<10	<100	200	150	N	>50,000	30	N	1,500	15,000	N	150	<500
RTH126	N	<10	10	100	300	N	N	1,000	50	N	N	700	N	300	N
RTH7301B	N	70	N	100	500	10	N	15,000	20	N	>10,000	1,500	N	300	500
RTH7302	N	30	N	150	700	100	N	3,000	20	N	10,000	150	N	500	N
RTH7303	N	<10	N	300	1,000	N	N	1,500	20	N	10,000	150	N	300	N
RTH7304B	<20	1,000	N	150	1,000	500	N	>50,000	30	N	10,000	5,000	N	200	700
RTH7305B	N	20	N	<100	200	20	N	500	N	N	>10,000	500	N	70	<500
RTH7312	N	50	<10	100	1,000	N	N	50	200	N	<200	200	N	1,500	N
RTH7313	<20	10	10	100	500	N	N	<20	200	N	500	150	N	1,500	N
RTH7314	<20	20	30	100	1,000	N	N	<20	100	50	500	150	N	1,000	N
RTH7317	N	<10	N	200	1,000	N	N	30	100	N	700	300	N	700	N
RTH7318	50	50	N	N	500	N	N	50	15	N	>10,000	700	N	200	N
RTH7319B	20	20	N	150	700	<10	N	>50,000	70	N	7,000	10,000	N	700	N
RTH7320B	N	15	N	N	150	30	N	3,000	<10	N	>10,000	300	N	100	N
RTH7322	N	N	N	N	300	200	N	1,500	N	N	>10,000	50	N	70	N
RTH7323	N	<10	N	N	500	<10	N	10,000	20	N	10,000	3,000	N	150	N

Table 7.--Results of analyses of raw panned-concentrate samples collected from the Ragged Top Wilderness Study Area, Pima County, Arizona

[<, less than value shown. Au-a in ppm. Weight, grams of raw panned-concentrate sample. Analyses by atomic absorption]

Sample	Latitude	Longitude	Au-a	Weight
RTG105	32 26 34	111 27 28	<.05	11.01
RTG106	32 27 5	111 27 18	<.04	13.09
RTG107	32 27 16	111 27 29	<.05	11.02
RTG108	32 27 46	111 27 54	<.05	9.97
RTG113	32 27 2	111 27 17	<.06	7.95
RTG114	32 28 8	111 28 50	<.04	14.45
RTG115	32 28 31	111 30 4	<.05	10.04
RTG116	32 28 19	111 30 30	<.05	11.35
RTG117	32 27 43	111 30 39	<.07	6.55
RTG118	32 26 57	111 30 35	150.00	7.44
RTG126	32 26 14	111 29 4	<.05	11.55
RTG7301	32 26 56	111 30 34	2.30	21.57
RTG7302	32 26 53	111 30 31	.20	15.18
RTG7303	32 26 55	111 30 27	.03	19.68
RTG7304	32 26 50	111 30 16	3.40	13.13
RTG7305	32 27 1	111 30 43	.03	17.80
RTG7312	32 27 9	111 27 44	<.03	21.45
RTG7313	32 27 8	111 27 43	.03	19.83
RTG7314	32 27 5	111 27 21	<.03	16.69
RTG7317	32 26 31	111 29 57	.06	15.89
RTG7318	32 26 39	111 30 3	<.02	26.66
RTG7319	32 26 42	111 30 13	.11	16.62
RTG7320	32 26 40	111 30 14	.23	25.10
RTG7321	32 26 30	111 30 15	.03	18.29
RTG7322	32 26 9	111 30 16	.04	13.32
RTG7323	32 26 15	111 30 18	.99	20.00

Table 8.--Results of analyses of rock samples collected from the Ragged Top Wilderness Study Area, Pima County, Arizona

[N, not detected; <, detected below limit of determination shown for emission spectrographic analyses, less than value shown for other methods; >, greater than value shown; ---, not determined. Methods: As-i, Bi-i, Cd-i, Sb-i, Zn-i, inductively coupled spectroscopy; Au-a, Hg-a, Te-a, Tl-a, atomic absorption; W-v, visible spectrophotometry; F-is, ion selective electrode; others, emission spectrography. Values in ppm except Ca, Fe, Mg, Na, P, Ti, and F-is, which are weight percent]

Sample	Latitude	Longitude	Ca	Fe	Mg	Na	P	Ti	Ag	B	Ba	Be
RTR130AA	32 27 4	111 30 31	.70	5.0	1.0	3.0	N	.500	N	10	3,000	1.5
RTR130BA	32 27 5	111 30 31	1.00	5.0	2.0	3.0	N	.500	N	15	1,000	<1.0
RTR130CA	32 27 6	111 30 31	.30	7.0	2.0	2.0	N	.700	N	100	1,000	1.5
RTR130DA	32 27 7	111 30 31	.20	5.0	2.0	3.0	N	.500	<.5	20	1,000	1.0
RTR130DB	32 27 7	111 30 31	.20	5.0	1.5	3.0	N	.500	N	20	1,000	1.0
RTR130EA	32 27 8	111 30 30	.30	5.0	.5	1.0	N	.300	N	70	1,500	<1.0
RTR130EB	32 27 8	111 30 30	.15	3.0	.2	.5	N	.500	N	50	700	<1.0
RTR130FA	32 27 10	111 30 31	.20	3.0	1.5	3.0	N	.300	.5	30	200	1.0
RTR130GA	32 27 11	111 30 31	.07	7.0	.3	.5	N	.700	1.0	300	1,500	1.0
RTR130HA	32 27 12	111 30 31	.20	7.0	.7	1.5	<.2	.700	<.5	500	1,500	1.0
RTR130IA	32 27 13	111 30 30	.15	5.0	1.5	2.0	N	.300	N	150	1,000	1.5
RTR130JA	32 27 14	111 30 30	.20	7.0	1.5	3.0	N	.700	N	50	1,000	<1.0
RTR130KA	32 27 15	111 30 31	.30	7.0	2.0	2.0	N	.700	N	50	2,000	1.5
RTR130LA	32 27 15	111 30 32	.15	10.0	3.0	2.0	N	.700	N	300	1,000	1.5
RTR130MA	32 27 16	111 30 33	.30	3.0	1.0	<.2	N	.500	N	50	1,500	1.5
RTR130NA	32 27 17	111 30 33	.30	7.0	.7	3.0	N	.700	N	50	1,500	1.0
RTR130OA	32 27 18	111 30 34	.15	5.0	1.0	2.0	N	.700	N	100	2,000	1.0
RTR130PA	32 27 19	111 30 34	2.00	7.0	2.0	3.0	N	.700	N	70	1,500	1.5
RTR130QA	32 27 20	111 30 34	3.00	7.0	3.0	3.0	N	.700	N	10	700	<1.0
RTR130RA	32 27 21	111 30 34	2.00	7.0	3.0	2.0	N	.700	N	30	1,000	1.5
RTR130SA	32 27 22	111 30 34	1.50	7.0	3.0	3.0	N	.500	N	<10	1,000	<1.0
RTR130TA	32 27 25	111 30 35	1.00	7.0	1.5	3.0	N	.500	N	20	1,000	<1.0
RTR130UA	32 27 27	111 30 34	.30	5.0	1.5	3.0	N	.700	N	20	1,000	1.0
RTR130VA	32 27 29	111 30 33	.20	3.0	.5	3.0	N	.300	N	10	2,000	2.0
RTR130WA	32 27 30	111 30 33	3.00	10.0	3.0	2.0	.7	1.000	N	10	300	2.0
RTR130XA	32 27 31	111 30 34	.70	3.0	.7	2.0	N	.500	N	15	1,000	1.5
RTR130YA	32 27 32	111 30 34	3.00	20.0	5.0	2.0	.2	>1.000	N	15	500	2.0
RTR130ZA	32 27 34	111 30 35	.30	5.0	.3	3.0	N	.500	N	10	1,000	1.5
RTR106A	32 27 5	111 27 18	15.00	10.0	10.0	<.2	N	.200	N	<10	200	1.5
82S-023	32 27 29	111 30 48	.50	5.0	1.0	3.0	N	.200	N	<10	1,500	<1.0
82S-044	32 26 59	111 31 20	1.50	7.0	2.0	3.0	N	.500	N	10	1,000	N
82S-122	32 26 11	111 30 15	1.00	2.0	.5	2.0	N	.200	N	10	1,500	1.0
82S-133	32 25 32	111 30 25	.70	3.0	.3	3.0	N	.300	N	<10	2,000	<1.0
82S-135	32 25 29	111 30 23	1.50	5.0	1.5	3.0	N	.300	N	10	1,500	<1.0
82S-150	32 26 15	111 29 35	1.50	7.0	2.0	3.0	N	.300	N	<10	1,000	<1.0
82S-382	32 26 47	111 29 18	.30	2.0	.2	5.0	N	.200	N	N	1,000	1.5
RT7306A	32 26 54	111 30 39	2.00	3.0	.7	1.5	N	.200	.5	10	>5,000	<1.0
RT7306BA	32 26 54	111 30 39	5.00	.1	.1	N	N	.015	N	<10	>5,000	N
RT7306BB	32 26 54	111 30 39	3.00	2.0	.5	N	N	.070	N	70	>5,000	5.0
RT7307A	32 26 58	111 30 18	.50	2.0	.1	N	N	.500	<.5	20	1,000	N
RT7308A	32 26 58	111 30 5	.07	5.0	.5	3.0	N	.300	.5	<10	1,500	N
RT7309A	32 27 2	111 30 6	7.00	7.0	.3	>5.0	N	.150	150.0	10	150	N
RT7309B	32 27 2	111 30 6	1.00	5.0	1.5	2.0	N	.500	100.0	10	1,500	<1.0
RT7309C	32 27 2	111 30 6	.30	7.0	.5	1.5	N	.500	20.0	20	300	<1.0
RT7309D	32 27 2	111 30 6	20.00	5.0	1.5	.3	N	.200	1.0	30	2,000	1.0

Table 8.--Results of analyses of rock samples collected from the Ragged Top Wilderness Study Area, Pima County, Arizona--Continued

Sample	Bi	Cd	Co	Cr	Cu	Ga	La	Mn	Mo	Nb	Ni	Pb	Sc	Sr	V	W
RTR130AA	N	N	10	N	50	70	50	500	N	N	N	30	5	500	100	N
RTR130BA	N	N	20	20	30	70	<50	700	N	N	20	20	10	500	150	N
RTR130CA	N	N	15	30	70	50	50	500	N	N	20	100	15	200	200	N
RTR130DA	N	N	15	15	70	50	<50	1,500	N	N	30	200	10	300	150	N
RTR130DB	N	N	N	N	70	70	50	300	N	N	15	30	10	200	200	N
RTR130EA	<10	N	<10	10	30	70	<50	70	N	N	<5	150	7	150	150	N
RTR130EB	<10	N	N	30	30	50	<50	50	N	N	<5	500	7	100	200	N
RTR130FA	N	N	<10	15	50	70	<50	500	N	N	5	300	7	200	100	N
RTR130GA	N	N	N	30	100	50	<50	50	5	N	N	15	10	150	200	N
RTR130HA	N	N	<10	20	30	70	50	200	<5	N	<5	30	10	100	200	N
RTR130IA	N	N	10	15	50	50	<50	300	N	N	20	15	7	200	150	N
RTR130JA	N	N	10	10	50	70	<50	200	N	N	5	20	15	300	200	N
RTR130KA	N	N	50	10	70	70	<50	1,000	<5	N	30	20	10	200	150	N
RTR130LA	N	N	30	20	50	50	<50	1,000	N	N	10	15	15	100	300	N
RTR130MA	N	N	N	15	15	50	<50	100	N	N	N	150	7	100	150	N
RTR130NA	N	N	N	20	50	70	50	150	5	N	N	30	10	150	200	N
RTR130OA	N	N	N	15	30	70	<50	70	<5	N	N	50	10	100	150	N
RTR130PA	N	N	30	10	50	100	50	2,000	<5	N	15	50	10	300	200	N
RTR130QA	N	N	50	10	70	70	<50	1,500	N	N	20	10	20	500	200	N
RTR130RA	N	N	30	15	70	100	50	1,500	N	N	20	10	10	200	150	N
RTR130SA	N	N	70	10	70	70	<50	1,500	N	N	15	15	15	700	150	N
RTR130TA	N	N	100	15	70	100	N	5,000	5	N	20	15	7	500	150	N
RTR130UA	N	N	15	15	70	100	<50	1,500	<5	N	10	30	10	500	200	N
RTR130VA	N	N	N	N	5	100	70	300	<5	<20	N	100	5	200	20	N
RTR130WA	N	N	30	<10	100	100	N	2,000	N	N	<5	100	15	150	150	N
RTR130XA	N	N	15	<10	10	30	<50	500	<5	N	5	10	7	100	50	N
RTR130YA	N	N	100	50	100	100	N	3,000	N	N	100	10	30	300	300	N
RTR130ZA	N	N	<10	<10	30	70	50	300	<5	N	<5	15	10	100	70	N
RTR106A	N	N	150	N	70	20	N	3,000	N	N	100	100	20	200	500	N
82S-023	N	N	15	N	15	70	N	500	N	N	N	30	<5	200	100	---
82S-044	N	N	20	15	70	100	N	700	N	N	10	30	10	500	200	N
82S-122	N	N	10	N	<5	30	N	500	N	N	N	30	<5	150	50	---
82S-133	N	N	N	N	<5	70	70	500	N	N	N	20	5	100	20	N
82S-135	N	N	20	30	5	100	N	500	N	N	20	30	7	300	150	N
82S-150	N	N	20	20	50	100	N	500	N	N	15	15	7	200	150	N
82S-382	N	N	N	N	<5	70	50	300	N	N	N	50	N	<100	15	N
RT7306A	N	N	<10	10	30	50	N	200	N	N	7	300	<5	3,000	100	N
RT7306BA	N	N	N	N	15	10	N	200	N	N	N	300	N	>5,000	150	N
RT7306BB	N	N	N	<10	50	10	50	1,000	N	N	10	500	<5	200	200	N
RT7307A	N	N	N	<10	5	20	N	10	N	N	N	N	<5	N	100	N
RT7308A	N	N	<10	10	7	100	N	300	N	N	<5	20	<5	<100	70	N
RT7309A	15	>500	<10	N	3,000	30	N	2,000	150	N	N	>20,000	<5	N	50	N
RT7309B	N	N	20	15	200	70	N	1,500	<5	N	20	150	5	<100	100	N
RT7309C	<10	70	15	20	200	50	N	300	20	N	15	5,000	5	N	150	N
RT7309D	N	N	10	N	100	30	50	3,000	<5	N	5	200	<5	150	70	N

Table 8.--Results of analyses of rock samples collected from the Ragged Top Wilderness Study Area, Pima County, Arizona--Continued

Sample	Y	Zn	Zr	As-i	Bi-i	Cd-i	Sb-i	Zn-i	Au-a	Hg-a	Te-a	Tl-a	W-v	F-is
RTR130AA	10	N	150	---	---	---	---	---	<.001	---	---	---	---	---
RTR130BA	15	<200	100	---	---	---	---	---	<.001	---	---	---	---	---
RTR130CA	15	<200	100	---	---	---	---	---	.004	---	---	---	---	---
RTR130DA	15	<200	100	---	---	---	---	---	.002	---	---	---	---	---
RTR130DB	20	<200	200	---	---	---	---	---	.004	---	---	---	---	---
RTR130EA	15	N	500	---	---	---	---	---	.002	---	---	---	---	---
RTR130EB	10	N	200	---	---	---	---	---	.002	---	---	---	---	---
RTR130FA	15	200	100	---	---	---	---	---	.005	---	---	---	---	---
RTR130GA	10	N	150	---	---	---	---	---	.008	---	---	---	---	---
RTR130HA	15	N	200	---	---	---	---	---	.002	---	---	---	---	---
RTR130IA	10	<200	100	---	---	---	---	---	.001	---	---	---	---	---
RTR130JA	15	N	300	---	---	---	---	---	.001	---	---	---	---	---
RTR130KA	20	<200	70	---	---	---	---	---	.004	---	---	---	---	---
RTR130LA	30	N	200	---	---	---	---	---	.002	---	---	---	---	---
RTR130MA	20	N	200	---	---	---	---	---	.002	---	---	---	---	---
RTR130NA	20	N	200	---	---	---	---	---	.002	---	---	---	---	---
RTR130OA	15	N	200	---	---	---	---	---	.001	---	---	---	---	---
RTR130PA	20	N	150	---	---	---	---	---	.003	---	---	---	---	---
RTR130QA	30	<200	150	---	---	---	---	---	<.001	---	---	---	---	---
RTR130RA	30	<200	200	---	---	---	---	---	<.001	---	---	---	---	---
RTR130SA	15	<200	100	---	---	---	---	---	<.001	---	---	---	---	---
RTR130TA	50	N	200	---	---	---	---	---	.001	---	---	---	---	---
RTR130UA	15	N	150	---	---	---	---	---	.001	---	---	---	---	---
RTR130VA	30	N	200	---	---	---	---	---	<.001	---	---	---	---	---
RTR130WA	50	<200	100	---	---	---	---	---	<.001	---	---	---	---	---
RTR130XA	70	N	100	---	---	---	---	---	<.001	---	---	---	---	---
RTR130YA	50	<200	150	---	---	---	---	---	<.001	---	---	---	---	---
RTR130ZA	50	N	200	---	---	---	---	---	<.001	---	---	---	---	---
RTR106A	70	<200	20	---	---	---	---	---	.001	---	---	---	---	---
82S-023	N	N	100	11	<2	.5	25	59	<.001	<.02	<.05	.35	---	.03
82S-044	10	N	70	<5	<2	.7	3	37	<.001	.04	<.05	.40	1.2	.03
82S-122	10	N	70	<5	<2	.2	9	19	<.001	<.02	<.05	.50	---	.02
82S-133	15	N	500	<5	<2	.3	3	37	<.001	.02	<.05	.70	1.2	.03
82S-135	<10	N	100	<5	<2	.8	5	54	<.001	.02	<.05	.45	1.5	.03
82S-150	10	N	150	<5	<2	.7	3	44	<.001	.02	<.05	.30	.9	.03
82S-382	10	N	150	<5	<2	<.1	<2	29	<.001	<.02	<.05	.70	1.0	.02
RT7306A	10	2,000	50	<5	<2	.8	<2	1,600	.006	.12	<.05	.50	2.0	1.70
RT7306BA	15	<200	N	12	<2	.3	<2	130	.002	.02	<.05	<.05	.6	1.30
RT7306BB	30	500	30	23	<2	6.1	6	370	.007	.04	<.05	.25	3.3	2.40
RT7307A	N	N	20	<5	<2	.1	<2	3	.003	<.02	<.05	1.10	3.4	.02
RT7308A	N	N	50	27	<2	.4	<2	35	.015	<.02	.55	.85	2.2	.02
RT7309A	10	>10,000	15	<5	2	1,600.0	<2	>40,000	---	2.90	7.30	.50	1.6	.90
RT7309B	10	300	100	17	<2	4.7	3	610	.015	<.02	.35	1.10	2.5	.03
RT7309C	10	>10,000	100	16	6	53.0	5	6,400	.090	.20	2.00	1.60	5.4	.04
RT7309D	15	200	100	13	<2	3.5	6	580	.020	.02	.10	.50	1.4	.07

Table 8.--Results of analyses of rock samples collected from the Ragged Top Wilderness Study Area, Pima County, Arizona--Continued

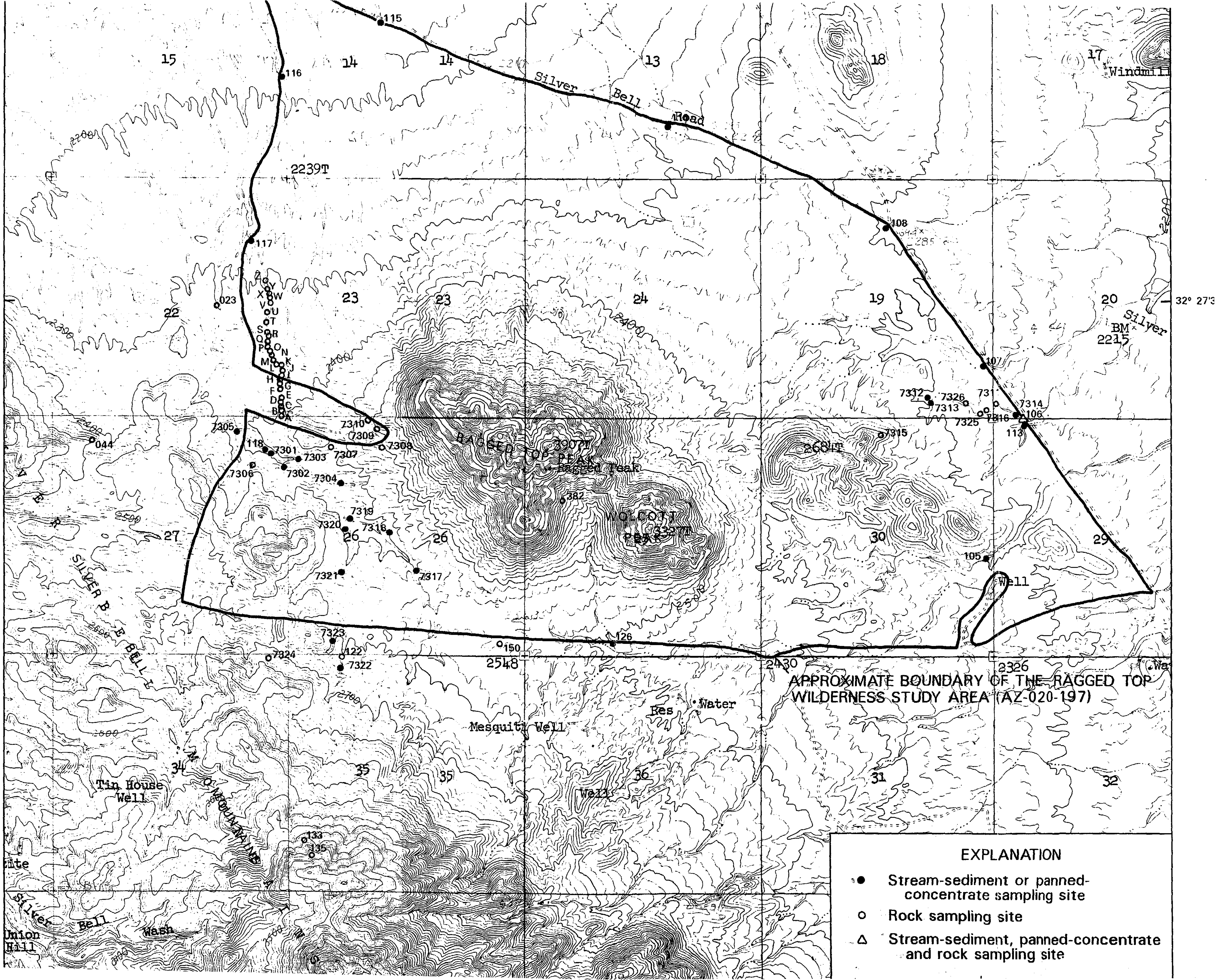
Sample	Latitude	Longitude	Ca	Fe	Mg	Na	P	Ti	Ag	B	Ba	Be
RT7309EA	32 27 2	111 30 6	>20.00	10.0	.3	N	N	.002	50.0	15	1,500	N
RT7309EB	32 27 2	111 30 6	15.00	3.0	.3	N	N	.150	15.0	15	150	N
RT7309F	32 27 2	111 30 6	1.00	5.0	2.0	2.0	N	.700	<.5	10	200	<1.0
RT7309G	32 27 2	111 30 6	.70	7.0	1.5	3.0	N	.700	<.5	<10	2,000	<1.0
RT7310A	32 27 4	111 30 8	.70	5.0	1.5	1.5	N	.700	1.5	10	700	1.0
RT7310B	32 27 4	111 30 8	10.00	5.0	1.0	1.0	N	.300	30.0	10	500	<1.0
RT7311AA	32 27 8	111 27 26	20.00	7.0	3.0	.2	N	.030	N	<10	3,000	N
RT7311AB	32 27 8	111 27 26	20.00	3.0	1.0	N	N	.015	N	<10	150	N
RT7315A	32 27 1	111 27 56	5.00	5.0	2.0	<.2	N	.200	N	10	700	1.5
RT7315B	32 27 1	111 27 56	1.00	5.0	.1	N	N	.300	N	15	1,500	1.0
RT7315CA	32 27 1	111 27 56	1.50	2.0	.5	2.0	N	.200	N	10	300	N
RT7315CB	32 27 1	111 27 56	.50	5.0	.7	3.0	N	.200	<.5	10	200	N
RT7316A	32 27 7	111 27 28	7.00	10.0	5.0	3.0	N	1.000	N	<10	500	N
RT7324A	32 26 11	111 30 34	.07	1.0	.3	1.5	<.2	.100	2.0	<10	>5,000	N
RT7324B	32 26 11	111 30 34	.50	1.5	.1	N	<.2	.700	3.0	N	>5,000	N
RT7324CA	32 26 11	111 30 34	.10	.5	.1	N	N	.020	N	<10	700	<1.0
RT7324CB	32 26 11	111 30 34	.20	2.0	.2	.2	N	.100	2.0	<10	1,000	5.0
RT7325A	32 27 6	111 27 30	1.50	10.0	3.0	2.0	N	1.000	N	<10	150	<1.0
RT7326A	32 27 8	111 27 34	5.00	7.0	3.0	2.0	N	.050	N	<10	150	<1.0

Table 8.--Results of analyses of rock samples collected from the Ragged Top Wilderness Study Area, Pima County, Arizona--Continued

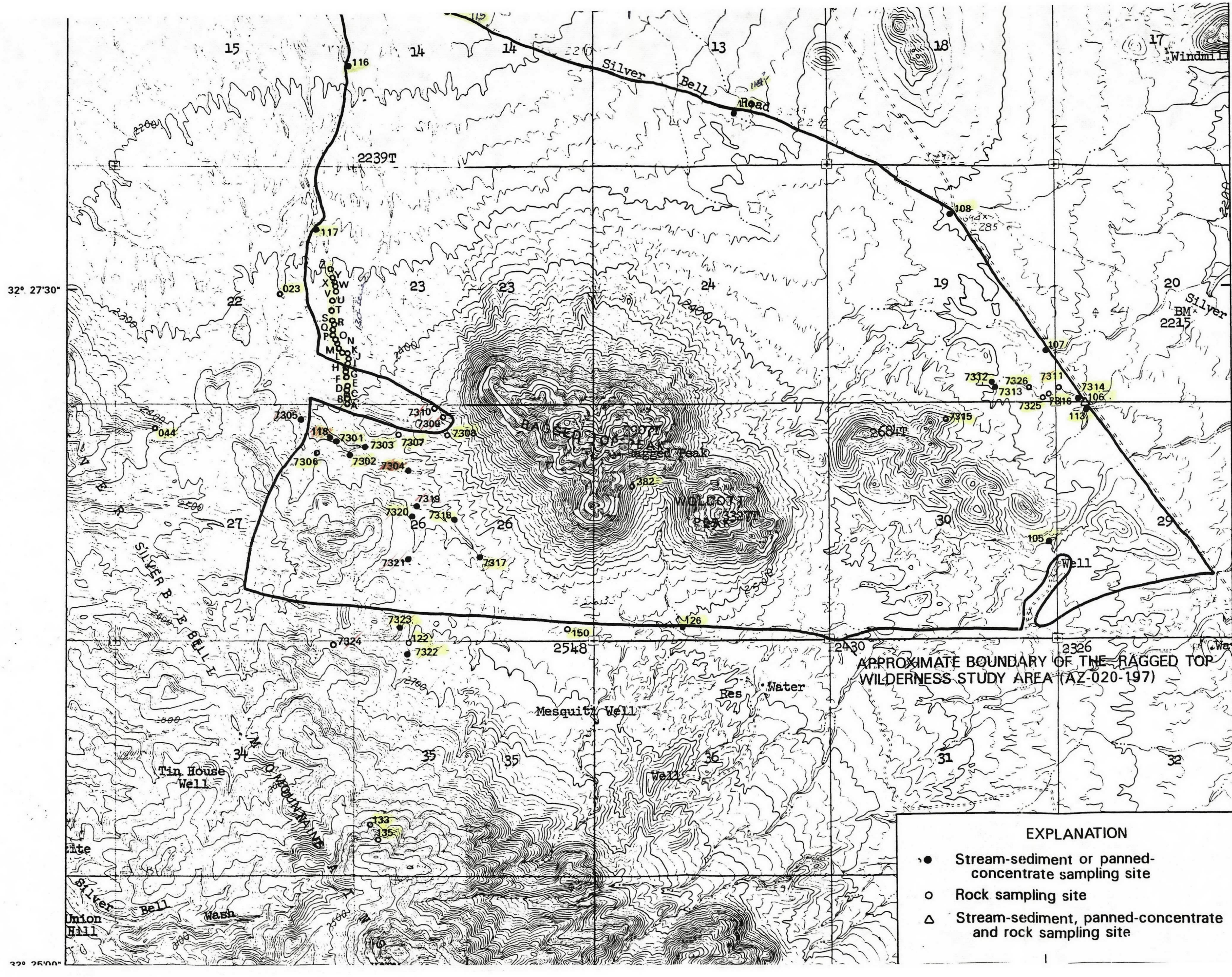
Sample	Bi	Cd	Co	Cr	Cu	Ga	La	Mn	Mo	Nb	Ni	Pb	Sc	Sr	V	W
RT7309EA	N	500	N	<10	15,000	30	<50	>5,000	10	N	<5	>20,000	20	500	10	N
RT7309EB	10	20	<10	<10	700	50	<50	2,000	10	N	<5	20,000	N	100	50	N
RT7309F	N	N	20	20	100	70	N	1,500	N	N	20	50	5	N	150	N
RT7309G	N	N	15	15	200	100	N	2,000	N	N	10	70	7	<100	100	N
RT7310A	N	N	20	20	70	30	N	1,500	N	N	15	50	7	<100	100	N
RT7310B	15	N	15	10	15	70	<50	2,000	<5	N	10	20,000	5	N	100	N
RT7311AA	N	N	20	30	30	N	N	3,000	N	N	30	20	15	100	50	N
RT7311AB	N	N	<10	10	10	<5	N	2,000	N	N	10	N	N	<100	30	N
RT7315A	N	N	10	N	15	30	<50	1,000	N	N	<5	10	<5	N	50	N
RT7315B	N	N	15	N	15	20	<50	700	N	<20	<5	<10	5	N	50	N
RT7315CA	N	N	N	N	7	50	<50	500	N	<20	<5	10	N	<100	30	N
RT7315CB	N	N	N	N	10	100	N	200	N	N	N	50	N	N	50	N
RT7316A	N	N	100	500	100	70	N	1,000	N	N	100	N	30	<100	300	N
RT7324A	N	N	N	N	20	15	N	200	300	N	N	1,000	N	>5,000	15	N
RT7324B	N	N	N	150	100	<5	N	100	200	N	5	500	<5	>5,000	70	<20
RT7324CA	N	N	N	N	5	10	N	300	N	N	N	N	N	N	10	N
RT7324CB	N	N	N	N	20	20	N	700	7	N	<5	30	N	N	20	N
RT7325A	N	N	70	300	50	70	N	1,500	N	N	150	50	30	N	300	N
RT7326A	N	N	70	<10	70	50	N	2,000	N	N	50	50	<5	N	150	N

Table 8.--Results of analyses of rock samples collected from the Ragged Top Wilderness Study Area, Pima County, Arizona--Continued

Sample	Y	Zn	Zr	As-i	Bi-i	Cd-i	Sb-i	Zn-i	Au-a	Hg-a	Te-a	Tl-a	W-v	F-is
RT7309EA	200	>10,000	N	<5	<2	410.0	4	34,000	.080	1.20	2.00	.10	<.5	<.01
RT7309EB	20	7,000	10	10	4	28.0	6	3,400	.100	.08	1.60	.90	2.7	.02
RT7309F	<10	<200	150	7	<2	.8	<2	110	.009	<.02	<.05	.70	2.9	.02
RT7309G	10	<200	30	8	<2	6.0	8	160	.005	<.02	<.05	.85	1.7	.02
RT7310A	<10	<200	100	13	<2	.7	<2	110	.026	<.02	.70	1.00	2.5	.03
RT7310B	15	700	30	14	9	6.4	6	770	.380	.02	4.00	.80	1.7	.03
RT7311AA	20	N	10	<5	<2	2.4	<2	36	.007	.38	<.05	.15	<.5	<.01
RT7311AB	<10	N	N	<5	<2	1.2	<2	13	.044	2.20	<.05	.15	<.5	<.01
RT7315A	50	N	100	<5	<2	1.1	3	34	.001	.40	<.05	.55	1.3	.01
RT7315B	30	N	70	<5	<2	.4	5	50	<.001	<.02	<.05	.30	1.2	.02
RT7315CA	10	N	50	<5	<2	.2	<2	23	.002	<.02	<.05	.50	.6	.01
RT7315CB	<10	N	30	<5	<2	.1	<2	26	.002	<.02	<.05	.50	.7	<.01
RT7316A	15	N	70	<5	<2	.4	<2	20	.006	.10	<.05	.10	.5	<.01
RT7324A	N	N	15	<5	<2	.2	4	69	.023	.12	<.05	.30	3.2	<.01
RT7324B	15	N	100	9	<2	.4	3	71	.023	.50	<.05	1.60	7.4	.01
RT7324CA	N	N	N	<5	<2	.3	<2	10	.021	.02	<.05	.25	.5	.04
RT7324CB	10	N	20	5	<2	1.0	3	46	.250	.02	<.05	.55	1.6	.03
RT7325A	10	300	20	<5	<2	1.8	<2	290	.004	.04	<.05	.05	4.3	.02
RT7326A	10	<200	100	<5	<2	1.6	<2	190	.002	.02	<.05	.05	.6	.01



32° 27'30"
Silver Bell Road
Ragged Top Peak
Ragged Peak
Wolcott Peak
Mesquite Well
Tin House Well
Well
Res
Water
Windmill
Silver Bell Wash
Union Hill
Silver Bell Mountains
2239T
2548
2430
2326
BM 2215
APPROXIMATE BOUNDARY OF THE RAGGED TOP WILDERNESS STUDY AREA (AZ-020-197)
EXPLANATION
Stream-sediment or panned-concentrate sampling site
Rock sampling site
Stream-sediment, panned-concentrate and rock sampling site



118 stream
non-mag-pan conc.
raw pan

Au-Ag "anomalous"

"Non-anomalous"

United States Department of the Interior

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DENVER FEDERAL CENTER
DENVER, COLORADO 80225

TAKE PRIDE IN AMERICA

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David Sawyer (303) 236-1082
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GOLD IN THE SILVER BELL MOUNTAINS, PIMA COUNTY, ARIZONA

A reconnaissance geochemical survey of the Ragged Top Wilderness Study Area, Pima County, Arizona, by the U.S. Geological Survey (USGS) revealed highly anomalous concentrations of gold in samples of stream sediment collected from ephemeral streams draining part of the wilderness study area. The samples also contain highly anomalous concentrations of silver, lead, vanadium, and barium, and weakly anomalous concentrations of strontium, molybdenum, copper, zinc, cadmium, and bismuth.

The 4,460-acre Ragged Top Wilderness Study Area is in the northern part of the Silver Bell Mountains about 35 miles northwest of Tucson, Arizona. The Bureau of Land Management (BLM) recommended against wilderness status for the Ragged Top Wilderness Study Area in the Arizona Mohave Draft Wilderness Environmental Impact Statement, dated June 1987 and it has not been closed to mining or development. The anomalous samples are generally from an area adjoining the outer alteration halo of known porphyry copper ore deposits that have been mined in the Silver Bell mining district. The district has produced more than 90 million tons of ore since 1885, including more than 1.3 billion pounds of copper and nearly 6 million ounces of silver, but only 2,200 ounces of gold. Because only minor amounts of gold have been mined in the past, the geochemical anomaly may represent a previously unrecognized type of mineral deposit in the Silver Bell mining district.

Gold contents of anomalous panned-concentrate samples are as high as 150 ppm (equivalent to approximately 0.12 ppm, or 0.0035 oz/ton, in the stream sediment), and more than three samples in the vicinity have gold contents from 1 to 30 ppm (equivalent to 2-21 ppb in the stream sediment). Bedrock samples of vein and altered rock material contain as much as 380 ppb gold; several channel samples at the Ragged Top mine collected and analyzed by the U.S. Bureau of Mines (USBM) contain as much as 4 ppm gold. Concentrations of the highly anomalous elements in the nonmagnetic heavy fraction of stream-sediment concentrates were as high as 1,000 ppm for silver; >50,000 ppm for lead; 15,000 ppm for vanadium; and >10,000 ppm for barium.

The geochemically anomalous zone is located on the southwest side of Ragged Top, a middle Tertiary (Oligocene) rhyolite lava dome emplaced along a major west-northwest-trending fault, the Ragged Top fault. Movement on the Ragged Top fault was probably strike-slip, and the fault was active between 69 and 25 million years ago. The fault separates two fundamentally different geologic terranes: Precambrian granite overlain by Tertiary volcanic rocks to the north, and Late Cretaceous volcanic and sedimentary rocks that accumulated within a caldera to the south. The porphyry copper deposits of the Silver Bell mining district formed within granitic intrusions emplaced during the final stages of the Late Cretaceous caldera volcanism at Silver Bell.

Details of the mineralization are not yet fully known, but at least three explanations are possible for the origin of the geochemical anomaly. The first is that mineralization occurred during the Late Cretaceous, and was related to the outer precious-metal halo around the Laramide porphyry copper system. A second explanation is that the mineralization was caused by middle Tertiary volcanism and structural activity associated with the Ragged Top rhyolite dome and related north-northwest-striking dikes. The third possibility is that mineralization was caused by middle Tertiary remobilization and concentration of precious metals deposited by the Late Cretaceous porphyry copper system. This last interpretation and its implications will be discussed in a poster session presented by David A. Sawyer and Gary A. Nowlan, USGS, at the Geological Society of America Annual Meeting in Denver, Colorado on November 3, 1988. The geochemical signature and geologic setting of the stream-sediment anomaly are very similar to the Mammoth-St. Anthony vein ore deposit, adjoining the San Manuel porphyry copper system.

The geochemical survey was undertaken as part of a mineral survey of public lands administered by BLM. The Federal Land Policy and Management Act of 1976 (Public Law 94-579) instructed BLM to review all public lands under its jurisdiction to determine their suitability for wilderness status. Mineral surveys by the USGS and the USBM were required for areas judged by BLM to be suitable for possible wilderness status.

The results of the geochemical survey of the Ragged Top Wilderness Study Area are tabulated in U.S. Geological Survey Open-File Report 88-587, co-authored by USGS analysts John B. McHugh and John H. Bullock, Jr., and USGS geologists Gary A. Nowlan and David A. Sawyer. The report, titled "Analytical Results and Sample Locality Map for Stream-Sediment, Panned-Concentrate, and Rock Samples from the Ragged Top Wilderness Study Area, Pima County, Arizona," may be examined at U.S. Geological Survey Public Inquiries Offices at the following addresses:

Room 169
Federal Bldg.
1961 Stout St.
Denver, CO 80294

Room 7638
Federal Bldg.
300 North Los Angeles St.
Los Angeles, CA 90012

Room 504
Customs House
555 Battery St.
San Francisco, CA 94111

Room 8105
Federal Building
125 South State St.
Salt Lake City, UT 84138

The report can also be purchased from the Books and Open-File Reports Section, U.S. Geological Survey, Federal Center, Box 25425, Denver, Colo. Prices are $4.75 for each paper copy and $4.00 for microfiche. Orders must specify the report number (OFR 88-587) and include checks or money orders payable to the Department of the Interior, USGS.

ASARCO Incorporated

OCT 1 9 1988

SW Exploration

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Department of the Interior
U.S. Geological Survey
119 National Center
Reston, Virginia 22092

Public Affairs Office David Terrell (703) 648-4460

For Release: UPON RECEIPT (Mailed October 17, 1988)

GOLD FOUND IN ARIZONA WILDERNESS STUDY AREA

Scientists with the U.S. Geological Survey, conducting a geochemical study in the Ragged Top Wilderness Study Area of Pima County, Ariz., have discovered unusually high concentrations of gold in selected stream sediments.

After panning, samples of stream sediments have yielded gold concentrations as high as 150 parts per million (ppm), indicating concentrations of about 0.12 ppm, or 0.0035 ounce per ton, in unpanned stream sediments. These and other geochemical data are available in a USGS report released Monday (Oct. 17, 1988).

Gary Nowlan and David Sawyer, USGS geologists in Denver, Colo., who conducted the survey, termed the concentrations "highly anomalous." The gold in some samples is in yellow flakes large enough to be seen in pans, Nowlan said.

Because only minor amounts of gold have been mined from the area, the detection by the USGS scientists may indicate a previously unrecognized gold deposit in or near the adjacent Silver Bell Mining District.

Accompanying the relatively high amounts of gold in the samples are significantly high concentrations of silver, lead, vanadium and barium. Additional exploration will be needed, however, to confirm the extent of any deposits of gold.

Sawyer and Nowlan will present a poster session on the existence and possible origin of a gold deposit in the Ragged Top area at the Geological Society of America's annual meeting Nov. 3 in Denver, Colo.

The 4,460-acre study area in the northern Silver Bell Mountains is about 35 miles northwest of Tucson. The concentrations of gold were in streams near the mining district.

The district contains deposits that have produced more than 90 million tons of mineral ore since 1885. The production has included more than 1.3 billion pounds of copper and 6 million ounces of silver, but just 2,200 ounces of gold.

The U.S. Bureau of Land Management recommended in a draft environmental impact statement in 1987 that the Ragged Top study area not be designated a wilderness area by Congress, and it has not been closed to mining or development.

The Federal Land Policy and Management Act of 1976 instructed the BLM to review all the lands under its jurisdiction to determine their suitability for wilderness designation. This study was one of a series of mineral assessment surveys required of the USGS and the U.S. Bureau of Mines in areas selected by the BLM as possible wilderness areas.

(more)

Details of the geochemical data and sampling sites and methodology used in the study were released as USGS Open-File Report 88-587, titled "Analytical Results and Sample Locality Map for Stream-Sediment, Panned Concentrate, and Rock Samples from the Ragged Top Wilderness Study Area, Pima County, Arizona." Copies are available at $4.75 on paper or $4 on microfiche from the USGS, Books and Open-File Reports Section, Box 25425, Denver, Colo. 80225.

* * * USGS * * *

(Note to editors: Review copies of the report are available to news media from the Public Affairs Office, U.S. Geological Survey, 119 National Center, Reston, Va. 22092, telephone 703-648-4460; or from the Public Affairs Office, U.S. Geological Survey, 345 Middlefield Road, Menlo Park, Calif. 94025, telephone 415-329-4000).

"Tim"

- Nothing in BLM's Claimant Index 10-8-87

Contact this prospector & arrange to visit the area. I had asked for location, but as you read — He didn't provide such. Jim 2/15/88

Timothy Conroy
Box 539 Arizona City
85223
ph. 466-5113

ASARCO Incorporated

FEB 5 1988

SW Exploration

To: Mr. Sell
re: possible exploration

PORTIONS OF Sec. 30, 31, 32 T10S, R7E } Leased/or staked by Conroy as per 4-7-88 phone call from Conroy.

Dear sir:

Rec. 2-10-88 HG

This is a brief prospecting summary of the surface on the area discussed by phone Feb 1, firstly, I realize that it would seem unlikely that any mineralized area in southern Arizona would not have been thoroughly prospected by mining/exploration companies or in part be noticed and cited by U.S. geog. survey teams that mapped the area, yet I feel this property was overlooked.

The rocks of the area are monzonite/diorite porphyries with quartz in excess (quartz monzonite/diorite), these rocks were in turn intruded by diabase dikes of irregular form. Limestone is scarce, some conglomerate beds were formed and cemented mostly by carbonates so little replacement is noticed on veins in this area.

What attracted me to this area was a iron stained leached outcrop which appeared to be a fissure vein, faulting was evident as seen by slickensided quartz and the gliding plane down the fissures strike, there are no apparent walls on the surface. Specularite and epidote are seen as contact minerals, in places specularite floods the rock, copper stained barite with fluorite are also found in places, hematite and other iron oxides are abundant on and near this outcropping, although no carbonate veins are seen on the surface it appears that siderate veinlets were converted to iron as witnessed in other veins near this outcrop, in some places a greenish yellow clay appears, this material showed .25 cu. and .001 au. on assay. The length of this vein is 2000 ft. and 75 ft. in width. This outcrop may have been superficially explored before, some shallow holes are noticed along the outcrop, perhaps the low au. value discouraged further work, in checking with the state land office and pinal co. records no claims were ever recorded in this area.

He had 640 ac. "down" under state? at one time

I filed permits to explore this outcrop, but decided that after a year of exploring that the outcropping was to lean of au. and to small to persue as a copper prospect. Last year I started searching away from the vein, in following a diabase dike I was surprised at the amount of the oxidized veinlets that ran from the dike laterally into the porphyry, in tracing these veinlets they showed to be siderate veins converted to iron, this dike was abruptly sheared between two small hills with diabase going in all directions, I followed a vein of rhodocrosite and found apple green copper stained quartz diorite going up one small hill, this rock showed disseminated blebs of copper material, but in places relic chalcopyrite had not yet fully oxidized, I found more greenish iron stained clay at the base of the hill, the porphyry here was almost as altered as the vein I described earlier.

2-12-88 Mr. Conroy said area of interest is within 25 miles of Silver Bell, and the land is open to location & state lease. He controls none of it. I told him he needs to acquire the minerals before bringing it to Asarco. He wants to go on a finder's fee, and I told him ASARCO never works on a finder's fee basis.

Conroy has done alot of prospecting.

The big difference was the amount, this stained porphyry was bedded with no hills or rolling plain, I spent 3 months exploring this mineralized land, the porphyry was colored with subtle shades of brown,yellow and red, I found large kaolin blankets, anhydrite veins and in places more apple green porphyry, calcite and quartz veins also run through this rock, aplite veins with a sugary texture are common. I realized that I was'nt looking at 2 or more deposits, but one large mineralized deposit with a somewhat enriched peripheral zone, because of alluvium I cannot give an accurate measure of the size, but a mile square would not to far off.

As you can see I've painted a pretty picture, but the reality is that I don't know whats under this rock. It would be impractable if not futile for me to explore this area on my own, my knowledge is limited to basic prospecting, and my finances are limited to basic beer drinking. I believe this area warrants exploration on a different level than I'm able to give. If you or your company would like to examine this area please contact me.

Thank you,
yours truly,
Tim Conroy

JDS

ASARCO

Mineral Beneficiation Department

September 9, 1988

Mr. J. D. Sell, Manager
Southwestern Exploration Dept.
TUCSON OFFICE

The sample splitter in use at Silver Bell for samples from the current drilling program is in poor condition, resulting in loss of material during splitting. For this reason, I looked for another splitter of about the same size at the Ventura Warehouse. I found a suitable one (approx. 10"x18"x1" riffle spacing) and borrowed the splitter and stand for use at Silver Bell during the duration of the drilling program. Mr. Kreis advised that this splitter should not be needed in the near future. There are also several others of about the same size on hand in the warehouse.

T. D. Henderson, Jr.

TDH:brw

cc: D. C. Duncan
H. G. Kreis
DEC/File - SB 2.18

JDS

ASARCO

Southwestern Exploration Division

October 26, 1988

F. T. Graybeal
New York Office

Gold Anomalies
Ragged Top WSA
Pima County, AZ

You may have seen/heard of the Silver Bell gold rush -- or the gold rush that never happened -- and I now submit Mr. Miller's assessment and the OFR 88-587 for your files.

Perhaps it can be summed up by saying: "One anomalous gold value in a panned concentrate does not make a project."

However, as you note, Mr. Miller did collect a few more samples which he will report on later.

Sawyer and Nowlan will also present this and additional data at a poster session at the Denver GSA meeting next week.

James D. Sell

James D. Sell

JDS:mek
Att.

cc: W.L. Kurtz

ASARCO

Southwestern Exploration Division

2 DS

January 11, 1988

W. D. Gay

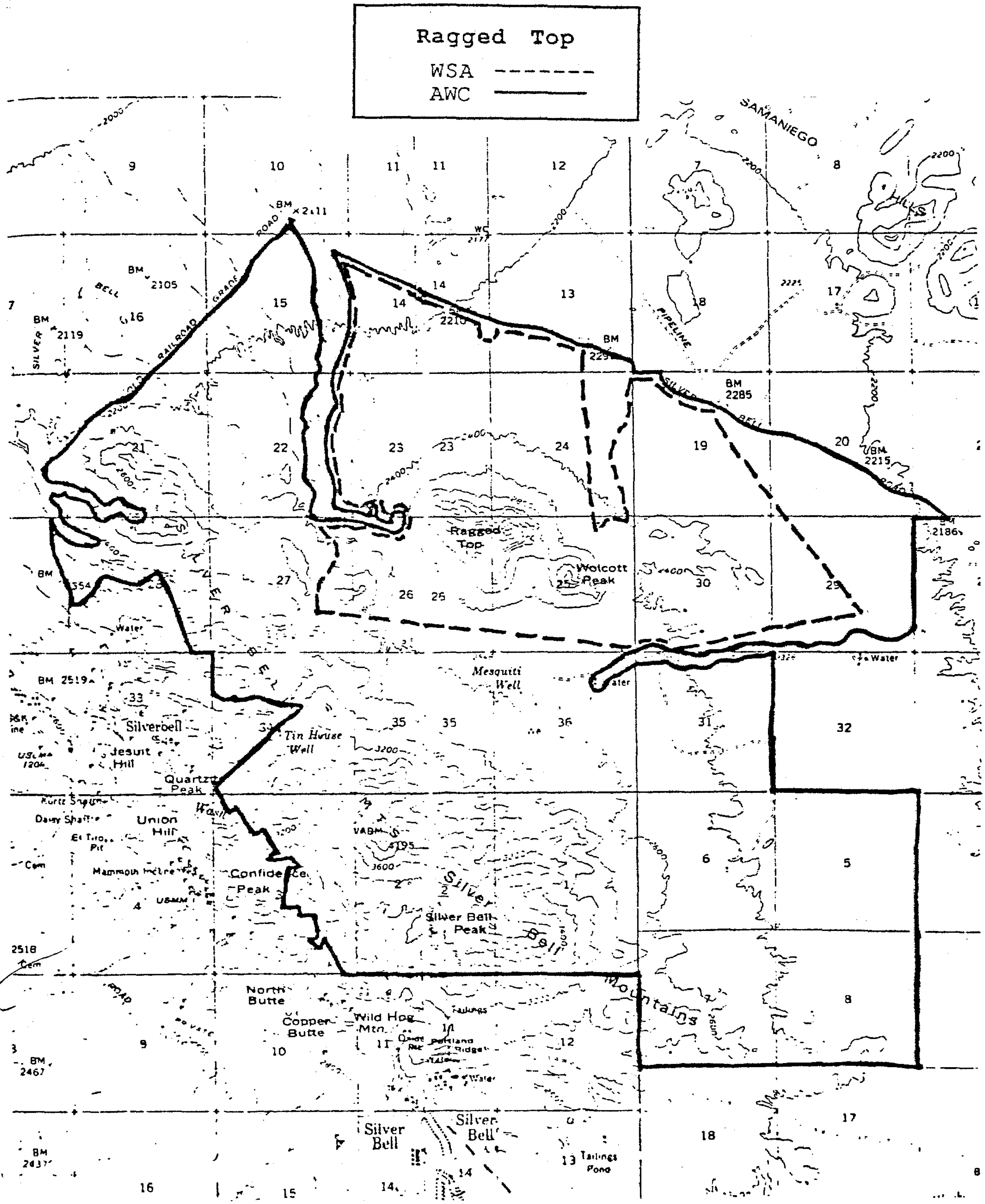
Silver Bell Mine Area
Ragged Top WSA
Pima County, Arizona

Per your request I have looked at the "expanded version" of the Ragged Top WSA. As one can see from the attached map, the expanded WSA encroaches on the Silver Bell Mine area. From a mining point of view this encroachment might limit expansion at the Silver Bell Mine and especially with regard to the North Silver Bell deposit (as yet undeveloped), and from a wilderness point of view this expansion of the WSA would impact on the wilderness experience; that being an operating mine within sight of the WSA. Reference is made to MLA 80-87 "Mineral Investigation of the Ragged Top WSA (AZ 20-197) Pima Co., AZ." The author states in the report that within the WSA at the Ragged Top Mine the alteration seen there is consistent with being in the outside alteration zone of a large porphyry Cu orebody.

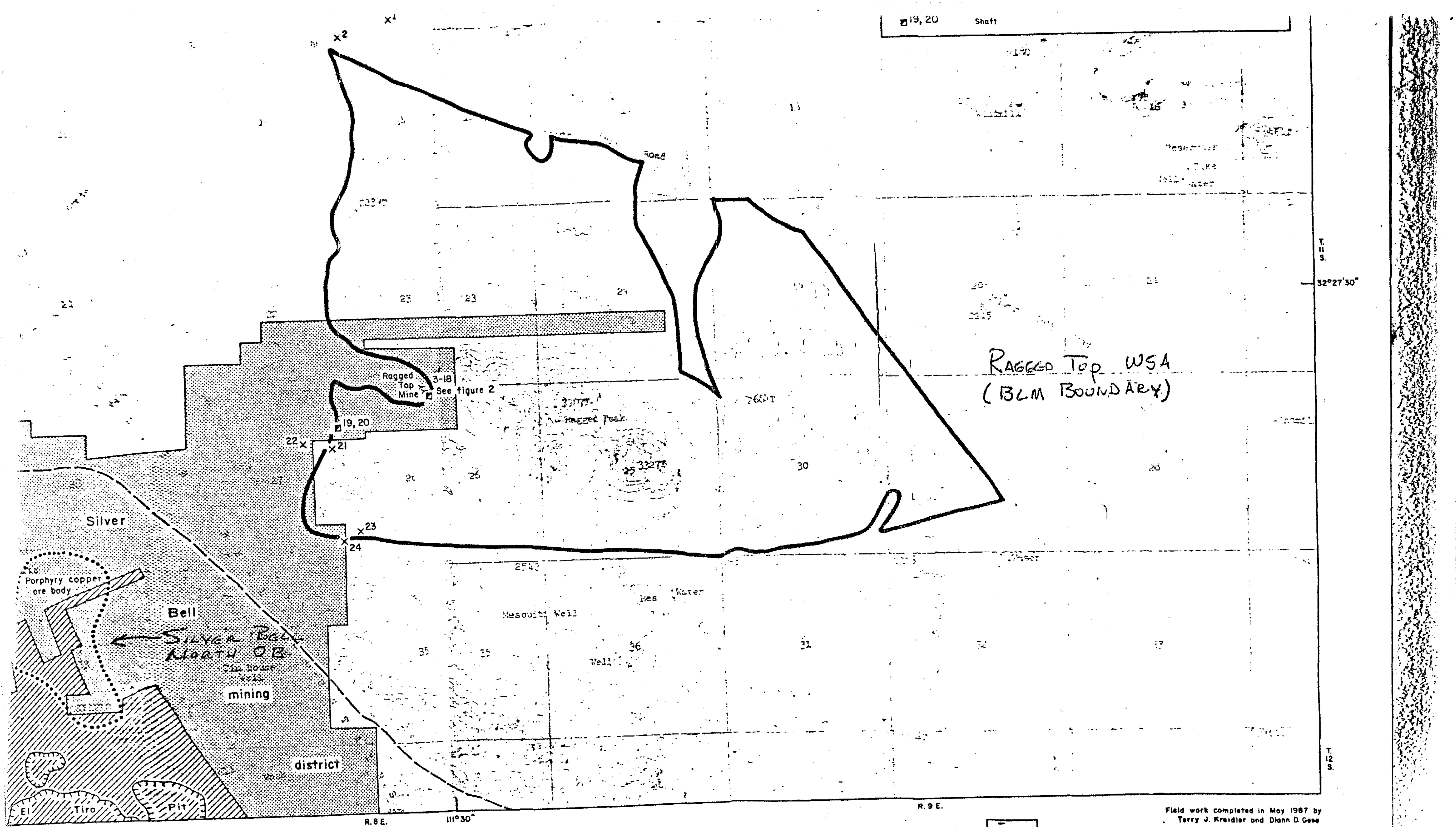
This observation suggests that the entire WSA may have mineral potential.

Mark A. Miller

MAM:mek
Att.



AREA NAME & NUMBER: RAGGED TOP, AZ-020-197/SILVER BELL
WSA ACREAGE: 4,460
BLM PROPOSED ACREAGE: 0
AWC PROPOSED ACREAGE: 14,995
INHOLDING: 1,240 acres of state land
LOCATION: 33 miles northwest of Tucson



Base from the U.S. Geological Survey, 1:24,000
Silver Bell NE, 1959, Tucson Mtns NW, 1959

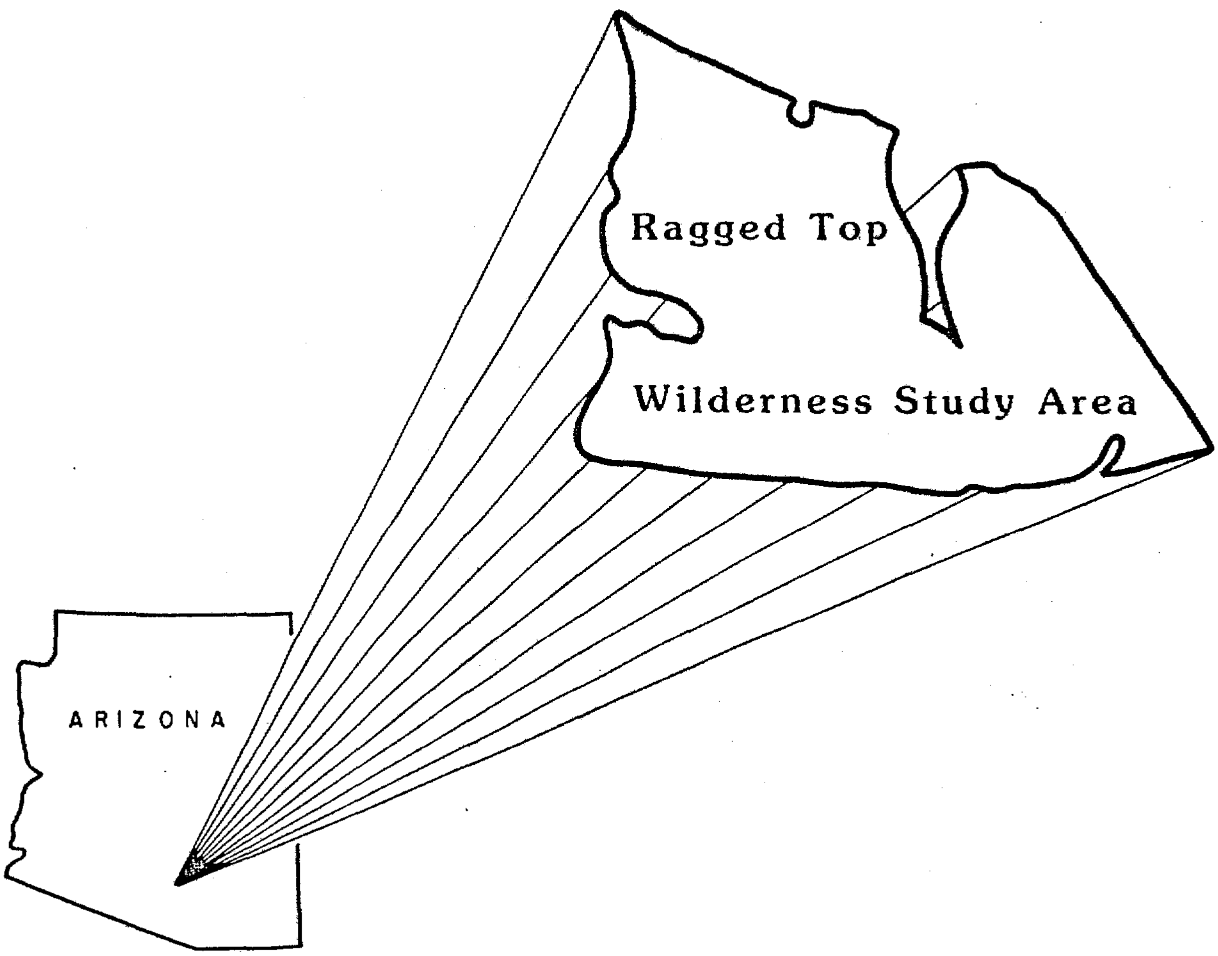
SCALE 1:24,000

Field work completed in May 1987 by Terry J. Kreidler and Diann D. Gese

MLA 80-87

Mineral Land Assessment
Open File Report/1987

Mineral Investigation of the Ragged Top Wilderness Study Area (AZ-020-197), Pima County, Arizona



U.S. DEPARTMENT OF THE INTERIOR · MINERAL INDUSTRIES · BUREAU OF MINES

BUREAU OF MINES
UNITED STATES DEPARTMENT OF THE INTERIOR

MINERAL INVESTIGATION OF THE RAGGED TOP WILDERNESS STUDY AREA (AZ-020-197), PIMA COUNTY, ARIZONA

by

Terry J. Kreidler

MLA 80-87
1987

Intermountain Field Operations Center
Denver, Colorado

UNITED STATES DEPARTMENT OF THE INTERIOR
Donald P. Hodel, Secretary

BUREAU OF MINES
David S. Brown, Acting Director

United States Department of the Interior

BUREAU OF MINES

P. O. BOX 25086
BUILDING 20, DENVER FEDERAL CENTER
DENVER, COLORADO 80225

Intermountain Field Operations Center

December 17, 1987

Mr. S. A. Anzalone
Asarco, Inc.
P.O. Box 5747
Tucson, Arizona 85703

Dear Mr. Anzalone:

Enclosed is one copy of the following U.S. Bureau of Mines Open-File Report you requested:

MLA 80-87 MINERAL INVESTIGATION OF THE RAGGED TOP WILDERNESS STUDY AREA (AZ-020-197), PIMA COUNTY, ARIZONA

Sincerely,

Terry J. Kreidler
Physical Scientist

Enclosure(s)
cc: Project File

PREFACE

The Federal Land Policy and Management Act of 1976 (Public Law 94-579) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine the mineral values, if any, that may be present. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a mineral survey of the Ragged Top Wilderness Study Area (AZ-020-197), Pima County, Arizona.

This open-file report summarizes the results of a Bureau of Mines wilderness study. The report is preliminary and has not been edited or reviewed for conformity with the Bureau of Mines editorial standards. This study was conducted by personnel from the Branch of Mineral Land Assessment (MLA), Intermountain Field Operations Center, P.O Box 25086, Denver Federal Center, Denver, CO 80225.

CONTENTS

ILLUSTRATIONS

TABLES

LIST OF ABBREVIATIONS USED IN THIS REPORT

°	degree
ft	foot
in.	inch
lb	pound
mi	mile
oz	ounce
ppb	part per billion
ppm	part per million
%	percent

MINERAL INVESTIGATION OF THE RAGGED TOP WILDERNESS STUDY AREA (AZ-020-197), PIMA COUNTY, ARIZONA

by

Terry J. Kreidler, Bureau of Mines

SUMMARY

In accordance with the Federal Land Policy and Management Act of 1976, and at the request of the Bureau of Land Management, the Bureau of Mines conducted a mineral investigation in May 1987 to appraise the mineral resources of the 4,460-acre Ragged Top Wilderness Study Area.

No mineral resources were identified in the wilderness study area. Base- and precious-metal anomalies and enrichment in arsenic and barium in samples from in and near the study area are related to alteration halos surrounding the porphyry copper deposits at the Silver Bell Mine to the south and west. A barite occurrence in the southwestern part is not now or in the foreseeable future of commercial interest.

INTRODUCTION

In May 1987 the Bureau of Mines, in a cooperative program with the U.S. Geological Survey (USGS), conducted a mineral investigation of the 4,460-acre Ragged Top Wilderness Study Area (WSA), Pima County, Arizona, on lands administered by the Bureau of Land Management (BLM). The Bureau surveys and studies mines, prospects, and mineralized areas to appraise reserves and identified subeconomic resources. The USGS assesses the potential for undiscovered mineral resources based on regional geological, geochemical, and geophysical surveys. The USGS will open file the results of its report separately. A joint report, to be published by the USGS, will integrate and summarize the results of both surveys. This report presents the results of the Bureau's study, which was completed prior to the USGS investigation.

Geographic and geologic setting

The Ragged Top WSA is on the northeast side of the Silver Bell Mountains, about 3 mi northeast of the Silver Bell Mine, a porphyry copper deposit. The WSA is about 40 mi west of Tucson, AZ, and about 28 mi south of Casa Grande, AZ. Access is via the Silver Bell Road from Interstate Highway 10 (fig. 1).

Topography in the northern and eastern parts of the WSA is desert pediment, a rolling alluvial plain of low relief. The southeastern part is marked by the Ragged Top, a steep-sloped, jutting outcrop of high relief. Elevations range from 3,907 ft on Ragged Top to about 2,140 ft at the northwestern corner. The climate, typical of the Sonoran desert, is very hot and dry (about 8 in. of precipitation a year); vegetation is mostly cactus and desert brush.

The Silver Bell Mountains, a small, northwest-trending range in the Basin and Range physiographic province, comprise a complexly folded and faulted series of igneous, metamorphic, and sedimentary rocks ranging in age from Precambrian to Quaternary. Copper-lead-zinc-silver deposits occur in a relatively narrow band along the southwest flank of the range. Here, a thick sequence of Paleozoic- and Mesozoic-age clastic and carbonate sediments have been deformed and intruded by a series of mineralizing Laramide- and Tertiary-age stocks, dikes, and sills. (See Keith, 1974, p. 44-45.)

Ragged Top is an erosional remnant of Tertiary rhyolite, perhaps a volcanic plug or subvolcanic stock. Other rocks in the WSA include Precambrian granitics, mid-Tertiary sediments, and Laramide and Tertiary volcanics of intermediate composition. A northeast-trending fault cuts through the center of the WSA. (See Cruver and others, 1982, p. 98.)

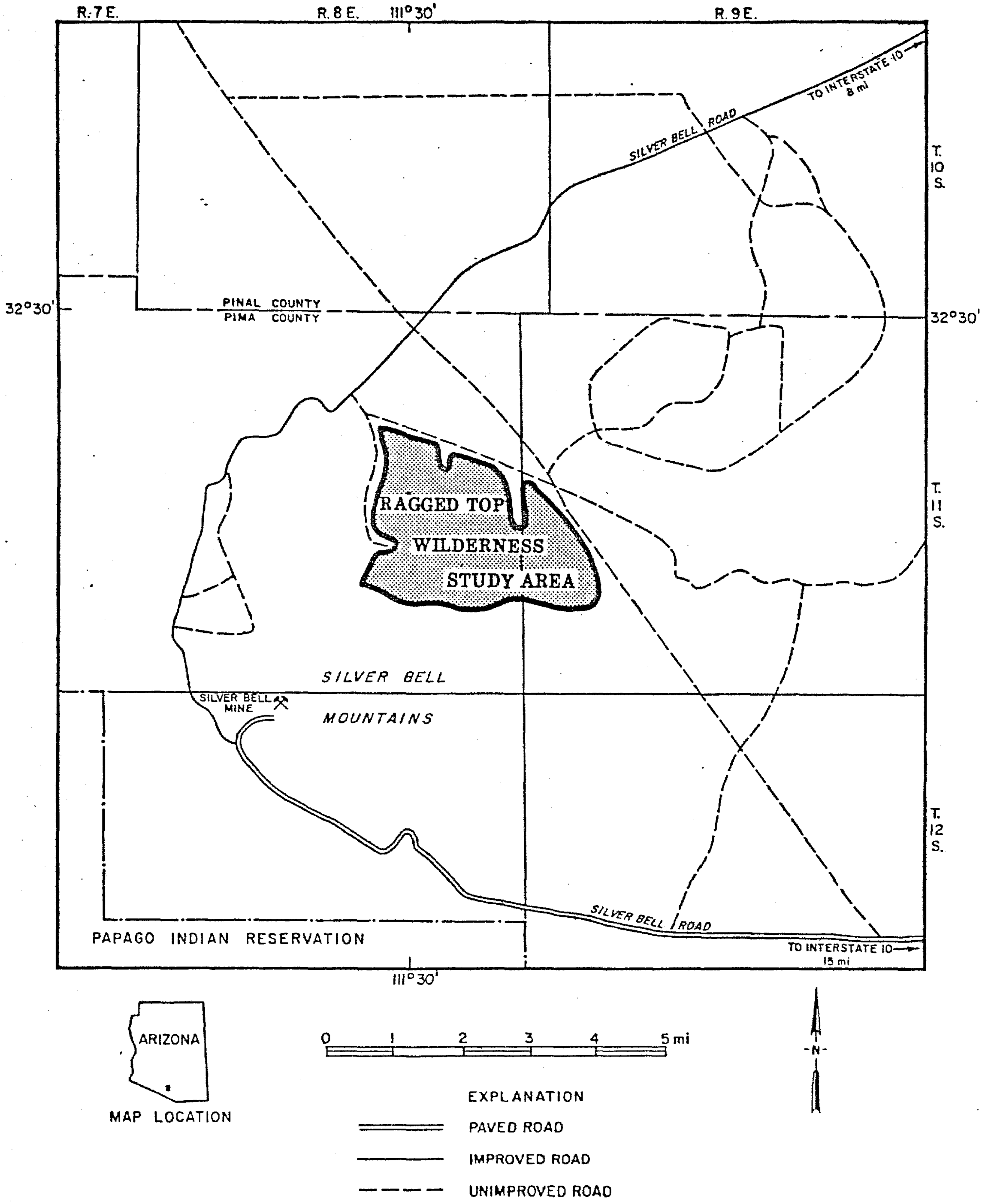


Figure 1.--Index map of the Ragged Top Wilderness Study Area, Pima County, Arizona.

Previous work

Previous geologic investigations in the Silver Bell Mountains centered on the copper deposits on the southwest flank. Stewart (1912) did the first comprehensive studies of the Silver Bell mining district. Richard and Courtright (1966) studied the structure and mineralization of both the Oxide and El Tiro porphyry deposits that make up the Silver Bell Mine; Graybeal (1982) discussed the geology of the El Tiro deposit. The only known previous study of the WSA is the geology, energy, and minerals (GEM) report on the area by Cruver and others (1982) done under contract for the BLM.

Methods of investigation

Bureau personnel reviewed sources of minerals information including published and unpublished literature, Bureau files, and mining claim and oil and gas lease records at the BLM State Office in Phoenix. Discussions on the mineral occurrences in the study area were held with BLM personnel at the Phoenix District Office.

Field work, completed in eight employee-days, consisted of mapping and sampling mines and prospects. Twenty-four samples were taken, 16 from the Ragged Top Mine and 8 from prospects, 4 inside and 4 outside the WSA. All samples were analyzed for gold, silver, and 32 other elements by neutron activation; 4 for copper, lead, zinc, manganese, molybdenum, and silver by direct coupled plasma emission spectroscopy; and 20 for copper, lead, and zinc by wet chemistry and atomic absorption. Analyses were done by Bondar-Clegg, Lakewood, CO. Complete analytical data are available for inspection at the U.S. Bureau of Mines, Intermountain Field Operations Center, Building 20, Denver Federal Center, Denver, CO.

Mining and leasing activity

The nearest mining district to the study area is the Silver Bell, about 1 mi south and west (pl. 1). The first production from the district came in 1865 when oxidized copper ores containing minor lead-silver concentrations were mined at the Boot Mine from replacement deposits in garnetized limestone. By 1909 the economic possibilities of low-grade disseminated copper in igneous rocks were recognized, and over the next three years, extensive churn drilling partially delineated the Oxide and El Tiro ore bodies of the Silver Bell Mine, which at that time were subeconomic. However, production from vein and replacement ore bodies similar to those at the Boot Mine continued intermittently until 1930. Asarco began further exploration drilling on the Silver Bell porphyry copper deposits in 1948 and production in 1954. (See Richard and Courtright, 1966, p. 157.) The mine has been on standby since 1984; the only production since then has been from precipitate recovery (Asarco annual report, 1986). Total production from the district, 1885-1981, amounts to 1.3 billion lbs of copper; about 50 million lbs of lead, zinc, and molybdenum combined; about 6 million oz of silver; and about 2,000 oz of gold (Keith and others, 1983, p. 48). Recently, Asarco drilled out another porphyry copper body, the North Silver Bell deposit, in sec. 33, T. 11 S., R. 8 E., less than 1 mi southwest of the WSA. The company has plans for future development of the deposit pending further increases in the price of copper (S. A. Anzalone, Asarco, Inc., Tucson, AZ, written commun., 1987).

Within the WSA, little mining activity has taken place. Of a block of mining claims covering the Ragged Top Mine area, 21 lie wholly or partly in the WSA (pl. 1). The history of the mine is not known beyond the fact that it was previously known as the Franco Riqueza Claims and reportedly produced some copper-lead-zinc ore (Cruver and others, 1982, p. 98). South of the Ragged Top Mine are two barite prospects, one pit, and one shallow shaft; it is unlikely there was any production.

There are no oil and gas leases in the vicinity of the wilderness study area. Ryder (1983) rated the petroleum potential of the study area as zero because it is in a region intruded by Mesozoic- and Tertiary-age igneous rocks.

APPRAISAL OF SITES EXAMINED

Sites examined include the Ragged Top Mine, two barite prospects, and five other prospect pits. Geochemical anomalies in the samples from these sites indicate that the southwestern part of the WSA is in the outer part of the propylitic alteration zone surrounding the three ore bodies of the Silver Bell Mine.

Ragged Top Mine

The Ragged Top Mine is in the "cherry stem" on the western boundary of the WSA, in secs. 23 and 26, T. 11 S., R. 8 E., and can be reached by way of a four-wheel-drive road from the Silver Bell Road (pl. 1). Workings consist of two adits, and a shallow prospect shaft. The upper adit, 95 ft long, was driven along a mineralized zone and ends in a partially collapsed and filled winze, now only 30 ft deep. The lower adit, about 500 ft long and 67.5 ft below the upper adit, is a crosscut that intersects the mineralized zone approximately 300 ft from the portal (fig. 2). Sixteen samples were taken in the mine, all but two (fig. 2, no. 17 and 18) from the mineralized zone.

An alteration zone surrounds the deposit, extending over an area about 200 ft in diameter. Observed from a distance, this zone appears yellowish-orange, a color due in large part to altered and weathered sulfides, particularly pyrite.

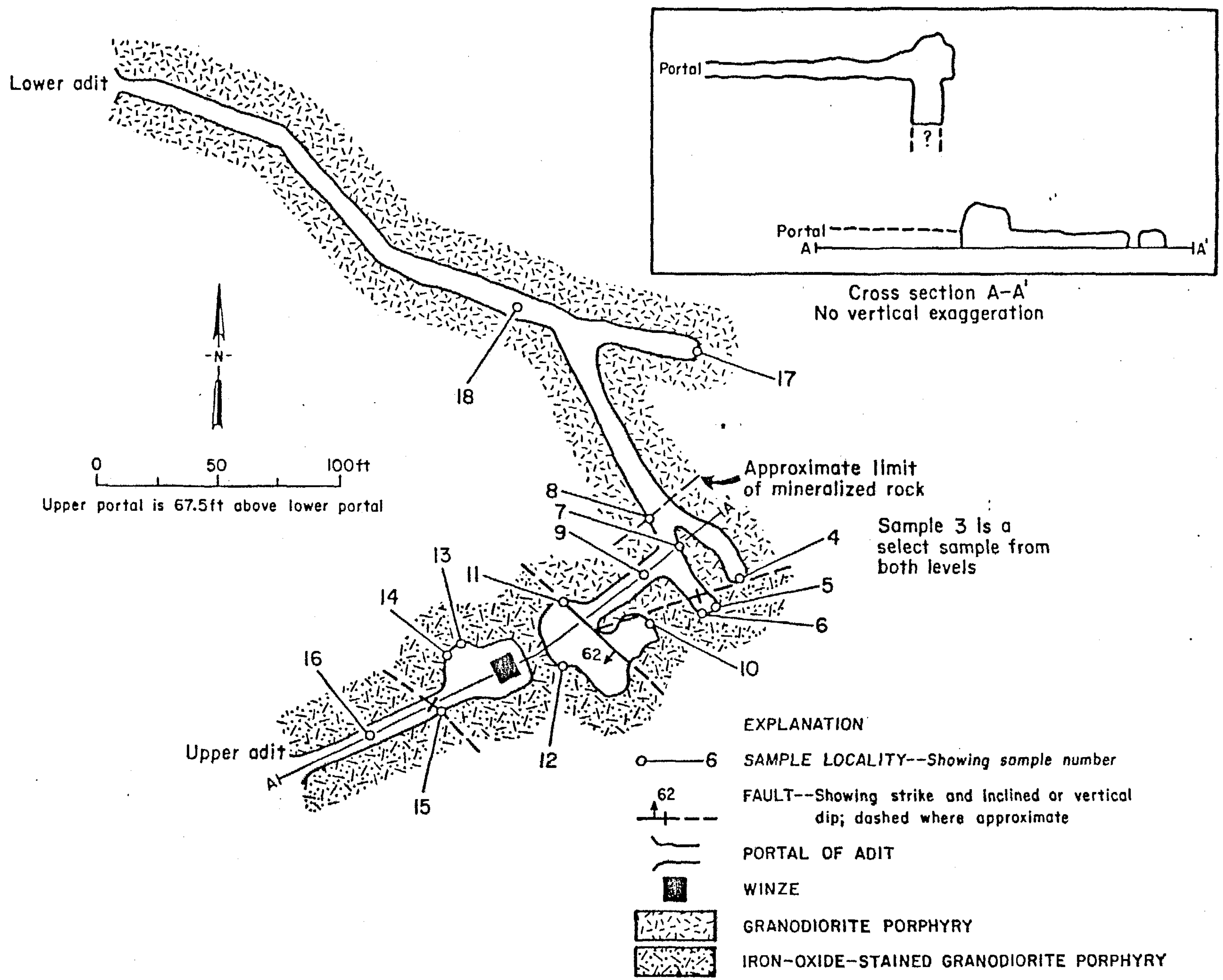


Figure 2.--The Ragged Top Mine.

Sphalerite, galena, and minor amounts of chalcopyrite occur in the mineralized zone as small irregular-shaped pods and veinlets filling fractures in a weathered and altered granodiorite porphyry. A select sample of sulfides was taken from several veinlets and pods in both levels to ascertain the base-metal content of the ore minerals; it contained 29% zinc, 15.3% lead, and 1.56% copper (table 1, no. 3). However, the average metal content (0.95% lead, 0.82% zinc, and 0.24% copper) of the remaining 13 samples from the

Table 1.--Data for samples from the Ragged Top Mine, Ragged Top Wilderness Study Area, Pima County, Arizona.

[Gold (Au), silver (Ag), barium (Ba) and arsenic (As) determined by neutron activation, detection limits 5 ppb, 5 ppm, 100 ppm, and 1 ppm respectively; copper (Cu), lead (Pb), and zinc (Zn) determined by wet chemistry and atomic absorption, detection limits 0.01%; symbols used: ---, not detected.]

Sample No.	Length (in.)	Au ppb	Ag ppm	Cu percent	Pb percent	Zn percent	Ba ppm	As ppm
3	select	58	8	1.56	15.3	29.0	760	20
				Mineralized zone				
4	45	66	7	.08	.21	.49	820	34
5	62	24	---	.01	.05	.08	1100	24
6	55	35	7	.01	.01	.14	890	33
7	44	75	25	.13	1.12	1.39	250	28
8	42	4050	190	1.37	4.42	.98	390	35
9	45	70	---	---	---	---	850	39
10	38	84	10	.20	.56	.54	700	34
11	48	3660	140	.69	2.32	2.70	---	33
12	30	597	36	.21	.41	1.06	380	41
13	33	240	5	.19	3.15	1.65	600	39
14	54	4270	240	.04	.26	.22	---	29
15	52	140	10	.06	.85	.83	300	33
16	42	170	12	.16	.61	.58	850	38
				Nonmineralized zone				
17	37	64	---	---	---	.01	1100	38
18	39	11	---	.01	---	.01	880	8

mineralized zone (table 1, no. 4-16) shows the sparse concentration of the metals in the rock, even though lead and zinc contents are locally high enough to be of possible economic interest (table 1).

Of the 13 samples from the mineralized zone (table 1, no. 4-16); 3 contain concentrations of gold and silver far above the average for the other samples (nos. 8, 11, and 14). The average gold content of the 10 low-gold samples is 141.7 ppb; the 3 anomalous samples averaged nearly 4,000 ppb. The average silver content in the 10 low-silver samples is 11.8 ppm; the 3 anomalous samples average 190 ppm. Several samples have greater than 1% copper, lead, and zinc. There is no apparent correlation between precious-metal content and base-metal content.

Arsenic and barium are both highly mobile in a mineralizing environment, forming halos around deposits, and are often used as a geochemical-prospecting tool to locate deposits of base and precious metals. All 16 samples from the Ragged Top Mine have higher than average arsenic content, and ten samples, including the two from the nonmineralized zone, have higher than average barium content. The average content for an igneous rock of intermediate composition is 2 ppm arsenic and 500 ppm barium (Levinson, 1980, p. 865).

The erratic nature and small exposed size of this occurrence precludes the identification of a base- or precious-metal resource at the Ragged Top Mine. However, the nature of the occurrence is consistent with being in the propylitic alteration zone of a large porphyry copper ore body.

Barite prospects

Two barite prospects are in the WSA (sec. 27, T. 11 S., R. 8 E.) approximately 2,500 ft west southwest of the Ragged Top Mine, (pl. 1, nos. 19-21).

The northernmost working (pl. 1, no. 19, 20), a partially collapsed shaft about 30 ft deep, was sunk on a 4.5-ft-wide, vuggy quartz vein. The vein strikes N. 15-20° E., dips vertically, and contains pods of barite. The barite pods vary in size from a few inches to about 1.5 ft. Other minerals observed in the vein are pyrite, hematite, and limonite. The vein can be traced on the surface for about 20 ft before it disappears beneath the alluvium. A select sample of barite pods contained 48.6% barium, equivalent to 82.6% barite, (table 2, no. 20); a grab sample of dump material, primarily vein quartz, contained 5,100 ppm barium (0.86% barite), less than 36 ppb gold, and less than 5 ppm silver (table 2, no. 19).

The second working is a prospect pit (pl. 1, no. 21) about 700 ft southwest of the shaft on a quartz-barite vein 2-6 ft wide. Although untraceable on the surface, it appears to be an extension of the vein exposed at the shaft. The strike of the vein is N. 21° E. and it dips vertically. Unlike the vein at the shaft, the quartz and barite here are more homogeneous. A sample of the vein contained 4.8% barium (8.2% barite) (table 2, no. 21).

No barite resource was identified. The lowest commercial grade in use today is 92% $BaSO_4$ (equivalent to a specific gravity of 4.2) for use in drilling fluids, other uses require grades between 96% and 98% (Brobst, 1983, p. 486, 496). Barite exposed in the prospect pit is of too low a grade to be commercially of interest. Selective mining of the vein and hand sorting of the barite pods at the shaft would yield a concentrate containing about 80% $BaSO_4$, requiring further beneficiation to bring it up to minimum commercial grade. Even so, the exposure at this site is limited and the extent of the pod-bearing part of the vein is not known. A drilling program would be required to evaluate the extent and grade of barite mineralization, but the most crucial factor in any future development of this vein would be in establishing a local market for the final product. This seems unlikely as barite has not been mined in Arizona for several years, and as of September 1987, all domestic barite production comes from bedded and residual deposits; none is mined from veins (S. G. Ampian, U.S. Bureau of Mines, 1987, personal commun.).

Table 2.--Data for samples 1, 2, and 19-24 from the Ragged Top Wilderness Study Area, Pima County, Arizona.

[Gold (Au), silver (Ag), and barium (Ba) determined by neutron activation, detection limits 5 ppb, 5 ppm, and 100 ppm respectively; copper (Cu), lead (Pb), zinc (Zn), and manganese (Mn) determined by wet chemistry and atomic absorption, detection limits 0.01%; symbols used: na, not analyzed; ---, not detected; >, greater than. Ba in ppm unless otherwise noted.]

Sample No.	Length (in.)	Au ppb	Ag ppm	Cu percent	Pb percent	Zn percent	Mn percent	Ba ppm	As ppm
1	grab	---	---	na	na	na	27.5	>3%	489
2	26	---	---	0.14	0.02	0.01	.3	1,100	71
19	grab	---	9	---	.1	.02	na	5,100	27
20	select	---	---	na	na	na	na	48.6%	45
21	35	---	---	na	na	na	na	4.8%	16
22	27	170	63	1.3	4.2	3.1	na	1,400	10
23	55	220	---	.02	.23	.26	na	3,200	---
24	42	34	280	1.8	3.3	4.5	na	1,800	---

This localized enrichment in barium may be related to the mineralizing system responsible for the mineral occurrences at the Ragged Top Mine.

Other prospects

Two prospect pits were found outside the northwestern tip of the WSA (pl. 1, nos. 1, 2). At locality 1, a manganese mineral covered the dump of a small pit dug in an intermediate volcanic rock. None was seen in place; however, indicating the manganese probably occurred in an isolated pod. A sample from the dump contained 27.5% manganese and greater than 3% barium (table 2, no. 1). No resource is indicated.

The second pit was dug in an altered volcanic rock of intermediate composition laced with thin veinlets of quartz or calcite, but no sulfides. A chip sample from the pit did not contain any appreciable metal concentrations (table 2, no. 2).

Three prospect pits are near the southwestern corner of the area. The northernmost pit (pl. 1, no. 22) is in highly altered granodiorite porphyry. Malachite and azurite coat fractures and the rock is heavily iron stained. No structure is apparent, and no sulfide minerals were seen. A chip sample from the pit contained relatively high concentrations of copper (1.3%), lead (4.2%), and zinc (3.1%) (table 2, no. 22).

The remaining two prospects are along the southern boundary, one inside and one outside the WSA (pl. 1, no. 23, 24). Both are pits in an altered, highly fractured volcanic rock of intermediate composition. At locality 23, inside the WSA, fracture surfaces are stained by iron oxide; at locality 24, malachite and azurite as well as a black, amorphous mineral, possibly an oxidized copper mineral, were also observed. Sample 23 did not contain any metal concentrations of interest. Sample 24, however, contained concentrations of copper (1.8%), lead (3.3%), and zinc (4.5%) similar to sample 22 (table 2). No resources were identified.

Samples 22-24 contained an average of 141 ppb gold, and samples 22 and 24 contained 63 and 280 ppm silver, respectively.

All samples from the prospects discussed in this section contained anomalous amounts of barium and all but two (no. 23, 24) contained anomalous arsenic.

CONCLUSIONS

No mineral resources were identified in the Ragged Top Wilderness Study Area.

The geochemical anomalies in the samples from this study area are consistent with those found in the propylitic alteration zone surrounding a large porphyry copper system. Since the mineralized area is within a mile of the North Silver Bell porphyry copper deposit, the alteration is most likely related to that mineralizing system.

The barite-bearing quartz vein is not at this time or in the foreseeable future of commercial value.

REFERENCES

Brobst, D. A., 1983, Barium minerals; in Lefond, S. J., ed., Industrial minerals and rocks: New York, American Institute of Mining, Metallurgical, and Petroleum Engineers, p. 485-501.

Cruver, S. K., Wodzicki, Antoni, and Krason, Jan, 1982, Geology, energy, and mineral resources assessment of the Wymola area, Arizona: prepared for the Bureau of Land Management by Geoexplorers International, Denver, CO, 109 p.

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JDS

ASARCO

Southwestern Exploration Division

October 26, 1988

F. T. Graybeal
New York Office

Gold Anomalies
Ragged Top WSA
Pima County, AZ

You may have seen/heard of the Silver Bell gold rush -- or the gold rush that never happened -- and I now submit Mr. Miller's assessment and the OFR 88-587 for your files.

Perhaps it can be summed up by saying: "One anomalous gold value in a panned concentrate does not make a project."

However, as you note, Mr. Miller did collect a few more samples which he will report on later.

Sawyer and Nowlan will also present this and additional data at a poster session at the Denver GSA meeting next week.

James D. Sell

James D. Sell

JDS:mek
Att.

cc: W.L. Kurtz

FILE

ASARCO

Southwestern Exploration Division

October 26, 1988

J. D. Sell

Gold Anomalies
Ragged Top WSA
Pima County, AZ

A newly released USGS Open File Report #88-587 has indicated anomalous amounts of gold in pan concentrates and rock chip samples within the Ragged Top WSA. The inference from discussion with the USGS is that gold mineralization may be associated with the formation and collapse of a cauldera during Late Cretaceous time along the trace of the Ragged Top Fault. I cannot refute this model; however, the trace elements' signature (lack of As, Sb, Hg) etc. does not suggest an epithermal system at work. The best values obtained from an argillically altered granodiorite was 9 ppb with no trace element determination. The highest rock chip gold values were obtained in a Pb, Zn vein ~6" thick, hosted in an altered granodiorite. The highest pan concentrate values (150 ppm Au) were obtained from a major drainage downstream from the Pb, Zn vein. Additional samples were taken along the vein structure and at the high pan concentrate site, and results are pending.

Public interest in the area has been slight since the article in the local newspaper (attached). If there is any significant impact at all, I think that it would be a reassessment of the wilderness designation of the area; but the implied gold potential does not appear to be very favorable.

Mark A. Miller

MAM:mek

Table 1.--Descriptions of analyzed rock samples from the Ragged Top Wilderness Study Area, Pima County, Arizona. Au, Ag (ppm)

Sample	Description	
RTR130AA	Granodiorite porphyry	<.001, N
RTR130BA	Granodiorite porphyry	<.001 N
RTR130CA	Granodiorite porphyry, slightly altered	.002 N
RTR130DA	Granodiorite porphyry, slightly altered	.002, N
RTR130DB	Granodiorite porphyry, altered	.004, <.5
RTR130EA	Granodiorite porphyry, altered	.002, N
RTR130EB	Granodiorite porphyry, altered	.002, N
RTR130FA	Granodiorite porphyry, altered	.005, .5
RTR130GA	Granodiorite porphyry, highly altered, brecciated	.008, 1.0
RTR130HA	Granodiorite porphyry, highly altered, brecciated	.002, N
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RTR130JA	Granodiorite porphyry, highly altered, brecciated	.004, N
RTR130KA	Granodiorite porphyry, highly altered,	.002, N
RTR130LA	Fine grained rock, highly altered	.002, N
RTR130MA	Granodiorite porphyry, altered	.002, N
RTR130NA	Potassium-rich rock	.001, N
RTR130OA	Potassium-rich rock	.003, N
RTR130PA	Granodiorite porphyry, slightly altered	<.003, N
RTR130QA	Granodiorite porphyry, slightly altered	<.001, N
RTR130RA	Granodiorite porphyry, slightly altered	<.001, N
RTR130SA	Granodiorite porphyry	<.001, N
RTR130TA	Granodiorite porphyry, slightly altered	.001, N
RTR130UA	Granodiorite porphyry, slightly altered	.001, N
RTR130VA	Granodiorite porphyry	<.001, N
RTR130WA	Diabase	<.001, N
RTR130XA	Oracle-type granite	<.001, N
RTR130YA	Diabase	<.001, N
RTR130ZA	Oracle-type granite	<.001 N
RTR106A	Oracle-type granite from shear zone	.001, N
82S-023	Granodiorite porphyry	<.001, N
82S-044	Granodiorite porphyry	<.001, N
82S-122	Lithic tuff	<.001, N
82S-133	Rhyolite welded tuff	<.001, N
82S-135	Rhyodacite porphyry	<.001, N
82S-150	Rhyodacite porphyry	<.001, N
82S-382	Rhyolite	<.001, N
RT7306A	Barite-fluorite vein	.006, 0.5
RT7306BA	Barite vein	.002, N
RT7306BB	Altered wall rock by barite vein	.007
RT7307A	Granodiorite porphyry, altered	.003, <.5
RT7308A	Granodiorite porphyry, altered	.015, .5
RT7309A	Sulfide minerals and calcite	[illegible], 150
RT7309B	Granodiorite porphyry with sulfide minerals	.015, 100
RT7309C	Granodiorite porphyry with sulfide minerals	.090, 20.0
RT7309D	Dolomite (?) vein with sulfide minerals	.02, 1.0
RT7309EA	Rhodochrosite (?) vein with sulfide minerals	.08, 50
RT7309EB	Granodiorite porphyry with rhodochrosite (?) and sulfide minerals	.10, 15
RT7309F	Granodiorite porphyry with sulfide minerals	.009, <.5
RT7309G	Granodiorite porphyry with sulfide minerals	.005, <.5
RT7310A	Granodiorite porphyry	.026, <.5
RT7310B	Granodiorite porphyry with calcite and sulfide minerals	.38, 30
RT7311AA	Quartz vein	.007, N
RT7311AB	Quartz vein	.044, N
RT7315A	Quartz vein	.001, N
RT7315B	Quartz vein	<.001, N
RT7315CA	Quartz vein	.002, N
RT7315CB	Altered granite	.062, <.5
RT7316A	Diabase	.006, N
RT7324A	Barite vein	.023, 2
RT7324B	Barite vein	.023, 3
RT7324CA	Quartz vein	.021 N
RT7324CB	Quartz vein	.25, 2
RT7325A	Quartz vein	.004, N
RT7326A	Quartz vein with sulfide minerals	.002, N

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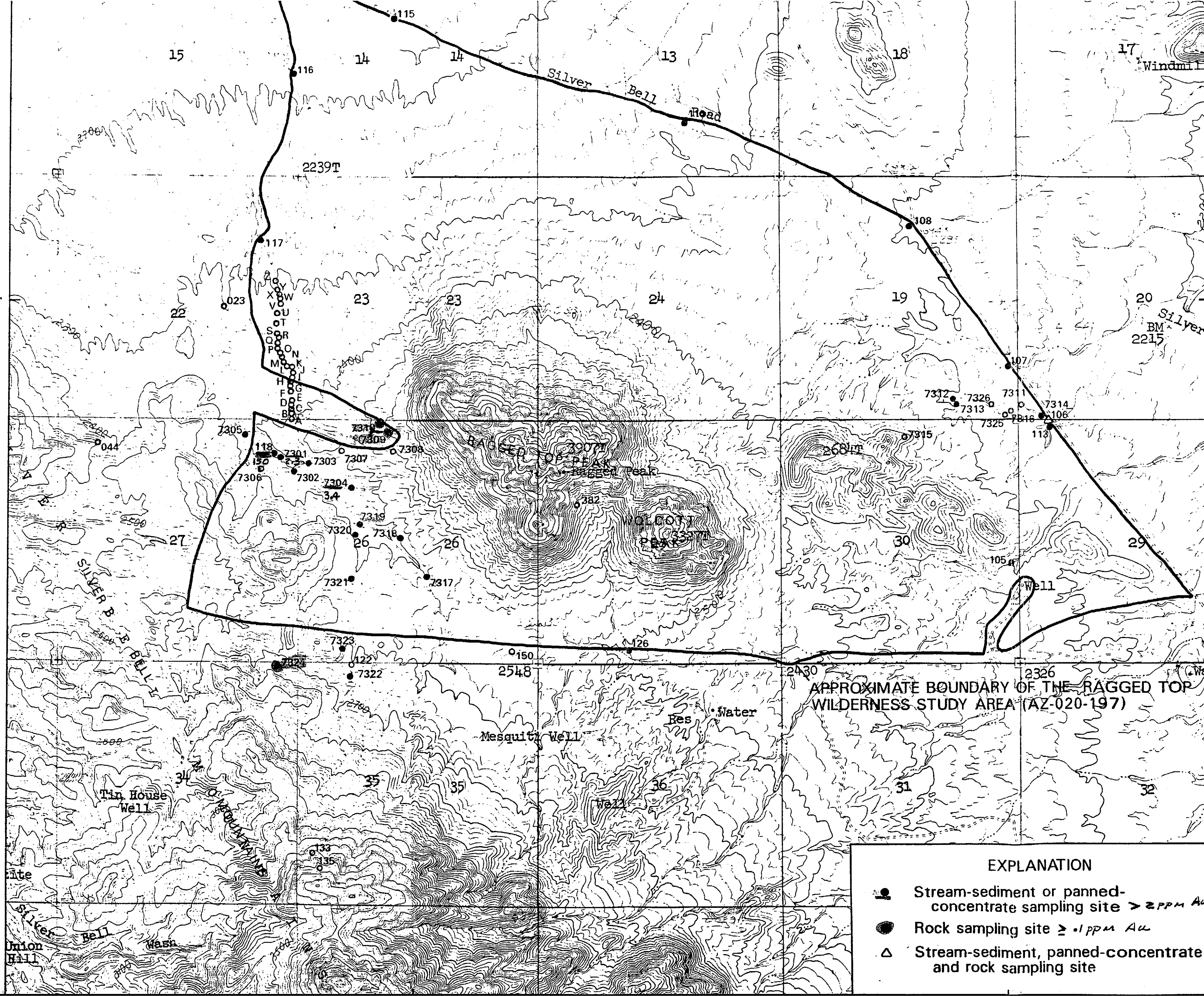

Silver Bell Road
Windmill
Ragged Peak
RAGGED TOP PEAK
WOLCOTT PEAK
Well
Mesquite Well
Water
Res
Tin House Well
Union Hill
Silver Bell Wash
SILVER BELL MOUNTAINS
32° 27'30"
APPROXIMATE BOUNDARY OF THE RAGGED TOP WILDERNESS STUDY AREA (AZ-020-197)
EXPLANATION
Stream-sediment or panned-concentrate sampling site > 2 ppm Au
Rock sampling site ≥ .1 ppm Au
Stream-sediment, panned-concentrate and rock sampling site

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Analytical results and sample locality map for stream-sediment, panned-concentrate, and rock samples from the Ragged Top Wilderness Study Area, Pima County, Arizona

By

John B. McHugh*, Gary A. Nowlan*,
David A. Sawyer**, and John H. Bullock, Jr.*

Open-File Report 88-587

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

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1988

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STUDIES RELATED TO WILDERNESS

Bureau of Land Management Wilderness Study Areas

The Federal Land Policy and Management Act (Public Law 94-579, October 21, 1976) requires the U.S. Geological Survey and the U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine their mineral values, if any. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a geochemical survey of the Ragged Top Wilderness Study Area (AZ-020-197), Pima County, Arizona.

INTRODUCTION

In March 1987, the U.S. Geological Survey conducted a reconnaissance geochemical survey of the Ragged Top Wilderness Study Area, Pima County, Arizona. Additional samples were collected in December 1987. The wilderness study area and nearby sampled terrain are termed the "study area."

The Ragged Top Wilderness Study Area comprises 4,460 acres (about 7 mi^2) in the north central part of Pima County, Arizona, and lies about 35 mi northwest of Tucson, Arizona (see fig. 1). Access to the study area is provided by the Silver Bell, Avra Valley, and Red Rock roads.

Topography of the study area is dominated by the rugged mass of Ragged Top Peak, elevation 3,907 ft, and a shorter subsidiary peak called Wolcott Peak which rise abruptly to a maximum of 1,700 ft above the surrounding bajada. The two peaks, which are collectively known as Ragged Top, are the northeastern peaks of the Silver Bell Mountains. Ragged Top is separated from the main mass of the Silver Bell Mountains by a mile-wide valley.

Vegetation is characteristic of the Sonoran Desert. Common species include saguaro and other cacti, paloverde, acacia, ironwood, mesquite, and creosote bush.

The southwest part of the study area lies within the Silver Bell mining district (Richard and Courtright, 1966; Graybeal, 1982). The first recorded mining activity in the district was in 1865 about 2 miles south-southwest of the wilderness study area; silver and copper were recovered from skarn. Exploitation of porphyry copper deposits at the El Tiro and Oxide pits began in 1954 and continued until 1985. The El Tiro pit is about 2 miles southwest of the wilderness study area and the Oxide pit is about 3 miles south. A third, unexploited, porphyry copper deposit, the North Silver Bell deposit, lies about 1 mile from the southwest corner of the wilderness study area. Production from the El Tiro and Oxide deposits from 1954 to 1977 totaled 75,655,000 tons averaging 0.80 percent copper, 0.07 oz/ton silver, and 0.022 percent molybdenum sulfide (Graybeal, 1982). Copper has been the predominant commodity produced in the Silver Bell district but two mines about 2 miles southwest of the wilderness study area produced about 150,000 tons of ore averaging 16 percent zinc, 1.3 percent copper, 0.6 oz/ton silver, and minor lead and gold (Keith, 1974). Total production of base and precious metals in the Silver Bell district from 1885 to 1981 amounted to 90,351,000 tons (Keith and others, 1983).

Geology of the study area is included in reports by Sawyer (1986, 1987). A major structural feature in the study area is the Ragged Top fault, a probable strike-slip fault that runs from near the southeast tip of the wilderness study area west-northwest across the wilderness study area. Precambrian Oracle-type granite predominates on the north side of the fault

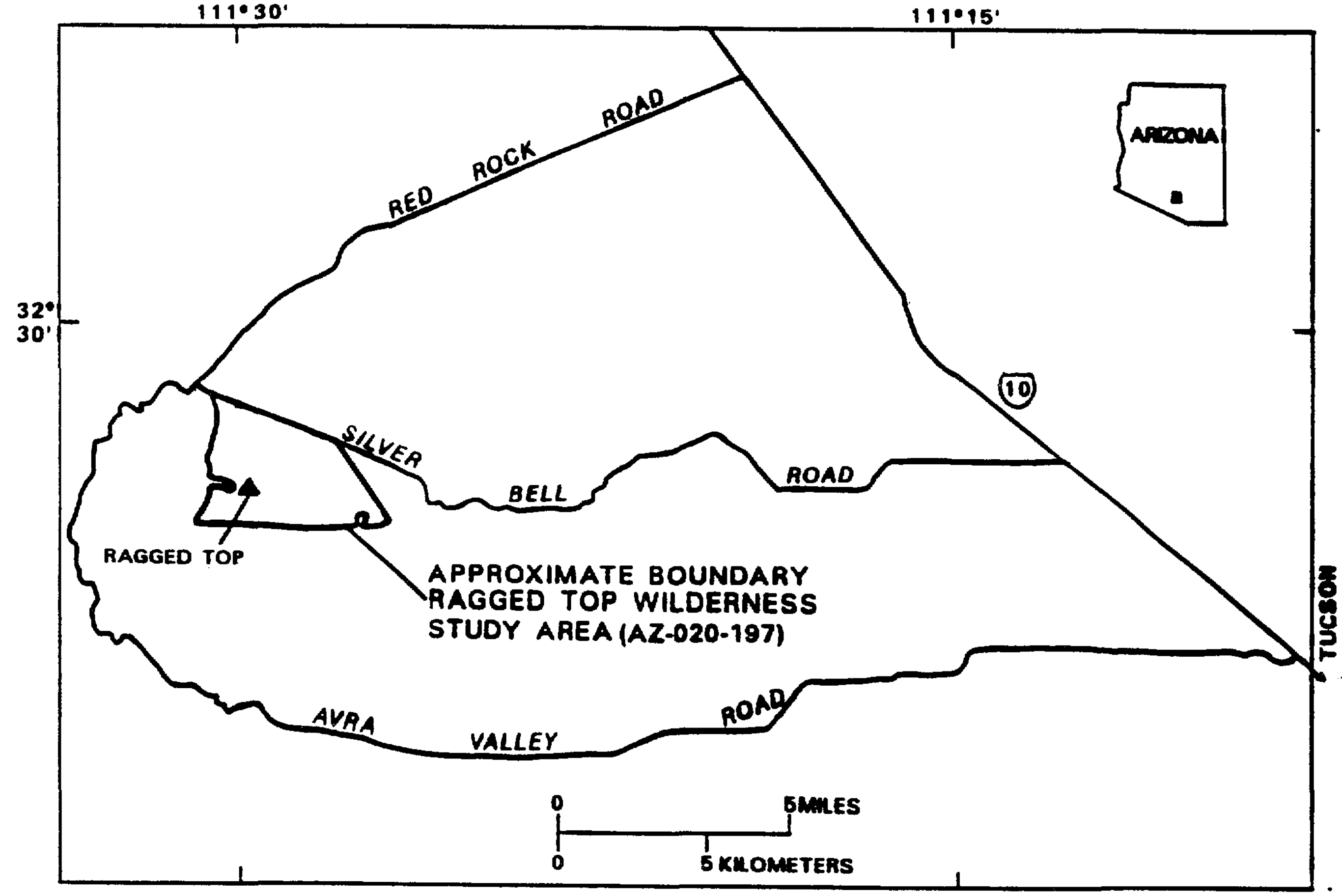

Figure 1. Index map, Ragged Top Wilderness Study Area, Pima County, Arizona.

although Middle Proterozoic Apache Group sedimentary rocks crop out east of Ragged Top. Upper Cretaceous volcanic rocks predominate south of the Ragged Top fault. The volcanic rocks consist of andesite-to-dacite extrusive rocks and rhyolite tuffs. Upper Cretaceous sedimentary rocks southwest of Ragged Top contain clasts that include Precambrian schist, Paleozoic sedimentary rocks, probable Lower Cretaceous sandstone, Cretaceous algal limestone, and volcanic rocks. An Upper Cretaceous granodiorite porphyry laccolith underlies part of the southwestern section of the wilderness study area. Ragged Top is an Oligocene rhyolite dome that was extruded along the trace of the Ragged Top fault. Quaternary sediments that are mostly unconsolidated cover the flatter sections of the study area.

Sawyer (1986, 1987) and Lipman and Sawyer (1985) present evidence to support the concept that the Upper Cretaceous sedimentary rocks, the Upper Cretaceous andesite-to-dacite extrusive rocks, and certain of the Upper Cretaceous rhyolite tuffs are the results of the formation and later collapse of a caldera during Late Cretaceous time.

METHODS OF STUDY

Sample Media

Analyses of stream-sediment samples represent the chemistry of the rock material eroded from the drainage basin upstream from each sample site. Such information is useful in identifying those basins which contain concentrations of elements that may be related to mineral deposits. Panned-concentrate samples derived from stream sediment provide information about the chemistry of certain minerals in rock material eroded from the drainage basin upstream from each sample site. The selective concentration of minerals in panned-concentrate samples, many of which may be ore related, permits determination of some elements that are not easily detected in stream-sediment samples. Analyses of unmineralized or unaltered rock samples provide background geochemical data for individual rock units. Analyses of mineralized or altered rocks may provide useful geochemical information about the major- and trace-element assemblages associated with a mineralizing system.

Sample Collection and Preparation

Sampling sites are represented on plate 1. During the initial reconnaissance sampling in March 1987, a stream-sediment sample and two panned-concentrate samples derived from stream sediment were collected at each of the 11 sites (numbers 105-108, 113-118, 126). The two panned-concentrate samples from each site were treated differently, as described below, and after preparation were respectively termed a "nonmagnetic heavy-mineral-concentrate sample" and a "raw panned-concentrate sample." Average sampling density during the reconnaissance sampling was about one sample site per 0.7 mi^2 and the drainage basins ranged from 0.2 mi^2 to 1.5 mi^2 in area. During the follow-up sampling in December 1987, nonmagnetic heavy-mineral-concentrate and raw panned-concentrate samples were collected at 15 localities (numbers 7301-7305, 7312-7314, 7317-7323) except that no nonmagnetic heavy-mineral-concentrate sample was collected at site 7321. Samples were collected by Gary A. Nowlan and David A. Sawyer.

Stream-sediment samples

The stream-sediment samples consisted of active alluvium collected primarily from first-order (unbranched) and second-order (below the junction of two first-order) streams as shown on U.S. Geological Survey topographic maps (scale = 1:24,000). The stream-sediment samples were dried, then sieved using 30-mesh (0.595-mm) stainless-steel sieves. The portion of the sediment passing through the sieve was pulverized to approximately minus-100 mesh (minus-0.15 mm) for analysis.

Nonmagnetic heavy-mineral-concentrate samples

Ten to twenty pounds of stream sediment were collected from the active alluvium. Most of the samples were panned without screening. However, samples from sites 105-108 and 113-114 were screened with a 2.0-mm (10-mesh) screen to obtain about 20 lb after removal of the coarse material. The samples were panned to remove most of the quartz, feldspar, organic matter, and clay-sized material. The resulting concentrates were estimated to weigh between 1 and 4 oz.

After drying, bromoform (specific gravity 2.8) was used to remove the remaining quartz and feldspar from the samples that had been panned. Each heavy-mineral sample was then separated into three fractions using a large electromagnet (in this case a modified Frantz Isodynamic Separator). The most magnetic material, primarily magnetite, was not analyzed. The second fraction, largely ferromagnesian silicates and iron oxides, was saved for archival storage. The third fraction (the least magnetic material which may include the nonmagnetic ore minerals, zircon, sphene, etc.) was split using a Jones splitter. One split was hand ground for spectrographic analysis; the other split was saved for mineralogical analysis. These magnetic separates are approximately the same separates that would be produced by using a Frantz Isodynamic Separator set at a slope of 15° and a tilt of 10° with a current of 0.2 ampere to remove the magnetite and ilmenite, and a current of 0.6 ampere to split the remainder of the sample into paramagnetic and nonmagnetic fractions.

Raw panned-concentrate samples

Raw panned-concentrate samples were collected and panned in the same manner as the heavy-mineral-concentrate samples except that the samples were panned to a smaller amount. The raw panned-concentrate samples were dried and then were analyzed for gold without further preparation.

Rock samples

Sixty-four samples of bedrock were collected (table 1). The 28 samples from the RTR130 series were collected from outcrops at generally 100-ft intervals along a traverse crossing an area of altered bedrock along the west side of the wilderness study area. Sample RTR106A is from a shear zone. The seven samples from the 82S series were collected in 1982 and are representative of bedrock units where mineralization is absent and alteration is slight. The 28 samples from the RT7300 series are samples of mineralized rock, altered rock, and vein material. Descriptions of the rock samples are in table 1. Rock samples were crushed and then pulverized to approximately minus-100 mesh (minus-0.15 mm) with ceramic plates.

Sample Analysis

Spectrographic method

The stream-sediment samples were analyzed for 31 elements and the nonmagnetic heavy-mineral-concentrate and rock samples for 35-37 elements using a semiquantitative, direct-current arc emission spectrographic method (Grimes and Marranzino, 1968). The elements analyzed and their lower limits of determination are listed in tables 2 and 3. Spectrographic results were obtained by visual comparison of spectra derived from the sample against spectra obtained from standards made from pure oxides and carbonates. Standard concentrations are geometrically spaced over any given order of magnitude of concentration as follows: 100, 50, 20, 10, and so forth. Samples whose concentrations are estimated to fall between those values are assigned values of 70, 30, 15, and so forth. The precision of the analytical method is approximately plus or minus one reporting interval at the 83 percent confidence level and plus or minus two reporting intervals at the 96 percent confidence level (Motooka and Grimes, 1976). Values determined for the major elements (iron, magnesium, calcium, titanium, sodium, and phosphorus) are given in weight percent; all others are given in parts per million (ppm). Emission spectrographic analyses were performed by John H. Bullock, Jr.

Other methods

Table 4 lists other methods of analysis used on samples from the Ragged Top Wilderness Study Area and lists limits of determination, precision, and references for the methods. Rock and stream-sediment samples were analyzed for gold by graphite furnace atomic absorption spectroscopy and for antimony, arsenic, bismuth, cadmium, and zinc by inductively coupled plasma emission spectrometry. Rock samples were analyzed for mercury by cold vapor atomic absorption spectroscopy, for tellurium and thallium by flame atomic absorption spectroscopy, for fluorine by ion selective electrode, and for tungsten by visible spectrophotometry. Stream-sediment samples were analyzed for uranium by ultraviolet fluorimetry. Raw panned-concentrate samples were analyzed for gold by flame atomic absorption spectroscopy. Analysts were Paul H. Briggs, Alonza H. Love, John B. McHugh, Richard M. O'Leary, Theodore A. Roemer, John D. Sharkey, and Eric P. Welsch.

Analytical results for stream-sediment, nonmagnetic heavy-mineral-concentrate, raw panned-concentrate, and rock samples are listed in tables 5, 6, 7, and 8, respectively.

DATA STORAGE SYSTEM

Upon completion of analytical work, the results were entered into a U.S. Geological Survey computer data base called PLUTO. This data base contains both descriptive geological information and analytical data. Any or all of this information may be retrieved and converted to a binary form (STATPAC) for computerized statistical analysis or publication (VanTrump and Miesch, 1977).

DESCRIPTION OF DATA TABLES

The numeric portion of each sample identification in tables 5-7 and of RT7300-series rock samples and sample RTR106A in table 8 corresponds to the site number on plate 1. However, only the last three numbers in sample identifications for 82S-series rock samples in table 8 correspond to site numbers on plate 1. Sites A-Z on plate 1 show the sampling sites of RTR130-series rocks and correspond to the letter immediately following 130 in each sample identification in table 8.

A letter "N" in the tables indicates that a given element was looked for but not detected at the lower limit of determination. If an element determined by emission spectrography was observed but was below the lowest reporting value, a "less than" symbol (<) was entered in the tables in front of the lower limit of determination. No distinction was made between "not detected" and "less than" for samples analyzed by methods other than emission spectrography. If an element was above the highest reporting value, a "greater than" symbol (>) was entered in the tables in front of the upper limit of determination. The lower limit of determination for gold in raw panned-concentrate samples by atomic absorption spectroscopy is 0.05 ppm, based on a 10-g sample. Because the sample weight for raw panned-concentrate samples was variable, the lower limits of determination varied from 0.02 to 0.07 ppm. The weights of the raw panned-concentrate samples (table 7) are given in grams and are in the column headed by "weight".

Because of the formatting used in the computer program that produced tables 5-8, some of the elements listed in these tables (Ca, Fe, Mg, Na, P, Ti, Ag, Be, Cd-i, Au-a, Hg-a, Te-a, and Tl-a) carry one or more nonsignificant digits to the right of the significant digits. The spectrographic determinations for As, Au, Bi, Cd, Mo, Sb, Th, and W in stream-sediment samples; for As, Co, Ge, Nb, Pd, Pt, Sb, and Th in nonmagnetic heavy-mineral-concentrate samples; and for As, Au, Ge, Sb, Sn, and Th in rock samples were all below the lower limits of determinations shown in tables 2 and 3; consequently, the columns for these elements were omitted from tables 5, 6, and 8, respectively. The spectrographic determinations for Zr in nonmagnetic heavy-mineral-concentrate samples were all greater than the upper limit of determination and so that element was omitted from table 6.

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Table 1.--Descriptions of analyzed rock samples from the Ragged Top Wilderness Study Area, Pima County, Arizona. Au, Ag (ppm)

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RTR130IA	Granodiorite porphyry, highly altered, brecciated	.001, N
RTR130JA	Granodiorite porphyry, highly altered, brecciated	.004, N
RTR130KA	Granodiorite porphyry, highly altered,	.002, N
RTR130LA	Fine grained rock, highly altered	.002, N
RTR130MA	Granodiorite porphyry, altered	.002, N
RTR130NA	Potassium-rich rock	.001, N
RTR130OA	Potassium-rich rock	.003, N
RTR130PA	Granodiorite porphyry, slightly altered	<.003, N
RTR130QA	Granodiorite porphyry, slightly altered	<.001, N
RTR130RA	Granodiorite porphyry, slightly altered	<.001, N
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RTR130TA	Granodiorite porphyry, slightly altered	.001, N
RTR130UA	Granodiorite porphyry, slightly altered	.001, N
RTR130VA	Granodiorite porphyry	<.001, N
RTR130WA	Diabase	<.001, N
RTR130XA	Oracle-type granite	<.001, N
RTR130YA	Diabase	<.001, N
RTR130ZA	Oracle-type granite	<.001 N
RTR106A	Oracle-type granite from shear zone	.001, N
82S-023	Granodiorite porphyry	<.001, N
82S-044	Granodiorite porphyry	<.001, N
82S-122	Lithic tuff	<.001, N
82S-133	Rhyolite welded tuff	<.001, N
82S-135	Rhyodacite porphyry	<.001, N
82S-150	Rhyodacite porphyry	<.001, N
82S-382	Rhyolite	<.001, N
RT7306A	Barite-fluorite vein	.006, 0.5
RT7306BA	Barite vein	.002, <1
RT7306BB	Altered wall rock by barite vein	.007
RT7307A	Granodiorite porphyry, altered	.003, <.5
RT7308A	Granodiorite porphyry, altered	.015, .5
RT7309A	Sulfide minerals and calcite	[illegible], 150
RT7309B	Granodiorite porphyry with sulfide minerals	.015, 100
RT7309C	Granodiorite porphyry with sulfide minerals	.040, 20.0
RT7309D	Dolomite (?) vein with sulfide minerals	.02, 1.0
RT7309EA	Rhodochrosite (?) vein with sulfide minerals	.08, 50
RT7309EB	Granodiorite porphyry with rhodochrosite (?) and sulfide minerals	.10, 15
RT7309F	Granodiorite porphyry with sulfide minerals	.009, <.5
RT7309G	Granodiorite porphyry with sulfide minerals	.006, <.5
RT7310A	Granodiorite porphyry	.026, <.5
RT7310B	Granodiorite porphyry with calcite and sulfide minerals	.38, 30
RT7311AA	Quartz vein	.007, N
RT7311AB	Quartz vein	.044, N
RT7315A	Quartz vein	.001, N
RT7315B	Quartz vein	<.001, N
RT7315CA	Quartz vein	.002, N
RT7315CB	Altered granite	.062, <.5
RT7316A	Diabase	.006, N
RT7324A	Barite vein	.027, 2
RT7324B	Barite vein	.023, 3
RT7324CA	Quartz vein	.021 N
RT7324CB	Quartz vein	.25, 2
RT7325A	Quartz vein	.004, N
RT7326A	Quartz vein with sulfide minerals	.002, N

TABLE 2.--Limits of determination for the spectrographic analysis of stream-sediment samples, based on a 10-mg sample

Elements	Lower determination limit	Upper determination limit
	Percent	
Iron (Fe)	0.05	20
Magnesium (Mg)	.02	10
Calcium (Ca)	.05	20
Titanium (Ti)	.002	1
	Parts per million	
Manganese (Mn)	10	5,000
Silver (Ag)	0.5	5,000
Arsenic (As)	200	10,000
Gold (Au)	10	500
Boron (B)	10	2,000
Barium (Ba)	20	5,000
Beryllium (Be)	1	1,000
Bismuth (Bi)	10	1,000
Cadmium (Cd)	20	500
Cobalt (Co)	5	2,000
Chromium (Cr)	10	5,000
Copper (Cu)	5	20,000
Lanthanum (La)	20	1,000
Molybdenum (Mo)	5	2,000
Niobium (Nb)	20	2,000
Nickel (Ni)	5	5,000
Lead (Pb)	10	20,000
Antimony (Sb)	100	10,000
Scandium (Sc)	5	100
Tin (Sn)	10	1,000
Strontium (Sr)	100	5,000
Vanadium (V)	10	10,000
Tungsten (W)	50	10,000
Yttrium (Y)	10	2,000
Zinc (Zn)	200	10,000
Zirconium (Zr)	10	1,000
Thorium (Th)	100	2,000

TABLE 3.--Limits of determination for the spectrographic analysis of heavy-mineral-concentrate samples based on a 5-mg sample

[The spectrographic limits of determination for rock samples are based on a 10-mg sample and are therefore two reporting intervals lower than the limits listed in this table]

Elements	Lower determination limit	Upper determination limit
	Percent	
Iron (Fe)	0.1	50
Magnesium (Mg)	.05	20
Calcium (Ca)	.1	50
Titanium (Ti)	.005	2
Sodium (Na)	.5	10
Phosphorus (P)	.5	20
	Parts per million	
Manganese (Mn)	20	10,000
Silver (Ag)	1	10,000
Arsenic (As)	500	20,000
Gold (Au)	20	1,000
Boron (B)	20	5,000
Barium (Ba)	50	10,000
Beryllium (Be)	2	2,000
Bismuth (Bi)	20	2,000
Cadmium (Cd)	50	1,000
Cobalt (Co)	20	5,000
Chromium (Cr)	20	10,000
Copper (Cu)	10	50,000
Lanthanum (La)	100	2,000
Molybdenum (Mo)	10	5,000
Niobium (Nb)	50	5,000
Nickel (Ni)	10	10,000
Lead (Pb)	20	50,000
Antimony (Sb)	200	20,000
Scandium (Sc)	10	2,000
Tin (Sn)	20	2,000
Strontium (Sr)	200	10,000
Vanadium (V)	20	20,000
Tungsten (W)	50	20,000
Yttrium (Y)	20	5,000
Zinc (Zn)	500	20,000
Zirconium (Zr)	20	2,000
Thorium (Th)	200	5,000
Gallium (Ga)	10	1,000
Germanium (Ge)	20	200
Platinum (Pt)	20	1,000
Palladium (Pd)	5	1,000

TABLE 4.--Analytical methods used other than emission spectrography

[AAC, cold vapor atomic absorption; AAF, flame atomic absorption; AAG, graphite furnace atomic absorption; F, ultraviolet fluorimetry; ICP, inductively coupled plasma spectrometry; ISE, ion selective electrode; VS, visible spectrophotometry; <, less than value shown]

Element determined	Sample type	Method	Lower limit of determination, ppm	Precision, percent relative standard deviation	References
Mercury (Hg)	rocks	AAC	0.02	<5	Crock and others, 1987.
Tellurium (Te)	rocks	AAF	0.1	4.5-7.3	Hubert and Chao, 1985.
Thallium (Tl)	rocks	AAF	0.05	1.6-12.5	Hubert and Chao, 1985.
Gold (Au)	raw panned concentrates	AAF	0.05[a]	9.3-42.5	Thompson and others, 1968; O'Leary and Meier, 1986.
Gold (Au)	rocks, stream sediments	AAG	0.001	3.7-21.1	Meier, 1980; O'Leary, and Meier, 1986.
Uranium (U)	stream sediments	F	0.1	6.9-14.2	Centanni and others, 1956; O'Leary and Meier, 1986.
Antimony (Sb)	rocks, stream sediments	ICP	2	6.4-11	Crock and others, 1987.
Arsenic (As)	rocks, stream sediments	ICP	5	3.5-20	Crock and others, 1987.
Bismuth (Bi)	rocks, stream sediments	ICP	2	2.2-11.9	Crock and others, 1987.
Cadmium (Cd)	rocks, stream sediments	ICP	0.1	2.8-8.8	Crock and others, 1987.
Zinc (Zn)	rocks, stream sediments	ICP	2	1.4-11.9	Crock and others, 1987.
Fluorine (F)	rocks	ISE[b]	100	0.98-5.51	Hopkins, 1977; O'Leary and Meier, 1986.
Tungsten (W)	rocks	VS	1	2.9-6.9	Welsch, 1983; O'Leary and Meier, 1986.

[a]Based on 10-g sample

[b]Hot nitric acid digestion

Table 5.--Results of analyses of stream-sediment samples collected from the Ragged Top Wilderness Study Area, Pima County, Arizona

[N, not detected; <, detected below limit of determination shown for emission spectrographic analyses, less than value shown for other methods; >, greater than value shown; ---, not determined. Methods: Au-a, atomic absorption; As-i, Bi-i, Cd-i, Sb-i, Zn-i, inductively coupled plasma spectroscopy; U-f, ultraviolet fluorimetry; others, emission spectrography. Element values in ppm except Ca, Fe, Mg, and Ti, which are weight percent]

Sample	Latitude	Longitude	Ca	Fe	Mg	Ti	Ag	Au-a	As-i	B	Ba	Be	Bi-i	Cd-i	Co
RTA105	32 26 34	111 27 28	1.5	5	1.5	.7	N	---	7	50	700	3.0	<2	.8	30
RTA106	32 27 5	111 27 18	1.0	10	1.5	.7	N	.001	6	20	300	2.0	<2	2.3	70
RTA107	32 27 16	111 27 29	1.0	7	1.0	1.0	N	<.001	<5	30	500	3.0	<2	1.4	30
RTA108	32 27 46	111 27 54	.3	15	.3	.5	N	---	7	70	300	3.0	<2	2.5	70
RTA113	32 27 2	111 27 17	.5	7	.7	1.0	N	<.001	9	70	300	2.0	<2	1.9	30
RTA114	32 28 8	111 28 50	.7	7	1.0	1.0	N	---	6	15	500	3.0	<2	1.3	15
RTA115	32 28 31	111 30 4	.7	10	1.5	.7	N	<.001	<5	30	500	3.0	<2	1.3	20
RTA116	32 28 19	111 30 30	.7	10	.7	.7	N	.002	9	50	1,500	3.0	2	1.4	30
RTA117	32 27 43	111 30 39	1.0	5	1.5	.5	.5	.005	8	50	1,000	2.0	<2	1.3	15
RTA118	32 26 57	111 30 35	.5	5	1.0	.3	N	.010	<5	10	500	1.0	<2	.7	5
RTA126	32 26 14	111 29 4	.7	7	1.0	.5	N	.001	7	10	300	1.5	<2	.8	10

Sample	Cr	Cu	La	Mn	Nb	Ni	Pb	Sb-i	Sc	Sn	Sr	U-f	V	Y	Zn	Zn-i	Zr
RTA105	30	30	30	500	<20	30	50	2	15	N	200	1.1	150	20	N	68	500
RTA106	50	70	<20	1,000	N	50	50	11	15	<10	<100	2.2	200	50	200	88	200
RTA107	30	50	20	1,500	N	20	50	<2	20	N	<100	3.0	200	70	200	71	300
RTA108	200	30	N	700	<20	50	30	<2	10	N	N	7.5	500	500	N	31	300
RTA113	30	50	<20	300	<20	30	30	14	15	<10	N	1.9	200	50	N	89	300
RTA114	20	50	70	700	<20	15	30	<2	20	<10	<100	3.7	150	100	N	75	1,000
RTA115	30	30	50	2,000	<20	15	50	<2	15	N	100	2.8	200	100	N	81	500
RTA116	50	50	50	1,000	<20	30	150	<2	20	<10	100	2.9	300	70	N	77	1,000
RTA117	30	70	30	2,000	N	20	300	<2	15	N	150	1.1	100	20	200	150	200
RTA118	20	30	<20	500	N	7	70	<2	<5	N	100	1.2	70	<10	<200	68	70
RTA126	20	20	<20	500	N	15	50	<2	5	N	100	1.1	100	10	N	80	100

Table 6.--Results of analyses of nonmagnetic heavy-mineral-concentrate samples from the Ragged Top Wilderness Study Area, Pima County, Arizona

[N, not detected; <, detected below limit of determination shown; >, greater than value shown. Analyses by emission spectrography. Element values are ppm except Ca, Fe, Mg, Na, P, and Ti, which are weight percent]

Sample	Latitude	Longitude	Ca	Fe	Mg	Na	P	Ti	Ag	Au	B	Ba	Be	Bi	Cd
RTH105	32 26 34	111 27 28	5	1.00	.30	1.5	2.0	2.0	N	N	20	>10,000	3	N	N
RTH106	32 27 5	111 27 18	3	1.50	.30	.7	2.0	2.0	N	N	20	5,000	7	50	N
RTH107	32 27 16	111 27 29	5	.70	.20	.5	5.0	1.0	N	N	30	3,000	10	70	N
RTH108	32 27 46	111 27 54	5	1.00	.20	5.0	1.5	.2	N	N	20	1,000	5	N	N
RTH113	32 27 2	111 27 17	5	1.00	.50	2.0	1.5	1.5	N	N	30	>10,000	5	N	N
RTH114	32 28 8	111 28 50	10	.50	.20	1.5	10.0	.7	N	N	<20	700	5	N	N
RTH115	32 28 31	111 30 4	10	1.00	.30	2.0	5.0	1.5	N	N	20	3,000	7	N	N
RTH116	32 28 19	111 30 30	5	.70	.30	1.0	1.0	.7	N	N	<20	>10,000	7	N	N
RTH117	32 27 43	111 30 39	10	1.50	.50	3.0	2.0	1.5	<1	N	30	>10,000	2	N	N
RTH118	32 26 57	111 30 35	2	.30	.10	1.0	1.0	.5	1,000	>1,000	N	>10,000	N	30	N
RTH126	32 26 14	111 29 4	7	.70	.15	2.0	1.5	1.5	2	N	<20	10,000	3	N	<50
RTH7301B	32 26 56	111 30 34	7	.10	.10	N	2.0	.3	2	N	N	>10,000	N	N	N
RTH7302	32 26 53	111 30 31	20	.20	.10	N	7.0	.7	2	N	N	>10,000	N	N	N
RTH7303	32 26 55	111 30 27	30	.30	.10	N	7.0	.5	<1	N	N	>10,000	N	N	N
RTH7304B	32 26 50	111 30 16	20	.20	.15	N	1.5	.5	300	N	N	>10,000	N	300	70
RTH7305B	32 27 1	111 30 43	10	.10	.07	N	.5	.1	30	N	N	>10,000	N	N	N
RTH7312	32 27 9	111 27 44	15	.70	.15	.5	2.0	1.5	N	N	20	3,000	5	30	N
RTH7313	32 27 8	111 27 43	15	.70	.30	1.0	.7	1.0	N	N	20	>10,000	3	N	N
RTH7314	32 27 5	111 27 21	20	1.50	1.00	2.0	1.0	2.0	N	N	30	10,000	2	30	N
RTH7317	32 26 31	111 29 57	20	1.00	.15	N	7.0	1.5	N	N	N	>10,000	<2	N	N
RTH7318	32 26 39	111 30 3	5	.20	.10	<.5	.7	.3	N	N	N	>10,000	<2	N	N
RTH7319B	32 26 42	111 30 13	10	.20	.10	<.5	2.0	1.0	15	70	<20	>10,000	N	N	N
RTH7320B	32 26 40	111 30 14	2	.10	.07	N	<.5	.2	N	N	N	>10,000	N	N	N
RTH7322	32 26 9	111 30 16	3	<.10	.07	N	<.5	.2	N	N	N	>10,000	N	N	N
RTH7323	32 26 15	111 30 18	3	.15	.10	N	.5	.2	1	N	N	>10,000	N	N	N

Sample	Cr	Cu	Ga	La	Mn	Mo	Ni	Pb	Sc	Sn	Sr	V	W	Y	Zn
RTH105	<20	70	20	N	300	N	<10	70	50	N	700	50	N	500	N
RTH106	20	20	15	<100	500	N	<10	1,000	200	N	N	200	N	1,500	N
RTH107	N	15	10	<100	700	N	<10	70	200	N	N	100	N	1,500	N
RTH108	N	<10	30	N	700	N	<10	50	70	N	N	50	50	1,000	N
RTH113	<20	50	70	N	700	N	<10	2,000	100	N	200	100	N	1,500	N
RTH114	N	N	15	100	1,000	N	N	70	150	N	N	50	N	1,500	N
RTH115	N	10	30	100	700	N	N	100	100	N	N	50	N	1,000	N
RTH116	N	<10	15	N	700	N	N	200	150	N	700	30	N	1,000	N
RTH117	20	50	50	150	700	<10	<10	3,000	50	N	700	100	N	500	N
RTH118	N	150	<10	<100	200	150	N	>50,000	30	N	1,500	15,000	N	150	<500
RTH126	N	<10	10	100	300	N	N	1,000	50	N	N	700	N	300	N
RTH7301B	N	70	N	100	500	10	N	15,000	20	N	>10,000	1,500	N	300	500
RTH7302	N	30	N	150	700	100	N	3,000	20	N	10,000	150	N	500	N
RTH7303	N	<10	N	300	1,000	N	N	1,500	20	N	10,000	150	N	300	N
RTH7304B	<20	1,000	N	150	1,000	500	N	>50,000	30	N	10,000	5,000	N	200	700
RTH7305B	N	20	N	<100	200	20	N	500	N	N	>10,000	500	N	70	<500
RTH7312	N	50	<10	100	1,000	N	N	50	200	N	<200	200	N	1,500	N
RTH7313	<20	10	10	100	500	N	N	<20	200	N	500	150	N	1,500	N
RTH7314	<20	20	30	100	1,000	N	N	<20	100	50	500	150	N	1,000	N
RTH7317	N	<10	N	200	1,000	N	N	30	100	N	700	300	N	700	N
RTH7318	50	50	N	N	500	N	N	50	15	N	>10,000	700	N	200	N
RTH7319B	20	20	N	150	700	<10	N	>50,000	70	N	7,000	10,000	N	700	N
RTH7320B	N	15	N	N	150	30	N	3,000	<10	N	>10,000	300	N	100	N
RTH7322	N	N	N	N	300	200	N	1,500	N	N	>10,000	50	N	70	N
RTH7323	N	<10	N	N	500	<10	N	10,000	20	N	10,000	3,000	N	150	N

Table 7.--Results of analyses of raw panned-concentrate samples collected from the Ragged Top Wilderness Study Area, Pima County, Arizona

[<, less than value shown. Au-a in ppm. Weight, grams of raw panned-concentrate sample. Analyses by atomic absorption]

Sample	Latitude	Longitude	Au-a	Weight
RTG105	32 26 34	111 27 28	<.05	11.01
RTG106	32 27 5	111 27 18	<.04	13.09
RTG107	32 27 16	111 27 29	<.05	11.02
RTG108	32 27 46	111 27 54	<.05	9.97
RTG113	32 27 2	111 27 17	<.06	7.95
RTG114	32 28 8	111 28 50	<.04	14.45
RTG115	32 28 31	111 30 4	<.05	10.04
RTG116	32 28 19	111 30 30	<.05	11.35
RTG117	32 27 43	111 30 39	<.07	6.55
RTG118	32 26 57	111 30 35	150.00	7.44
RTG126	32 26 14	111 29 4	<.05	11.55
RTG7301	32 26 56	111 30 34	2.30	21.57
RTG7302	32 26 53	111 30 31	.20	15.18
RTG7303	32 26 55	111 30 27	.03	19.68
RTG7304	32 26 50	111 30 16	3.40	13.13
RTG7305	32 27 1	111 30 43	.03	17.80
RTG7312	32 27 9	111 27 44	<.03	21.45
RTG7313	32 27 8	111 27 43	.03	19.83
RTG7314	32 27 5	111 27 21	<.03	16.69
RTG7317	32 26 31	111 29 57	.06	15.89
RTG7318	32 26 39	111 30 3	<.02	26.66
RTG7319	32 26 42	111 30 13	.11	16.62
RTG7320	32 26 40	111 30 14	.23	25.10
RTG7321	32 26 30	111 30 15	.03	18.29
RTG7322	32 26 9	111 30 16	.04	13.32
RTG7323	32 26 15	111 30 18	.99	20.00

Table 8.--Results of analyses of rock samples collected from the Ragged Top Wilderness Study Area, Pima County, Arizona

[N, not detected; <, detected below limit of determination shown for emission spectrographic analyses, less than value shown for other methods; >, greater than value shown; ---, not determined. Methods: As-i, Bi-i, Cd-i, Sb-i, Zn-i, inductively coupled spectroscopy; Au-a, Hg-a, Te-a, Tl-a, atomic absorption; W-v, visible spectrophotometry; F-is, ion selective electrode; others, emission spectrography. Values in ppm except Ca, Fe, Mg, Na, P, Ti, and F-is, which are weight percent]

Sample	Latitude	Longitude	Ca	Fe	Mg	Na	P	Ti	Ag	B	Ba	Be
RTR130AA	32 27 4	111 30 31	.70	5.0	1.0	3.0	N	.500	N	10	3,000	1.5
RTR130BA	32 27 5	111 30 31	1.00	5.0	2.0	3.0	N	.500	N	15	1,000	<1.0
RTR130CA	32 27 6	111 30 31	.30	7.0	2.0	2.0	N	.700	N	100	1,000	1.5
RTR130DA	32 27 7	111 30 31	.20	5.0	2.0	3.0	N	.500	<.5	20	1,000	1.0
RTR130DB	32 27 7	111 30 31	.20	5.0	1.5	3.0	N	.500	N	20	1,000	1.0
RTR130EA	32 27 8	111 30 30	.30	5.0	.5	1.0	N	.300	N	70	1,500	<1.0
RTR130EB	32 27 8	111 30 30	.15	3.0	.2	.5	N	.500	N	50	700	<1.0
RTR130FA	32 27 10	111 30 31	.20	3.0	1.5	3.0	N	.300	.5	30	200	1.0
RTR130GA	32 27 11	111 30 31	.07	7.0	.3	.5	N	.700	1.0	300	1,500	1.0
RTR130HA	32 27 12	111 30 31	.20	7.0	.7	1.5	<.2	.700	<.5	500	1,500	1.0
RTR130IA	32 27 13	111 30 30	.15	5.0	1.5	2.0	N	.300	N	150	1,000	1.5
RTR130JA	32 27 14	111 30 30	.20	7.0	1.5	3.0	N	.700	N	50	1,000	<1.0
RTR130KA	32 27 15	111 30 31	.30	7.0	2.0	2.0	N	.700	N	50	2,000	1.5
RTR130LA	32 27 15	111 30 32	.15	10.0	3.0	2.0	N	.700	N	300	1,000	1.5
RTR130MA	32 27 16	111 30 33	.30	3.0	1.0	<.2	N	.500	N	50	1,500	1.5
RTR130NA	32 27 17	111 30 33	.30	7.0	.7	3.0	N	.700	N	50	1,500	1.0
RTR130OA	32 27 18	111 30 34	.15	5.0	1.0	2.0	N	.700	N	100	2,000	1.0
RTR130PA	32 27 19	111 30 34	2.00	7.0	2.0	3.0	N	.700	N	70	1,500	1.5
RTR130QA	32 27 20	111 30 34	3.00	7.0	3.0	3.0	N	.700	N	10	700	<1.0
RTR130RA	32 27 21	111 30 34	2.00	7.0	3.0	2.0	N	.700	N	30	1,000	1.5
RTR130SA	32 27 22	111 30 34	1.50	7.0	3.0	3.0	N	.500	N	<10	1,000	<1.0
RTR130TA	32 27 25	111 30 35	1.00	7.0	1.5	3.0	N	.500	N	20	1,000	<1.0
RTR130UA	32 27 27	111 30 34	.30	5.0	1.5	3.0	N	.700	N	20	1,000	1.0
RTR130VA	32 27 29	111 30 33	.20	3.0	.5	3.0	N	.300	N	10	2,000	2.0
RTR130WA	32 27 30	111 30 33	3.00	10.0	3.0	2.0	.7	1.000	N	10	300	2.0
RTR130XA	32 27 31	111 30 34	.70	3.0	.7	2.0	N	.500	N	15	1,000	1.5
RTR130YA	32 27 32	111 30 34	3.00	20.0	5.0	2.0	.2	>1.000	N	15	500	2.0
RTR130ZA	32 27 34	111 30 35	.30	5.0	.3	3.0	N	.500	N	10	1,000	1.5
RTR106A	32 27 5	111 27 18	15.00	10.0	10.0	<.2	N	.200	N	<10	200	1.5
82S-023	32 27 29	111 30 48	.50	5.0	1.0	3.0	N	.200	N	<10	1,500	<1.0
82S-044	32 26 59	111 31 20	1.50	7.0	2.0	3.0	N	.500	N	10	1,000	N
82S-122	32 26 11	111 30 15	1.00	2.0	.5	2.0	N	.200	N	10	1,500	1.0
82S-133	32 25 32	111 30 25	.70	3.0	.3	3.0	N	.300	N	<10	2,000	<1.0
82S-135	32 25 29	111 30 23	1.50	5.0	1.5	3.0	N	.300	N	10	1,500	<1.0
82S-150	32 26 15	111 29 35	1.50	7.0	2.0	3.0	N	.300	N	<10	1,000	<1.0
82S-382	32 26 47	111 29 18	.30	2.0	.2	5.0	N	.200	N	N	1,000	1.5
RT7306A	32 26 54	111 30 39	2.00	3.0	.7	1.5	N	.200	.5	10	>5,000	<1.0
RT7306BA	32 26 54	111 30 39	5.00	.1	.1	N	N	.015	N	<10	>5,000	N
RT7306BB	32 26 54	111 30 39	3.00	2.0	.5	N	N	.070	N	70	>5,000	5.0
RT7307A	32 26 58	111 30 18	.50	2.0	.1	N	N	.500	<.5	20	1,000	N
RT7308A	32 26 58	111 30 5	.07	5.0	.5	3.0	N	.300	.5	<10	1,500	N
RT7309A	32 27 2	111 30 6	7.00	7.0	.3	>5.0	N	.150	150.0	10	150	N
RT7309B	32 27 2	111 30 6	1.00	5.0	1.5	2.0	N	.500	100.0	10	1,500	<1.0
RT7309C	32 27 2	111 30 6	.30	7.0	.5	1.5	N	.500	20.0	20	300	<1.0
RT7309D	32 27 2	111 30 6	20.00	5.0	1.5	.3	N	.200	1.0	30	2,000	1.0

Table 8.--Results of analyses of rock samples collected from the Ragged Top Wilderness Study Area, Pima County, Arizona--Continued

Sample	Bi	Cd	Co	Cr	Cu	Ga	La	Mn	Mo	Nb	Ni	Pb	Sc	Sr	V	W
RTR130AA	N	N	10	N	50	70	50	500	N	N	N	30	5	500	100	N
RTR130BA	N	N	20	20	30	70	<50	700	N	N	20	20	10	500	150	N
RTR130CA	N	N	15	30	70	50	50	500	N	N	20	100	15	200	200	N
RTR130DA	N	N	15	15	70	50	<50	1,500	N	N	30	200	10	300	150	N
RTR130DB	N	N	N	N	70	70	50	300	N	N	15	30	10	200	200	N
RTR130EA	<10	N	<10	10	30	70	<50	70	N	N	<5	150	7	150	150	N
RTR130EB	<10	N	N	30	30	50	<50	50	N	N	<5	500	7	100	200	N
RTR130FA	N	N	<10	15	50	70	<50	500	N	N	5	300	7	200	100	N
RTR130GA	N	N	N	30	100	50	<50	50	5	N	N	15	10	150	200	N
RTR130HA	N	N	<10	20	30	70	50	200	<5	N	<5	30	10	100	200	N
RTR130IA	N	N	10	15	50	50	<50	300	N	N	20	15	7	200	150	N
RTR130JA	N	N	10	10	50	70	<50	200	N	N	5	20	15	300	200	N
RTR130KA	N	N	50	10	70	70	<50	1,000	<5	N	30	20	10	200	150	N
RTR130LA	N	N	30	20	50	50	<50	1,000	N	N	10	15	15	100	300	N
RTR130MA	N	N	N	15	15	50	<50	100	N	N	N	150	7	100	150	N
RTR130NA	N	N	N	20	50	70	50	150	5	N	N	30	10	150	200	N
RTR130OA	N	N	N	15	30	70	<50	70	<5	N	N	50	10	100	150	N
RTR130PA	N	N	30	10	50	100	50	2,000	<5	N	15	50	10	300	200	N
RTR130QA	N	N	50	10	70	70	<50	1,500	N	N	20	10	20	500	200	N
RTR130RA	N	N	30	15	70	100	50	1,500	N	N	20	10	10	200	150	N
RTR130SA	N	N	70	10	70	70	<50	1,500	N	N	15	15	15	700	150	N
RTR130TA	N	N	100	15	70	100	N	5,000	5	N	20	15	7	500	150	N
RTR130UA	N	N	15	15	70	100	<50	1,500	<5	N	10	30	10	500	200	N
RTR130VA	N	N	N	N	5	100	70	300	<5	<20	N	100	5	200	20	N
RTR130WA	N	N	30	<10	100	100	N	2,000	N	N	<5	100	15	150	150	N
RTR130XA	N	N	15	<10	10	30	<50	500	<5	N	5	10	7	100	50	N
RTR130YA	N	N	100	50	100	100	N	3,000	N	N	100	10	30	300	300	N
RTR130ZA	N	N	<10	<10	30	70	50	300	<5	N	<5	15	10	100	70	N
RTR106A	N	N	150	N	70	20	N	3,000	N	N	100	100	20	200	500	N
82S-023	N	N	15	N	15	70	N	500	N	N	N	30	<5	200	100	---
82S-044	N	N	20	15	70	100	N	700	N	N	10	30	10	500	200	N
82S-122	N	N	10	N	<5	30	N	500	N	N	N	30	<5	150	50	---
82S-133	N	N	N	N	<5	70	70	500	N	N	N	20	5	100	20	N
82S-135	N	N	20	30	5	100	N	500	N	N	20	30	7	300	150	N
82S-150	N	N	20	20	50	100	N	500	N	N	15	15	7	200	150	N
82S-382	N	N	N	N	<5	70	50	300	N	N	N	50	N	<100	15	N
RT7306A	N	N	<10	10	30	50	N	200	N	N	7	300	<5	3,000	100	N
RT7306BA	N	N	N	N	15	10	N	200	N	N	N	300	N	>5,000	150	N
RT7306BB	N	N	N	<10	50	10	50	1,000	N	N	10	500	<5	200	200	N
RT7307A	N	N	N	<10	5	20	N	10	N	N	N	N	<5	N	100	N
RT7308A	N	N	<10	10	7	100	N	300	N	N	<5	20	<5	<100	70	N
RT7309A	15	>500	<10	N	3,000	30	N	2,000	150	N	N	>20,000	<5	N	50	N
RT7309B	N	N	20	15	200	70	N	1,500	<5	N	20	150	5	<100	100	N
RT7309C	<10	70	15	20	200	50	N	300	20	N	15	5,000	5	N	150	N
RT7309D	N	N	10	N	100	30	50	3,000	<5	N	5	200	<5	150	70	N

Table 8.--Results of analyses of rock samples collected from the Ragged Top Wilderness Study Area, Pima County, Arizona--Continued

Sample	Y	Zn	Zr	As-i	Bi-i	Cd-i	Sb-i	Zn-i	Au-a	Hg-a	Te-a	Tl-a	W-v	F-is
RTR130AA	10	N	150	---	---	---	---	---	<.001	---	---	---	---	---
RTR130BA	15	<200	100	---	---	---	---	---	<.001	---	---	---	---	---
RTR130CA	15	<200	100	---	---	---	---	---	.004	---	---	---	---	---
RTR130DA	15	<200	100	---	---	---	---	---	.002	---	---	---	---	---
RTR130DB	20	<200	200	---	---	---	---	---	.004	---	---	---	---	---
RTR130EA	15	N	500	---	---	---	---	---	.002	---	---	---	---	---
RTR130EB	10	N	200	---	---	---	---	---	.002	---	---	---	---	---
RTR130FA	15	200	100	---	---	---	---	---	.005	---	---	---	---	---
RTR130GA	10	N	150	---	---	---	---	---	.008	---	---	---	---	---
RTR130HA	15	N	200	---	---	---	---	---	.002	---	---	---	---	---
RTR130IA	10	<200	100	---	---	---	---	---	.001	---	---	---	---	---
RTR130JA	15	N	300	---	---	---	---	---	.001	---	---	---	---	---
RTR130KA	20	<200	70	---	---	---	---	---	.004	---	---	---	---	---
RTR130LA	30	N	200	---	---	---	---	---	.002	---	---	---	---	---
RTR130MA	20	N	200	---	---	---	---	---	.002	---	---	---	---	---
RTR130NA	20	N	200	---	---	---	---	---	.002	---	---	---	---	---
RTR130OA	15	N	200	---	---	---	---	---	.001	---	---	---	---	---
RTR130PA	20	N	150	---	---	---	---	---	.003	---	---	---	---	---
RTR130QA	30	<200	150	---	---	---	---	---	<.001	---	---	---	---	---
RTR130RA	30	<200	200	---	---	---	---	---	<.001	---	---	---	---	---
RTR130SA	15	<200	100	---	---	---	---	---	<.001	---	---	---	---	---
RTR130TA	50	N	200	---	---	---	---	---	.001	---	---	---	---	---
RTR130UA	15	N	150	---	---	---	---	---	.001	---	---	---	---	---
RTR130VA	30	N	200	---	---	---	---	---	<.001	---	---	---	---	---
RTR130WA	50	<200	100	---	---	---	---	---	<.001	---	---	---	---	---
RTR130XA	70	N	100	---	---	---	---	---	<.001	---	---	---	---	---
RTR130YA	50	<200	150	---	---	---	---	---	<.001	---	---	---	---	---
RTR130ZA	50	N	200	---	---	---	---	---	<.001	---	---	---	---	---
RTR106A	70	<200	20	---	---	---	---	---	.001	---	---	---	---	---
82S-023	N	N	100	11	<2	.5	25	59	<.001	<.02	<.05	.35	---	.03
82S-044	10	N	70	<5	<2	.7	3	37	<.001	.04	<.05	.40	1.2	.03
82S-122	10	N	70	<5	<2	.2	9	19	<.001	<.02	<.05	.50	---	.02
82S-133	15	N	500	<5	<2	.3	3	37	<.001	.02	<.05	.70	1.2	.03
82S-135	<10	N	100	<5	<2	.8	5	54	<.001	.02	<.05	.45	1.5	.03
82S-150	10	N	150	<5	<2	.7	3	44	<.001	.02	<.05	.30	.9	.03
82S-382	10	N	150	<5	<2	<.1	<2	29	<.001	<.02	<.05	.70	1.0	.02
RT7306A	10	2,000	50	<5	<2	.8	<2	1,600	.006	.12	<.05	.50	2.0	1.70
RT7306BA	15	<200	N	12	<2	.3	<2	130	.002	.02	<.05	<.05	.6	1.30
RT7306BB	30	500	30	23	<2	6.1	6	370	.007	.04	<.05	.25	3.3	2.40
RT7307A	N	N	20	<5	<2	.1	<2	3	.003	<.02	<.05	1.10	3.4	.02
RT7308A	N	N	50	27	<2	.4	<2	35	.015	<.02	.55	.85	2.2	.02
RT7309A	10	>10,000	15	<5	2	1,600.0	<2	>40,000	---	2.90	7.30	.50	1.6	.90
RT7309B	10	300	100	17	<2	4.7	3	610	.015	<.02	.35	1.10	2.5	.03
RT7309C	10	>10,000	100	16	6	53.0	5	6,400	.090	.20	2.00	1.60	5.4	.04
RT7309D	15	200	100	13	<2	3.5	6	580	.020	.02	.10	.50	1.4	.07

Table 8.--Results of analyses of rock samples collected from the Ragged Top Wilderness Study Area, Pima County, Arizona--Continued

Sample	Latitude	Longitude	Ca	Fe	Mg	Na	P	Ti	Ag	B	Ba	Be
RT7309EA	32 27 2	111 30 6	>20.00	10.0	.3	N	N	.002	50.0	15	1,500	N
RT7309EB	32 27 2	111 30 6	15.00	3.0	.3	N	N	.150	15.0	15	150	N
RT7309F	32 27 2	111 30 6	1.00	5.0	2.0	2.0	N	.700	<.5	10	200	<1.0
RT7309G	32 27 2	111 30 6	.70	7.0	1.5	3.0	N	.700	<.5	<10	2,000	<1.0
RT7310A	32 27 4	111 30 8	.70	5.0	1.5	1.5	N	.700	1.5	10	700	1.0
RT7310B	32 27 4	111 30 8	10.00	5.0	1.0	1.0	N	.300	30.0	10	500	<1.0
RT7311AA	32 27 8	111 27 26	20.00	7.0	3.0	.2	N	.030	N	<10	3,000	N
RT7311AB	32 27 8	111 27 26	20.00	3.0	1.0	N	N	.015	N	<10	150	N
RT7315A	32 27 1	111 27 56	5.00	5.0	2.0	<.2	N	.200	N	10	700	1.5
RT7315B	32 27 1	111 27 56	1.00	5.0	.1	N	N	.300	N	15	1,500	1.0
RT7315CA	32 27 1	111 27 56	1.50	2.0	.5	2.0	N	.200	N	10	300	N
RT7315CB	32 27 1	111 27 56	.50	5.0	.7	3.0	N	.200	<.5	10	200	N
RT7316A	32 27 7	111 27 28	7.00	10.0	5.0	3.0	N	1.000	N	<10	500	N
RT7324A	32 26 11	111 30 34	.07	1.0	.3	1.5	<.2	.100	2.0	<10	>5,000	N
RT7324B	32 26 11	111 30 34	.50	1.5	.1	N	<.2	.700	3.0	N	>5,000	N
RT7324CA	32 26 11	111 30 34	.10	.5	.1	N	N	.020	N	<10	700	<1.0
RT7324CB	32 26 11	111 30 34	.20	2.0	.2	.2	N	.100	2.0	<10	1,000	5.0
RT7325A	32 27 6	111 27 30	1.50	10.0	3.0	2.0	N	1.000	N	<10	150	<1.0
RT7326A	32 27 8	111 27 34	5.00	7.0	3.0	2.0	N	.050	N	<10	150	<1.0

Table 8.--Results of analyses of rock samples collected from the Ragged Top Wilderness Study Area, Pima County, Arizona--Continued

Sample	Bi	Cd	Co	Cr	Cu	Ga	La	Mn	Mo	Nb	Ni	Pb	Sc	Sr	V	W
RT7309EA	N	500	N	<10	15,000	30	<50	>5,000	10	N	<5	>20,000	20	500	10	N
RT7309EB	10	20	<10	<10	700	50	<50	2,000	10	N	<5	20,000	N	100	50	N
RT7309F	N	N	20	20	100	70	N	1,500	N	N	20	50	5	N	150	N
RT7309G	N	N	15	15	200	100	N	2,000	N	N	10	70	7	<100	100	N
RT7310A	N	N	20	20	70	30	N	1,500	N	N	15	50	7	<100	100	N
RT7310B	15	N	15	10	15	70	<50	2,000	<5	N	10	20,000	5	N	100	N
RT7311AA	N	N	20	30	30	N	N	3,000	N	N	30	20	15	100	50	N
RT7311AB	N	N	<10	10	10	<5	N	2,000	N	N	10	N	N	<100	30	N
RT7315A	N	N	10	N	15	30	<50	1,000	N	N	<5	10	<5	N	50	N
RT7315B	N	N	15	N	15	20	<50	700	N	<20	<5	<10	5	N	50	N
RT7315CA	N	N	N	N	7	50	<50	500	N	<20	<5	10	N	<100	30	N
RT7315CB	N	N	N	N	10	100	N	200	N	N	N	50	N	N	50	N
RT7316A	N	N	100	500	100	70	N	1,000	N	N	100	N	30	<100	300	N
RT7324A	N	N	N	N	20	15	N	200	300	N	N	1,000	N	>5,000	15	N
RT7324B	N	N	N	150	100	<5	N	100	200	N	5	500	<5	>5,000	70	<20
RT7324CA	N	N	N	N	5	10	N	300	N	N	N	N	N	N	10	N
RT7324CB	N	N	N	N	20	20	N	700	7	N	<5	30	N	N	20	N
RT7325A	N	N	70	300	50	70	N	1,500	N	N	150	50	30	N	300	N
RT7326A	N	N	70	<10	70	50	N	2,000	N	N	50	50	<5	N	150	N

Table 8.--Results of analyses of rock samples collected from the Ragged Top Wilderness Study Area, Pima County, Arizona--Continued

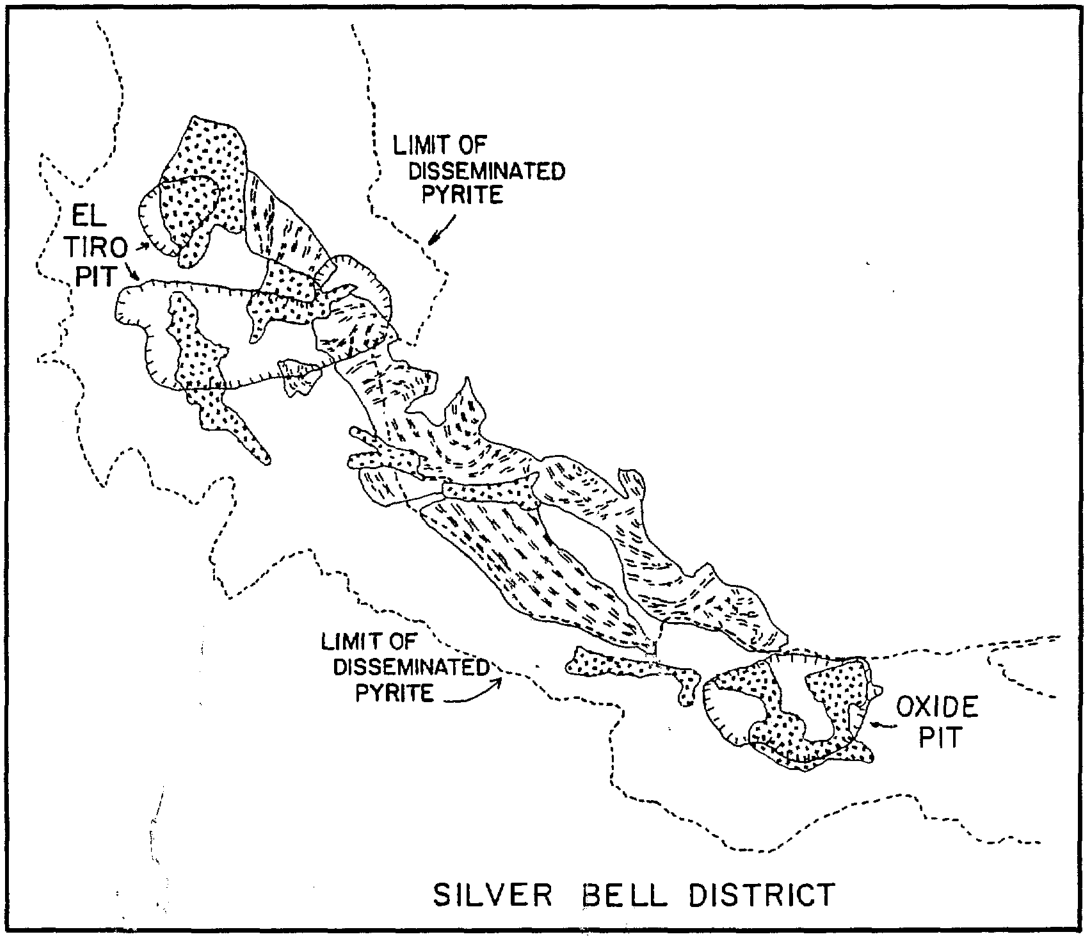
Sample	Y	Zn	Zr	As-i	Bi-i	Cd-i	Sb-i	Zn-i	Au-a	Hg-a	Te-a	Tl-a	W-v	F-is
RT7309EA	200	>10,000	N	<5	<2	410.0	4	34,000	.080	1.20	2.00	.10	<.5	<.01
RT7309EB	20	7,000	10	10	4	28.0	6	3,400	.100	.08	1.60	.90	2.7	.02
RT7309F	<10	<200	150	7	<2	.8	<2	110	.009	<.02	<.05	.70	2.9	.02
RT7309G	10	<200	30	8	<2	6.0	8	160	.005	<.02	<.05	.85	1.7	.02
RT7310A	<10	<200	100	13	<2	.7	<2	110	.026	<.02	.70	1.00	2.5	.03
RT7310B	15	700	30	14	9	6.4	6	770	.380	.02	4.00	.80	1.7	.03
RT7311AA	20	N	10	<5	<2	2.4	<2	36	.007	.38	<.05	.15	<.5	<.01
RT7311AB	<10	N	N	<5	<2	1.2	<2	13	.044	2.20	<.05	.15	<.5	<.01
RT7315A	50	N	100	<5	<2	1.1	3	34	.001	.40	<.05	.55	1.3	.01
RT7315B	30	N	70	<5	<2	.4	5	50	<.001	<.02	<.05	.30	1.2	.02
RT7315CA	10	N	50	<5	<2	.2	<2	23	.002	<.02	<.05	.50	.6	.01
RT7315CB	<10	N	30	<5	<2	.1	<2	26	.002	<.02	<.05	.50	.7	<.01
RT7316A	15	N	70	<5	<2	.4	<2	20	.006	.10	<.05	.10	.5	<.01
RT7324A	N	N	15	<5	<2	.2	4	69	.023	.12	<.05	.30	3.2	<.01
RT7324B	15	N	100	9	<2	.4	3	71	.023	.50	<.05	1.60	7.4	.01
RT7324CA	N	N	N	<5	<2	.3	<2	10	.021	.02	<.05	.25	.5	.04
RT7324CB	10	N	20	5	<2	1.0	3	46	.250	.02	<.05	.55	1.6	.03
RT7325A	10	300	20	<5	<2	1.8	<2	290	.004	.04	<.05	.05	4.3	.02
RT7326A	10	<200	100	<5	<2	1.6	<2	190	.002	.02	<.05	.05	.6	.01

28th International Geological Congress

Porphyry Copper Deposits in the American Southwest

Field Trip Guidebook T338

Leader: Spencer R. Titley



Tucson to Globe—Miami, Arizona
July 19–23, 1989

Frontispiece. Giants in geology and pioneers in the study of mineral deposits, copper ores, and regional geology of the American Southwest. Shown at Bisbee, Arizona during the 16th IGC (1933) are, left to right, Bert S. Butler, Waldemar Lindgren (President, 16th IGC), and Frederick Leslie Ransome. Photographed by Robert E. Heineman, Tucson. S. R. Titley, collection.

Porphyry Copper Deposits in the American Southwest

Tucson to Globe—Miami, Arizona
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Field Trip Guidebook T338

Leader: *Spencer R. Titley*

Associate Leaders:
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IGC FIELD TRIP T338: PORPHYRY COPPER DEPOSITS IN THE AMERICAN SOUTHWEST

Spencer R. Titley[1], S. A. Anzalone[2], and Elizabeth Y. Anthony[3]

Trip Headquarters and Date: Tucson, Arizona, 19-23 July 1989

INTRODUCTION

Welcome to Tucson, Arizona, and the four-day stay to visit and study a group of classic copper deposits. The field trip comprises four, single-day, excursions to copper districts during which you will have the opportunity to spend time in a region with a unique geological history, and to examine the geology of a selected group of distinctive and different porphyry copper deposits.

In outline, the four trips will be carried out from Tucson to visit the deposits in southeastern Arizona at Silver Bell, Red Mountain, the Globe-Miami-Ray region and in the Pima district. A map of this part of Arizona with mines, ranges, and routes is shown in Figure 1. The visit to this group of deposits will allow the study of parts of porphyry copper deposits from altered and oxidized lithocaps downward into metallized systems where both sedimentary and crystalline rocks host the metals and alteration. Further, the location of these deposits and the routes traveled will afford a sightseer's view of parts of two of the major geomorphic provinces of the State of Arizona, the Basin and Range Province in the Sonoran Desert, and the Central Mountain Province, which marks the geomorphic and geological transition between the Basin and Range region to the south and the Colorado Plateaus to the north.

The following sections of this guidebook will provide an overview of geology of this region, and a generalized summary of the important features of the porphyry copper ore deposits that occur here. A brief geological overview of each of the districts to be visited is presented in order to acquaint the visitor with some relevant details of local geology. On the occasion of the visits to specific sites, the geological information presented in this guidebook will be augmented by materials provided by mine geological staffs.

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Some Geological Facts Concerning Tucson

Tucson occupies an intermontane basin in the southern Basin and Range Province of the western United States and overlies a land area of about 600 km^2. This old city, believed to have been built above still older indian ruins and a Spanish presidio, had its center near the Santa Cruz River, adjacent to the present-day interstate highway (see Figure 1), a river which our history books tell us was flowing in the late 17th Century. This "river" and its channel occupy the topographically low axis that trends and drops to the northwest across the western side of the city. The north side of the city rises among foothills that front the Santa Catalina Mountains, a metamorphic core complex or gneiss dome that rises to an elevation of nearly 3400 m. To the east, the rocks of the Catalina Mountains continue as a group of separately named ranges, the Tanque Verde and the Rincon Mountains, which complete a quarter circle arc around the city. An interesting aspect of these ranges and the city is that they represent extremes in climate and growth zones in this region, going from vegetation of the Sonoran Desert Province to that of Alpine provinces across a driving distance of less than 60 km but an elevation difference of 1850 m in the Santa Catalina Mountains.

On its western side, and west of the Santa Cruz River axis, the city is flanked by a north-trending mountain range, the Tucson Mountains, dominated by Mesozoic and Cenozoic volcanic rocks. South and southeast of the city, some 40 km away, the Santa Rita Mountains, a typical Basin and Range landform, appear to continue a part of a circle — and to the southwest, the low dome-like character of the Sierrita Mountains closes the arc, broken by the Santa Cruz Valley.

The city and its surrounding areas comprised a population of about 600,000 in 1987. The geologically significant aspect of this fact is that water for the population came entirely from beneath the city — groundwater being the sole source of potable water. The city expected to receive surface water, moved overland in a canal from the Colorado River, in about 1990; in the late 1980s decisions as to the disposal of that water, recharge vs. direct purification, had not been decided.

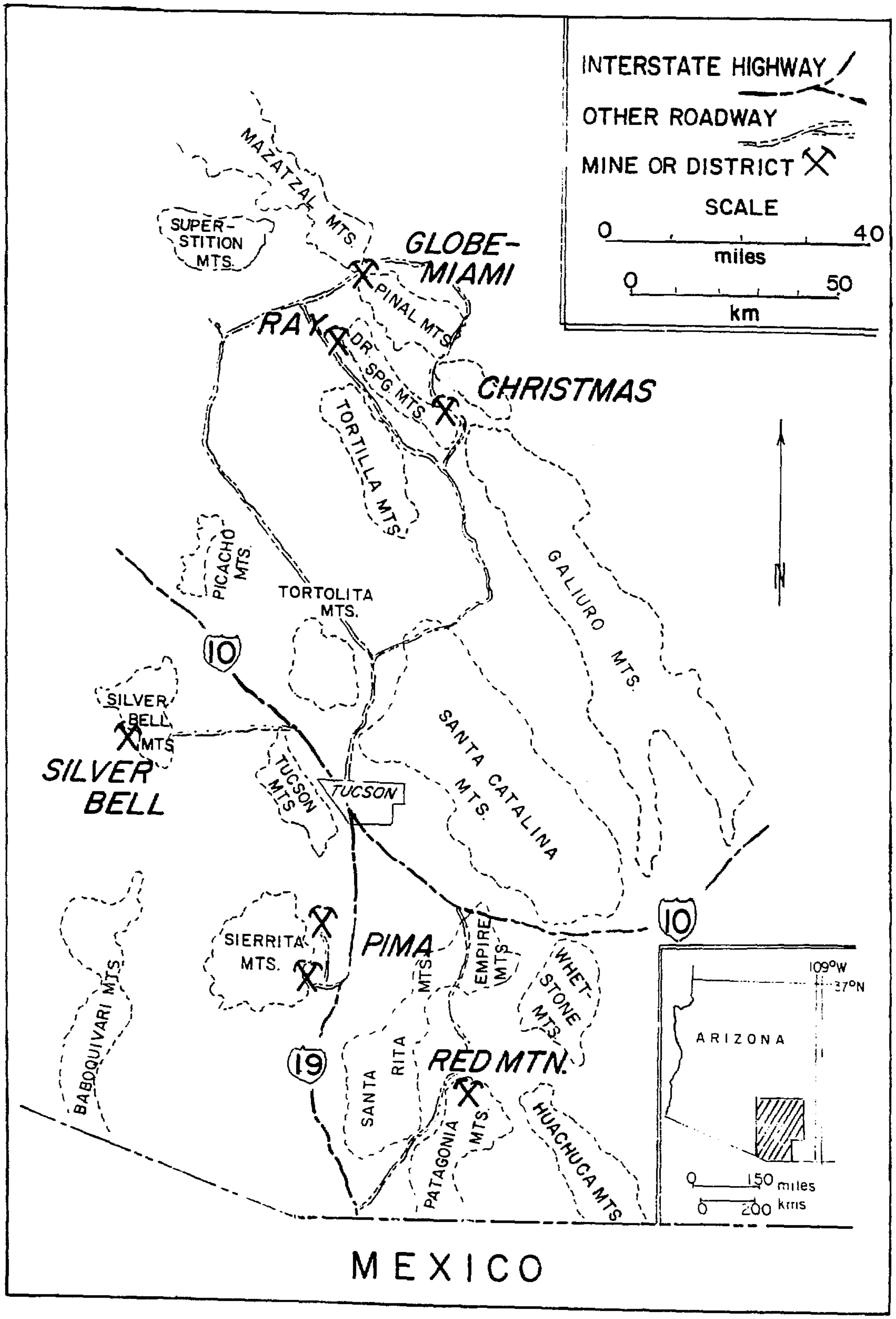

FIGURE 1 Sketch map of relevant physiographic features, roads and routes to be traveled and mines or districts to be visited in southeastern Arizona (see inset, lower right corner).

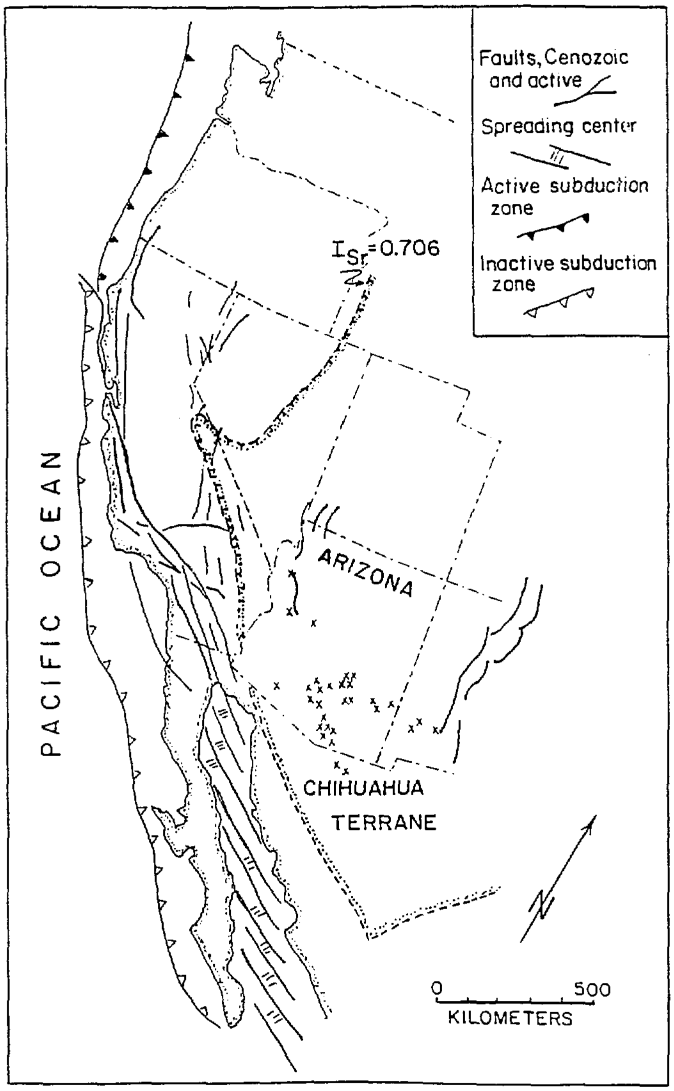

FIGURE 2 Tectonic map of the western United States and northeastern Mexico showing Arizona and its relationship to some major tectonic elements. The x's show the location of major porphyry copper deposits in Arizona and contiguous regions. The heavy stippled line, tracing the ISr value of 0.706 in the United States and the edge of the Chihuahua Terrane of Mexico (Campa and Coney, 1983) is interpreted to approximate the edge of the North American craton. Map adapted from Crowell (1988) and modified from Titley (1988, submitted).

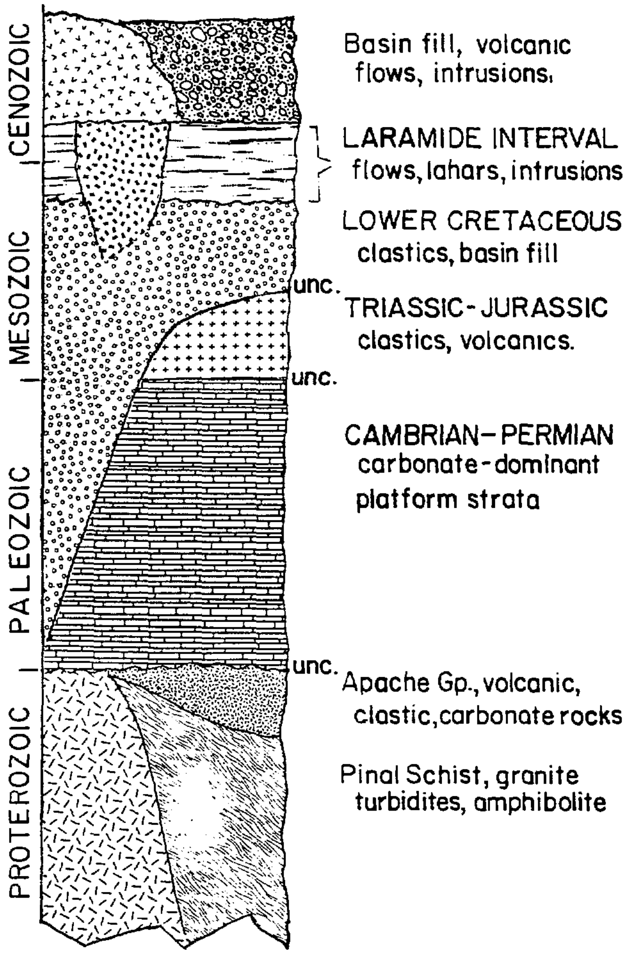

FIGURE 3 Generalized and composited stratigraphic column in southeastern Arizona. No vertical scale but diagram approximates proportional thicknesses of units above the Proterozoic basement. The Proterozoic section is of unknown thickness, but at least 7 km, the original thickness of the Paleozoic at least 2 km, the thickness of the Mesozoic extremely variable but in some locations 3 km in the Lower Cretaceous and a corresponding amount in the Jurassic and Triassic. Valley fill in some instances at least 4 km.

REGIONAL GEOLOGY

Southern Arizona lies at a corner of the North American craton where the continental edge has been affected by many different kinds of geological and tectonic forces since the Proterozoic. This setting is shown in Figure 2. In this region, marked contrasts in the style of geological evolution, as well as in tectonic and igneous events, may be seen in the kinds and distribution of both rocks and landforms. Among the most significant of these events were those of the Laramide (ca. 75-50 Ma) during which the preponderance of the porphyry systems were formed. The Laramide, however, was but one of several episodes of geological evolution in this region. The following outline of geology is summarized in a composited stratigraphic column in Figure 3.

Proterozoic Overview

Contrasting styles of Proterozoic evolution in this region are interpreted from the history of basement rocks. In southeastern Arizona, this basement, the Pinal Schist, is composed of a succession of clastic rocks (turbidites) of a thickness greater than 7 km (Cooper and Silver, 1964), that contains thin rhyolite flows and local amphibolites. This succession of rocks, about 1.68 Ga in age (Silver, 1978) has been invaded during two intrusive episodes (ca. 1.4 and 1.6 Ga) by granites. In the Globe-Miami-Ray area, a still younger Proterozoic succession, the Apache Group, is present where its thin marine and clastic strata have been locally dilated by diabase sills of about 1.1 Ga age. Our trips into the Globe-Miami area will traverse exposures of these rocks, which make up much of the exposed terranes in the southeastern part of the Central Mountain Province; Pinal Schist and younger Proterozoic granites comprise the basement rocks of most of the porphyry copper deposits in this part of North America.

The basement in this southeastern part of the state contrasts with the basement to the west and southwest where the Proterozoic succession, of about 1.78 Ga (Anderson and others, 1972), is dominated by mafic to felsic volcanic flows and pyroclastic rocks; these rocks constitute the Yavapai Series. Within this volcanic basement are also widespread exposures of Proterozoic granitic rocks of ages 1.75-1.70 Ga, in addition to granitic bodies of the younger Proterozoic dates exposed to the east. A few porphyry metal systems of Laramide age, all of which occur in the Central Mountain region, are known to be hosted by these basement rocks. Metallogeny during the Proterozoic was characterized by formation of massive volcanogenic sulfide ores and precious metal veins; although we will not visit such sites, Proterozoic ores have been economically important in this region.

Paleozoic Strata

Platform marine strata of Paleozoic age are widely exposed in many mountain ranges of southeastern Arizona where an aggregate thickness of about 2 km may be inferred to have been originally deposited. These rocks are believed to have been uniformly deposited westward and northwestward across Arizona where, to the northwest, the Paleozoic succession thickens drastically within the Cordilleran Miogeocline. Only a few widely scattered remnants of lowermost Paleozoic strata exist in western Arizona; the dominant occurrence of these strata is in the southeastern part of the state.

Paleozoic carbonate rocks are locally important hosts to copper mineralization in those places where they occur as wallrocks to certain Laramide intrusions. Important copper orebodies have evolved in Cambrian carbonate rocks as well as within Pennsylvanian and Permian strata. In those settings where carbonate-bearing strata have been involved in the process of copper formation, they have been altered to assemblages of calc- and magnesium-silicate minerals and compose important and well-studied skarns. No intrusion events of Paleozoic age are known in this part of the American southwest and no Paleozoic ores have been reported.

The Mesozoic Section

Layered rocks of Mesozoic age of this region are diverse in character, distribution, and mode of origin. Within the Central Mountains, the Mesozoic section is represented only by a few exposures of uppermost Cretaceous volcanic flows and pyroclastic rocks. In the southern part of southeastern Arizona, a greater variety of rock types, representing many volcanic and sedimentation events has been recognized; carbonate strata are scarce or absent in Triassic and Jurassic sections and compose only a small part of the Cretaceous section. The lower Mesozoic section is dominated by clastic and volcaniclastic rocks, with clastic strata becoming increasingly abundant upwards into most of the Lower Cretaceous section. In southeastern Arizona, the Triassic through Jurassic rocks may have attained local thicknesses in excess of 3 km; the Lower Cretaceous section, which in Arizona includes thin (1 km) foreland facies rocks, thickens significantly into northern Mexico where sections may locally exceed 4 km. Upper Cretaceous rocks are mostly volcanic flows, pyroclastic, and volcaniclastic units.

Mesozoic Intrusive Rocks

The Mesozoic was a time of three recognized (dated) episodes of igneous intrusion (180 Ma, 150 Ma, and ca. 70 Ma). Except for a few Laramide bodies in the Central Mountains of Arizona, all other known intrusive bodies of Mesozoic age occur in the southern part of the state. The porphyry ores of Bisbee, Arizona, together with a few widely separated small base metal districts of inconsequential production and reserves, formed at about 180 Ma. An episode of intrusion of small granite bodies during the Cretaceous at about 150 Ma is revealed in a few scattered centers but, except for local anomalous but non-economic molybdenum values no metallogenic event has been identified with this intrusive period.

The Laramide

Across southern Arizona, widespread Late Cretaceous volcanic activity heralded the

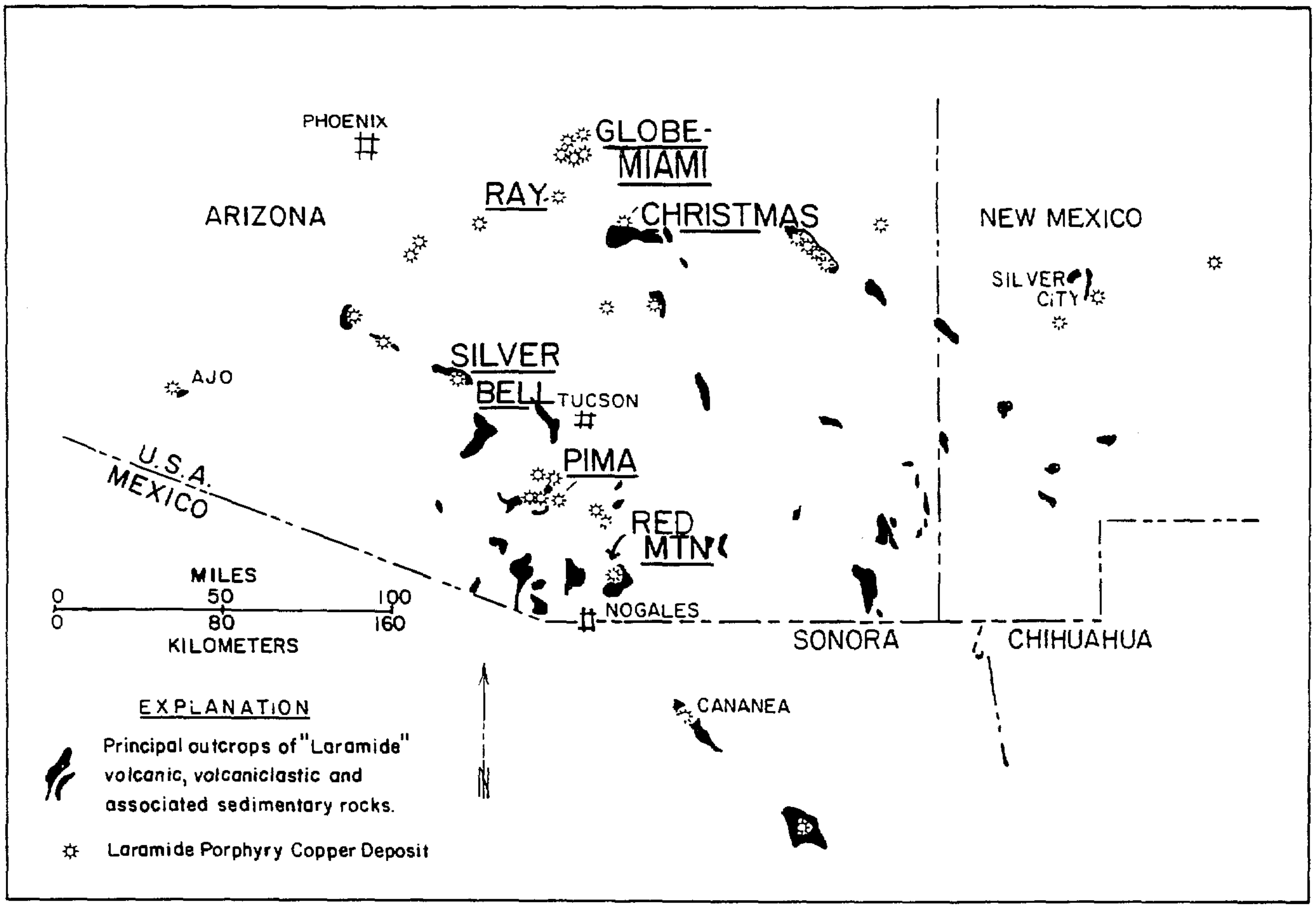

FIGURE 4 Map of southeastern Arizona and contiguous regions showing distribution of Laramide volcanic and sedimentary rocks as well as the distribution of major Laramide porphyry copper deposits of this region. Districts noted in bold are those to be considered in the field trip.

emplacement of numerous small plutons in localized centers; a map of these rocks is shown in Figure 4. These small igneous stocks, seldom more than 3 or 4 km in diameter, were most likely subvolcanic plutons; their emplacement to shallow crustal levels, and convective cooling resulted in the numerous porphyry copper systems of this region. This process of pluton emplacement and, at least locally, continuing volcanic activity, spanned a period of about 15 to 20 my, and appears to have died in the early Eocene. The igneous events are associated with a time of high rates (ca. 10-15 cm/yr) of normally directed convergence between the North American continent and the Farallon Plate of the Pacific Ocean. Consequently, the igneous activity is inferred to be related to a time of crustal compression. Weathering as deep as 2 km during subsequent times (as revealed by evidence from plutons and stratigraphic reconstructions) resulted in destruction of volcanic superstructures, but the close proximity of Laramide volcanic rocks to small porphry plutons remains as testimony to their common origin at scattered volcanic centers.

The Laramide Metallogenic Episode in the American Southwest

The Laramide episode, established by various workers as between about 45-50 Ma and 75-80 Ma and believed to bracket the Cretaceous and Tertiary, was a time of widespread volcanism and intrusion in this part of the Western Hemisphere. The evidence available indicates that the region stood in relief but thin units of clastic strata within thick volcanic successions are the only indication of sedimentation. Results of abundant and widespread radiometric age determinations in this region indicate that a large population of volcanic and intrusive rocks evolved as well as synchronous mineralization in as many as 125 different centers shown now by exposed mined areas or districts in southern Arizona and contiguous Mexico and New Mexico. The most characteristic feature of all of the districts is the presence of Laramide intrusive rocks ranging in size and style from batholiths to small dikes or dike swarms. These igneous bodies clearly transferred great amounts of heat to the shallow crust result-

TABLE 1 Production of Metals as Percentages of Total Production from Ores of Different Metallogenic Epochs in Arizona

Metallization Epoch	% Cu	% Pb	% Zn	% Ag	% Au	% Mo
Proterozoic	6	18	45	19	26	—
Nevadan	11	23	15	16	5	—
Laramide	81	41	31	47	33	83
Mid to Late Tertiary	2	18	9	18	36	17
Totals	100	100	100	100	100	100

Data from Titley (1987).

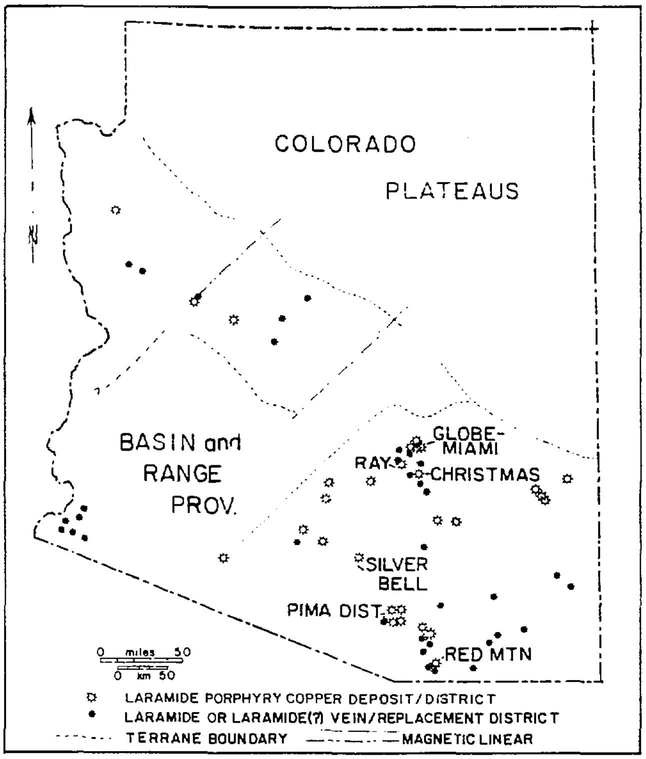

FIGURE 5 Map of Arizona showing location of major Laramide deposits and districts, that includes both the porphyry copper districts and vein and replacement ore districts. The dotted lines show separation of geologic domains in Arizona suggested from Phanerozoic geologic histories and basement characteristics. Modified from Titley and Anthony (1988, in press).

ing in fluid flow which facilitated transfer and deposition of metals. Whereas the Laramide porphyry copper deposits are the most significant and obvious manifestation of the results of this process, there also exist numerous smaller districts characterized by epigenetic mineralization in veins and in various kinds of replacement ores in sedimentary and volcanic rocks. The distribution of these deposits is shown in Figure 5 where geological domain boundaries are shown, based upon regional characteristics and geological history of the basement and Phanerozoic geology. A view of the importance of the Laramide as a time of ore formation may be gained from the data shown in Table 1 that compares production (and by inference, endowment) from the various epochs of mineralization in Arizona.

The Cenozoic

The modern landscapes through which we pass are a product of several complex Cenozoic events. The high convergence rates of the Laramide ceased, apparenty, with the overriding of the East Pacific rise by the continental mass, at sometime between about 35 and 40 Ma ago. The path of geological evolution changed from one of compressional tectonics in the Laramide to extensional tectonics by mid-Tertiary times. Volcanism recommenced at about 30 Ma across southern Arizona and has continued intermittently until very recent geological times. The Basin and Range geomorphic province commenced its evolution under the regime of extensional tectonics, and basin-fill by alluvium, lake sediments and volcanic rocks became the dominant style of sedimentation. Metallogeny during the mid to late Cenozoic has been characterized mostly by formation of precious metal vein and replacement ores during episodes of extensional tectonism and periods of volcanism.

GEOLOGY OF PORPHYRY COPPER DEPOSITS

It is appropriate to review some important characteristics of the genetic class of porphyry copper deposits. Whereas the visitor will have the opportunity to view many of the characteristics described herein at some of the sites to be visited, an overview and integration of the nature and importance of certain features here will provide a meaningful basis for further observations and interpretations.

The deposits of this genetic class share many common characteristics that allow certain generalized statments to be made about them. In the context of descriptions of deposits around the Pacific Basin perimeter, generalizations have been outlined by Titley and Beane (1981). An overview of the regional geological settings has been presented by Titley (1982a) and an outline of features of Laramide porphyry deposits of Arizona has been presented in Titley (1982b). Within the framework of commonly shared features, however, many important differences exist, among deposits, in such characteristics as volcanic and igneous rock types and in the style and evolution of metals and alteration. Most of these differences are interpretable in the context of either the levels of exposure or the composition of wall rocks.

Briefly described, the porphyry copper deposit of the American Southwest is a body of fracture and veinlet controlled disseminated copper sulfides; other subsidiary metals in these systems are commonly molybdenum, silver, and in a few deposits, gold. It is noteworthy that a "significant" amount of the platinum group metals mined in the United States is derived from the electrowinning of copper mined from these deposits (Cabri, 1981).

This body of mineralized rocks is ordinarily centered on an intrusive mass of porphyry which, with one exception in Arizona (Bisbee, ca. 180 Ma), is of Laramide age. Metallic mineralization, together with different kinds of alteration mineralogy, is laterally zoned; the economic mineralization is revealed in assay, rather than mineralogical boundaries.

Common Characteristics of Porphyry Copper Deposits

The first of three essential and unifying elements of these systems is the presence of a small (1-2 km diameter) porphyry intrusion that is usually central to zoned alteration and metals. Although there is current lively debate concerning the nature and extent of the role played by the intrusion in the mineralizing process, the results of dating of both intrusions and mineralization consistently reveal that both are generally of the same age; at the very minimum, the intrusions served as a source of thermal energy that drove the hydrothermal processes which formed the system. The deposits are not known to occur as primary result of the process of emplacement and cooling of phanerocrystalline rocks, nor are they recognized to evolve as part of the emplacement and cooling of volcanic rocks. In Arizona, porphyry copper deposits are almost entirely associated with rocks of calc-alkaline series affinity and many of the deposits occur as parts of larger intrusive complexes of which the porphyry is invariably one of the youngest of the intrusive phases. The rocks have been assigned different names but they are nearly always quartz, two-feldspar, biotite and/or hornblende, magnetite-bearing porphyritc rocks.

A second commonly-shared element is that of extensive fracture control of both alteration and metal deposits. Whereas some sulfide mineralization may commonly appear as isolated and "disseminated" in host rocks, it is a matter of widespread observation that such dissemination is within domains of intensely shattered rock. The fractures occur within the central porphyry masses but also commonly extend for kilometers of distance into wall rocks.

The third common element in these systems is that of zoned alteration and zoned distribution of both metal abundances and metal types. Many Arizona porphyry copper deposits are porphyry cores to large (up to 100 square kilometer) base and precious metal districts in which other metals such as lead, zinc, silver, and gold have been historically and economically important.

A common terminology has evolved in descriptions of alteration that is related to some dominating characteristic of a mineral-forming component or mineralogy. Thus, in most systems, a potassic alteration stage occurs as a core to zoning. In potassium silicate host rocks, this stage is ordinarily characterized by potassium feldspar, with or without alteration biotite. Recent studies (Beane and Titley, 1981) point to simultaneous evolution of propylitic alteration peripheral to potassic alteration. In potassium silicate rocks, common minerals of the propylitic assemblage are albite, carbonate, chlorite, "clay," epidote and in some instances zeolite. At high and oxidizing levels of the system, advanced argillic alteration also appears to form simultaneously with the others and is characterized by an assemblage of alunite, silica and pyrophyllite, an assemblage that is usually texturally destructive. A late stage of important alteration, termed phyllic, is usually present and revealed in the overwhelming and complete conversion of affected rocks to an assemblage of quartz and sericite, usually with pyrite. An overview and analysis of the conditions and chemistry of alteration in potassium silicate rocks is presented by Beane (1982). A widespread and common succession of alteration types within the alteration aureole around porphyries is shown in Figure 6. In this diagram one-half of a symmetric alteration envelope is shown at different times in the alteration process; no depth is inferred. The common mineral assemblages developed in potassium silicate wall rocks adjoining an intrusion are shown in their ordinary and widely recognized succession, the vertial axis of the diagram showing only the change from high to low

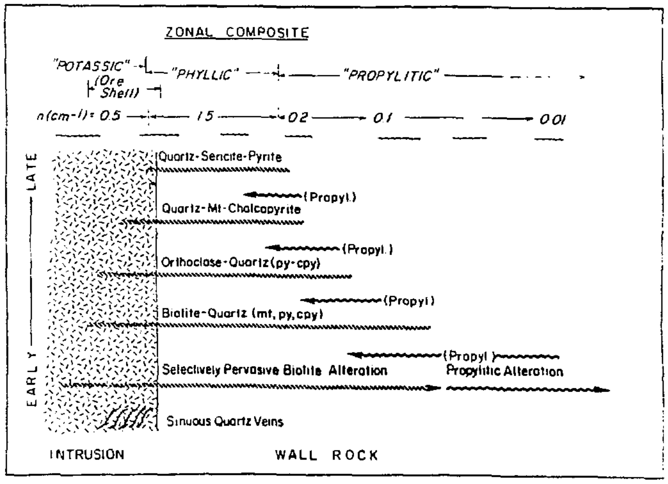

FIGURE 6 Composite alteration section showing, from bottom to top, oldest to youngest alteration assemblages in potassium silicate rocks seen in Arizona porphyry deposits. Successive stages of fracturing and subsequent alteration reveal progressive "collapse" of the alteration process on the proximity of the intrusion and its wall rock contact. Alteration progresses from areally-wide potassic alteration, inward to the latest stages of quartz-sericite-pyrite alteration by superposition of successive alteration stages. Inward collapse of the propylitic envelope is traced from the conversion by chloritization of early formed secondary biotite. The value "n" is the quantified value of fracture abundance determined from length/area values in outcrop. Modified from Titley (1982) and Titley and others (1986).

(bottom to top) temperatures during the life of the system. Superposition of fractures formed at different stages results in cross-cutting veins of different alteration types; it is the superposition of the different zones, dominated in early stages by potassic and propylitic alteration and at late stages by phyllic alteration that results in a common zoning pattern, described across the top of the diagram.

In carbonate wall rocks, typical calc-silicate assemblages evolve that parallel the style of evolution of alteration in potassium silicate rocks (Einaudi, 1982). Early stages are characterized by anhydrous minerals such as grandite garnet and diopsidic pyroxene. Advanced stages of alteration with copper minerals occur with hydrous magnesium-rich mineral assemblages along younger fractures in the early formed skarn.

The styles of alteration in any rock may be described at the mesoscopic scale in three modes. Pervasive alteration affects most minerals in a rock to a degree that the original composition of the rock is essentially masked. There may be inherited textures that allow inference as to original composition. Selective or selectively pervasive alteration affects only certain minerals of a rock and usually results in an artificial enhancement of texture. Vein or veinlet alteration is that which affects the walls of joints or faults.

Contrasting Elements in Porphyry Copper Systems

There is considerable uncertainty concerning the levels to which most of the Laramide porphyry copper deposits in Arizona have been weathered. In a few instances data from fluid inclusion studies allow interpretations of original levels from 2 to 4 km higher than the present surface; stratigraphic reconstructions in some instances are consistent with this figure. In view of the fact that there is overwhelming evidence for deep erosion, that may be different from deposit to deposit, many contrasting elements of these deposits may be a manifestation of the different original levels at which the deposits presently are being viewed.

An important and principal difference between deposits is the style of mineral zoning. Symmetry of distribution and compositional characteristics seen in systems of unvarying wall rocks, either potassium silicate or carbonate is broken and distorted when the wall rocks contrast in composition. As a general characteristic in "classic" cases, alteration aureoles formed in potassium silicate wall rocks are broad and uniformly developed (Lowell and Guilbert, 1970); those in carbonate-bearing hosts are irregular and restricted more closely to intrusion centers. In both types, however, ore-grade and distribution as well as tonnages are otherwise comparable.

Accessory metal content and distribution in the porphyry ores of Arizona is variable and known in only a general way. The distribution and character are discussed below as they are understood in the primary ores.

Gold occurs in some but not all of the systems but its relationship to copper ores and other metals has not yet been well-defined. Similarly, molybdenum is highly variable in its occurrence and distribution. Although generally sympathetic with the occurrence of copper, in some deposits it is central to the shells of alteration, in others it is peripheral. In Arizona, most of the porphyry deposits carry at least 1 g/t of silver; it is an intriguing fact that high molybdenum grades (more than 0.02% Mo) are attended by comparatively high silver values (more than 2 g/t). Silver grades, as well as gold grades, are sympathetic with grades of copper; gold phases have not been described but silver appears to occur with tetrahedrite. In secondarily enriched copper ores, silver as well as gold is also believed to be concentrated. There is at least one occurrence of enriched copper (Hillsboro, New Mexico; Dunn, 1982) in which field evidence suggests that molybdenum also may be enriched with copper in the weathering process.

Many uncertainties exist concerning the compositions of the original Laramide plutonic rocks. In a great number of deposits, the combinations of pervasive and destructive hydrothermal alteration and subsequent weathering have so modified textures and compositions that meaningful chemical and petrographic work with currently conventional methods is not possible. Notwithstanding these problems, sufficient observations and data developed in the peripheral regions of the deposits reveal that a range of petrologic compositions is represented in the plutons of this province. The influence of these petrological differences in affecting results of the hydrothermal processes is unknown. Results of a study of one suite of Laramide rocks from this region suggest deep crust as an important provenance of copper-related magmas in these systems (Anthony and Titley, 1988a,b).

Some Relevant Aspects of Porphyry Copper Genesis

The numbers and accessibility of the porphyry systems in this region, coupled with excellent exposures of mineralized rocks and continuous data collection have resulted in an unparalleled information base. These data have been widely used in a variety of kinds of studies that have resulted in well-modeled and documented theories of process. Less well-understood are geological factors that relate to the localization of porphyry copper deposits in this region and the fundamental questions of the nature and origin of this copper province.

Regional controls. The clear and unequivocal relationship of evolution of porphyritic rocks to sites of subduction found in island arc settings is less clear in the inboard setting of the craton-sited systems of southestern North America (see Figure 2). A large rectilinear area contains the deposits of the American southwest and only with the presumption of a considerable flattening of the Benioff Zone, resulting from high plate convergence rates (Coney and Reynolds, 1977; Heidrick and Titley, 1982), may cause and effect be inferred. Within the region, the effects of a widespread overprinting by mid- and late-Tertiary extensional tectonism has obscured the Laramide tectonic framework and a distinctive regional control has not been identified for certain.

Primary (hypogene) processes. The porphyry system evolves as a direct consequence of the evolution of the magmas that give rise to the porphyry copper deposit. Rapid rise of magmas to shallow crustal levels, probably as subvolcanic bodies, and their subsequent cooling, results in generation of thermal-mechanical energy which fractures great volumes (cubic kms) of crustal rocks. The evidence from the rocks reveals that fracturing takes place episodically through the period of pluton cooling, possibly on the order of 0.5 to 1 million years. Fractures produced in the porphyry and its wall rocks provide an interconnected network of open planes through which fluids of both magmatic and meteoric origin flow, altering rocks and depositing metal sulfides.

The episodic nature of fracturing is revealed in the ubiquitous existence of distinctive parageneses of alteration assemblages in cross-cutting veins. Ordinarily potassic alteration is succeeded by phyllic alteration, in turn succeeded by propylitic alteration in parts of the system (Titley and others, 1986). The provenance of waters has been shown from results of light isotope studies of alteration minerals (Sheppard and others, 1971; Taylor, 1974). Temperatures and thermal history have been documented in numerous studies, cited by Roedder (1984).

Evolution of the igneous rocks and its relationship to the formation of the porphyry copper deposits have been reviewed by Burnham (1967, 1979); Knapp and Norton (1981) and Knapp and Knight (1977) have studied the effects of aspects of pluton history on fracture evolution, and Norton (1979) has modeled the results of a study of fluid flow and reaction in a cooling pluton environment. Whereas there are some points in agreement concerning the evolution of the fracture networks in the porphyry-centered system, namely that there is a cause and effect relationship between the cooling of the porphyries and fracture evolution, there remains an area of doubt concerning effects that are petrogenetic such as "second-boiling" and hydrafracturing, and those that are thermal-mechanical, such as stresses produced in wall rocks by heating of pore fluids. It is likely that both phenomena are significant and may overlap in the genesis of these systems.

Secondary (supergene) processes. The economic vitality of copper ores in this region has been enhanced as a consequence of secondary supergene enrichment. When the ores were discovered and developed, the presence of enriched copper provided a source of rich metal ore that could be easily and quickly mined to amortize capital investments; enriched ores were still being mined and treated in the 1980s, after decades of operation, in the Globe-Miami district, at Ray, Morenci, Silver Bell, Chino, Tyrone, and in Mexico at La Caridad. Whereas enriched sulfide ores have been traditionally important and remained so in the 1980s, bodies of oxidized copper minerals of many types assumed increasing importance as a consequence of widespread application of solvent extraction of copper in ores.

The process of oxidation of ores probably commences during the waning stages of hypogene activity at high (shallow) levels in the hydrothermal systems. In the deeply exposed systems of the American Southwest, however, weathering has been the dominating process, a process which has been enhanced by geological and mineralogical properties of the hypogene systems. Two fundamental and necessary requirements of the enrichment process are the capacity of the primary system to develop acid (Locke, 1926; Blanchard, 1968) and to have sufficient intrinsic permeability to permit downward or lateral flow of solutions. These requirements are met in the presence of abundant pyrite in the typically densely fractured rocks of the "phyllic" alteration zone. The characteristics of superposition of the vertical zoning induced by supergene processes upon lateral zoning of alteration in potassium silicate rocks is shown in Figure 7. It is the process of leaching of primary ores and of earlier enriched ores that has resulted in the characteristic and unique cappings above secondary enrichment (Anderson, 1982).

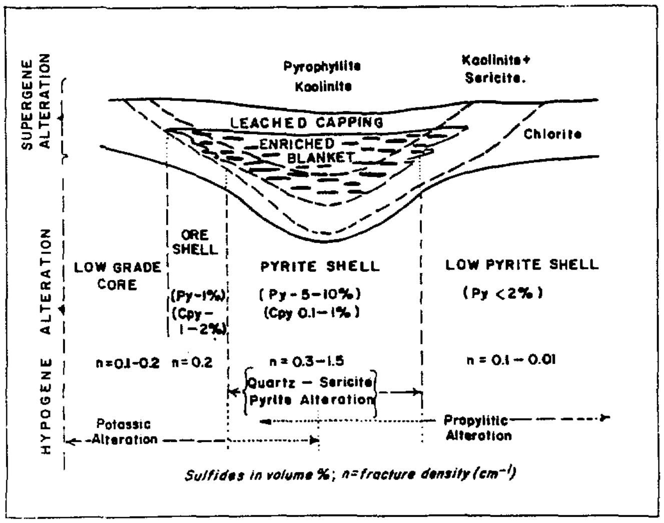

FIGURE 7 Vertical cross section through a weathered and eroded, altered mineralized porphyry system in potassium silicate rocks. Distribution of alteration zones and characteristic features composited from data shown in Figure 6. Superimposed are the effects of oxidation, weathering and leaching of the primary mineralization and alteration to form an enriched blanket above the zone of primary quartz-sericite-pyrite, and its low copper grades.

An additional, and coincidental, set of geological circumstances have operated in the American Southwest to produce the enriched blankets of copper. Lowering of the water table to permit flow is a requirement considered in the conventional wisdom concerning the process. Such lowering is believed to have taken place in at least some instances by uplift at either regional or local scales. Once formed, protection of the blanket from erosion is necessary. In this part of the southwest, pre-Oligocene enrichment of Laramide systems is believed to have been covered by mid-Tertiary volcanic flows, which prevented further erosion. Kilometer thick mid-Tertiary dacite flows in the Superior-Globe-Miami-Ray interval are such units. Younger (than mid-Tertiary) uplift is believed to have resulted in erosion that exhumed copper ores, resulting in exposure with some additional enrichment; in the current stage of geological evolution, the zones of oxidation and some enrichment were and are being eroded.

Features to Observe and Study

In view of the relevant aspects of deposit genesis outlined above, certain important features in these deposits merit close observation. Listed below, for the information of those not familiar with these deposits are questions of importance that may be addressed in mineralized rocks of the orebodies, and that may be of interest to those familiar with similar deposits in other regions.

1. What was the original composition of the rock as revealed in relict textures or original minerals?

2. Is the rock part of the "progenitor" porphyry suite or simply wall rock to the porphyry magmas?

3. What is the style of alteration of the sample? Pervasive? Selective? Vein-veinlet? Are there combinations?

4. From compositional differences between specimens, what may be said concerning the composition of pervasive alteration?

5. If biotite is present, can its igneous or hydrothermal origin be determined?

6. Note the abundance of vein and veinlets in the rock containing ore compared with rocks at the edge of the mineralized systems.

7. How many different kinds of vein or veinlet alteration are visible and what is the sequence of the alteration types? (By such determinations and distinctions, the chemical evolution of solutions may be evaluated.)

8. Are there contrasting alteration mineralogies that appear to relect the compositions of the original rock type? (Most anhydrous alteration mineral assemblages are strongly dependent upon the composition of the original host rocks.)

9. What is an estimate of the percent sulfides (usually made on a volumetric basis) and of the ratio of different sulfide minerals? (Such estimates are relevant to determination of zoning patterns and are of value as a basis for interpreting some types of geophysical measurements.)

10. Are there any apparent differences of sulfide ratios with respect to the kinds of veinlet alteration, or kind of pervasive alteration?

11. What is the nature of the weathered surface on the system? Low pyrite abundances do not ordinarily give rise to strikingly red exposures; high pyrite volumes (more than 4% volume) do.

OVERVIEW OF DEPOSITS AND DISTRICTS TO BE VISITED

The following sections present geological summaries of the districts and mines to be visited during the four days of the field trip. The summaries will focus upon both generalized district and orebody geology as well as aspects of ore occurrence and exposure that are particularly characteristic of the specific bodies in which they occur. Specific details concerning the exposures to be visited will be provided at the site.

Pima Mining District

Four open pits mine disseminated copper ores from six originally discovered orebodies. In the visit to this district, we will see ores formed entirely within potassium silicate host rocks and almost entirely hypogene in character (Sierrita) and a complex orebody in which hypogene ores have evolved with calc-silicate alteration in carbonate hosts and with potassium silicate alteration in clastic host rocks (Mission-Pima). At the scale of district geology, the orebodies in the south part of the district are autochthonous, those to the north are allochthonous, interpreted to be faulted away from their roots to the south.

Trip to the Pima District. Our first visit will be to the Sierrita-Esperanza orebody complex in the south part of the district; after lunch we will visit the Pima-Mission complex in the allochthonous plate in the northern part of the district. The drive takes us along interstate highway and mine roads south and southwest from Tucson to the southern part of the district, a distance of about 60 km; in this trip we will ascend from Tucson (700 m), in the Santa Cruz River Valley, to the facilities and mine at Sierrita on the pediment surface at about 1100 m elevation.

The Santa Cruz Valley, which flanks the western edge of the Tucson Basin, is an intermontane basin typical of this region. It is flanked to the west in the vicinity of Tucson by the Tucson Mountains, a strongly deformed succession of Laramide volcanic rocks. To the southeast, as viewed from Tucson, the Santa Rita Mountains, which comprise a complex of Proterozoic and Phanerozoic rocks, rise to an elevation of about 2600 m and are capped by Triassic(?) volcanic rocks. The Sierrita Mountains, on the flank of which occur the mines of the Pima district, are a dome-like feature cored by Laramide granite. The visitor will be able to observe, during the course of the brief trip, the typical landforms of this part of the Basin and Range Province, manifested for the most part in the Santa Rita and the Tucson Mountains. This is also a classic region in which to observe the geomorphic characteristics of pediments, low-angle, uniformly sloping surfaces carved upon bedrock near the mountains' edges and formed upon basin fill toward the valley centers. These features may be seen in profile on the northern side of the Sierrita Mountains where a long (10 km) surface dips about 3° northward, and another pediment east of the interstate highway that slopes upward toward the Santa Rita Mountains.

As we drive southward out of the Tucson metropolitan area, the east-dipping pediment of the Sierrita Mountains may be seen to be the site of numerous stripping dumps from mines of the district. Large waste-to-ore stripping ratios (i.e., 5,10-1) to maintain exposure of bedrock beneath alluvium in two large open pits have resulted in large volumes of waste, a characteristic of such mining that requires continuous control and monitoring. Dumps exposed along the highway for the next 15 km may be seen to be terraced and planted with desert vegetation in order both to minimize the visual impact of waste piles and to control slopes and dust.

We encounter vegetation typical of the Sonoran Desert Province in our drive upward and across the pediment and we will see most of this biota in short foot excursions outside of the pits. In this region of sparse rainfall (ca. 30-40 cm/yr), vegetation is present but only the hardiest varieties are common and survive. The most abundant trees are the Palo Verde, Mesquite and varieties of acacia, with scrub Oak at the highest desert elevations; shrubs comprise Creosote, varieties of Composita or Rabbit Bush, and the tall stalks of varieties of Yucca and of Ocotillo. Cacti are abundant, the most conspicuous of which is the widely known

TABLE 2 Production and Mined Grades of Ore of Some Orebodies in the Pima District

Mine	Tons Mined (to yr)	% Cu	% Mo	Ag (g/t)	Au (g/t)
Mission/Pima	108,993,000 (1978)	0.63	0.011	2.3	0.00X
Sierrita	224,750,000 (1978)	0.27	0.022	1.0	0.00X
Esperanza	86,342,000 (1978)	0.40	0.021	1.4	0.00X

Data from Keith and others (1978).

tree-like Saguaro with its numerous arms, together with abundant Cholla, Prickly Pear, and Barrel Cactus. Numerous varieties of small cacti may be seen in almost any foot traverse and a variety of grasses are widely present.

History. Mineralization in the Pima district is, presumably, among some of the earliest discoveries of metal made by Europeans in this part of the North American continent. Jesuit and, subsequently, Franciscan fathers entered this part of Arizona at the turn of the 18th Century and carried out exploration that resulted in opening of several silver mines. The presence of turquoise and native copper in outcrop was likely an object of excavation by indigenous people prior to this time. The path of exploration is not clear but by the early to mid 19th Century there were mines operating on numerous exposures of high grade copper, as well as lead-silver mineralization in the Pima district.

By the early 20th Century, underground mining was taking place in many parts of the district with lead, copper, and silver the principal products. Mining in the district was confined to underground methods on high grade copper ores until about 1955 when disseminated copper ore was discovered by geophysical methods beneath post ore cover at the Pima mine and bulk mining ensued. Subsequent discovery of the Mission and Esperanza orebodies in the late 1950s, and the Sierrita, Twin Buttes, Eisenhower and San Xavier orebodies in the 1960s resulted in development of one of the largest reserves of copper in any North American district. In the 25-year period between 1955 and 1980, the district was the site of nearly continuous mining in all orebodies as they were discovered and developed. By the mid-1980s, open pit mining operations had extended in two sites (Mission-Pima-Eisenhower and Esperanza-Sierrita) to envelope contiguous orebodies and two operations, San Xavier and Twin Buttes had shut down.

The district and most of its orebodies have been objects of both modern and older geological investigations. Much of this is summarized in Titley (1982b). However, noteworthy reports are those of Ransome (1922), Cooper (1960, 1971, 1973), Barter and Kelly (1982), West and Aiken (1982), Jansen (1982) and King (1982).

Ore grades and tonnages mined in some of the important operations are shown in Table 2.

District geological summary. The general consensus of geological interpretations holds that the district actually consisted of two separate centers of mineralization at the south end of the district (the Twin Buttes and the Sierrita-Esperanza orebodies). Low angle faulting of about 29-30 Ma age resulted in decapitation of one of the mineralized centers at the south end of the district (Twin Buttes) and movement of that part of the orebody some 11.5 km north to its present site as the Mission-Pima orebody complex (Cooper, 1960). Drilling has indeed revealed that the Mission complex is floored by a low angle fault. It remains a matter of speculation as to whether the Twin Buttes ore system was moved from a position near the Sierrita orebody but stratigraphic reconstruction suggests that the vertical structural separation between the Twin Buttes and Sierrita system is on the order of kilometers. Nonetheless, the current understanding is that orebodies of the northern part of the district are allochthonous, and orebodies of the southern part are autochthonous. The principal structural elements and mines of the district are shown in Figure 8.

Rocks exposed in the district comprise at least some parts of each of the rock Systems known in southeastern Arizona. Proterozoic rocks are represented by xenolith-rich exposures of granite of about 1.4 Ga. The entire known Paleozoic section is present, as are representatives of the entire Mesozoic section. The Sierrita Mountains, in which the district is situated, has been a site of numerous episodes of Mesozoic and younger intrusive activity and the Mesozoic section contains numerous volcanic strata that range upward in age from the Triassic(?). For unknown reasons, only the Laramide intrusive episode appears to have generated ores. Older intrusive episodes at about 185 Ma and 150 Ma emplaced phanerocrystalline felsic igneous rocks and a mid-Tertiary episode is represented by widely scattered andesite porphyry dikes. The core of the

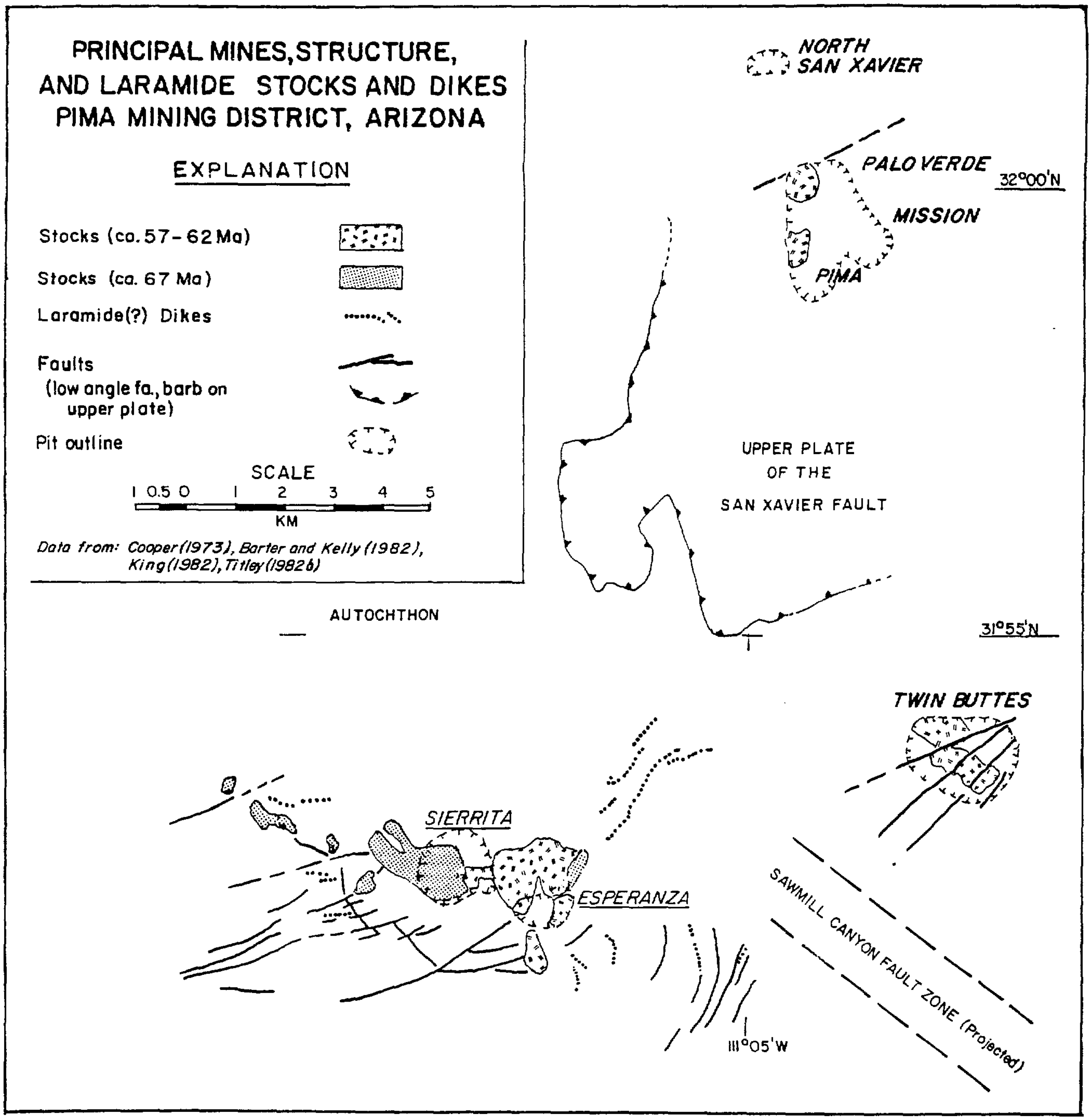

FIGURE 8 Geological map of the Pima mining district, southwest of Tucson, Arizona. Mission and Pima mines in the transported sheet and interpreted as moved from the proximity of the Twin Buttes mine. Modified from Titley and others (1986). The southern part of the district on the autochthon lies along or astride the projection of a regional linear fault, the Sawmill Canyon fault zone, exposed to the southeast in the Santa Rita Mountains.

Sierrita Mountains comprises Laramide-aged granite-granodiorite rocks, which also compose most of the exposed autochthon and are believed to underlie the allochthonous rocks of the northern part of the district. Trace element and isotopic studies of Laramide igneous rocks in this district (Anthony and Titley, 1988a,b) have revealed that the compositional trend from early andesite to latest porphyries is traced by increasingly negative values of ε_{Nd} and increasing values of Initial Strontium ratios. An interpretation of these characteristics suggests that the Sierrita Laramide prophyries reflect increasingly greater crust to mantle ratios of magma parents during igneous evolution.

The Sierrita-Esperanza complex is an intrusion-centered ore system emplaced into a complex setting of granitic rocks, volcanic and volcaniclastic strata. Ore grades are generally symmetrically distributed about a center of porphyry intrusion and are associated with a stage of alteration characterized by alternation of orthoclase-biotite stable and chlorite-epidote stable alteration (Preece and Beane, 1982). Alteration is fracture-controlled, areally extensive and has been found to occur within an area of some 65 km^2, surrounding an area of exposed plutons of about 3 km^2 (Titley and others, 1986). The ores in the Sierrita part of the complex contain a low total sulfide volume (i.e., 3-4%) and lack the profound overprint by quartz-sericite alteration, so common in many otherwise comparable systems such as San Manuel or Silver Bell. As a consequence, the usual hematite-bearing red surface developed above other systems of higher pyrite content has not evolved; thus, secondary sulfide enrichment at this level of the system did not take place and mining commenced in hypogene primary ores. Greater pyrite volumes (i.e., 5-7%) in the ores at Esperanza correlate with the iron-bearing surface and secondary copper sulfide enrichment.

At the Mission mine, ores are mostly concentrated in calc-silicate altered rocks and, to a lesser degree, in potassium silicate altered clastic sedimentary and volcanic rocks. The ore here occurs in an overturned upper Paleozoic and Mesozoic section associated with a sill-like body or tongue of Laramide porphyry (Jansen, 1982). These rocks are part of an upper plate package of strata believed to have been transported from the upper part of the Twin Buttes orebody, about 11.5 km to the south (Cooper, 1960). The orebody is floored by a fault whose surface has been mapped from drilling and interpreted by Jansen (1982). In this orebody, the manifestations of the style and composition of calc-silicate alteration developed in different kinds of carbonate strata are conspicuous.

Silver Bell Mining District

The Silver Bell mine of Asarco, Inc. is situated in the Silver Bell Mountains approximately 60 km northwest of Tucson, about a 75 km driving distance. The "mine" comprises a series of centers of mineralization localized on separate centers of porphyry, aligned to the northwest over a distance of about 10 km. Copper-bearing rocks are present in most of the inter-porphyry areas and the part of the Silver Bell Mountains in which the ores occur may be viewed as a belt of nearly continuously mineralized rock.

Trip to Silver Bell. The drive to Silver Bell takes us northwest out of Tucson along the interstate highway to an exit where we will turn west into the Avra Valley, crossing it to the mine whose dumps are visible some 30 km away to the west on the other side of the valley. From Tucson, the route parallels the axis of the Tucson Mountains to the west. The 30 km trip across the Avra Valley traverses thousands of acres of cultivated land in the valley center. The crops seen are all irrigated from wells. This semiarid desert environment is characterized by low rainfall and high summer temperatures; temperature-resistant crops, such as cotton, do well but require high amounts of water. In this part of the southwest, where 99% of the water consumed for all purposes is taken from the ground, the debate over priorities of water use continues — for obvious reasons.

History. History of development and mining in the district has been outlined in Richard and Courtright (1966) and is summarized here. The earliest mining of note commenced in about 1865 in the northern part of the district with mining of oxidized copper ores containing some silver and lead. This was underground mining and the ores taken were from oxidized skarns; in the subsequent 50 years, many separate mines operated intermittently on such ores to produce about 10,000,000 pounds (about 4500 MT) of copper. In about 1910, lower grade disseminated ores were recognized and subsequent drilling revealed supergene copper ores in the two major centers of mining near the present El Tiro and Oxide pits, although of insufficient grade to constitute ore in the first half of the century.

Asarco, Inc. (then, ASARCO) commenced a systematic evaluation of the district in 1948, developed reserves, and commenced large scale copper mining in 1954. During the next 30 years open pit mining ensued in the El Tiro and Oxide pit centers and followed ore in subsequent discoveries that continued to expand reserves in and near these sites at the two ends of the district. Mining ceased with the downturn of prices in the early

TABLE 3 Production and Mined Grade of Ore from Silver Bell

Mine	Tons Mined (to yr)	% Cu	% Mo	Ag (g/t)	Au (g/t)
Silver Bell	75,655,000 (1977)	0.80	0.022	2.4	—

Values calculated from data of Graybeal (1982).

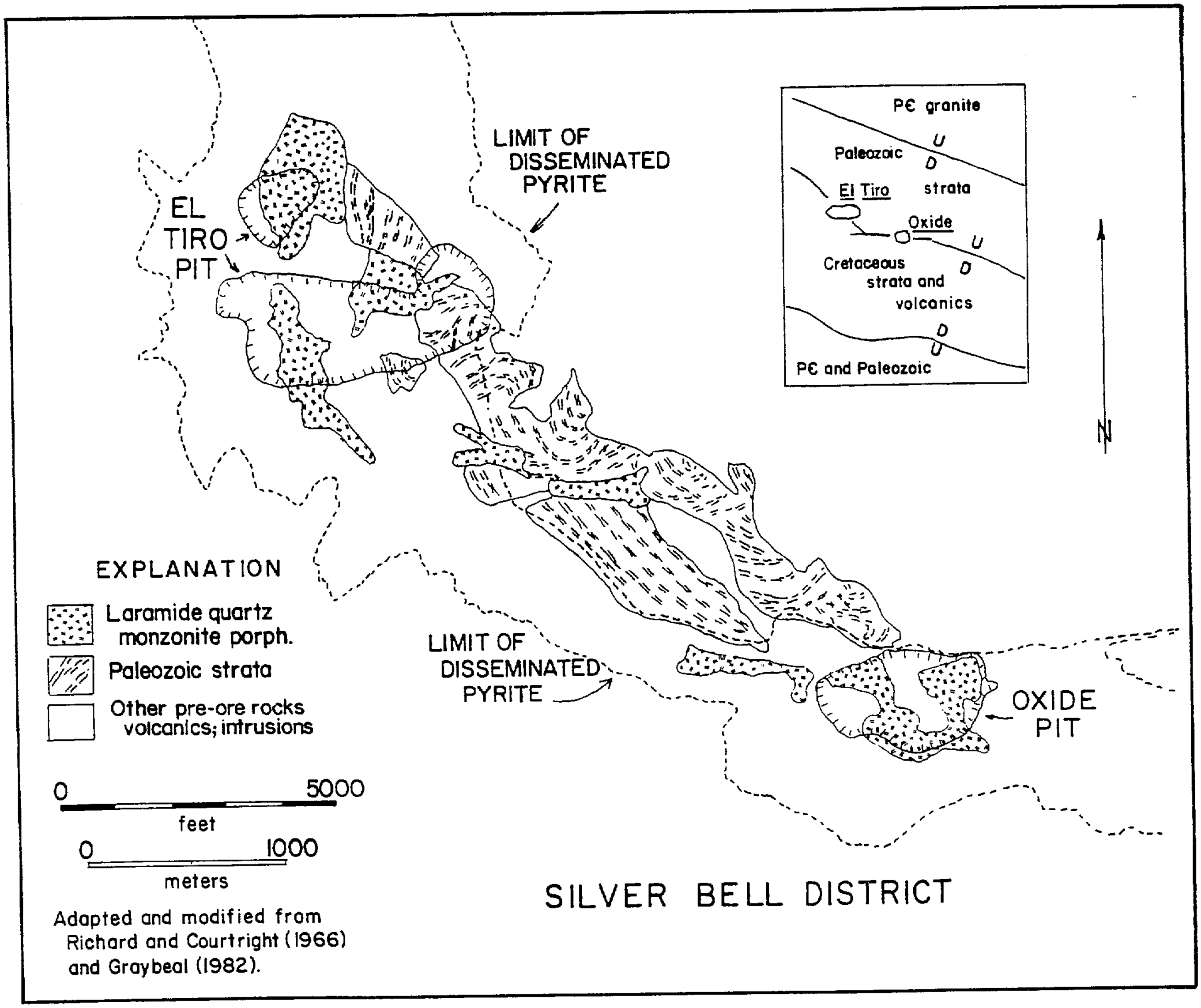

FIGURE 9 Geological sketch map of the Silver Bell mining district in the Silver Bell Mountains. Map adapted from several sources and shows only the location of the "ore-related" quartz monzonite plutons and carbonate-dominated Paleozoic strata. Contiguous exposures are of intra-Laramide plutons, dacite and smaller plugs of monzonite. The dotted line is approximate limit of disseminated pyrite in the system but in many parts of the perimeter, fracture localized alteration, mostly biotite or orthoclase, extends more than a kilometer further.

and mid-1980s but leaching and production of cement (precipitated) copper was continuing in the late 1980s. A reserve at Silver Bell of about 21,000,000 st of 0.68% Cu and 2.4 g/t Ag is reported in Beard (1986); the possibility of renewed mining and exploration at Silver Bell in the late 1980s was awaiting significant changes in metal prices and projected stability in the metal markets. Production at Silver Bell is given in Table 3.

District geological summary. Geology of the district has been an object of prolonged and contінous study by both Asarco geologists and independent investigators. A geological map showing pits, porphyries, and some major elements of structure is shown in Figure 9. The orebody was a site of one of the early significant studies of hydrothermal alteration of such systems (Kerr, 1951) and definitive papers have been written describing the structure, petrology and ores (Richard and Courtright, 1966), stratigraphy and petrology (Watson, 1964), and the character of district zoning, alteration and ore occurrence (Graybeal, 1982). An additional historical aspect of geological studies at Silver Bell is the important and significant role that interpretation of leached outcrop occupied in its exploration and development (Richard and Courtright, 1966). Examples of the leached capping remained in the late 1980s and could still be observed and studied. Additionally, interpretation of the geology at Silver Bell and elsewhere led Courtright (1958) and Richard and Courtright (1960) to expound the first published ideas concerning the style of geological evolution of early Laramide (Upper Cretaceous) geology in this southern Arizona region; the Silver Bell formation, a succession of andesite flows and lahars, was viewed as a volcanic presursor to the emplacement of Laramide porphyry plutons, not only at Silver Bell, but in other contiguous ranges and regions. Most recently, ideas that relate Silver Bell to a possible caldera complex have been outlined by Lipman and Sawyer (1985).

"Silver Bell" in the broader context, alludes to the group of porphyry copper deposits localized in the periphery of several small (ca. 1 km) diameter plutons in the Silver Bell Mountains. Although isolated at the levels exposed, the plutons are considered as essentially contemporaneous and their emplacement and cooling has resulted in a single broad aureole of alteration that encloses the entire group (Figure 8). Low grade copper ores or anomalous copper values in rock (ca. 0.05-0.1%), both hypogene and supergene, are said to be more or less continuous in wall rocks between intrusive centers (Courtright, pers. verbal comm., 1970).

The intrusions have been emplaced within a succession of Paleozoic rocks and Laramide volcanic strata that occur in a down-faulted block that lies southwest of the "district fault" (Richard and Courtright, 1966); the fault block lies in contact with Precambrian granite to the northeast (Figure 9). The complex stratigraphy within the mineralized centers — carbonates, clastic rocks, volcanic flows ranging from andesite to rhyolite, and intrusions — has resulted in correspondingly complex patterns, styles, and composition of mineralization and alteration. These contrasting characteristics have also influenced the style and distribution of supergene secondary sulfide enrichment.

Skarn (calc-silicate) alteration together with hypogene copper ores occurs within certain carbonate units of the Paleozoic section where they are juxtaposed with the Laramide stocks; otherwise typical potassium silicate alteration occurs in non-carbonate rocks. In the Silver Bell porphyry systems, inclusion of calc-silicate alteration within the extensions of aureoles of the different phases of K-silicate alteration allows the study and comparison of these different alteration types within aureoles of comparable alteration intensity.

Hypogene ores, consisting mostly of chalcopyrite in low total sulfide (3-4% volume) mineral assemblages, have been important ore types at Silver Bell, especially in skarn-altered parts of the system. Little hypogene ore has been mined at Silver Bell from the porphyries. The significant economic mineralization has been secondary sulfide enrichment (chalcocite) in porphyries and wall rock, where it has evolved in the weathering of phyllic (quartz-sericite-pyrite) altered rocks with abundant fractures and high (6-8%) volumes of pyrite. Grades of more than 0.8% enriched copper have been locally important and have evolved above protores of 0.1% copper in chalcopyrite (Graybeal, 1982). Early mining of copper in the Oxide pit was of both oxides of copper (tenorite, malachite, chrysocolla) and rich (more than 1%) chalcocite blankets. More recently, both low-grade chalcocite-bearing and oxidized ores have been mined for leaching and, combined with leachates from older dumps, have become the present-day source of copper in the extraction of the metal at Silver Bell.

Globe-Miami Mining Area

The Globe-Miami district lies in the Central Mountain or Transition Province, 175 km north of Tucson. In this district, Laramide plutons have been emplaced in wall rocks of Proterozoic age, represented by the Pinal Schist and by younger Precambrian granites. Ores are combinations of pluton-hosted ores as well as ores in the wall rock; early mined ores were secondarily enriched, more recently they have contained some hypogene copper.

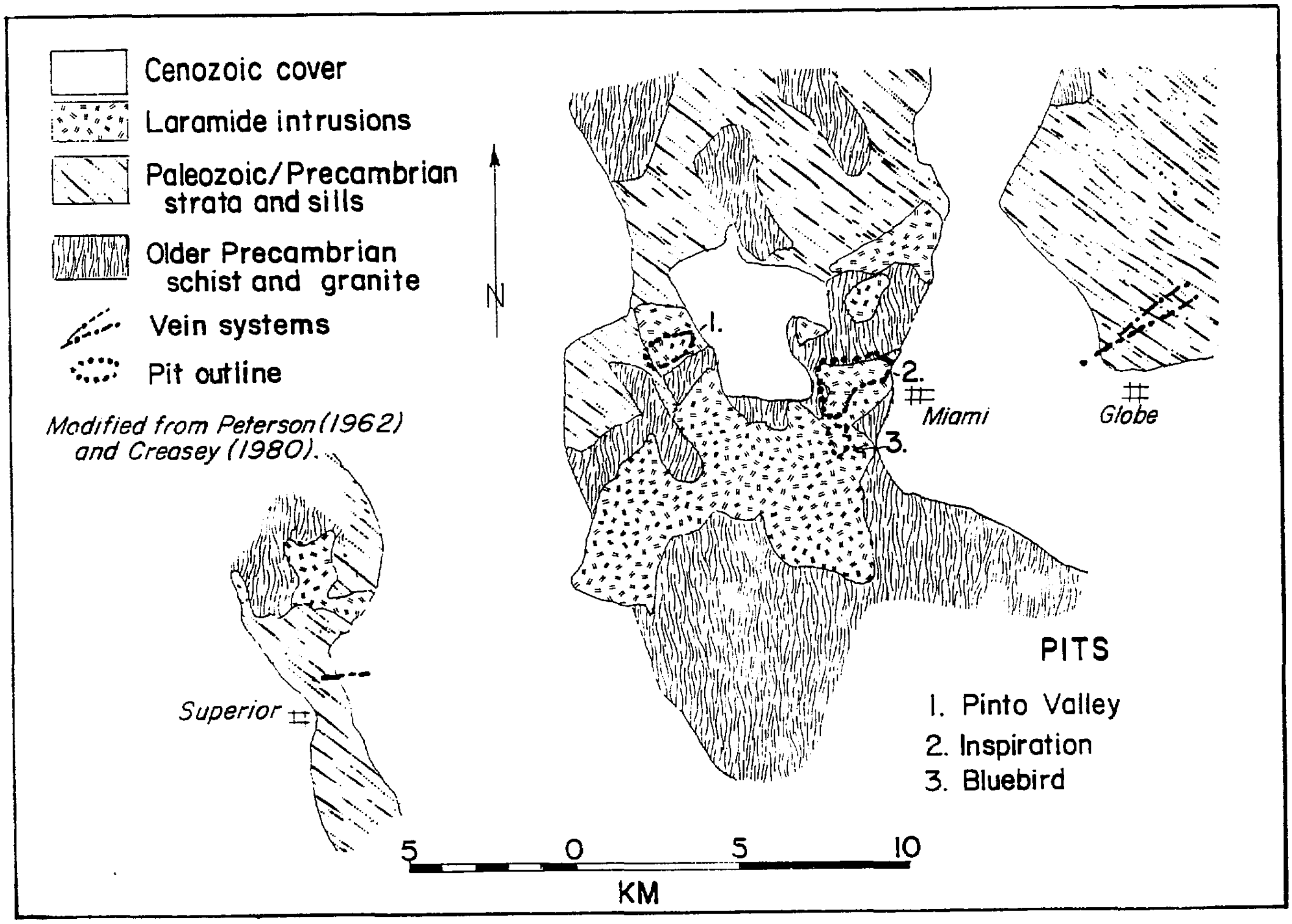

FIGURE 10 Geological sketch map of the principal mines of the Globe-Miami-Superior interval. Map adapted from Peterson. Most porphyries are phases of the Schultze granite; the deposits may be seen to be preferentially localized at regional contacts of the plutons and Precambrian host rocks.

Trip to the Globe-Miami District. The trip proceeds north from Tucson to Florence Junction, crossing a major part of the Sonoran Desert region of Arizona to the foot of the central mountains at which point the road climbs some 600 m into the terrane of the transition zone and the Globe-Miami center. The visitor will have the opportunity to see the contrasts in geological and geomorphic style between these two regions as well as contrasts in climatic zones and vegetation.

The Basin and Range Province reveals in its morphology and geology isolated ranges and intermontane basins. In most ranges of this province, geology is complex, characterized by faulting and folding, tilted beds and juxtaposition of strata ordinarily separated by kilometers of section. The central mountains of Arizona reveal the transition between this geological style and that of the Colorado Plateaus to the north where strata are essentially flat-lying and topography flat or mesa-like in character. In the transition region, the geological style of Phanerozoic strata is closely similar to that of the plateaus but the topography is that of mountains and peaks, lacking only the broad intermontane basins of the province to the south.

The highway from Apache Junction, through Superior, Arizona, climbs steeply and takes us from the desert surface into the mountains. In almost any season of the year, the climatic change is striking but in July the contrast between desert temperatures in excess of 40°C and the balmy temperatures betwen 25°C and 30°C is that sought by many desert dwellers and is a relief, indeed.

The journey by road passes through the Pinal Parkway, a state park that displays the typical desert region vegetation, which is that seen in the trip to the Pima district south of Tucson. As the road climbs out of Superior to Globe, the changes

TABLE 4 Production and Mined Grades from Districts in Superior-Globe Interval

Mine	Tons Mined (to yr)	% Cu	% Mo	Ag (g/t)	Au (g/t)
Miami-Inspiration	759,476,000 (1978)	0.67	0.001	0.42	0.002
Globe Hills	12,133,000 (1978)	4.3	—	23	0.30
Superior	26,280,000 (1978)	4.5	—	53	0.92

Values for Superior are those of the Pioneer district as formally named and include the Superior deposit as well as small amounts of production from numerous other producers. Data from Keith and others (1983).

in this vegetation become striking with desert types giving way to scrub Oaks, Pinon, Juniper, Manzanita and, in the Globe area, to conifers.

History. Ores of the Globe-Miami area are reported to have been first located around 1874 when rich veins of chrysocolla were discovered in the hills surrounding the present city of Globe. These veins, and others subsequently mined, comprise the Globe Hills district in current vernacular; the Globe Hills mineralization represents metallization commonly developed peripherally to many large intrusion-centered districts of this region and is characterized by high lead and zinc content (1-10% combined) as well as silver and locally gold. Mining took place intermittently on vein ores for the next 30 years; although veins carrying some 2-3% copper were known, they were below the economic grade of about 4% necessary at the turn of the century. Not until the late 1930s was bulk mining taking place and by the early years of WWII the district became quite active, mining taking place in the Inspiration and Miami ore zones, with mining initiated at Castle Dome (Pinto Valley), discovered as a "War Baby" during the early 1940s. By the late 1980s, and as a result of the depressed nature of the domestic copper industry, there were two centers of mining. The Castle Dome deposit developed originally in a secondary blanket, and ultimately mined for hypogene copper had become the Pinto Valley deposit; and the extensions of the ores mined underground by block caving on the Inspiration ground in the 1940s and 1950s were being mined in open pit.

Although separated from the porphyry ores by a distance of some 8-10 km, the vein and replacement copper ores at Superior, Arizona, are interpreted as an integral part of Globe area mineralized centers, as shown in Figure 10. At Superior and in veins nearby, underground mining of rich copper and silver took place over a period extending from the 1920s into the mid-1970s. The economics of hard times overtook operations in these mines as well and they are no longer productive, although a reserve of about 4,000,000 tons of 5.6% copper at Superior is reported in Beard (1986).

Production from mines in the Globe-Miami-Superior interval is shown in Table 4.

Geological summary of the Globe-Miami area. Ore deposits of this area have received a significant share of scientific attention over the past 90 years and remain important objects of study. Most noteworthy of the early reports are those by F. L. Ransome (1903, 1904, 1919). In these U.S. Geological Survey publications, Ransome (as was characteristic of other geologists of his time) not only described features of the ore deposits but also reported the results of regional studies in which definitive stratigraphic work was carried out and described. Parenthetically, it should be noted that other U.S. Geological Survey workers in the western United States carried out similar studies elsewhere while also focusing study upon the character of ore districts. In so doing, geologists such as Ransome, Waldemar Lindgren, B. S. Butler (see frontispiece), A. C. Spencer, E. S. Larsen, and Whitman Cross, to name a few, contributed not only to the foundations of economic geology in these regions but also importantly and significantly to developing the modern knowledge of the geological framework of the western United States.

More recently the geology of the Globe-Miami area has been reported by N. P. Peterson and coworkers in a series of papers that began in 1946, among the most recent of which is the work of Peterson (1962). The results of extensive radiometric age dating have been reported by Creasey (1980) and the district remains an important object of study in the 1980s.

The ores of the Globe-Miami porphyry systems are mostly localized in Proterozoic wall rocks in the periphery of a group of Laramide intrusions. By means of many K/Ar determinations on numerous phases and multiple samples within the district, Creasey (1980) has closely approximated a mean age of intrusion in the district at about 61.5 Ma and a date of mineralization at about 59.5 Ma. These ages fall within the spread of other Laramide ages determined in other districts of the southern Arizona region.

Mining of the Miami-Inspiration and contiguous orebodies has extracted sulfide ores, mostly secondarily enriched, comprising chalcocite and oxidized copper minerals; the other large systems, Pinto Valley (Castle Dome) and Copper Cities, are orebodies from which mostly hypogene ores (chalcopyrite) have been taken. In forming the supergene ores, wall rock character, particularly that of the Pinal Schist has been important in having both numerous fractures with high pyrite content and acid buffers such as abundant primary or secondary sericite to aid the process. Exploration and mining beneath the enriched blanket at Miami-Inspiration reveals the presence of subjacent pyritic copper mineralization of low grade.

Hydrothermal alteration studies in the Miami-Inspiration part of the Globe-Miami district are complicated by the presence of a heavy supergene alteration overprint. Similar problems attended some of the first systematic studies of alteration mineralogy and alteration zoning reported in porphyry copper deposits, carried out at Castle Dome (Peterson and others, 1946). There, zones of abundant sericite and kaolinite were delineated and a correspondence to enriched copper ore was shown. Hydrothermal alteration in the Pinto Valley deposit, which represents the deeper hypogene parts of the Castle Dome system, manifests the same characteristics of mineralogy seen elsewhere in deposits with potassium silicate wall rocks and at the level observed consists of veins altered to or carrying biotite or orthoclase, and overprinted younger veins carrying quartz-sericite and pyrite. In the Globe-Miami deposits, thus, mining has transited the vertical profile of meteorically to hydrothermally altered rocks, consequently from oxidized to enriched to hypogene copper minerals. In doing so, mining has thus gone from extraction of ores of 4% copper (oxidized) to 1% (enriched) to 0.5% or less hypogene ore. It is noteworthy that this history of grades mined corresponds in general ways to, and traces in time and the rocks, the evolution of progressively more refined and efficient engineering practices and metallurgy during the past 50 years.

Ray (Mineral Creek) Mining District

The mine at Ray lies in the Dripping Spring Mountains, some 20 km south of the Globe-Miami district. This orebody occurs almost entirely in Proterozoic wallrocks comprising Pinal Schist and diabase sills; exposures of Laramide intrusions are present but trivial in comparison with strata and igneous rocks of the Precambrian. Alteration, together with sulfide volumes and composition is zoned and transects the geometry of rock type distribution (Figure 11).

Trip to the Ray District. From Globe to Superior, we trace our path back down Queen Creek and across extensive outcrops and road-cut exposures of Precambrian strata and mid-Tertiary dacite. The road from Superior southward crosses a complex of Precambrian and lower Paleozoic rocks that lie on the west flank of the Dripping Spring Mountains. We remain in the transitional geology of the Central Mountain Province where strata are still subhorizontal but within closely spaced (10 km) Basin and Range landforms.

Departing the Ray district we will proceed southward to Hayden, site of smelting activities, and parallel the San Pedro River to the town of Mammoth. This part of the trip takes us through extensive road-cut exposures of typical Gila conglomerate, mostly basin fill in the Gila Valley, which contains the San Pedro River. At Mammoth, we turn southwestward, ultimately crossing the railroad transporting ore from the San Manuel mine to the smelter at San Manuel, south of the highway. After passing through the town of Oracle, we rejoin the Pinal Parkway at Oracle Junction and drive southwestward along the northwest side of the Catalina Mounains to Tucson, via the Oracle Highway.

History of the Ray District. Early events affecting the ores at Ray are reported by Ransome (1919) and Parsons (1957) and are summarized here. First mining of record was of silver prior to or about 1880 with ensuing expansion of claim groups, changing ownerships, and underground mining during the next 20 years. The absence of infrastructure during these early times required hauling of supplies and metal to and from Red Rock, Arizona, a distance of 70 km. Early attempts to mine up to reported grades of 4-5% copper were unsuccessful as recovered grades were on the order of 2%. The Ray orebody was recognized at the turn of the century as having extensive reserves of 2% copper. It was not until 1907, however, that the potential of the orebody was realized when a group involving D. C. Jackling (who had been so successful in making Bingham Canyon profitable) bought the property and formed the Ray Consolidated Copper Company. Corporate changes, mergers, selling and buying property, all characterized a fluid ownership during the next 25 years with formation of the Nevada Consolidated Mining Company, subsequent ownership by Kennecott Copper Corporation, and most recently by Asarco, Inc.

In a way comparable with ores of the Globe-Miami area, underground mining of high grade ore, subsequently block caving, and finally open pit

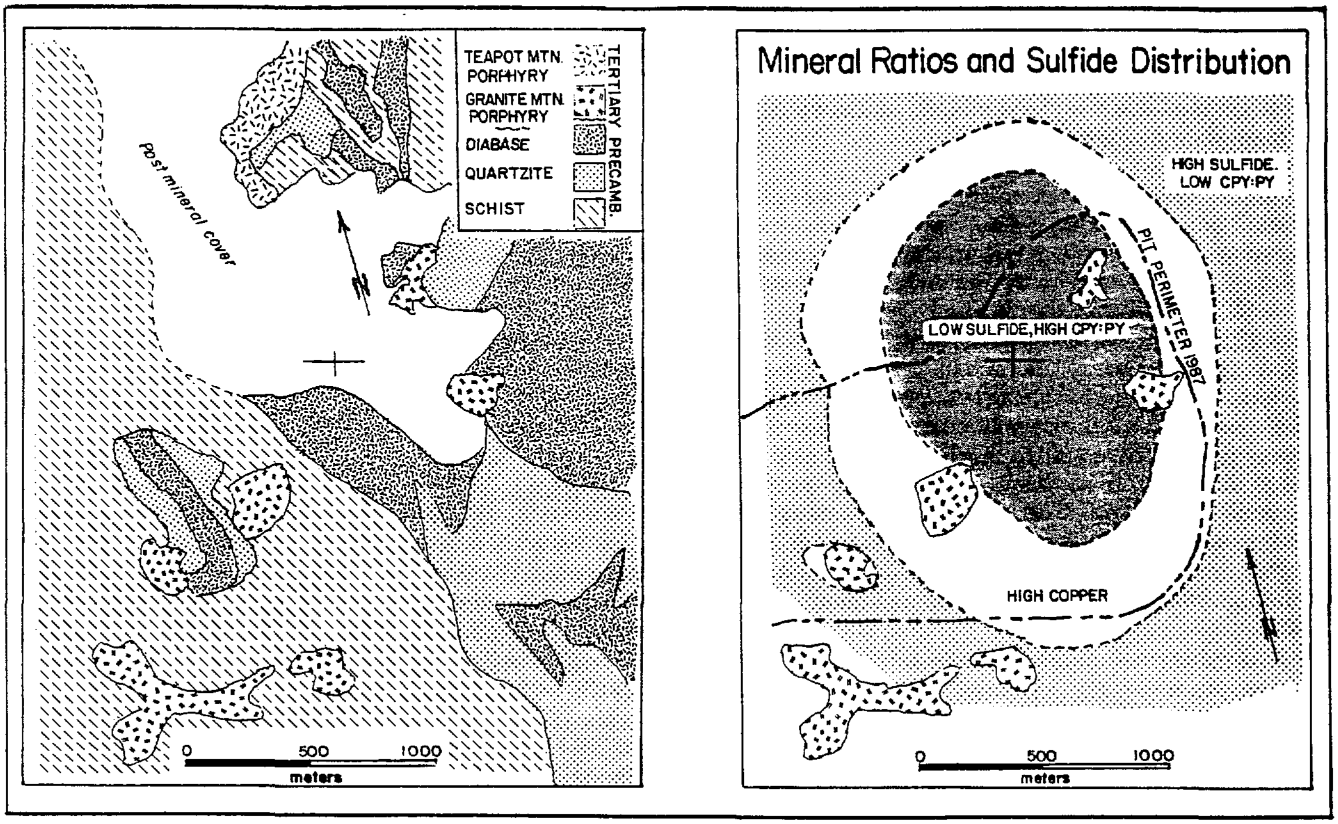

FIGURE 11 Geological map of the Ray area (left) and of metal and sulfide zoning (right). Maps at the same scale and registered by grid intersection in the center. Maps adapted and modified from Phillips and others (1974). Pit outline modified to 1987 in personal communication from N. A. Gambell (1988).

TABLE 5 Production and Mined Grades of Ore in the Mineral Creek District

Mine	Tons Mined (to yr)	% Cu	% Mo	Ag (g/t)	Au (g/t)
Ray Orebody	327,507,000 (1981)	0.85	0.001	0.92	0.006

Data from Keith and others (1983).

mining in 1954 (Parsons, 1957) trace the history of extraction. The transition from high to low grade ores parallels the history and trends of technology. Production from the Mineral Creek district is shown in Table 5.

District geological summary. The Ray ores were the object of study by Ransome (1919) who reported on them in a paper that also included ores of the Miami area. Tenney (1935) describes the Ray district in a context that includes the ores at Christmas, a porphyry district some 25 km southeast in the Dripping Spring Mountains (see Figure 1). The porphyries at Ray span a range of K-Ar ages between about 70.5 Ma and 60.8 Ma with mineralization reported to be of still younger but Laramide age (Banks and others, 1972). A similar span of ages has been reported in the porphyries and ores at Christmas by Koski and Cook (1982). These ages bracket the shorter span of time (ca. 2 m.y.) determined for the life of the porphyry systems at Globe-Miami by Creasey (1980).

We view the effects of alteration and mineral deposition at Ray in host rocks different from those in other ore systems of the region. Paleozoic strata are present within the Dripping Spring Range but are absent in the proximity of the orebody. Ores are hosted by Pinal Schist and diabase sills (ca. 1.1 Ga) that have invaded the Apache Group (Proterozoic) section. A consequence of the mafic mineralogical and chemical composition of the diabase is the development of abundant biotite as a primary alteration mineral —

in contrast to the abundance of orthoclase seen in rocks of granitic composition elsewhere. There is, nonetheless, a widespread, early development of orthoclase veining in this system, reported by Phillips and others (1974). Figure 11 shows the zoning of sulfides and metal ratios in the primary alteration halo at Ray; the pit limits, however, extend across and beyond the primary zones to include extensive enrichment of ore and exotic copper within the Pinal Schist.

Harshaw Mining District

The Harshaw mining district lies some 120 km by highway southeast of Tucson in the Patagonia Mountains. The district is an old one, characterized up to this point in time by production of high grade complex base and precious metals from veins and replacement ores. At its heart lies Red Mountain, a high and vividly colored feature (outside of the small town of Patagonia), which is the top of a large and very deep (ca. 1-1.5 km) porphyry system. It is the purpose of the visit to this site to see the surface exposures of high-level, acid-sulfate or advanced argillic alteration, together with a leached cap in the lithocap of an unmined setting, and to view something of the nature of district-wide base metal mineral settings.

Trip to the Harshaw District. The route to the Harshaw district follows the interstate highway east from Tucson to the turnoff to Sonoita. The road to Sonoita follows the trend of the Santa Rita Mountains (to the west) some 50 km to Sonoita, thence southwest 30 km to the town of Patagonia. The route via interstate to the Sonoita turnoff traverses a part of the Sonoran Desert, to the south of which lies the north end of the Santa Rita Mountains; north of the highway may be seen the metamorphic rocks of the south end of the Rincon Mountains.

The route to Sonoita rises some 500 m and traverses grasslands with Mesquite and scrub Oak. (It is a curious fact that the moving picture "Oklahoma" was filmed in this part of Arizona.) As we departed Tucson, we paralleled, for a short distance, the Santa Cruz River in which drainage is to the north. As we drive to Sonoita, we move into a part of the headwaters of the Santa Cruz drainage which, from here, drains southward into Mexico before turning northward to drain past Tucson.

Drill-access roads may be seen concentrated in two parts of the northern end of the Santa Rita Mountains to the north. These roads were built during exploration of two porphyry copper systems (Rosemont and the Copper King) during the 1960s and 1970s. Except for small amounts of historical high grade production, these explored orebodies remain otherwise undeveloped in the 1980s.

The highway from Sonoita to Patagonia moves down Sonoita Creek past a monument that describes the site of the former Ft. Crittenden, one of several cavalry outposts built in southern Arizona during the mid-1880s to help contain Apache raids in this region. Near Patagonia the road parallels an old railroad grade from Tucson to Patagonia, the station of which remains in the center of the town. As we approach Patagonia, Red Mountain may be seen directly ahead. From Patagonia, the route follows improved dirt roads to Red Mountain and further into the Harshaw district growth zones are present in which Oak and Sycamore trees abound along the Harshaw Creek drainage.

History. This part of Arizona is rich in frontier history that goes back more than 200 years and includes events influencing mining and settlement of this region. The region was a site of some of the earliest settlements by the Spanish padres, a region where the influences of the American Civil War played significant roles in the history of mining and inviduals, and where the interplay of the effects of the Indian wars resulted in profound influences on settlement and mining. A summary of much of this history as it relates to mining is contained in a classic U.S. Geological Survey Bulletin on the geology of the Santa Rita Mountains by Schrader (1915). Other authors, such as Hilton (1898), Hamilton (1884), and contemporary historians have studied the history of the region, providing a wealth of written material on the subject.

A short distance west from Patagonia, across the south end of the Santa Rita Mountains is the old Salero mine, said to be one of the first significant discoveries made by Jesuits in the early 18th Century and mined intermittently over a period of 150 years for rich silver ores. Some 18 km southeast of Patagonia lies the Mowry mine located by an army officer in 1859, but "known long before by the Jesuits" (Schrader, 1915, p. 296). It was closed by events of the Civil War, visited by Pumpelly (1863), and was an object of many mining promotions.

In more contemporary terms, the Harshaw district was a site of mining of base and precious metal ores during the 1940s and 1950s, in operations now closed down. In the mid-1970s exploration and deep drilling by the Kerr McGee Corporation resulted in discovery of deep (1200 m) primary copper ores beneath capping and a dissected enriched sulfide blanket under Red Mountain; continued exploration drilling during a five-year period revealed something of the extent of this ore and mineralization but no specific reserve had been published. Beard (1986) gives some 100,000,000 tons of 0.71% copper as indicated in annual reports by the corporation. The primary ore is deep.

Geological summary of the Harshaw District. The geology of parts of the district is summarized in several publications; Red Mountain is described by Corn (1975), Bodnar and Beane (1980) and Quinlan (1981). Simons (1971) describes some of the stratigraphy of the region and has published a map (1974) that covers the southern part of the mineralized system.

The district, which lies at the north end of the Patagonia Mountains, is cored by a deeply buried, copper-bearing Laramide(?) quartz-monzonite complex of uncertain size and extent. It is known mostly from drill hole data, and only informal verbal reports of dates of about 62 Ma from alunite give it its Laramide(?) age. This is the Red Mountain mineralization center and the site of the visit. A geologic map is shown in Figure 12. The intrusion penetrates a volcanic lithocap which is strongly fractured and bears the results of acid-sulfate or advanced argillic alteration of a dacite-quartz-latite, rhyolite volcanic succession. These pre-ore volcanic rocks have been dated elsewhere in the district by K-Ar (Simons, 1974) as about 72 Ma. Closely contiguous with the intrusion center are a few mines that have taken complex base and precious metal ores from veins and replacement bodies in volcanic rocks; manganese-silver mineralization in carbonate rocks is known in two sites to the south. Multiple Laramide intrusion in closely spaced centers in the Patagonia Mountains leaves uncertain the specific genetic relationship of the base metal mines to any particular intrusion center, one of which lies several kilometers south-southwest of the edge of the Red Mountain complex.

Red Mountain is the most striking feature of the district, standing in about 800 m of relief above surrounding valleys and the town of Patagonia, brightly colored from oxidized sulfides in its cap. The system is not believed to be tilted to any significant degree and consequently when standing near the top of the mountain and within the aureoles of alteration, one is standing above the thermal center and mineralization. Virtually all rocks exposed and seen at Red Mountain are part of the Laramide volcanic succession. These volcanic rocks, andesite, trachyandesite, and tuffs, extend in outcrop for distances of several kilometers north, east, south and southwest. The northeast side of Red Mountain is cut off by a post-ore fault.

The destructive effects of pervasive advanced argillic alteration, coupled with destructive acid weathering are seen in most outcrops an
rock identification in outcrop difficult.
the top of the system is in the upper tuff
the pyroclastic nature of this rock is so
revealed in ghost textures. As the road t
from the valley bottom to the top of the m
stops will allow the study of the cont
alteration effects from propylitic-altered
to the silica-flooded, alunite-pyrophylite
bearing rocks in the center of the syst
increasing depth, drilling has revealed the
characteristics of "typical" deep potassic
tion characterized by orthoclase,
anhydrite, and chalcopyrite.

The return to Tucson. We will re
Patagonia and continue our drive south
vicinity of Nogales, at which point we
west and then north into the Santa Cruz
and thence to Tucson. Nogales is a bor
with its twin (Nogales) in Sonora, Mexic
entry point into the United States is an ir
economic center as much of the farm prod
is grown further south in Sonora and Sinalo
here and is subsequently distributed wide
United States and Canada. In addition
years have seen the development
Maquiladoras, manufactuing plants whic
American and other manufacturers op
Mexican cities such as Nogales. M
American produced commodities in the la
were becoming more common in th
American market place.

The drive north to Tucson on the ir
highway, which is also a part of the Pan-A
Highway, retraces the route down the Sa
River believed to have been followed by t
est Spanish fathers and soldiers in the lat
The ruins of the first Spanish missions (ca.
Calabasas and Guevavi are presently ina
but lie only some 5-10 km north of Noga
the Santa Cruz River, about 2 km to the e
will pass the old mission at Tumacaccori
town of Tubac, originally a Spanish vi
presidio. Although visible only with d
some of the oldest mines of this region l
western side of the Santa Rita Mountains
the highway. These mines were opene
early Jesuits, operated by them and, subs
by the Franciscans. Hamilton (1884, p.
noted that the "Jesuit fathers were the
miners of Arizona." The earliest mining
be deciphered was that of oxidized silv
treated by the Spanish patio processes
region through which we pass is of h
interest because of that fact. Some 50 km
and closer to Tucson, we again pass th
scaped" dumps from mines of the Pima
visited on the first day, and we reenter T
its south side and return to the hotel.

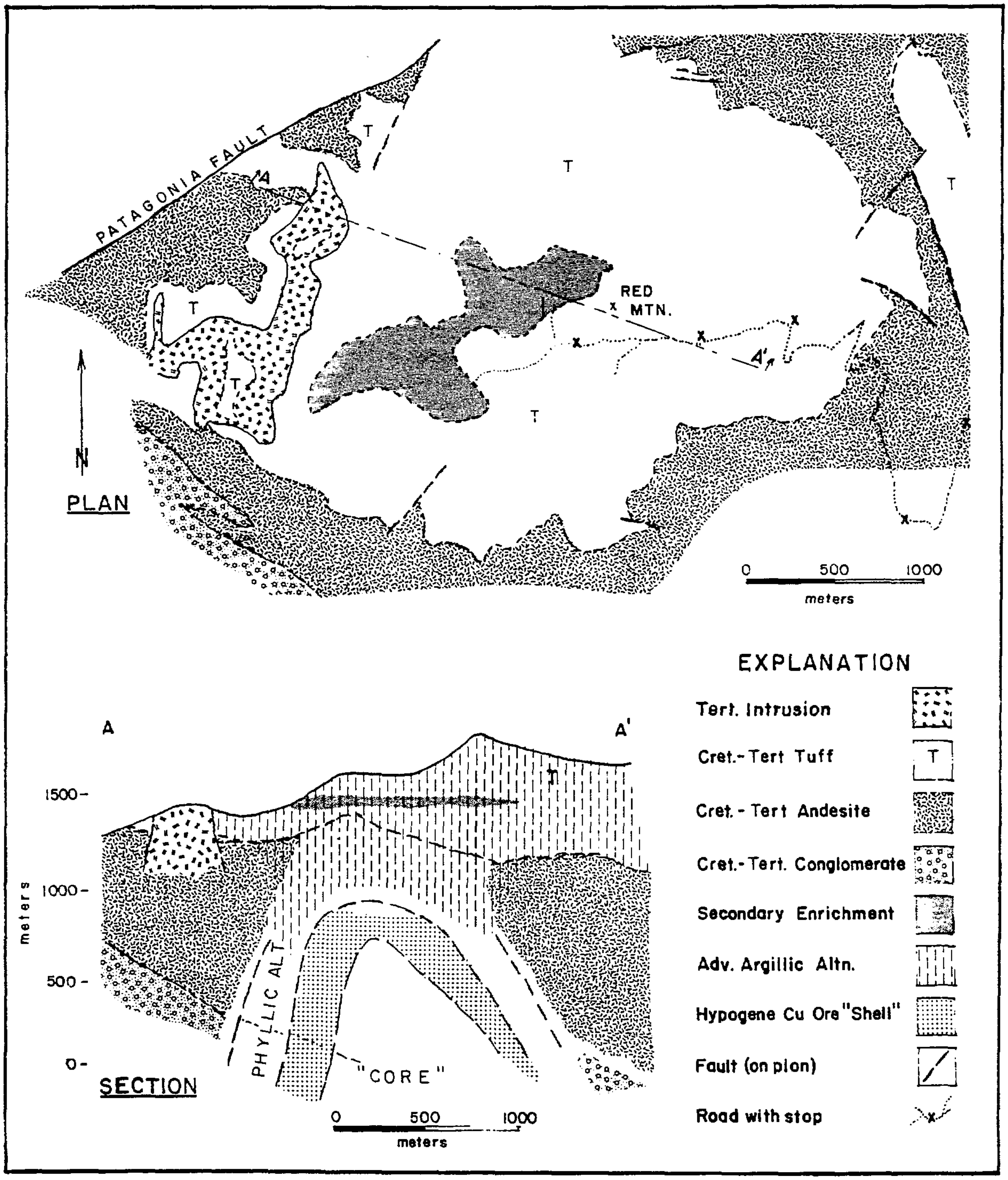

FIGURE 12 Geological map of the center of the Red Mountain porphyry copper system, Harshaw district. Map adapted and modified from Corn (1975) and Quinlan (1981). Vertical section shows vertical alteration zoning as shown by Quinlan (1981), modified to incorporate and include the interpretation of high level advanced argillic alteration in this report.

Acknowledgments

Thanks are extended to officials of Asarco, Inc., Cyprus Mines, and the Kerr McGee Corporation for permission to visit mining properties on this trip. We also acknowledge with thanks the work of Jo Ann Overs at the University of Arizona in helping us to prepare this guidebook.

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ASARCO

Silver Bell Unit

DESCRIPTION	1993 INFORMATION
LOCATION 40 miles NW of Tucson **CURRENT STATUS** Mines and Mill on standby since August 1984 Copper Leach - Precipitation operations continue 1993 production: 4,811 tons of copper Plans and Permitting are underway to construct an SXEW plant to produce 18,250 tons per year of Cathode Copper **SIZE** 18,400 acres **PRODUCTION CAPACITY** 80,000 tons/yr copper concentrates 4,800 tons/yr copper in precipitates 22,400 tons/yr of copper total	**EMPLOYEES** 22 **ANNUAL PAYROLL** $899,000 **ARIZONA TAXES** $416,000 **HISTORY** Mine stripping began December 1951 Mill operations began March 1954 Dump Leach and copper precipitation began March 1960 Mine and Milling operations suspended July 1984

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Southwestern North America

Spencer R. Titley, *Editor*

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Geology of the El Tiro Area

SILVER BELL MINING DISTRICT, PIMA COUNTY, ARIZONA

Frederick T. Graybeal

The Silver Bell mining district is located 35 miles northwest of Tucson on the south side of the Silver Bell Mountains at elevations varying from 2,500 to 3,000 ft. Recorded mining activity began in 1865 with the discovery of an altered limestone outcrop near El Tiro pit which contained up to 17 oz. Ag and mixed copper oxides. Further exploration located massive chalcopyrite pods in skarn which were mined until 1930. Production for the period 1865–1930 is estimated at 1,400,000 tons averaging 3.5 percent Cu.

An extensive churn drill program was started in 1909 to investigate the possibility of disseminated copper mineralization in the igneous rocks and resulted in the discovery of the Oxide and El Tiro deposits, which were then submarginal. ASARCO acquired control of the district in 1917 and did some mining until 1930. The district was inactive until 1948, when check drilling confirmed the existence of two separate deposits of disseminated chalcocite ore. Production began in 1954 at an annual rate of 18,000 tons of copper and for the time period 1954–1977 yielded 75,655,000 tons averaging 0.80 percent Cu, 0.07 oz. Ag, and 0.022 percent MoS_2. In the late 1970s some production was derived from disseminated chalcopyrite in skarn in the eastern portion of El Tiro pit.

The first geologic study of the Silver Bell district was by Stewart (1912). This was followed by Kingsbury and others (1941), who mapped the El Tiro-Oxide area in detail; Richard and Courtright (1966), who published the only general study of the geology and mineralization in the Silver Bell district; Kerr (1951), who studied hydrothermal alteration; Watson (1964), who studied the Mesozoic stratigraphy and structure in the area east of the pits; Cummings (1973), who made the first attempt to define hypogene zoning patterns; and Davis (1977), who mapped the North Silver Bell area.

About 1970 mining reached the base of the chalcocite blanket and it became possible to study hypogene mineral assemblages previously masked by strong supergene alteration. It is the purpose of this chapter to report and interpret data on these assemblages with respect to modern concepts of porphyry copper zoning and genesis. The study is restricted to the El Tiro area (Fig. 24.1), which forms a center of mineralization separate from the Oxide area. Emphasis is on the entire hydrothermal system rather than geology within the pit walls. The El Tiro area was selected because of the abundance of exposures below the chalcocite blanket where hypogene patterns are best preserved. The data are primarily the result of detailed field mapping at scales larger than 1 in. = 1,000 ft. supplemented by chemical analyses and petrographic studies.

GENERAL GEOLOGY

Rocks which vary in age from Precambrian to Recent are exposed in the Silver Bell Mountains. These rocks are cut by an elongate zone of pyritic mineralization more than 8 miles long, which varies from 200 ft. to 2 miles wide. East of Oxide pit the pyrite zone is linear, with a strike of N80°W. In the El Tiro area the pyrite zone strikes N5°W. Although sulfide mineralization is continuous, the pyrite zone is very narrow between the two pits, and it is clear that two separate centers of mineralization are present. Control of the mineralization is attributed by Richard and Courtright (1966) to a well-developed fault zone. Northeast of the fault zone Paleozoic sedimentary rocks and Mesozoic volcanic and minor clastic rocks form a gently northeast-dipping homocline. Southwest of the fault zone Mesozoic clastic rocks are intruded by a large pluton of alaskite, and volcanic rocks are mostly absent. Dikes, sills, and small stocks of quartz

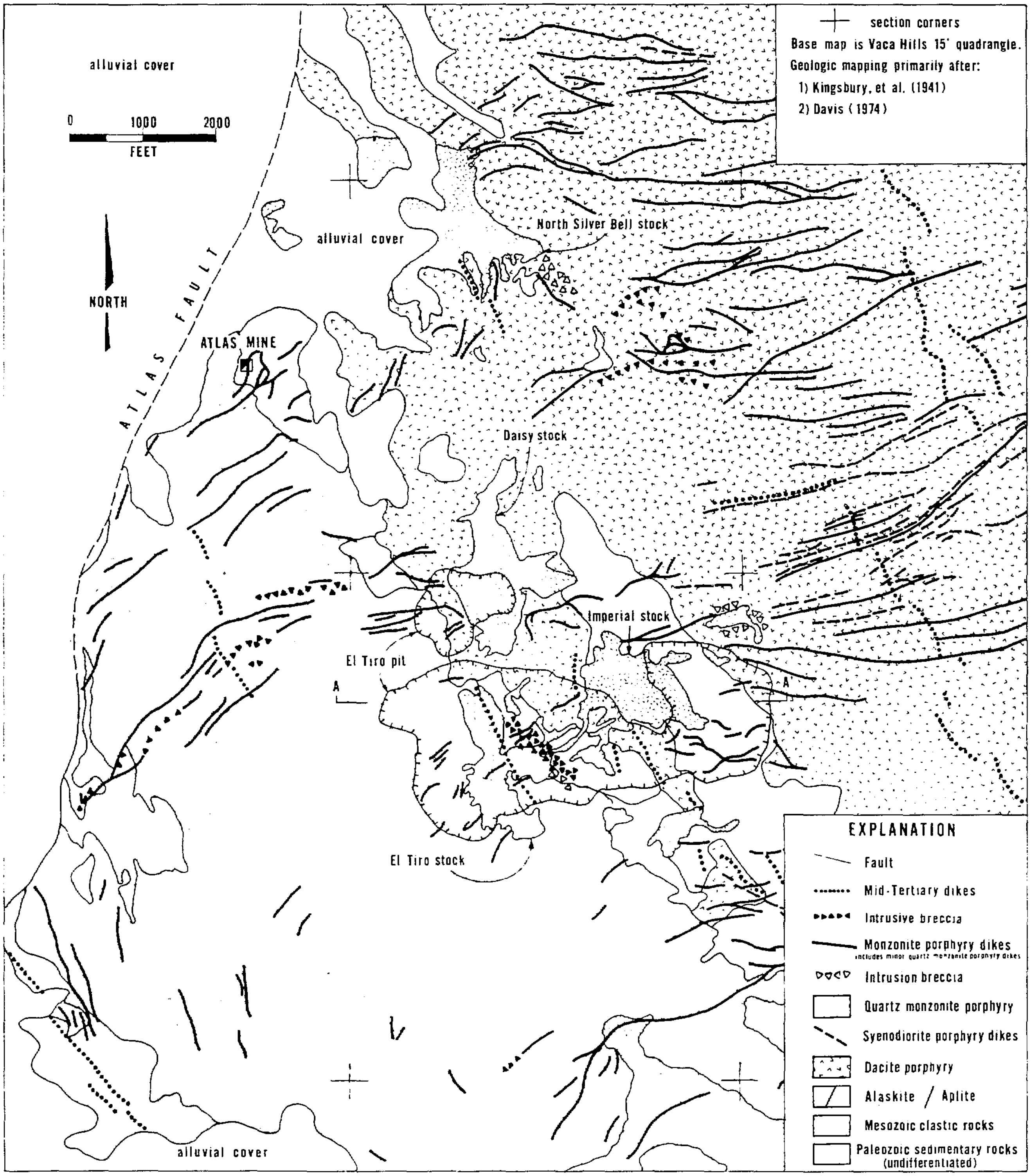

Figure 24.2. Geologic map of the El Tiro area (geology projected through dump areas)

which have been interpreted as faults may instead be fractures along which large blocks have been pulled apart during emplacement of the dacite.

Mesozoic

Clastic rocks are exposed in the southwestern corner of the area mapped in Figure 24.2. They consist of well-sorted glomerate units, all varying in color from buff to maroon. They generally dip 20 to 40° SW and are locally contorted where cut by later igneous rocks.

Alaskite underlies the western half of the El Tiro alteration zone. It is a buff-colored, medium- to coarse-grained, generally equigranular intrusive rock which contains 25 percent quartz, 54 percent weakly perthitic orthoclase, 18 per-

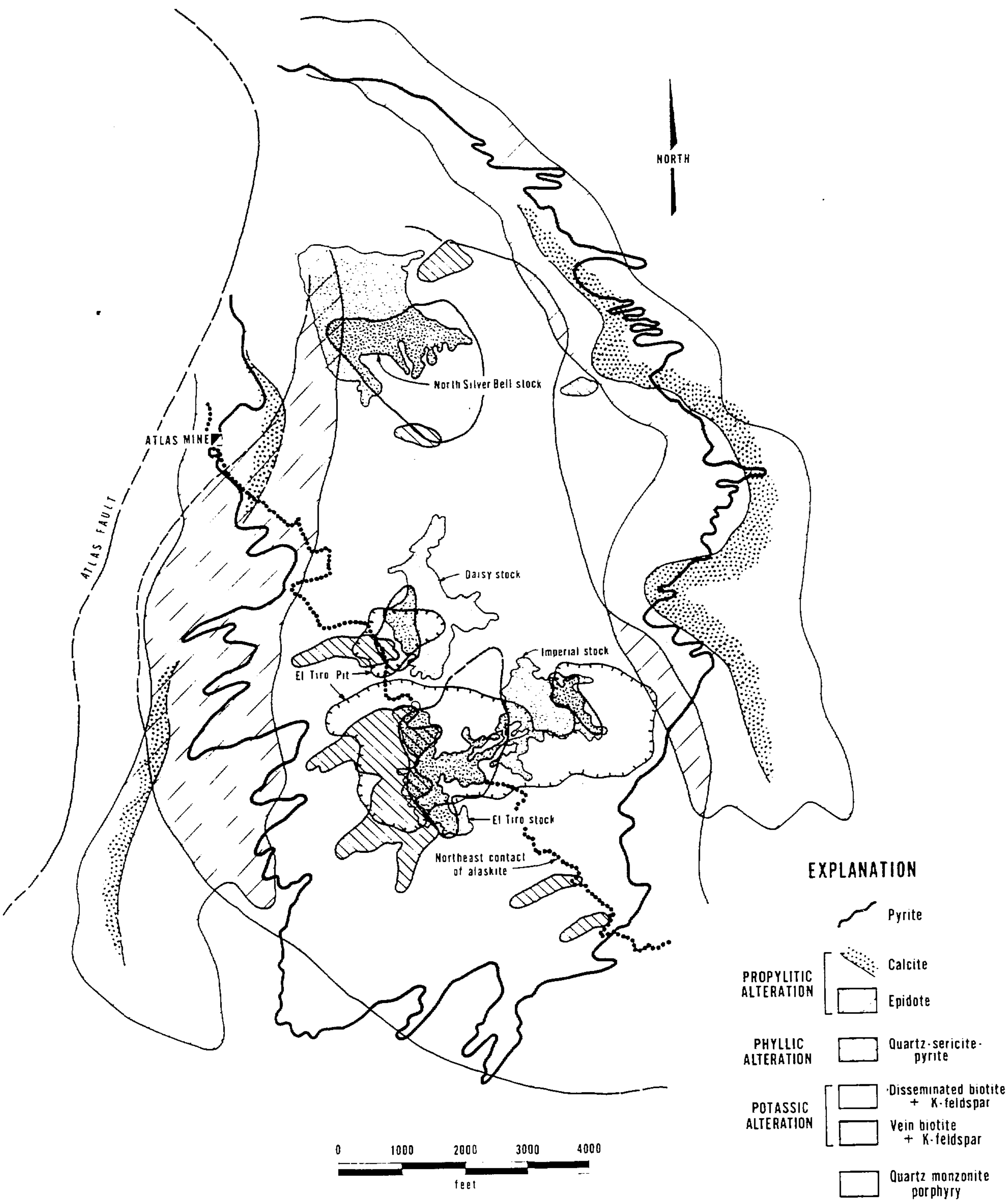

Figure 24.5. Alteration zones in the El Tiro area. Southwest of the alaskite contact potassic and propylitic assemblages are poorly developed and discontinuous, and zone boundaries are drawn on relatively few data points.

of other, earlier assemblages. The overall extent of phyllic alteration at Silver Bell is clearly less than had been previously thought.

Zoning of sulfide mineralization in the El Tiro area follows the general pattern seen in porphyry copper deposits (Lowell and Guilbert, 1970). Within the El Tiro and North Silver Bell stocks the pyrite:chalcopyrite ratio is less than 3:1 and it increases outward to greater than 50:1 in the propylitic zone. Hypogene copper grades in silicate rocks are centered on the El Tiro, Daisy, and North Silver Bell stocks and in dikes near the contact of the Imperial stock and decrease rapidly outward as shown on Figure 24.6. The distribution of molybdenum at the +25 ppm contour is very similar to the distribution of 0.1 percent Cu. Highest Mo values occur as

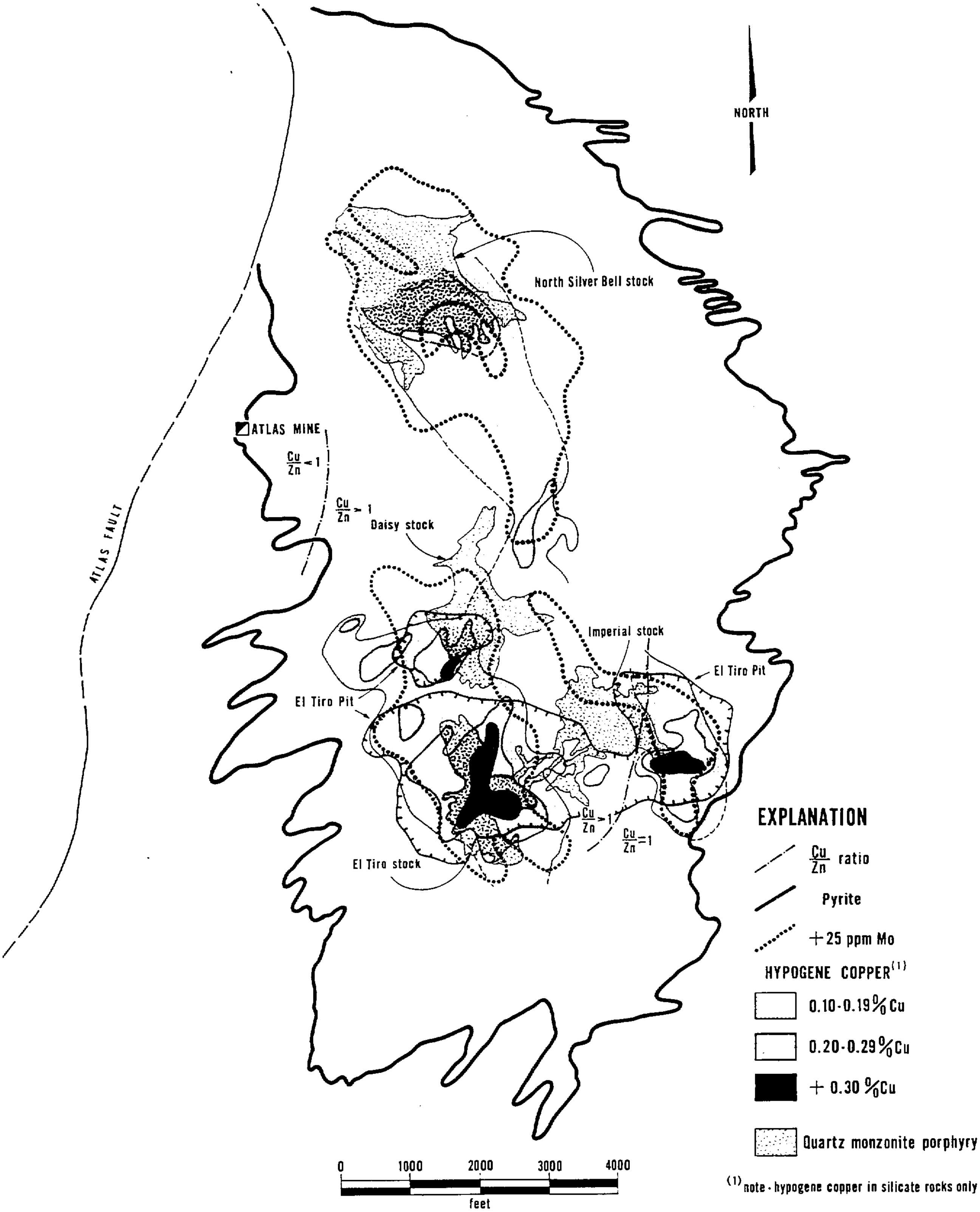

Figure 24.6. Mineralization zones in the El Tiro area

a halo around areas of highest copper and vein biotite and coincide with areas of most abundant vein-related K-feldspar. Zinc is most abundant in the skarns outside the 0.5 percent Cu contour line. The disseminated:vein ratio for sulfides is greatest in the areas of highest-grade chalcopyrite (2:1) and decreases outward with discontinuities at the dacite and the alaskite contacts. Total sulfide contents are generally highest where the phyllic assemblage is superimposed on the potassic assemblage in areas adjacent to, but not coincident with, areas of highest-grade hypogene copper mineralization.

4/12/94
Silver Bell Tour group

BHP MINERALS INTERNATIONAL

1. JOHN GILLIGAN.
   ENGLAND.
2. DAVE EVANS.
   WALES.
3. ISSAC BOADI.
   GHANA.
4. JOAS KABETE.
   TANZANIA.
5. AUDACE NTUNG-CIM-PAYE.
   BURUNDI.
6. SAN TAYLOR.
   U.S.A. — RENO & TUCSON.

CALDERA VOLCANISM AND PORPHYRY COPPER MINERALIZATION AT SILVER BELL, ARIZONA

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Silicic magmatism related to caldera formation is closely associated in time and space with the Late Cretaceous porphyry copper deposit at Silver Bell, Arizona. Detailed geologic mapping, geochronology, and petrologic and geochemical studies have shown an intimate relationship of porphyry copper progenitor plutons with coeval caldera volcanism. This finding refutes commonly accepted models for porphyry copper genesis and suggests that significant copper mineral resources may be associated with silicic volcanic rocks erupted from calderas.

Regional setting: The Silver Bell Mountains are located in south-central Arizona, about 60 km northwest of Tucson (fig. 1). This part of the State is in the Basin and Range province, a product of late Cenozoic extension. This is but the latest of a complex series of geologic events that are recorded in the bedrock geology of the region. Major crust formation took place at about 1.7 b.y., with widespread intrusion of anorogenic granites at 1.4 b.y. Cratonic platform sedimentation during the Paleozoic is recorded in 1-2 km sections dominated by carbonates. During the early and mid-Mesozoic, several episodes of volcanism and continental sedimentation occurred. In Late Cretaceous and early Tertiary (Laramide) time, widespread magmatic activity was closely associated with formation of many porphyry copper deposits (PCD hereafter). Another episode of andesitic to silicic volcanism in the mid-Tertiary was closely followed by regional crustal extension. All these geologic

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episodes are represented in the geologic record of the Silver Bell Mountains, but the focus of this discussion will be on the Late Cretaceous magmatic activity and its relation to PC mineralization.

Cretaceous magmatism: Igneous activity at Silver Bell began in the latest Cretaceous following mid-Cretaceous continental sedimentation and minor local volcanism. At 73 m.y., as indicated by U/Pb dating of zircon, these earlier Mesozoic deposits were intruded by the El Tiro biotite granite. It is an alkali granite to syenogranite with coarse perthitic potassium feldspar and 2-3 percent biotite. Shortly thereafter, the lithic tuff of Confidence Peak was erupted and faulted against the biotite granite during caldera collapse. The lithic tuff is a low-silica rhyolite tuff with 35-40 percent phenocrysts of quartz, plagioclase, and biotite. It has an exposed thickness of at least 1.5 km, and its base has not been encountererd in several deep drill holes. It is overlain depositionally by moat-filling sediments of the Claflin Ranch Formation, a sequence dominantly made up of debris flows, volcaniclastic sediments and nonwelded tuffs. Extrusion of the post-collapse Silver Bell volcanics as lavas, domes, and breccias followed; these rocks are compositionally dacites and andesites, containing phenocrysts of plagioclase and biotite along with minor quartz, amphibole, and pyroxene. The volcanic sequence is capped by the Mount Lord tuff, a high-silica rhyolite that may have a source outside the Silver Bell Mountains. The final igneous event during this late Cretaceous magmatic episode was the emplacement of a suite of plutons ranging from monzodiorite to monzogranite in composition, that were hosts to PC mineralization.

Mineralization: Porphyry copper mineralization in the Silver Bell mining district occurs at two main centers: the Oxide pit and, 4 km to the northwest of it, the El Tiro pit (fig. 1). The first of the suite of PC-related intrusions were monzodiorite porphyries (syenodiorite porphyry in the literature). These are fairly mafic (55-59 percent SiO_2) intrusions containing 50-70 percent plagioclase, biotite, and pyroxene. They were closely followed in time by plutons, ranging from quartz monzodiorite porphyry to monzogranite in modal composition, that were the main progenitors to PC mineralization. This suite is dated by an unmineralized pluton of the same composition at 68.6 by K/Aron biotite (Mauger, 1966). This brackets the entire Late Cretaceous magmatic activity as between 73 m.y. and 68.6 m.y., because dikes from the quartz monzodiorite porphyry suite cut the entire volcanic section.

Mineralization and alteration at Silver Bell takes several forms (Graybeal, 1982). Hypogene potassic alteration in the quartz monzodiorite porphyries consists of biotite-chalcopyrite-quartz-pyrite and quartz-molybdenite-potassium-feldspar stockwork veins and veinlets. Phyllic and propylitic alteration extend into the wall rocks of the plutons. Skarn mineralization and alteration is well developed in the Paleozoic sedimentary blocks enveloped by the lithic tuff, and carries the highest grade hypogene mineralization as chalcopyrite-pyrite replacement masses. Supergene secondary enrichment formed a chalcocite blanket which has provided most of the economic mineralization exploited by open-pit mining. Production of copper at Silver Bell began in the late 1800's and continued through the 1920's, mostly mining high-grade skarn ore. In 1954 ASARCO began open-pit mining at both the Oxide and El Tiro pits, and it has continued mining nearly continuously until 1984 when the mine shut down due to depressed market conditions. Total production to date has been approximately 90 million tons of ore averaging 0.80 percent Cu and 0.022 percent Mo (Graybeal, 1982).

<u>Caldera Volcanism</u>: Several lines of evidence support the occurence of

caldera volcanism at Silver Bell coeval with PC mineralization. The great thickness of the lithic tuff of Confidence Peak (more than 1.5 km thick) is generally rcognized as a charateristic of ponding of the erupting tuff within a concurrently subsiding caldera (Lipman, 1984). In contrast, equivalent outflow tuffs in the western Silver Bell Mountains are airfall and weakly welded tuffs less than 200 m in thickness. Paleozoic sediments occur as stucturally chaotic blocks up to 0.5 km in length and completely enclosed by lithic tuff; these are interpreted as caldera collapse megabreccia resulting from gravitational failure of oversteepened caldera walls. Similar collapse breccias are known from many younger, deeply eroded calderas (Lipman, 1984). The caldera margin is a well-defined, nearly arcuate zone extending 150 along the SW side of the Silver Bell Mountains. The eastern boundary of the caldera is poorly constrained due to alluvial cover, but local pediment exposures of the intracaldera tuff on the eastern side of the range indicate a minimum diameter of 14 km for the caldera. While the structural boundary of the caldera is grossly arcuate, in detail it is the intersection of several pre-existing linear structures re-activated during caldera collapse. Mineralized plutons of the quartz monzodiorite porphyry suite are localized along this ring-fracture zone, particularly at the intersection of these older stuctures. These may represent structurally favorable zones where the subjacent magma chmaber intruded up to shallower levels. These relations document the close spatial and structural association of PC intrusion and mineralization with caldera volcanism.

Geochemistry: The geochemical relation of volcanic rocks to PC plutons have been addressed using the detailed stratigraphy developed during geologic mapping as a guide to sampling. Careful sampling of least altered parts of each of the major rock units has revealed meaningful petrologic variation in these Late Cretaceous volcanic rocks, which are no more altered than many mid-Tertiary volcanic rocks from the western United States. Volcanic and plutonic rocks at Silver Bell are calc-alkaline (based on AFM and FeO*/MgO vs. SiO2 variation diagrams), as is typical of the products of arc magmatism. They are all high-K andesites, dacites, and rhyolites with relative volumes of 10:30:60 respectively. Titanium and the high field strength elements (Y, Nb, Ta) are low, as is common in magmas erupted from convergent plate margins.

The comagmatic nature of volcanic and plutonic rocks at Silver Bell is supported by several aspects of their chemistry. Major-element mass-balance calculations, using Stormer and Nicholls (1978) XLFRAC program, show that the major volcanic units and and PC-related plutons can be related by modest amounts of crystal fractionation. Only 5-20% fractionation of the common phases plagioclase, clinopyroxene, amphibole, and magnetite are needed, and good agreement is indicated by very low residuals. Rare-earth-element data are consistent with the comagmatic derviation of of the lithic tuff, Silver Bell volcanics, and quartz monzodiorite suite relted to PC mineralization. REE patterns (fig. 3) all have strong LREE/HREE fractionation and little or no europium anomaly. The lower HREE of the PC-related plutons could be caused by amphibole fractionation removing middle and heavy REE. In plots of Rb/Sr vs. Sr, a steep curvature of the data suggest significant assimilation in addition to crystal fractionation. This is consistent with the crustal assimilation indicated by published isotopic analyses of initial Sr ratios (.7096-.7111) and epsilon Nd values of -8 (Mauger, 1966; Farmer and DePaolo, 1984).

Discussion: Porphyry copper mineralization is widely appreciated to occur in subvolcanic environments; the question is, what kind of volcanism? The type of volcanism is largely dependent on the the tectonic setting of the magmatic activity. Many currently popular models (Sillitoe, 1973, 1980) are based on well-studied examples of PCD associated with young, oceanic volcanic arcs such as those in the SW Pacific (Gustafson and Titley, 1978). Volcanic rocks related to these PCD are most often andesitic, but volcanic rocks associated with PCD in continental arcs can be considerably more silicic, as at El Salvador, Chile (Gustafson and Hunt, 1975; Francis et al., 1983). In continental volcanic arcs, the chemistry of magmas is related to the the type of continental crust and the chemical processes that take place in the crust. Style of volcanic activity is a function of the chemistry of the erupted magma, and PC mineralization does not seem to be restricted to any one compositional range of magmas.

Based on the evidence presented above, southern Arizona is a continental volcanic arc province and a good place to examine the relationship between PC mineralization and calderas. Late Cretaceous magmatism was clearly calc-alkaline and arc-related; based on their chemistry, these magmas have also interacted with continental crust. As a result, the chemistry of the volcanic rocks is dominantly silicic, with large volumes of rhyolite, dacite, and andesite, with little basalt. There is growing evidence that late Cretaceous calderas are widespread in southern Arizona. Lipman and Sawyer (1985) have identified 10-12 late Cretaceous caldera fragments based on reconnaissance mapping using the criteria of thick accumulations of intracaldera tuff, caldera collapse megabreccia, and marginal granitic intrusions. Close associations of PCD with calderas seem likely at Silver Bell, Sierrita, Ajo, Hillsboro, and at well-known PC prospects such as Copper Creek, Red Mountain, Tombstone-Robbers Roost, Gleeson-Courtland, and the Tucson Mountains. Perhaps other PCD are caldera-related but have been eroded so deeply to remove the volcanic suprastructure necessary for identification.

Level of erosion may be a controlling factor on the type of mineralization observed to be associated with calderas. In shallowly eroded caldera fields such as the Oliogocene San Juan volcanic field of Colorado, the dominant mineralization is epithermal base and precious-metal veins (Steven et al., 1974). If we were to see deeper into the roots of the San Juan calderas, porphyry Cu or Mo mineralization might be encountered. Southern Arizona may be an analog for this level of erosion into a major caldera field. Deeper levels in magmatic systems such as those bearing W mineralization (Newberry and Einaudi, 1981) or batholithic PCD may not have vented.

That there is an intimate spatial and temporal association of PC mineralization with continental arc volcanism is irrefutable. Many details of the relationship still remain to be worked out: (1) Temporal relationships: more accurate means of dating igneous events are needed, particularly for the late Cretaceous of Arizona. In other caldera fields mineralization may post-date the caldera cycle by several million years (Steven et al., 1974). The K/Ar method, as widely applied, has essentially failed to discriminate igneous emplacement ages within this age range. Rb/Sr and U/Pb dating have been successfully applied in some cases with a great deal of effort, but also have drawbacks. Perhaps incremental release 40/39 Ar will help resolve some of the detailed geochronologic problems. (2) Basic geologic mapping using modern volcanological concepts: Although one caldera closely associated with PC mineralization has been identified (Silver Bell), much stratigraphic work needs to be done to resolve individual ash-flow cooling units, correlate them regionally, and relate them to source areas. In strongly altered and mineralized areas, application of these concepts may help elucidate the structural controls of ore mineralization. Many pyroclastic matrix "breccia pipes" with poorly constrained margins, that often have been used as guides to mineralization, could be caldera collapse megabreccia. (3) Petrologic-geochemical: are the PC plutons comagmatic with the associated volcanic rocks? This question needs all the petrologic and geochemical tools we have to bring to bear on the problem of their petrogenesis. Detailed study of the chemistry of well-constrained evolutionary sequences in conjunction with the above approaches may bring better understanding of the processes leading to PC formation, as well as illuminating the general links between magmatism and mineralization.

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ARIZ,caldera,02/12/85

MESOZOIC ASH-FLOW CALDERA FRAGMENTS IN SOUTHEASTERN ARIZONA AND THEIR RELATION TO PORPHYRY COPPER DEPOSITS

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ABSTRACT

Jurassic and Upper Cretaceous volcanic and associated granitic rocks in SE Arizona are remnants of large composite silicic volcanic fields, characterized by voluminous ash-flow tuffs and associated calderas. Presence of 10-15 large caldera fragments is inferred primarily from: (1) ash-flow deposits more than 1 km thick, with features of intracaldera ponding; (2) "exotic-block" breccias within a tuff matrix, interpreted as caldera-collapse megabreccias; and (3) local granitic intrusions along arcuate structural boundaries of the thick volcanic sequences. These Mesozoic caldera-related rocks are remnants of a typical cratonic volcanic arc. Several major porphyry copper deposits are associated with late granitic intrusions within the calderas or along their margins.

INTRODUCTION

Recent concepts concerning caldera formation and silicic volcanism, developed by volcanologists investigating igneous processes in little-eroded or active volcanoes, can provide new insights in interpreting the altered eroded roots of Mesozoic volcanoes associated with mineral deposits in SE Arizona (Fig. 1). Calderas associated with large ash-flow eruptions characteristically begin to subside concurrently with the pyroclastic eruptions, causing intracaldera ponding of tuff to thicknesses an order of magnitude greater than in the associated outflow sheet (Lipman, 1984). Oversteepening of caldera walls during subsidence produces landslide megabreccias that interfinger with the concurrently accumulating intracaldera tuff. In contrast, lithic fragments larger than a few cm across are unknown

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within regional outflow ash-flow sheets. Thus, kilometer-plus thicknesses of ash-flow tuff, associated with megabreccia, are indicators of caldera-fill assemblages.

In many subvolcanic settings, silicic magma overlies intermediate-composition magma within vertically zoned chambers (Smith, 1979; Hildreth, 1981). Eruption of silicic magma as ash-flow tuff, accompanied by caldera collapse, is common late in the evolution of volcanic fields that earlier erupted intermediate-composition magma as lava and breccia. In several Tertiary calderas in the western U.S., exposed batholithic granitic rocks can be shown by geochemical and geochronologic evidence to represent the consolidated magma chambers into which the associated ash-flow caldera had subsided earlier (Lipman, 1984). Before completely crystallizing, such subvolcanic magma bodies commonly rose into lower parts of their cogenetic volcanic ejecta, especially along caldera ring faults. Similar relations are believed common in the Mesozoic igneous terranes of SE Arizona.

Southern Arizona and adjacent areas constitute one of the largest porphyry Cu provinces in the world (Titley, 1982). Most of these deposits are associated with Late Cretaceous-Early Tertiary intrusions; related volcanic rocks, ranging in composition from andesite to silicic rhyolite (Hayes and Drewes, 1978), record the development of a continental-margin volcanic arc. In most models for the origin of porphyry Cu deposits, copper mineralization has been regarded as associated with the roots of andesitic volcanoes (Sillitoe, 1973; Branch, 1976), or to intrusions that did not vent at all. Silicic magmatism has commonly been considered unrelated to Cu mineralization, in contrast to its generally recognized association with porphyry Mo systems.

Recognition of primary large-scale volcanic features in mineralized SE Arizona rocks has been complicated by hypogene alteration and multiple structural complexities including Laramide compressive deformation, mid-Tertiary low-angle extensional faulting, and late Cenozoic block faulting. More than half the pre-Cenozoic bedrock is covered (Fig. 1), and only fragments of calderas are exposed. The resolution of K-Ar and fission-track methods to separate closely spaced events at many centers has been limited by the effects of high geothermal gradients or later episodic heating. The SE Arizona igneous rocks also contain remarkable structural and stratigraphic features, for which various hypotheses have been proposed in the past, including widespread "intrusive pyroclastic phenomena" (Watson, 1968), regional "exotic-block" breccias (Simons and others, 1966), and the concept of "volcanic orogeny" (Mayo, 1963). Because analogs for these inferred processes have not been recognized in active volcanic regions, many of the observations are open to reinterpretation.

Our interpretations are based on detailed study of one area (Silver Bell Mtns.), supplemented by field reconnaissance of areas mapped and dated by others. We especially acknowledge the prolific mapping of John Cooper, Harald Drewes, Philip Hayes, and Frank Simons; the geochronology generated by Paul Damon, M. Shafiqullah, and Richard Marvin; and the detailed investigations of porphyry Cu deposits in volumes edited by Spencer Titley. Except where noted, all isotopic ages are from Marvin and others (1978).

CALDERA FRAGMENTS

Six Late Cretaceous-early Tertiary (Laramide) calderas have been identified and five more tentatively recognized in the porphyry Cu belt of SE Arizona and SW New Mexico.

Silver Bell Mountains

The Silver Bell area has long been known as a key site where Upper Cretaceous volcanic rocks are associated with porphyry Cu mineralization

(Richard and Courtright, 1966). Detailed mapping by Watson (1968) led to interpretation of one major unit, the "dacite porphyry," as a sill-like pyroclastic intrusion 8 km in length and at least 1 km thick.

Intrigued and puzzled by this unorthodox interpretation, we have restudied the field and petrologic relations (Sawyer and Lipman, 1983; Sawyer, 1985) and have found that the "dacite porphyry" is a thick intracaldera welded tuff of low-silica rhyolite (Fig. 2A). This unit, redesignated the lithic tuff, becomes nonwelded toward its upper contact, and is conformably overlain by volcaniclastic sedimentary rocks (Claflin Ranch Fm.) that contain fragments of the lithic tuff, proving its extrusive origin. Large blocks of Paleozoic limestone, enveloped by lithic tuff that was considered by Watson to be intrusive, are interpreted by us as caldera-collapse megabreccia. The Silver Bell caldera was further filled by andesitic and dacitic flows (Silver Bell Fm), and by welded Mount Lord Tuff, perhaps erupted from another source. Late ring-fault intrusions of quartz monzodiorite to monzogranite host the porphyry Cu mineralization. New U/Pb-dating of zircon indicates that the entire igneous and mineralization sequence occurred between 73 and 69 Ma. This narrow age range, together with petrologic data, suggests that the mineralized intrusions are comagmatic with the lithic tuff and represent upper parts of the consolidated magma chamber into which the Silver Bell caldera collapsed.

Our study of the Silver Bell area links, for the first time, a silicic Mesozoic magmatic system, displaying voluminous ash-flow volcanism and associated caldera collapse, to a major Arizona porphyry Cu deposit. These results provide a conceptual framework for reconnaissance of relations between Mesozoic ash-flow magmatism and mineralization in adjacent areas.

Southern Sierrita Mountains

Along the SE Sierrita Mountains, large porphyry Cu deposits of the Pima district are associated with late intrusive phases of the batholithic 58-61-Ma Ruby Star Granodiorite (Cooper, 1973; Titley, 1982). In the southern Sierrita Mountains (Fig. 2B), a thick Mesozoic volcanic sequence, intruded and altered by the Ruby Star, is capped by the Upper Cretaceous Red Boy Rhyolite, a welded tuff at least 300 m thick with its top eroded.

Unusual contact relations between the Red Boy and underlying Upper Cretaceous Demetrie Volcanics indicate that this welded tuff constitutes remnants of thick caldera fill, probably involving collapse into a magma body represented by the Ruby Star Granodiorite. The Demetrie beneath the Red Boy Rhyolite is lithologically and stratigraphically chaotic andesitic breccia, containing irregular matrix of rhyolitic tuff that is in places continuous into the overlying Red Boy. These contacts, considered locally intrusive by Cooper (1971), are interpreted by us as a gradational boundary between caldera-collapse breccia and intracaldera tuff. Isolated andesitic megabreccia blocks of Demetrie lithology, some several tens of meters across, also occur locally higher within the main Red Boy Rhyolite. The distribution of the Red Boy and associated Demetrie breccia suggest a remnant of the west topographic wall and fill of a Sierrita caldera, with the older Mesozoic volcanic rocks to the east perhaps representing resurgently uplifted caldera floor (Fig. 2B). Onlap of the Red Boy to the west, against older volcanic rocks without intervening Demetrie, requires the brecciated Demetrie to have been deposited in a depression. In contrast to the chaotic andesite breccia beneath and within the Red Boy, Demetrie Volcanics mapped farther east are stratigraphically coherent and may represent another part of the Sierrita caldera floor (Fig. 2B). Thus, in the Sierrita Mountains, as at Silver Bell, major porphyry Cu deposits are associated with late intrusions related to a large silicic caldera.

Southwestern Santa Rita Mountains

The Upper Cretaceous Salero Formation was described as a stratified volcanic sequence as much as 800 m thick, containing exotic blocks, and burying rugged erosional topography on Jurassic granite (Drewes, 1971b; Simons and others, 1966). We have found that the bulk of the Salero (lower-andesite, exotic-block, and 72-Ma welded-tuff members of Drewes) constitutes a single intergradational deposit, several kilometers thick, containing blocks of varying size and lithology in a welded tuff matrix (Fig. 2C). Andesitic blocks are dominant in the lower part (lower-andesite member); blocks higher in the sequence (exotic-block member) include Cretaceous andesite, Jurassic welded tuff, and Jurassic granite; and yet higher larger blocks, some 1 km across, are internally shattered Jurassic granite surrounded by welded tuff. There blocks were interpreted as buried hills (Drewes, 1971b), but welding foliation in the Salero tuff projects gently beneath such blocks, and exposed contacts disclose tuff underlying granite.

We interpret this thick Salero succession as caldera fill, in which the changing lithologies of the enclosed blocks reflects progressively lower rocks on the caldera wall. Steep depositional contacts of Salero rocks to the northeast against older granite, including fossil talus deposits in tuffaceous matrix, are interpreted as remnants of the original topographic caldera wall (Fig. 2C). This caldera-wall granite, previously interpreted as a younger intrusion cutting the Salero deposits, closely resembles nearby Jurassic granite. Undoubted Upper Cretaceous granitic rocks (Josephine Diorite, Elephant Head Quartz Monzonite) along north and east sides of the proposed Santa Rita caldera probably are ring intrusions and constitute upper parts of the magma body into which the caldera subsided. Southwest of the Salero exposures, the shape of the Santa Rita caldera is obscured by younger rocks.

Although economic porphyry Cu mineralization has not been identified in the SW Santa Rita Mountains, base- and precious-metal veins are widespread (Drewes, 1971a), and the potential for concealed mineralization seems high.

Tombstone-Charleston area

The Uncle Sam Porphyry, considered intrusive rhyolite by Gilluly (1956), was identified as a 74-Ma welded tuff by Drewes (1971b, p. 75). Our observations (Fig. 2D) confirm previous brief suggestions of a possible Cretaceous caldera in this area (Drewes, 1980, section D-D′; J. A. Briscoe, written commun., 1982). The Tombstone-Charleston area contains a little deformed caldera-fill assemblage 15x20 km across, including intracaldera Uncle Sam tuff and associated collapse breccia, intruded by the 76-Ma Schieffelin Granodiorite. Exposed granodiorite is inferred to constitute a ring-fault intrusion, representing upper parts of a larger magma body cogenetic with the caldera-forming tuff. Southwest of Tombstone, the Uncle Sam "Porphyry" encloses variably rotated megabreccia blocks of Lower Cretaceous sedimentary rocks; the tuff is at least 1 km thick, with no base exposed and the top eroded. Northwest of Charleston, gently dipping Uncle Sam tuff abruptly thickens to the east, truncates an older ash-flow sheet, and farther east becomes the matrix of compositionally diverse blocks of lava tens of meters across. These features are interpreted to mark the western topographic wall of the Tombstone caldera. Northeast of Charleston, within the inferred caldera, gently dipping Uncle Sam tuff directly overlies shattered monolithologic breccia of a welded tuff that resembles Jurassic units in adjacent mountains; this breccia is interpreted as Cretaceous intracaldera landslide debris. The productive Ag-Pb-Zn-Cu veins of the Tombstone district are along the northeast caldera margin, and porphyry Cu-type alteration is locally strong within the caldera Newell, 1974).

Dos Cabezas Mountains

Cretaceous volcanic rocks in the northern Dos Cabezas Mountains were recognized as fragmental pyroclastic breccias by Erickson (1968), who considered them to be intrusive. The area has been restudied by Drewes and others (in press), who interpreted the pyroclastic breccias as partly intrusive, partly extrusive, and perhaps related to caldera subsidence. We interpret the entire pyroclastic assemblage as an eruptive caldera-fill sequence at least 3-4 km thick and dipping homoclinally SW, as indicated by compaction foliation. The sequence is relatively lithic-poor welded tuff in its lower part; fragments increase in size and abundance upward, but the upper part is again lithic-poor tuff. At least part of a mapped rhyolite "ring dike" (Drewes and others, in press) is concordant lithic-poor densely welded tuff low in the caldera-fill sequence. Several areas mapped by Drewes as intrusive breccia are semi-concordant lithic-rich horizons gradationally within homoclinal caldera fill. Mineralized rock is associated with several Cretaceous granitic intrusions into the intracaldera tuff and breccia, but assessment of the mineral potential would benefit from improved genetic understanding of the volcanic rocks.

Tucson Mountains

The "Tucson Mountain Chaos" contains sedimentary and volcanic blocks tens of meters across, set in a pyroclastic matrix, and ascribed to diverse tectonic and igneous processes (Mayo, 1963). The "Chaos" underlies the Upper Cretaceous Cat Mountain Rhyolite (72 Ma), a welded tuff at least 300-400 m thick. Much of the matrix of the "Chaos" is petrographically similar to weakly welded Cat Mountain, and the contact between these units is locally gradational. A caldera-collapse breccia origin has been inferred previously for the "Chaos" (Lipman, 1976, p. 1409), and we interpret the entire central and southern Tucson Mountains to be remnants of the fill and floor of a large Late Cretaceous caldera that was the source of the Cat Mountain Rhyolite. Caldera boundaries to the east and west are under adjacent valley fill, but the 73-Ma Amole pluton in the northern Tucson Mountains is interpreted as a caldera-margin intrusion. Several porphyry Cu prospects have been identified in the Tucson Mountains, although none have been developed.

Other probable Late Cretaceous caldera fragments

Hillsboro, NM: A nearly circular exposure of Upper Cretaceous andesite 5-6 km across, within which is centered the 72-Ma Copper Flat Quartz Monzonite and associated porphyry Cu deposits, was interpreted as a small caldera by Dunn (1982). No Cretaceous ash-flow tuff is preserved as regional outflow, but quartz-bearing tuff breccia occurs locally within the exposed andesite and also was encountered during exploratory drilling (Dunn, 1982). The presence of this tuff, and the lack of stratigraphy in the thick intracaldera andesite (base not penetrated in a 900-m drill hole), suggest that the Copper Flat caldera may have been a source of ash-flow eruptions whose outflow deposits have been completely eroded. The intracaldera andesite may be collapse breccia, as suggested by the intermixed tuff. This caldera, though smaller than many ash-flow calderas, is similar in size to Crater Lake, Oregon, if structural margins are compared.

Courtland-Gleason: The Sugarloaf Quartz Latite, discontinuously exposed in the SE Dragoon Mountains, was recognized as pyroclastic by Gilluly (1956) and dated at 75 Ma at its type locality (Drewes, 1971b). There, it is relatively unaltered quartz latite welded tuff several hundred meters thick, with no depositional top exposed. In the adjacent Courtland mining district, which contains porphyry Cu mineralization (D. Norton, oral commun., 1984), altered rhyolitic tuff correlated with the Sugarloaf by Gilluly contains map-scale megabreccia blocks of Paleozoic sediments (Drewes, 1981, pl. 4). If Gilluly's correlation is valid, the thickness of the Sugarloaf Quartz Latite and its enclosed blocks make it an attractive candidate for caldera fill, associated in space and time with porphyry Cu mineralization.

Ajo: The 63-Ma Cornelia Quartz Monzonite, host to the porphyry Cu system at Ajo, intrudes the Cretaceous Concentrator Volcanics, an assemblage of andesitic flows, breccia, and rhyolitic tuff. Stratigraphic relations are obscure among these rocks, which are likely more than 1,000 m thick, with neither base nor top exposed. In places, the tuff forms matrix surrounding and veining irregular masses of andesite (Watson, 1968), suggesting a deeply eroded caldera-collapse breccia.

Red Mountain (Patagonia Mtns.): Intense hydrothermal alteration obscures the origin of Upper Cretaceous-Lower Tertiary tuffaceous silicic rocks at least 1 km thick overlying a major porphyry copper system at Red Mountain. Preservation in a small (5-km diameter) caldera seems possible (Corn, 1975).

Central Galiuro Mountains: In the Copper Creek area, features of the Upper Cretaceous Glory Hole Volcanics (Simons, 1964) suggest a caldera-fill assemblage, intruded by the 68-Ma Copper Creek Granodiorite which generated a porphyry Cu system. The Glory Hole Volcanics are described as a chaotic assemblage of ash-flow tuff and andesitic breccia more than 500 m thick, without depositional base or top exposed; pyroclastic rocks are dominant and tuffaceous breccia abundant. Mappable Paleozoic rocks, interpreted as later landslide deposits (Krieger, 1968) but locally enclosed within the Glory Hole Volcanics, could be synvolcanic megabreccia related to caldera collapse.

Jurassic caldera fragments

The Cretaceous pyroclastic rocks and associated caldera fragments just summarized overlie tectonically disrupted remnants of Jurassic arc volcanics that also display local evidence of ash-flow and caldera origin. Little mineralization has been reported from these rocks, but association of the porphyry Cu deposit at Bisbee with a Jurassic intrusion suggests additional potential in Jurassic rocks.

Canelo Hills: A phenocryst-rich Jurassic welded tuff at least 2 km thick (Simons, 1972; Kluth, 1983), enclosing "exotic-block" breccias of Paleozoic limestone and sandstone, resembles younger caldera-fill deposits. A lower major volcanic unit, the "rhyolite lava" member, also contains abundant megabreccia blocks (Hayes and Raup, 1968; Simons and others, 1966). Although these rocks are mostly contorted and flow layered, relict welded-tuff textures preserved adjacent to contacts with Paleozoic blocks demonstrate that the rhyolite is rheomorphic welded tuff. Such large-scale rheomorphism of tuff likely requires oversteepening of the land surface during deposition, events especially common in proximity to caldera walls (Lipman, 1984). Both the rhyolite member and the welded tuff member are likely fragments of Jurassic caldera fills.

Huachuca Mountains: Finely porphyritic welded tuff, containing abundant large masses (up to 1.5 km) of Paleozoic sedimentary rocks, is as much as 1,300 m thick over an area about 15 km across in the southern Huachuca Mountains (Hayes and Raup, 1968). These rocks, which are lithologically distinct from the Canelo Hills volcanics, are accordingly interpreted as another dismembered Mesozoic caldera-fill sequence, probably cogenetic with the 167-Ma Huachuca Quartz Monzonite which intrudes the tuff.

Pajarito Mountains: Thick Jurrasic welded tuff, that depositionally underlies Lower Cretaceous sedimentary rocks (N. Riggs, oral commun., 1985), is also a probable caldera-fill fragment. These rocks were interpreted as Upper Cretaceous, partly intrusive, and possibly related to a caldera by

Drewes (1980, section D-D'; 1981)

Other areas: Kilometer-plus-thick Jurassic pyroclastic sequences in the Patagonia and Santa Rita Mountains, locally containing "exotic blocks" (Simons and others, 1966; Drewes, 1971b) are additional probable fragments of Mesozoic caldera fills.

DISCUSSION

Mesozoic volcanic and associated granitic rocks in SE Arizona and adjacent areas are interpreted as remnants of large composite silicic volcanic fields, characterized by voluminous ash-flow eruptions and large calderas, that have been dismembered by Basin-Range and older structures, covered by younger rocks, and dissected by erosion. Regionally, the Mesozoic volcanic sequences include intermediate-composition lavas and breccias, overlain by ash-flow tuffs, and cut by granitic intrusions.

At least 10 latest Cretaceous-early Tertiary (Laramide) calderas have been identified within a region of about 20,000 km^2 (Fig. 1), and at least 5 more of Jurassic age are probably present. These are minimum numbers, as more than half the region is covered by younger rocks and basin fill. The dismembered late Cretaceous volcanic field appears to represent remnants of a cratonic arc similar in size, volcanic evolution, and petrologic character to the well-known Oligocene San Juan field of SW Colorado which contains one of the world's major ash-flow fields (Lipman, 1984). Twelve major ash-flow calderas are exposed within the 25,000 km^2 San Juan field, which lacks surficial cover on a scale sufficient to hide major calderas. Even if calderas are not proportionally present under the vast basin fills of SE Arizona, this area was a major locus of ash-flow eruption and caldera formation in the Mesozoic. Caldera fragments may have been preferentially preserved and exposed in SE Arizona because (1) in comparison with readily erodable equivalent outflow volcanics, the intracaldera accumulations are relatively thick, indurated by thermal metamorphism, and structurally low, and (2) Basin-Range faults may have tended to wrap around structurally coherent caldera-related intrusions. Most evidence for concepts of "volcanic orogeny" (Mayo, 1963), which relates some "exotic-block" breccias to volcanic-related pyroclastic intrusive activity, can be readily explained by caldera subsidence processes, and some features interpreted as mineralized breccia pipes could be alternatively interpreted as caldera-collapse breccias. In addition to collapse breccias within calderas, large Paleozoic blocks within some Mesozoic sedimentary sequences (Simons and others, 1966; Davis and others, 1979) probably represent landsliding off growing fault scarps analogous to Tertiary slide deposits in the Basin-Range province (Longwell, 1951; Krieger, 1977).

Well-stratified outflow welded tuff sheets of the Mesozoic volcanic fields are not widely exposed in SE Arizona; the only major area of such rocks isolated from any apparent caldera is in the Roskruge Mountains (Bikerman, 1968), where at least 5 major ash-flow sheets and associated air-fall tuffs are present. Even there, a granodiorite intrusion into the tuffs is coeval in age, suggesting a possible source nearby. Areas of stratified intermediate-composition lavas, subordinate ash-flow tuff, and volcaniclastic sedimentary rocks, as in the NE Santa Rita Mountains (Finnell, 1971), represent remnants of outflow volcanics outside any caldera, from which most outflow tuffs have been eroded. More detailed stratigraphic and petrologic study is needed to understand the caldera features in SE Arizona and to correlate regional ash-flow sheets between mountain ranges.

Important mineral resources, including several major porphyry Cu systems and many smaller mineralized centers, are associated with granitic intrusions within Mesozoic calderas or along their margins--especially at Silver Bell, Sierrita, Tombstone, Ajo, and Hillsboro. Other porphyry Cu deposits could be present in the roots of Arizona calderas that are so deeply eroded that only precaldera rocks are preserved. The clustering of porphyry Cu deposits in Arizona may be partly due to level of erosion, intermediate between the base/precious metal veins of a San Juan volcanic field and deeper plutonic mineralization such as tungsten skarns in the Sierra Nevada (Newberry and Einaudi, 1981). The close spatial and temporal association of many porphyry Cu deposits with caldera-related silicic magmatism in Arizona casts doubt on models that associate porphyry Cu deposits exclusively with intermediate-composition stratovolcanoes (Sillitoe, 1973; Branch, 1976). Throughout southern Arizona, silicic volcanism and caldera formation closely predate porphyry-Cu-related plutons. Intermediate-composition plutons, such as those associated with Cu mineralization in Arizona, commonly have been emplaced elsewhere within ash-flow calderas or along their margins after collapse and record renewed upward movement of less evolved lower parts of the ash-flow magma chamber (Lipman, 1984). Porphyry Cu mineralization is closely related spatially to caldera-forming magmas, but the petrologic relations and timing require more rigorous evaluation. Elsewhere, important mineralization has occurred millions of years after caldera collapse, associated with younger magmas utilizing caldera structures (Steven and others, 1974). Nevertheless, calderas and porphyry Cu mineralization, rather than being antithetic (Sillitoe, 1980), are commonly associated in Arizona and probably in other cratonic continental arcs.

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FIGURES

Proposed cover photo (color): Chaotic volcanic breccia, interpreted as caldera-collapse megabreccia in the Upper Cretaceous Salero Formation. Compositionally diverse blocks, ranging in size up to at least as much as several tens of meters across, are surrounded by quartz latitic welded tuff matrix. Block include Upper Cretaceous andesite, Jurassic welded tuff of the Mt Wrightson Formation, and Juassic Squaw Gulch Granite. Cottonwood Creek, southwestern Santa Rita Mountains.

Alternative: Silver Bell Mountains and open pit mines at sunset

Figure 1. Map of southeastern Arizona showing distribution of Upper Cretaceous-lower Tertiary (Laramide) igneous rocks discussed in text, and associated major Cu porphyry deposits. Modified from Titley (1982) and Keith (1984). Areas of Tertiary and older rocks shown in outline. Ajo, AZ, is west of map area; Hillboro, NM, is to the east.

Figure 2. Generalized geologic maps of areas interpreted as containing fragments of Late Cretaceous calderas (most regional structures omitted).

A. Silver Bell Mountains, Arizona (from Saywer, 1985)

B. Southern Sierrita Mountains (modified from Cooper, 1973)

C. Southwest Santa Rita Mountains (modified from Drewes, 1971a)

D. Tombstone-Charleston area (modified from Gilluly, 1956; Drewes, 1980)

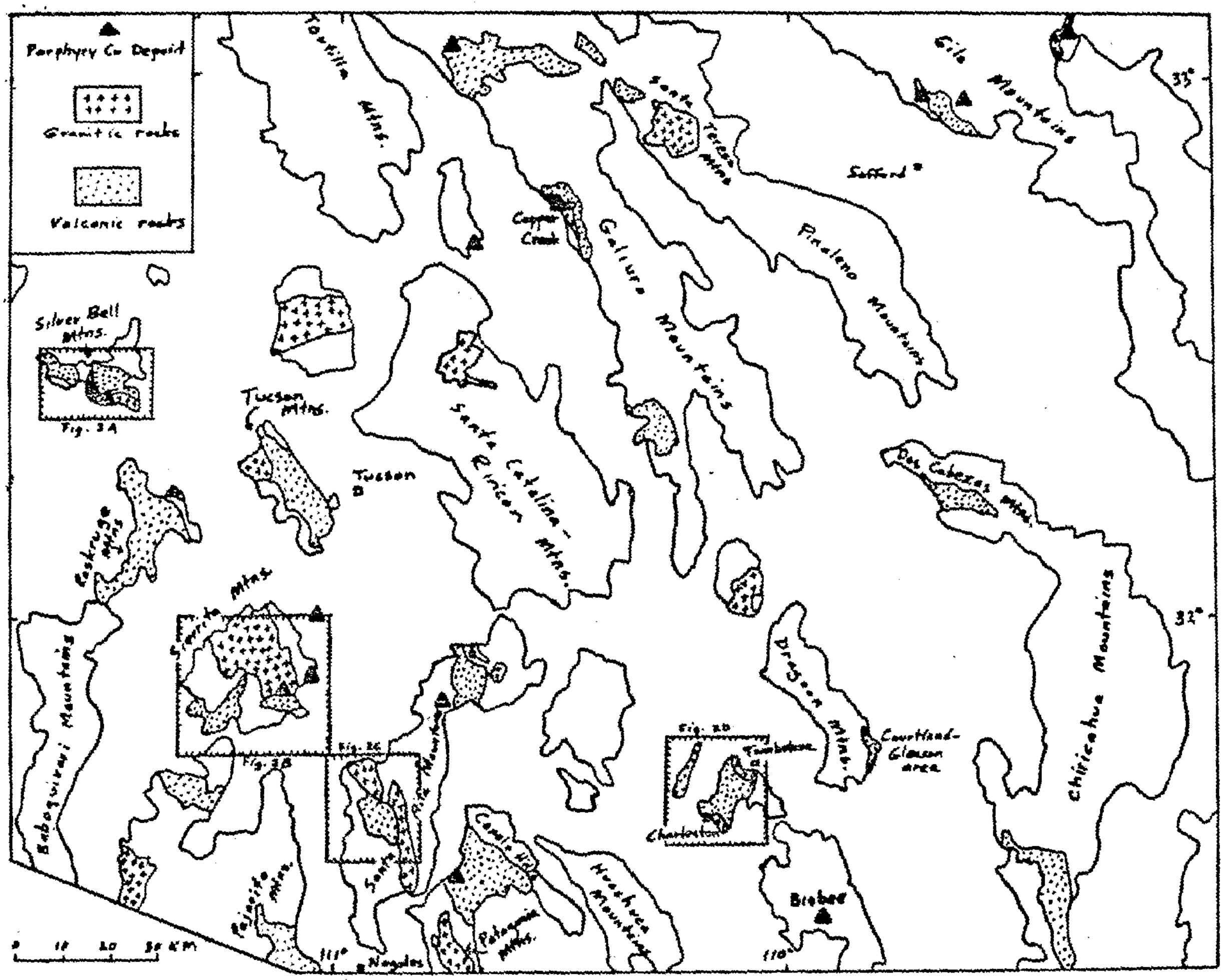

Porphyry Cu Deposit
Granitic rocks
Volcanic rocks
Tortilla Mtns.
Santa Teresa Mtns.
Gila Mountains
33°
Safford
Copper Creek
Galiuro Mountains
Pinaleno Mountains
Silver Bell Mtns.
Fig. 3A
Tucson Mtns.
Tucson
Santa Catalina-Rincon Mtns.
Dos Cabezas Mtns.
Roskruge Mtns.
Sierrita Mtns.
32°
Chiricahua Mountains
Dragoon Mtns.
Courtland-Gleeson area
Fig. 3D
Tombstone
Charleston
Fig. 3B
Fig. 3C
Baboquivari Mountains
Santa Rita Mountains
Canelo Hills
Huachuca Mountains
Bisbee
Pajarito Mtns.
Patagonia Mtns.
0 10 20 30 KM
111°
Nogales
110°

Fig. 1

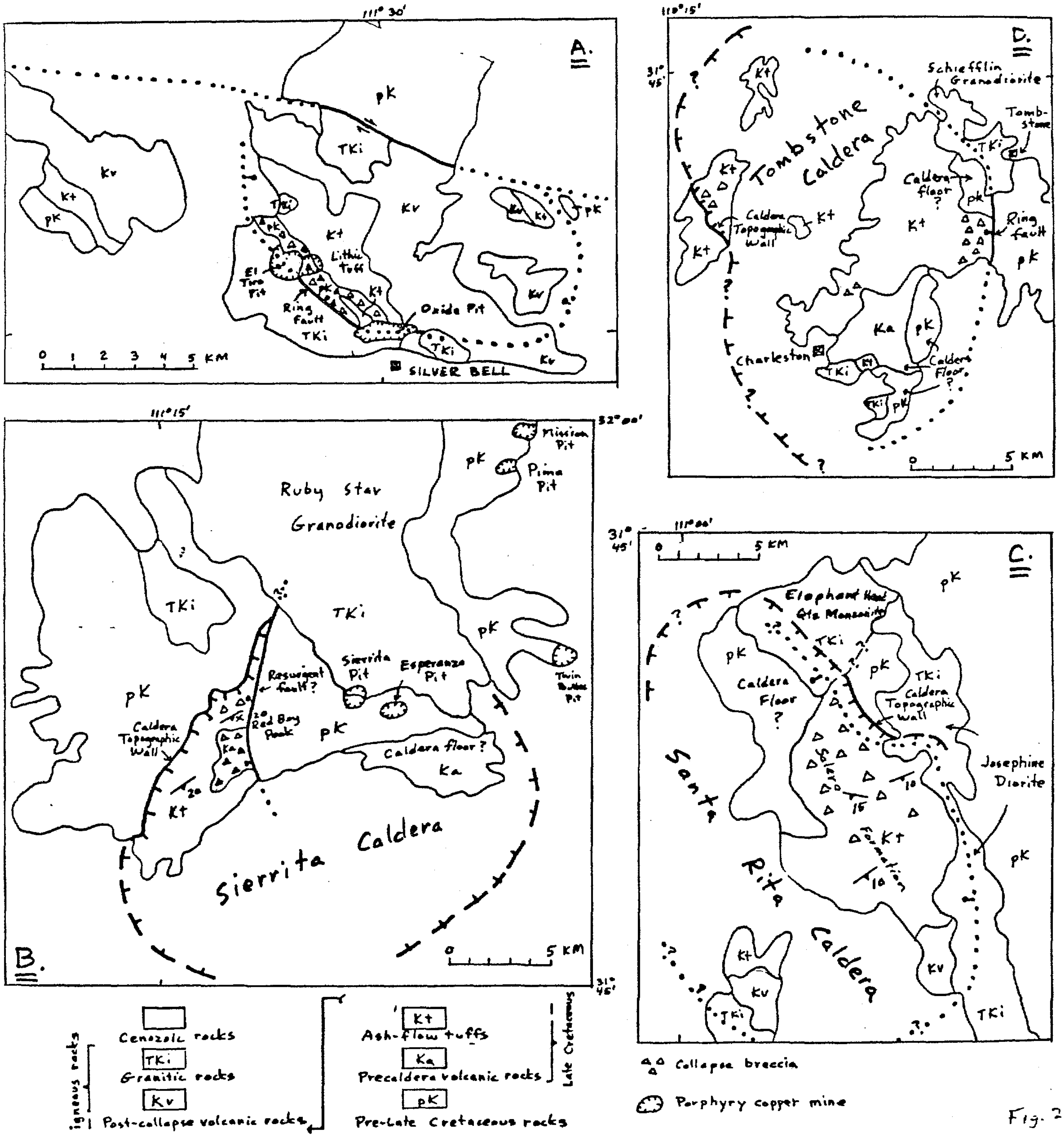
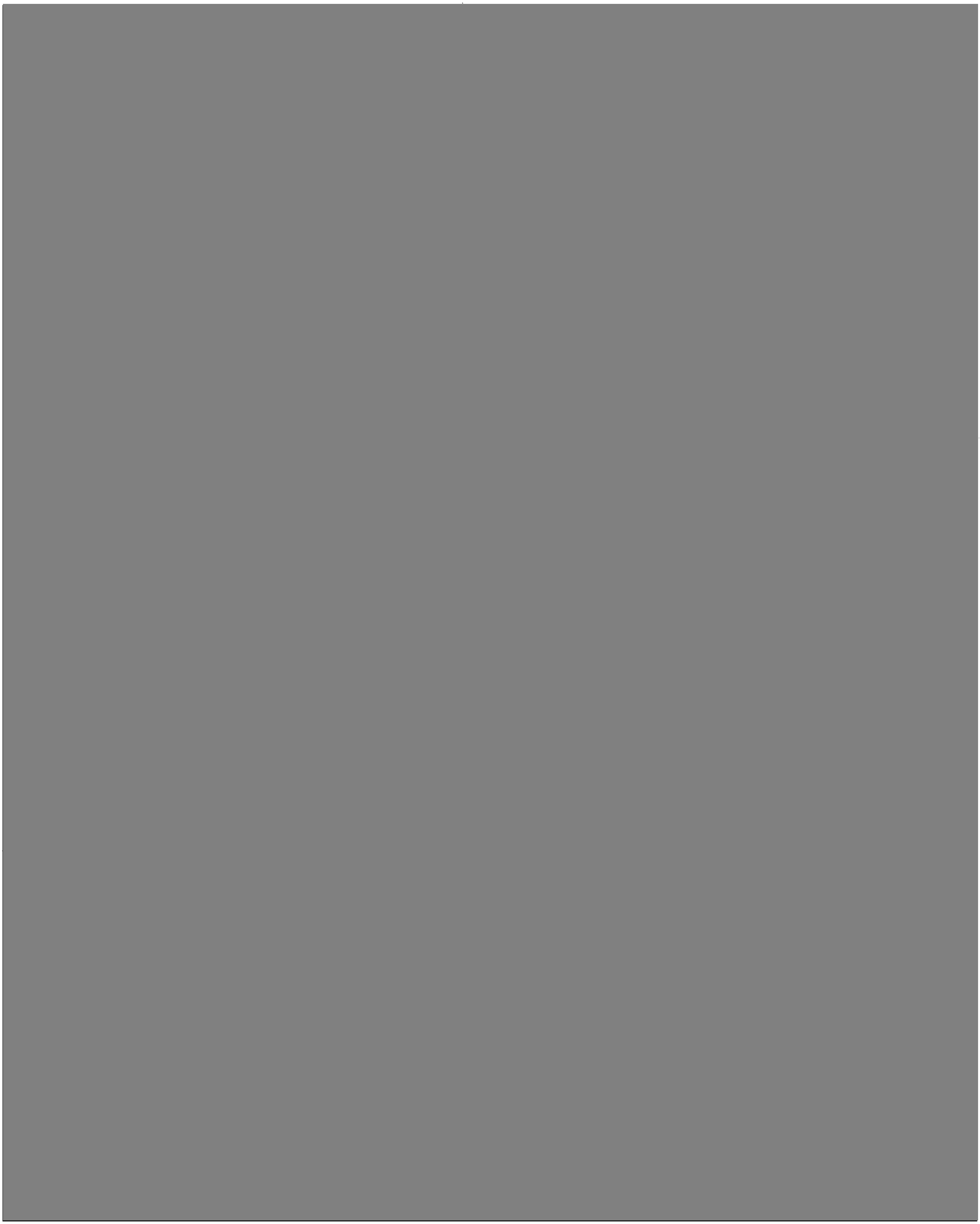
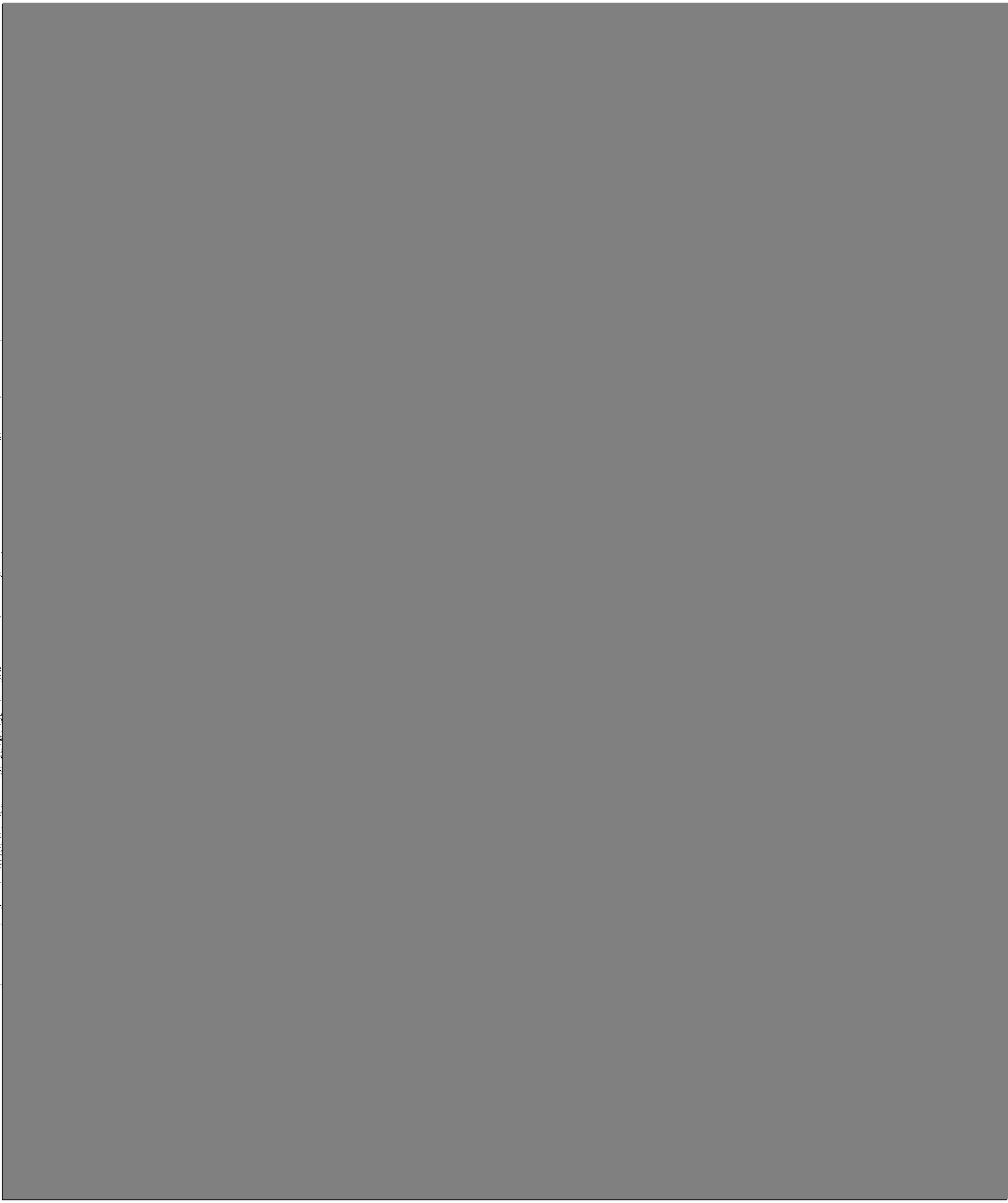

A.
111°30'
pK
TKi
Kv
Kt
Lithic Tuff
El Tiro Pit
Ring Fault
Oxide Pit
0 1 2 3 4 5 KM
SILVER BELL
B.
111°15'
32°00'
31°45'
Mission Pit
Pima Pit
Ruby Star Granodiorite
Sierrita Pit
Esperanza Pit
Twin Buttes Pit
Resurgent fault?
Red Boy Peak
Caldera Topographic Wall
Caldera floor?
Ka
Sierrita Caldera
0 5 KM
D.
110°15'
31° 45'
Schieffelin Granodiorite
Tombstone
Tombstone Caldera
Caldera floor ?
Caldera Topographic Wall
Ring fault
Charleston
Caldera Floor ?
0 5 KM
C.
111°00'
31° 45'
0 5 KM
Elephant Head Qtz Monzonite
Caldera Floor ?
Caldera Topographic Wall
Josephine Diorite
Santa Rita Caldera
Salero Formation
Cenozoic rocks
Granitic rocks
Post-collapse volcanic rocks
Igneous rocks
Ash-flow tuffs
Precaldera volcanic rocks
Pre-Late Cretaceous rocks
Late Cretaceous
Collapse breccia
Porphyry copper mine

Fig. 2





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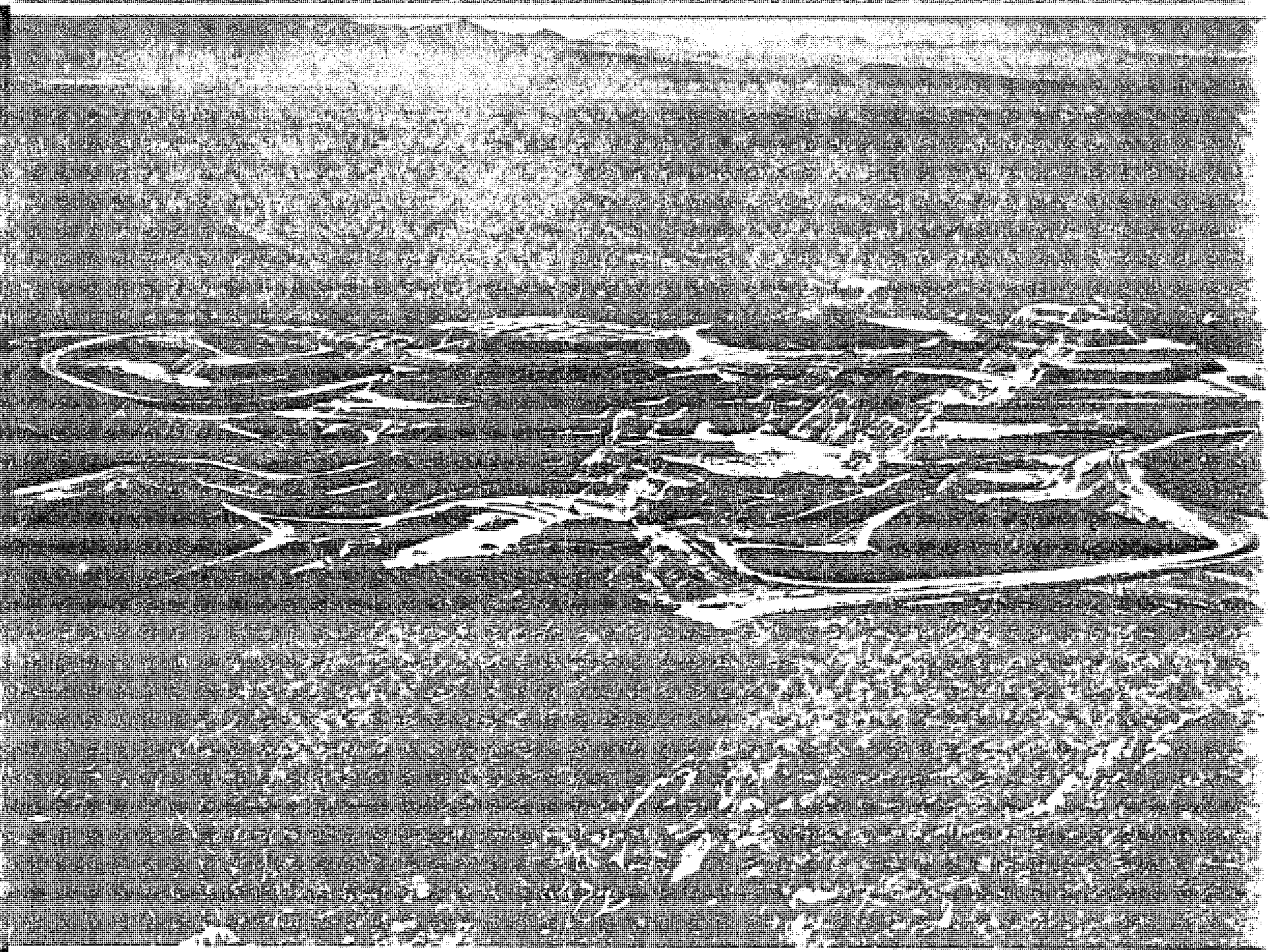
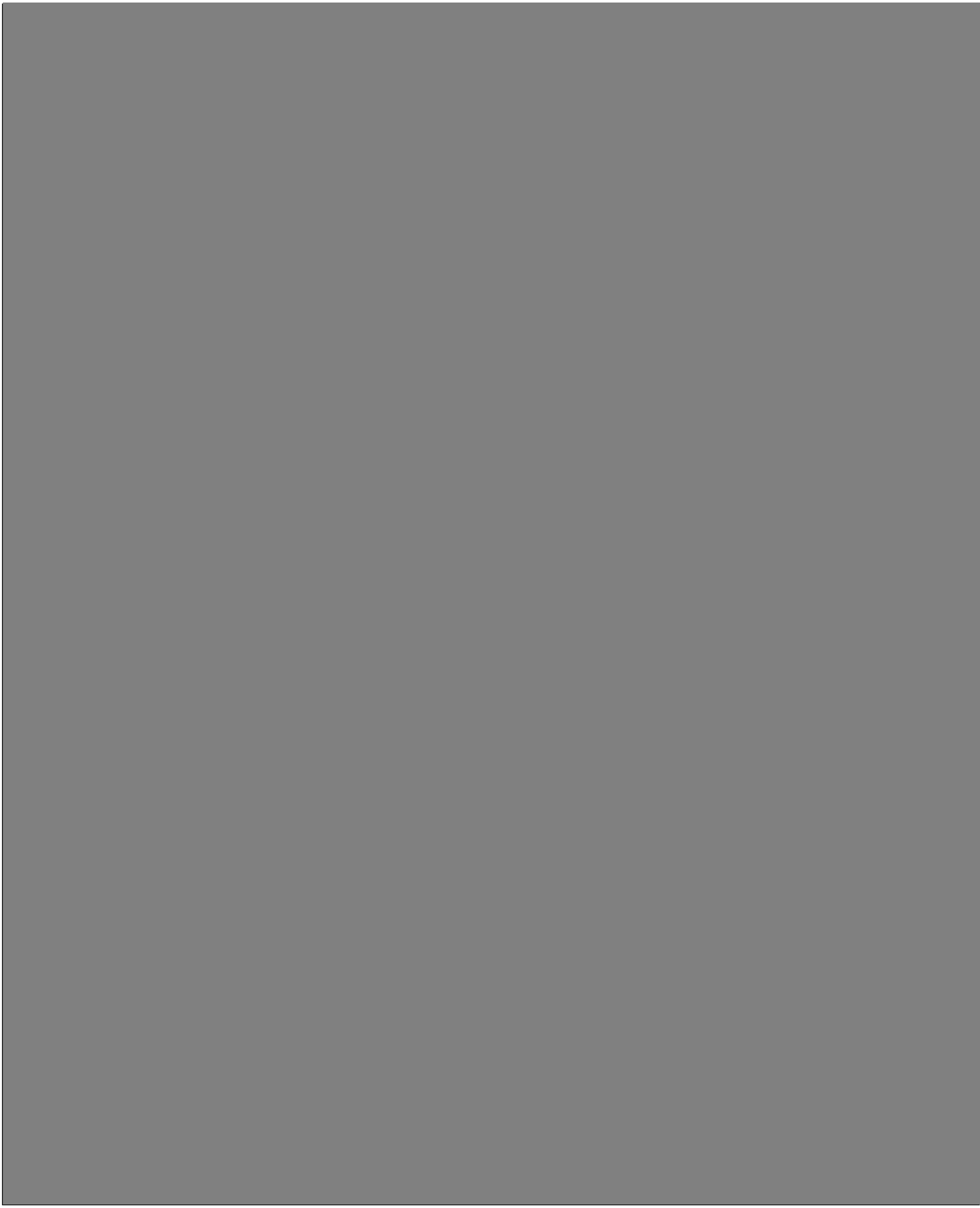
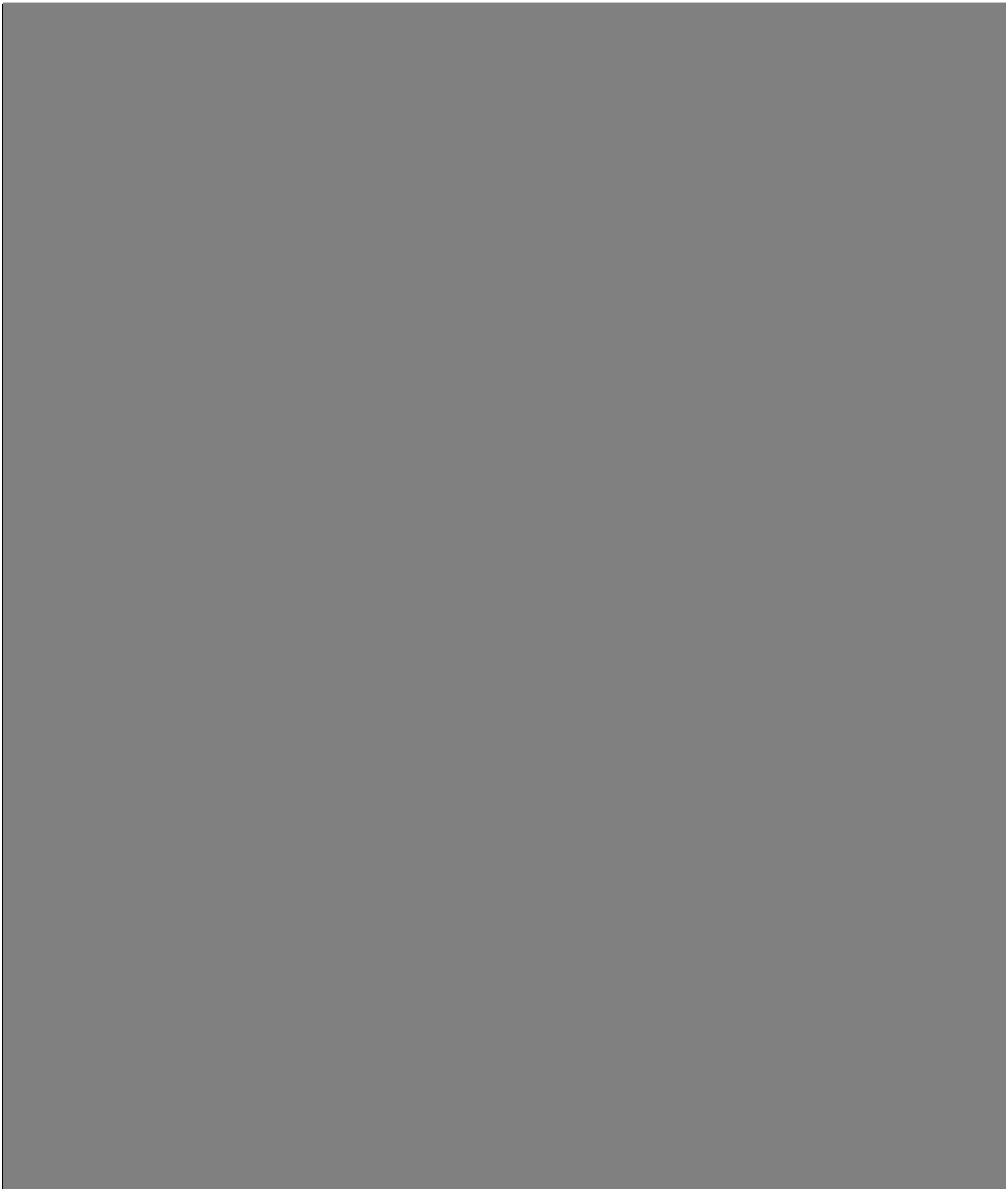


Williston Basin and below
p. 620, 624

Amphibolite chemistry and fault displacement
p. 604

Cambrian-Ordovician winds and shale
p. 607





EXPLORATION POTENTIAL
OF THE
GREATER SILVER BELL AREA
PIMA COUNTY, ARIZONA

The main Silver Bell district has produced many million of tons of ore ranging from 0.6% copper up to 3.5% copper. Of course, the higher grade was from the early years, 1865-1930, when oxide and sulfide ores were mined underground, and from shallow surface workings, in the tactite zones in altered limestone, whereas, the bulk of the tonnage from 1954 has been of the lower grade, large tonnage open-pit operations. This production is continuing by mining lower-grade material which is placed on dumps, leached, and the copper recovered in a solvent extraction-electro winning (SXEW) plant.

The advent of better equipment, improved control of equipment by the use of GPS, real-time monitors on equipment, the rapid turn around on assays, modeling of mineralized blocks, as well as the improved SXEW plants, has placed a new face on mining and producing copper from lower grade ores.

Drilled mineral resources, or reserves, are still being found in the Silver Bell district, as exploration thoughts are being re-examined.

The classic curve of the main Silver Bell zone was reported by Richard and Courtright (1966). The eastward extension of the alteration-mineralized was mapped and the zone shown to be covered by alluvium cover to the east. Drilling of a number of holes through the alluvial cover, indicated that the zone continued, but not of sufficient mineral grade at the time.

Graybeal (1982) reported on the northern El Tiro pits and the north Silver Bell area of alteration-mineralization. Graybeal noted that the alteration-mineralization on the north end curved back westward before the zone was cut by the northerly-trending Atlas fault. Several drill holes were place west of the fault to locate the offset portion, but were unsuccessful. It was then suggested that the Atlas fault had considerable displacement, with the west side moving to the south.

The West Silver Bell Mountains were mapped and alteration-mineralization was noted, suggesting better values might be found to the south under alluvial cover. Several holes were drilled, and although of interest, did not return sufficient copper values to continue the exploration.

Jaba, Inc., took up a position in the West Silver Bell mountains and did geochemical and geophysical work, confirming the work of ASARCO, and also drilled several holes, but again did not find what was needed at the time.

Noel McAnulty (1976) wrote an interesting paper on "Resurgent cauldrons and associated mineralization" in which he documented the various styles of mineralization found within and around the cauldrons.

Peter Lipman, and others, (1976,1981, 1984, 1985, 1990, 1993) also was interested in this relationship of calderas and mineralization. He suggested that the Silver Bell Mountains was one such caldera with the associated mineralization. This later work was also with Sawyer(1986, 1987, 1989) who completed his PhD dissertation at Silver Bell and proposed the late Cretaceous Silver Bell Caldera with its late monzonite porphyries intruding along the margin of the ring zone.

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9108

Saginaw Hill (Amole Mining District)
5 short drill holes, 270 to 374 ft. which released copper values of 0.25% to 0.54%, average 0.41% Cu, tho individual 5 foot samples varied from 0.10% to 1.5% Cu.
Conoco Oil drilled to west as did Kern County (Rock Hill) (Diss values in porphyry & sediments). (mag high)
I have drill holes 3, 4, & 5 w/assays.

Batamote 10 miles WSW of Esperanza Mine)
IP Anomaly 1 X 2 miles, depth 400-700 ft
(Portions of T18-19S, R9-10E. ~~[illegible]~~
in Section 8. T19S, R10E., 700' E of the W 1/4 corner,
Drill hole 850± ft stayed in conglomerate, ie did not reach pre-mineral unit.

Border Arivaca Mining District
Ten reverse-circulation holes totalling 3300 ft straddling the Border fault, 4000 ft long x 100 ft + wide, anomalous gold values 0.028 → 0.056 ounces per ton. See Oro Blanco 15' Quad
1000 feet W of E side line of Sec. 4, T23S, R.9E, on S line of Sec. 4, & N line of Sec. 9. 37 holes total in zone. 30' @ 0.103 opt Au; way south, 15' @ 0.071 opt

CWT Property T17S, R12E & part of R13E (Dragoon? gap)
Abundant drilling by Bear Creek, Anaconda, & Continental Material has found variable copper & lead, zinc mineralization in the hanging wall sediments, little in the granite under the "San Xavier Thrust".

Choctaw Mine, Arivaca Dist 1/4 mile east of main Arivaca Ruby Road, directly east of Horn Ranch.

Ag - Pb - Zn
4-6oz 8-12%

EXPLORATION POTENTIAL
OF THE
GREATER SILVER BELL AREA
PIMA COUNTY, ARIZONA

The main Silver Bell district has produced many million of tons of ore ranging from 0.6% copper up to 3.5% copper. Of course, the higher grade was from the early years, 1865-1930, when oxide and sulfide ores were mined underground, and from shallow surface workings, in the tactite zones in altered limestone, whereas, the bulk of the tonnage from 1954 has been of the lower grade, large tonnage open-pit operations. This production is continuing by mining lower-grade material which is placed on dumps, leached, and the copper recovered in a solvent extraction-electro winning (SXEW) plant.

The advent of better equipment, improved control of equipment by the use of GPS, real-time monitors on equipment, the rapid turn around on assays, modeling of mineralized blocks, as well as the improved SXEW plants, has placed a new face on mining and producing copper from lower grade ores.

Drilled mineral resources, or reserves, are still being found in the Silver Bell district, as exploration thoughts are being re-examined.

The classic curve of the main Silver Bell zone was reported by Richard and Courtright (1966). The eastward extension of the alteration-mineralized was mapped and the zone shown to be covered by alluvium cover to the east. Drilling of a number of holes through the alluvial cover, indicated that the zone continued, but not of sufficient mineral grade at the time.

Graybeal (1982) reported on the northern El Tiro pits and the north Silver Bell area of alteration-mineralization. Graybeal noted that the alteration-mineralization on the north end curved back westward before the zone was cut by the northerly-trending Atlas fault. Several drill holes were place west of the fault to locate the offset portion, but were unsuccessful. It was then suggested that the Atlas fault had considerable displacement, with the west side moving to the south.

The West Silver Bell Mountains were mapped and alteration-mineralization was noted, suggesting better values might be found to the south under alluvial cover. Several holes were drilled, and although of interest, did not return sufficient copper values to continue the exploration.

Jaba, Inc., took up a position in the West Silver Bell mountains and did geochemical and geophysical work, confirming the work of ASARCO, and also drilled several holes, but again did not find what was needed at the time.

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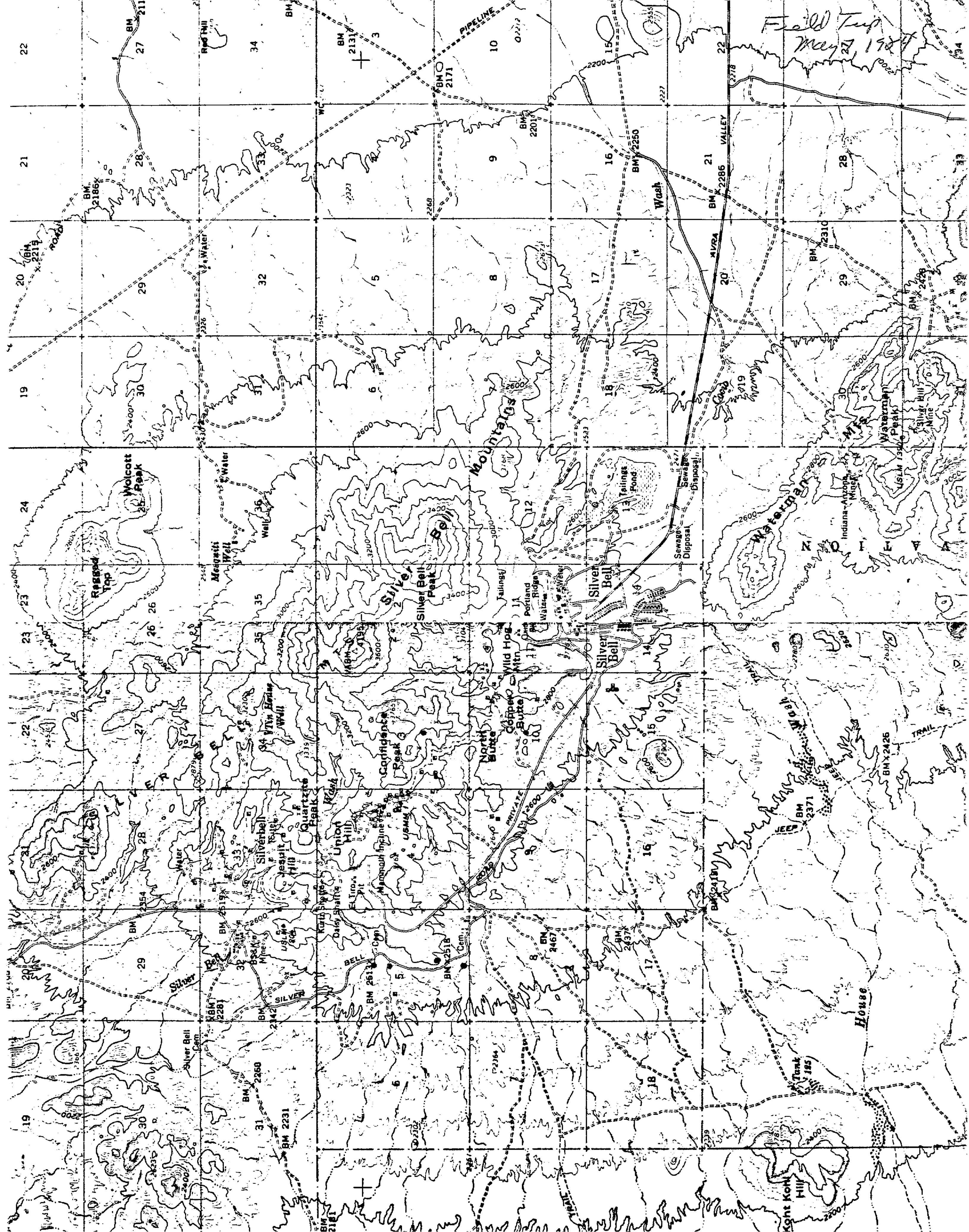
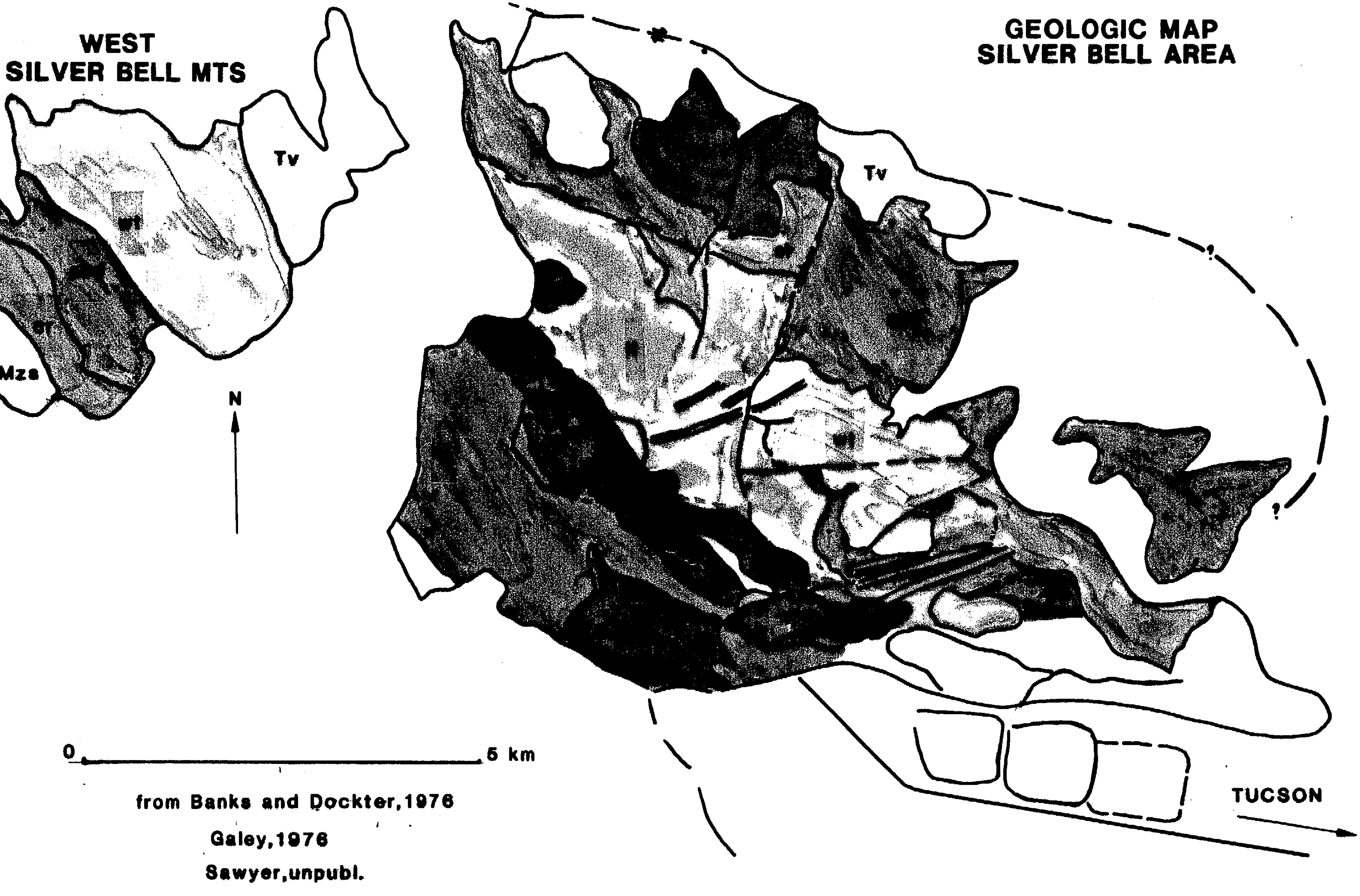
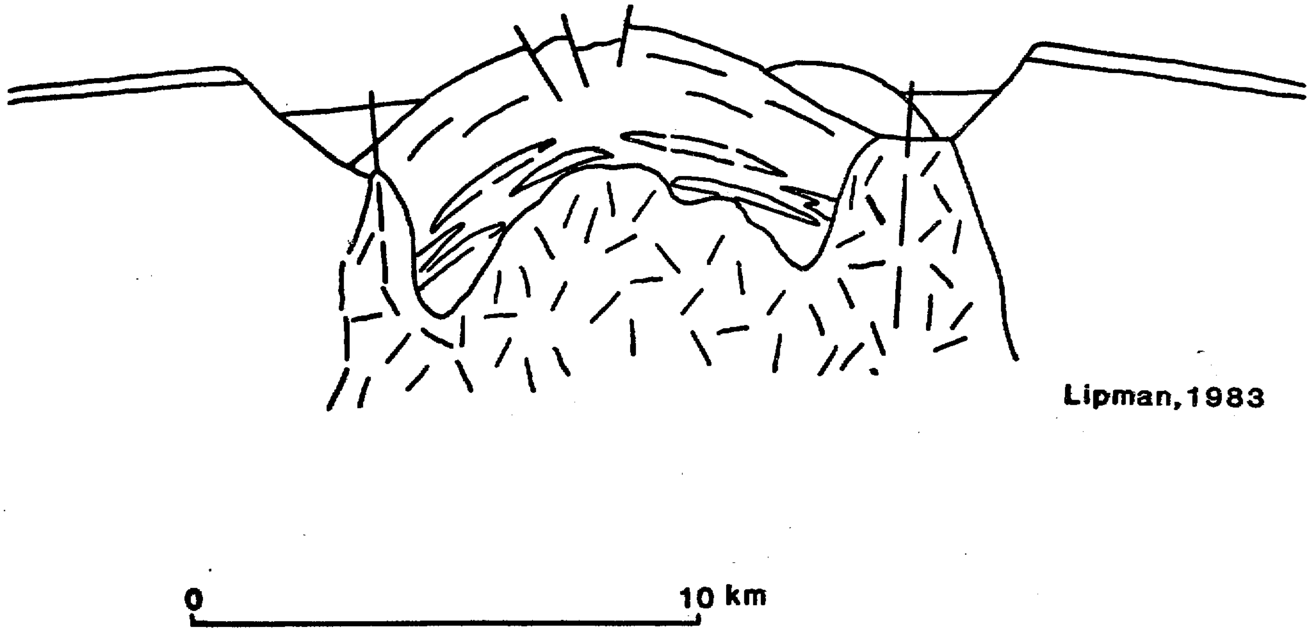


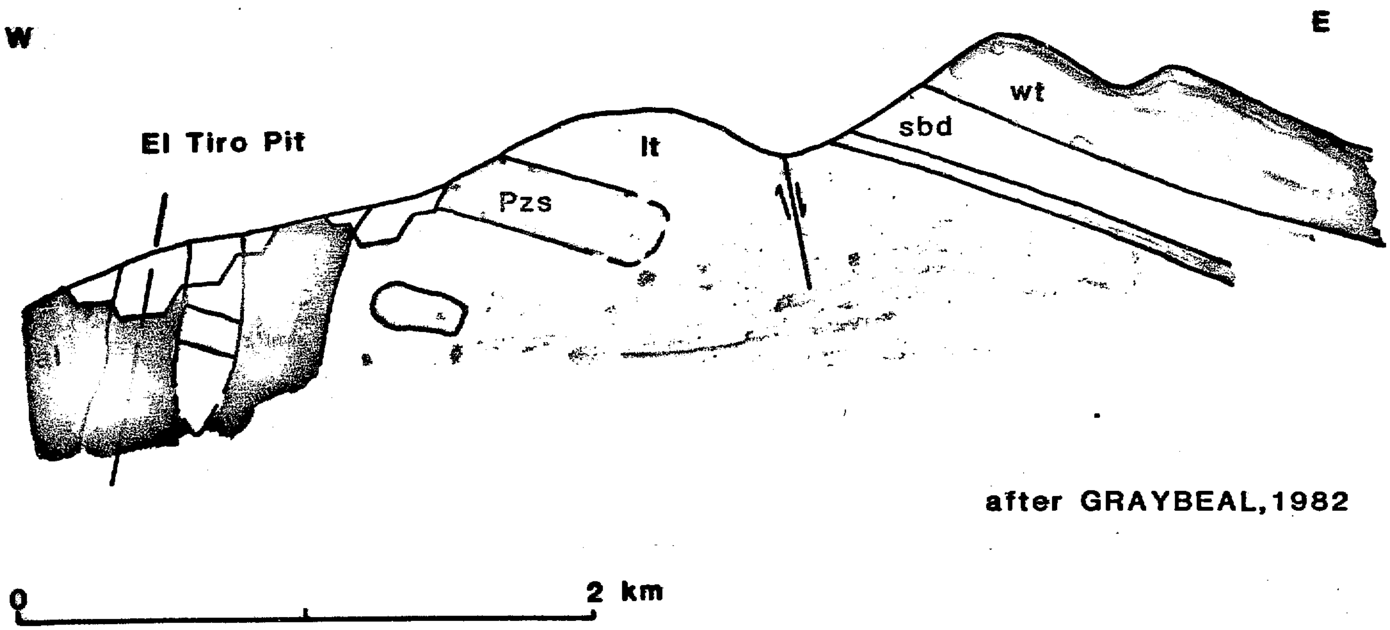
Field Trip May 27, 1984
PIPELINE
Red Hill
Wolcott Peak
Ragged Top
Mesquite Well
Silver Bell Mountains
Silver Bell Peak
Silver Bell
Tailings Pond
Sewage Disposal
Portland Ridge
Wild Hog Mtn
Copper Butte
North Butte
Confidence Peak
Quartzite Peak
Union Hill
Silverbell Butte
Jesuit Hill
Mammoth Incline
El Tiro Pit
Kurtz Shaft
Daisy Shaft
Silver Bell Cem.
Waterman Mts
Waterman Peak
Silver Hill Mine
Indiana-Arizona Mine
AVRA VALLEY
House
Kont Kont Hill
Tin House Well
PRIVATE ROAD
JEEP
TRAIL


GEOLOGIC MAP
SILVER BELL AREA
WEST
SILVER BELL MTS
Tv
Tv
Mzs
N
0
5 km
TUCSON
from Banks and Dockter, 1976
Galey, 1976
Sawyer, unpubl.



Lipman,1983

GEOLOGIC CROSS-SECTION SILVER BELL



after GRAYBEAL,1982

JDS

ASARCO

Southwestern Exploration Division

June 17, 1992

Dave Skidmore
Tucson Office

Bill Rehrig
Applied Geologic Studies, Inc.
2875 West Oxford, Suite #3
Englewood, CO 80110

Here is Dr. Rehrig's name, company, address, city, state, zip and phone 303/761-5624.

I have called Rehrig's office and they should send a brochure.

Rehrig believes he could do you a great job on interpretation of the structure of the greater Silver Bell area with special interest in the North Silver Bell area. This to help evaluate and guide pit designs, tailings/leach pile substrates, etc. by analysis of the fracture pattern, density, orientation, mineral/gangue content, et al.

Two-Three month program, ±$10K expenditure.

Should you have any thoughts that need answers/suggestions, then Rehrig says to call him and he'd be pleased to chat about the problem/solution.

James D. Sell
James D. Sell

JDS:mek

cc: W.L. Kurtz