The Arizona Geological Society and the University of Arizona

1981 Symposium on

"RELATIONS OF TECTONICS TO ORE DEPOSITS IN THE SOUTHERN CORDILLERA"

AGS/UA Mine Tour and Field Trip data for

TRIP #10

"Silver Bell - North Silver Bell Deposits"

March 21

Leaders: C. Dilbert (ASARCO),
S. Davis (Homestake)

Field Trip Coordinator: Joe Wilkins (GMRC)

ARIZONA GEOLOGICAL SOCIETY
P.O. BOX 40952, UNIVERSITY STATION
TUCSON, ARIZONA 85719

TO: Registrants for AGS field Trip #10, Silver Bell-North Silver Bell Deposits

As field trip chairman for the Arizona Geological Society, I would like to take this opportunity to welcome you to the Southwest and thank you for registering for AGS field trip #10. Your overwhelming interest in this symposium and for the field trips in particular has provided the Society and our profession a unique opportunity to observe, examine, and discuss on a first hand basis the geology of a number of diverse structure-tectonic settings and mineral deposits scattered throughout Arizona and adjoining southwestern New Mexico.

The central theme of the symposium is tectonics and its relationship to ore localization; however, as for specific trip content, this must necessarily remain in the able hands of each respective field trip leader. This particular excursion will take you to the Oxide and El Tiro pits at Silver Bell and the northwest extension of this system at Silver Bell North. It is intended in part to provide registrants with an opportunity to review and appreciate the influence of both regional and local structural elements on controlling the emplacement of Laramide intrusions and localizing multiple centers of Cu-Mo metallization. Details of potassic, phyllic, and propylitic alteration assemblages and metallic mineralization will be considered in terms of regional/local structural controls and wallrock chemistry. The effects of post-mineral Basin and Range rotational tectonics will be characterized and its influence on orebody geometry portrayed.

Our appreciation is extended to ASARCO (Cliff Dilbert), Homestake Mining Co. (Steve Davis), and BS&K Mining Co., for providing our field leaders ample time to prepare and lead this trip as well as granting registrants permission to visit their operations and properties. The continual efforts of the trip's logistics coordinator, Joe Wilkins of Gulf Mineral Resources Co., and the assistance offered by Bill Payne and Nora Colburn of Noranda in helping bring the excellent handout materials included herein, are similarly appreciated.

Again, welcome to the American Southwest, happy rock knockin', and here's hoping that each of you will take the time to contribute to the trip's success by participating in timely and stimulating discussions of the rocks at hand on their terms.

Sincerely,

Tom L. Heidrick

Tom L. Heidrick
AGS Field Trip Chairman

TLH/gr

ITINERARY

10. SILVER BELL-NORTH SILVER BELL DEPOSITS

General Leader:	Cliff Dilbert (792-3010)
Coordinator:	Joe Wilkins (882-4030)

March 20, 1981

7:30PM	Orientation, overview, and discussion session for field trip, U of A campus Economics Bldg., Room 111 (see map below)

March 21, 1981

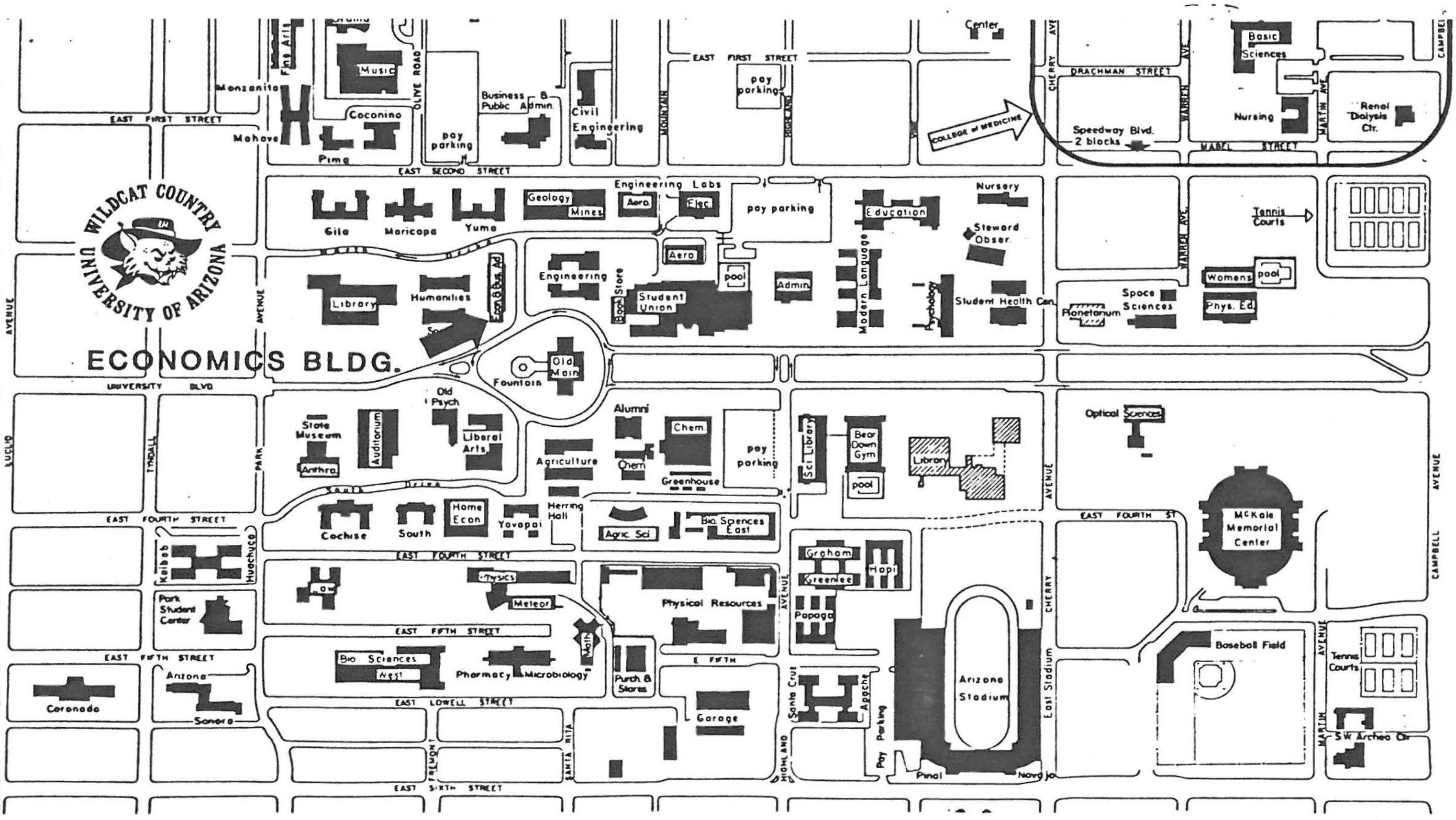
6:30AM	Board busses from U of A
6:30-7:30AM	Travel to Silver Bell
7:30-10:30AM	Tour pits
10:30-11:30AM	Busses to North Silver Bell
11:30-12:00Noon	Lunch
12:00-4:00PM	Tour North Silver Bell
4:00-5:30PM	Return to U of A, Tucson

Support vehicle - Bill Payne and Nora Colburn (Noranda)

ASARCO has 20 hard-hats

AGS needs <u>63 hats</u> (coming from Mission Mine)

Field boots required (no sandals, tennis shoes, etc.)



Campus map of the University of Arizona showing the location of the Economics Building where the pre-field trip overview talks will be presented.

MINE TOUR NOTICE

PLEASE NOTE

When visiting the mines and their environs, remember, ABOVE ALL, SAFETY FIRST!

-Wear your hard hat and safety glasses at all times within designated areas.

-Wear steel-toed or protective boots.

-Stay on or near the toes of benches - don't climb up bench faces.

-Watch out for loose rock, bad footing, bench edges, production vehicles.

-Stay in designated stop areas in the pits - don't go off on your own without an okay.

-Obey all signs, your trip guides, and - common sense!

-Please 'go easy' on outcrops that are destructible - there are lots of collectable materials in the toes.

-Alcoholic beverages are strictly prohibited within pit limits, and therefore from our buses.

-Be wary of bench rims - it's a long fall, so stay back several feet.

GEOLOGIC ROAD LOG--TUCSON-SILVERBELL

Vehicles enter Interstate 10 northbound, Tucson Mountains on left (W), Santa Catalina Mountains at 1:00 o'clock (NE). The Freeway continues N over an intermontane valley with as much as 3 Km of post-Paleocene gravels below.

Drive N successively past Grant, Orange Grove, and Ina Exits past Wasson Peak on your left. At Cortaro Road overpass (about 10 minutes), Safford Peak (3576') is at 10:00, the Old Yuma Mine south of Contzen Pass at about 8:00. Most of this northern end of the Tucson Mountains is composed of mid-Tertiary (26 my) andesites and dacites in a long narrow ridge (purple on the PCGM) which obstructs our westward journey. Safford Peak is Safford Dacite, a young unit. The Santa Catalinas at 4:00 are a gneiss dome composed of Precambrian age metasediments 'reset' at their upheaval date of 26 my. It will be best perceived in the afternoon light when we return. The San Manuel-Kalamazoo PCD at the town of San Manuel is at 3:00 behind the gneiss-Apache Group ridge. At 1:00-2:00 are the Tortolita Mountains, mainly Precambrian but shown by G. H. Davis and coworkers to be a complex metamorphic core complex. (As the N end of the Tucsons is approached, their foothills are spiked with saguaro cactus, palo verde is in the median strip, and mesquite is on the right shoulder.)

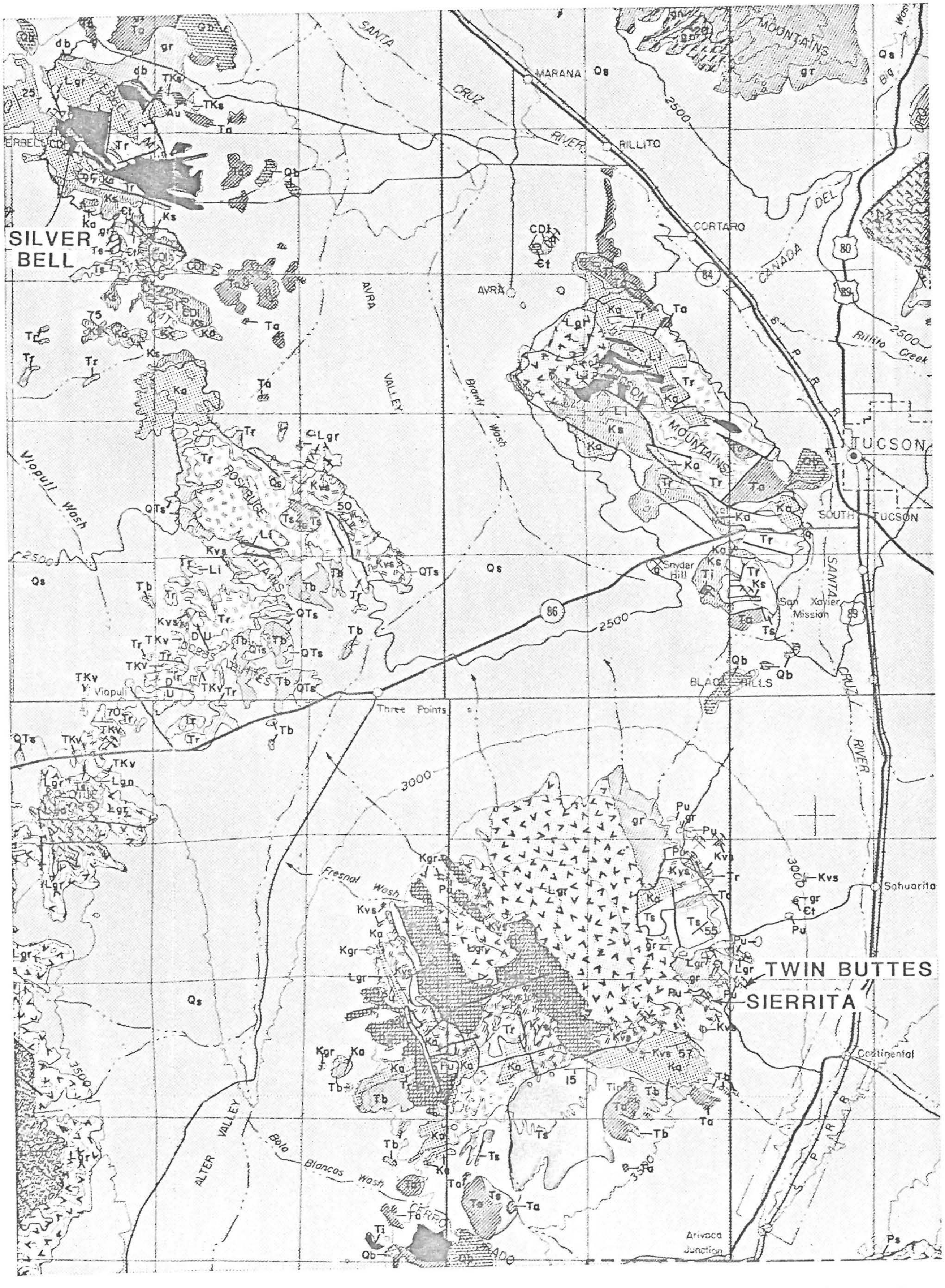
Exit I-10 at Rillito following Silverbell signs, duck under freeway, cross Santa Cruz River, and (1 mile) pass Arizona Portland Cement plant. Cement rock is quarried 5 miles away at Twin Peaks, carried by conveyor belt to the coal, gas, or diesel-powered kilns. Plant serves all of southern Arizona, is in fact a gold mine.

2.5 miles later (on higher ground), you can see the Tucsons (9:00), the cement quarry hills (Twin Peaks, fraternal, not identical-the quarry is in shaley Devonian Martin and Mississippian Escabrosa limestone, the other Cambrian Bolsa quartzite) at 10:00, the Coyotes and Quinlans at 10:30 in the distance with Kitt Peak (the NASA-AURA observatory) and Baboquivari Peak (both LGr) prominent, the Roskruge Mountain Laramide and Tertiary volcanics low to the Pass south of the El Paso Natural Gas pump plant, the Cretaceous and Paleozoic Watermans at 11:00, and the Silver Bells, dominated by Silver Bell Peak and Mt. Lord, at 12:00. Ragged Top, a Miocene ignimbrite plug to be part of the North Silver Bell skyline, is at 12:30, out of the Silver Bell cluster. Picacho Peak, another young volcanic neck, is at 2:00, and the Precambrian Picacho Mountains are to their east.

We traverse square miles of fields of vegetables and cotton (famous PIMA long staple cotton--your shirt may be made of it!). Portland Ridge and the Silver Bell tailings loom ahead.

At Anway Road (12 miles and 15 minutes from I-10), we begin to climb the long gradual pediment surface to Silver Bell. The thick gravels of the down-faulted basin (see Avra Valley basin, profile B-B^1 on the 1" = 50 mile foldout map, ABGMT) are behind; from here to Silver Bell, veneers of gravel conceal __ porphyry copper deposits (?!). At 10:00 to 12:00, the Watermans, the Roskruges to the left in middle distance. Volcanics are S of pump station, Paleozoic and Cretaceous sediments N of conspicuous saddle. The gray-brown cliffs are Escabrosa limestone. Tailings are on the right.

After the bend, waste dumps on the left, the mill and Portland Ridge at right center, and Silver Bell Peak beyond. Stop at ASARCO offices having passed townsite on left.



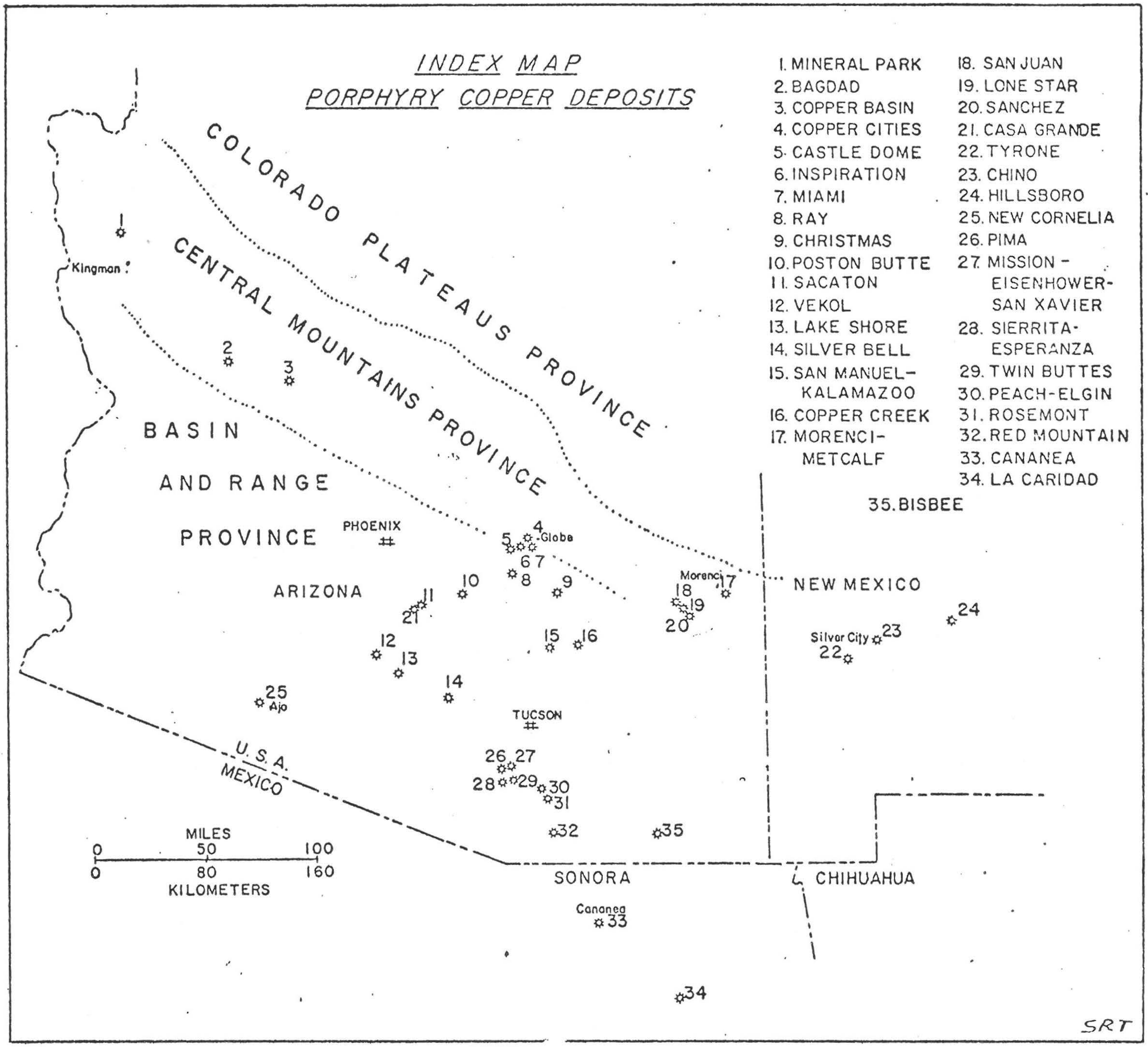
Regional geologic map of central Pima County, Arizona, showing locations of Silver Bell, Twin Buttes, and Sierrita mines (from: Wilson, E.D., Moore, R.T., and O'Haire, R.T., 1960).

AGS/UA ORE DEPOSITS-TECTONIC SYMPOSIUM

Field Trip 10. Silver Bell/North Silver Bell

INTRODUCTION .

In excess of 35 named occurrences of porphyry copper mineralization occur in southeastern Arizona and adjoining regions. (Index Map, next page) These deposits, which are characterized, generally, by porphyry intrusion-centered, fracture-localized, zoned copper-molybdenum mineralization, occur in a variety of geologic settings within this restricted part of North America. These varied geologic settings have resulted in broad differences, in detail, of the style of evolution of the porphyry systems and, consequently, the manifestation of mineralization and alteration effects. Because we cannot, during the short period of a field conference observe and study all of the permutations of influence of variations in host rock, structure, alteration, mineralization, and supergene effects, we have selected two deposits in the vicnity of Tucson which reveal many extremes in the expression of these phenomena. These deposits, Sierrita-Esperanza and Silver Bell, (see area geologic map, following Page 7) reflect major differences in both their detailed and areal geology, in many respects which range from regional geometrical patterns, to different host rock and porphyry progenitor characteristics and finally, to striking differences in the habits of observed intrusion and hydrothermal effects.



INDEX MAP
PORPHYRY COPPER DEPOSITS

1. MINERAL PARK
2. BAGDAD
3. COPPER BASIN
4. COPPER CITIES
5. CASTLE DOME
6. INSPIRATION
7. MIAMI
8. RAY
9. CHRISTMAS
10. POSTON BUTTE
11. SACATON
12. VEKOL
13. LAKE SHORE
14. SILVER BELL
15. SAN MANUEL-KALAMAZOO
16. COPPER CREEK
17. MORENCI-METCALF
18. SAN JUAN
19. LONE STAR
20. SANCHEZ
21. CASA GRANDE
22. TYRONE
23. CHINO
24. HILLSBORO
25. NEW CORNELIA
26. PIMA
27. MISSION - EISENHOWER- SAN XAVIER
28. SIERRITA- ESPERANZA
29. TWIN BUTTES
30. PEACH-ELGIN
31. ROSEMONT
32. RED MOUNTAIN
33. CANANEA
34. LA CARIDAD
35. BISBEE

Objectives

A basic objective of the conference is to provide the opportunity to examine the megascopic physical characteristics of the hypogene mineralization and alteration as they are revealed in these two deposits. A secondary objective is that of comparing broader aspects of geology of the two deposits in order that these details may be more fully and meaningfully understood and appreciated. From consideration of the comparisons of broad and detailed geology, a final objective will be that of examining manifestations of mineralogy and alteration and interpreting those features at the surface and in the zone of supergene effects.

SIERRITA - ESPERANZA AND SILVER BELL COMPARED

Both deposits reflect the results of mineralization related to multiple centers of porphyry intrusion. However, wall rocks to the intrusions differ in composition in the two deposits and the geometry of ore occurrence and alteration show similar disparity in style. These and other features are briefly discussed below.

Geometry

Sierrita-Esperanza consists of two, closely adjacent centers of mineralization about 0.3 km apart. The hydrothermal activity at each center has apparently produced overlapping of at least some features of hydrothermal origin. Silver Bell consists of multiple centers of mineralization which, by contrast, are separated by a distance of over 3.5 km along a northwest-trending axis.

Rock Types

Both deposits have hypogene copper mineralization centered on quartz monzonite porphyries. At Silver Bell, hosts to the porphyries which also carry copper mineralization, include dacite porphyry, alaskite, and sedimentary rocks of the Paleozoic section. At Sierrita-Esperanza, host rocks include a biotite-rich quartz diorite and a much older Jurassic body of mafic-rich quartz monzonite. In the Esperanza orebody, some mineralization is also hosted by volcanic rocks. Each rock type in each setting reveals its own characteristic type of mineralization and alteration.

Alteration Styles

Igneous mineralogies of the host rocks at Sierrita-Esperanza are apparently reflected in the alterationmineral assemblages. Pervasive, selectively pervasive, and vein-veinlet alteration mineral assemblages are those of igneous rocks. Potassium silicate or iron-magnesium-silicate minerals, together with zeolites, anhydrite, and minor carbonate veining present there, are characteristic of centrally-restricted parts of "potassically-altered" parts of other porphyry systems where igneous rocks of intermediate or more felsic compositions predominate. Although widely distributed, quartz-sericite alteration products on veins are subordinate to other types of alteration assemblages. The presence of relatively magnesium-rich diorite and granodiorite among the host rocks has apparently been responsible for development within the zone of potassic alteration, chlorite and epidote, the characteristic minerals of propylitic assemblages, as major alteration products. Except for parts of the Esperanza orebody where sulfide content was apparently high, the metal assemblage at Sierrita-Esperanza is low total sulfide (2-3% volume) and the cpy-py ratio is relatively high. The body lacks the significant quartz-sericite alteration overprinting observed at Silver Bell.

The diverse mineralogies of host rocks at Silver Bell have given rise to magnesium and calc-silicate alteraion types in carbonate-bearing rocks of the Paleozoic, and the variation in this mineralogy reflects these variations in host rock composition. In addition to the "typical" potassium silicate and propylitic alteration of the quartz monzonite porphyry, dacite porphyry, and the alaskite, much of Silver Bell reflects profound and widespread development of quartz-sericite alteration in the igneous rocks. This late stage of alteration, masks much of the earlier potassic and propylitic types. The copper is part of a higher (than Sierrita) total sulfide assemblage - probably 4-6% volume, which results chiefly from addition of pyrite by the result of late stage development of quartz-sericite alteration.

Supergene Effects

Silver Bell is characterized by widespread development of secondary sulfide enrichment especially where the quartz monzonite, dacite porphyry or alaskite, altered to quartz-sericite, were present. Except for a small but important tonnage of secondary enrichment ore which was mined initially at Esperanza, the Sierrita-Esperanza ore bodies are especially noteworthy because of the absence of secondary sulfides. Hypogene chalcopyrite was present in some rock types at Sierrita at the grass roots. Although there may be many additional reasons for this difference, the presence or absence of abundant pyrite and fracture permeability is seen as one potentially important reason for this difference.

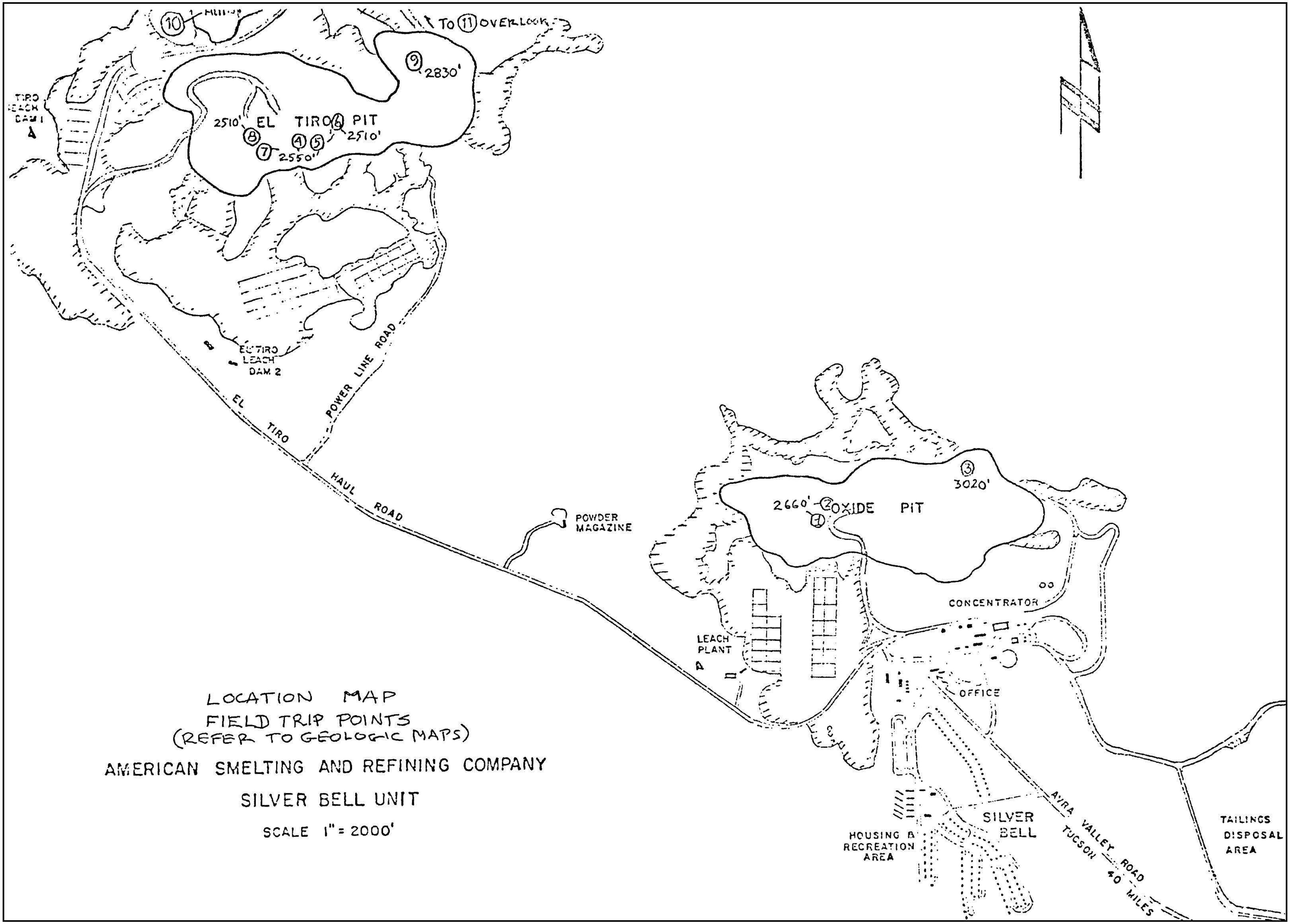
The different styles of alteration result in different manifestations of mineralization at the surface. Silver Bell has been enriched through several cycles of oxidation and leaching. The result is a capping developed in rocks originally strongly modified by hypogene alteration that, from place to place, shows the residual products from destruction of old chalcocite blankets. The result is a comparatively spectacular surface with hues from hematitic goethitic and jarositic limonites. Jarosite is exposed on some higher benches. Where sulfide contents are lower and the rocks have not been strongly modified by hypogene processes, capping is less spectacular and at Sierrita, is characterized more by goethitic or goethitic-jarositic oxidation products, strongly localized in and near the veins from which they have been derived. Much of the North Silver Bell capping reflects low hypogene inheritance, although better zones of hematitic limonites will be pointed out.

ANNOTATED EXPLANATION FOR REGIONAL GEOLOGIC MAP

(From: Geologic Map of Pima and Santa Cruz Counties, Arizona: Ariz. Bur. Mines; E. D. Wilson, R. T. Moore, and R. T. O'Haire, 1960)

Grid Scale is 6 miles (9.6 km)

Qs	Quaternary sediments - basic fill cover	
Qb	Quaternary Basalt -	At least some exposures of this unit may be mid-Tertiary in age - from results of post-mapping radiometric age dating.
Ti Lgr	Tertiary Intrusions -	mapped in the Silver Bell Mountains and the Sierrita Mountains. Mostly Laramide in age. See separate summaries for respective ages.
Tr Ta	Tertiary andesite - rhyolite	most exposures shown are known or inferred to be Upper Cretaceous-Laramide and pre-ore. In the Roskruge Mountains, some ages of about 100my have been measured.
Ks	Lower Cretaceous - strata	mostly arkoses and sandstones of Amole affinity (Tucson Mountains) or Angelica Arkose (Sierrita Mountains)
Kvs	Cretaceous volcanics - and sedimentary rocks	mostly mapped in the Roskruge Mountains and includes Mesozoic volcanics of possibly older age.
Pu	Paleozoic undivided -	carbonate and clastic sedimentary rocks.
Ps	Permian sedimentary rocks undivided	Includes the Rain Valley Formation and the Naco Group
CDi	Carboniferous and Devonian rocks undivided	Includes the Escabrosa Limestone and Martin Formations
Ct	Cambrian strata	Includes here the Abrigo Limestone and Bolsa Quartzite.
gr	Precambrian granite	On this map, mostly in the Sierrita Mountains.



LOCATION MAP
FIELD TRIP POINTS
(REFER TO GEOLOGIC MAPS)

AMERICAN SMELTING AND REFINING COMPANY

SILVER BELL UNIT

SCALE 1" = 2000'

◇ ◇ ◇ STRUCTURE AND MINERALIZATION AT SILVER BELL, ARIZONA

BY KENYON RICHARD AND JAMES H. COURTRIGHT

INTRODUCTION

This material was originally published (12) in November 1954. Exploration and mining during subsequent years have provided additional information; accordingly, a number of revisions of text and figures are included herein. Basic concepts, however, remain essentially the same as originally presented.

Watson (oral communication, 1962) has prepared a doctoral dissertation based on detailed mapping in the Silver Bell Mountains. Mauger et al. (9) are making potassium-argon age determinations of most of the igneous rocks in the district. These two lines of research should, among other things, materially improve upon the knowledge of certain age relations that are noted only briefly herein.

Silver Bell is 35 airline miles northwest of Tucson, Arizona, in a small rugged range rising above the extensive alluvial plains of this desert region. Its geographical relation to other porphyry copper deposits of the Southwest is shown on the inset map in the lower left corner of figure 1. The climate is semiarid. Altitudes range from 2,000 to 4,000 feet.

Opening of the Boot mine, later known as the Mammoth, in 1865, was the first event of note in the district's history. Oxidized copper ores containing minor silver-lead values were mined from replacement deposits in garnetized limestone and treated in local smelters. Copper production had approached 45 million pounds by 1909 when the disseminated copper possibilities in igneous rocks were recognized. Extensive churn-drill exploration was carried out during the next 3 years and resulted in the partial delineation of two copper sulfide deposits—the Oxide and El Tiro. Although the then submarginal tenor discouraged exploitation of these disseminated deposits, selective mining of ore bodies in the sedimentary rocks continued intermittently until 1930, providing a production total of about 100 million pounds of copper.

The American Smelting and Refining Co. began exploratory and check drilling in 1948 and subsequently made plans for mining and milling the Oxide and El Tiro ore bodies at the rate of 7,500 tons per day. Production began in 1954 and has been maintained at a rate of about 18,000 tons of copper annually.

GENERAL GEOLOGY

Formations ranging in age from Precambrian to Recent are exposed near Silver Bell. The more erosion-resistant of these—Paleozoic limestone and Tertiary(?) volcanics—predominate in the scattered peaks and ridges comprising the Silver Bell Mountains. Porphyry copper mineralization occurs along the southwest flank of these mountains in hydrothermally altered igneous rocks. These are principally intrusives which cut Tertiary(?), Cretaceous, and older sediments and are considered to be components of the Laramide Revolution.

For three-fourths of its length, the zone of alteration strikes west-northwest (fig. 1). There now is no single structure that accounts for this alignment. However, indirect evidence suggests that a fault representing a line of profound structural weakness existed in this position prior to the advent of Laramide intrusive activity. This line will hereafter be referred to as the "major structure." It 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 influence of fault structures on the shapes of intrusives in other porphyry copper districts has been noted by Butler and Wilson (2).

As shown on the inset map on figure 2, a fault of parallel trend and considerable displacement lies to the north. This fault is now marked by a line of small intrusive bodies. To the south is a third fault of large displacement. Evidence of its age in relation to the Laramide intrusions and mineralization is not recognized, but its conformance in strike with the other two major faults is significant. These three breaks establish a pronounced trend of regional faulting, and it has been suggested (11) that they be named, from south to north, the Waterman thrust, the Silver Bell fault zone, and the Ragged Mountains fault. The two northerly ones are high angle, and the southerly one may be

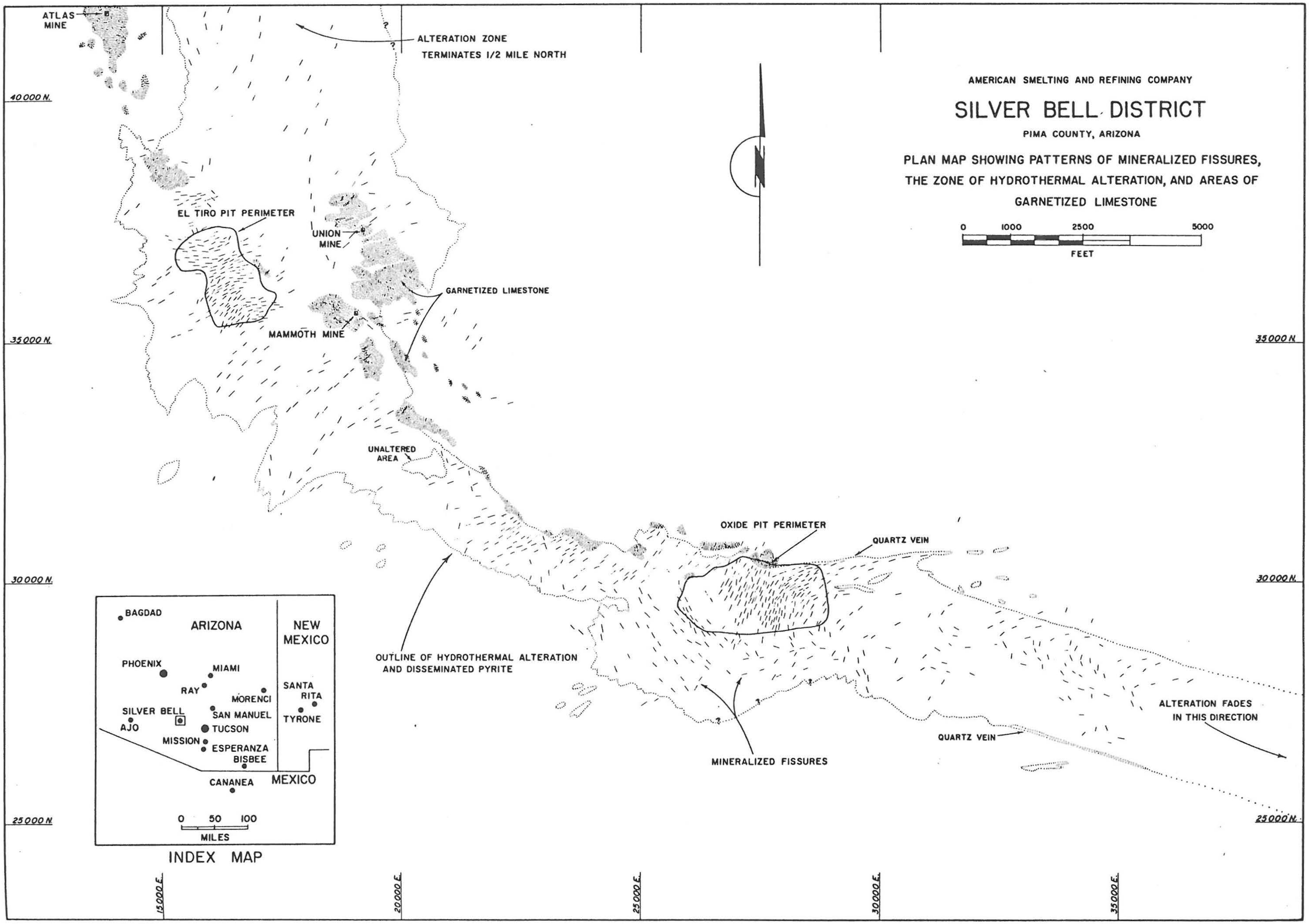

AMERICAN SMELTING AND REFINING COMPANY
SILVER BELL DISTRICT
PIMA COUNTY, ARIZONA
PLAN MAP SHOWING PATTERNS OF MINERALIZED FISSURES, THE ZONE OF HYDROTHERMAL ALTERATION, AND AREAS OF GARNETIZED LIMESTONE
0
1000
2500
5000
FEET
ATLAS MINE
ALTERATION ZONE TERMINATES 1/2 MILE NORTH
EL TIRO PIT PERIMETER
UNION 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
40000 N.
35000 N.
30000 N.
25000 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
SAN MANUEL
TYRONE
AJO
TUCSON
MISSION
ESPERANZA
BISBEE
CANANEA
MEXICO
0
50
100
MILES
INDEX MAP

FIGURE 1.

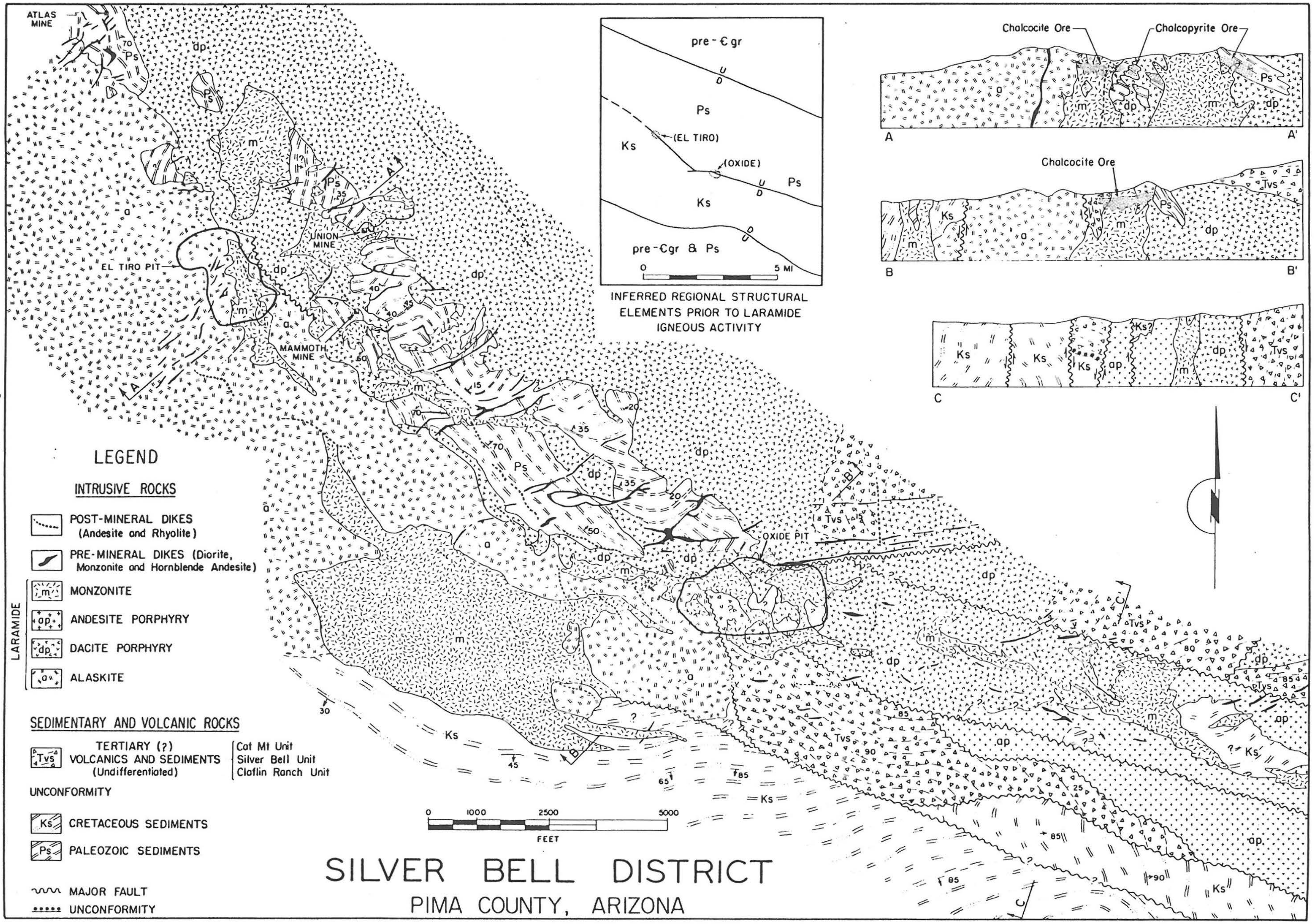

SILVER BELL DISTRICT
PIMA COUNTY, ARIZONA
LEGEND
INTRUSIVE ROCKS
POST-MINERAL DIKES (Andesite and Rhyolite)
PRE-MINERAL DIKES (Diorite, Monzonite and Hornblende Andesite)
LARAMIDE
m MONZONITE
ap ANDESITE PORPHYRY
dp DACITE PORPHYRY
a ALASKITE
SEDIMENTARY AND VOLCANIC ROCKS
Tvs TERTIARY (?) VOLCANICS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

FIGURE 2.

reverse. Stratigraphic separations on these faults are on the order of several thousand feet.

The local Paleozoic section is 4,400 feet thick (10). It is composed predominantly of limestone with a basal quartzite member. The Cretaceous section appears to be more than 5,000 feet thick, but this figure is not a result of careful measurement. Conglomerate, red shale, and arkosic sandstone characterize the lithology. Volcanic and sedimentary rocks of early Tertiary(?) age aggregate more than 2,000 feet in thickness. Three units are recognized by the writers (14): (a) the Claflin Ranch (earliest)—conglomerate and coarse sandstone made up largely of igneous fragments and containing a few pyroclastic interbeds; (b) the Silver Bell—andesite porphyry breccia, principally of mudflow origin; and (c) the Cat Mountain[1]—pyroclastics, composed mainly of ashflows (oral communication, Watson, 1962).

Intrusion of alaskite marked the beginning of Laramide igneous activity. It was emplaced as an elongate stock with its northeast side closely conforming to the major structural line for a distance of nearly 4 miles. The alaskite was at one time regarded as a thrust block of Precambrian rock (6); however, clear evidence of its intrusive relation with Paleozoic limestone and Cretaceous(?) arkose has since been found.

The intrusive activity was at this stage interrupted by an interval of erosion, resulting in partial exposure of the alaskite stock, followed by deposition of the Claflin Ranch, Silver Bell, and Cat Mountain units. (These three units are grouped as Tertiary(?) volcanic and sedimentary rocks on figure 2 herein, and were termed "dacite agglomerate" on figure 2 (12) by Richard and Courtright.) A similar sequence has been recognized by the writers elsewhere in the Southwest (14).

The next event was the intrusion of a large stock or sill of dacite porphyry about 3 miles in width and at least 6 miles in length in a northwesterly direction. Its main mass is outside and along the northeast edge of the mineralized zone. Although its southwesterly side consists of irregular stocks, sills, and dikes extending into the mineralized zone, these apophyses of the dacite porphyry are limited in this direction by the major structural line. A number of large pendants of folded and faulted Paleozoic sedimentary rocks occur in the southwest edge of the dacite porphyry. Thus, it is inferred that the original major fault between the Paleozoic and Cretaceous(?) sedimentary rocks became a contact between alaskite and Paleozoic sedimentary rocks and then a contact between dacite porphyry and alaskite.

Andesite porphyry may have been intruded later than the dacite porphyry, but relations are not clear; it may be simply a facies of the latter.

Subsequent parallel faulting along the major structural line sliced the volcanic and Cretaceous (?) rocks into horst and graben structures. These faults are remarkably persistent southeasterly, extending several miles beyond the map. They probably extended through the northwest part of the district, but there is little direct evidence. The formation of these faults indicates at that time a still existent deep-seated zone of weakness along the major structural line.

Monzonite stocks and contemporaneous dikes were then emplaced along and near this line, obliterating parts of the faults described in the foregoing paragraph. The stocks are elongate parallel to the major structural line; but the dikes trend across it, for the most part, with an average east-northeast strike. The dikes are elements of an extensive swarm having a general northeasterly trend and occurring throughout the Silver Bell Mountains.

Systems of close-spaced *parallel* fractures then developed. These systems are distributed along the major structural line and generally strike across it.

Alteration and sulfide mineralization took place next. The deposition of sulfides, particularly chalcopyrite, was controlled in detail by the cross-trending fractures. Although these are distributed along the major structural line as a narrow band, it is notable that throughout much of its length there are now no fault structures to account for the trend of this zone.

Post-sulfide dikes of andesite and rhyolite represent the last intrusive activity in the immediate district. Curiously, most of these andesite dikes are parallel to the major structure, although it would seem that the cross-breaking fractures represented available lines of weakness. This serves to emphasize the major structural line as being a profound deep-seated zone of weakness persisting through a long period of time.

Uplift and erosion of the region exposed the lean primary mineralization to processes of leaching and enrichment, resulting in the accumulation in the district of a thin blanket of chalcocite. Two open-pit ore bodies occur in this blanket.

Remnants of flows of andesite and basalt occur in the flats surrounding the Silver Bell range. In at least one locality to the east these flows are nearly flat and overlie conglomerate, which dips about 25° and contains boulders and fragments eroded from *completely* leached capping of the mineralized zone. Damon et al. (3) have determined an age of 27.9 m.y. for these flows. This is particularly interesting because it indicates that, prior to that date, there existed an environment permitting formation of leached capping and, presumably, a chalcocite zone.

STRUCTURAL CONTROL OF HYPOGENE MINERALIZATION

As in the majority of porphyry copper deposits, the principal primary sulfide minerals at Silver Bell are

---

[1] K-Ar ages of 56 to 70 m.y. have been obtained for various Cat Mountain Rhyolite occurrences by Damon et al. (3). According to Holmes (5), Tertiary time beginning is 70±2 m.y.

pyrite and chalcopyrite. Although occurring as discrete grains, they are more abundant—accompanied by quartz—in systems of veinlets or seams that are usually near vertical in attitude and persistently parallel. Varying in thickness from paper thin to several inches and in spacing from inches to several feet, these thin sulfide sheets occur as groups of various sizes in the narrow northwest-trending zone of hydrothermal alteration. (Due to the small scale, any single line in the pattern of "Mineralized Fissures" on figure 1 diagrammatically represents a large number of parallel veinlets, rather than an individual.) In detail the average individual fissure appears as a thin quartz-sulfide seam encased by a rather uniform band of sericite. The fissures are predominantly oriented in the northeast quadrant; a small proportion strike northwest and a few are random. From a broad viewpoint there are, among these systems or groups, no intersections of consequence. Within a group, changes in strike occur gradually and result in curving trends. As noted earlier, these groups of mineralized fissures are distributed along the major structural line, and it is assumed that they were formed in response to deep-seated uniform stress related to that line.

At least a few hundredths of 1 percent copper is present nearly everywhere in the zone of disseminated sulfides; better values occur where there are veinlets; and the best values occur where the veinlets are close spaced. The two comparatively large groups of these close-spaced structures coincide with the positions of the two ore bodies (fig. 1). However, the actual structural, mineralogical, and lithological distinctions among these and other smaller groups are minor, and the factors that controlled the position and size of these two groups are not clearly evident. A strong east-west fault that terminates in the Oxide area may have influenced the concentration of fracturing there, and at El Tiro the sharp bend in the alteration zone and the group of northeast-striking dikes likewise may indicate a cross-trending line of weakness that localized stresses. Nonetheless, the importance of these structural conditions is not clearly demonstrated, and no good evidence is found to explain the structural cause of the more intense fracturing which localized the two ore bodies in their present positions in preference to other locations along the major structural line.

Outside the zone of alteration the dacite porphyry is finely fractured and jointed in most of its large exposed area. In sharp contrast to the systems of parallel fissures in the alteration zone, these fractures in the dacite porphyry are almost completely of random orientation; parallelisms are rare and traceable for only a few inches or feet. They are pre-mineral in age where they are found in the alteration zone in the westerly and southwesterly parts of the dacite porphyry. It would seem that in physical aspect this formation was exceptionally well prepared to be mineralized—perhaps better than the rocks of the ore-zone proper. The fact that it was mineralized only locally may be accounted for, in part, by the absence of *systematic* fractures. That is, only the systems of parallel fractures were connected with the deep-seated source of mineralization, and the pervasive breaking of the dacite porphyry did not alone qualify it for mineralization.

Excepting the post-mineral andesite dikes, all igneous rocks in the narrow northwest-trending zone shown on figure 1 are hydrothermally altered. Variations in the intensity or in the completeness of the process have been subdivided by Kerr (6) into five stages. His analysis demonstrated, among other things, that the known ore bodies are in the more strongly altered areas. The area outlined by the writers on figure 1 includes all degrees of alteration, but no differentiation is made. It merely represents the areal extent of bleached-appearing igneous rocks showing evidence in the leached outcrops of pre-existing disseminated sulfides—principally pyrite. The transition to relatively fresh rock is quite sharp in many places, particularly along the contact with sedimentary rocks and on the faults in the southeast part. However, along most of the southwest margin the transition is gradational, and the limit is an arbitrary line.

Tactite—composed essentially of garnet, diopside, other lime-silicate minerals, and quartz—is confined to a narrow belt along the southwest margin of the limestone pendants, except near the Mammoth and Union mines where it has replaced the full width of the sedimentary block. There, parts of the tactite contain sufficient disseminated chalcopyrite to be classed as low-grade ore. As in the Mission deposit (13), this mineralized tactite is regarded by the writers as having been formed by the same processes that altered and mineralized the intrusive rocks. Thus, it is a product of hydrothermal metasomatism rather than contact metamorphism caused by the dacite porphyry and the monzonite as proposed by Stewart (15).

SUPERGENE ENRICHMENT

The two ore deposits consist of rudely tabular accumulations of chalcocite from 100 to 200 feet thick. Lying beneath about 100 feet of leached capping, they were formed by twofold to threefold enrichment of the copper contained in the primary mineralization. Typical ore is composed of altered rock and sulfides in a ratio of about 10:1 by weight.

Most of the capping over the ore bodies contains less than one-tenth of 1 percent copper as cuprite or other oxidation products mingled with the limonite. Occasionally, somewhat higher values occur where copper has been precipitated as silicates and carbonates by reactive gangue material present in less altered rock. In the ore bodies where alteration is strong and the gangue is nonreactive, the upper limit of the sulfide zone (or the base of oxidation) appears on open-pit bench faces as a sharply defined highly irregular interface. Only rarely is there a transition zone of mixed sulfide and oxide copper minerals. Some of the irregularities of the base of oxidation are caused by displacement on post-chalcocite faults, but most seem to be due to variations in rock permeability. This is evidenced by the dense siliceous character of a few sulfide remnants occurring well up in the leached zone and by leached indentations of the sulfide zone along many of the fissures.

The present water table at Silver Bell is well below the chalcocite zone, a condition that exists in many of the porphyry copper districts (4). This indicates that the Silver Bell chalcocite zone now is in an environment of oxidation, and it should be undergoing leaching rather than enrichment. This current climatic cycle may have been relatively short and dry and may have caused only minor modifications of the chalcocite blanket.

The base of oxidation conforms in general shape to modern topography, although local relief is more than 200 feet. This rude conformance would seem to require a relatively wet climate with the water table being no more than a few tens of feet below the ground surface as the modern physiography developed.

In the early days at Morenci, Lindgren (7) observed that oxidation and leaching had, in some instances, penetrated along fissures down through the chalcocite into underlying primary sulfides; he also observed that erosion of Chase Creek Canyon had left the principal chalcocite zones stranded high above the canyon bottom, indicating that the chalcocite formed originally about an ancient water table several hundred feet above the present water table. Although erosion at Silver Bell has not penetrated as deeply as at Morenci, its chalcocite zone currently is in a similar unbalanced environment of oxidation with no appreciable enrichment now taking place. Reshaping of the upper surface of chalcocite zones in both districts to conform to the existing ground surface appears, then, to have occurred during formation of the modern topography but at some time prior to the current dry climatic cycle.

LEACHED OUTCROPS

In the formation of many disseminated chalcocite deposits the enrichment process is presumed to have taken place progressively—copper having been repeatedly dissolved, carried downward, and precipitated. It has been well established by Blanchard (1), Locke (8), and others that under these conditions "limonites" of certain colors and textures are left behind in the leached capping as evidence of the preexisting chalcocite. The Silver Bell district provides exceptionally good examples of this phenomenon, but limonites of chalcocite derivation are not confined to the outcrops over the ore bodies. They are widely dispersed through the zone of alteration. Proper interpretation of their significance in respect to ore possibilities has rested mainly on quantitative rather than qualitative appraisal. Mapping of the Silver Bell outcrops on this basis has provided a valuable guide in exploration drilling for the last 15 years. Results have demonstrated that the pattern of relatively strong chalcocite at depth is reflected in the outcrops by the distribution and abundance of diagnostic limonites.

It may be of interest at this point to mention the ancient excavations that are numerous in the outcrops of the mineralized zone at Silver Bell. There is evidence indicating that they are several centuries old. Since there are no precious metals or visible copper in these cuts, it is plausible to assume that the limonite and clay minerals were considered valuable, perhaps for pottery or warpaint. Thus, in the history of leached-outcrop investigations, it seems that some early Arizona Indian tribe deserves at least honorable mention.

Previous work and acknowledgments.—The first scientific study of the district was published in 1912 by Stewart (15). Considerable field and laboratory work has been done in more recent years by several groups and individuals, including the writers, all reporting privately to the American Smelting and Refining Co. Roland Blanchard conducted leached-outcrop studies in part of the area. Harrison Schmitt, H. M. Kingsbury, and L. P. Entwistle mapped structure and mineralization in the central part of the district. P. F. Kerr studied the alteration features and later published a comprehensive paper (6) on the district. Thomas Mitcham mapped structural features in the surrounding area. The writers have drawn considerably on these and other unpublished data, particularly in compilation of the geologic map. The high quality and usefulness of this material is gratefully acknowledged, but unfortunately it is not feasible to give special individual credits. Thanks are due the American Smelting and Refining Co. for permission to publish this paper.

LITERATURE CITED

1. Blanchard, Roland, 1939, Interpretation of leached outcrops: Jour. Chem., Met. and Min. Soc. of S. Africa, May.
2. Butler, B. S., and Wilson, E. D., 1938, Clifton-Morenci district: Arizona Bur. Mines Bull. 145, p. 74.
3. Damon, et al., 1963, Correlation and chronology of ore deposits and volcanic rocks: Univ. Arizona, Ann. Progress Report no. 5.
4. Emmons, W. H., 1917, The enrichment of ore deposits: U.S. Geol. Survey Bull. 625.
5. Holmes, Arthur, 1960, A revised geologic time-scale: Edinburgh Geol. Soc. Trans., v. 17, p. 183–216.

6. Kerr, P. F., 1961, Alteration features at Silver Bell, Arizona: Geol. Soc. America Bull., v. 62, p. 457–480.
7. Lindgren, Waldemar, 1905, The copper deposits of the Clifton-Morenci district: U.S. Geol. Survey Prof. Paper 43, p. 206.
8. Locke, Augustus, 1926, Leached outcrops as guides to copper ore: Baltimore, Williams and Wilkins.
9. Mauger, R. L., Damon, P. E., Gilletti, B. J., 1963, Age of ore deposition within the southwestern copper metallogenetic province in Arizona: Am. Inst. Mining Metall. Petroleum Engineers, Dallas, Texas, February.
10. McClymonds, N. E., 1959, Paleozoic stratigraphy of the Waterman Mountains, Pima County, Arizona: Arizona Geol. Soc., Southern Arizona Guidebook II.
11. Mitcham, T. W., 1955, Discussion of paper, Structure and mineralization at Silver Bell, Arizona: Am. Inst. Mining Metall. Petroleum Engineers, v. 202, p. 300.
12. Richard, Kenyon, and Courtright, J. H., 1954, Structure and mineralization at Silver Bell, Arizona: Mining Eng., November, and Am. Inst. Mining Metall. Petroleum Engineers Trans., v. 199, p. 1095–1099.
13. ——— 1959, Some geologic features of the Mission deposit: Arizona Geol. Soc., Southern Arizona Guidebook II.
14. ——— 1960, Some Cretaceous-Tertiary relationships in southern Arizona and New Mexico: Arizona Geol. Soc. Digest, v. III.
15. Stewart, C. A., 1912, The geology and ore deposits of the Silver Bell mining district, Arizona: Am. Inst. Mining Metall. Petroleum Engineers Bull., v. 65, p. 455–506.

GENERAL GEOLOGY AND HYDROTHERMAL ALTERATION OF THE SILVER BELL PORPHYRY COPPER DEPOSIT

Presented to the

Society of Economic Geologists

Silver Bell Field Conference

April 1979

J. L. Galey

Fluor Mining & Metals, Inc.

GENERAL GEOLOGY AND HYDROTHERMAL ALTERATION OF THE SILVER BELL PORPHYRY COPPER DEPOSIT

INTRODUCTION

The Silver Bell Unit of ASARCO Incorporated is located 32 airline miles northwest of Tucson, Arizona. The porphyry copper deposit is situated on the western flank of the Silver Bell Mountains which protrude out of the surrounding alluvial plains.

Initially, the deposit was mined in 1865 as a silver prospect. More intense mining using underground methods started at the turn of the century and concentrated in skarn mineralization.

Initial stripping by present open-pit methods began in December 1951. The ore is from two open pits: Oxide and El Tiro. As of December 1978, 75,655,000 tons of ore had been mined which contained 0.80 percent copper, 0.07 oz/ton silver, and 0.013 percent molybdenum.

The ore cutoff grade is 0.40 percent copper, and the mill is rated at 11,400 tons per day. In both mined and reserve tonnages, 85 percent of the economic copper is from the chalcocite blanket and 15 percent is from skarn mineralization. Average protore values of the intrusives within the limits of the pits is approximately 0.25 percent copper and is not of economic interest. Thus, most of the ore at Silver Bell is from the supergene blanket.

STRATIGRAPHY

The stratigraphic section in the Silver Bell district is composed of Precambrian through Tertiary age strata.

Precambrian. Exposures of Precambrian rocks are not found in the immediate vicinity of the Silver Bell deposit. However, limited exposures of Precambrian Oracle Granite and Pinal Schist are noted peripheral to the district (Watson, 1968).

Paleozoic. Approximately 2,000 feet of Paleozoic sediments are located in the Silver Bell district. The section consists of Cambrian Bolsa through the Permian Sherrer Formation. The Permian Concha and Rainvalley formations are located to the south and west of Silver Bell. The Paleozoic section consists principally of carbonates and arenaceous carbonates with the exception of two quartzite formations: the Cambrian Bolsa and the Permian Sherrer.

Mesozoic. The lower Mesozoic is composed of arkoses and sandstones equivalent to the Amole Arkose, and it is overlain by a redbed unit called the Village Redbeds (Watson, 1968). Overlying the lower Mesozoic units in an apparent angular unconformity is the Claflin Ranch Formation. It is composed of volcanic flows and tuffs, volcanoclastics, sandstones and conglomerates. This formation is of importance as it marks the beginning of the Laramide volcanic events. Above the Claflin Ranch is the Silver Bell Formation. It consists of dark gray to purple andesite through rhyodacite flows and breccias, nonwelded and welded ash-flow tuffs, and conglomerate. The Silver Bell Formation grades vertically, and, to a less extent, laterally into the Claflin Ranch Formation.

Overlying the Silver Bell Formation is the Mount Lord Volcanics and they represent the last phase of the Laramide extrusives. They are generally quartz latitic in composition and consist of five or more cooling units of welded ash-flow tuffs. These cooling units are interbedded with nonwelded tuffs, water-lain tuffs, flows and clastic sediments. The Laramide intrusives are possibly coeval to post-Mount Lord in age.

Tertiary. The Tertiary units are present as gravels with intermittent basaltic flows. Ages of 19.5 through 22.2 million years were determined for units which represent the bulk of the basaltic flows (Banks and Dockter, 1976). An intrusive quartz latite that is found throughout the district was dated at 25 million years (Mauger and others, 1965).

LARAMIDE INTRUSIVE SEQUENCE

The first Laramide intrusive is the alaskite and its emplacement was apparently controlled by the northwest trending Silver Bell Fault Zone (Figure 1). The fault zone traverses diagonally through the district. Compositionally, the alaskite is a coarsely crystalline monzonite. The biotite has been replaced by sericite and clays in the zone of more intense hydrothermal activity. Thus, the rock was originally named "alaskite" because of the lack of mafics in the zone of alteration. This name has been retained to avoid confusion in the literature.

The second Laramide intrusive is the dacite. Compositionally it is a sub-volcanic quartz latite porphyry. The dacite intruded up along the Silver Bell Fault Zone, and upon encountering the Claflin Ranch Formation pushed toward the northeast. It has been suggested that the dacite is a sill which is floored by Paleozoic sediments and roofed by the Claflin Ranch Formation (Watson, 1964).

The third intrusive phase is that of the monzonite porphyries. They represent a composite intrusive phase which vary texturally and compositionally. One phase of the monzonites was dated at 65.5 million years (Mauger and others, 1965). The earliest intrusion was by an extensive pyroxene-bearing phase called syenodiorite. The later bulk of the intrusions were quartz monzonitic to granodioritic in composition. The intrusion of the monzonites were less controlled by the Silver Bell Fault Zone than the alaskite and dacite. The monzonites occur as stocks inside the more intense zone of alteration and intrude along ENE trending tensional faults which are located to the east of the district. Drilling suggests that the monzonites possibly become more voluminous at depth. This indicates that the stocks at the present erosional level represent fingers from a more massive body at depth.

STRUCTURE

Regional Structures. Regional structural features in the Silver Bell district are exemplified by major WNW trending faults. The Silver Bell Fault Zone, which represents one of these faults, has played a key role in the localization of the Laramide intrusives and possible channeling of the hydrothermal fluids. The fault zone is probably a Precambrian structure with intermittent movement throughout geologic time. No definite major post mineral movement has been identified. One exception is in the El Tiro pit where a linear breccia feature is located. However, the lack of evidence for offset and the anamalous tungsten values may suggest a late or post mineral explosive hydrothermal event.

It has been suggested that the Silver Bell structure continues into the Bisbee mining district (Titley, 1976). The structure has been referred to as the Silver Bell-Bisbee discontinuity.

Thus, the faults appear to be regional features and have their origins in Precambrian time.

ENE Tensional Fractures. The dikes that are prominent to the east of the deposits are oriented in an ENE direction (Figure 1). These dikes represent intrusions into tensional fractures which probably resulted from weak continental compressional forces oriented in an ENE - WSW direction and tensile stress fields localized over crests of NNW-oriented arches (Rehrig and Heidrick, 1976).

Mineralized Veins. Orientation of the mineralized veins, particularly the phyllic veins, have a northeast to ENE direction and a minor NNW set is present. However, in the Oxide Pit the NNW set often becomes more prominent than the NE set.

Tertiary Tectonics. Analysis of the regional stratigraphy, dips of sedimentary units and foliations in the volcanics shows that the entire area has been tilted toward the northeast. From this data it must be concluded that the entire alteration system is tilted approximately 30° to the northeast resulting in a plunge of 60° toward the southwest. The age of tilting is younger than 19 million years and is undoubtedly associated with Basin and Range tectonics.

HYDROTHERMAL ALTERATION AND MINERALIZATION

General Description. The general pattern of hydrothermal alteration and mineralization is a wide propylitic zone with the more intense potassic and phyllic alteration occurring in the Oxide and El Tiro pit areas. The alteration zone is linear and its position is generally centered along the Silver Bell Fault Zone. If the monzonites are the causitive intrusive for the porphyry system, it is suggested that the alteration zonation reflects the position of the more voluminous monzonites at depth. Thus, the position of the alteration phases along the Silver Bell Fault Zone may reflect the position of the monzonite more than an actual channeling of hydrothermal fluids by the fault zone. However, it is recognized that the fault zone could possibly have some influence on the channeling of the hydrothermal fluids.

The alteration assemblages defined at Silver Bell are potassic, propylitic and phyllic. As discussed later in the paper the potassic and propylitic assemblages are coeval and the phyllic phase is paragenetically later than the potassic-propylitic phase.

Each alteration assemblage will be described as a cumulative of all rock types. It is noted that at Silver Bell and other deposits, each rock type will vary in alteration effects within each alteration type. Thus, the chemistry of each rock type is a control on the alteration mineralogy.

Potassic Alteration. Potassic alteration at Silver Bell is defined as the introduction of secondary k-feldspar quartz, biotite, chalcopyrite, pyrite and molybdenite. Secondary k-feldspar occurs as flooding of the groundmass, replacement of plagioclase and in vein assemblages. The secondary biotite is present as a recrystallization of primary biotite, as a dusting throughout the groundmass, as a replacement of hornblende and in vein assemblages. The occurrence of secondary biotite is minor and is more notable with microscopic examination as compared to megascopic identification.

Propylitic Alteration. The propylitic assemblage is defined by the presence of secondary chlorite, epidote and calcite. All three minerals occur as replacement of the groundmass and in vein assemblages. Microscopic examination of the vein chlorites, particularly on the southwest side of the deposit, shows that the chlorite sometimes replaces vein biotite. It is suggested that biotite was deposited originally, and as the hydrothermal system progressed in time and chemistry, chlorite and epidote became the dominant alteration assemblage.

Phyllic Alteration. Phyllic alteration is defined as the vein occurrence of quartz-sericite-pyrite. The quartz and sericite occur as vein selvages around a pyrite core. An abundance of disseminated sericite occurs in the groundmass. However, this occurrence is not included in the phyllic alteration as its origin is questionable. Much of the disseminated sericite is associated with supergene enrichment. It has been suggested that some of the disseminated sericite could be of supergene origin.

Metallic Mineralization. The principal metallic minerals associated with the hydrothermal mineralization are pyrite, chalcopyrite, molybdenite and less amounts of sphalerite, bornite, galena and magnetite. The metallic mineralization is viewed as an integral part of the alteration assemblages.

The assay contour map shows the relative occurrence of chalcopyrite and molybdenite in the protore zone of the intrusives. The general pattern in the El Tiro Pit is a depleted chalcopyrite center that is flanked by higher chalcopyrite to the east and west. The east and west limbs of the high chalcopyrite zone coalesce immediately north of the El Tiro Pit, but opens again in the North Silver Bell area.

The assay contours in the Oxide Pit show an enriched center of chalcopyrite in the east and central portion of the pit. However, at the west end of the pit a greater amount of chalcopyrite occurs on the north and south sides, and the interior of the alteration shows a decrease in chalcopyrite relative to the sides. It is suggested that the east end of Oxide is higher in the porphyry system than the west end. Further evidence for this hypothesis is the knowledge that the deposit is tilted to the northeast. Thus, the erosional level of the system on the west end would be deeper than that on the east.

Two large quartz veins on the north and south sides of the Oxide Pit have apparently channeled the hydrothermal fluids. An elevated copper content paralleling each quartz vein indicates a damming and channeling of the fluids (Figure 3). The silicate alteration assemblage also suggests channeling has occurred. Phyllic alteration is abruptly terminated at the veins. Also, a marked change of potassic alteration on the inside of the veins and propylitic alteration on the outside is noted. This evidence indicates the quartz veins are pre or early mineralization in age.

Molybdenite is erratic in occurrence. The 0.010 percent molybdenite contour is delineated on the assay contour map and greater amounts of molybdenum occur inside the contour. Contour patterns inside the 0.010 percent molybdenum contour could not be established with the available data.

Paragenesis. The paragenesis of the different alteration assemblages was evaluated by cross cutting vein relationships. This was supplemented by microscopic examination. The results of the study revealed that the potassic and propylitic assemblages are coeval and the bulk of the phyllic assemblage is later than the potassic-propylitic phase (Figure 3).

Examination of the potassic paragenesis showed that most of the biotite and chalcopyrite are paragenetically earlier than the molybdenite.

The evidence suggests that the hydrothermal system was continually changing with time. These changes in the chemistry of the hydrothermal fluids appear to be slow. For example, the chalcopyrite deposition overlaps in time with the molybdenite, demonstrating that the chemical change was not abrupt. However, the bulk of the molybdenite alteration phase is later than the bulk of the earlier chalcopyrite phase as evidenced by cross-cutting vein relationships. This same overlap of time of depositional environments is noted with the later phyllic alteration and its partial overlap with the earlier potassic-propylitic phase.

Thus, the data at Silver Bell demonstrates that the depositional environments for the different minerals evolve with time. A distinct boundary between each mineral or alteration phase is nonexistent. The hydrothermal system does not stop and another influx of fluids creates a different alteration phase. The system continually evolves with time.

CONTROLS OF MINERALIZATION

Localization of mineralization at Silver Bell has been partially controlled by regional structure. Also, rock chemistry has apparently controlled the deposition of chalcopyrite.

Structural Controls. The more intense alteration and metallic mineralization occur in the Oxide and El Tiro areas. Analysis of the geologic map shows that to the east and northeast of each pit, the density of the ENE trending dikes increases.

It is suggested that the structural intersection of the ENE fault system and the Silver Bell Fault Zone provided an avenue for intrusion of the monzonites and possible channeling of the hydrothermal fluids.

Controls of Chalcopyrite Deposition. The chalcopyrite mineralization was influenced by the rock chemistry. The chalcopyrite appears to have been controlled by the mafic content of the intrusives. Generally, the higher the mafic content of the intrusives, the higher the chalcopyrite content. This close association of mafic minerals and chalcopyrite may suggest that the chalcopyrite is acquiring some of its iron from the mafics. It is interesting to note that the available data does not show a major increase in iron content in the mineralized rock as compared to the less altered rock.

FLUID INCLUSION DATA

A fluid inclusion study was conducted on vein quartz from the alteration assemblages of the El Tiro Pit. Table 1 depicts the maximum and mean filling temperatures of each alteration assemblage. The results of the data suggest the highest temperatures occurred during early potassic alteration and chalcopyrite deposition. The mean filling temperature for this stage was 360°C. The temperature declined in the later potassic phase and molybdenite deposition as marked by a mean filling temperature of 325°C. The coeval propylitic alteration formed at a lower temperature than the interior potassic assemblage. The temperature of the paragenetically later phyllic assemblage denotes a cooling of the porphyry system with time. Its mean filling temperature was 305°C.

The fluid inclusion study also revealed a late and lower temperature event with a mean temperature of 220°C. It is unknown if this population of inclusions represents the final hydrothermal event or a later heating event not associated with copper mineralization. A vein assemblage of sericite selvages with alunite cores has been identified as cross-cutting phyllic veins. This might represent the last and low temperature stage of the hydrothermal system. Also, a post copper mineralizing assemblage of sphalerite, galena, fluorite, barite and calcite has been identified. Filling temperatures of fluid inclusions for this system are in the low 200°C range.

The temperatures represent filling temperatures which have not been corrected for pressure. Thus, the actual temperatures of formation of each alteration assemblage is slightly higher than those temperatures that are reported.

SUMMARY

In summary, an environment consisting of Precambrian, Paleozoic and Mesozoic rocks was intruded by three Laramide intrusive phases: alaskite, dacite and monzonites. The emplacement of the intrusives was structurally controlled by the Silver Bell Fault Zone. The hydrothermal alteration followed the intrusion of monzonite porphyrites which has been dated at 65.5 million years. The more intense alteration occurred in two areas as exemplified by the location of potassic and phyllic alteration. These two intense centers are surrounded by a broad linear zone of propylitic alteration. The phyllic alteration is paragenetically later than the coeval potassic-propylitic assemblage.

Regional tilting associated with Basin and Range tectonics tilted the deposit 30° toward the northeast. Exposure of the deposit to surficial weathering conditions resulted in the formation of the chalcocite blanket.

TABLE 1

SUMMARY OF FILLING TEMPERATURES

Alteration Phase	Maximum Filling Temp. (°C)	Mean Filling Temp. (°C)
Early Potassic (K-spar, biotite, chalcopyrite)	394	360
Late Potassic (quartz, molybdenite, ± K-spar)	344	325
Propylitic	286	286 (?)
Phyllic	344	305
Late Hydrothermal		220

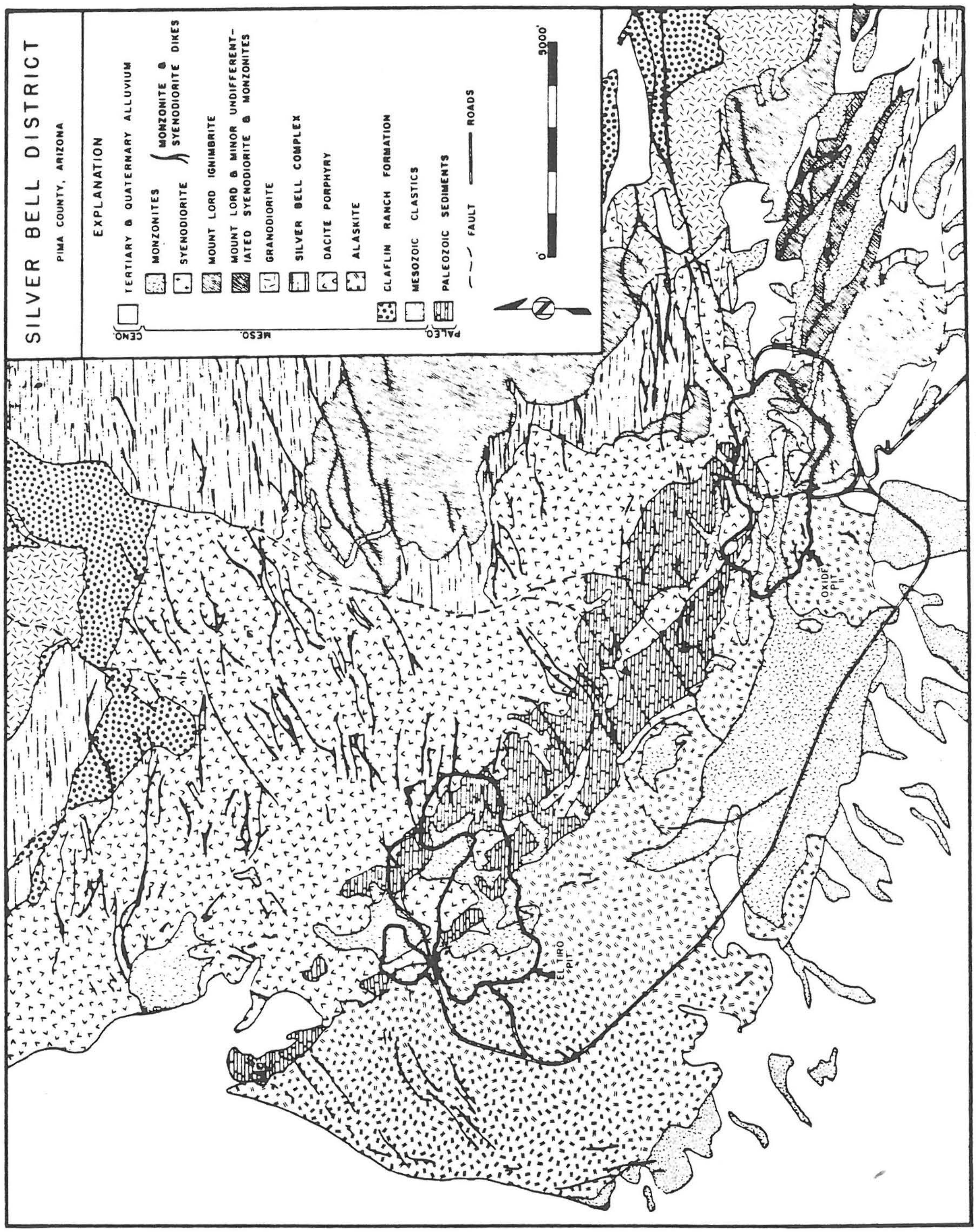
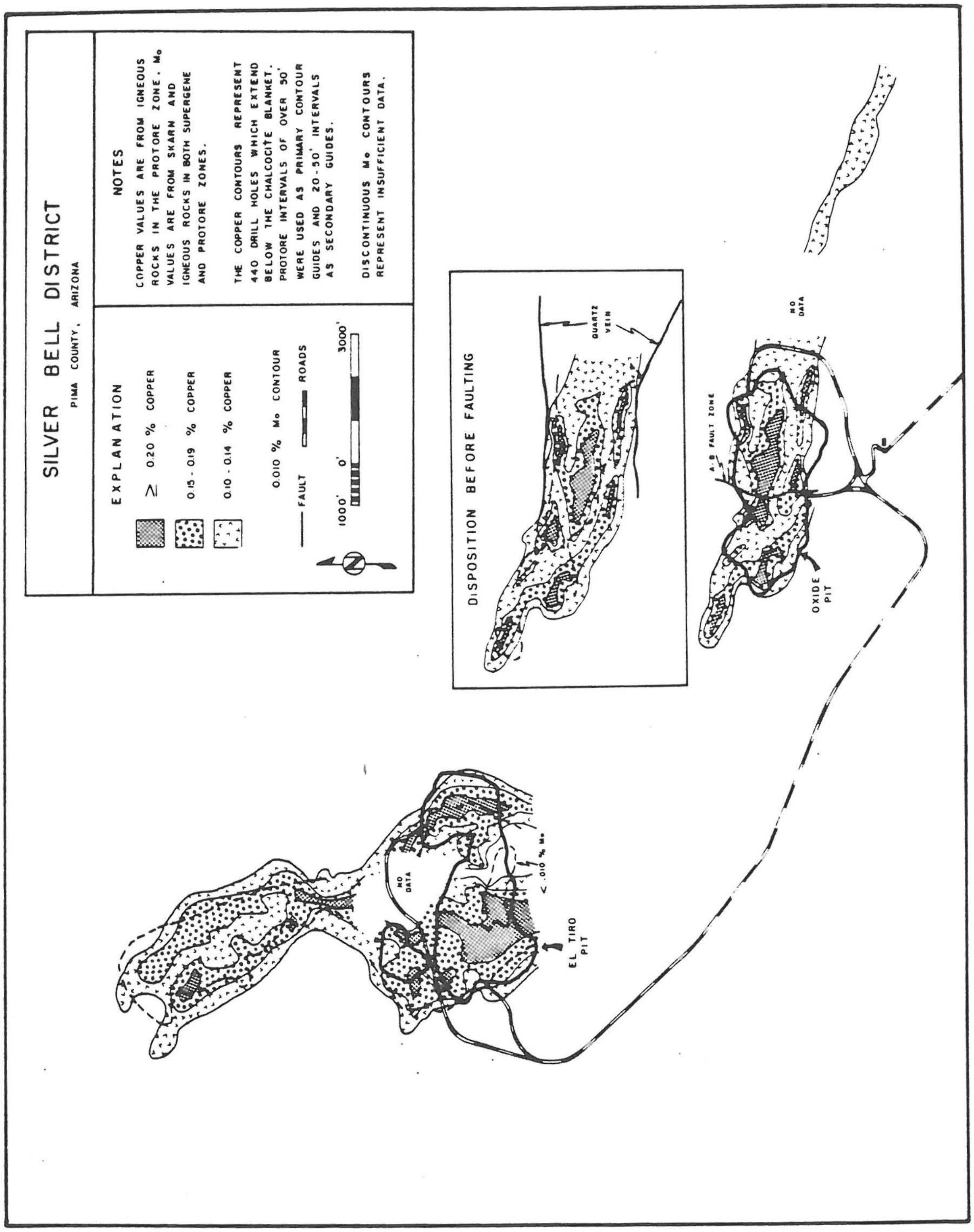

SILVER BELL DISTRICT
PIMA COUNTY, ARIZONA
EXPLANATION
CENO.
TERTIARY & QUATERNARY ALLUVIUM
MESO.
MONZONITES
SYENODIORITE
MONZONITE & SYENODIORITE DIKES
MOUNT LORD IGNIMBRITE
MOUNT LORD & MINOR UNDIFFERENTIATED SYENODIORITE & MONZONITES
GRANODIORITE
SILVER BELL COMPLEX
DACITE PORPHYRY
ALASKITE
CLAFLIN RANCH FORMATION
MESOZOIC CLASTICS
PALEO.
PALEOZOIC SEDIMENTS
FAULT
ROADS
N
0
3000'
EL TIRO PIT
OXIDE PIT

FIGURE 1


SILVER BELL DISTRICT

PIMA COUNTY, ARIZONA

NOTES

COPPER VALUES ARE FROM IGNEOUS ROCKS IN THE PROTORE ZONE. Mo VALUES ARE FROM SKARN AND IGNEOUS ROCKS IN BOTH SUPERGENE AND PROTORE ZONES.

THE COPPER CONTOURS REPRESENT 440 DRILL HOLES WHICH EXTEND BELOW THE CHALCOCITE BLANKET. PROTORE INTERVALS OF OVER 50' WERE USED AS PRIMARY CONTOUR GUIDES AND 20-50' INTERVALS AS SECONDARY GUIDES.

DISCONTINUOUS Mo CONTOURS REPRESENT INSUFFICIENT DATA.

FIGURE 2

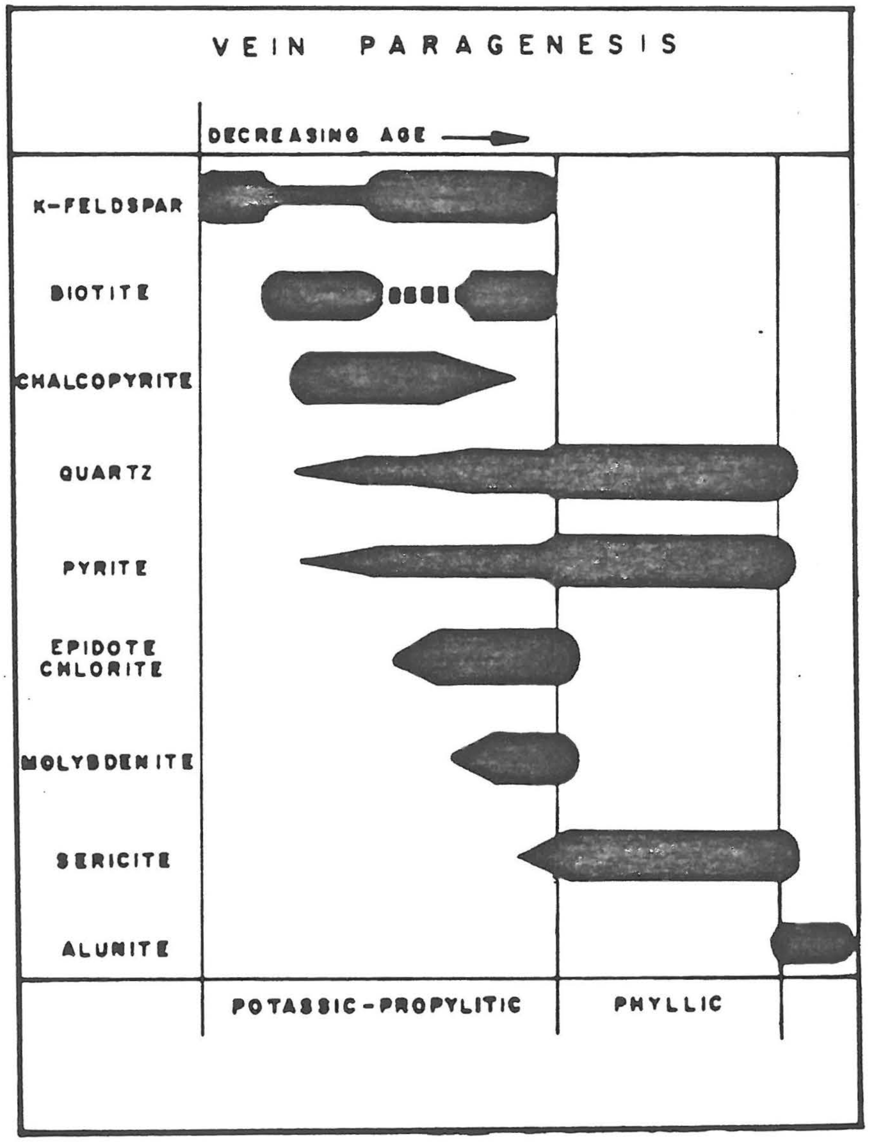

VEIN PARAGENESIS
DECREASING AGE
K-FELDSPAR
BIOTITE
CHALCOPYRITE
QUARTZ
PYRITE
EPIDOTE CHLORITE
MOLYBDENITE
SERICITE
ALUNITE
POTASSIC-PROPYLITIC
PHYLLIC

FIGURE 3

BIBLIOGRAPHY

Agenbroad, Larry D., 1962, The geology of the Atlas Mine area, Pima County, Ariz.: unpublished M.S. Thesis, Univ. of Ariz., Tucson.

Banks, Norman G., and Docktor, Roger D., 1976, Reconnaissance geologic map of the Vaca Hills quadrangle, Arizona: U.S. Geol. Survey Map MF-793.

Banks, N.G., Docktor, R.D., Silberman, M.L., and Naeser, C.W., 1978, Radiometric ages of some Cretaceous and Tertiary volcanics and intrusive rocks in south-central Arizona: Jour. Research U.S. Geol. Survey, v. 6, p. 439-445.

Buseck, Peter R., 1962, Contact metasomatic deposits at Concepcion del Oro, Mexico; Tem Piute, Nevada; and Silver Bell, Arizona: unpublished Ph.D. dissertation, Columbia University, New York.

Clarke, Craig W., 1966, The geology of the El Tiro Hills, West Silver Bell Mountains, Pima County, Arizona: unpublished M.S. Thesis, Univ. of Ariz., Tucson.

Docktor, R.D., 1976, Mount Lord Volcanics, Pima County, Arizona, in Contributions to Stratigraphy, U.S. Geol. Survey Bull. 1435.

Kerr, P.F., 1951, Alteration features at Silver Bell, Arizona: Geol. Soc. Amer. Bull., v. 62, p. 457-480.

Mauger, R.L., 1966, A petrographic and geochemical study of Silver Bell and Pima mining districts, Pima County, Ariz.: unpublished Ph.D. dissertation, Univ. of Ariz., Tucson.

Mauger, R.L., Damon, P.E., and Giletti, B.J., 1965, Isotopic dating of Arizona ore deposits: Am. Inst. Mining, Metall. and Pet. Eng. Trans., v. 232, p. 81-87.

McClymonds, Neal E., 1957, The stratigraphy and structure of the Waterman Mountains, Pima County, Arizona: M.S. Thesis, Univ. of Ariz., Tucson.

_____, 1959, Paleozoic stratigraphy of the Waterman Mountains, Pima County, Ariz.: in Southern Arizona Guidebook II, L.A. Heindl (ed.): Tucson, Ariz., Arizona Geological Society.

Merz, Joy L., 1967, The geology of the Union Hill area, Silver Bell district, Pima County, Ariz.: unpublished M.S. Thesis, Univ. of Ariz., Tucson.

Rehrig, W.A. and Heidrick, T.L., 1976, Regional tectonic stress during the Laramide and late Tertiary intrusive periods, Basin and Range province, Arizona; in Arizona Geological Society Digest, Volume X, Tucson, Arizona, Arizona Geological Society.

Richard, K., ad Courtright, J.H., 1966, Structure and mineralization at Silver Bell, Arizona: in Geology of the Porphyry Copper Deposits, Southwestern North America, S.R. Titley and C.L. Hicks (eds.): Tucson, Ariz., the Univ. of Ariz. Press, p. 157-163.

Shoemaker, A., 1924, Geology of the El Tiro Deposit, Silver Bell, Arizona: unpublished B.S. Thesis, Univ. of Ariz., Tucson.

Stewart, C.A., 1912, The geology and ore deposits of the Silver Bell mining district, Ariz.: Amer. Inst. Mining, Metall. and Pet. Eng. Bull., v. 65, p. 455-560.

Titley, S.R., 1976, Evidence for a Mesozoic Linear Tectonic Pattern in Southeastern Arizona: in Arizona Geological Society Digest, Volume X: Tucson, Arizona, Arizona Geological Society.

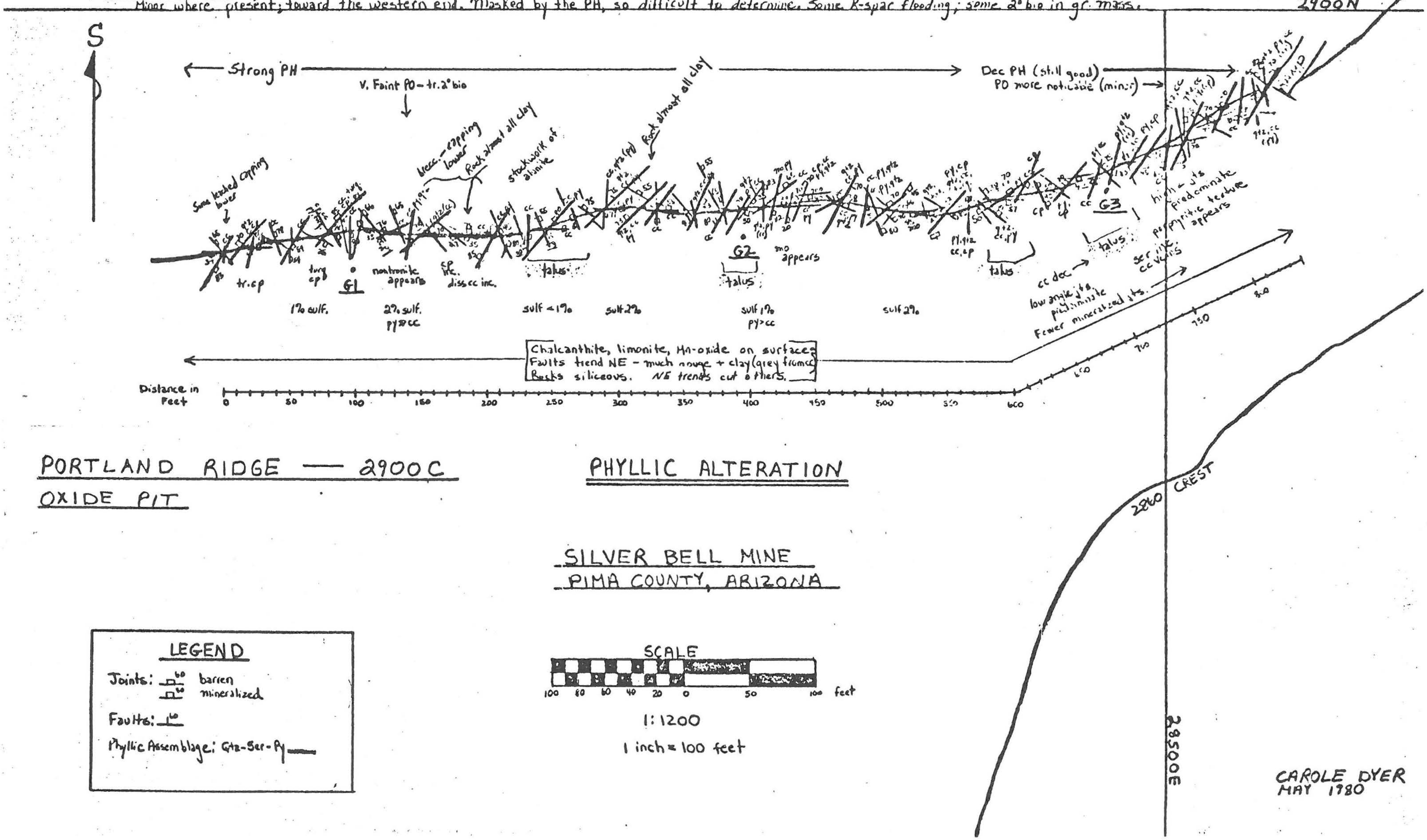
Watson, Barry N., 1964, Structure and petrology of the eastern portion of the Silver Bell Mountains, Pima County, Arizona: unpublished Ph.D. dissertation, Univ. of Ariz., Tucson.

_____, 1968, Updating the geology and ore controls at Silver Bell, Arizona: talk to Mining Geology Div., Ariz. Section A.I.M.E.

Quartz-Monzonite Porphyry (Qmp)
Qtz, plag, K-spar, bio in fresh rock. Here very altered. Nondescript until western end where porphyritic texture is recognizable again. Sulfides are diss. or commonly as coatings along fractures. Total sulfides 1-3%. Chalcocite due to 2° enrichment—most along NE jts. Py most common. Trace amounts of chalcopyrite and molybdenite also present. Overall Cu-content low.

Phyllic Alteration (PH) (Argillic Alteration incl. here)
Strong. Decreases in the western end. Rock is extremely altered – clay and sericite very abundant. Throughout the section veinlets of qtz-ser-py occur primarily in NE trends. The ser selvages give the veinlets a greasy-grey appearance. The entire section lies immediately beneath the leached capping, which sometimes extends down into the face where the rock is well brecciated.

Potassic Alteration (PO)
Minor where present; toward the western end. Masked by the PH, so difficult to determine. Some K-spar flooding; some 2° bio in gr. mass.



PORTLAND RIDGE — 2900C
OXIDE PIT

PHYLLIC ALTERATION

SILVER BELL MINE
PIMA COUNTY, ARIZONA

1:1200
1 inch = 100 feet

CAROLE DYER
MAY 1980

GEOLOGIC ROAD LOG — SILVER BELL-NORTH SILVER BELL

Follow the country road west of townsite. Beyond corrals, occasional outcrops of Amole sediments, Recreation Redbeds. Then outcrops of Silver Bell alaskite with occasional Qmp.

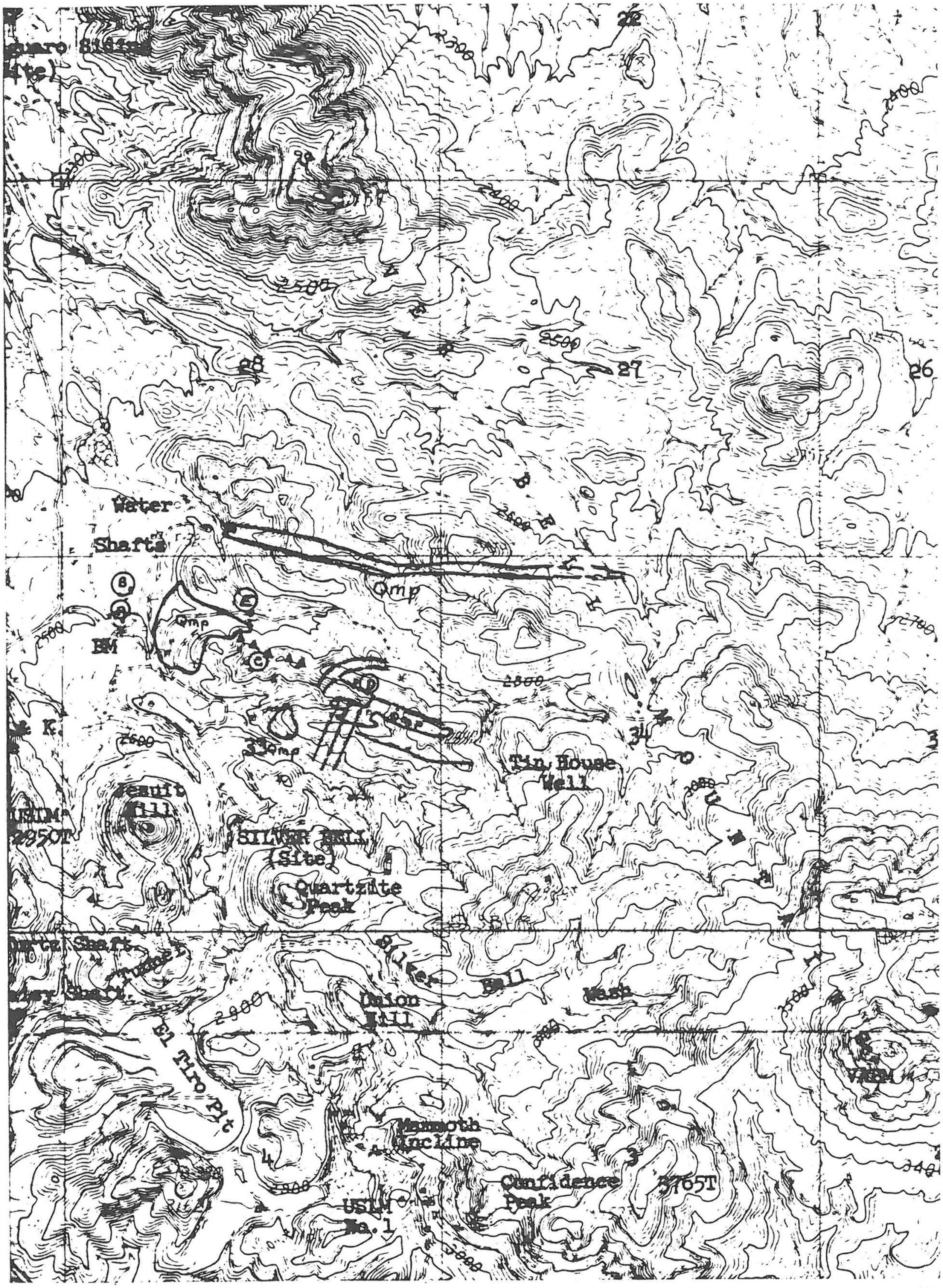
At 3.5 miles is a pre turn-of-the-century smelter site, with foundations and slag, a unit which served early (pre-SASCO smelter, 1906) Pb-Zn-Cu-Ag interests, was served by railroad from the North.

For the next few miles - the Santa Rosas (see county map) are due west, the South Comobabis to the south in the distance. In the middle distance are two Papago Indian preserves, Koht Kohl (to left, upper Paleozoic) and Ka Kohl (to right, mid-Tertiary volcanics). To the northwest are the Slates (Lakeshore) and the Vekols (Vekol).

The road curves back, heads NE past the Atlas Mine, a BS & K property of veins of sphalerite-pyrite, minor chalcopyrite-galena in hydrothermally skarnified Paleozoic limestones.

At 6.5 miles and 20 minutes out of Silver Bell, the road is on the old RR grade through thick caliche.

At 7.0 miles, go through gate on RR grade. The West Silver Bell Mountains are to the left in a spectacular saguaro forest, the North Silver Bell property is immediately ahead.



NORTH SILVER BELL Scale:1 in : 2000 ft

North Silver Bell Tour Guide by Cliff Dilbert (ASARCO)

The North Silver Bell (NSB) area is jointly controlled, in 1981, by BS & K Mining Company and ASARCO, Inc. It has long been recognized as a northwesterly extension of the Silver Bell (SB) system. As such, it provides an extraordinary display of first order PCD characteristics at intermediate to shallow levels (probably not more than 1-1.5 km) consistent with Silver Bell proper and of an interaction of hypogene and supergene phenomena. Here you will see epizonal activity manifested by pebble dikes and breccias, which are the upward forerunners of Qmp dikes, and Qmp dikes which themselves flare 200 to 300 feet down to merge into a Qmp stock. You will see potassic alteration, with ~1000 ppmCu and 50 ppmMo, yield laterally (not temporally) to phyllic and then propylitic alteration assemblages, with variable silicification. You will see capping over secondary ores, and characteristics of weathering of different alteration and litho types. Geologic maps showing geology, alteration assemblages, Cu-Mo-Pb-Zn, total sulfide, vein-veinlet-structure relations, silicification, trace element variation, and supergene effects show conventional patterns.

The field tour will be self guided, so that ample time for mapping, contemplation, comparison, and discussion may be apportioned. The 'stops' are all relevant and interesting, and the overall tour about 6-8 km long, so don't indulge yourself too much at any one locale.

The overall direction of the tour is to the east from Point A along Tin House Wash, then southerly toward the SB mine proper, then westerly along either Breccia Ridge or North Silver Bell Wash, or both.

The rock types at NSB include major dacite porphyry and quartz monzonite porphyry, and minor andesite. The 'dacite porphyry' is predominant, outcropping over about 75% of the map area. It is locally better-termed rhyodacite porphyry (granodiorite equivalent) or even quartz latite porphyry (quartz monzonite equivalent). It may well be a large sill, or even a thick extrusive unit. To the northeast it has lower lithic fragment content and abundant biotite, and maybe part of a stock. Here at NSB the dacite porphyry (field term) has many lithic fragments and low biotite and appears more sill-like, and is perhaps even a thick extrusive body. It fractured readily, and its ratio of veinlet to disseminated sulfide is high. It appears distinctly quartz porphyritic ('quartz eye porphyry'), fractures relatively abundantly and closely, shows little or no biotite, and has sparse phenocrysts of K-feldspar. It contains about 20% rounded 'quartz eye' phenocrysts, 30-40% plagioclase and K-feldspar phenocrysts, and 40-50% aplitic quartz and K-feldspar groundmass. It is an excellent 'reactant' and recorder of alteration effects, and its homogeneity facilitates area to area comparisons. The alteration pattern extends over a 3000 meter east-west 'half distance'.

Proceed about 200 feet east into RR grade cut.

Proceed eastward to adit area.

POINT B. The 'new' portal is in sericitized Dp. A vesicular andesite dike slashes through - note that it is faulted, downdropped to the eastern, mountain-ward side, unusual in this Basin and Range terrane. Note 'spotty' high-Cu dendrites and quartz-veinlet silicification.

(We can't go underground in the adit. It goes - 10° for 315' N87°E, levels and forks, one drive 300' NE, one 200' SE. It samples the enriched blanket terrane under the hill before you, shows excellent structure control of sec cc on py, moderate tonnages of ~0.5% Cu, and Mo).

The old adit 60-70' N of the new adit shows quartz veining and sericitization, excellent fracturing, highly visible quartz eyes characteristic of Dp - get used to them. You are already east of the K-alt center, into superimposed phyllic alteration.

(From here, you can either proceed up Tin House Wash (THW) to Points D-L, or reverse the itinerary by proceeding DUE EAST beyond the New Adit toward Point L on the drill pad up on the hill and reading the trip log 'back to front'. All points are identified and color-coded -- you can approach them in random order if you prefer).

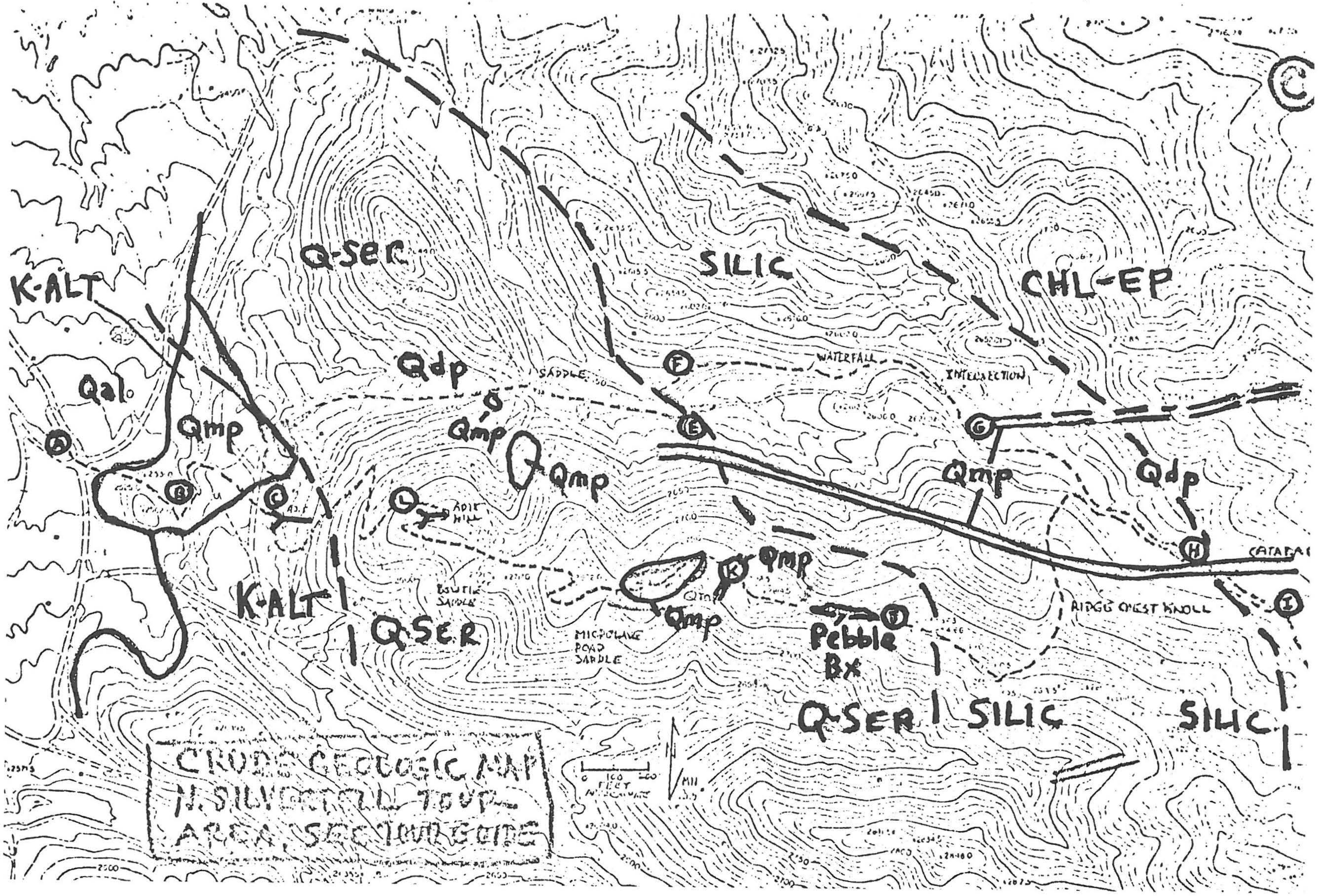
Follow pink flags up to skyline saddle, (where Silver Bells(?) are in bloom, with lupine, California poppies, brittlebrush). 50 feet SE of saddle is a knoll with a thin pebble--breccia dike with Dp and qtzite pebbles which projects to Point J. SB obvious; mines and prospects down to SE near road to microwave tower are along another Qmp dike.

Follow Breccia Ridge to west. Note that N70W jt direction yields progressively to stockwork. Structure more pron. westerly--well devel near Survey Beacon, leached vlts, stkwks. 20' from Beacon on crest is pebble dike marked with orange flagging.

POINT D, white flagging. Nearby orange flagging traces clear-cut pebble dike 1-2 feet wide, 50 feet long, well-rnded pebbles, traceable precisely along ridge crest. Almost certainly 'leading edge' of Qmp dike 200-300' below. Excellent fracture net-stkwk here, alun vlts. Mod. leaching.

Proceed W along ridge. Old prospect pit--ironwood tree prob. 100 years old means Silver era prospect. Cu stain in shear. Some prospects contain 30-foot saguaro, indicate a +150 year age of the prospect. Some of these early pits must have been dug by Indians or early Spaniards.

100'east from lowest saddle or ridge (orange and pink flag) is excellent breccia dike zone, round and angular frags. We are approaching breccia pipes--structure, alt, and min will augment westerly. Look west to next hill and its hem stain, part of the augmentation. Move over to it, note pron. incr. in q veining-silic. Look west from here (yellow-green flagging), another picture stop, of shatter and true breccia pipes. The topographic arc low on the S side of the prominent pipe-hillock is a Qmp dike. Breccia bottoms in Qmp and is cut by Qmp dikes.



North Silver Bell, generalized alteration zoning map showing AGS/UA Field Trip Stops.

Scale 1 in : 400 ft

FIELD NOTES AND SKETCHES

FIELD NOTES AND SKETCHES