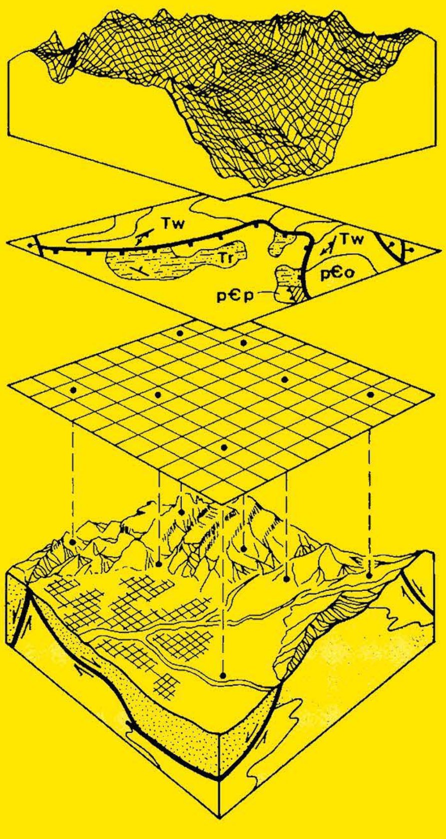
FRONTIERS IN GEOLOGY AND ORE DEPOSITS OF ARIZONA AND THE SOUTHWEST

Arizona Geological Society and the University of Arizona 1986 Symposium

FIELD TRIP GUIDEBOOK
7



Proterozoic Greenstone Belts and Mineral Deposits, Central Arizona: Jerome Camp and Bradshaw Mountains

March 21-23, 1986

Leader: P. O’Hara (Kaaterskill Expl.) and D. Armstrong (Consultant)

Coordinators: R. Lawrence (Santa Fe Mng.) and C. Newton (U. of A.)

ARIZONA GEOLOGICAL SOCIETY
TUCSON, ARIZONA

Cover preparation by Beverly Morgan, modified from J. Mehulka
and P. Mirocha, AGS Digest Volume XVI

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

To: Field Trip Participants

Welcome to Arizona and the 1986 Arizona Geological Society Symposium "Frontiers in Geology and Ore Deposits of Arizona and the Southwest." As field trip chairman I would like to wish you an enjoyable and informative conference and a worthwhile field trip experience.

The field trip committee set out many months ago to provide field exposure to a broad spectrum of geological disciplines. The results include trips to recent precious-metal discoveries, areas of new and developing stratigraphic and structure concepts, industrial mineral resources, lithologic features significant to the petroleum potential in the Southwest, geologic hazards in the community, and an opportunity to attend trips from previous Arizona Geological Society meetings. We hope you find your chosen field trip as exciting as we intended.

At this time of very limited support from industry, it is especially important to acknowledge the personal efforts of so many. I include in those the planning and follow through of the field trip committee, the many hours of preparation by the trip leaders, and the commitment of the trip coordinators to a smooth-running trip. A special thanks goes to Maggie Morris of the University of Arizona Conference Department for the transportation, lodging, and meal arrangements.

Please enjoy the Southwest and remember this week of field trips and meetings as a step toward the frontiers of the future.

Best regards,

Parry D. Willard
Field Trip Chairman

Field Trip Committee

Annon Cook
Norm Lehman
Beverly Morgan
Jon Spencer
Erick Weiland
Joe Wilkins Jr.
Jan Wilt

ITINERARY

FIELD TRIP 7

PROTEROZOIC GREENSTONE BELTS AND MINERAL DEPOSITS, CENTRAL ARIZONA: JEROME CAMP AND BRADSHAW MOUNTAINS

Leaders:	Patrick F. O'Hara (Kaaterskill Expl.) and Dale G. Armstrong (Consultant)
Coordinators:	J. R. Lawrence (Santa Fe Mining), and Clay Newton (U of A)

Friday, March 21, 1986

6:00 pm	Depart from University of Arizona, front of Student Union
10:00 pm	Arrive and check in at Autorest Motel,* Prescott, Ariz. (602-445-1440)

Saturday, March 22, 1986

7:00 am	Depart Prescott for Jerome
8:00 am	Jerome - UVX mine overview—Paul A. Handverger
10:00 am	UVX mine geology—Don White
12:00 noon	Lunch* at Copper Chief mine
12:30 pm	Copper Chief mine discussion—Paul A. Lindberg
5:30 pm	Return to Prescott
6:30 pm	Steak fry* at Bronze Saddle Restaurant

Sunday, March 23, 1986

7:00 am	Check out and depart from Prescott
7:30 am	Iron King mine and McCabe mine stops—Phillip Anderson, Patrick. O'Hara, J. R. Lawrence, and R. L. Dixon
10:45 am	Boggs mine stop—Douglas F. Hurlbut
11:55 am	Big Bug stock—Patrick R. O'Hara
12:45 pm	Lunch* at Copper Queen mine
1:15 pm	Copper Queen mine—Ralph E. Higgins, Patrick F. O'Hara, James M. Evensen, and Douglas F. Hurlbut
4:45	Return trip to Tucson
8:45	Arrival at Tucson with stops at University of Arizona and Holiday Inn (Broadway)

*Included in fees

Drivers:	Clay Newton Nancy Johnson

Field boots required. If possible, bring hard hat and safety glasses for mine tours.

FRONTIERS IN GEOLOGY
7. Proterozoic Greenstone Belts, Jerome Camp-Bradshaw
Mountains (March 21, 22 & 23)

March 11, 1986

Rec#:	Name:	Prot Gr 7. $130:
13	Jack L. Benham	1
90	Severn P. Brown	1
264	Jerry W. Dawson	1
88	Darrel A. Dean	1
62	Wendy J. Feuer	1
1	Fleetwood Koutz	1
22	Hank Kreis	1
46	Peter Kurisoo	1
24	Paul A. Lindberg	1
5	Maurice Magee	1
20	Phil Matthews	1
75	Virginia T. McLemore	1
199	S.C. Moore	1
111	William Nelson	1
213	Nyal J. Niemuth	1
32	John Petersen	1
82	Charles R. Sewell	1
130	Gordon Wieduwilt	1
79	Bruce Yeomans	1
	Grand Total	19

Patrick O'Hara
Dale Armstrong
Paul Handverger
Don White
Phillip Anderson
Rick Lawrence
R. L. Dixon
Douglas Hurlbut
Ralph Higgons
James Evensen

Clay Newton
Nancy Johnson

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FIELD TRIP 7

PROTEROZOIC GREENSTONE BELTS AND MINERAL DEPOSITS, CENTRAL ARIZONA: JEROME CAMP AND BRADSHAW MOUNTAINS

March 21–23, 1986

General Leaders: Patrick F. O'Hara (Kaaterskill Expl.) and Dale G. Armstrong (Consultant)

Associate Leaders:

Paul A. Handverger	R. L. Dixon
Don White	Douglas F. Hurlbut
Paul A. Lindberg	Ralph E. Higgins
Phillip Anderson	James E. Evensen
J. R. Lawrence	

Coordinators: J. R. Lawrence (Santa Fe Mining)
Clay Newton (University of Arizona)

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Arizona Geological Society Digest Volume XVI, 1986

PROTEROZOIC GREENSTONE BELTS AND MINERAL DEPOSITS, CENTRAL ARIZONA: JEROME CAMP AND BRADSHAW MOUNTAINS

ROAD LOG AND TRIP GUIDE

Patrick F. O'Hara[1]

and

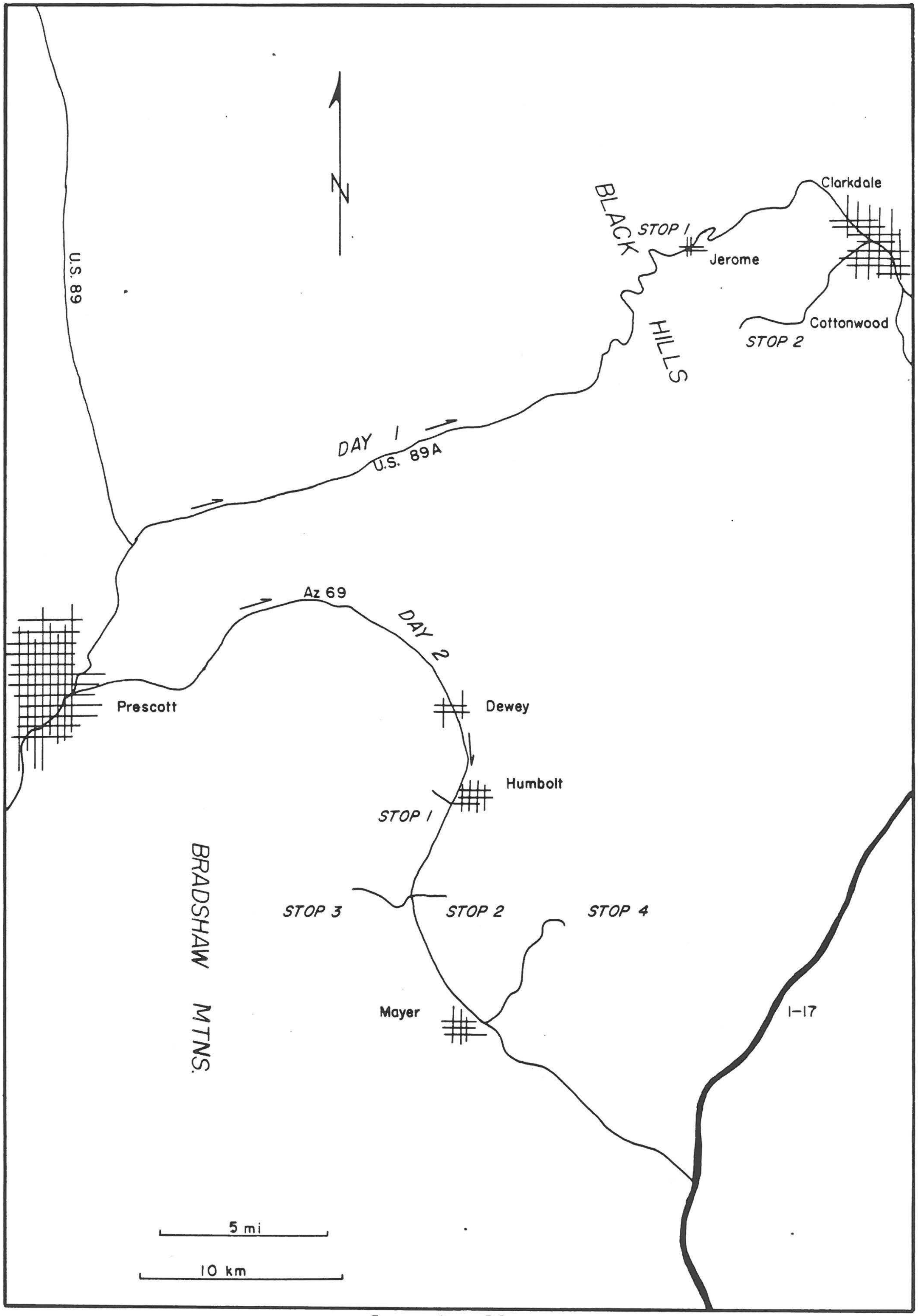
Dale Armstrong[2]

DAY 1. D. Armstrong, Trip Leader

Mileage Cum.	Inc.	
0.0	0.0	The start of the field trip will be in the Prescottonian Motel parking lot at the intersection between Arizona Route 69 and U.S. 89 at the east end of town on Gurley Street. The mileage here will be 0.0. Our destinations are the United Verde Extension and Copper Chief mines. The rock units observed to the north on the hillside behind Yavapai College are Tertiary gravels, which extend to the east and cover the Government Canyon granodiorite. The Government Canyon granodiorite is a premetamorphic, pretectonic intrusive rock that may be roughly correlated with the Brady Butte Granodiorite, The Bland Hill Granodiorite, the Crooks Canyon Complex, and the Prescott granodiorite. All of these are lithologically fairly similar and are probably of similar age. Krieger attempted to break apart each rock unit and to derive approximate relative ages based on field relations. There are no modern U-Pb zircon dates on the Government Canyon granodiorite or the Prescott granodiorite, and they are assumed to be approximately 1.77 billion years old (using the old λ) based on the U-Pb date on the Brady Butte granodiorite. The Tertiary gravels form a thin zone above the Government Canyon granodiorite and are in turn covered by the Tertiary basaltic rocks of Glassford Hill.
0.3	0.3	From the Prescottonian parking lot, we will turn right onto Route 69 and drive about a hundred yards and turn left under the underpass along Route U.S. 89. At mileage 0.3 is the turnoff to the left to the Veterans Hospital and on the right outcrops of Tertiary gravels can be seen.
0.8	0.5	Across the railroad tracks and Granite Creek on the left is the Prescott granodiorite, a premetamorphic, pretectonic intrusion, probably very similar in age to the Government Canyon granodiorite.
3.1	2.3	Watson Lake. To the northeast, are the first outcrops of the Granite Dells. This granite is easily identified by its orthogonal fracturing with weathering along these fractures forming the bold rounded outcrops. This intrusion is a lithophile element-enrichment, anorogenic, 1.4. b.y.-old granite.
5.0	1.9	Make a right turn off of U.S. 89 onto U.S. 89A.
5.3	0.3	Crossing Granite Creek and pass outcrops of the Dells granite.
5.7	0.4	The last Precambrian rocks are observed and between this locality and the east side of Prescott Valley, all Precambrian rocks are covered by Tertiary and Quaternary gravels.
6.2	0.5	Underpass of the Santa Fe Railroad.
7.0	0.8	The San Francisco Peaks can be observed at about 10:00 o'clock.
7.2	0.2	At 3:00 o'clock the basalt flows of Glassford Hill can be seen. On the far side of the hill, the flows are breached and there is a small flow dome in the neck of this volcanic complex. There is no isotopic date available, but this

[1]Kaaterskill Exploration. 691 Robinson Drive., Prescott, Arizona 86301

[2]Consulting Geologist, 1525 E. Lind Road, Tucson, Arizona 85719



Location Map

complex is assumed to be Tertiary in age.

8.0 0.8 Straight ahead at 12:00 is Mingus Mountain, which is a part of the Black Hills. Mingus Mountain is made up of Paleozoic sandstones and limestones, which unconformably overlie the Precambrian rocks and are in turn overlain by the Hickey basalt, which is Tertiary in age.

In the immediate foreground and to the north are outcrops of Mazatzal-equivalent quartzite that are thought to be the youngest Precambrian rocks in the area.

10.2 2.2 North entrance to the town of Prescott Valley

14.0 3.8 Hills off to the north at 10:00 o'clock are Indian Hills volcanics.

15.8 1.8 The low rolling hills at 2:00 o'clock at the south side of the road are Indian Hills volcanics. These are a sequence of Precambrian metavolcanic rocks that can be traced into the Grapevine Gulch stratigraphic section (P. Anderson, 1985, personal commun.). The Tertiary and Quaternary cover between the Indian Hills volcanics and the Iron King and Spud Mountain Volcanics precludes any correlation between these units at the present time.

19.0 3.2 The power line runs approximately along the Shylock lineament in this area. To the south the Texas Gulch Formation crops out. This is the youngest rock unit and has undergone polyphase deformation. The Shylock fault zone is characterized by highly attenuated F_1 folds, which may be associated with thrusting. Work on this problem is in progress. Map outcrops patterns within the Shylock zone suggest polyphase deformation.

The outcrops to the left of the road are of the older metavolcanic metasedimentary Grapevine Gulch Formation, Paleozoic rocks crop out on top of the hill at 10:00 o'clock on the north side of the road.

20.3 1.3 A good exposure of banded iron formation crops out within the Grapevine Gulch Formation. This iron formation consists of very fine grained hematite up to 65 percent in a matrix of quartz and various clays.

21.5 1.2 The unconformity between the Precambrian Grapevine Gulch Formation and the Cambrian Tapeats Sandstone is exposed.

21.7 0.2 The first outcrops of the Martin Limestone (Devonian).

22.4 0.7 The Mississippian Redwall Limestone crops out.

22.6 0.2 The unconformity between the Hickey Formation and the underlying Paleozoic sedimentary rocks.

23.7 1.1 The crest line of Mingus Mountain crosses the highway at an elevation of 7,023 feet.

25.3 1.6 The unconformable contact between the Hickey volcanics and the Paleozoic limestones.

26.7 1.4 The dirt road leaving Highway 89A from the southeast leads to the Verde Central mine and into Mescal Gulch.

28.7 2.0 Possible fault contact between the Precambrian Grapevine Gulch Formation and the Paleozoic limestones.

29.0 0.3 Contact between the Precambrian Grapevine Gulch Formation and the Precambrian Deception Rhyolite. The Deception Rhyolite has been subdivided into several subunits by numerous past and present workers; the most common divisions are those defined by Anderson and others (1971). These consist of: upper Deception, Cleopatra Quartz Porphyry, breccia in Mescal Gulch, chloritized rocks, bedded breccia, and andesite breccia.

29.4 0.4 By looking south across the valley, the dumps of the Verde Central mine can be seen. The Verde Central mine is contained within the Deception Rhyolite, more specifically within the Cleopatra quartz porphyry, and is a small volcanogenic massive sulfide deposit. The mineralization is located at the contact between the Cleopatra Quartz Porphyry and the upper Deception Rhyolite. Reserves indicated at the Verde Central mine are estimated to be 121,000 tons of 2.9% Cu and unknown amounts of precious metals (P. Handverger, unpublished data).

30.4 1.0 Exposures of the Cleopatra volcanics exhibit varying degrees of footwall-style Mg alteration. Some of these alteration features can be traced into the main sulfide mass of the United Verde deposit located less than a quarter of a mile to the north.

30.7 0.3 Entrance to the town of Jerome.

31.2 0.5 Main switchback. The road on the left leads to the entrance of the United Verde pit.

31.8 0.6 An approximate location for the Verde fault.

32.0 0.2 Make a sharp left turn and follow the signs to the Jerome State Historic Park.

32.2 0.2 The Jerome State Historic Park is located in what was the Douglas House. This is the large white building on the crest of the hill located straight ahead. Located to the left of the Douglas House are some of the old mine offices of the United Verde Exploration Company. The headframes also to the left of the Douglas House are over the Edith and the Audrey shafts of the United Verde Extension mine. The original Edith headframe was recently replaced to support the current phase of underground gold exploration.

32.7 0.5 STOP 1. Entrance to the Jerome Historic Park is straight ahead. We will park at the base of the Edith headframe. At this stop the trip will be directed by Paul Handverger, who will give a brief historical review of the mining activity for both the United Verde and the United Verde Extension deposits. There will also be a brief tour through the museum. At the completion of Handverger's presentation, a review of the current gold exploration at the United Verde Extension mine will be given by Don White. After his presentation, return to the vehicles and retrace the route back to Highway 89A. We will proceed to the Copper Chief mine area located a few miles to the south.

33.6 0.9 Route 89A, turn left and drive down the hill. As we travel down the switchbacks, we are within the hanging-wall rocks of the Verde fault. Exposures of Paleozoic sedimentary rocks and Tertiary basalts and gravels are encountered all the way into the town of Cottonwood.

34.5 0.9 Major switchback. At this point, access to the pipe-line road can be seen. The pipe-line road can be driven from this point south for several miles through most of the Precambrian exposures of Mingus Mountain. The road ends at the crest of Mingus Mountain at Highway 89A.

36.7 2.2 The Arizona Portland Cement Co. installation can be seen to the north.

37.5 0.8 Continue right on Highway 89A.

39.9 2.4 Turn right on Mingus Avenue, the Cottonwood City airport road.

40.2 0.3 On the left is the Cottonwood airport. Continue straight ahead. We are now on Forest Service Road 493.

41.1 0.9 Foothills straight ahead are composed of Paleozoic sedimentary rocks and Tertiary basalts and gravels, all within the hanging wall of the Verde fault.

41.7 0.6 Stay to the left.

42.1 0.4 Exposures of the Hickey basalt, within the hanging wall of the Verde fault.

42.3 0.2 Good view of the Mogollon Rim can be seen to the left.

42.9 0.6 The road to the left leads to the smelter site that was used to treat the ore from the Copper Chief mine. Continue straight ahead.

43.3 0.4 Both the Hickey basalt and the Paleozoic carbonate sequences can be observed. In the canyons north and south of the road, exposures of these Verde fault hanging-wall rocks are folded, overturned, and generally highly disrupted, suggesting that there is a component of reverse movement for the Verde fault system. This reverse movement is of probable Laramide age. Exposure thickness for the Verde fault (swarm) in this area may occasionally exceed 150 feet. As we cross the Verde fault, we enter the Precambrian and are probably within the Shea Basalt.

44.1 0.8 The road is now paralleling the Cliff fault, which is striking generally east-west. On the left of the road is an exposure of a late-kinematic or post-kinematic granodiorite intrusion. The Cliff mine, which is straight ahead, is a footwall feeder alteration-mineralization system for which no associated massive sulfide has ever been located.

44.5 0.4 Drive straight ahead. The road to the right leads to the Cliff mine.

44.9 0.4 On the hills directly ahead are the Copper Chief mine cuts and workings.

45.0 0.1 Switchback. At this location the mafic rocks in the road cut contain numerous small banded iron formation laminations. These units exhibit strong semi-chaotic folding. Most of the fold noses in these exposures also exhibit an axial-plane foliation suggesting that this deformation is related to regional metamorphism.

45.3 0.3 STOP 2. Park in this area. The lower road leads to the lowest adit of the Copper Chief mine. At this location the trip will be directed by Paul Lindberg. After lunch and for the remainder of the day he will review the past and current exploration and revised geology of the Copper Chief mine area.

END OF DAY 1

DAY 2. P. O"Hara, Trip Leader

Mileage Cum.	Inc.	
0.0	0.0	Start of today's field trip to the Bradshaw Mountains leaving from the Prescottonian parking lot. Government Canyon granodiorite is overlain by Tertiary gravels.
0.1	0.1	Turn right on Route 69 and pass a cemetery on the right. Government Canyon turns up to the right.
0.3	0.2	On the left-hand side of the road there are outcrops of the Government Canyon granodiorite.
0.7	0.4	Outcrops of Government Canyon granodiorite are on the left.
1.5	0.8	Just pass the sign for the Bradshaw Ranger Station. Outcrops of Government Canyon granodiorite.
1.9	0.4	Outcrops of Government Canyon granodiorite.
2.1	0.2	Tertiary gravels
2.7	0.6	At the top of Bullwacker Hill, outcrops of Tertiary basalt associated with the Glassford Hill Tertiary volcanic complex.
3.2	0.5	Road heading off to the right leads to Lynx Lake. Outcrops on the left side of the road are of Government Canyon granodiorite.
3.8	0.6	Outcrops of the rocks of the Green Gulch Volcanics of the Big Bug Group.
4.1	0.3	Entrance on the left to Yavapai Hills.
4.4	0.3	Outcrops on the left are of the Green Gulch Volcanics of the Big Bug Group.
4.8	0.4	Outcrops of Tertiary gravels.
5.4	0.6	Outcrops on the left side of the road are of the Green Gulch Volcanics.
5.8	0.4	Hills off to the left are made up of basalts from Glassford Hill, and they overlie Tertiary gravels.
6.4	0.6	Entrance to the town of Prescott Valley. Straight ahead in the distance are the Black Hills and Mingus Mountain, which we traversed on the Day 1 trip to Jerome.
6.7	0.3	On the right side of the road the hills are made up of the Crooks Canyon Complex. The rocks are a series of premetamorphic, pretectonic granodiorite similar to the Prescott granodiorite and the Government Canyon granodiorite.
8.7	2.0	Town center Prescott Valley.
9.5	0.8	Leaving town of Prescott Valley. The valley is underlain by Tertiary and Quaternary gravels.
12.4	2.9	Outcrops of Tertiary sediments on both sides of the road.
12.6	0.2	Entrance to the Prescott Country Club on the right.
13.3	0.7	Bible Training Center.
13.6	0.3	View off to the southwest at 2:00 o"clock. The rounded hill is Spud Mountain, type locality of Spud Mountain Volcanics. Off to the right at 3:00 o'clock are the outcrops of the Crooks Canyon granodiorite complex, and in between the two is the Chaparral shear zone, which has a right-lateral component of movement. This ductile shear zone may be a controlling influence on the emplacement of the Laramide Walker and Big Bug stocks.
15.1	1.5	Route 169 intersects Route 69 on the left side of the road.
15.6	0.5	The hills off to the left from 3:00 to 12:00 o'clock are the northern extent of the Iron King Volcanics.
15.9	0.3	Outcrops of Tertiary or Quaternary gravels.
16.7	0.8	Off to the left is the stack of the old Humboldt smelter.
17.0	0.3	To the left is the turnoff to the town of Humboldt.
17.1	0.1	At 1:00 o'clock note the tailings from the Iron King mine.
17.5	0.4	Turn right onto the road to the Iron King mine.
17.6	0.1	Old railroad cut off to the left.
17.7	0.1	Tertiary Quaternary gravels.
17.9	0.2	Off to the right are the tailings of the Iron King mine.
18.1	0.2	STOP 1. The Iron King assay office. We will stop here. This is the first stop. Phil Anderson of Precambrian Research Inc. and Pat O'Hara of Kaaterskill Exploration will present a discussion on the regional stratigraphy, structural geology, and metamorphism. Richard Pape of Santa Fe Mining, Inc. will present a discussion on the geology of the McCabe mine, which is visible to the south. Rick Lawrence of Santa Fe Mining Inc. and Richard Dixon, consulting geologist, Reno, Nevada, will present a discussion on the geology of the Iron King mine and will lead a series of traverses within the Spud Mountain Volcanics and Texas Gulch Formation. Turn around and head back to Route 169.
18.8	0.7	Intersection with Route 169. Turn right. Reata Pass Steakhouse. At 11:00 o'clock a resistant knob on the hillside is the ferruginous quartzite that marks the Lone Pine horizon.

19.5 0.7 Outcrops on both sides of the road are Iron King Volcanics.

20.3 0.8 Carbonate-altered Iron King volcanic rocks.

20.6 0.3 On the left side of the road, the dump and mine shaft of the Montezuma property can be seen.

21.3 0.7 The road on the left leads to the Swindler property, and over the hills to the left is the Lone Pine property. The hills on the right are in the contact metamorphic zone of the Big Bug stock.

22.3 1.0 Turn left on the road with the group of mailboxes; immediately past the cattle guard turn left again.

22.5 0.2 Take the first right, Meadow Drive.

23.3 0.8 STOP 2. Boggs deposit. The Iron Queen deposit can be seen past the power line to the south on the first low, rolling hill. Doug Hurlbut of The University of Arizona will lead a traverse to see the nature of mineralization at the Boggs deposit.

Near Parn, drive east a hundred yards to a turnaround and then proceed back to Route 69.

23.6 0.3 Off to the right in the gulch lies the Matty property.

24.2 0.6 Turn left onto Oak Road; then turn right across the cattle guard to intersection with Route 69. Turn right and immediately turn left off of Route 69.

24.9 0.7 Outcrops of Iron King Volcanics.

25.0 0.1 Outcrops of the Laramide Big Bug stock on the right and on the left side of the road and across the creek.

25.5 0.2 Weathered outcrops of the Laramide stock on the right side.

25.3 0.1 More of these weathered outcrops can be seen on the hill to the right.

25.5 0.2 Turn left. Straight ahead on the side of the hill to the north are the dumps of the Henrietta mine. The vein is probably associated with the intrusion of the Big Bug stock.

25.6 0.1 Placer dredge spoils can be seen in Big Bug Creek.

25.8 0.2 Continue on main road. Road to the right leads to the Henrietta mine.

26.0 0.2 Take the road to the right, Forest Service Route 261.

26.2 0.2 STOP 3. Look at the fresh outcrops of the Laramide Big Bug stock. Discussion of the research of J. A. Sturdevant of South Dakota School of Mines, Rapid City, and his students on the mineralization and alteration associated with the Big Bug stock by Pat O'Hara, Kaaterskill Exploration.

Retrace the route back to Arizona Route 69.

Precambrian schists cropping out in this area belong to the Spud Mountain Volcanics as identified by Anderson and Blacet (1972).

27.2 1.0 Off to the right between the two hills are outcrops of the Texas Gulch Formation. The Texas Gulch Formation also crops out on the north side of the Laramide stock and continues northward occupying an axis of a northward-closing fold, which is covered by Tertiary gravels at the Iron King mine.

28.0 0.8 Turn sharp left across the cattle guard to Route 69 and then at the stop sign turn right onto Route 69. Off to the right at 2:00 to 3:00 o'clock are Yavapai Series Big Bug Group rocks, which are capped by the Tertiary Hickey basalt. To the left are low rolling hills of the Iron King Volcanics.

28.9 0.9 Crossing a possible fold axial plane, which has a southward closure. The axial plane of this fold is occupied by a fault that may have originally been a thrust fault associated with folding. The possibility also exists that there has been some later movement associated with this fault. The Hackberry, Pentland, and Upshot properties are located to the southwest.

29.6 0.7 Approximate location of the corresponding northward axial plane.

31.0 1.4 Entrance to the town of Mayer on the right leads to the uptown Mayer business district. Off to the left are Iron King Volcanics with many ferruginous quartzites interlayered within mafic to andesitic volcanics and sediments derived from the volcanics.

31.6 0.6 The Onyx quarry; a Tertiary travertine deposit.

32.0 0.4 The midtown Mayer business district can be observed off to the right.

32.2 0.2 Crossing Big Bug Creek

32.3 0.1 Turn left onto the dirt road. Do NOT follow the paved road because it will lead into a trailer park.

32.4 0.1 Off to the right is the Mayer smelter stack. The stack was completed just before the copper bust in the early 1920s. The rest of the smelter was never built, and it serves as an excellent place for the Mayer volunteer fire department to set off the homecoming bonfire for the high school every year.

32.5 0.1 Off to the left is the storage area for the building stone quarried from altered felsic volcanics. It is interesting to note that the building-stone industry is making more use of the altered rocks in the region than the metallic mining industry.

32.8 0.3 Crossing the cattle guard, stay on the main road. Do NOT take any of the small dirt roads that lead off to the left or the right. Outcrops here are graywackes and pelites that are probably members of the "Cleator pelite."

33.4 0.6 Gas Line Road. About a half mile off to the left along the Gas Line Road are outcrops of ferruginous quartzite that are intensely folded and are the key area for analyzing the deformation history that Jim Evensen (1980) described.

33.8 0.4 Stay to the left. Do NOT take the road to the right. It leads to the Stoddard mine and U-Cross Ranch. Rocks on the left have a felsic volcanic protolith and are within the basal Iron King Volcanics. Rocks to the right in the valley are the "Cleator pelite," and the hills in the distance to the east are rocks that occupy the eastern volcanic assemblage, a mixture of felsic and mafic rocks in which the Binghampton, Copper Queen, Stoddard, and Copper Mountain mines are located. In the felsic rocks through which we are driving, silica composition indicates that the protolith was probably rhyodacite; this is assuming that during sericitization the silica was not mobile and it remained in the rock.

35.3 1.5 "Cleator pelite."

35.7 0.4 In the steep cuts in the wash just to the north and down on the Agua Fria River are minor folds that have preexisting S_1 foliation and S_0 layering folded into northwardly plunging folds. It is thought at this time that these are F_2 folds although they may be associated with fault movement along a north-south shear zone within this area.

36.0 0.3 Off to the right are the felsic and intermediate volcanics of the eastern metavolcanic belt with several very large ferruginous quartzite units and very light colored chert units marking the approximate contact with the pelites. The contact in this area with the pelites on the west and the metavolcanics on the east is thought to be an unconformity, with the pelites being younger.

36.4 0.4 Gate in the road. Take the lower road, which passes through the gate.

36.5 0.1 The road curves to the east (to the right). Follow it to the right and follow the course of the Agua Fria River, which lies just to the left.

36.6 0.1 The eastern metavolcanic zone is informally named the Rattlesnake formation. Details about these rocks will be discussed at the field trip stop just ahead.

36.7 0.1 STOP 4. Giant cottonwood tree. We will stop here and have lunch. After lunch, we will make the field trip traverse to the Copper Queen mine and discuss stratigraphy and structure within this belt of rock. The trip will be led by Ralph Higgins of Conoco Inc.

END OF DAY 2

REFERENCES

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RECENT GEOLOGICAL INVESTIGATIONS OF THE JEROME MASSIVE SULFIDE CAMP, VERDE MINING DISTRICT, NORTH-CENTRAL ARIZONA, A BACKGROUND REVIEW

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and

Paul A. Handverger[2]

INTRODUCTION

The purpose of this paper is to review some of the historical and background data from the Verde mining district, Yavapai County, Arizona (fig. 1). This information will help to establish the important contributions in this volume of recent investigations and exploration in this highly complex portion of the Proterozoic of Arizona.

The colorful mining history of the Verde district dates from prehistoric times. The Verde Valley–Black Hills region was a significant area of mining by the ancient Indians who exploited many of the region's mineral resources for local use and for trade throughout their world. Archaeological evidence indicates that copper-related artifacts were mined from the cropping-out oxide zone of the United Verde massive sulfide. Stone axes were fabricated from the Proterozoic diorite bodies of the Black Hills. Ancient open-pit mines that produced pipestone for trade are located in the younger Proterozoic rocks in Chino Valley just west of Mingus Mountain. The underground mining of salt at the southern end of the Verde Valley dates back to the earliest migration of man into the area.

The staking of the first claims in the Verde mining district occurred in 1876. This was followed by large-scale mining operations in the late 1800s, which continued until 1953 with small-scale mining continuing on to 1975. Total production from the United Verde mine was approximately 33 million tons of ore containing 4.8% copper, 1.6 opt silver, and 0.04 opt gold (Anderson and Creasey, 1958). An estimation of the total sulfide content, predominantly pyrite, is 85 million tons of which 10 million tons are zinc rich (Handverger, unpublished data).

The United Verde Extension mine, which is located about a quarter mile east of the United Verde mine across the Verde fault, did not crop out. The initial discovery of rich copper ore was made in 1914 by J. S. Douglas and G. Tener by sinking a shaft and drifting underground in the hanging wall of the Verde fault. Production ended in 1938 after a total of 3.9 million tons of ore containing 10.23% copper, 1.71 opt silver, and 0.039 opt gold were produced. A comprehensive review of the more recent mining history of the century can also be found in the report by Anderson and Creasey (1958).

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A significant contribution of explorationists in the Verde district over the past two decades has been the recognition that these ore deposits are syngenetic-volcanogenetic in origin and that the postore deposition tectonic history has played a very a significant role in the current positioning and distribution of the numerous lithologic assemblages. The methods of investigations have utilized detailed geological mapping, new and more detailed petrologic and geochemical characterization of the various lithologies, and enhanced geophysical investigations.

GENERAL PRECAMBRIAN STRATIGRAPHY OF THE JEROME REGION

Upon entering the Jerome area via U.S. 89A from Prescott, the spectacular views of the Verde Valley show the setting of the Verde district to be in the transition area between the Mogollon Rim, which defines the Colorado Plateau province of northern Arizona from the Basin and Range province of southern Arizona. This structurally high province of central Arizona is indicated by the oldest dated rocks in the southwestern United States, which are found at elevations exceeding 6,000 feet in the Jerome area. The highway offers a good chance to observe many of the stratigraphic and structural aspects of the Precambrian Ash Group, which is itself only a portion of the Yavapai Supergroup of Conway (1985) and others. All of the rocks in this district have been subjected to greenschist facies metamorphism and polyphase deformation. The rocks, which contain many relict structures and textures, are referred to by their protolithological classifications throughout the remainder of this paper. The major portion of the Proterozoic units are overlain by younger stratigraphy restricting the exploration and hampering a more complete understanding of the Verde district.

Figure 2 shows the stratigraphy of the Ash Creek Group as interpreted by Anderson and others (1971). They interpreted the Grapevine Gulch Formation to be the youngest member. The Grapevine Gulch Formation is composed of numerous volcanoclastic and epiclastic units, ferruginous cherts, dacite flows, and hypabyssal intrusive rocks. Much of this unit has obvious submarine characteristics as do many of the underlying units. Anderson and Creasey (1958) estimated the thickness of this formation to be in excess of 8,000 feet. They did note that there are complicated internal structural features that probably reduce the accuracy of their thickness estimates.

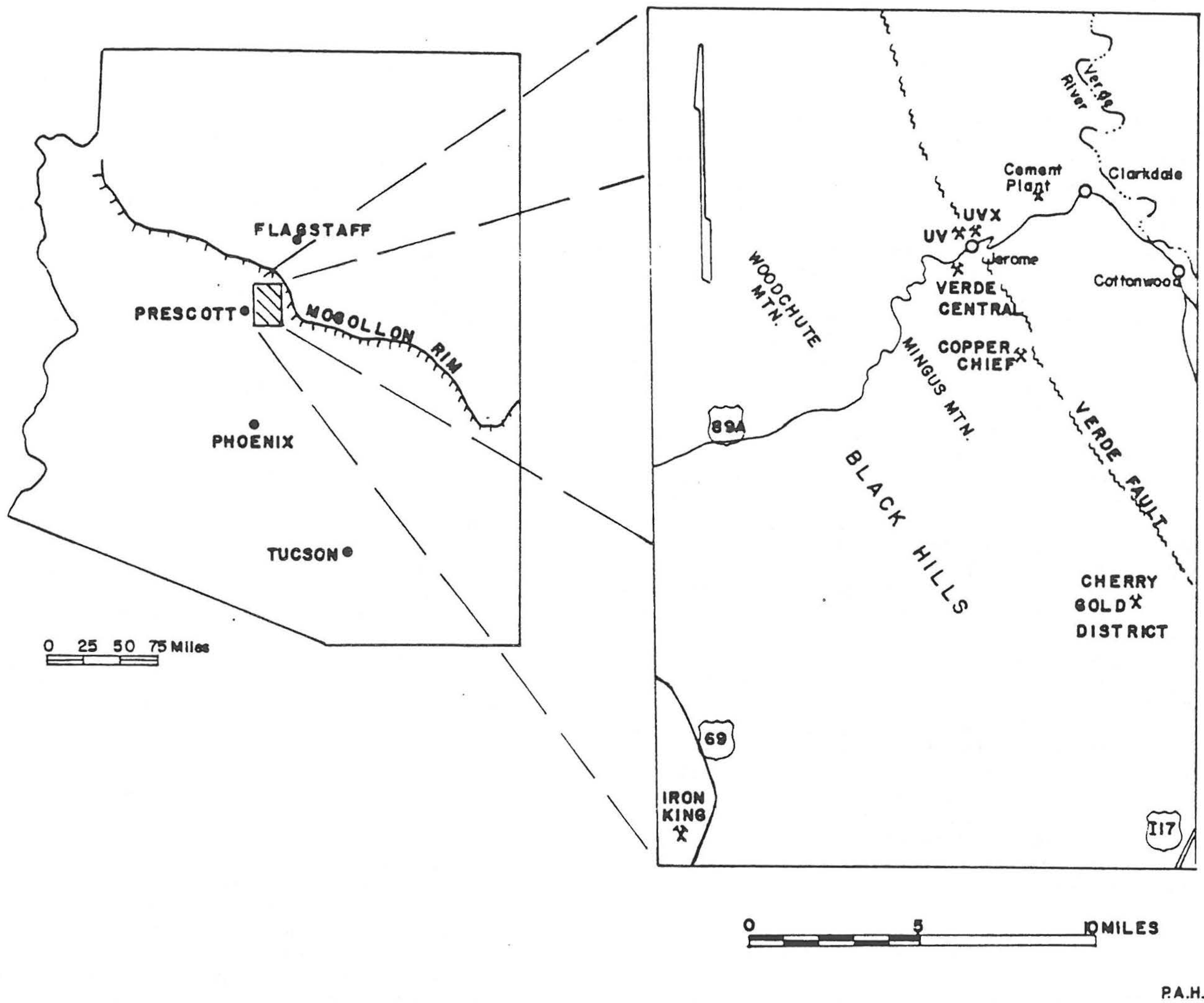

Figure 1. Location map for Verde mining district, Yavapai County, Arizona

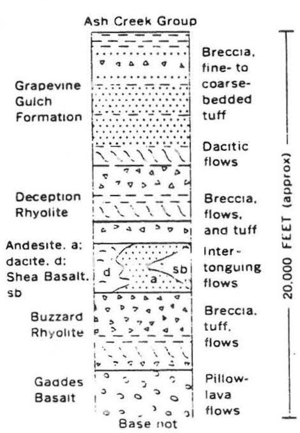

Figure 2. Stratigraphy of the Ash Creek Group. From Anderson and others (1971).

The Deception Rhyolite underlies the Grapevine Gulch Formation. Anderson and others (1971) recognized seven units within the Deception Rhyolite, which from youngest to oldest consist of: upper Deception, Cleopatra quartz porphyry, breccia in Mescal Gulch, chloritized rocks, lower unit, bedded breccia, and andesite breccia. Technically, they do not treat the chloritized rocks as a singular unit but as alteration products of other units. It is within the Deception Rhyolite that most of the past investigations have taken place. In detail, local vertical and horizontal volcanic facies variations have been identified and local volcanic and eruptive centers recognized (Handverger, 1975). It is within this unit that the United Verde, United Verde Extension, and numerous lesser orebodies occur.

Anderson and others (1971) interpreted the units directly beneath the Deception Rhyolite to be "time equivalent." These units are known as the Burnt Canyon Dacite, the Brindle Pup Andesite, and the Shea Basalt. These units are exposed in the vicinity of and south of the Copper Chief mine. The lowermost units identified and described by Anderson and others

(1971) are the Buzzard Rhyolite and the lowermost unit in the section, the Gaddes Basalt.

DEFORMATION

During the past 15 years there has been a concerted effort by numerous geologists to unravel the complex deformation history of the Verde district. Polyphase fabrics have long been recognized (Lindberg, 1974) as a major source for the complicated and somewhat unpredictable nature of the rock distributions. Those who have visited the pit area of the United Verde mine have seen the highly deformed sediments at the beginning of the haulage road that leads into the bottom of the pit. Close examination of this exposure reveals small-scale transposition and isoclinal fold features that are, in turn, formed by a less intense, open to tight fold system.

When the United Verde orebody is viewed in an isometric or three-dimensional nature, it becomes apparent that the orebody geometry in space is strongly influenced by the deformation fabrics observed in this northern portion of the camp. The orebody trends in a N. 65° W. direction and plunges toward the northwest from 50 degrees to near vertical and is, in effect, a very large boudin. The style of deformation observable in the United Verde pit is axial-plane, penetrative fabrics. At least two deformation events are suggested.

Future attempts to define the stratigraphic relations and locate favorable ore horizons must include a consideration and understanding of the nature and intensity of the deformation found in the region. Efforts to resolve the deformation problems or to "see through" them are underway. These investigations include structural reanalysis of old information, as well as the collection and interpretation of new data. This is being complemented by various petrologic, whole-rock, trace- and rare-earth-element geochemical investigations.

RECENT EXPLORATION ACTIVITIES

The key exploration objectives used at Jerome over the past several years have been aimed at recognizing the known ore—lithology—alteration associations and then locating areas of similar associations elsewhere in the district. The previous work of talented individuals and exploration companies identified the mineral potential and ore significance of the district. It is the responsibility of the present explorationists to improve and enhance the work of the former generation of geologists.

Within the Verde district, numerous mining companies over the past 30 years have continued the quest for additional base- and precious-metals discoveries. Most of the latest exploration projects in the district have emphasized various geophysical techniques in hopes of "seeing" sulfide responses from concealed bodies. However, from the widespread scope of the papers presented in this volume, it is apparent that the newest geological and geochemical ideas and techniques are presently being employed in the Verde district by various workers.

The gold potential of this area was recognized in 1980 by one of us (PAH). Identification of this mineralized area was based on assay data from old mine records as well as from numerous rock specimens collected during the last years of production. The target area as now envisioned encompasses the Gold Stope, an area that contained mineralization in excess of 0.5 oz/t Au. Stratabound and recrystallized ferruginous cherts were recognized as the host for this gold environment. A volcanogenic exhalative origin for the gold is suggested. The mine maps have helped to identify other areas having potential for additional reserves if they are reinterpreted using a volcanogenic source model. The paper by Don White in this volume will review and expand on an ongoing exploration project at the United Verde Extension mine.

Recent exploration in the area of the Copper Chief mine by Phelps Dodge has also expanded the level of geologic knowledge in the Verde district considerably. Most of the work in the Copper Chief area has consisted of surface mapping supported by geophysics and drilling. The paper by Lindberg in this volume addresses this newest exploration at the Copper Chief mine in the southern portion of the Verde district. Additionally, a study of the trace-element chemistries of the ferruginous exhalative cherts in the Copper Chief area is discussed by N. Johnson in this volume. The results of this study should be of value to geologists interested in characterizing other Precambrian volcanic exhalatives.

Preliminary results from a petrographic, trace-element, and isotopic study of the alteration zone associated with the United Verde massive sulfide body are presented by M. Gustin in this volume. Results from this study should advance the understanding of hydrothermal system within Proterozoic volcanic terrains of Arizona. It is hoped that these alteration studies will also enhance the understanding of the distribution of areas exhibiting the most intense deformation. Areas of either prekinematic or synkinematic phyllosilicate production should reflect the greatest amount of strain and thus produce the areas of greatest complexities.

CONCLUDING REMARKS

The Verde Mining district has been the focus of several generations of mineral exploration plus numerous miscellaneous investigations by some of the best geologists in the business. Their contributions have in several ways aided and greatly assisted the development of the current understanding of this camp.

The history of exploration in this district is a prime example of how the entire spectrum of geological investigations and techniques must be utilized in concept if a clear picture of the geology is to be had. The most recent wave of explorations will hopefully follow the footsteps of Douglas and Tenor, discoverers of the United Verde Extension, and develop new economic metal deposits in the Verde district. It is hoped that the following papers will help in leading the way.

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GOLD DISTRIBUTION AT THE UNITED VERDE EXTENSION, A MASSIVE BASE-METAL SULFIDE DEPOSIT, JEROME, ARIZONA

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ABSTRACT

The United Verde Extension mine operated from 1915 through 1938, principally as a high-grade copper mine. By the 1930s, however, it was a significant gold producer. The gold accompanied high silica flux containing virtually no base metals and was mined within a few hundred feet of the main base-metal orebody. Overall production was 3.9 million tons grading 10.2% Cu, 0.04 oz/t Au, and 1.7 oz/t Ag. Silica flux was produced from one area more notably than others, the "gold stope," containing 35,000 tons of 0.4 oz/t Au and 2.0 oz/t Ag. There is a clear spatial separation between massive base-metal sulfide ore and siliceous flux ore which contained the gold.

The siliceous flux ore is a meta-chert. Cherts form wedges, thinning laterally from the stratigraphic top of the massive base-metal sulfide body. These wedges of chert are the demarcation between the footwall, flow-dominate volcanics and massive sulfide deposits and the hanging wall of dominantly pyroclastic rocks. Cherts closer to the massive sulfide body are more brecciated and more steeply inclined. Matrix material in the breccia is iron stained, comminuted chert of nearly the same composition as the clasts. Gold probably occurs in very fine quartz-healed fractures within clasts and possibly in some of the siliceous matrix. It is probably fine disseminated native metal with or without electrum, although the definitive work on this has yet to be done.

Hydrothermal alteration is dominantly feldspar destruction by argillization of the immediate hanging-wall and footwall volcanic rocks and a more distant hanging-wall carbonate impregnation and veining. Gold is associated with a trace-element assemblage of Ag, As, Sb, Bi, Sn, Mo, V, and the base metals. Of these, only silver offers much help as an exploration aid as it occurs in a broader area than the gold. All the other trace elements trail off across stratigraphy at least as rapidly as the gold.

The present exploration, mainly by underground diamond core drilling, is an effort to find other "gold stopes." These are probably small deposits about smaller, less vigorous vents peripheral to those of the base-metal orebodies. They formed slightly later than the base-metal deposits and contain higher gold grades and higher gold-to-silver ratios. They are expected to be lens shaped, a few hundred feet in length, and now stand near vertical. The separateness of the precious and base-metal ores probably reflects the evolution of the ore-forming fluids.

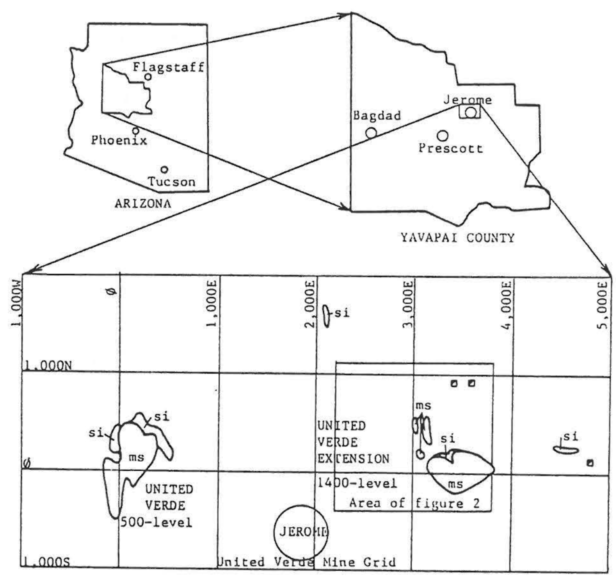


Figure 1. Location map

INTRODUCTION

Since April, 1985, DMEA Ltd., representing an individual investor, has been exploring for gold at the old United Verde Extension (U.V.X.) mine at Jerome, Arizona (fig. 1). All current work is confined to some 90 acres in the immediate mine vicinity, leased from Verde Exploration, Ltd., successors to James S. Douglas' famous United Verde Extension Mining Company. Longyear Company has been retained for underground diamond core drilling and Brooks Minerals, Inc. for cleanup, excavation of drill stations, and other support services.

The current exploration is an extension of that commenced by Phelps Dodge, a previous lessee, from 1981 to 1983. Phelps Dodge installed a steel headframe and a single-drum electric hoist and rehabilitated the Edith shaft. They drilled two holes totaling about 1,000 feet before dropping the property. Their goal was apparently 1 to 2 million tons of 0.1 to 0.2 oz/t auriferous siliceous smelter flux. Although such grades occur, they do not persist for thicknesses necessary to provide that tonnage. The current work is focused mainly on auriferous siliceous flux as well, but with expectation of higher gold grade and a more modest tonnage.

Search for precious metals in proximity to known base-metal massive sulfide deposits is a popular approach of the 1980s. Such work is in progress at the Horne mine, Noranda, Quebec, the Bathurst district, New Brunswick, the Ducktown district, Tennessee, and in proximity to the Crandon deposit in Wisconsin. The purpose of this paper is to familiarize the reader with the occurrence of gold at the U.V.X, its historical importance, grades, geometry, host rocks, alteration, trace-metal associates, possible origins, and significance to further exploration.

HISTORICAL BACKGROUND

Production

The fame of the United Verde Extension mine stems from its base-metal production and profitability. From 1915 through 1938, the high-grade copper body produced nearly 3.9 million short tons averaging 10.2% Cu, 0.04 oz/t (1.2 g) Au and 1.7 oz/t (52.9 g) Ag. Overall gold production was in excess of 150,000 ounces. Profitability is reflected by the $50 million in dividends paid to stockholders compared to the $5.6 million required to develop the mine and smelter.

These overall grades must be put in perspective for there was much variability over the mine life. Copper grades ranged from nearly 30% in 1917 to about 6% in the 1930s. Final-year production via the concentrator, as opposed to smelting ore, was only about 1.5% Cu. Gold grades were reciprocal to copper content. World War I and 1920's base-metal era production averaged 0.04 oz/t Au. Gold content climbed to 0.055 oz/t by 1933 and to over 1.0 oz/t in the final year of mining, 1938. This shifting grade reflects both the exhaustion of the base-metal ores and changes in gold's market price.

Massive Sulfide Ores versus Precious-metal Ores

A recurring point in this paper is the spatial separateness of the base-metal versus precious-metal mineralization. The U.V.X. was principally a base-metal massive sulfide deposit owing its high grade to geologic happenstance; the deposit was almost fully enriched to chalcocite and cuprite. The bulk of total production came from a single, nearly equidimensional orebody lying between the 1300 and 1600 levels. Lesser base-metal production came from so-called drag orebodies along and within the Verde fault and higher in elevation than the main orebody. These massive sulfide bodies averaged only 0.04 oz/t Au.

Two other ore types are of import here. One is the siliceous sulfide ores such as the Maintop (1110, 1202, and 1210) stope, the 1307-A stope, and the 1205 stope. These stopes locally contained in excess of 1.0 oz/t Au and 5.0 oz/t Ag and averaged over 0.1 oz/t Au and 1.0 oz/t Ag while producing significant amounts of copper. The other ore type is base metal poor and precious metal rich. These ores were very siliceous and contain base metals in the parts per million range only. Precious-metal abundances in these ores, however, were the greatest in the mine, often running over 0.5 oz/t Au and 3.0 oz/t Ag and averaging in production 0.4 oz/t Au and 2.0 oz/t Ag. It is this ore type that has been the focus of attention since the mid 1930s.

United Verde Extension production was sent to its own smelter in Clemenceau (Cottonwood) as a custom blend of massive sulfide and auriferous flux material shipped directly from the mine to the smelter. Sulfide and silica ores went to separate ore pockets, which controlled the flow to rail cars in the Josephine haulage tunnel (1300 level). Thus the appropriate amount of necessary flux could be shipped with each train load of sulfide ore. The flux carried enough gold to more than pay its own way. This advantage was one of many that made the U.V.X. such a profitable operation.

Development and Present Access

The Edith shaft provides the current exploration access (fig. 2). It and an adjacent shaft, the Audrey, 200 feet farther east, are both concrete-lined, three-compartment shafts. The Edith bottoms at the 1900 level, the Audrey at the 1700 level. Water level fluctuates around the sill of the 1300-level haulage tunnel. The mine has not been dewatered since its shutdown in 1938.

Levels accessible via the Edith shaft are the 550, 800, 950, 1100, and 1200. Levels below that are all on 100-foot intervals. Most of the sulfide ores were mined from the 1300 through 1500 levels. Siliceous ores came dominantly from the 950 and 1100 levels.

Caving of workings precludes easy access to any of the productive base-metal sulfide orebodies. Only a few siliceous bodies with insignificant production and insignificant gold content are accessible on the 800 and 1200 levels. These areas have been hand sampled. The prohibitive expense of reopening old workings limits exploration to underground diamond core drilling. Drilling is being done, at the time of writing, from stations on the 800, 950, and 1100 levels.

GEOLOGIC SETTING

The U.V.X. is a Proterozoic volcanogenic massive sulfide deposit (Anderson and Nash, 1972). It is within structurally deformed volcanic intermediate to felsic submarine flows, pyroclastics, and chemical precipitates. That sequence is now standing nearly vertical. Therefore, the level plans in figure 2 are effectively cross sections of the primary stratigraphy. Stratigraphic tops are to the northeast within the mine area.

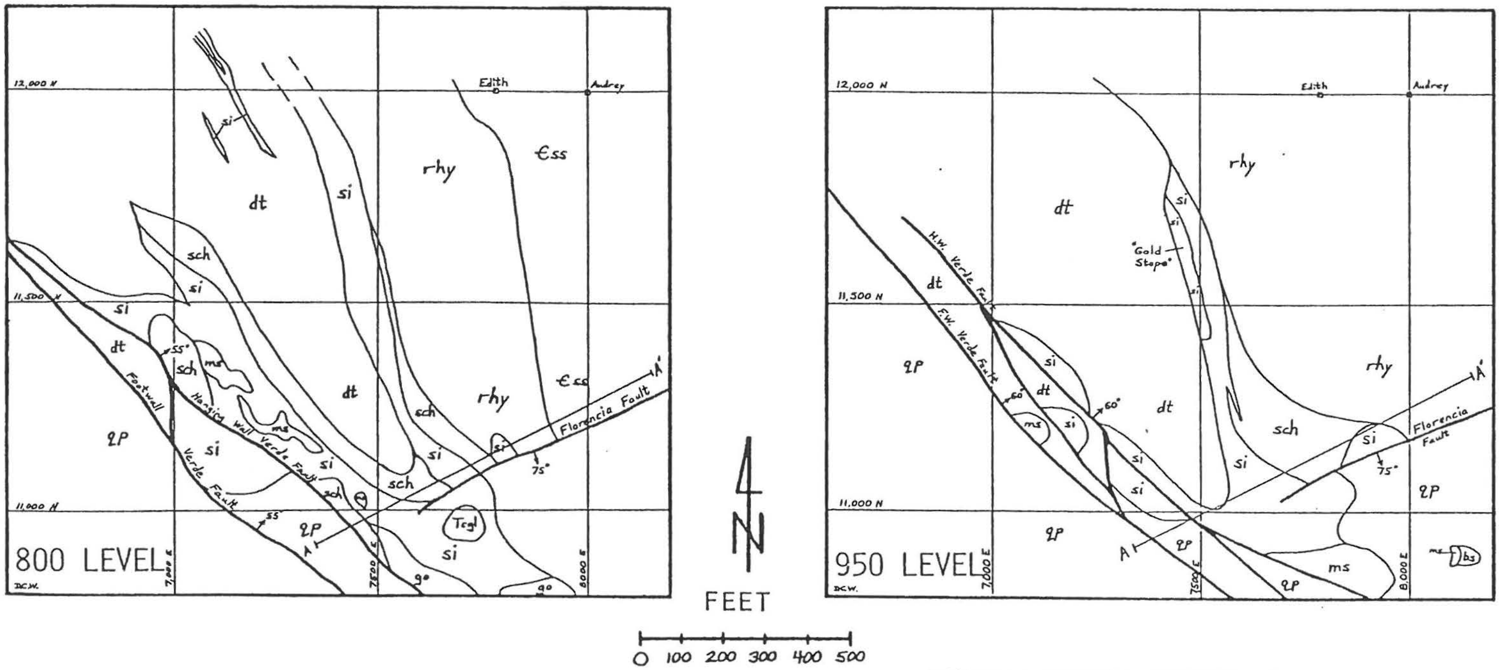
All rocks are in the greenschist facies of regional metamorphism. That and structural deformation intense enough to create isoclinal folds at a regional and outcrop scale have made recognition of protoliths a challenge. No current petrographic work backs the following discussion, which is based upon megascopic examination of rock textures and minerals in samples of drill core and of underground exposures.

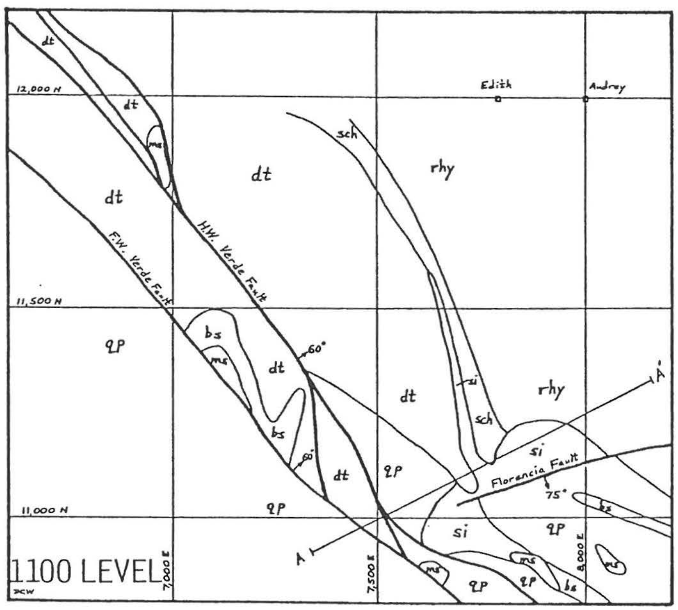
The U.V.X. is a blind orebody. It is completely buried by a sequence from the Cambrian Tapeats sandstone through Tertiary Hickey conglomerate, ash, and basalt flows. This burial is in part explained by the orebodies' location within the hanging wall of the Verde fault, a major northwesterly trending normal had a long and episodic history of complex movements. The result has been the slicing off of various-size chunks of the main massive sulfide body, which abuts the Verde fault, and their movement to higher elevations.

NATURE OF THE GOLD OCCURRENCES

Meta-chert Breccias

Gold occurs principally in meta-chert breccias extending laterally from the main massive sulfide orebody. These breccias, hereafter referred to only





UNITED VERDE EXTENSION MINE
LEVEL PLAN GEOLOGY

Tertiary	cgl	Conglomerate (Hickey Fm.)
Devonian	ls	Limestone (Martin Fm.)
Cambrian	ss	Sandstone (Tapeats Fm.)
Proterozoic	rhy	Rhyolitic and intermediate flows and pyroclastics
	sch	Schistose volcanics (Grapevine Gulch Fm.)
	si	Silica; massive, banded, and brecciated chert and silicified volcanics
	go	Gossan after ms
	ms	Massive sulfide
	bs	Black (chloritized) schist
	qp	Quartz porphyry (incl. Cleopatra Fm.)
	dt	"Diorite"; may be subvolcanic dome or possibly an extrusive andesitic flow

Figure 2. Mine-level plan view geology

as cherts, thin with distance from the main orebody, pinching to insignificance, both horizontally and vertically, within about 1,000 feet (figs. 2 and 3). They vary from massive, uniformly dark red from hematite stain through welded silica lapilli types to brecciated varieties with various size and color clasts, various matrix types, and even a diversity of breccia textures or degrees of brecciation.

The chert breccias display a variety of textural patterns suggestive of their origin. The simplest are the "jigsaw puzzle" and "crackle" breccias with very little matrix. Clasts have not been rotated away from their original positions or their neighbors, only fractured, thus slightly expanding total volume. Matrix material is hematite-stained and/or limonite-stained silica, sometimes containing a rock flour of the same composition as the clasts. Breccia fragments of this type are very angular.

Clasts themselves generally have more vague or ghostlike outlines of internal fragments. Second-generation breccias seem to be more the rule than the exception. First-generation clasts are sometimes lithic fragments, such as quartz porphyry, and commonly have some rounding. The fine fractures sometime cross only the internal fragments of the first-generation breccia but more often cut across those boundaries to the walls of the second-generation breccia fragments.

There is a continuum of breccia types from crackle breccias to fully matrix-supported breccias. Matrix can be up to 80 percent of the rock volume. Matrix-supported chert breccias more often have a heterogeneity of clast types and display variations in color. They are also more likely to have evidence of clast milling.

Thus far the massive cherts have been found nearly barren of gold, usually containing <0.005 oz/t. The most auriferous cherts are those that are brecciated. The gold is not visible. It may be extremely fine native metal with or without electrum. Assays check very consistently from one laboratory to another, suggesting the fineness and dissemination of the gold. It appears that this fine disseminated gold is probably occurring along the silica-healed fractures.

All the cherts run in excess of 90% SiO_2, sometimes over 98 percent. Iron content varies from less than 1% Fe_2O_3 to possibly 10 percent in certain thin ironstone facies. Many of the cherts contain vugs up to 10 percent by volume. They are generally merely voids but sometimes contain dark-red hematitic linings or clear microcrystalline drusy quartz linings. If malachite occurs, it is the last layer within vugs or along fractures, usually as a botryoidal crust. The vugs seem to result from hydraulic fracturing rather than from mineral removal such as dissolution of sulfides or carbonates.

Alteration

Two alteration types have been recognized as being of possible significance to understanding the gold occurrences. One is a characteristic clay alteration in both the hanging wall and footwall adjacent to the chert. Another is carbonate in the distant hanging wall, generally 100 to 300 feet stratigraphically above the chert.

The clay alteration is intense enough that the hanging-wall rock for 40 to 80 feet is bleached white, kaolinitic, and soft. Footwall clay alteration extends as little as 5 feet but is usually just as intense as the immediate hanging-wall alteration. Wall rocks are intermediate composition pyroclastics, except for one area where the footwall has been called meta-diorite. The feldspars of the tuffs and the diorite are pseudomorphed by the clay minerals. In some places a massive sericite layer, 1 to 3 feet thick, is at the hanging-wall contact between chert and the altered tuffs. Nearly pure kaolinite can also occur locally for thicknesses up to 5 feet.

The carbonate alteration is dominantly a distant hanging-wall phenomenon. Carbonate occurs as disseminated calcite and as discordant fine calcite veins, making up as much as several percentage of the rock. This carbonate rarely occurs within a hundred feet of the chert. It typically extends from 100 to 300 feet within the stratigraphic hanging wall, with the disseminated carbonate less distant from the chert and veinlets more distant. Although only a few drill penetrations of mineralized chert have been made at the time of this writing, it seems that the hanging-wall carbonate alteration is more prevalent above mineralized than unmineralized chert.

The silica, clay, carbonate alteration is in direct contrast to the Mg-rich black chlorite in masses and on fractures within the footwall to the base-metal massive sulfide body (Handverger, 1984).

Trace-metal Associations

A tight correlation exists between gold and silver and a series of trace metals (fig. 4). It is clear that whatever system(s) gave rise to the chert and gold also concentrated silver, arsenic, antimony, bismuth, tin, molybdenum, vanadium, copper, lead, and zinc. The contrast, for most of these elements, between mineralized versus unmineralized chert is just as great as the contrast between chert and wall rock.

Of all the trace elements correlated with gold, only silver is any more useful than gold itself in the search for gold. All the others have large abundances coincident with those of gold but no broader distribution and hence are not useful as guides to gold. Silver does slightly straddle the gold peaks. Hence large silver abundances without gold may indicate proximity to gold and suggest the merits of further sampling or another drill hole.

The base-metal association also requires comment. Although the semi-quantitative spectrographic analyses indicate "strong" copper, lead, and zinc distributions over broader intervals than the precious-metal concentrations, it is also true that those base-metal abundances may be obtainable anywhere within hundreds of feet of the stratigraphic succession. Within the chert analyzed for figure 4 there are no visible base-metal minerals except supergene malachite as fracture coatings and vug linings. With respect to contained metal value, the cherts are certainly base metal poor and precious metal enriched.

Gold Distribution and Geometry

Compilation of data from old mine records reasonably well documents the auriferous chert zone. The most productive area is known as the "gold stope," which was mined in the mid 1930s up to the time of shutdown. It accounted for nearly all the mining on the property in the last few months of operation.

The gold stope (fig. 2) is about 500 feet southwest of the Edith shaft. It is enlarged in longitudinal and cross section in figure 5. The gold stope is about 150 feet high and 350 feet long and averages 15 feet thick. It is nearly vertical and is wholly chert hosted. It is bounded to the west (footwall) and downdip by the diorite. The immediate hanging wall is a manganiferous, cherty ironstone, massive to faintly banded, and is silver rich. Above that is the characteristically clay-altered hanging-wall tuff, well

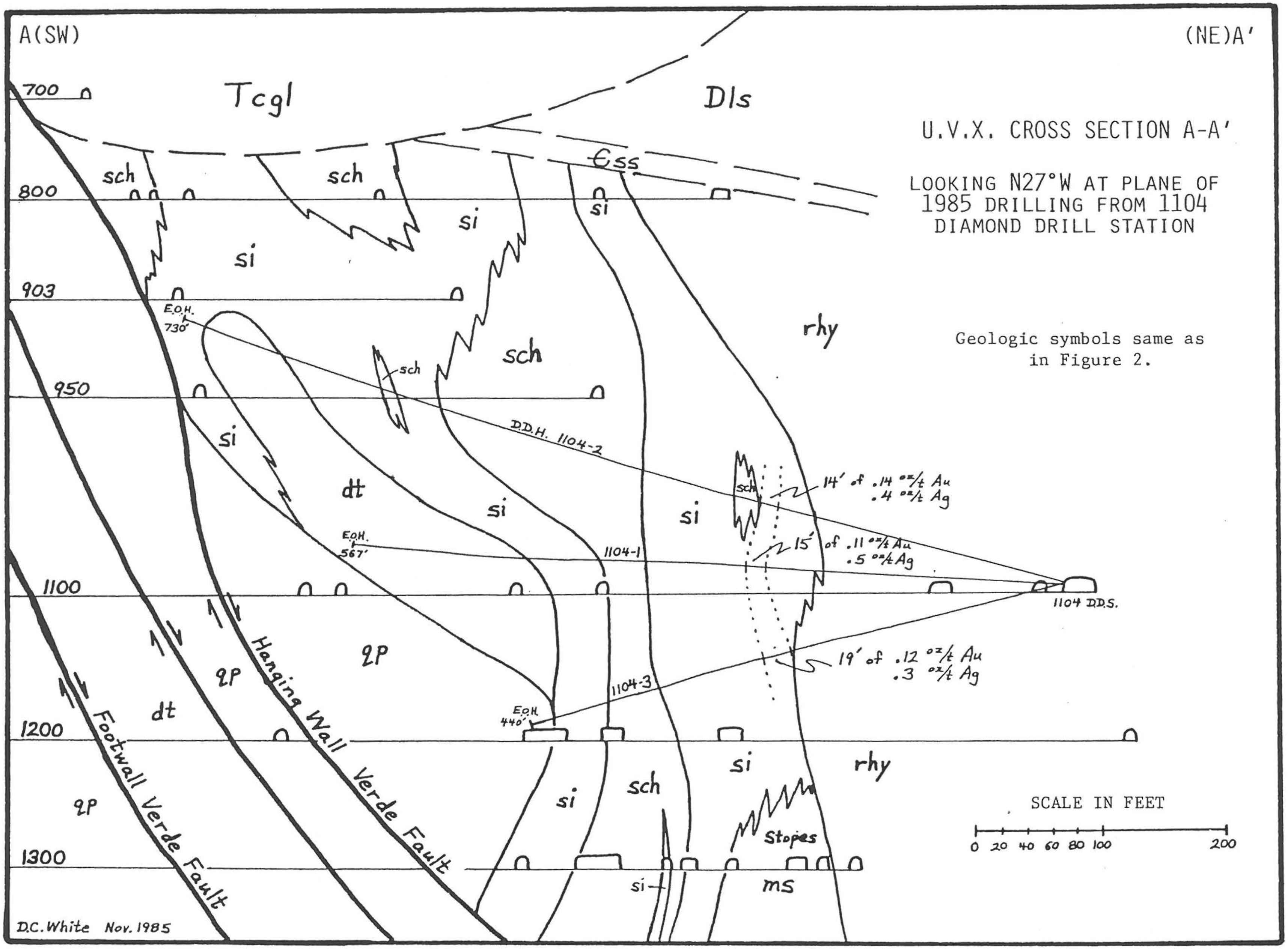
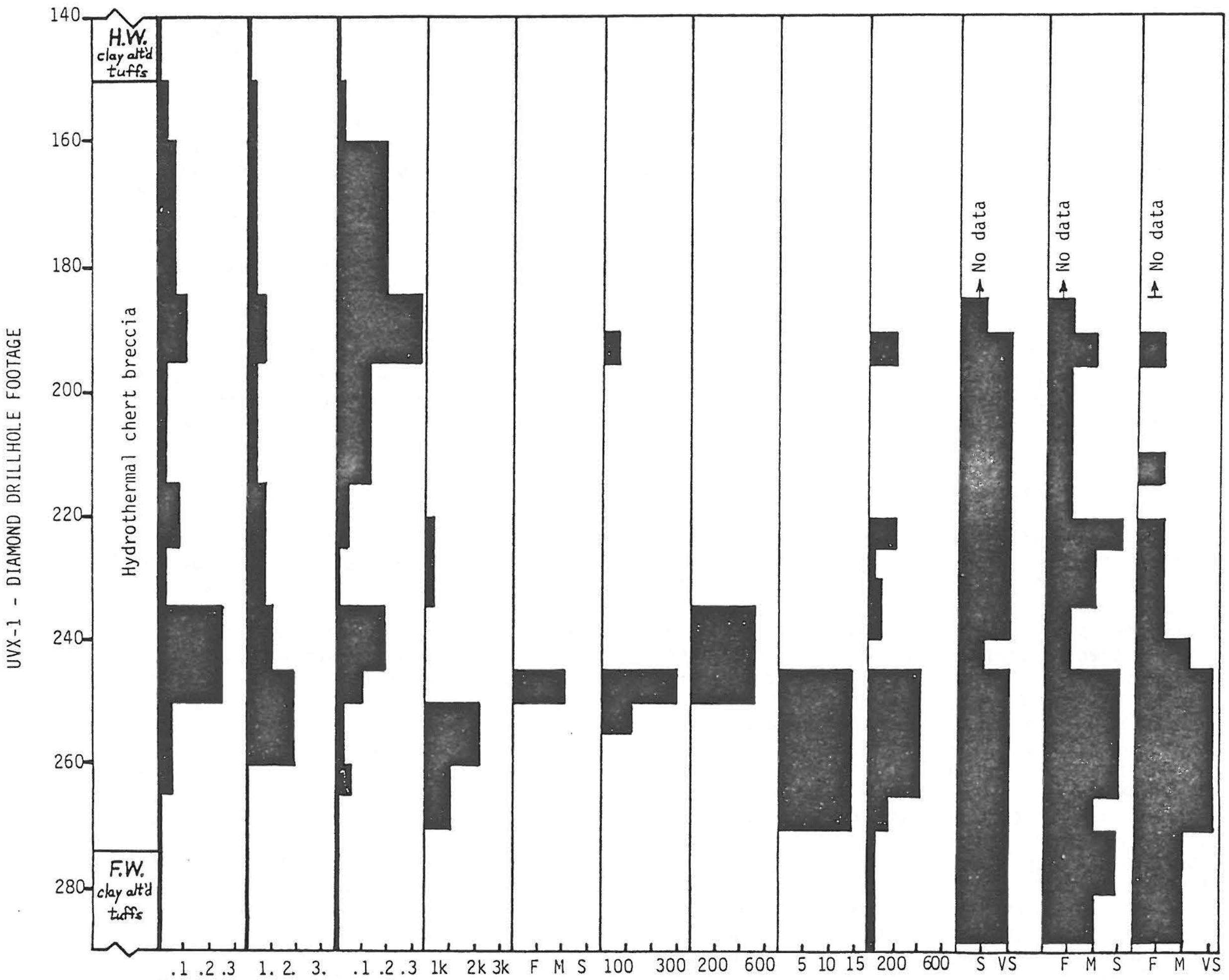


Figure 3. Cross section



	Au oz/t	Ag oz/t	Au/Ag	As ppm	Sb semi-quant.	Bi ppm	Sn ppm	Mo ppm	V ppm	Cu semi-quant.	Pb semi-quant.	Zn semi-quant.
Hanging Wall	<.005	≤ 0.4	<.05	< 200	Not detected	< 20	< 10	< 5	< 20	Strong-Very strong	Not detected-Medium	Not detected-Strong
Less mineralized chert	<.005-.05	0.2-2.0	.1-.5	200-400	Not detected	< 20	10-50	< 5	20-200	Strong-Very strong	Faint-Strong	Not detected-Strong
More mineralized chert	.05-0.5	0.2-4.0	.1-.5	400-3,000	"Medium"	20-300	50-1500	5-25	200-500	Very strong	Strong	Very Strong
"Gold stope" high grade	0.5-5.0	0.5-8.0	.1-5.	-	-	-	-	-	-	-	-	-
Footwall	< .005	≤ 0.4	< .05	< 200	Not detected	< 20	< 10	< 5	< 20	Very strong	Faint-Strong	Medium-strong

Figure 4. Trace-metal associates, histogram, and chart

foliated, and known here and at the United Verde mine as the Grapevine Gulch Formation.

The gold stope contains no visible base metals, although, as is typical, they do occur in the parts per million range. It contained gold, ranging up to 5 oz/t. Distributions of grade by tonnage are summarized adjacent to figure 5. Overall, the gold stope produced about 35,000 tons averaging 0.4 oz/t Au and 2.0 oz/t Ag.

Some trends in the geometry of the mineralization are apparent in contoured grades (fig. 5). First, there are two bull's-eyes in excess of 1.0 oz/t, major bodies over 0.5 oz/t, and margins 0.1 to 0.5 oz/t gold. In the cross sections the mineralization is seen to form a cone with base against the footwall and top toward the hanging wall. Best gold grades cluster at the footwall. Both the shape and grade distribution are suggestive of a vent accumulation.

DISCUSSION AND CONCLUSIONS

The capping and lateral extension relationship of the cherts to the main U.V.X. massive sulfide body suggest a sequence of deposition. Cherts thin with distance from the main vent and massive sulfide body. The primary cherts were likely a combination of massive chemical precipitates and admixed explosion and hydrothermal breccias. These are effectively chert agglomerates just as the higher parts of the section contain rhyolite agglomerate. The ratio of massive to brecciated materials is a function of proximity to the main vent and force of vent explosions.

Gold, if mainly confined to the quartz veinlets in clasts of early or first-generation breccia, must have occurred during some of the earliest hydrothermal and explosion—fracturing episodes of the chert's history. Alternatively, if gold content of the matrix is appreciable, it could have been emplaced during the later matrix-forming and/or matrix-silicification phases, perhaps even after the accumulation of several hundred feet of overlying pyroclastic rocks.

These later stages of hydraulic fracturing, expansion in volume, matrix injection, and silicification include the alteration phases with footwall and hanging-wall argillization and distant hanging-wall carbonate alteration. Graphic displays of the hydrofracturing and fluid movement are the crackle breccias, tiny pebble dikes with flow banding, the matrix of fine rock flour, and clasts rounded by tumbling. The present chert with its multiple generation breccias is the product of sea-floor cherty iron formation exhalites (particularly more distal) hydrothermal breccias (particularly on the vent slopes) and later, after burial and development of a plug and confining pressure, hydraulic fracturing, and further silicification.

The gold stope with its massive manganiferous cherty ironstones was probably formed in a more quiescent environment flanking the massive sulfide body. This environment allowed undisturbed accumulation of small but high-grade auriferous vent deposits around subordinate vents. The vent cones were only a few feet high and gently sloped to extremes of only a few hundred feet corresponding to the mined-out gold stope.

Although all the gold is considered originally hypogene, the extent to which any of the present gold distribution has been affected by later supergene mechanisms or early sea floor oxidation is not known. Some enrichment must be suspected because of the extent of oxidation and the distribution of gold at higher elevations than the massive sulfides, along vertically standing stratigraphy. Indeed, at the United Verde mine, DeWitt and Waegli (1985) reported approximately an order-of-magnitude increase in gold concentration (0.03 to 0.2 oz/t) from unoxidized to oxidized ores. That contrast is not displayed at the U.V.X. because almost everything is oxidized, including the main orebody. Only the protore from the 1700 level down is unoxidized. Although gold abundances are not known there, the fact that they are not reported suggests 0.04 oz/t or less.

There is also some evidence against supergene enrichment such as association of gold with silver and numerous trace metals. It is difficult to rationalize that correlation with secondary enrichment. Thus it seems we are dealing with reasonably well-preserved Proterozoic syngenetic gold deposits.

The U.V.X. chert-hosted gold represents an episode of volcanogenic mineralization, following a major flow-dominated sequence and massive sulfide formation, and preceding a major volcaniclastic-dominated sequence. This closely matches current interpretations at the United Verde and at other similar deposits. The gold's location in a hydrothermal environment on a vent slope explains why the gold deposits are in detail discordant but overall stratabound.

There are increasing evidence and interpretation that "gold-only" deposits (Hodgson and MacGeehan, 1982) are distinct in both space and time from the pyritic base-metal sulfide deposits. The gold-only deposits occur at the interface of the flow-dominated part of the section with the pyroclastic-epiclastic parts of the section rather than enveloped by flows and are associated with Ag, Cr. W, F, Sn, CO_2 rather than Fe, Cu, Zn, Pb, and Cl as in the base-metal deposits. Both deposit types are stratabound but, although base-metal massive sulfides are usually stratiform, gold-only deposits are discordant in detail.

Henley (n.d.) reported that the fluids transporting gold in geothermal systems to be H_2S and CO_2 rich. Gold, silver, and their associates are capable of thiosulfide, carbonate, and carbonyl complexing in addition to chloride complexing like the base metals. It is suggested here that the gold-bearing fluids were not rapidly convecting sea water as in the instance of base-metal transport and deposition but were later much more modified and evolved fluids comparable to Henley's acid-sulfate fluids of volcanic fumeroles and that this changing fluid composition resulted in the separation of base and precious metals in time and space.

Acknowledgments. The keen insight and unreserved sharing of knowledge by Robert W. Hodder is most appreciated. Thanks to Ben F. Dickerson, III and Carole A. O'Brien for their continuing trust in my work and for permission to present these data. Credit is due Paul A. Handverger and Verde Exploration for recognizing the gold potential of the U.V.X. and bringing it to others' attention. I also thank Paul A. Lindberg for sharing his views on the Verde district geology. This paper's content, however, does not necessarily coincide with the views of any of the above.

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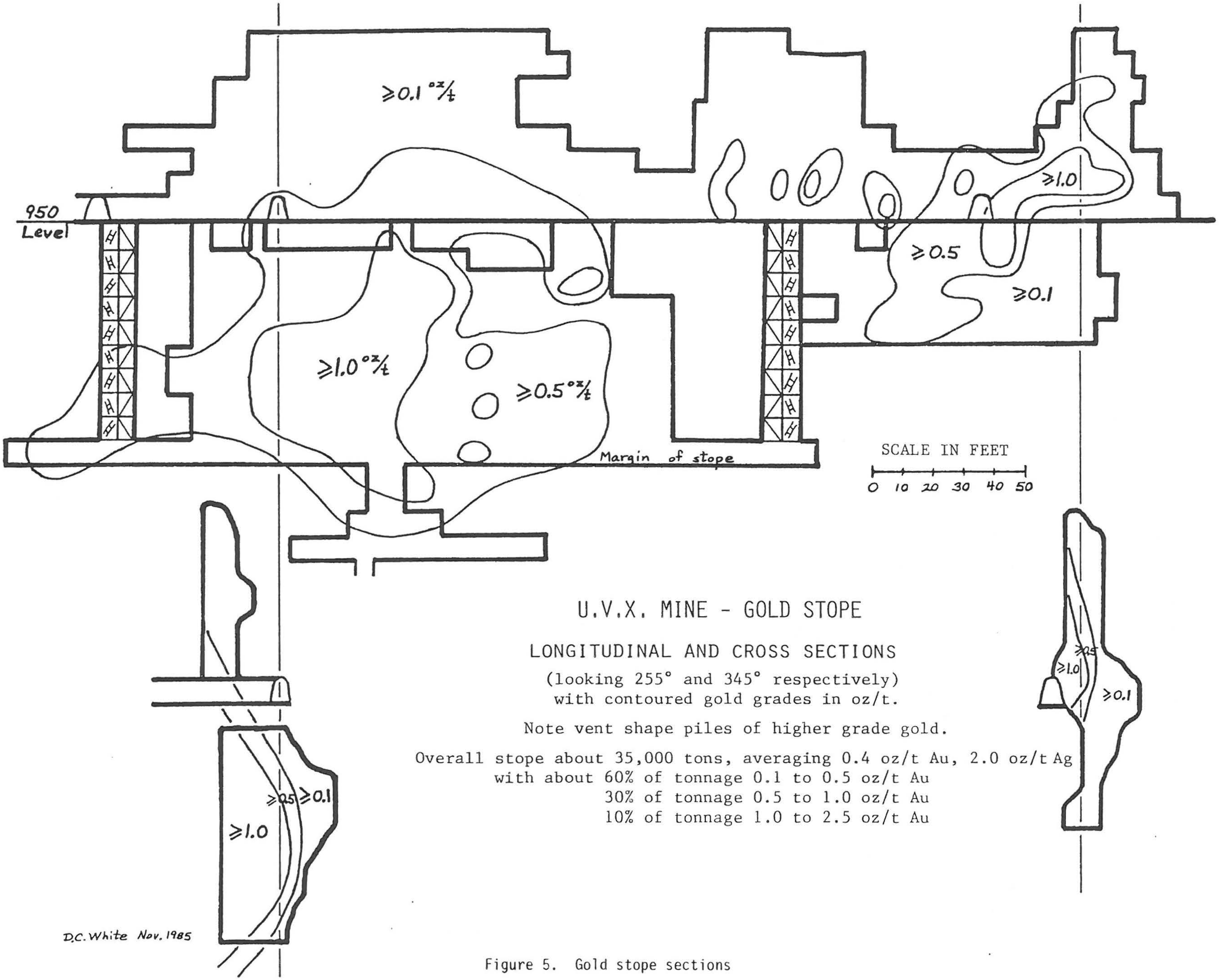

Figure 5. Gold stope sections

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A PRELIMINARY REPORT ON A PETROLOGICAL, GEOCHEMICAL, AND STABLE-ISOTOPE STUDY OF THE OREBODY AND ASSOCIATED ALTERATION, UNITED VERDE VOLCANOGENIC MASSIVE SULFIDE DEPOSIT JEROME, ARIZONA

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INTRODUCTION

This is a preliminary report on an ongoing petrographic, geochemical, and stable-isotope study of the orebody and associated alteration at the United Verde volcanogenic massive sulfide deposit, Jerome, Arizona. This work is for a dissertation being prepared under the direction of Drs. Chris J. Eastoe and S. R. Titley.

The project entails detailed mapping of the lithologic units and alteration in the Cleopatra Quartz Porphyry of Anderson and Creasey (1958) (fig. 1) and less detailed mapping of alteration in the underlying Deception Rhyolite and Shea Basalt. In conjunction with field work, petrographic and microprobe analyses of thin sections will aid in identifying minerals, textures, phase relations, and chemical components of certain phases within the rocks. Major- and trace-element analyses will facilitate discussion of alteration effects, qualitatively and quantitatively, and allow determination of progenitor rock types prior to alteration. Carbon, sulfur, and oxygen isotopes will be used to discuss physicochemical conditions within the altering hydrothermal system. Oxygen isotopes will also be used to delineate the extent of the hydrothermal circulation cell. Some fluid-inclusion analyses will be done to test the results of Anderson and Nash (1972), who believed that fluid inclusions should not be used to discuss the hydrothermal system because of metamorphism.

This paper summarizes the mapping completed thus far and will discuss alteration facies and present a preliminary interpretation of sulfur isotope data.

GENERAL GEOLOGY

The Cleopatra Quartz Porphyry, as shown in figure 1, is typically lumped as one unit (e.g., Anderson and Creasey, 1958). Field work for this project has defined distinct mappable lithologic units within the Cleopatra Quartz Porphyry. The portion of the quartz porphyry north of the Hull fault (fig. 1) consists of two dominant lithological types: a quartz porphyry unit and a quartz feldspar porphyry unit (fig. 2). Volcaniclastic sediments and some chert beds are also present.

The quartz porphyry has a very characteristic appearance in both hand sample and thin section. The rock is typically massive with 10-20% quartz phenocrysts. In thin section these quartz phenocrysts have secondary overgrowths of quartz defined by fine inclusions and lie within a matrix of 0.1-0.2-mm subrounded quartz grains surrounded by phyllosilicates and/or fine-grained quartz. The rounding of quartz in the matrix appears to be an alteration phenomenon, as does the lack of feldspars in this rock. The quartz porphyry unit is interpreted to be a massive flow and/or subvolcanic intrusion.

The quartz feldspar porphyry is interpreted to lie in the stratigraphic hanging wall of the United Verde orebody (fig. 2). It is massive to brecciated and consists of quartz and feldspar phenocrysts in a fine-grained matrix of quartz±sericite±feldspar±chlorite±hematite±carbonate.

The Cleopatra Quartz Porphyry exposed south of the Hull fault and in Deception Canyon is an interesting assemblage of rock types, including crystal tuffs, lapilla tuffs, breccias, fine to coarse sedimentary layers, chert horizons, and massive fresh quartz feldspar porphyry representing intrusions or flows. The mapping of this area is ongoing; therefore, a map is not available. A stratigraphic section through the Cleopatra package, located on figure 1, is shown in figure 3. Other sections through the package often contain a much more tuffaceous component than this one. The (pillowed?) dacite has been previously mapped as part of the Deception Rhyolite rather than the Cleopatra Quartz Porphyry (e.g., Anderson and Creasey, 1958; Lindberg and Jacobson, 1974). The quartz feldspar porphyry immediately overlying the Deception Rhyolite is a massive to fragmental rock interpreted at the present to represent a large flow or package of flows.

ALTERATION

Four alteration assemblages have been identified within the Cleopatra Quartz Porphyry north of the Hull fault. These include:

1. A chloritic assemblage—chlorite±sericite±quartz.
2. A sericitic assemblage—sericite±chlorite±quartz.
3. A hematitic assemblage—hematite+quartz±chlorite±carbonate±sericite.

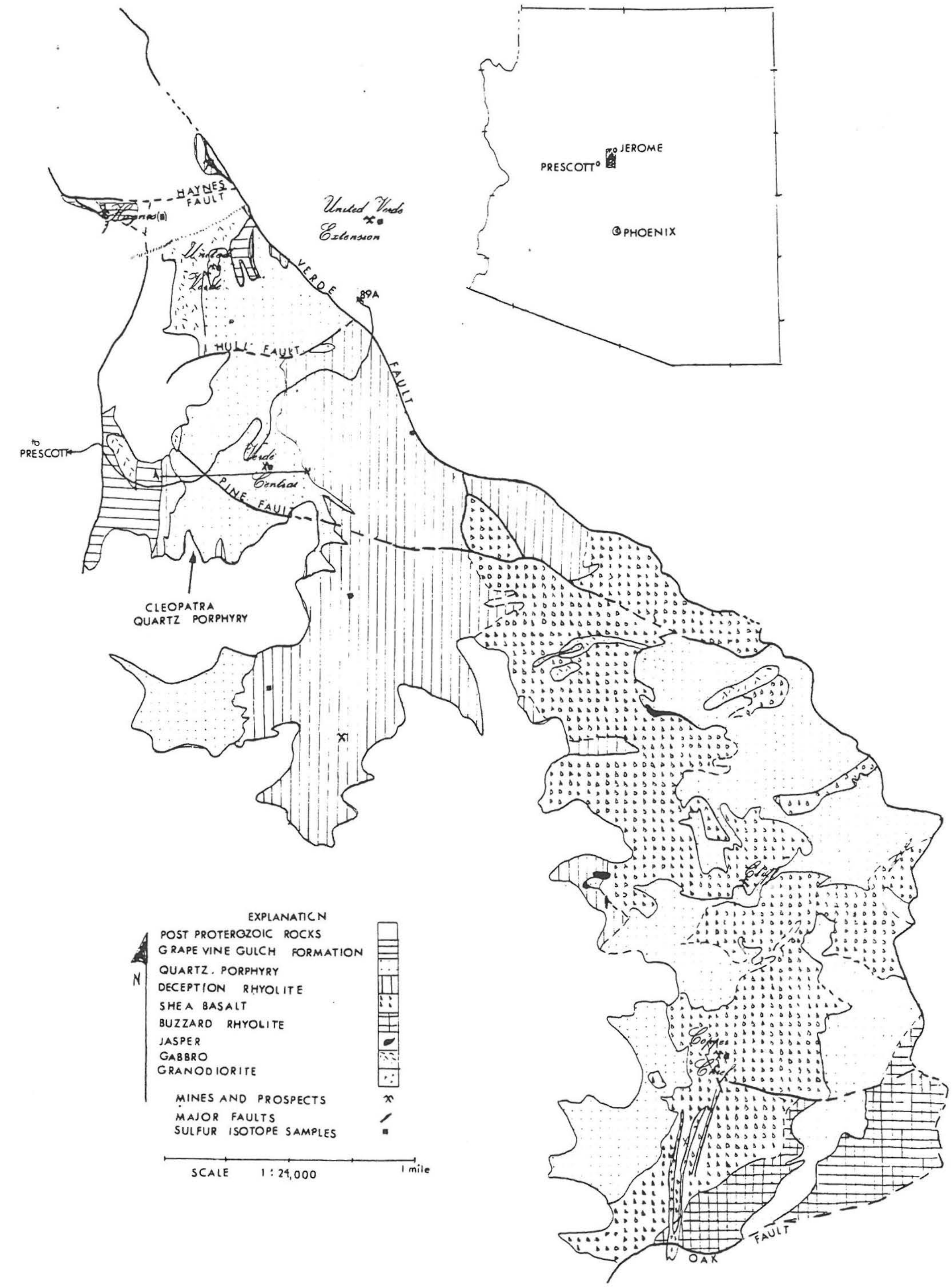

Figure 1. Geologic map of the study area. (Adapted from Anderson and Creasey, 1958).

4. A 'mottled' assemblage—sericite+quartz+chlorite+hematite+carbonate±epidote.

The chloritic assemblage varies from 10-20% chlorite, 30-50% sericite, and the remainder quartz (chloritic in fig. 2) to 95% chlorite (black schist). The sericitic assemblage varies from sericite schist to a siliceous and sericitic massive quartz porphyry. These two alteration assemblages occur predominantly in the footwall of the orebody. The chloritic assemblage is also found in the hanging wall, where the chlorite appears to be more iron rich than that in the footwall chloritized porphyry.

Hematitic alteration varies from hematitic chert-like veining to a pervasive hematization of the rock.

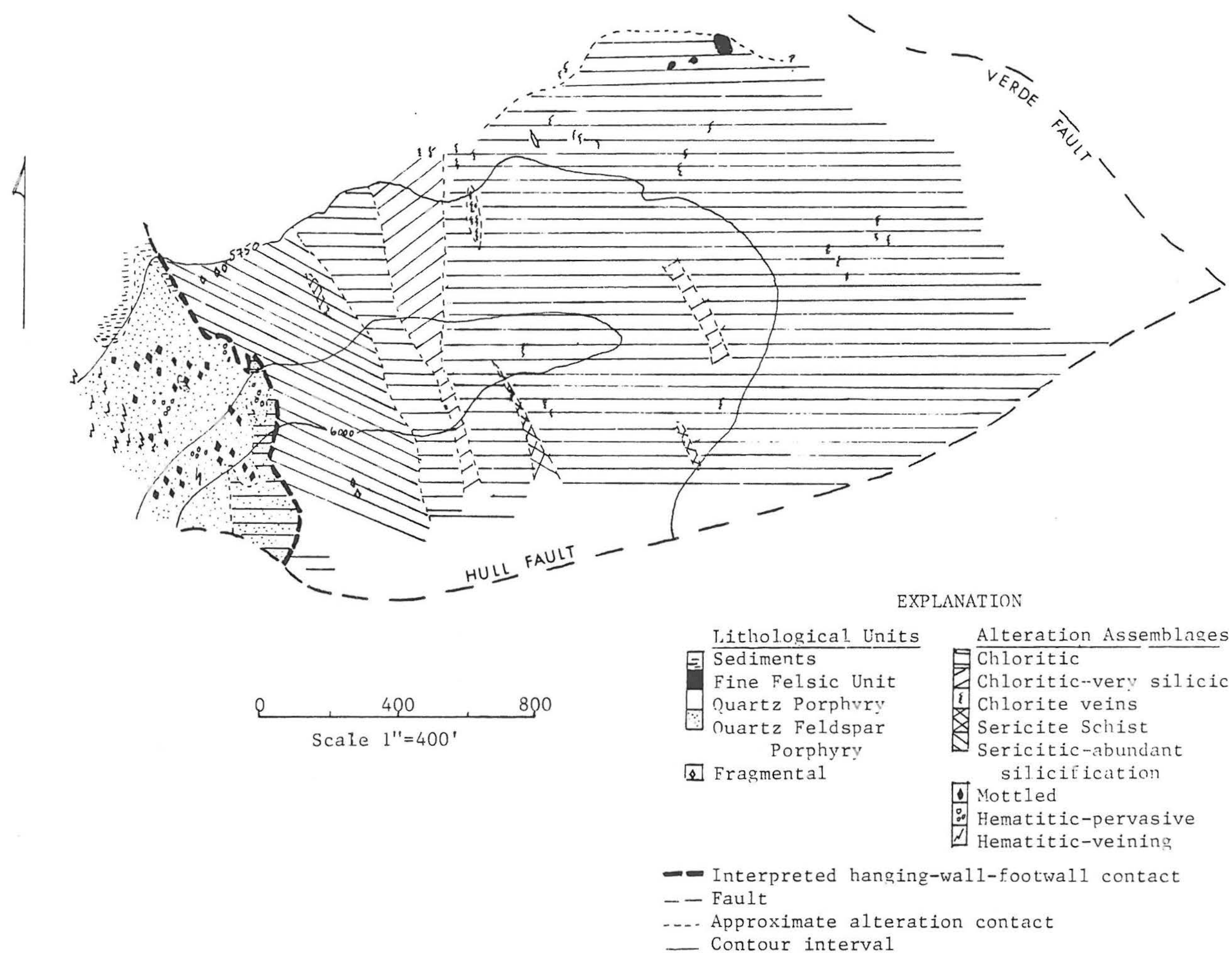

Figure 2. Map of lithologic units and alteration assemblages, Cleopatra Hill

The latter has occurred along with the addition of silica and carbonate to produce a matrix of 10% hematite, 60% quartz, 15% sericite, and up to 15% carbonate. Carbonate partially replaces both quartz and feldspar phenocrysts. Rock that has abundant hematitic veining is typically very silicified.

The 'mottled' assemblage is found solely in fragmental rocks. In hand sample these rocks consist of irregularly shaped pinkish fragments in a greenish-gray matrix. The boundaries between these domains are irregular and diffuse in both hand specimen and thin section. The lighter colored domain consists of predominantly sericite with some small lenses of plagioclase (albite?). This domain is typically the coarser grained of the two and contains subhedral quartz and feldspar phenocrysts. The greenish-gray domain consists of 80-90% fine quartz with angular pieces of quartz and feldspar that are being replaced by the matrix quartz. Carbonate, chlorite, hematite, and epidote are present in both domains.

The hematitic and mottled alteration types are presently interpreted to represent a hanging-wall hydrothermal alteration phenomenon.

PRELIMINARY INTERPRETATION OF THE HANGING-WALL—FOOTWALL CONTACT OF THE UNITED VERDE OREBODY

The hanging-wall—footwall contact north of the Hull fault is represented by the sudden appearance of feldspars and relatively fresh rock that is petrographically distinct from the footwall quartz porphyry and by the appearance of hematitic and 'mottled' alteration.

South of the Hull fault this contact becomes somewhat obscured because of the preservation of feldspars in the footwall rocks. This is due to a lower intensity of alteration laterally away from the orebody. The petrographic identity of the footwall may also be lost due to volcanic facies changes. However, if one uses the presence of fresh rocks and hematitic alteration as criteria for identification of the hanging wall, recognition of the contact between the distal hanging wall and footwall appears possible. In figure 3 this contact is tentatively interpreted to be the basal sediment and chert horizon. Above this horizon is hematitic alteration, 'mottled' alteration, and fresh felsic rocks.

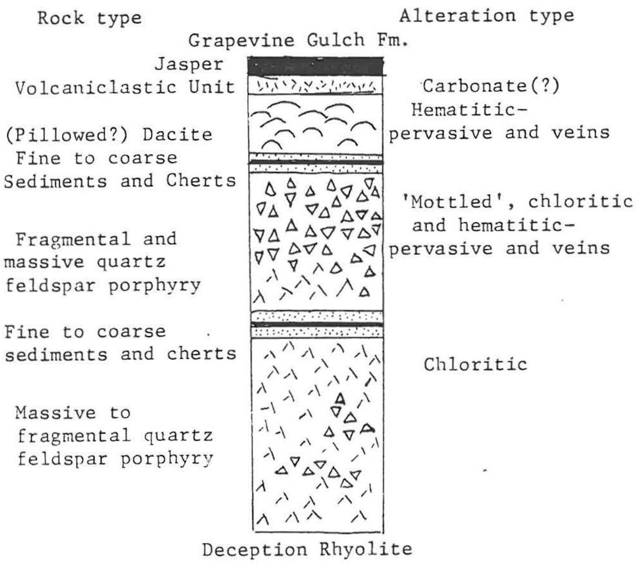

Figure 3. Schematic stratigraphic section through the Cleopatra Quartz Porphyry south of the Hull fault. General location of section is shown in figure 1.

DECEPTION RHYOLITE—CLEOPATRA QUARTZ PORPHYRY CONTACT

Along the Deception—Cleopatra contact lie small lenses of black schist, cherts, sericite schist, and sulfides. Carbonate alteration is present as is silicification. One exposure along the contact revealed a coarse fragmental unit with silicified blocks up to 1 meter in the maximum direction and what appear to be room-size blocks. This fragmental unit may represent a slump breccia based on the size of the blocks, their angular shapes, and the chaotic nature of the unit.

SULFUR ISOTOPE DATA

Sulfur minerals from the following occurrences were sampled for sulfur-isotope analyses: (1) laterally and vertically through the United Verde orebody, (2) United Verde Extension orebody, (3) Copper Chief orebody, (4) Verde Central orebody, (5) Haynes orebody, (6) several prospects within the Deception Rhyolite, and (7) cherts in the locality of the Copper Chief orebody (fig. 1). All analytical results were within -1 and +1.3 per mil similar to other Archean and Proterozoic volcanogenic massive sulfide deposits (Franklin, :Lyndon, and Sangster, 1981). If there was no homogenization of $\delta^{34}S$ following deposition, the implications of these data are that (1) there was no biogenic activity, (2) no significant oxidation-reduction reactions occurred within the solution that deposited the sulfides, and (3) the potential sources of sulfur include magmatic, volcanogenic, and/or an H_2S-dominated seawater reservoir.

CONCLUSIONS

Preliminary work at Jerome has defined distinct footwall and hanging-wall alteration packages as well as mappable lithological units in the Cleopatra Quartz Porphyry. The chlorite assemblage (predominantly Mg-chlorite) and sericitic assemblage are dominant in the footwall to the United Verde orebody. The hematitic and 'mottled' assemblages represent a hanging-wall phenomenon.

Completion of mapping should validate the delineation of the hanging-wall—footwall boundary. Analytical methods as well as thin-section analyses will serve to place constraints on the extent and physicochemical conditions of the alteration and ore-depositing system.

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GEOLOGY OF THE COPPER CHIEF MINE, JEROME DISTRICT, ARIZONA

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GENERAL BACKGROUND:

The Copper Chief mine was the third largest mine in the Jerome Mining District. Moderate amounts of copper, gold, and silver were produced during the interval from 1904-1933 and minor copper oxide ore was mined during World War II. The known ores outcropped as oxidized gossans after massive sulfide. The adjacent Shea vein mine is unique in the Jerome area in that high grade pods of silver ore were mined from a quartz-siderite vein which crosscuts rock units, polyphase folds, and the post-folding granodiorite intrusive dikes.

The name "Copper Chief" is now applied to the entire massive sulfide zone and associated gossans. At the time of Waldemar Lindgren's visit in 1922 (1) it was separated into the Copper Chief and Iron King claim (Equator Mining Company). Because of confusion with the Iron King mine near Humboldt, Arizona the name was unofficially dropped. The term "Iron King" may still appear on some topographic maps, however.

The original shaft which was sunk on the Copper Chief gossan found oxidation to depths of 230 feet. Most of the sulfide ore which was mined below this point was located on the deeper eastern portion of the orebody. Lindgren (1) reported that "less than half the oxidized material was ore and that 15 percent of the sulphide body could be mined at a profit," and that "the oxidized ore is siliceous and contains a little copper carbonate and in places cerussite indicating that galena must have occurred in the primary ore. The ore milled yielded 0.3 ounce of gold and about 6 ounces of silver to the ton." He further reported that a 5 foot thick supergene ore blanket contained sooty chalcocite and contained "as much as 40 ounces of silver and 0.75 ounce of gold to the ton."

Complete production figures are poorly documented but statistics cited (2) report 1,300,000 pounds of copper produced from the Equator mine during the period from 1904-1905. Between 1916-1923 the Copper Chief mine produced \$530,000 in gold and \$372,000 in silver, with no copper production reported. Ores produced after these dates were probably minor in quantity and value. Lindgren (1) reported that the Shea vein had produced small amounts of ore containing "pyrite, tetrahedrite, chalcopyrite, arsenopyrite, and also a little galena. In the best part of the ore lens, west of the shaft on the 200 foot level, the banded tetrahedrite ore contained as much as 100 ounces of silver to the ton. A few carloads of this ore were shipped."

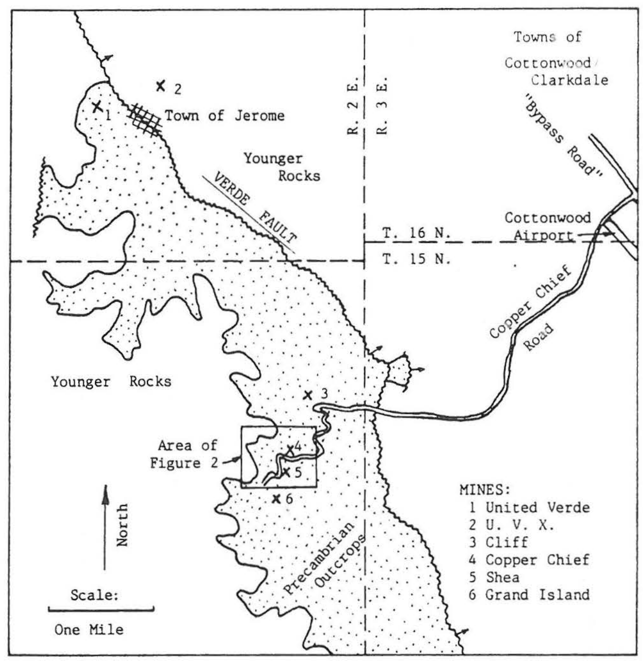

Figure 1, Location map of the Jerome Mining District showing selected mines and prospects.

PRE-1971 GEOLOGIC MAPPING AND CONCEPTS:

The published maps and information contained in the U.S.G.S. professional paper on Jerome (3) are a generalization of G.W.H. Norman's 1"=200' geologic mapping completed in early 1950 (4). During the time of mining ores throughout the Jerome District it was believed that all massive sulfide ores were produced by hydrothermal replacement of selected volcanic and sedimentary host beds.

Norman did not differentiate between various types of "quartz porphyry" which are now distinctly mapped as separate units. Nor did any of the earlier workers in the Copper Chief area make any distinction between basalt flows (sometimes pillowed), and the intrusive diorite found all along the western margin of the mine area. It also became clear that effects of folding were either misunderstood or ignored in the mapping and exploration processes.

Nevertheless, the work of Norman (4) and Anderson and Creasey (3) had a profound influence on the overall understanding of the district and laid a solid foundation for future work.

POST-1971 GEOLOGIC MAPPING AND CONCEPTS:

Following the publication of the professional paper on Jerome in 1958 (3) there was an increasing acceptance by a number of workers that many massive sulfide deposits throughout the world were products of volcanic processes. The volcanogenic concept unlocked many of the mysteries that were not understood clearly before. Paul Handverger's work on magnesian chlorite in the footwall of the massive sulfide bodies (5) was patterned after similar studies in the Noranda District in Canada.

Beginning in 1971 the author began mapping in the Jerome District with the Anaconda Company, and this led to an agreement to map a large portion of the outcropping Precambrian rocks. Much of this land belonged to the Phelps Dodge Corporation. By 1975 much of the complex stratigraphic and structural synthesis was completed. A specific request by Phelps Dodge in 1983 led to the detailed mapping on scales of 1"=200' and 1"=100' in the immediate Copper Chief mine area.

The mapping techniques used by the author in this district utilize the best available topographic base map, survey control as required for accuracy, and the tracing out of individual contacts throughout their folded courses. This form of "contact mapping" is the only method known by the author to delineate the complexities of folding and facies changes occurring in poly-phase deformed terrain.

The Copper Chief deposit is a classic example of a volcanogenic massive sulfide. There is a clear dichotomy between an altered "Lower Succession" and a post-ore "Upper Succession" as postulated by Meyer for the United Verde area in 1972 (6). The small size of the deposit is a direct reflection of the small volumes of pre-ore, host rhyolites. There are a number of similarities of the Copper Chief deposit to many of the described Kuroko ore sites located close to the apex of small siliceous submarine domes and breccia piles.

GEOLOGIC NOMENCLATURE:

Anderson and Creasey have applied the term Ash Creek group to the volcanic and sedimentary rocks of the Jerome District (3). The individual formations within this group have been widely applied to the region, but the only one retained in this report is the Shea Basalt. Post-1971 mapping in the district demands that a re-interpretation of the stratigraphy for the Jerome District is in order, especially based upon more detail and structural understanding.

PRECAMBRIAN GEOLOGY OF THE COPPER CHIEF AREA:

The unambiguous base to the rock succession in the Copper Chief mine area is the Shea Basalt. It is generally a massive, structureless flow rock but sometimes it exhibits large, well-formed pillow structures. At the tops of thick flows a thin hyaloclastite horizon can be discerned. On occasion a thin, discontinuous jasper horizon can effectively trace out superimposed structural effects. In a general way the Shea Basalt lies at lower topographic levels than other rocks and it outcrops extensively to the east and southeast of the mine area. Excellent pillow structures can be seen in the gully exposures approximately 250 feet due north of the Shea mine shaft. An interflow jasper horizon, now folded, can be seen crossing the access road (Forest Service No. 493) where it first encounters the large, eastern-most Copper Chief mine dump.

Figure 2 shows the geology of the area based on the 1983 detailed mapping. The Shea Basalt, and perhaps other higher level basalts, hyaloclastites and associated tuffs are all marked with the symbol B for simplicity.

Outcrops of rhyolite lava and associated breccia conformably overlie the basalt flows. A continuous rhyolite sheet, severely poly-phase folded, extends from outcrops seen below the access road (east of the mine) to a point subjacent to the main massive sulfide gossan. On the map this is shown by the symbol R which includes massive to rinded flows, flow breccias, and local minor tuff layers. It is clear from mapping that this rhyolite sheet has distinct areal limits. It is found from the area near the western end of the orebody and extends to the east where much of it has been eroded off the Shea Basalt basement.

In sharp contrast is a localized mass of rock of uncertain parentage, but tentatively classed as a dacite. It outcrops to the west of the orebody and may represent an emission of flows, tuffs, and breccias that were time equivalent with the rhyolite, but separated in space. On the maps this unit is shown by the symbol Dc. It is not known to be in contact with massive sulfide lenses but it contains associated jasper exhalites related to ore-forming processes.

The most important rock type believed to be responsible for massive sulfide development is the "quartz porphyry" which directly underlies the western end of the Copper Chief orebody. Megascopically it is identical to the "Silver Plate quartz porhyry" further to the north, and to the Cleopatra "quartz porphyry" which hosts the United Verde and U.V.X. ores further to the north. It is the author's belief that this quartz phenocryst-rich rhyolite is most likely time-equivalent with the Cleopatra.

Field relationships are somewhat ambiguous as to the exact sequencing of rhyolite, dacite (?), and quartz porphyry. There are a number of reasons for the ambiguity. Poly-phase folds are very severe in this area and it is sometimes unclear whether or not an observed fold closure is anticlinal or synclinal. Another problem arises with the pinching out of mappable horizons, followed by tight folding. The main Copper Chief adit was driven to the north into the orebody but, unfortunately, lies beneath the "Flat Fault" which moves the upper plate and surface exposures an undetermined distance to the east. To complicate matters further the extant mine maps and cross sections from the days of mining used such terms as: "Ledge Matter, Greenstone, Acid Eruptive, etc." to describe the rocks encountered (7).

A preferred stratigraphic model is suggested in Figure 3 which attempts to show the relationships in a pre-fold position. This tentative model will, no doubt, be subject to modification as exploration continues in the area. Less ambiguous, however, is the field observation that each of the three units can lie directly on the Shea Basalt basement because of their limited areal extent. The "quartz porphyry" is believed to have been a flow rock and where it underlies ore it is strongly chloritized.

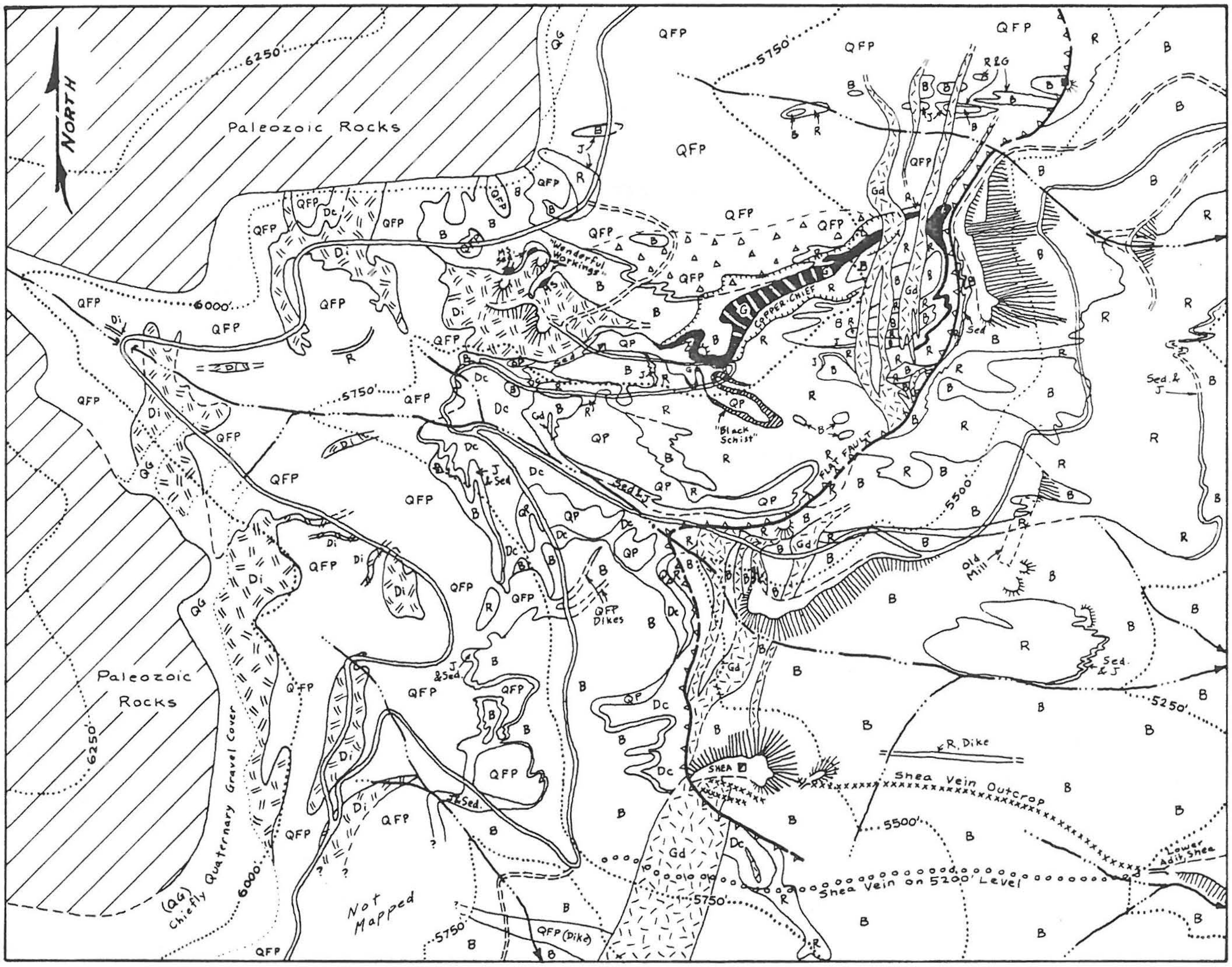

Figure 2, Geologic map of the Copper Chief and Shea mine area, Jerome Mining District, Arizona.

This map is derived from 1"=200' and 1"=100' geologic mapping in 1983. Portions of the detail have been simplified for purposes of clarity. Access to the property is by Forest Service Road No. 493, or from Jerome via the Pipeline Road (See Figure 1).

Mapping Symbols:

- Roads
- Copper Chief Caved Zone
- Flat Fault (± Quartz vein)
- Shea Vein Quartz Outcrop
- Mine Portal
- Mine Dump
- Key Drainages
- 6000 250 Foot Contour

0 500 1000

Scale in Feet

Rock types:

Intrusives:

Gd	Granodiorite (Post-folding)
Di	Diorite (Pre-folding)

Volcanic and Sedimentary Rocks:

QFP	Quartz Feldspar Porphyry (Crystal Tuff)
J	Jasper
Sed	Sediments; chiefly volcaniclastic
MS/G	Massive Sulfide/Gossan
QP	Quartz Porphyry; Lava
Dc	Dacite (?); Flows, tuffs
R	Rhyolite; Flows, Breccias, Tuffs
B	Basalt; Mostly Shea Basalt, but includes post-ore flows and tuffs

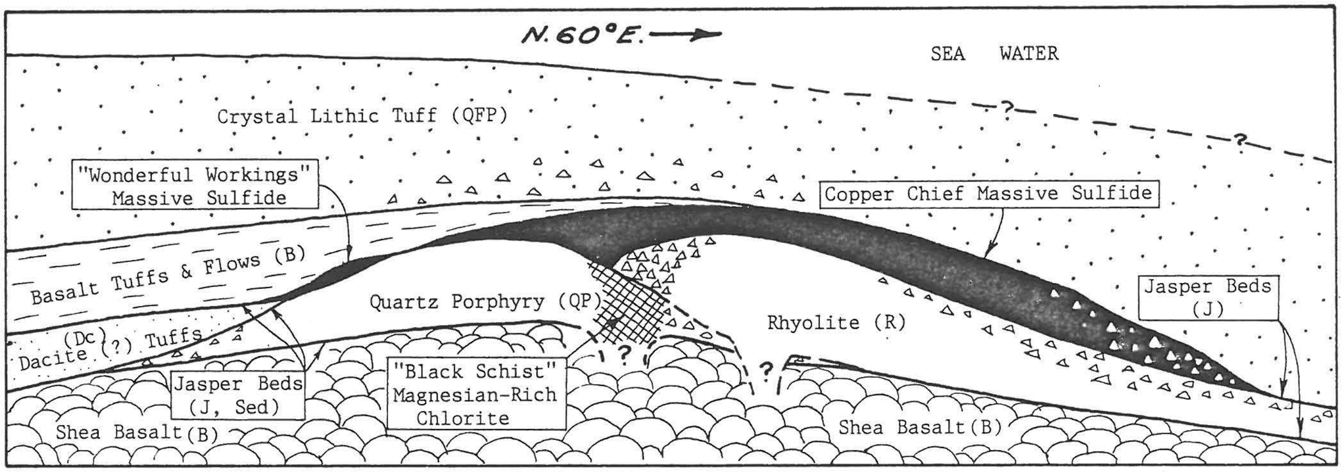

Figure 3, Schematic Pre-Fold Section Through Copper Chief Orebody.

This idealized cross section shows the preferred interpretation of stratigraphic succession. The doming of the rhyolites and hydrothermal venting at a relatively high point in the submarine vent appears to have formed exhalite layers at several stratigraphic horizons. The rhyolite, dacite, and quartz porphyry rest conformably on Shea Basalt, and all are pre-ore in age. The massive sulfide lense forms on the top surface of the rhyolite and the quartz porphyry. Post-ore rock units include Basaltic types, chiefly hyaloclastites and tuffs, and a large sheet of crystal lithic tuff (QFP). The QFP contains conspicuous quartz and fresh feldspar phenocrysts plus some basal clasts of jasper.

The "quartz porphyry" lavas (QP) were probably quartz-feldspar porphyritic flows prior to sericitic and chloritic alteration. Norman's mapping made no distinction between the two, but field relationships demand a clean separation into pre- and post-ore time allocations. Wherever the QFP blankets the succession, massive sulfide exploration must revert to indirect means of search to reach down to the prospective horizon.

Near the western end of the Copper Chief caved zone, at the point where the road intersects the southern wall, the gossan after massive sulfide can be seen resting on the top of strongly chloritized quartz porphyry. At the United Verde mine in Jerome this concentration of magnesium-rich chlorite would be known as Black Schist. This was obviously a site of hydrothermal venting. A very short distance to the northeast (approximately 100 feet) is the abrupt western edge of the rhyolite dome, complete with a vent breccia. Gossan permeates this fractured zone which had to be one of the main points of entry onto the sea floor of the hydrothermal fluids. The former massive sulfide blanket extends for another 750 feet to the northeast. At that point, just above the top of the largest of the eastern dumps, a gossan after massive sulfide breccia can be seen. It is possible that this breccia is located at the toe of the dome, resulting from ores broken loose from the high portion of the sheeted dome.

Once the ore blanket was deposited, hydrothermal venting nearly came to an end. Basaltic tuffs, and possibly some flows (?), lapped against the rhyolite/ore dome for a short time. Minor jasper beds were formed on each of their surfaces.

At this point in time a catastrophic event took place which eclipsed all local events up to that time. An extensive crystal lithic tuff was ejected over the seascape, burying the Copper Chief deposit. Because of its relatively unaltered feldspars and abundant quartz phenocrysts, it is called the QFP (quartz feldspar porphyry). Near the base of the otherwise monotonous unit there are abundant jasper clasts. It is believed that these were torn up from the apex of the rhyolite dome where late stage jaspers formed a cap over the end phases of the mineralization event. From the areal extent of the QFP, and the local geology, it appears that an eruptive center may have been located nearly 3000 feet to the northwest of the Copper Chief mine site. The QFP blanket extends over several miles of outcrop and was confused for "intrusive quartz porphyry" by Anderson and Nash (8, see especially Figure 9, Page 857). They attempted to show that Na_2O was removed in the altered footwall and that K_2O increased as one approached the ore zone. Their logic was correct, assuming one used the same formation, but their results are invalid since they compared an altered pre-ore rock with a different, fresh post-ore rock.

The pre-ore quartz porphyry at the Copper Chief mine would be expected to contain diminished Na_2O and increased K_2O relative to a "normal" value for the fresh, overlying QFP. In essence this is the significance of Meyer's Upper and Lower Succession (6). The critical potential ore horizon will lie at the top of the altered units and be buried by fresh rock of one sort or another.

Jasper beds, often associated with thin reworked volcaniclastic debris, can be followed for considerable distances outward from the presumed site of venting. Nancy Johnson (9) is currently conducting research into the chemical variations and fundamental characteristics of these interesting strata. Very often the jasper beds measure only a few inches thick but occasionally are ponded into low spots on the irregular volcanic terrain and reach 20 feet thick and more. They may also disappear completely where the chemical and mechanical debris bypasses a high point. In this area it appears that the submarine topography was locally abrupt, but overall exhibited low slopes.

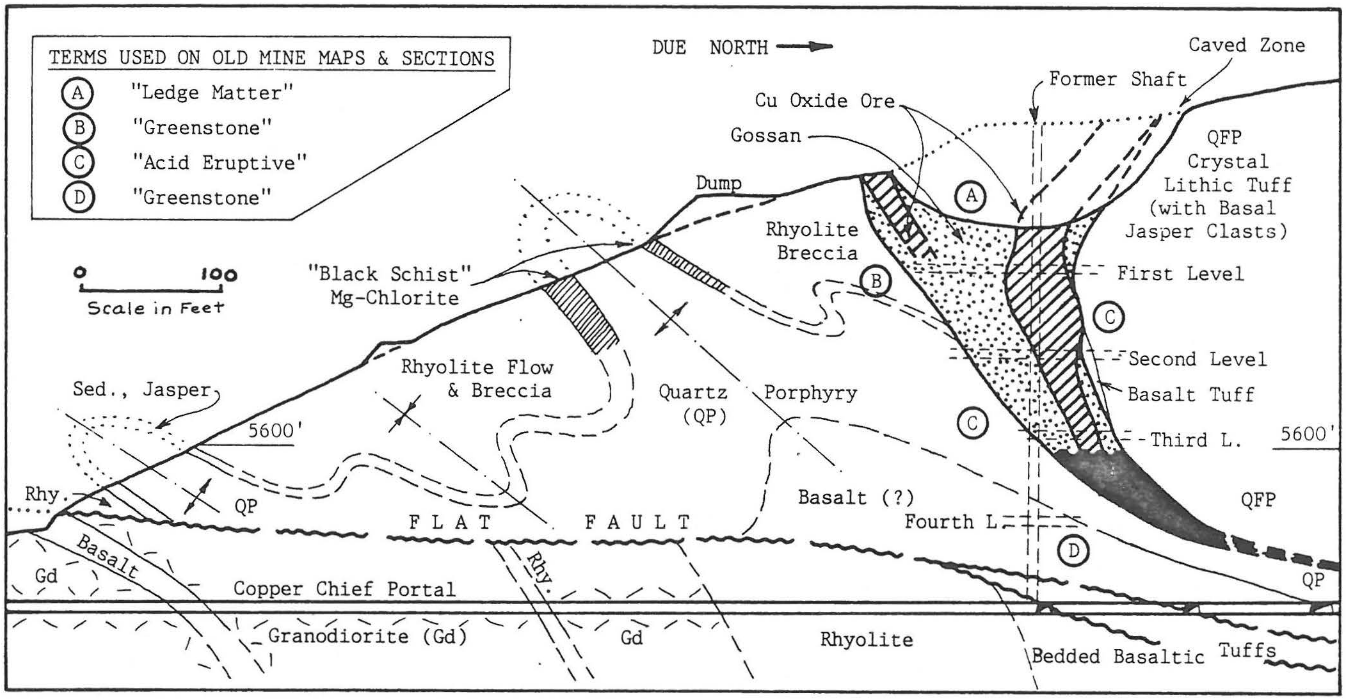

Figure 4, North-South Cross Section Through Copper Chief Orebody (Viewing to West).

This cross section passes through the main Copper Chief adit and shows the location of the mine cave zone. The former location of the in-situ gossan is shown as it was described in the old mine records. Geologic interpretations have been based on the best available data, but hard evidence between the adit level and surface outcrop is not available at present. This presentation is in compliance with the preferred model shown in Figure 3.

INTRUSIVE ROCKS:

Intrusive rocks are found in the Copper Chief mine area. They can be divided into two distinct types; pre- and post-folding. The pre-folding types were not recognized as intrusives by earlier workers and the diorite was mapped as basalt (4). Other pre-folding dikes include sparse, thin basic types as well as feeder dikes to the overlying QFP unit.

The largest masses of diorite can be seen high in the sequence, with many good examples outcropping along the pipeline road. Most of the diorite is wholly contained within the QFP strata where it takes the form of sill-like bodies. The texture is quite fine-grained and it is easy to see how it was mistaken for a massive flow rock. But the complete lack of any associated bedded units, the chilled margins, and feeder dike apophyses demand that this rock is truly an intrusive. It typically intrudes the QFP which is devoid of internal bedding features. It is uncertain whether the observed irregular nature of the diorite bodies is due to its uneven emplacement or due to superimposed polyphase folding. It is probable that both features have contributed to the present distribution.

The recognition of the diorite intrusive has also cleared up another mystery that troubled the old miners at the Copper Chief. There is a prospect, open to the surface, with good massive sulfide ore lenses, but it appears disconnected with the main ore zone. It is also isolated in a mass of what had formerly been mapped as "basalt." When considered in context with the volcanogenic model, the massive sulfide at the Wonderful Workings simply does not fit the accepted scheme of things. The 1983 mapping revealed that the "basalt" was in large measure a diorite sill.

Figure 5 shows a sketch map of the Wonderful Workings area to the west of the main Copper Chief orebody. The disjointed massive sulfide bodies in 3 prospect workings at the site contain pods that were dilated away from their associated rhyolite host rocks. Once this dilation effect has been taken into account, the massive sulfide lenses fit their proper host units. Following the mapping phase the Copper Chief adit was re-opened by Phelps Dodge and the exploratory tunnels beneath this site were inspected. Similar isolated pods of good looking massive sulfide ores were seen with fine-grained diorite boundaries. It is unknown whether or not a new ore zone might be found in this area with additional exploration.

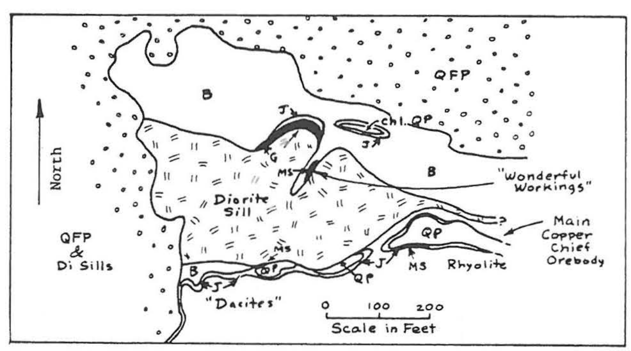

Figure 5, Sketch Map of Wonderful Workings.

The recognition of the intrusive diorite within the "Upper Succession" is very similar in relationship to the large gabbro sill which intrudes the post-ore Grapevine Gulch formation rocks above the United Verde deposit at Jerome.

The post-folding granodiorite dikes are quite different, and these dikes can be followed in swarms to the south all the way to the Cherry batholith. These dikes cut across all types of lithologies as well as across poly-phase folded horizons. No known mineralization is associated with these intrusives. The injection of these dikes, however, predates the development of the Flat Fault which thrust the Copper Chief ore zone anywhere from 160 to 300 feet (or more?) to the east. The Flat Fault and associated vein material will be discussed later under the sub-heading of Faulting History.

FOLDING HISTORY:

It is difficult to unravel realistic fold interpretations based on previous mapping by Norman (4) and the scenarios presented in the professional paper (3, especially as shown in Figures 3 and 4, pages 64 and 67). This attempted synthesis merges primary folds trending north-northwest with secondary folds ("cross folds") that trend near east-west.

Many of the folds have gone unrecognized due to the lack of mapping detail, but their effects are seen everywhere in the district. Figure 6 shows an example of the poly-phase folded strata to the south of the Copper Chief mine along the access road leading up to the pipeline road. The major folds here trend nearly north-south. A primary syncline passes through the two "pods" of QFP which lie on top of the basalt. Cross folds pass across the zone at right angles and generate interference patterns. Where two synclines coincide there is a basin formed. Two superimposed anticlines form a dome in the basement. Anticline and syncline more or less nullify one another. Within the area of this small figure there are at least 2 pairs of anticline-syncline of the north-south primary type, and at least 3 pairs of cross folds.

Figure 7 is a highly stylized block diagram showing the effect in three dimensional form. No area in the entire Jerome District is free of this poly-phase folding in the experience of the author. Individual strata (including ore horizons) may show a flat attitude in one area and then turn vertical to overturned within a very short distance.

FAULTING HISTORY:

The Copper Chief mine area is unaffected by the Verde Fault which lies east of the deposit. Within the volcanic pile itself faults are either unrecognized or of very small amplitude and their effects obliterated by subsequent folding. There is one late-stage fault, however, that did play a major role in the Copper Chief and Shea mines.

The "Flat Fault" has been known for a long time, and Reber devoted a great deal of effort in understanding the amount of offset on the structure in exploring for potential ore below the Copper Chief mine (10). The Flat Fault is often healed by bull quartz which can reach thicknesses of several feet in places. In other spots the secondary healing effects by silica are minimal, and the structure does look like a fault.

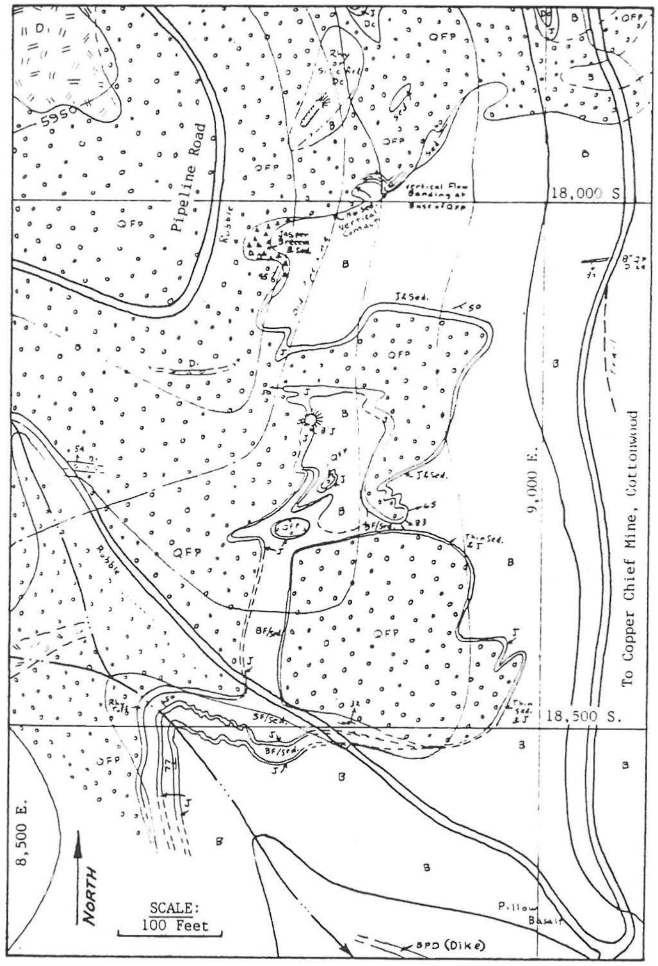

Figure 6, An example of poly-phase folded strata seen south of the Copper Chief mine area. The QFP unit is preserved in infolds on top of the Shea Basalt basement.

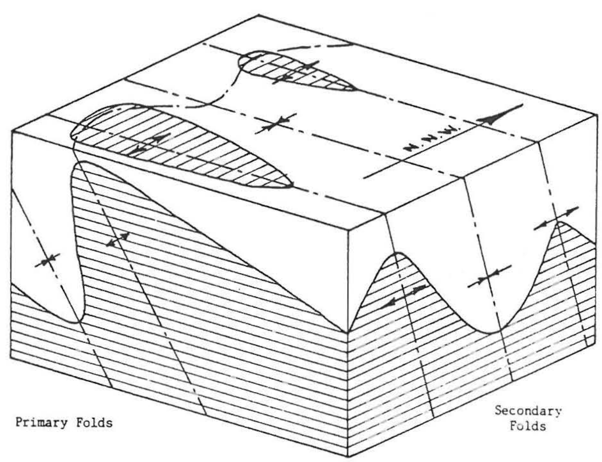

Figure 7, Stylized block diagram showing interference patterns formed by poly-phase folding. Only the major folds are shown in this simplified scenario. Uneven erosional effects complicate the patterns.

The age of movement on the Flat Fault is unknown but is assumed to be Late Precambrian. There is a remote possibility, however, that it could be as young as Tertiary, since the fault only cuts Precambrian rocks where observed. The only exact age relationship that can be established with any certainty is that it cuts the granodiorite dikes which postdate the folding in the district.

The recent work shows that the quartz-siderite veins of the Shea mine and Flat Fault are on one and the same system. The Shea vein strikes nearly east-west and dips at a low angle to the south, but it merges with the west-dipping Flat Fault to the north of the Shea mine dump.

Despite the difference in age and mineralogy of the veins versus the older volcanogenic massive sulfide deposits, the close proximity of the two ore types presents an interesting problem for future mineral exploration programs to contemplate.

ACKNOWLEDGEMENTS:

The author wishes to thank Phelps Dodge Corporation for the opportunity to investigate the complex geological problems of the Copper Chief mine area, and for the opportunity to share some of those findings with the Arizona Geological Society. Additional insight into the understanding of the Jerome District has been shared on many occasions by Charles Meyer and by Paul Handverger of the Verde Exploration Company.

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PRELIMINARY DISCUSSION OF THE GEOCHEMISTRY OF SOME EXHALITES FROM THE COPPER CHIEF MINE, JEROME DISTRICT, ARIZONA

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INTRODUCTION

The volcanogenic massive sulfide deposits of the Jerome district, Arizona, occur within the Proterozoic Yavapai "greenstone" Supergroup (Conway, 1985). Locally at the Copper Chief mine, eight distinct lithologies making up a complex volcanic package have been distinguished. The geochemistry of exhalites associated with this volcanic package is currently being studied to identify spatial and temporal geochemical changes that may be useful in mineral exploration.

Because the volcanic package is complicated by alteration and folding in addition to original depositional discontinuity of most units, stratigraphic reconstruction is not easy. By using the 1" = 100'-scale map compiled by Paul Lindberg for the Phelps Dodge Corporation (Lindberg, 1986), reconnaissance mapping was done to determine stratigraphic up. Once done, the stratigraphic succession was unraveled and correlation of exhalites became more than just speculation. In the following geologic description, key up-indicating contacts are described as is the disposition of exhalites in the stratigraphic succession.

GEOLOGY

Shea Basalt

The Shea Basalt is believed to be the oldest rock unit in the mapped area. The term used for the Shea in this report will be the "lower basalt." The rest of the units described here are given lithologic field names.

Petrographic work done by Phelps Dodge personnel indicates that this rock is a moderately chloritized basalt (Duhamel, 1985, personal commun.) with minor disseminated pyrite, which becomes andesitic in the upper portion of this sequence. In outcrop, change within the lower basalt can be best seen by walking up the creek bed from 8775E, 1866S to 8680E, 18500S (fig. 1). Here the unit changes from massive flows to more thinly bedded, ropy flows with a moderate amount of amygdules. The top foot of this unit comprises small pillows (1 foot long by 6 inches wide) with siliceous rinds. Elsewhere the lower basalt becomes thinly bedded and fissile near its upper contact.

Rhyolite

The rhyolite within the mapped area has been petrographically determined to be a rhyodacite (Duhamel, 1985, personal commun.), which is locally albitized, silicified, and chloritized. In outcrop, two textural varieties exist, massive and brecciated, with excellent exposures of both types seen in the vicinity of 10500E, 18000S (see Lindberg, 1986, fig. 2). The contact between the lower basalt and the rhyolite is seldom sharp but is more typically marked by a thin and discontinuous, brecciated to bedded exhalite layer. At 10300E, 18075S (see Lindberg, fig. 2, this volume) the basalt is overlain by 1-2 feet of brecciated felsic tuff and exhalite with fragments averaging 1-2 inches long. The amount of chert and tuffaceous fragments rapidly decreases toward its upper contact and gradationally becomes a silicified and sericitized rhyolite breccia, which locally exhibits moderate chloritization. The massive variety of rhyolite is typically cryptocrystalline and featureless; however, flow banding is locally present between the massive variety and the breccia.

The upper rhyolite contact is not easily defined because rhyolite extrusion was occurring synchronously with other volcanism. The best example of this contact is seen at 9305E, 17150S (fig. 1, NJ-OH sample site). Here the breccia contains rhyolite, exhalite and gossan fragments, disseminated pyrite in both matrix and clasts, and abundant carbonate veinlets. Overlying the rhyolite breccia is a finely brecciated to bedded chert pod (approximately 9 feet thick at widest point), which is in turn overlain by a thin (6-10 inches) bed of rhyolite breccia. This chert pod can be traced out and shown to be the lateral equivalent of the Copper Chief orebody; this finding indicates that some rhyolitic volcanism postdated ore deposition. Intense chloritization of the rhyolite immediately adjacent to the massive sulfide deposit, however, indicates preore deposition for the bulk of the rhyolite in the mapped area.

Quartz Porphyry

The unit mapped as quartz porphyry is a pinkish-beige cryptocrystalline rock with quartz phenocrysts (average diameter, 1 mm). The quartz porphyry is locally silicified, albitized, and chloritized. Petrographic analysis by Phelps Dodge personnel (Duhamel, 1985, personal commun.) indicates that this rock is also a rhyodacite. Intense chloritization of the quartz porphyry has occurred immediately underlying the massive sulfide mineralization.

Transitional Unit

The transitional unit is a complex package of both volcanic and sedimentary constituents. The volcanic component has been petrographically determined to be an andesite (Duhamel, 1985, personal commun.). Although this unit is locally a breccia, it is predominantly composed of thin andesite flows and tuffaceous sedimentary rocks. Field observations indicate that the tuffaceous component is andesitic and rhyolitic. The contact between the lower basalt and the transitional unit is not clear but rather appears to be gradational.

Massive Sulfide Mineralization

Little remains to be seen of the main Copper Chief orebody due to caving; however, old mining records reported that most of the ore mined between 1916–1918 was siliceous oxide ore yielding 0.3 oz/t Au and 6 oz/t Ag (Lindgren, 1926). Anderson and Creasey (1958) reported that during this same period 71,849 tons of ore were mined. An unknown amount of chalcocite ore containing up to 0.75 oz/t Au and 40 oz/t Ag was reportedly mined in 1922 (Anderson and Creasey, 1958).

Upper Basalt

Thinly bedded basalt flows immediately overlie the massive sulfide ore at 9100E, 17075S (fig. 1). Here the presence of fragments of gossan and exhalite at the base of the basalt indicates that the upper basalt postdates the ore and is not the same unit as the lower basalt.

Quartz Feldspar Porphyry

A massive outpouring of quartz feldspar porphyry followed extrusion of the upper basalt and blankets possible ore horizons to the west. Because the feldspars are relatively unaltered, this rock is considered postore. Evidence for extrusion can be seen locally along the lower contact where it contains exhalite fragments (fig 1. 8680E, 17130S).

Sedimentary Units

Sedimentary units at the Copper Chief mine fall into two basic categories: clastic and chemical. Because the two types are commonly associated in the field, they are discussed together here. The clastic constituent comprises mafic and felsic, bedded, tuffaceous epiclastics. An excellent example of these clastic sedimentary rocks can be seen in the sedimentary package overlying the upper basalt at 8560E, 18600S (fig. 1).

Chemical sedimentary units, or exhalites, at the Copper Chief mine occur as both bedded and brecciated, laterally discontinuous chert horizons, which can be found at all contacts as can be seen from the map (fig. 1). It should be noted here that the discontinuous nature of these units is probably due to several factors: (1) original discontinuous deposition in topographic lows, (2) boudinage during folding, and (3) availability of outcrop. Individual exhalite horizons are typically bedded on the millimeter to centimeter scale, can be black, gray, green, red, or white, are rarely greater than a foot thick, and are rarely continuous in outcrops for distances over 5 feet. One exception to this is the stratigraphically highest exhalite horizon seen at 8560E, 18600S (fig 1), hereafter referred to as the Acme horizon, which was chosen for the geochemical study because it is continuous in outcrop for several hundred yards.

Petrographically, the bedded exhalites are predominantly fine-grained quartz with hematite spherules, magnetite, and minor pyrite cubes, which are commonly oxidized to limonite. Millimeter-thick layers of tuff are common but make up a relatively small part of the exhalite. Most exhalites examined contain a moderate amount of chlorite. Samples of exhalite collected underground contain up to 10% pyrite and have abundant carbonate. The red, black, and green color is a function of the presence of hematite, magnetite, and chlorite, respectively.

The less common massive pods of exhalite are finely brecciated (millimeter to centimeter-scale fragments that commonly appear to be rotated) and recemented with silica. The breccias are mineralogically similar to the bedded variety with quartz and quartz-pyrite veinlets abundant in the breccia. Examples of the breccia are seen at 8775E, 18200S and at 9310E, 17150S (fig 1. base of ore-horizon exhalite).

GEOCHEMISTRY OF SOME SELECTED EXHALITES

Possibly the most significant units found associated with volcanogenic massive sulfide deposits are the exhalites, or chemical sedimentary units. Because these units are commonly found above or away from the massive sulfide ore, it seems to be a reasonable conclusion that the volcanic emanations responsible for ore deposition are also responsible for exhalite deposition. As such, the geochemistry of exhalites should change with the degree of sea-water mixing (or distance from volcanic vent). Studies done to determine the usefulness of exhalites as geochemical exploration tools at Bathurst, New Brunswick (Graf, 1977) and at Kuroko, Japan, and Noranda, Canada (Kalogeropoulos, 1982) have shown that, although certain trace and rare earth elements are present in elevated concentrations near the massive sulfide ore, multiple vent sites greatly complicate the picture.

Preliminary examination of the geochemistry of the exhalites indicates that exhalite geochemistry on a local scale may be helpful in delineating favorable ore horizons and hydrothermal vent sites.

Nine exhalite samples from several stratigraphic horizons at the Copper Chief mine and one sample of the exhalite on the south wall of the United Verde pit at Jerome were analyzed by instrumental neutron activation at the Lunar Planetary Laboratory, The University of Arizona, for 30 major, trace, and rare earth elements. Only the analyses pertinent to this discussion are reported in table 1 with sample locations given on figure 1.

As previously mentioned, exhalites are not laterally continuous for great distances, and therefore the Acme horizon, being the most continuous exhalite at the Copper Chief mine, was the likely candidate for this study. This unit is composed of two 4-6-inch-thick layers of finely bedded, black, red, and green chert separated by approximately 2 feet of mafic sedimentary rock that contains an increasing amount of exhalite fragments to the north. The Acme horizon is not correlative with the ore horizon but rather is stratigraphically above it.

Four samples were taken along the Acme horizon to identify lateral geochemical changes. Preliminary examination of the geochemical data shows that the Jerome exhalite is enriched up to several orders of magnitude in Ti, Co, Zn, As, Au, and U relative to the Copper Chief ore horizon and Acme units (table 1).

Concentration vs. distance plots for the Acme horizon show that of the Acme samples, sample Acme 1 has the most Mo, Ta, As, and Au, that sample Acme 2 has the most Ti, Ba, Sb, Ca, and Co, and that sample Acme 3 has the most Fe, Zn, Th, U, Sc, Lu, Na, K, and rare earth elements.

Ohmoto and others (1983) reported that the solubility of elements in fluids issuing from hydrothermal vents associated with Kuroko-type ore formation is a

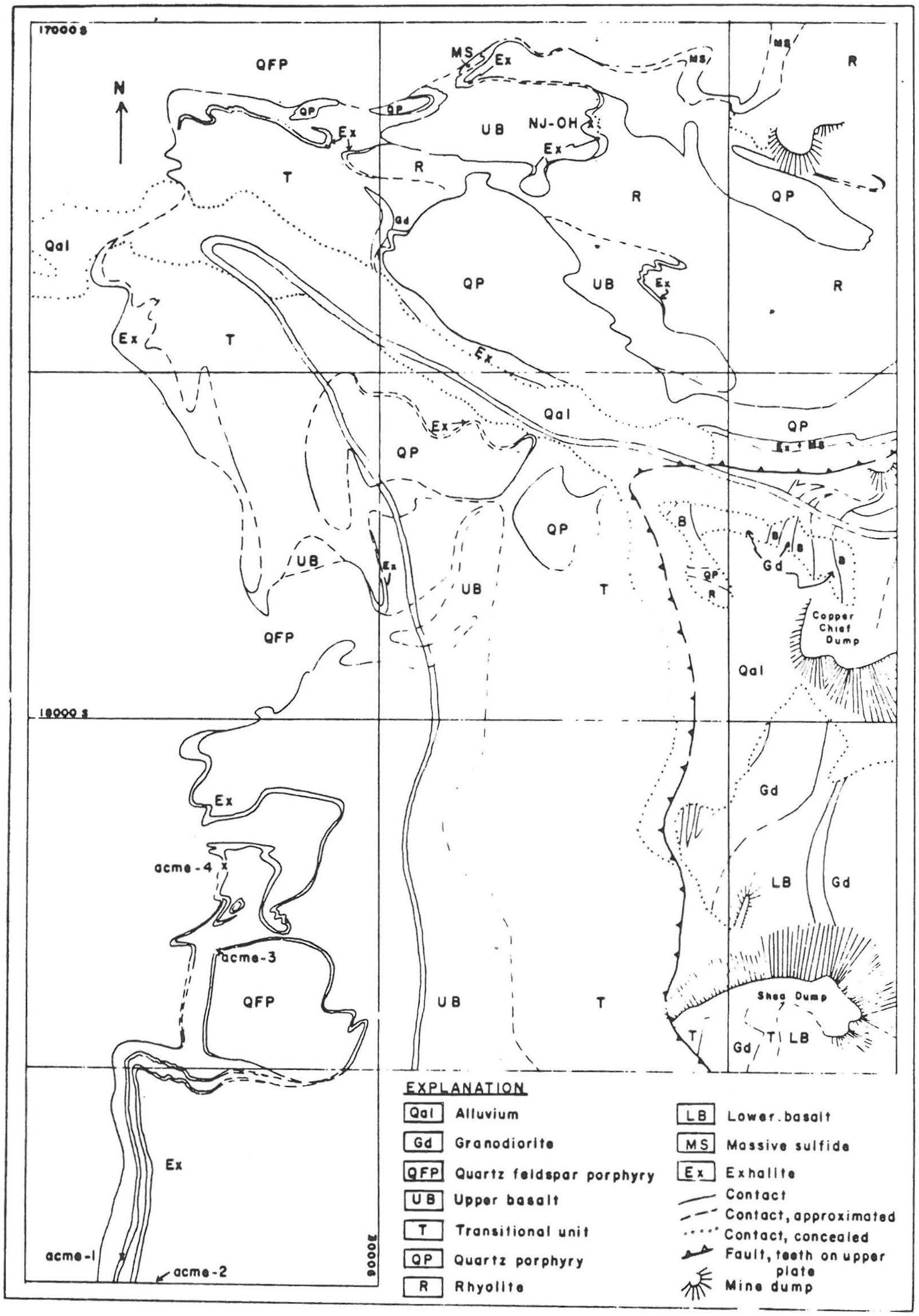

Figure 1. Geologic map, Copper Chief mine, showing Acme sample sites. Mapped on a 500-foot grid by P. A. Lindberg for Phelps Dodge Corporation with minor modification by N. Johnson.

Table 1. Element concentrations for selected meta-exhalites from the Copper Chief mine, Arizona in order of increasing distance from the Copper Chief orebody

Element	Concentration (in ppm) for sample					
	NJ-OH	Acme-4	Acme-3	Acme-1	Acme-2	Jerome
Na	44.97	35.33	202.7	881.8	96.79	90.93
K	345.8	139.7	935.1	1,522	563.5	353.3
Sc	0.8349	0.4937	0.6171	1.99	0.644	1.287
Ti	51.57	32.84	355.6	295.8	140.6	586.3
Fe	52,660	97,240	159,200	65,120	99,720	91,420
Co	9.469	4.567	7.941	7.218	5.209	13.53
Zn	137.3	24.87	29.31	35.28	17.02	53,890
As	25.72	43.3	24.82	13.62	19.44	55.56
Rb	1.583	2.655	2.402	3.868	n.d.	n.d.
Mo	1.648	7.953	2.18	1.747	2.164	1.185
Sb	6.561	14.61	16.87	10.72	11.64	n.d.
Ba	48.88	38.53	228.1	174.7	133.5	n.d.
La	0.9567	0.44	3.789	6.744	3.121	1.985
Ce	1.869	0.74	8.491	15.06	8.348	8.995
Nd	0.8422	0.7016	3.549	7.157	2.998	n.d.
Sm	0.2354	0.1775	0.7631	1.558	0.6691	0.5202
Eu	0.0993	n.d.	0.302	0.4066	0.1895	0.1186
Tb	0.0424	n.d.	0.1232	0.2755	0.096077	0.1247
Yb	0.2527	0.1013	0.4618	1.076	0.3977	0.5377
Lu	0.0419	0.0164	0.0657	0.1593	0.05585	0.0953
W	0.5986	1.332	2.025	1.811	2.245	0.9145
Au	0.01255	0.02058	0.00989	0.00826	0.00535	2.817
Th	0.1818	0.1259	0.1162	0.4354	0.1643	0.4317
U	0.06455	0.06914	0.1792	0.3511	0.2083	1.107

function of temperature, pH, activity of O_2, Cl^-, H_2S^-, and $SO_2^=$, and the concentration of the element in the hydrothermal fluid. Metal-ion solubility, predominantly a function of the activity of the sulfur species present, decreases as H_2S activity increases. Nearest the vent, where the H_2S species is most concentrated, the metal ions are insoluble and will precipitate. As mixing between the hydrothermal fluid and sea water takes place, the $SO_2^=$ species becomes the dominant sulfur species and more oxidized minerals precipitate.

A plot of residence time vs. the sea-water–upper crust partition coefficient (from Taylor and McLennan, 1985) is shown in fig. 2. This graph shows that Fe, Th, Al, Sc, Co, and the rare earth elements have short residence times and low partition coefficients and therefore should be expected to precipitate nearest the volcanic vent. It can be seen that sample Acme 3 is relatively enriched in those elements associated with short residence times and low partition coefficients and that elements with longer residence times are relatively enriched in sample Acme 1. In addition, the concentration of metal ions is greatest in sample Acme 3, a finding that indicates that it was taken from a location closer to a hydrothermal vent than the other Acme sample sites. Barium concentrated in sample Acme 2 can be explained by the fact that barium precipitates virtually instantaneously in the presence of $SO_2^=$, thus explaining its relative depletion in sample Acme 1.

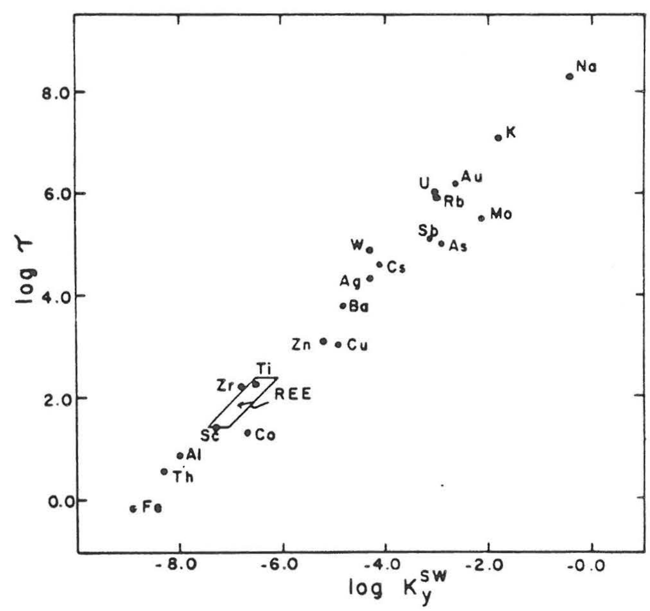

Figure 2. Plot of residence time (log γ) vs. sea-water–upper-crust partition coefficient (log K_y^{SW}). Data from Taylor and Mclennan, 1985).

SUMMARY

From the geochemical information presented, it appears that the vent responsible for the deposition of the main orebody at the Copper Chief mine may not have been the only hydrothermally active vent contributing to the formation of the Acme exhalative horizon. Moreover, the geochemical evidence seems to indicate that the Acme 3 site was closer to another hydrothermally active vent than the other Acme sites sampled. The effects of greenschist-facies metamorphism and mineralization of the nearby Shea vein need to be considered; however, it appears thus far that distribution patterns of elements do exist in the exhalites and that these patterns may be helpful to the exploration geologist in the district.

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PREVIOUS GEOLOGIC WORK IN THE PRESCOTT-MAYER AREA, ARIZONA

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Jagger and Palache (1905) published the first geologic map of the Bradshaw Mountain region. They separated the Precambrian schists from Precambrian intrusive rocks and Tertiary volcanic rocks. Metasedimentary and minor metavolcanic lithologies make up the schistose rocks, which they considered to be the oldest rocks in the region. The schists were thought to be involved in several episodes of deformation including isoclinal folding. Attitudes of bedding planes are near vertical with a northerly strike. Granitic intrusions are divided into the Bradshaw granite and separate stocks of quartz diorite, which are recognized as the latest intrusive rocks. Metamorphism is considered to be a contact event near the intrusions with hornblende produced in the schist.

Lindgren (1926), using Jagger and Palache's (1905) map as a base, described the geology of many ore deposits and their host rocks. The presence of metavolcanic lithologies within the Yavapai schist was noted. Amphibolite was interpreted as a schistose-altered mafic volcanic rock, and rhyolitic protoliths within the Yavapai schist were described for the first time.

Jerome (1956) described rocks within the Black Canyon schist belt according to his interpretation of the original protolith. A major overturned asymmetrical anticline is believed to exist near Cleator with the "Cleator" granite intrusive into the core (Jerome, 1956). Rocks extending along the east side of Black Canyon are on the overturned limb of this fold, and the top of the section is considered to lie to the east. Metamorphic grade increases from east to west based on the first appearance of biotite, garnet, and staurolite. These minerals are considered evidence of Barrovian-type metamorphism, although kyanite and sillimanite were not reported. Andalusite is considered a contact metamorphic mineral related to the intrusion of the "Cleator" granite.

Since 1958 parts of the Prescott-Jerome district were mapped at scales of 1:24,000 and 1:62,500 by the U.S. Geological Survey. Recognition of Jerome, Arizona, as a stratabound massive sulfide deposit (Anderson and Nash, 1972) led to the realization that exploration for new massive sulfide deposits in the district would require detailed knowledge of stratigraphy and structure. C. A. Anderson and his co-workers developed a stratigraphic and structural model for the area surrounding (Mingus Mountain quadrangle) and attempted to extend this model to other areas within the district. This pioneering work provided an excellent base that allowed later authors to pursue more detailed projects in the region.

Krieger (1965) mapped the area north of the Chaparral fault (Prescott and Paulden quadrangles), while Anderson and Creasey (1967) mapped the Mingus Mountain quadrangle and Anderson and Blacet (1972a, 1972b) mapped the Mount Union and Mayer quadrangles. Blacet's (1968) Ph.D. dissertation covered the SE¼ of the Mount Union quadrangle (now know as the Battle Flat 7.5-minute quadrangle). Originally the Yavapai Series near Mingus Mountain was divided into the Ash Creek Group east of the Shylock fault and the Alder Group west of the Shylock fault. The U-Pb cogenetic zircon dates reported in 1971 completely revised the stratigraphy in the region (Anderson and others, 1971). The term "Big Bug Group" was substituted for the Alder Group, and the Texas Gulch Formation was recognized as a separate formation unconformably overlying the Big Bug Group. The Spud Mountain and Iron King Volcanics of the Big Bug Group and the Texas Gulch Formation are the metavolcanic and metasedimentary rocks exposed in the area investigated in this field trip guide.

Prior to the 1972 paper of Anderson and others the foliated nonporphyritic Brady Butte Granodiorite was considered to be the oldest rock unit in the region, with the Texas Gulch Formation unconformably overlying the granodiorite and the rest of the sequence overlying the Texas Gulch Formation. The porphyritic phase of the Brady Butte Granodiorite was considered intrusive into the older granodiorite and the Spud Mountain formation. The U-Pb dates on cogenetic zircons by Silver and Stern (cited in Anderson and others, 1972) indicate that both phases of the Brady Butte Granodiorite and the metavolcanic rocks are the same age within the resolution of isotopic methods (Anderson and others, 1971). The chemistry of both phases of the granodiorite is indistinguishable. Therefore, the Brady Butte Granodiorite is not the oldest rock in the region but is younger than the Spud Mountain Volcanics (field relationships) and older than the Texas Gulch Formation. A U-Pb date of 1748 m.y. B.P. by Silver (1978, oral commun.) indicates that the Texas Gulch Formation is significantly younger than all the other pretectonic rocks in the area.

Even though steeply plunging isoclinal folds were observed along with shallow-plunging folds (Anderson and Blacet, 1972a, 1972b), maps and cross sections show only shallow-plunging folds. Boundary faults are placed at the contact of the Texas Gulch Formation with older rocks everywhere except at the northern terminus of the Brady Butte Granodiorite. Most of these faults do not exist, and the contact can be reasonably reinterpreted as a refolded unconformity (O'Hara and others, 1978). If this model is correct, then several of the stratigraphic corrections of Anderson and Blacet (1972c) are suspect and the age relationships within the older metavolcanic rocks may have to be revised.

Blacet (1968) mapped several isograds and noted an increase in metamorphic grade from north to south.

This increase in grade is attributed to posttectonic intrusions.

Evensen (1969) completed a Ph.D. dissertation at The University of Arizona on the geology of the central portion of the Agua Fria mining district. Stratigraphic units within the Yavapai Series were subdivided and presented on a geologic map. The origin of the ore deposits and alteration assemblages was considered to be either epigenetic or remobilized during and after deformation from an original syngenetic source. Steeply plunging lineations were associated with a single deformation event during which the principal stress direction was vertical. Evensen is currently mapping folds associated with these lineations and has reinterpreted the origin of the ore deposits (Evensen, 1980).

DeWitt (1976, 1978, 1979) mapped stratigraphy, structure, and isograds in the Iron King and Spud Mountain Volcanics between the towns of Crown King and Mayer. A model that accounted for steeply plunging fold axes was presented for the first time. A regional fold pattern was interpreted by connecting isolated iron formation into an outcrop pattern. Evidence for polyphase deformation in the vicinity of the Brady Butte Granodiorite (O'Hara and others, 1978) is not recognized. The variations in style and orientation of fold geometry are ascribed to refraction of strain about the granodiorite "buttress" during one episode of deformation.

P. A. Anderson is currently completing a Ph.D. dissertation at The University of Arizona. His work includes determination of the stratigraphic and structural history of the older Precambrian in Arizona and the crustal setting of the Precambrian in Arizona (Anderson, 1978, n.d.; Anderson and Guilbert, 1978). Detailed mapping of the lower grade rocks in the Jerome-Prescott district is included in his project. Anderson (n.d.) considered the metavolcanic rocks as island arcs. These island arcs mark the site of new crust generated at a convergent plate boundary. Stratigraphic reconstructions are based upon cross-cutting relationships and the presence of unconformities within the stratigraphy. O'Hara (1980b, 1981c, O'Hara and others (1978), and Karlstrom and O'Hara (1984) have presented evidence for at least two episodes of regional deformation. The recognition of the polyphase deformation in these rocks led to an ongoing investigation of potential stratigraphic models within the older volcanic rocks that are consistent with the multiple-folding hypothesis. The conclusion that the pelitic rocks that crop out near Cleator are the oldest rocks in the region (O'Hara, 1980b) is now rejected. Metamorphic mineral assemblages are considered to be caused by a regional metamorphic event (O'Hara, 1980a, 1980b, 1981b; O'Hara and Stamm, 1978). Highly contorted isoreaction lines appear to be controlled by variations in the mole fraction of CO_2 in the metamorphic fluid (O'Hara, 1980b; 1981b). Recognition of felsic metavolcanic protoliths and alteration assemblages is presented by O'Hara (1981; n.d.a). The relationship between F_1 folding and thrusting is being reviewed.

Karlstrom (n.d.) presents a structural model that relates various orientations of F_1 and F_2 lineations, foliation, and fold axes to variable strain rates during each event. Two of Karlstrom's students at Northern Arizona University, Flagstaff, are working on structural problems within the region. Rebecca Williamson is studying the cataclasis associated with deformation in the Chaparral shear zone, and Mark Barrach is analyzing field data and petrofabric data from the Shylock zone.

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STRATIGRAPHY AND STRUCTURAL GEOLOGY IN THE PRESCOTT-MAYER AREA, ARIZONA

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INTRODUCTION

Isoclinal folding obscures the original stratigraphy (Anderson and Blacet, 1972c; DeWitt, 1976, 1979; Anderson, 1978; O'Hara and others, 1978); therefore, the only way to develop a stratigraphy is to fit the lithologic units into a fold model. The lack of marker horizons of adequate lateral extent hinders structural and stratigraphic analysis in the region. C. A. Anderson and co-workers using a structural model based on folds with shallow plunges extended stratigraphy southward from low-grade metamorphic rocks near Jerome into the high-grade rocks near Cleator and Crown King. Stratigraphy was based on the similarity between interpreted protoliths of high-grade rocks and low-grade rocks. Some of these correlations are in doubt because steeply plunging fold axes and the associated deformation were not considered in the model.

DeWitt (1976) chose the iron formations within the Iron King Volcanics as marker horizons. This approach assumes that the iron formations were either originally continouss units later broken during folding or were all deposited in the same stratigraphic horizon as pods which correlate with one another. The iron formations along with a basaltic agglomerate were used to interpret the stratigraphy within the framework of a structural model based solely on the steep fold axes. Shallow fold axes were attributed to refraction of structural elements by differential strain about the pretectonic Brady Butte Granodiorite.

Evidence of faulting is present locally at the boundaries of and within the Texas Gulch Formation. These zones of fracturing and brecciation have been cited as evidence for a boundary fault system surrounding the Texas Gulch Formation (Anderson and Blacet, 1972c). Nevertheless, many of the boundaries do not show evidence of faulting and appear to be sedimentary or sedimentary-volcanic contacts. Blacet (1966) presented evidence of an unconformable contact between the Brady Butte Granodiorite and the Texas Gulch Formation. Silver (1978, oral commun.) dated the Texas Gulch Formation at 1740 m.y. B.P. (no error reported; U-Pb on zircons, using the old λ). This date implies an unconformable relationship between the Texas Gulch Formation and the 1770 to 1760 m.y. B.P. granodiorite and the 1770 $\pm$ 10 m.y. B.P. metavolcanic rocks. O'Hara and others (1978) observed evidence of polyphase deformation north of the Brady Butte Granodiorite with the Texas Gulch Formation. The outcrop pattern of the Texas Gulch Formation demonstrates at least two episodes of folding and is somewhat modified by faulting.

STRATIGRAPHIC UNITS OF C. A. ANDERSON AND CO-WORKERS

Yavapai Series

Metavolcanic and metasedimentary rocks of the Yavapai Series (Anderson and Creasey, 1958) crop out within the area described in this study. These rocks were originally subdivided into the Ash Creek Group and Alder Group (Anderson and Blacet, 1972c). Isotopic data led Anderson and others (1971) to rename the Alder Group the Big Bug Group, which includes all the rocks of the Yavapai Series exposed in the area described in this study.

Big Bug Group. The Big Bug Group is divided into three formations. From oldest to youngest they are: (1) Green Gulch Volcanics, (2) Spud Mountains Volcanics, and (3) Iron King Volcanics (Anderson and Silver, 1976). The Green Gulch Volcanics are not present in the area of this study and will not be discussed. The thickness of the Big Bug Group cannot be measured with confidence because of the probability that unrecognized small folds on the flanks of major folds duplicate the section and because of probable thinning and thickening of units during deformation (Anderson and Blacet, 1972c).

The following description of the Spud Mountain and Iron King Volcanics is taken from the report by Anderson and Silver (1976, p. 17). For more detailed information the reader is referred to the many articles coauthored by C. A. Anderson listed in the references.

The lower part of the Spud Mountain Volcanics is characterized by andesitic-rhyolitic breccia containing interbeds of crystal tuff, tuffaceous sandstone, and siltstone. Clasts in the breccia range from 3 to 50 cm in diameter, and individual breccia beds range from 3 to 10 meters in thickness. The dominant rock type forming clasts is porphyritic andesite containing phenocrysts 4 to 8 mm long; clasts of rhyolite may be absent in many beds and abundant in others. The breccia beds form the core of an overturned anticline in the northeastern corner of the Mount Union quadrangle (fig. 1). In the southern part of the Mount Union quadrangle, the breccia beds are thin and appear as interbeds in thickly bedded and massive crystal tuff containing stubby crystals and clasts of quartz and albite.

The upper part of the Spud Mountain Volcanics is dominated by andesitic tuffaceous rocks, locally containing rhyolitic flows and tuffs. Zircons from one of these flows exposed north of the Big Bug Mesa gave

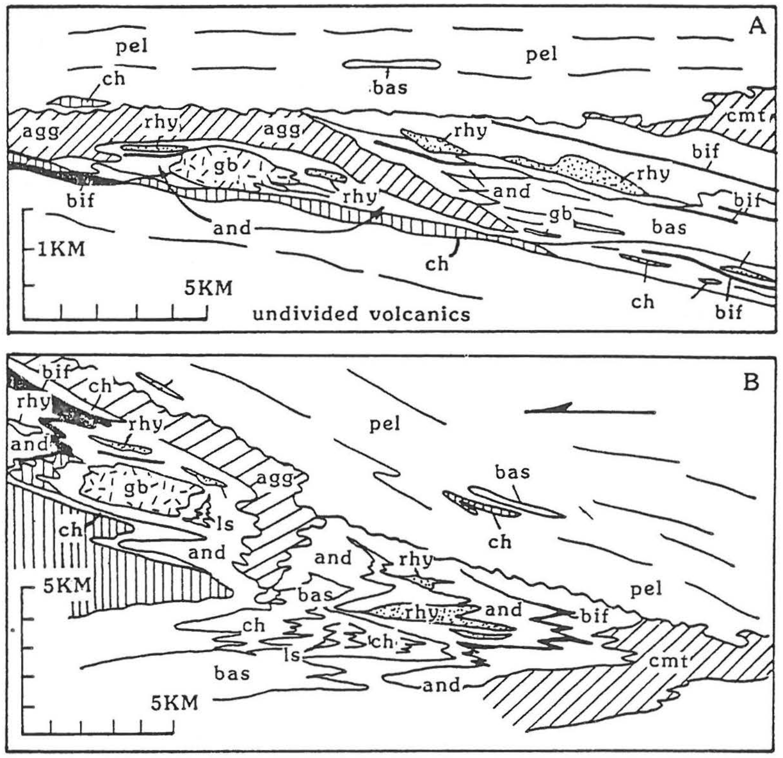

Figure 2. Simplified stratigraphic and structural reconstructions, Mayer–Crown King area. A. Simplified stratigraphic reconstruction (cross section) showing volcanic section truncated and unconformably overlain by pelites. B. Simplified structural reconstruction (plan map) prior to intrusion of Brady Butte Granodiorite, Crazy Basin quartz monzonite, or Laramide(?) intrusive rocks (from DeWitt, 1976).

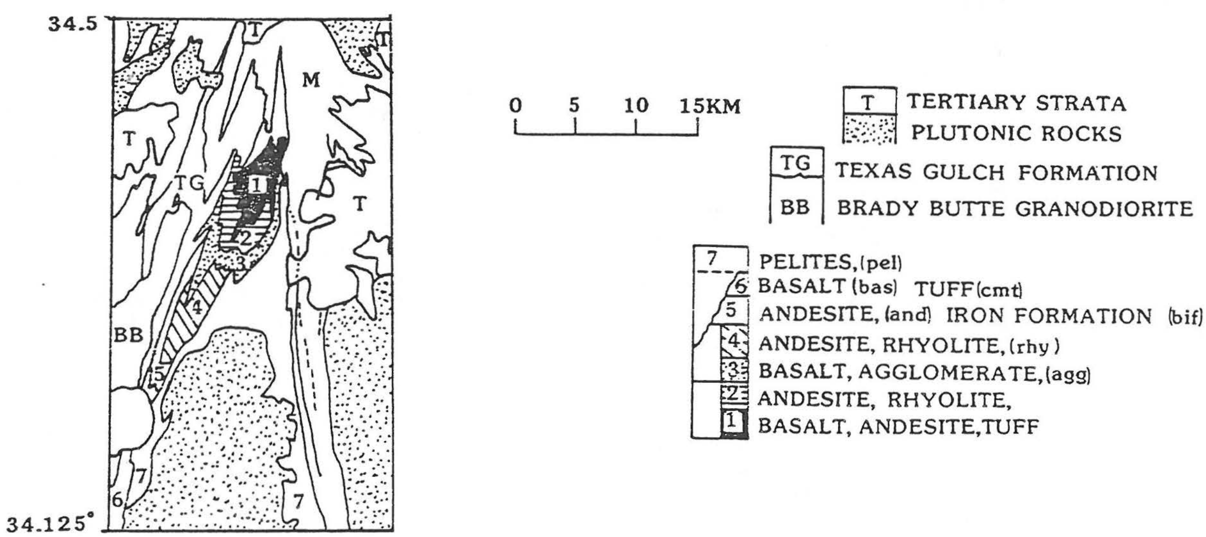

Figure 3. Stratigraphic and structural model of DeWitt (1976)

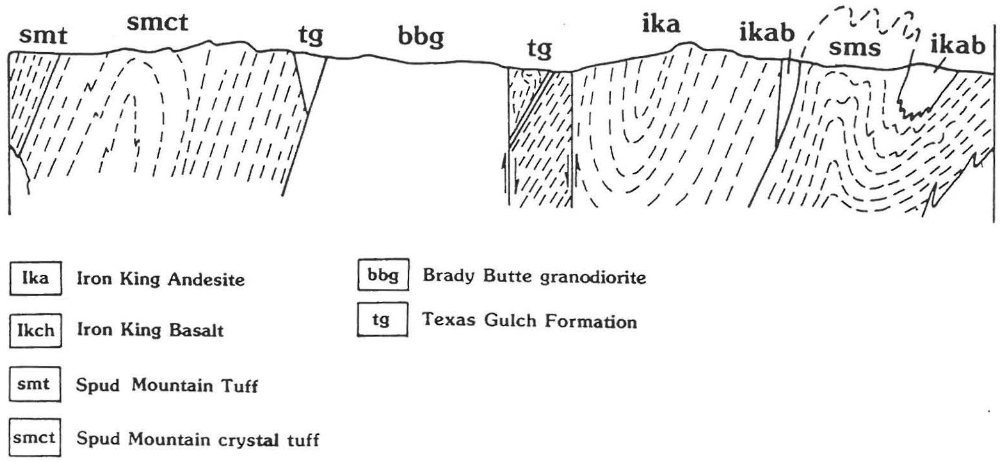

Figure 1. Cross section of the Mount Union quadrangle. From Anderson and Blacet (1972c).

an isotopic age of 1775 ± 10 m.y. (L. T. Silver, cited in Anderson and others, 1971). This date suggests that a large part of the Big Bug Group is younger than the Ash Creek Group.

In the northwest corner of the Mayer quadrangle, the andesitic tuffaceous rocks in the Spud Mountain Volcanics contain ferruginous cherts that intertongue with the Iron King Volcanics. Southward in this quadrangle and west of the Shylock fault zone, light-colored, sandy and silty tuffaceous rocks become dominant.

The Iron King Volcanics is a thick sequence of pillow and amygdaloidal andesitic and basaltic flows, locally containing thin interbeds of rhyolitic tuffs and flows. The youngest unit is a mixed andesitic-rhyolitic tuffaceous rock that crops out in the trough of the overturned syncline.

Metagabbro. Anderson and Blacet (1972c) reported sill-like and massive gabbroic units intruding rocks of the Big Bug Group. These gabbros have been recrystallized to varying degrees by later metamorphic events. Most of the metagabbros are massive and weakly foliated amphibolites. However, a few samples taken from the lower grade metamorphic terrain in the north contain relict diabasic texture (Anderson and Blacet, 1972c). Anderson and Blacet (1972c) suggested that the gabbro within the Iron King Volcanics represent sills of mafic magma injected during the accumulation of the Iron King Volcanics. Kreiger (1965) reported that the Crooks Canyon Granodiorite intrudes gabbroic rocks in the Prescott quadrangle. Cross-cutting relationships illustrate that a metagabbro south of Battle Flat within the area of this study is intruded by the Brady Butte Granodiorite.

Brady Butte Granodiorite. The Brady Butte Granodiorite was originally considered by Blacet (1968) to be the basement upon which the Yavapai Series was deposited. Later isotopic dates indicate that the age of the Brady Butte Granodiorite is 1770 ± 10 m.y., which is indistinguishable from the 1775 ± m.y. age of the Spud Mountain Volcanics. In the southeast corner of the Battle Flat quadrangle the Brady Butte Granodiorite appears to intrude the Spud Mountain Volcanics. Therefore, even though radiometric dating cannot distinguish age differences between those rock units, field evidence indicates that intrusion of the Brady Butte Granodiorite occurred after at least part of the Big Bug Group was deposited.

The Brady Butte Granodiorite is a tabular body, which is elongate north to south. This intrusive rock is medium or coarsely crystalline with average diameter of quartz and plagioclase grains ranging from 3 to 7 mm. Metamorphic foliation is developed to varying degrees throughout the exposed extent of the granodiorite and semischistose, and mylonitic textures are locally well developed (Blacet, 1968). Originally the porphyritic granodiorite near Tuscumbia Mountain was considered to be a younger intrusive rock (Blacet, 1968). However, later work indicated that it is a porphyritic phase of the Brady Butte Granodiorite (Anderson and Blacet, 1972c).

Texas Gulch Formation. The Texas Gulch Formation (Anderson and Blacet, 1972c) is made up of two distinct units: (1) slate (pelite) and (2) bedded rhyolitic tuff grading into sandy tuff and rhyolitic tuffaceous sandstones. Pebble-and-cobble conglomerates occur within the slate but more commonly with the sandy beds. Blacet (1966) observed the unconformity at the base of the Texas Gulch Formation where the Texas Gulch Formation overlies the Brady Butte Granodiorite. In this locality the basal conglomerate grades upward into cross-bedded sandstones, conglomerates and ultimately into slate. Even though the basal conglomerate is not continuous, O'Hara and others (1978) suggested that the contact between the Texas Gulch Formation and rocks of the Big Bug Group and Brady Butte Granodiorite may be interpreted as an unconformity. Locally, three faults are found along the contacts between these units.

Tertiary-Cretaceous(?) Granodiorite. Two stocks of posttectonic granodiorite intrude the Precambrian rocks in the region. The northern stock is located along Big Bug Creek (Anderson and Blacet, 1972c) and the southern stock is located west of Crown King (DeWitt, 1976). The northern stock has been dated 64 m.y. B.P. and 70 m.y. B.P. (Anderson and Blacet, 1972c). However, these are K-Ar determinations on biotites (Anderson, 1968) and therefore give a minimum age. The following description of the granodiorite is taken from Anderson and Blacet (1972c, p. 52).

The granodiorite in general is medium grained. It contains conspicuous zoned plagioclase crystals between 2 and 3 mm in length composed of sodic to calcic oligoclase. Potassium feldspar is generally smaller except for occasional poikilitic grains 2 mm or more in diameter. Interstitial quartz grains average about 1 mm in diameter, with some as small as 0.3 mm. Hornblende is conspicuous, particularly in hand specimen, and in the eastern part of the stock along Big Bug Creek, hornblende crystals are locally 5-7 mm long. In general, they average about 2 mm in length, and a few crystals are as long as 3 mm. The large hornblende crystals contain biotite and magnetite inclusions. Biotite is rarely larger than 21 mm in size, generally averaging between 1 and 2 mm. Accessories are magnetite, irregular sphene, stubby apatite, and minute zircon crystals.

STRUCTURAL INTERPRETATIONS OF C. A. ANDERSON AND CO-WORKERS

Detailed geologic maps summarizing the structural models of C. A. Anderson and co-workers, U.S. Geological Survey geologists, are available as GQ-996 and GQ-997 (Anderson and Blacet, 1972a, 1972b). The eastern half of the Poland Junction quadrangle and western half of the Mayer 7.5-minute quadrangle encompass the area of study. Fold structure consists of overturned folds with horizontal or shallow-plunging fold axes. The spud Mountain Volcanics in the Mount Union quadrangle cores an overturned anticline, and the Iron King Volcanics in the Mayer quadrangle are in the core of an overturned syncline. The anticline within the Texas Gulch Formation is cut off by the west boundary fault and apparently is considered a fold that was transported by faulting to its present position. The Texas Gulch Formation is bounded everywhere except at the northern contact of the Brady Butte Granodiorite by boundary faults. Figure 1 is a cross section that summarizes the structural model of Anderson and Blacet (1972c). The stratigraphic description is in part based on this model and is presented in its final form by Anderson and Silver (1976).

SUMMARY STATEMENT CONCERNING THE STRATIGRAPHY OF C. A. ANDERSON AND CO-WORKERS

A complete description of all rock units described by C. A. Anderson and his co-workers at the U.S. Geological Survey is beyond the scope of this report. The reader is referred to the many articles coauthored by C. A. Anderson included in the references in this study. The overall timing of events, description of rock units, and protolith interpretations for the most part are excellent. The stratigraphic relationships within the Big Bug Group and the structural interpretations are open to some question (O'Hara and others, 1978; DeWitt, 1979). Only detailed structural and stratigraphic analysis will further refine these problems. The rest of this section will describe DeWitt's (1979) structural model and the constraints imposed in the stratigraphic interpretations within the Big Bug Group and my own structural model, which differs from both of the previous models.

STRATIGRAPHIC AND STRUCTURAL MODEL OF DeWITT

DeWitt (1979) also presented a structural and stratigraphic model based on a single episode of deformation (fig. 2). The detailed geologic map presented by DeWitt includes the boundary of the Texas Gulch Formation on the west and the pelitic rocks east of the Iron King Volcanics. Steeply plunging fold axes and lineations are present in this area and are considered to be related to one episode of folding. Minor folds that plunge southward 30°-45° within the Texas Gulch Formation are considered to be the same F_1 folds but are oriented differently due to refraction of strain about the Brady Butte Granodiorite during deformation. The major regional folds interpreted from these data plus the map patterns of lithologic units have steep plunges. Therefore, stratigraphic interpretations are quite different from those of C. A. Anderson and co-workers. Stratigraphic units within the Iron King Volcanics are differentiated and mapped and extended farther to the south. The major structure interpreted by DeWitt (1976, 1979) is a south-closing, overturned, steeply plunging anticline within the Iron King Volcanics (fig. 3). Based on reconnaissance mapping, DeWitt (1979) inferred a north-closing, steeply plunging syncline cored by the pelitic unit (fig. 3).

A stratigraphic column (DeWitt, 1979) based on the structure model and protolith identification is presented in figure 3. For a complete description of specific stratigraphic units determined by DeWitt, the reader is referred to DeWitt (1976) or DeWitt (1979). Figure 2A illustrates DeWitt's (1979) stratigraphic reconstruction of the Iron King Volcanics and overlying pelitic rocks. The contact between the Iron King Volcanics and the pelitic rocks is considered to be an unconformity. Figure 2B illustrates the structural reconstruction of DeWitt (1979) with later intrusions not included.

POLYPHASE DEFORMATION MODEL AND IMPLIED STRATIGRAPHY

During initial reconnaissance mapping the following two problems with the previous work became apparent:

1. Steeply plunging fold axes are parallel to the dominant lineation directions. This indicates that the lineations are not "a" lineations as Blacet (1968) stated; therefore, the structures present are probably more complex than reported.
2. All previous workers identified and mapped the rock units as protoliths. Contrary to the previous workers' assertion of excellent primary feature retention, only an occasional cross-bed or graded bed was observed and in most cases these features were in the Texas Gulch Formation.

Aerial photographs were used to locate key areas to test the various stratigraphic and structural models. The map pattern of the Texas Gulch Formation (Anderson and Blacet, 1972c) apparently indicates the presence of a refolded fold. The proposed boundary faults (Anderson and Blacet, 1972c) surrounding the Texas Gulch Formation were investigated at several localities, and aside from the two faults along the eastern contact of the Texas Gulch Formation no evidence of faulting was observed. The unconformable relationship between the Texas Gulch Formation and Brady Butte Granodiorite (Blacet, 1968) was confirmed and on this basis, along with the isotopic date of 1740 m.y. B.P. on the Texas Gulch Formation, O'Hara and others (1978) claimed that the boundary surrounding the Texas Gulch Formation was a folded unconformity and that this is evidence for at least two episodes of deformation, Based on this interpretation, the Spud Mountain Volcanics and Iron King Volcanics can be interpreted as at least partially correlative.

During reconnaissance mapping in the Iron King Volcanics between Mayer and Crown King, no evidence of DeWitt's (1976, 1979) major fold or folded stratigraphy was observed. In fact, the rock unit cropping out below the Texas Gulch Formation on the Mayer—Goodwin

Road is intermediate to mafic rock, not a basalt or andesite as shown by DeWitt (1979). Therefore, the regional F_1 syncline is defined by the south-closing contact of the Texas Gulch Formation. The rock units deformed in the F_1 event are refolded about the northern boundary of the Brady Butte Granodiorite. The refolding causes the reappearance of the F_1 synclinal axis in the Battle Flat area west of the Brady Butte Granodiorite.

Revised Stratigraphy

The revised stratigraphy is based on the structural model proposed above and reconnaissance mapping in the pelitic and metavolcanic rock units. The youngest rocks are in the core of the F_1 syncline within the Texas Gulch Formation. Even though the sequence is in part duplicated by minor folds and thicknesses have been changed by deformation, the overall stratigraphic sequence can be determined. The base of the pelitic unit unconformably overlies the eastern metavolcanic sequence observed in the Shylock "zone." Near the top of the pelitic unit, metagraywacke(?), fragmental metafelsites, and minor cherty layers are interlayered with pelitic rocks. Included in this sequence is an amphibolite of unknown origin. In the DeSoto mine area an amphibole-bearing calcareous metapelite is interlayered with the pelitic sediments. Unconformably(?) overlying these rocks are amphibolites, quartz-muscovite schist, and silicified metarhyolite. An agglomerate (DeWitt, 1979) or lag conglomerate overlies and truncates these rocks and crops out north of Turkey Creek. This rock unit may mark the base of another unconformity. Overlying the agglomerate(?) are the amphibolites, quartz-muscovite schists, and metarhyolites of the Blue Bell mine area. These rocks may be intruded by a metagabbro (DeWitt, 1978) that is now an amphibolite. This metagabbro(?) may be a southward extension of a metagabbro (diabasic texture) that crops out southwest of Mayer. The rocks in the Blue Bell mine area are overlain by a sequence of amphibolites, quartz-muscovite schist, minor metagraywacke, and marble. The rocks in both the Blue Bell mine area and the DeSoto mine area are overlain by calc-silicate rocks intercalated with amphibolites (at lower metamorphic grade these rocks are greenstones) and marble. This unit thickens southward where it comes in contact with the pelites near Crown King. Northward this rock unit thins and is replaced by calcareous fragmental rocks that are similar to fragmental rocks in the Spud Mountain Volcanics west of the F_2 fold axis. The pebble-and-cobble conglomerates, metarhyolites, and quartz-muscovite schist of the Texas Gulch Formation overlie the Spud Mountain and Iron King Volcanics unconformably. The youngest rock unit in this unit appears to be the phyllitic pelite in the center of the area of outcrop of the Texas Gulch Formation. Stratigraphic relationships within the Texas Gulch Formation are difficult to decipher due to the extreme deformation (Blacet, 1968).

Deformation and Folding

Overturned steeply plunging isoclinal folds are the youngest folds (F_1) observed in the region. These folds are observed in thin section, outcrops, and as folds with up to 2-km amplitude. Layering (S_0), which in these rocks appears to coincide with lithologic contacts, is folded, whereas the observed foliation (S_1) is parallel to the axial planes. Lineations (either small-scale fold axes or the intersection of layering with foliation) are parallel to the fold axes. Therefore, the lineations are most likely "b" lineations. S_1 foliation is the dominant foliation observed in the region.

East of the Brady Butte Granodiorite, outcrops of the Texas Gulch Formation contain lineations and fold axes that plunge 30°-45° S. within the plane foliation. The foliation, which dips steeply to the west, is parallel to the regional foliation pattern in the area. There appears to be a transition from east to west from steeply plunging lineations to shallow-plunging lineations and fold axes. At present it is believed that these local folds are also F_1 folds but are designated F_1a because of the different orientation of the fold axes. DeWitt (1976) attributed these axial attitudes to refraction of strain about the Brady Butte Granodiorite during deformation. An alternate hypothesis will be proposed later.

A second generation of minor folds (F_2) is observed north of the Brady Butte Granodiorite in the Mule Canyon area. These folds are overturned and open to tight folds plunging 0° to 20° N. Layering (S_0) and schistosity (S_1) are folded by these F_2 folds. Small-scale F_1 or F_1a isoclinal folds are folded by the F_2 folds. S_2 foliation is represented by fracture cleavage that dips steeply to the west and is parallel to the axial planes of F_2 folds. The shear sense and level of flexure of these folds confirm the presence of the anticline of Anderson and Blacet (1972c) within the Texas Gulch Formation. Minor F_2 folds are rare in the rest of the region. The large number of minor F_2 folds in the Mule Canyon area is attributed to the fact that it lies in the axial area of the regional F_2 fold.

Faults and Fractures

Many faults and large fractures are observed in the field and on aerial photographs. The faults on the east limb of the F_2 antiform, which cut the Texas Gulch Formation and Iron King Volcanics, are the most obvious. These faults appear to have a major left-lateral strike-slip component. Detailed mapping on the southern structure indicates that it is a F_1 axial area that is cut off by the fault and that the fold axis is displaced to the south. Therefore, this structure cannot be interpreted as a simple left-lateral strike-slip fault. It can be explained in either of two ways: (as a left-lateral strike-slip fault through a minor fold displacing the axial area to the left or (2) as a vertically dipping normal fault with the west block displaced upward. This movement displaced the downplunged axis of the fold upward in contact with the west side of the fold. Other major fracture zones are observed on aerial photographs. Field evidence indicating the presence of faults include mylonitization, closely spaced individual fractures, quartz and carbonate veins, and changes in the attitude of S_0 and S_1 near the fractures. However, no apparent displacement can be measured on many of these fractures. All the fractures and faults are considered to postdate the folding and to predate the eruption of the Tertiary volcanics.

Shylock Fault Zone

Anderson and Blacet (1972c) interpreted a sequence of metavolcanic rocks about 2 km thick that are in contact with the western boundary of the Badger Spring Granodiorite as part of a major regional structure; the Shylock fault zone. Fracturing and mylonitization in the granodiorite and metavolcanic rocks along with the lack of a contact metamorphic aureole in the metavolcanic rocks suggests that the granodiorite is in fault contact with the metavolcanics. At least locally, the metavolcanics seem to be in fault contact with the metapelites. However, this contact is about 0.5 km west of the boundary of the Shylock fault zone. The rocks between these faults are vertically dipping quartz-muscovite schists. The vertical orientation in this region presents a very strong lineation on aerial photographs, but no evidence of crushing, fracturing, or granulation was observed in this zone. The rootless folds and en echelon slabs of iron formation (boudinage?) suggest that the rocks in this region underwent extreme transposition during F_1 deformation. For these reasons it appears that these rocks are not part of a fault zone but are a zone of extreme strain that occurred during the F_1 deformation.

Tectonic Model

Removing the posttectonic intrusive rocks and using the fold model presented above allow the formulation of a hypothesis concerning regional tectonic movements. If the stratigraphic arguments and fold history are reasonable, then F_1 folding would produce regional recumbent isoclinal folds with associated thrust faults(?) that are overturned from southwest to northeast. Axes of these folds would trend roughly northwest to southeast. During this event the overturned limb of the regional fold would be oversteepened as the folds formed, and at this time slumping of the youngest rocks into the core of the syncline might be expected. Blacet (1968) asserted that the stratigraphy within the Texas Gulch Formation is extremely complex. The complex stratigraphy and the presence of F_1a folds may be accounted for by the slump hypothesis if the allochthonous rocks moved down the slope of the basin at an angle to the direction of folding. Alternatively, the F_1a fold may have been caused by the refraction of strain about the Brady Butte Granodiorite (DeWitt, 1976). These structures would then be deformed by the F_2 event, which may have been accompanied by upward movement of the granodiorite in the core of the F_2 antiform. However, the granodiorite may have simply acted as a focal point for deformation. These deformations would be responsible for the present outcrop pattern, which was only locally modified by later events. Large-scale faulting and fracturing apparently postdates this event.

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GEOLOGIC OVERVIEW OF THE TRANSECT FROM THE IRON KING MINE TO THE COPPER QUEEN MINE

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INTRODUCTION

The Geology between the Iron King and Binghampton–Copper Queen mines is an important transect across the eastern half of the 1800 m.y.-old, Proterozoic Prescott volcanic belt. The rocks encountered span from almost the oldest to the youngest formation in the belt, but many of the unconformable contacts between the older and younger formations have been obscured by intense deformation in the Shylock tectonic zone, thus making the recognition of these important contacts difficult without extensive mapping of the stratigraphy in the belt.

A simplified geologic map of the major rock units between the Iron King and Binghampton–Copper Queen mines (fig. 1) is included with this discussion to help those participating in the field trip locate themselves and the mines they visit with respect to these major geologic formations. The formation terminology used here is in part new, is proposed by me for formal adoption, and will be published more explicitly in a forthcoming Arizona Geological Society Digest.

METAMORPHIC AND ALTERATION FEATURES

All rocks exposed in the region were originally Precambrian volcanic rocks and their tuffaceous or volcaniclastic derivatives, but most rocks have since been converted to fissile schists and semi-schists by low-grade greenschist metamorphism. This means that sericite, albite, and locally clays take the place of original volcanic feldspars, and usually chlorite, sericite, magnetite, and locally actinolite take the place of original pyroxene or hornblende. Quartz usually survives and is enhanced by most greenschist metamorphic reactions.

Not all rocks were originally fresh prior to metamorphism; in fact, large portions of the volcanic piles were extensively hydrothermally altered in their original depositional sites prior to metamorphism. The most widespread alteration types are chloritization and sericitization of thick felsic volcanic units, particularly in the Binghampton–Copper Queen area. Abundant quartz eyes in a strongly chloritic rock nearly always signifies original chloritic alteration. Elsewhere, rocks that are mostly sericite and clays also denote zones of original volcanic alteration rather than retrograde metamorphism.

In many places, the alteration systems worked up through the volcanic piles by circulation of magmatic fluids or heated sea-water brine, but in other places, such as above the Copper Queen adit, it is clear that the chlorite was an original exhalative product of volcanism and was deposited in thin layers within the main exhalite horizon. South of the Copper Queen area, the Stoddard mine is a classic example of a clay alteration pipe cutting through rhyodacitic fragmentals that has not significantly metamorphosed after original volcanic alteration.

MAJOR STRUCTURAL FEATURES

All Proterozoic stratified volcanic and clastic rocks in the Prescott volcanic belt are foliated to some degree, leaving them with the appearance of schists, semi-schists, phyllites, and locally slates. This foliation results from a major event of deformation 1700 m.y. ago in which the relatively incompetent stratified rocks acted passively and were penetratively imprinted by foliation and locally lineation, compared to adjacent relatively competent plutonic rocks, which were not as strongly foliated or lineated.

This pronounced north- to northeast-trending foliation is the dominant structural feature of stratified volcanic rocks in the Prescott belt. Lineations, folds, original bedding, and other structural features are much less obvious because of the relatively poorly bedded nature of volcanic piles. The predominance of this foliation and relative obscurity of other structural features has led to some controversy and misunderstanding as to exactly how the volcanic belts have been deformed, with the absence of any folding versus several periods of refolding being the two extreme viewpoints.

The foliation is a measure of the total strain experienced by the rocks, and it varies in direction and intensity from place to place across the volcanic belt. In the Bradshaw Mountains west of the field transect, the rocks are only weakly foliated and relatively slightly strained. From the Chaparral shear zone 1.5 miles west of the Iron King mine to the Agua Fria River 4 miles southeast of the Iron King mine, foliation trends N. 40° E. to N. 20° S. and is of moderate to strong intensity. East of the latter point, from Bell Ranch to the Binghampton–Copper Queen mine, foliation trends north-south and is of strong to extreme intensity.

Part of this eastern zone was originally mapped as the Shylock fault and was proposed by C. A. Anderson of the U.S. Geological Survey as a major strike-slip fault with transcurrent displacement. Subsequent detailed mapping in the north by me traced the Grape-

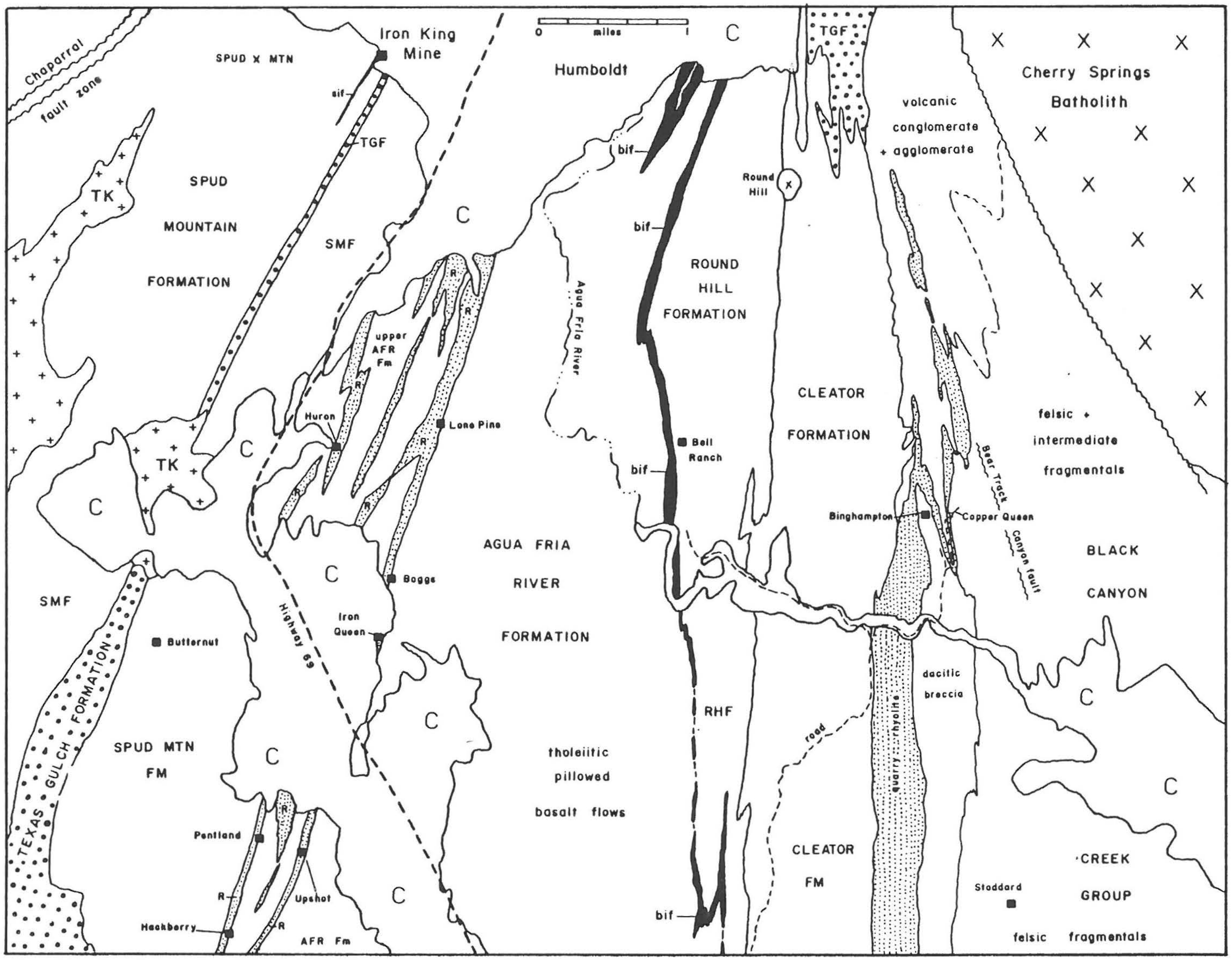

Figure 1. Geologic map of the Agua Fria River region

vine Gulch Formation from Mingus Mountain right across the Shylock zone west into the Indian Hills, thus disproving any strike-slip offset. A similar transect through continuous, but highly deformed rock types is possible from the Copper Queen mine area east across the Shylock zone but is complicated in the southern area by the presence of strongly deformed unconformities.

The Shylock zone is now understood to be a zone of very strong to extreme strain in which the stratified volcanic and clastic rocks have been intensely flattened and strongly extended in both north-south and vertical directions, leaving many of the rocks in the zone as fissile paper schists. Notwithstanding this extreme strain, there is general stratigraphic and structural continuity within the zone, and small faults within the zone, such as the Bear Track Canyon fault east of the Copper Queen mine, are not components of major strike-slip faults.

The rotation of foliation from its usual northeast trend in the rest of the Prescott volcanic belt into a true north-south direction in the Shylock tectonic zone results from the buttressing effect of two major plutonic or batholithic masses. The Cherry Springs batholith lies east of the volcanic rocks in the Mayer area, and much of the alluvial-covered valley from Humboldt north to Prescott Valley is underlain by Prescott-type granodiorite. These two competent plutonic masses effectively flattened the incompetent stratified rocks between them, causing them to flow both horizontally and vertically into a north-south elongate zone of high strain that is now call the Shylock tectonic zone. The southern part of the Shylock zone in the Black Canyon belt records similar flattening and extension between plutons.

MAJOR STRATIGRAPHIC UNITS

The following stratigraphic sequence has been worked out by me through detailed mapping of all quadrangles in the Prescott belt. It can only be gleaned from understanding the structure and stratigraphy of the entire volcanic belt and the complex, laterally interfingering nature of rock units within it. The sequence will not be evident from the brief field inspection involved in this transect. All formations described below are redefined as belonging to either the Mayer group, which extends from near the Iron King mine to the eastern outskirts of Mayer, or the Black Canyon Creek group, which occupies the easternmost part of the Prescott volcanic belt and is the younger of the two rock groups.

Mayer Group

Round Hill formation. The oldest rock sequence in the transect from the Iron King mine to the Binghampton– Copper Queen mines lies between the Agua Fria River and Round Hill and is newly named the Round Hill formation. It is a complex sequence of mafic, intermediate, and felsic flows, tuffs, and clastic equivalents in which many chert, iron formation, and exhalite horizons are interbedded. A white rhyolitic dome, visible from the Iron King mine and Highway 69, lies near the top of this volcanic sequence and produced the felsic tuffs in which the Bell Ran gold deposit lies. The Round Hill formation is capped by a thick and highly distinctive, dark-red to black, shaly iron formation, which extends from near Humboldt intermittently south to Mayer, thence under cover to reappear east of the Bluebell mine. This iron formation defines an important time horizon in the volcanic stratigraphy.

Agua Fria River formation. Stratigraphically overlying the Round Hill formation is a very thick sequence of tholeiitic basalt flows, pillow lavas, mafic tuffs, and hematitic cherts, which is named as the Agua Fria River formation. The pillowed basalt flow sequences are well exposed in the Agua Fria River canyon, where one finds pillowed tops alternating with massive microgabbroic flow cores and at the base of the sequence microgabbroic sills intruding strata of the Round Hill formation.

The Agua Fria River basalt sequence underwent fractional crystallization to produce more felsic feldspar-phenocrystic andesite and rhyolite end products, which are interbedded along the western edge of the sequence from the Lone Pine mine south through the Boggs–Iron Queen mine sites to the Pentland and Hackberry mine sites. All of the mines are related to rhyolite flows and fragmentals that were derived by fractional crystallization from the tholeiitic basaltic parent (Phillip Anderson, Ph.D. dissertation, in preparation).

Spud Mountain formation. In variable disconformable to unconformable relation upon the rhyolites and andesites described above is a thick sequence of intermediate breccias, tuffs, and agglomerates named the Spud Mountain formation for its type section on Spud Mountain, the rounded knob just west of the Iron King mine. The Spud Mountain formation began with deposition of andesite to dacite flows, breccias, and tuffs, now exposed on its eastern side along Highway 69. The nearby cuts of the old railroad grade expose elongate dacitic fragments in the breccias and agglomerates.

Dacitic pyroclastic volcanism originating from a center to the south near Battle Flat quickly overwhelmed earlier volcanism such that most of the Spud Mountain formation consists of dacitic pyroclastics, and lithic-crystal ash-flow tuffs, as seen in the Spud Mountain area. The Iron King mine itself and the Butternut mine to the south were produced by exhalative activity related to the waning or final volcanic stages of the Spud Mountain formation. Other mines in the same area may relate to later intrusion of the Laramide Big Bug pluton.

BLACK CANYON CREEK GROUP

The extremely thick sequence of felsic volcanic flows, fragmentals, tuff, and volcanic conglomerate that lies east of Mayer is part of the Black Canyon Creek group, a group that is both spatially and stratigraphically distinct from formations in the Mayer group, even though the difference is not shown on former U.S. Geological Survey maps. The group consists broadly of an older felsic volcanic component, just mentioned, and a younger sedimentary component named the Cleator formation.

Along its eastern side, the Cleator formation overlies felsic volcanics of the Black Canyon Creek group from the Black Canyon belt north into the Shylock zone, the contact varying from a disconformity to slight angular unconformity. However, the western contact of the Cleator formation more obviously unconformably truncates rock units in the underlying Mayer group, cutting downsection northerly from the Agua Fria River formation into the Round Hill formation (see map). Thus, prior to deformation, the Cleator formation was originally a shallow spoon-shaped deposit laid down unconformably across the underlying rock units.

The older part of the Black Canyon Creek group is a thick assemblage of felsic to intermediate (dominantly rhyodacitic to dacitic) pyroclastics, flows, and tuffs in which the complexity of facies changes, local unconformities, lensoidal depositional units, and alteration patterns defy resolution by all but the most painstaking detailed mapping. Of the many units identified, only two western ones in the Binghampton–Copper Queen mine areas are pertinent to this transect.

The two units are a prominent quartz-eye rhyolite, informally named the quarry rhyolite, which occupies a long ridge east of the road to the Copper Queen mine, and a unit of dacitic breccia immediately east of this; both are formally included in the Binghampton Mine facies. The quarry rhyolite is capped by a thin prominent ridge of hematitic chert and has a core of chloritic alteration, which is especially obvious in quartz-eye rhyolites either side of the Binghampton mine shaft. On the eastern ridge, the intimate interrelationship of syngenetic copper mineralization to this chloritic alteration is evident.

The dacitic breccia unit seen on the road up to the Copper Queen adit appears to occupy the local core of a fold where highly deformed in the canyon. The quartz-eye rhyolite unit wraps around the nose of this north-closing, steeply plunging fold continuously from the ridge west of the Binghampton shaft to the ridge between the Binghampton and Copper Queen mines and thence off to the north. Complex facies changes are present in the mine areas and were sites for localized high strain during later intense deformation in this part of the Shylock zone.

The youngest rock unit the Prescott volcanic belt (defined as part of the Ash Creek Group on Mingus Mountain) is the Texas Gulch Formation. This is a dominantly sedimentary formation of well-bedded, reworked volcaniclastic detritus, which is separated from the preceding, dominantly volcanic formations by an event of plutonism, uplift, and unroofing of some plutons. Thus, contacts of the Texas Gulch Formation, both to the north and south, are partly unconformable upon pluton rocks of the Brady Butte Granodiorite and the Cherry Springs batholith.

The Texas Gulch Formation is seen in two places along this transect: (1) just east of the Iron King mine, where sulfide-bearing clasts from the Iron King mine strata are recycled into basal units of the Texas Gulch, and (2) north of Round Hill, where Texas Gulch rocks unconformably overlie the Round Hill and Cleator formations as well as volcanic units in the Black Canyon Creek group.

PRECAMBRIAN VOLCANOGENIC MINERAL DEPOSITS

All stratabound base- and precious-metal deposits described here are part of a single, brief Proterozoic metallogenic event spanning the period between 1780 and 1750 Ma, which produced metal concentrations syngenetic to their enclosing strata (Anderson and Guilbert, 1979). The older deposits formed in the deep-water submarine environment at or near the sea floor, whereas the younger ones formed in shallower water marine environments or in volcanic edifices. Thus, each mineral deposit is intimately and uniquely related in age, geology, and geochemical characteristics to its enclosing volcanic or volcaniclastic strata. After deposition, metamorphism, and deformation substantially modified the geometry and mineralogy of each deposit and obscured the original sharp cut-off between mineralized and postore strata.

Iron King Mine

The Iron King mine lies entirely within the Spud Mountain formation near its upper contact with the Texas Gulch Formation. Feldspar-phenocrystic dacitic breccias distinctive of the Spud Mountain formation are found both east and west of the narrow strip of Texas Gulch sediments, thus refuting the uniqueness of a map unit labeled "Iron King Volcanics" on published U.S. Geological Survey maps of the area. Most rocks in this obsolete map unit have been reassigned to the Agua Fria River formation, and new mapping now recognizes that the Spud Mountain formation extends from the Iron King mine east to Highway 60 and west past the Chaparral fault.

Both 1,000 feet of and just east of the Iron King ore horizon, the distinctive feldspar-phenocrystic dacitic breccias can be seen in highly deformed condition. The eastern breccias are locally chloritically altered, whereas the western breccias are carbonate and epidote altered over a wide area. Stratigraphy less than 1,000 feet west of the ore horizon consists generally of fine-grained, finely bedded, intermediate to felsic, mostly dacitic tuffs in which tops to the east can be found. In this area, bedding is not paralleled by foliation, and stratigraphic units progress northeasterly across foliation.

As the Iron King ore horizon is approached from the west, the proportion of felsic material increases such that tuffs within 200 feet of the ore horizon are strongly iron-stained, silicic rhyolitic tuffs in which veinlets of hematite after sulfides are clearly apparent. Note that the most fissile sericite schists in this area are the most strongly crenulated. Immediately under the Iron King ore horizon are thin mafic units that may appear to be basalt flows, but upon closer inspection are seen to be mafic dikes that cross cut stratigraphy.

The Iron King ore horizon itself at surface is a classic sulfide facies iron formation, which is prominent because of its highly siliceous character, and consists entirely of bedded silica and limonite-goethite boxworks after sulfides, mainly pyrite. Right at the dump of the small timbered shaft, a 1-foot-wide exposure of massive goethite gossan can be found; this is the horizon that was slotted out near surface to produce the open cuts and, interestingly, was mined solely for its precious-metal content, primarily gold, in the early mining of the Iron King mine.

Only later did deeper drifting discover and mine the massive sulfide portion of the orebody, which plunges steeply to the north under the large waste dump and glory hole to the north in parallel with most other structures in the area. The massive sulfide ore from the Iron King mine consisted of mainly very fine, interbedded and fine-grained pyrite, sphalerite, galena, and chalcopyrite with 0.123 oz/t gold content and 3.7 oz/t silver content (Gilmour and Still, 1968).

Boggs–Iron Queen Area

The Boggs and Iron Queen mine shafts lie just east of Poland Junction, immediately north and south, respectively, of an alluvial-covered area that has a housing development on its western part. The Boggs mine is representative of the character of mineralization and host-rock types found in the upper portion of the Agua Fria River formation, where andesitic and rhyolitic rocks were extruded and interdeposited in repetitive succession. The oldest of three thin rhyolitic flows contains the Lone Pine mine to the north, the Boggs and Iron Queen mines in the central area. and the Upshot mine south of Highway 69 (cf. Webb, 1979). The middle rhyolite appears to be unproductive, but the upper, partly fragmental rhyolite produced the Huron deposit to the north and the Pentland and Hackberry mines to the south of the highway.

The Boggs mine involves a narrow, massive sulfide bed adjacent to a more broadly mineralized, pyritic, sericitically altered area of rhyolite. Both parts carry important base- and precious-metal values. Little of the massive sulfide bed is seen in outcrop as goethite-hematite gossan, and a much greater width is seen at the Iron Queen mine to the south. On the Boggs dump, samples of relatively coarse-grained sphalerite-pyrite-chalcopyrite-galena massive sulfide can be found.

Binghampton–Copper Queen Mines

The general setting of these two mines has been described above. The Binghampton mine lies in the western, and the Copper Queen adit in the eastern of two canyons occupied by north-facing closures of a recessive dacitic breccia unit rimmed by ridges of silicic rhyolite. The highest ridge between the Binghampton and Copper Queen mines is an altered chlorite-chalcopyrite (now malachite) feeder zone that underlies the Binghampton massive sulfide horizon. This horizon is not exposed at surface and is mostly mined out at depth. Massive pyrite on a small dump below the main Binghampton shaft marks the lateral pyritic facies of the ore horizon. The Binghampton is a small but ideal synvolcanic rhyolitic system where all three components—chlorite-chalcopyrite feeder zone, stratabound and bedded massive sulfide horizon, and siliceous pyritic cap—are well displayed.

The Copper Queen mine, in contrast, seems to be a distal expression of coeval rhyolitic volcanism, where most of the sulfides were deposited in a sulfide-facies iron formation. Samples of this iron formation bed on the dump well display a stratiform relationship between chalcopyrite, pyrite, sphalerite, and the hematitic chert unit. Other zinc mineralization, more broadly disposed than in a single iron formation bed, is reported at depth by several workers. On the ridge above the Copper Queen adit to the east, superb surface exposures of the stratiform nature of thin sulfide and chlorite layers between thicker beds of rhyolitic tuff, breccia, and chert, as well as facies variations in iron formation horizons, can be found, given sufficient time to trace them out in detail.

The Binghampton-Copper Queen area is a perfect example of the problem facing exploration geologists working in Precambrian volcanic belts: Given two adjacent mineral deposits shown to have originally lain at the same stratigraphic position, how can one correctly reconstruct the primary depositional geometry and facies changes of the original mineralizing system so as to accurately predict in three dimensions where its center of mineralization will be considering the extreme state of deformation and retrograded metamorphic condition of the rocks? An answer to this question demands successful integration of structure, detailed facies analysis, and ore deposit studies—perhaps the greatest frontier in the geology of the western United States.

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GEOLOGY OF THE SPUD MOUNTAIN TUFF IN THE VICINITY OF THE IRON KING MINE

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and

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INTRODUCTION

The Iron King mine, located 10 miles east of Prescott in Yavapai County, Arizona, is a polymetallic stratabound massive sulfide deposit of exhalative origin hosted by generally fine-grained epiclastic tuffaceous sediments of the Spud Mountain tuff. This paper brings to light new data regarding the Spud Mountain tuff as exposed along the southwest extension of the Iron King mine (fig. 1) and discusses aspects of related hydrothermal alteration and base-metal soil geochemistry.

Outstanding reports by Anderson and Creasey (1958), Anderson and others (1971), and Anderson and Blacet (1972) provide the regional geologic setting surrounding the Iron King mine. The geology and mineralization specific to the Iron King mine have been well described by Creasey (1962) and Gilmour and Still (1968). We wish to express our gratitude to Santa Fe Mining, Inc. and Stan West Mining Corporation for releasing the geologic and geochemical data presented here. We also thank Mr. Jack C. Pierce, former Iron King mine manager for Shattuck Denn Mining Corporation, for providing updated mine production figures.

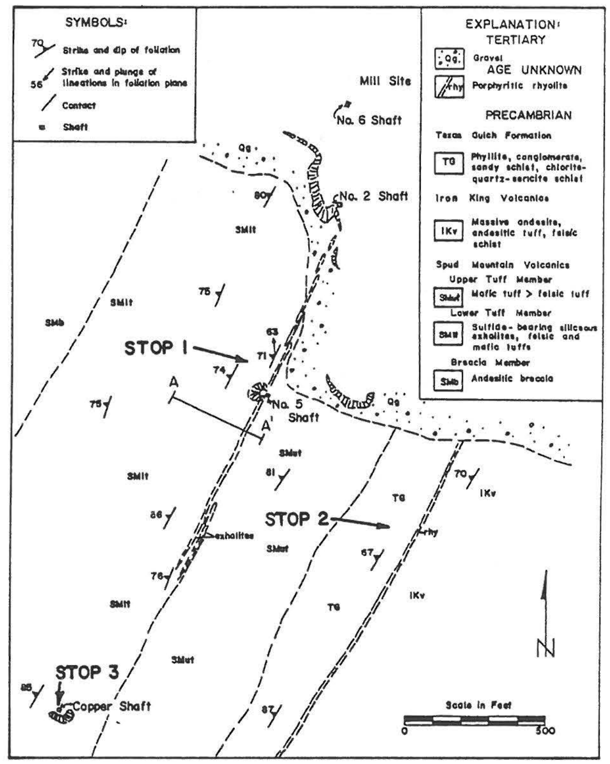

Figure 1. Generalized geologic map of the southwest extension of the Iron King mine showing location of cross section A-A' and points of interest for the Bradshaw Mountains and Jerome field trip. Figure modified from Gilmour and Still (1968).

HISTORY AND PRODUCTION

The Iron King mine, operated intermittently from about 1880 until its final closing by Shattuck Denn Mining Corporation in 1968. Early miners explored the oxidized portion of pyritic silica horizons for gold and silver prior to 1906, when production began for lead, zinc, and lesser copper. Data compiled by Shattuck Denn in 1968 (table 1) indicated that total production for the Iron King mine exceeded 6 million tons with an overall recovered grade of 0.115 opt Au, 3.42 opt Ag, 2.38 percent lead, 6.95 percent zinc, and 0.19 percent copper. Recoverable amounts of cadmium were also reported (Gilmour and Still, 1968). Principally known as a lead-zinc producer, its overall production of nearly 700,000 ounces of gold and more than 20 million ounces of silver make the Iron King the leading lode gold-silver deposit in the Big Bug district (Wilson, Cunningham, and Butler, 1967).

GEOLOGIC SETTING

Precambrian rocks in the immediate vicinity of the Iron King mine include the Spud Mountain and Iron King volcanic sequences, locally making up the Big Bug Group of the Yavapai Series (Anderson and Blacet, 1972). These strata of volcanic and related clastic and chemical sedimentary origin are dated at 1.77–1.88 b.y. B.P. (Anderson and others, 1971). Unconformably overlying the volcanics in the study area is the Texas Gulch formation composed of mixed fine-grained sediments, cobble conglomerates, and interlayered tuffaceous material. These rocks have undergone intense structural deformation, exhibiting isoclinal folds with steep axial planes and well-developed steep foliation and display greenschist facies regional metamor-

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Year	Tons	Gold (ounces)	Silver (ounces)	Lead (pounds)	Zinc (pounds)	Copper (pounds)
1906-38	78,452	15,690	313,808	3,138,080	6,276,160	470,700
1938	13,477	2,317	45,938	404,300	1,078,160	67,400
1939	70,227	9,911	272,604	1,872,680	5,854,020	351,120
1940	65,812	9,239	266,497	1,891,060	7,220,440	329,060
1941	69,159	9,720	331,746	2,320,040	7,617,100	345,800
1942	88,200	11,659	392,458	3,540,100	10,585,560	441,000
1943	73,721	9,167	307,465	3,164,380	10,095,300	220,720
1944	99,164	9,460	308,567	3,611,660	13,623,860	423,820
1945	117,287	13,068	436,506	5,259,640	16,156,180	455,280
1946	115,615	13,065	467,387	5,734,280	16,875,320	485,780
1947	122,368	15,298	533,642	6,194,880	16,925,320	411,820
1948	145,823	17,036	540,548	6,854,120	19,048,100	453,020
1949	175,111	21,432	737,925	8,414,680	23,547,440	546,660
1950	203,063	27,289	904,284	10,645,040	28,220,800	686,460
1951	202,581	27,135	764,731	9,528,680	26,075,380	657,100
1952	197,747	23,430	730,280	10,203,740	29,306,000	672,000
1953	190,735	26,703	730,515	10,528,000	27,008,000	610,000
1954	180,512	28,106	745,514	11,372,000	30,074,000	722,000
1955	222,909	31,296	884,949	12,170,000	32,902,000	758,000
1956	253,956	35,452	992,968	14,476,000	37,992,000	914,000
1957	300,729	38,644	1,118,712	16,540,000	47,696,000	1,082,000
1958	314,266	39,629	1,147,071	18,038,000	53,236,000	1,194,000
1959	299,981	38,728	1,124,929	17,338,000	51,476,000	1,140,000
1960	304,485	34,285	1,020,025	16,442,000	52,980,000	1,158,000
1961	235,885	22,857	702,937	11,700,000	39,912,000	1,038,000
1962	271,171	28,066	854,189	13,776,000	44,635,000	1,138,000
1963	280,807	27,463	901,390	12,468,000	39,200,000	1,010,000
1964	314,163	30,348	917,356	13,132,000	39,522,000	1,320,000
1965	333,743	25,738	713,930	12,518,376	38,135,352	1,254,987
1966	318,830	24,100	663,179	11,023,904	32,009,890	1,159,239
1967	273,737	21,586	569,741	9,869,966	25,988,296	961,727
1968	100,196	5,537	184,712	3,263,855	7,098,752	177,995
06-68	6,033,912	693,454	20,626,053	287,433,461	838,370,430	22,655,688

Table 1. Base- and precious-metal production at the Iron King mine for the period 1906-1968. Data compiled and furnished by Jack C. Pierce, former Iron King mine manager, Shattuck Denn Mining Corporation.

phic grade. At the Iron King mine, the steeply westward-dipping volcanic sequence is considered by Anderson and others (1971) to be overturned such that the stratigraphic footwall of the deposit is now the structural hanging wall.

SPUD MOUNTAIN TUFF

The Spud Mountain Volcanics were subdivided by Anderson and Creasey (1958) into the Spud Mountain breccia and younger Spud Mountain tuff. In the mine area the tuff unit is 1,200–1,400 feet thick. Following the terminology of Gilmour and Still (1968), we will refer to the lower member of the Spud Mountain tuff as that which hosts the massive sulfide mineralization at the Iron King mine; the upper tuff member contains no known mineralization of economic importance.

Lower Member, Spud Mountain Tuff

Recent detailed mapping in the lower member of the Spud Mountain tuff revealed a complex interfingered sequence, about 800 feet thick, of chlorite-quartz-sericite, quartz-sericite, and chlorite schists striking N. 25°-30° E. and dipping steeply westward. Locally well-reserved, abundant quartz and feldspar phenocrysts suggest that these rocks originated as crystal-rich tuffaceous sediments of alternating intermediate-to-mafic and felsic composition. Minor interbedded flow of intermediate composition have been identified in drill core. The upper 200 feet are marked by multiple sulfide-bearing siliceous exhalite horizons, which generally increase in thickness from a fraction of an inch to 14 feet at the top of the unit. The "footwall alteration zone" is a term used here for the strongly oxidized lower portion of this sequence containing numerous thin to laminar sulfide chert lenses (gossans) interlayered with pyritic schist. The uppermost exhalites, forming prominent iron-stained outcrops with adjacent open stopes and shafts in the study area, are laterally traceable for hundreds of feet. These define the "Ore Horizon" (Gilmour and Still, 1968) containing the tabular lenses of massive pyritic lead-zinc ore exploited to depths of 2,700 feet in the main parts of the mine. The exhalites gradually diminish in number and thickness along strike southwest of the mine, virtually disappearing approximately 2,500 feet from the No. 5 Shaft, as the ore horizon exhibits a gradual facies change to tuffaceous quartz-sericite±chlorite schistose rocks.

Thin sections from the footwall alteration zone and ore horizon show well-developed cataclastic textures indicating extreme shearing of all rock units present. Outcrop patterns also suggest that isoclinal folding and transposition of bedding has taken place. Small-scale isoclinal folds preserved in the exhalites commonly exhibit steep northerly plunges in the plane of foliation parallel to local lineation development. A later lineation and related chevron folds have a moderate south-southwest plunge. Structural transposition is considered to be so advanced as to have detached the limbs from the larger scale fold closures that may have existed. Two hypotheses are considered for the presence of multiple exhalite units in the ore horizon and for their en echelon arrangement: (1) isoclinal folding and transposition of a single exhalite horizon or (2) a stacked system containing several exhalites later displaced by shearing.

Zones of intense hydrothermal alteration occur in two distinct portions of the lower member of the Spud Mountain tuff. A band (10-50 feet wide) of black high-magnesium chlorite (nimite and leuchtenbergite by X-ray analyses) schist, commonly with abundant bull quartz and copper oxide staining, trends along foliation about 150 feet below the ore horizon. Termed the "copper zone" by Gilmour and Still (1968), this lensoidal pattern of magnesium metasomatic alteration can be traced at least 1,000 feet north and south of its thickest portion at the Copper Shaft from which minor tonnages of copper ore were exploited. The black chlorite alteration clearly affects both the felsic and mafic tuff units, and its outcrop pattern suggests a once-vertical footwall hydrothermal stringer zone, now severely deformed parallel to foliation. We interpret the Copper Shaft area as being one of possibly several centers of hydrothermal exhalative activity responsible for the overlying massive sulfides and chert horizons.

The footwall alteration zone, spatially associated with the zone of thin oxidized chert lenses and pyritic schist immediately below the ore horizon, is characterized by a quartz-sericite±kaolinite assemblage, which is particularly intense near the No. 5 Shaft. A narrow zone of similar alteration also exists near the Copper Shaft, immediately below the black chlorite schist.

Upper Member of the Spud Mountain Tuff

A sharp, apparently conformable contact exists between the ore zone and the upper member of the Spud Mountain tuff. The upper member, about 500 feet thick, is composed dominantly of mafic tuffs with 25 percent interlayered felsic tuff and minor ferruginous cherts and calcareous horizons. Tuffaceous units in the upper member are lithologically similar to those of the lower member.

SOIL GEOCHEMISTRY

Base-metal soil geochemistry was effective in locating the principal mineralized trends along the Iron King extension. The geologic and soil geochemical profiles shown in figure 2 typify copper, lead, and zinc distribution in soils with respect to the Iron King copper zone, footwall alteration zone, and ore horizon. The graphs illustrate the Iron King mine, as discussed by Gilmour and Still (1968, p. 1247). Strongly anomalous lead and zinc (up to 7,000 ppm Pb and 5,000 ppm Zn) shows a close spatial relationship to the thick sulfide-bearing ore horizon exhalites at the top of the lower member of the Spud Mountain tuff. This horizon contained the massive pyrite-sphalerite-galena lenses locally stoped out, as indicated in figure 2. Anomalous copper (up to 3,500 ppm Cu) is generally confined to the stratigraphic footwall of the deposit (copper zone), somewhat above the zone of black schist alteration.

The metal zonation demonstrated by the Iron King deposit is characteristic of numerous well-documented deposits, among them Sullivan, British Columbia (Sangster, 1972); Japan (Matsukuma and Horikoshi, 1970), and Crandon, Wisconsin (Schmidt and others, 1978). The massive sulfide deposit at Jones Hill, Pecos, New Mexico, similarly displays footwall copper mineralization and a zinc-rich upper horizon. The soil geochemical data here presented support the concept that the Iron King stratigraphic section and enclosed deposit have been overturned.

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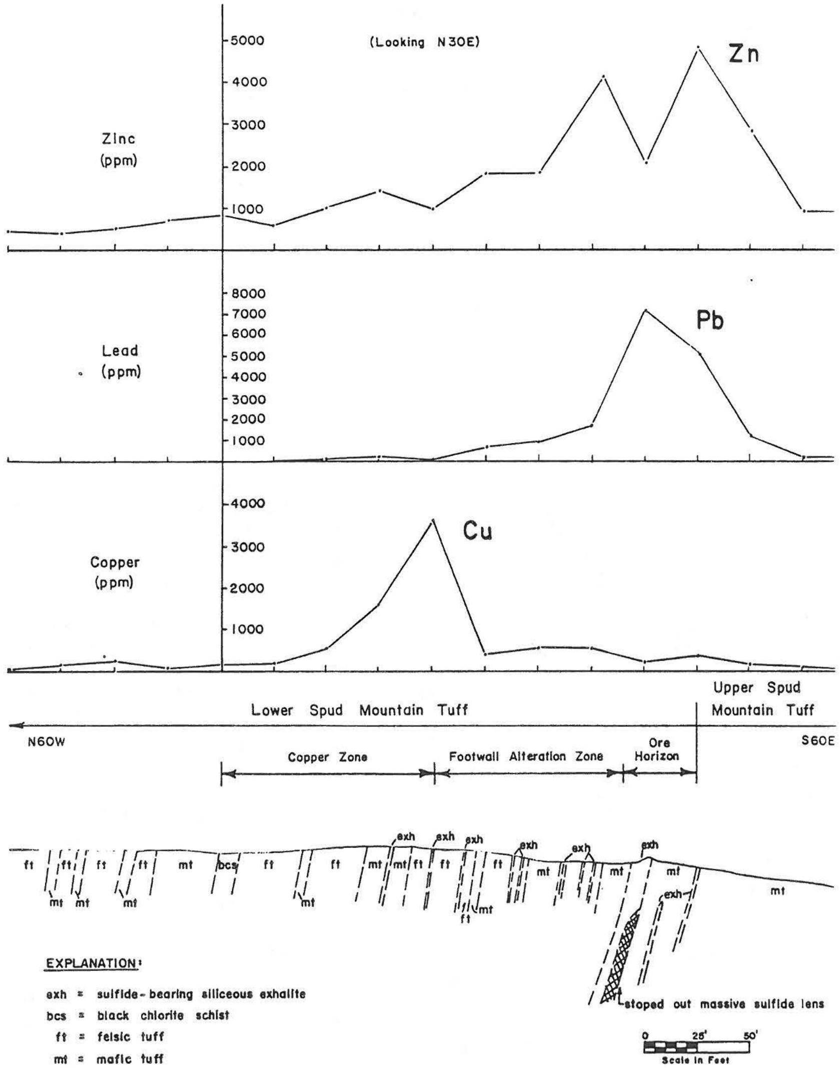

Figure 2. Geologic cross section A-A' showing relative position of Copper Shaft zone, footwall alteration zone, and ore horizon across the Iron King extension. Soil geochemical profiles for copper, lead, and zinc illustration metal zonation characteristics of the Iron King deposit.

THE GEOLOGY AND MINERALIZATION AT THE BOGGS MINE, YAVAPAI COUNTY, ARIZONA

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The Boggs mine is located near Poland Junction, Arizona, 2,500–3,000 feet east of Highway 69 within sec. 4, T. 12 N., R. 1 E. A well-maintained dirt road provides easy access from the highway at Poland Junction. The dumps of the Iron Queen mine are visible across Boggs Flat approximately 2,000 feet to the south of the Boggs mine.

Mining commenced at the Boggs and Iron Queen deposits in the late 1800s, and the mines were operated for a number of years by the Commercial Mining Company, a division of Phelps Dodge (Lindgren, 1926). From 1905 to 1909, these deposits were worked by the George A. Treadwell Company and ore was processed at the Mayer Smelter (Lindgren, 1926). Lindgren reported the grade of ore processed from the Iron Queen to be 0.025 ounces gold and 1.0 ounce silver per ton and 2.0 to 2.75 percent copper. This was apparently used as a flux for richer ores from other deposits, presumably the Boggs being one of them. No records of ore tonnage have been found for either deposit from this early period of mining. Lindgren reported that mining proceeded to the 500-foot level at the Boggs and the 300-foot level at the Iron Queen. From 1943 to 1945, Liberty Hills Mining Company leased and operated the Boggs mine. A shipment in 1943 of 98 tons from the 200-foot level assayed 0.45 ounces gold and 5.2 ounces silver per ton, 1.07 percent copper, and 4.3 percent zinc (Anderson and Blacet, 1972). Two holes drilled at the Iron Queen mine by the New Jersey Zinc Company in 1953 failed to encounter substantial mineralization at depths below the old workings.

The Boggs deposit lies stratigraphically within a package of interlayered quartz-sericite schist and chlorite schist interpreted as felsic to intermediate volcanic and volcaniclastic rocks (fig. 1). Porphyritic and clastic volcanic textures are common and fairly well preserved. A coarse felsic fragmental rock is a prominent unit in the structural footwall of the deposit with quartz-eye porphyry, both hosting and structurally overlying the ore. The ferruginous quartzite (chert) forms a broken but continuous horizon 200 feet east of the mine. Units are oriented roughly conformably with regional foliation at N. 15°-20° E. with a steep southeasterly dip. This lithologic package is confined to the west and east by massive porphyritic and clastic mafic volcanics and has a cross-sectional dimension of greater than 700 feet. Similar lithologies can be followed more than a mile north to the Lone Pine mine and can be projected to the south under and beyond extensive alluvial cover within the Big Bug drainage. This sequence of felsic to mafic volcanic rocks is included within the Iron King volcanics of Anderson and others (1971) and Anderson and Blacet (1972). The mineralogy of the rocks is indicative of greenschist facies metamorphism Webb, 1979).

Preliminary study indicates that the host rocks have been subjected to strong polyphase deformation. On a small scale near the ore horizon, two fold orientations have been observed. Steep northerly plunging isoclines are common, and superimposed shallowly plunging folds have been seen. Outcrop evidence of shearing is seen through transposition of fine folded layers near the ore horizon and highly attenuated fragments within the felsic fragmental unit to the west. Rocks within this felsic to intermediate host package show strong development of foliation.

The Boggs orebody has been described as a thin tabular deposit ranging in thickness from 10 inches to several feet, striking N. 20° E. with a steep northerly dip (Anderson and Blacet, 1972; Farnham (cited by Anderson and Blacet, 1972). The orebody lies within a schistose quartz-eye porphyry that is highly sericitized at the surface. Evidence of mineralization at the surface consists of bands and discordant veinlets of oxide iron and copper minerals and rare gossanous masses. Mineralization observed on the dumps consists of sulfide bearing siliceous hornfelsed rock, as replacement masses in carbonate associated with quartz, garnet, epidote, and tremolite and in veinlike quartz masses (Lindgren, 1926; and personal observations). Sulfides present are pyrite, sphalerite, chalcopyrite, and arsenopyrite. These mineralogic and textural relationships led Lindgren to propose a hydrothermal replacement origin for the ore.

In recent years, many workers have reinterpreted this and other similar deposits in the Poland Junction area to be of Proterozoic volcanogenic origin (Anderson and Blacet, 1972; Anderson and Guilbert, 1979; Webb, 1979). This interpretation was based on similarities in ore mineralogy and alteration typifying volcanogenic deposits and primarily their affinity with felsic volcanic host rocks and siliceous "exhalite" horizons. An important complication exists at the Boggs mine in the definite modification of ore mineralogy and host rocks by "Laramide" intrusive activity. Evidence for this comes from obvious replacement sulfide, skarn mineralogy, and late-stage discordant epidote veining. The presence of a "Laramide" granodiorite dike in the north pit and adjacent to the shaft at the south end of the workings is also evidence of intrusive activity. The dikes in themselves do not appear to have had a significant effect on adjacent surface rocks and show epidote alteration including crosscutting epidote veinlets. However, numerous cupolas of granodiorite crop out to the north adjacent to hornfelsed schist as at the Lone Pine mine. New Jersey Zinc Company's drill hole BIQ #2

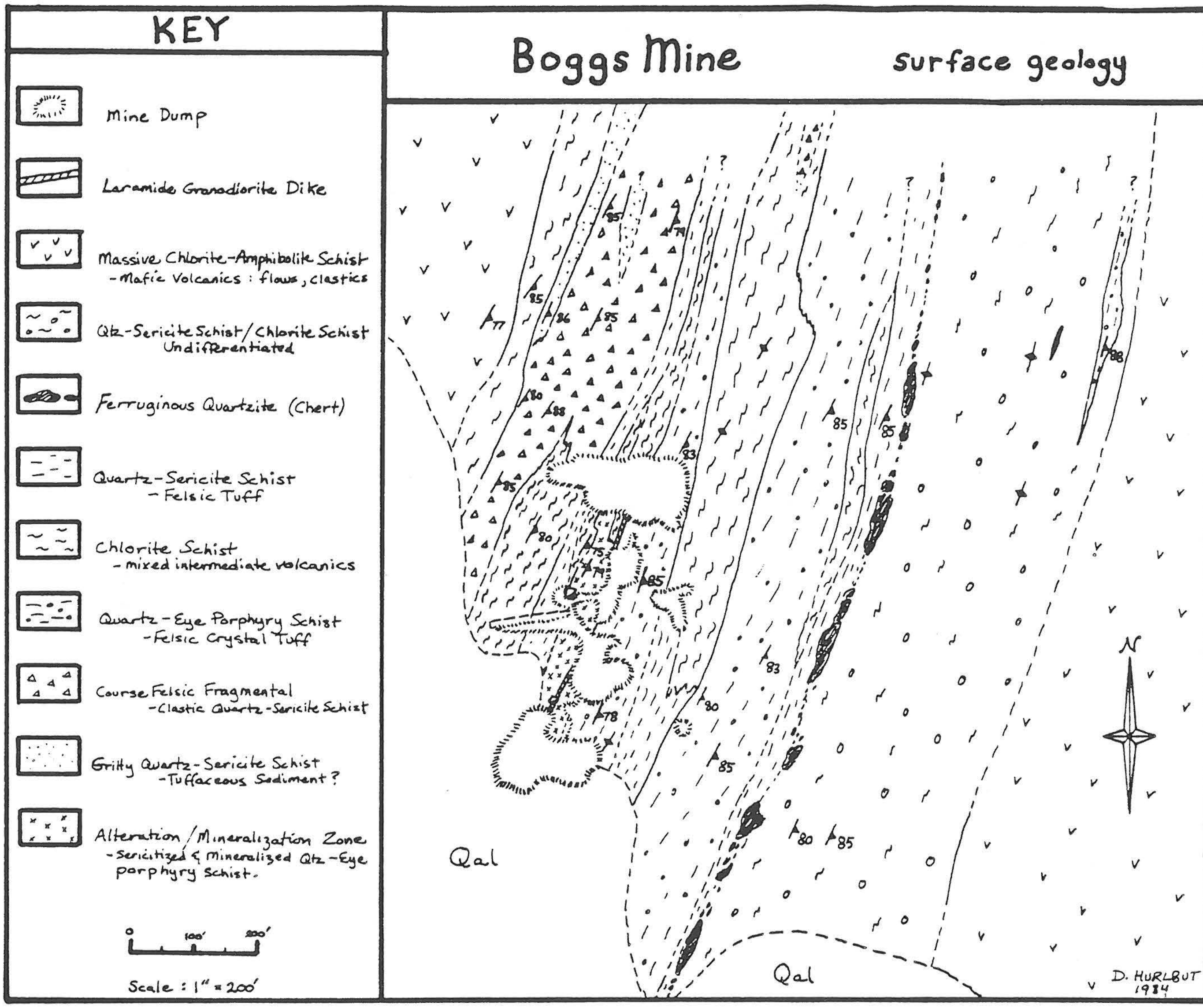

Figure 1. Surface geology of the Boggs mine

bottomed in zones of granodiorite and silicified schist within 1,000 feet of the surface near the Iron Queen mine.

A detailed study of surface geology at the Iron Queen mine is greatly inhibited by mine dumps and extensive alluvial cover. Other published accounts suggest strong similarities with the Boggs mine. Lindgren (1926) reported finding schist and calcite replaced with masses of garnet, epidote, actinolite, and magnetite in association with pyrite, chalcopyrite, sphalerite, galena, marcasite, and specularite. Webb (1979) found the host rocks to be very similar and considered the deposit to be in the same "stratigraphic position" as the Boggs deposit, although the alluvial cover between the deposits makes correlation difficult.

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GEOLOGY OF THE COPPER QUEEN MINE, MAYER, ARIZONA

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INTRODUCTION

The Copper Queen mine was active from the 1900s to 1920s and saw limited mining in 1948-49 and 1967. The 1900-1920 production produced 8 million pounds of copper, 33,000 oz silver/ton, and 200 oz gold. Estimated grade was 2.5%-3% copper/ton, 0.5 oz silver/ton, and 0.1 oz gold/ton from other mines in the district (Lindgren, 1926).

The area has been actively explored during the last 20 years. The recent activity is due in large part to the recognition of the nearby Iron King mine as a volcanogenic massive sulfide deposit (Gilmour and Still, 1968). Such types of deposits have strataform and possibly stratabound relationships with the surrounding lithologic units. Thus, the distribution of original rock units (protoliths) is highly important to exploration efforts. The map of the area (fig. 1) presented in this guide uses protoliths as map units. Therefore, it is interpretive.

LOCATION

The Copper Queen mine is located 4½ miles northeast of Mayer, Arizona, just north of the Agua Fria River, which bisects the area on an east-west course. The area is generally composed of north-south running ridges and valleys of moderate relief with juniper and catclaw vegetation. The area is accessible year-round by a gravel road from Mayer. Crossing the Agua Fria River in high water, however, can be hazardous.

REGIONAL GEOLOGIC SETTING

The Copper Queen area is with Proterozoic metavolcanic and metasediments in the eastern foothills of the Bradshaw Mountain Greenstone Belt. The rocks of the area have been assigned to the Spud Mountain Formation (Anderson and Blacet, 1972), which are part of the Big Bug Group. The formation is composed of submarine volcanic and sedimentary rocks, which have been regionally metamorphosed to mineral assemblages indicative of the greenschist facies.

STRUCTURE

Rocks of the Big Bug Group are well foliated, doubly deformed, and dissected by faults. The regional foliation is N. 10°-20° E. with 75°-90° westerly dips with subparallel to parallel contacts of foliation to lithology. Large-amplitude recumbent folds with east-west fold axes have been refolded into moderate-amplitude recumbent folds with north-south fold axes and steep plunges. The Copper Queen area is completely within a limb of a refolded fold, which has its fold nose 1½ miles to the north. Regional rake and plunge in the area are thought to be an important localizer of ore. Other mines in the area have rod-like ore zones with south-southwest rake and W. 70° dip.

Regional structural features in the area are an unconformity to the west and a fault zone to the east. The unconformity is marked by a large chert unit between the epiclastic siltstones and the lapilli tuffs (see map). There are truncations of units along this boundary. Major faulting in the region is confined to one major fault in the canyon to the east of the Copper Queen mine. This is the eastern edge of the Shylock fault zone of Anderson and others (1971). The sense of motion on the fault is not possible to determine due to a lack of stratigraphic relationships. Underground mapping shows many small shears, which are not recognizable at the surface.

LITHOLOGIC UNITS

The rocks in the area could be described in metamorphic terminologies as chlorite and sericite schists. However, protolith determinations are interpretive and necessary to define targets for exploration of volcanogenic massive sulfide deposits.

The westernmost unit is a group of epiclastic siltstones. They were probably derived from nearby volcanic material. These rocks are thought to be unconformably upon the lapilli tuffs to the east. The lapilli tuffs have chemical compositions indicating that they are rhyolites. The rocks have relict phenocrysts of quartz (2-10 mm), plagioclase (2-8) mm), and pumice fragments up to 10 cm in a quartz-sericite matrix. The rocks are lapilli tuffs and tuff breccias with mappable clast size distributions. The clasts are largest to the south and decrease in size to lapilli in the north.

The flows mapped as dacite feldspar porphyry have dominant relict plagioclase phenocrysts (1-2 mm) in a chlorite-epidote matrix. The textures indicate that brecciation dominated its history. I have interpreted the brecciation as one occurring during emplacement—autobrecciation.

The mine horizons are located in a series of dacite tuff and quartz porphyry. The relict phenocrysts quartz (1-5 mm) and plagioclase (2-7 mm) in a matrix of fine-grained chlorite, muscovite, and quartz. Patches (5-25 mm) of near-solid muscovite, which are different colored than other areas, are interpreted as lapilli or large-size pumice fragments.

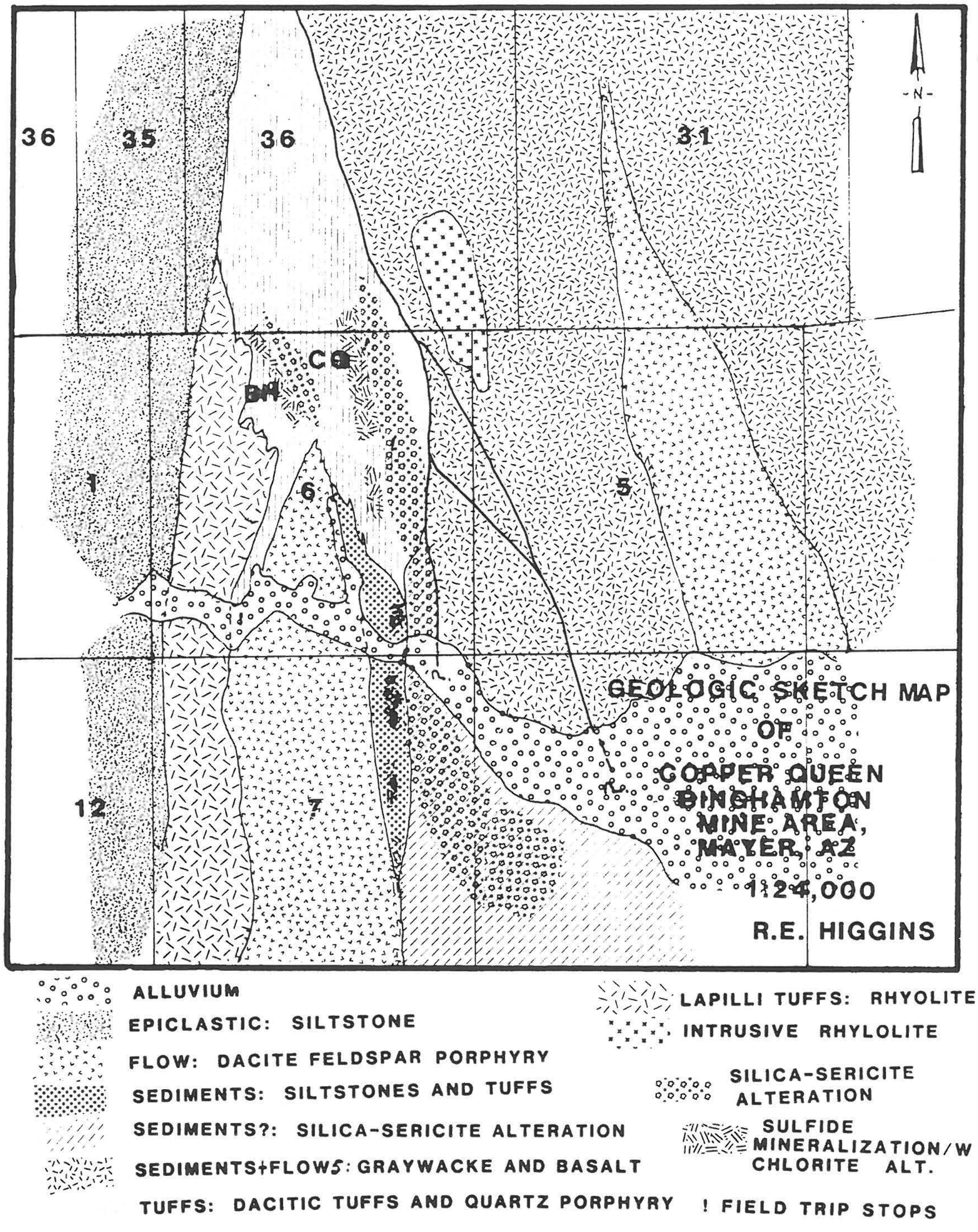

Figure 1. Geologic sketch map of Copper Queen–Binghampton mine area, Mayer, Arizona

The easternmost units are graywackes and basalts, which are massive units of black to dark-brown rocks with abundant iron oxide coatings of fractures. In fault contact with these rocks are the dacite tuffs and crystal tuffs. Intrusive into this unit is a quartz sericite rock interpreted as a rhyolite plug. Cherts are present in the eastern unit and along the western edge of the area. They are iron oxide rich (10%-15%) with magnetite and specular hematite the specific minerals.

ALTERATION

Alteration assemblages are composed of sericite and quartz with chlorite being minor, but it increases near sulfide mineralization. The silica-sericite rocks are thought to have formed when hydrothermal fluids passed through the pyroclastic units. The degree of alteration is variable and widespread throughout the area and is only mapped as a unit where it is dominant. Chlorite becomes a major alteration product near anomalous copper values (1,000 ppm or greater). On the ridges above the Copper Queen and Binghampton mines are well-developed chloritic alteration zones.

ORE MINERALIZATION

The Copper Queen mine was developed along an ore zone that I originally interpreted to be exhalative horizons interbedded with tuffs. The exhalative zones are composed of silica and sulfide minerals. Field and petrographic data indicate that selective replacement by hydrothermal fluids of existing pyroclastic layers is the most probable origin for much of the mineralization zones in the Copper Queen area.

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GEOCHEMICAL EVALUATION OF FOSSIL HYDROTHERMAL SYSTEMS IN PROTEROZOIC VOLCANIC ROCKS AND THE ORIGIN OF MINERALIZATION

Patrick F. O'Hara[1]

and

Ralph E. Higgins[2]

Stratabound mineralized systems that share some characteristics of stratiform "massive sulfide" deposits and some characteristics of epithermal systems exist in the Proterozoic rocks of central Arizona. Volcanic rocks associated with these mineralized systems are variably altered (silicification, silica-sericite and (or) chloritic alteration) containing semi-massive "ore" zones at best and do not occur at a major break in volcanic or sedimentary deposition (Copper Queen mine).

This type of mineralization is considered to be formed in the subsea-floor regime by processes intermediate between the "exhalative" system and that of a porphyry system at greater depth. An epithermal replacement-type system is hypothesized that may or may not vent at the sea-water interface as the hydrothermal fluid cools. A massive sulfide system such as Jerome is considered to have had a period of epithermal alteration and replacement at depth below the sea-water interface. As the fluid cooled (potentially by adiabatic boiling) the deposition of mineralization would have proceeded upwards through the volcanic pile and quenched when the fluid vented at the sea floor. Thus, Jerome is thought to be a true massive sulfide system in the "exhalative" sense and an epithermal system within the volcanic rocks below the sea-water interface. A "distal" deposit may have formed at greater depth by simple quenching of a hydrothermal fluid with very little associated alteration. A system such as that present at the Copper Queen mine may have never vented at the sea floor and may be interpreted as a replacement system.

Constraints on the type of mineralization present at any location are based upon depth of sea water, variations in lithostatic or hydrostatic pressure in the rocks below the sea-water interface, temperature and composition of the hydrothermal fluids, and rock preparation caused by accessible bedding structures, fracturing, and possible growth structures.

Examples illustrating the role of hydrothermal fluid temperature and salinity associated with mineral deposition will be presented at the Copper Queen mine field trip stop.

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MAP PATTERNS OF PROTEROZOIC ROCKS WITH TWO-DIMENSIONAL MODELS BETWEEN MAYER AND THE COPPER QUEEN MINE, ARIZONA

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Structural movements appear to have influenced the form, orientation, and size of ore deposits in the rocks of the Precambrian (1770 ± 10 m.y. B.P.) Big Bug Group of the Yavapai Series near Mayer, Arizona. The Big Bug Group has been divided into five facies: (1) chlorite schist (andesite to basalt), (2) quartz-sericite-chlorite schist (latite to dacite), (3) quartz-sericite (rhyolite), (4) metachert, and (5) metaconglomerate.

Principal structural elements in the Big Bug Group are lithologic contact (S_0), foliation indicated by schistosity and axial plane cleavage (S_1), flexural-flow and passive-slip to passive-flow folds (F_1), flexural-flow folds (F_2), joints, and faults. Subparallel lithologic contacts and foliation strike north to north-northeast and dip steeply west. The F_1 folds trend south to southwest and plunge 50 to 75 degrees. Attitudes of these structural elements suggest that the layered rocks of the Big Bug Group were isoclinally folded and that layering was transposed parallel to the foliation planes. The rocks were simultaneously rotated and (or) tilted (Evensen, 1980) or refolded (O'Hara, 1980).

Passive-slip models using simple shear are used to illustrate the manner in which deformation proceeds and produces the current outcrop patterns observed in the area. Depending on the initial angle of slip planes with S_0, S-C relationships can be demonstrated throughout deformation. Preliminary results of this study will be presented at the Copper Queen field trip stop.

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FIELD NOTES AND SKETCHES

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