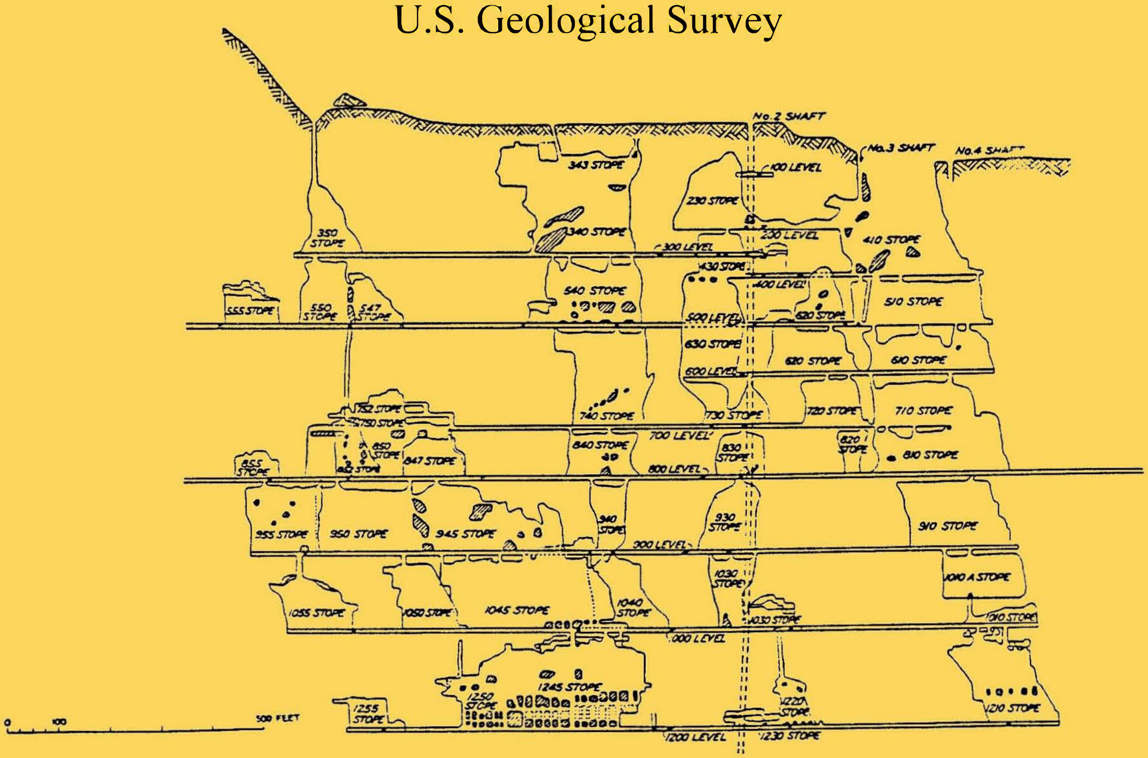
Proterozoic Geology and Ore Deposits of North-Central Arizona

Edited by Ed DeWitt
U.S. Geological Survey



Arizona Geological Society Field Trip
Spring 1991

Arizona Geological Society
P.O. Box 40952
Tucson, Arizona 85717

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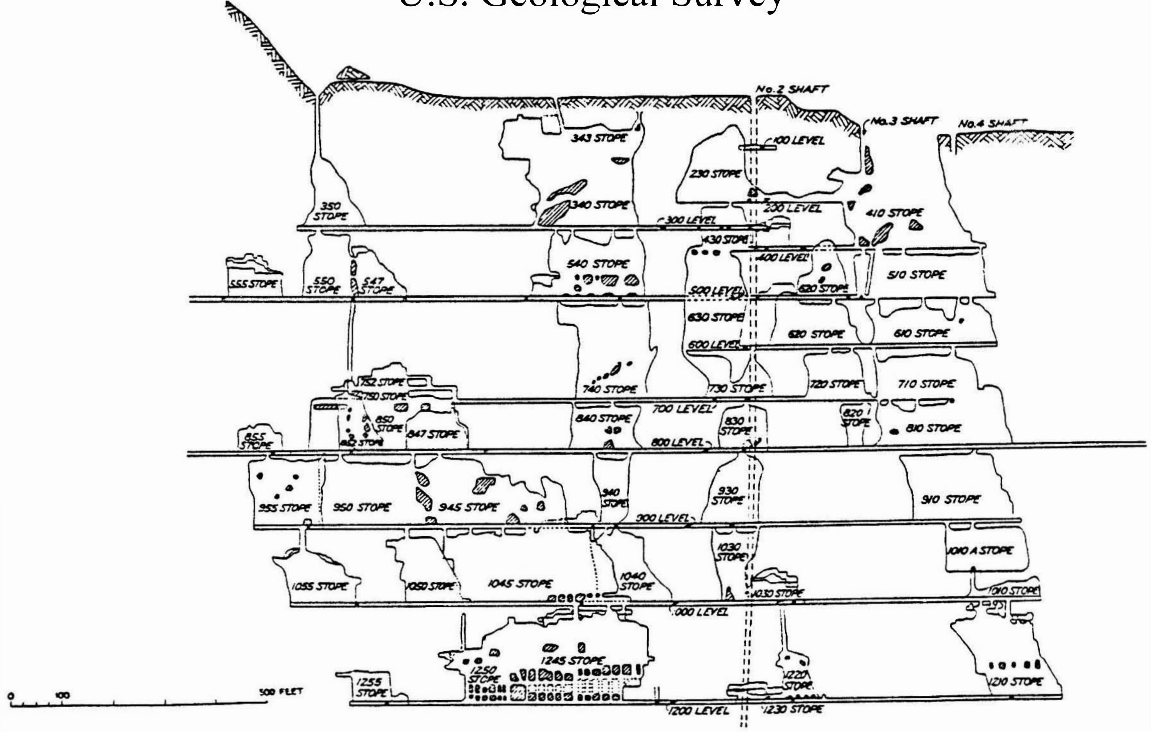

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Table of Contents

Cover Illustration: Longitudinal section of Bluebell Mine, from Lindgren, Waldemar, 1926, Ore deposits of the Jerome and Bradshaw Mountains quadrangles, Arizona: U.S. Geological Survey Bulletin 782, Plate 16

INTRODUCTION

The format and content of this publication are slightly different from past Arizona Geological Society (AGS) field trip guides and road logs. A road log and field trip guide, with supporting 1:100,000-scale geologic maps, are presented for both days of the trip. The maps are both color (with no topographic base) and black-and-white (with topographic base) to aid the field trip participant in understanding the stratigraphy and structure of the area. The road log for the trip is slightly longer than those in most previous AGS guidebooks and contains more geologic information; it was taken, in part, from the road log in DeWitt (1987). Because most of the papers referred to in this guidebook will appear, in entirety, in Arizona Geological Society Digest 19, only parts of the papers are reproduced here. Specifically, the abstract, relevant maps, figures, tables, and conclusions of those papers have been excerpted for this guidebook.

Field trip leaders include:

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DAY 1

The first day of the field trip will concentrate on Early Proterozoic massive sulfide deposits in the Mayer-Humboldt area and Early Proterozoic polyphase deformation in the Brady Butte area. After an initial stop at the Iron King Mine, southeast of Prescott, where we will discuss regional stratigraphic relations and metal ratios in massive sulfide deposits, our morning stop will be at the Huron-Victor-Swindler massive sulfide prospects south of Humboldt. These prospects afford a look Early Proterozoic stratigraphic relations and alteration assemblages at low greenschist facies metamorphic grades. After a lunch stop in Mayer, participants can go to either the Bluebell Mine south of Mayer to look at Early Proterozoic stratigraphic relations, alteration, and massive sulfide mineralization, or to the Texas Gulch Formation near Brady Butte to review stratigraphy, structure, and polyphase folding.

Road Log and Field Trip Guide

by Ed DeWitt

Day 1 - Morning: Prescott, Arizona, to Iron King Mine and Huron-Victor-Swindler massive sulfide prospects near Humboldt, Arizona

Road Log from Prescott, Arizona, to Iron King Mine: 17.8 miles

Cumulative
mileage

0.0 Prescottonian Motel, Prescott. Turn right onto Gurley Street and Arizona State Highway 69 to Phoenix.

0.2 Intersection with U.S. Highway 89 north to Ash Fork. Stay to the right, on Arizona Highway 69. Highway crosses the wash of Government Canyon. Roadcuts on the left beneath the Sheraton Hotel are Tertiary fanglomerate that locally overlies the 1740±15 Ma Government Canyon Granodiorite (fig. 1) exposed in the beveled roadcuts.

0.8 Chaparral-covered hillside to the right underlain by Government Canyon Granodiorite and Early Proterozoic gabbro. Large hill to the right is Badger Mountain, composed entirely of this gabbro.

1.6 Roadcuts on left are in Early Proterozoic metabasalt and meta-andesite that Krieger (1965) assigned to the Green Gulch Volcanics.

2.4 Roadcuts through mesa expose basalt flow and underlying scoria and tuff. Through the roadcut is a vista of the Bradshaw Mountains in the distance to the right. Mount Union, elev. 7,979, is the highest peak in the Bradshaw Mountains.

Small dumps on the right side of the road are the Bullwhacker prospect, one of several small vein deposits in the Prescott metallic mineral district, an Early Proterozoic copper-gold quartz vein district (Keith, Gest, and others, 1983; Welty and others, 1985).

2.9 Turnoff on the right to Walker and Lynx Lake. Continue east on Arizona Highway 69. Roadcuts on left at this intersection are in fine-grained granite and alaskite.

3.2 Metavolcanic rocks and metatuff intruded by Prescott Granodiorite in roadcuts. View ahead on the horizon, to the north of Woodchute Mountain in the Black Hills, is of the San Francisco Mountains, elev. 12,670 ft, north of Flagstaff, Arizona.

5.2 Glassford Hill, elev. 6,178, on the left is a Miocene? cinder cone that has been buried by its own basalt flows (Krieger, 1965).

6.0 Mingus Mountain, elev. 7,815 ft, and the Black Hills are in front of us on the skyline from 11:00 to 1:30. The mesa is underlain by basalt flows of the Miocene and Pliocene Hickey Formation. Beneath the dark basalt cap is a thin sequence of Mississippian to Cambrian shelf sedimentary rocks that unconformably overlies Early Proterozoic metavolcanic rocks that host the massive sulfide deposit at the United Verde mine near Jerome. Peaks to the right, about 4 miles to the south, are alaskite and aplite that are probably related to the Crooks Canyon Granodiorite. Now driving through Prescott Valley (fig. 1).

To the left at about 9:00 and 15 miles away, are the northern and westernmost outcrops of Mazatzal Quartzite in the hills near Del Rio (Krieger, 1965). The Mazatzal Quartzite (Wilson, 1922, 1939; Conway, 1976; Anderson and Wirth, 1981) is one of the youngest Early Proterozoic stratigraphic units in central Arizona.

8.5 Intersection of Robert Road in Prescott Valley. View straight ahead toward low hills at the southern end of the Black Hills is of metasedimentary and metavolcanic strata of the Grapevine Gulch Formation, one of the younger Early Proterozoic sequences in the Prescott-Jerome area (Anderson and Creasey, 1958). The Grapevine Gulch is intruded by the tonalite of Cherry (DeWitt, 1989) to the south.

9.8 Drainage on the right is Lynx Creek, which was extensively dredged and placered for gold in the early 1940's (Wilson, 1961). More than 29,000 ounces of gold are known to have been recovered from the drainage, and a total of 80,000 ounces of gold are estimated to have been recovered (Elsing and Heineman, 1936; Johnson, 1972), making Lynx Creek the second largest placer gold district in the Bradshaw Mountains. Only the Weaver district near Congress produced more gold. From 1902 through 1968 the drainage of Lynx Creek has produced the most gold of any placer district in Arizona. Some of the dredge heaps can be seen in isolated exposures to the right of the highway.

11.8 Bridge over Lynx Creek.

13.5 Turnoff on the right is the Bradshaw Mountains road. The unnamed, high peak on the right at 2:30 is underlain by Early Proterozoic alaskite (Crooks Canyon Granodiorite) that forms the reddish brown cliffs that are obvious from here.

14.2 Silicified metarhyolite at the north end of the Bell Ranch prospect (Swan, 1987; Swan and others, 1981) is visible at 12:15 as the rounded, nearly white peak on the near skyline. The town of Dewey is on the left.

14.7 Junction with Arizona State Highway 169 to the left that crosses the tonalite of Cherry to the west and connects with Interstate 17 south of Jerome, Arizona. We continue south on Arizona State Highway 69.

16.6 Humboldt, Arizona. Exxon station and old smelter stack on the left. Turnoff to the left in about one-quarter mile leads to the business district of the old town of Humboldt.

Figure 1 (below and two following pages). Geologic map of the Prescott area. Data from Krieger (1967), Anderson and Blacet (1972a, 1972b), Anderson and Creasey (1967), DeWitt (1987; unpub. mapping, 1989), Anderson (1989), O'Hara (1987, this volume), Swan and others (1981), and Swan (1987).

EXPLANATION

Qu	Quaternary units, undivided
Tvs	Tertiary volcanic and sedimentary rocks
TKg	Tertiary to Cretaceous granite to granodiorite
Xtg	Texas Gulch Formation
Xp	Prescott Granodiorite
Xgc	Government Canyon Granodiorite
Xc	Crooks Canyon Granodiorite
Xs	Pelitic metasedimentary rocks
Xgb	Gabbro
Xch	Metachert and iron-formation
Xr	Metarhyolite
Xt	Metatuff
Xb	Metabasalt and meta-andesite

Contact

Fault

Route of field trip

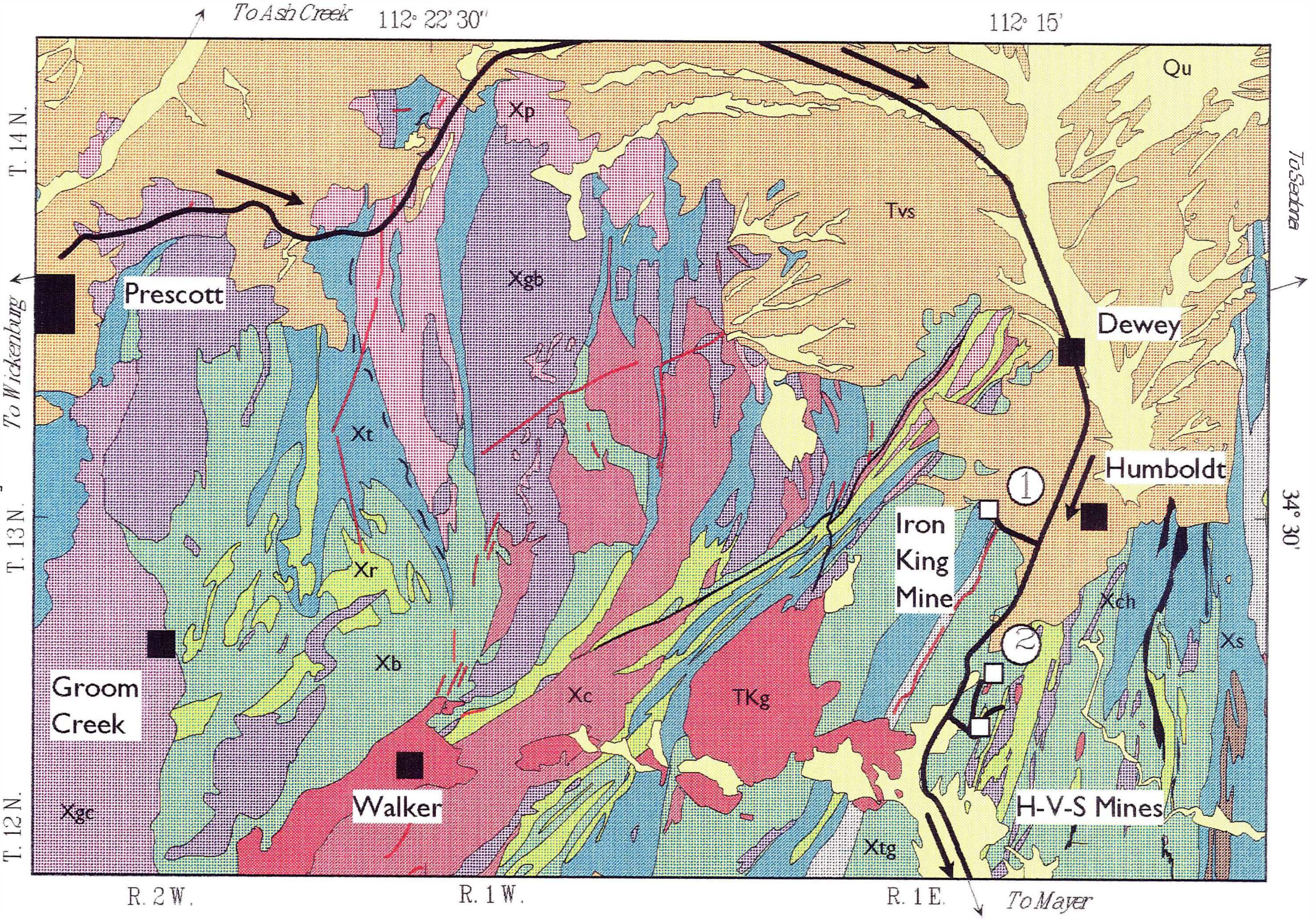
2 Stop number

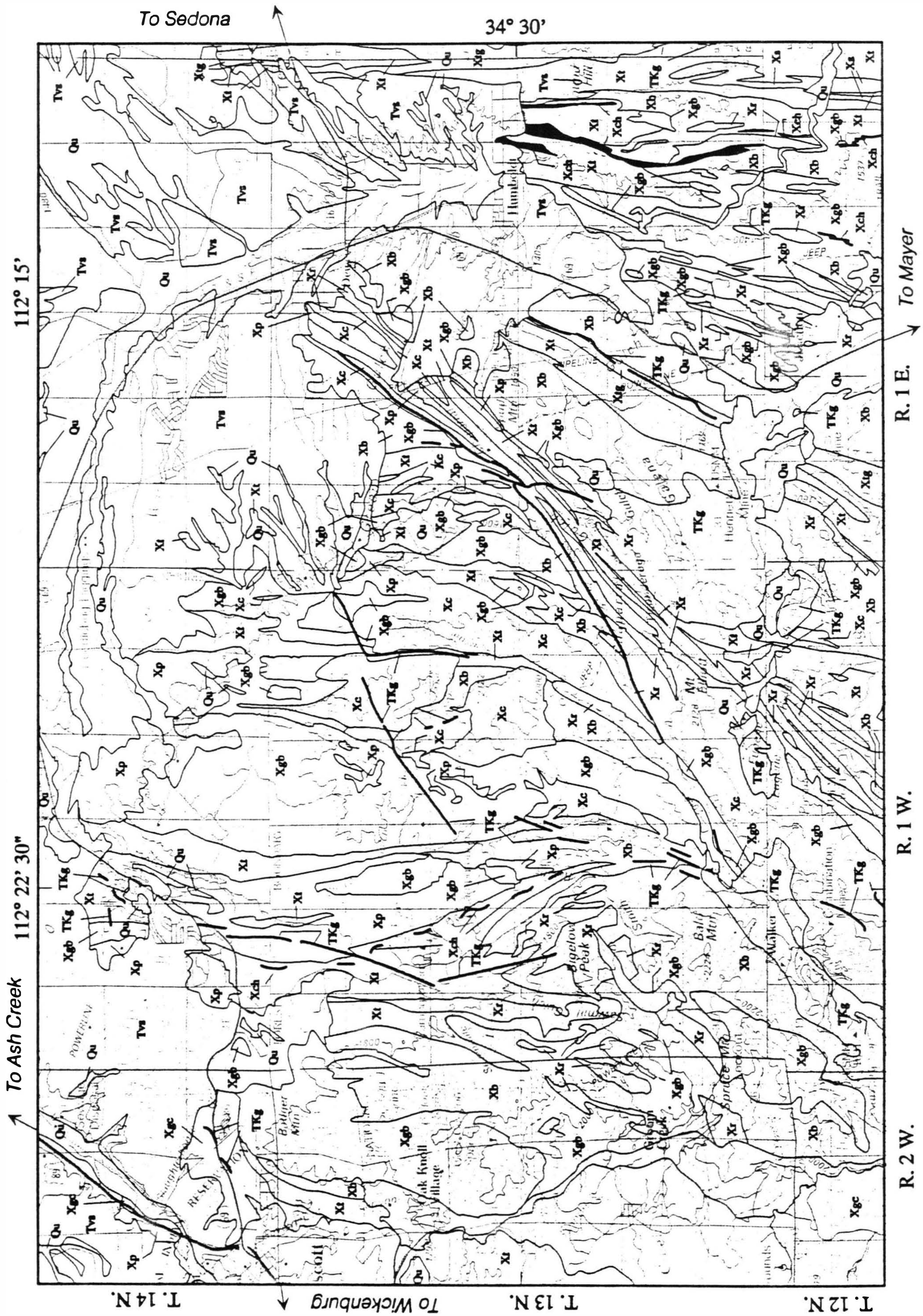
0 1 2 3 mi

0 1 2 3 km

Scale: 1:100,000

Base from U.S. Geological Survey
Prescott, 1981 and
Bradshaw Mountains, 1981


To Ash Creek
112° 22' 30"
112° 15'
To Sedona
34° 30'
T. 14 N.
T. 13 N.
T. 12 N.
To Wickenburg
R. 2 W.
R. 1 W.
R. 1 E.
To Mayer
Prescott
Dewey
Humboldt
Iron
King
Mine
H-V-S Mines
Groom
Creek
Walker
1
2
Qu
Tvs
Xp
Xgb
Xt
Xr
Xb
Xc
TKg
Xch
Xs
Xtg
Xgc



To Sedona
34° 30'
112° 15'
112° 22' 30"
To Ash Creek
To Mayer
To Wickenburg
R. 1 E.
R. 1 W.
R. 2 W.
T. 14 N.
T. 13 N.
T. 12 N.

16.9 Tailings ponds of the Iron King Mine clearly visible on the right and slightly above us. Large roadcut in Tertiary fanglomerate directly ahead. The turnoff to the Iron King Mine is on the right, past this roadcut.

17.2 Turnoff on the right to the Iron King Mine. Take the first of three turnoffs to the right and stay on the main road. Tailings ponds of the Iron King Mine are visible on the right.

17.8 Pavement ends. Waste dumps on the left; tailings ponds on the right. The old Iron King assay office is on the right. This will be our first stop of the day.

STOP 1. Iron King Mine. Assemble at the western dump piles near the discovery outcrops for a discussion of the regional geologic setting of Early Proterozoic massive sulfide and the distribution of precious metals within those deposits.

The large and famous massive sulfide deposit at Jerome is characteristic of only one type of volcanogenic massive sulfide deposits in Arizona. That deposit is developed at the top of a thick succession of rhyolite, has a very large chlorite pipe beneath the massive ore, and the ore grades laterally into chert, tuff, and volcanogenic sediments (Anderson and Nash, 1972; DeWitt and Waegli, 1986; Lindberg, 1986; Vance and Condie, 1987). Other deposits, such as the Iron King, Bluebell, and DeSoto, lack the extensive chlorite pipes. Some deposits, such as the Binghampton Copper Queen, are developed within rhyolite flows and tuffs. The significance of these differences will be one of the many topics of discussion at this stop and at the morning stop at the Huron-Victor-Swindler prospects.

The Iron King mine, the third largest massive sulfide deposit in Arizona, produced about 6,200,000 tons of ore from 1903 through 1969 that averaged 0.11% Cu, 1.88% Pb, 4.95% Zn, 0.073 oz/ton Au, and 2.69 oz/ton Ag (Arizona Geological Survey, unpub. data, cited in DeWitt, this volume). The deposit had the highest precious metal concentrations of any massive sulfide deposit in Arizona (DeWitt, 1983) and was unusual because of its very low concentration of copper and high concentration of lead.

The Iron King mine is the largest massive sulfide deposit in the Big Bug metallic mineral district (Keith, Gest, and others, 1983). Other, much smaller deposits such as those at the Hackberry, Boggs, and Long Pine mines, also averaged about 0.1 oz/ton Au, more than 3.0 oz/ton Ag, and as much as 2.3% Pb (DeWitt, this volume). Deposits in the Big Bug district had among the highest gold grades and lowest Ag/Au rations (~25) of any Early Proterozoic syngenetic deposits in Arizona (DeWitt, 1983).

After the stop at the Iron King mine we will return to Humboldt and drive to the Huron-Victor-Swindler prospects.

Road Log from Humboldt to Huron-Victor-Swindler prospects: 2.7 miles

Cumulative
mileage

0.0 Humboldt, Arizona. Proceed south on Arizona Highway 69 toward Mayer (fig. 1).

0.1 Deep roadcut in fanglomerate. Dump on the left is at the Lone Pine massive sulfide deposit (Anderson and Blacet, 1972b; Webb, 1979). On the skyline in the distance at 12:00 and 1:00 are Big Bug Mesa and Little Mesa, capped by basalt of the Hickey Formation.

1.1 Dumps on the right at 9:00, along the base of Spud Mountain, are on the Silver Belt-McCabe and Kit Carson vein systems. Mines visible from here include the Silver Belt, Arizona National, and Lookout, all in the Ticonderoga district, a Late Cretaceous to early Tertiary lead- and silver-rich vein system (Lindgren, 1926; Anderson and Creasey, 1958) associated with the Laramide stock at Poland Junction to the south (Anderson and Blacet, 1972b; Sturdevant, 1975). About 15 mines in the district accounted for most of the 340,000 tons of high-grade silver ore; some mines averaged more than 20 oz/ton Ag. The Ticonderoga district was the largest producer of all the Late Cretaceous to early Tertiary vein districts in the Bradshaw Mountains. Other large producers include the Walker and Mount Union districts to the west of Ticonderoga, and the Tiger district near Crown King. Although it is not visible from the highway, the McCabe-Gladstone mine produced about 70% of the ore from the district. An attempt was made in the late 1980's to put the mine into production, but the attempt failed.

1.6 The prospect pits at the far south end of the high voltage transmission line are the Victor-Swindler prospects, which will be visited as part of the next stop.

2.4 Approaching the high voltage transmission lines. Just past the No Passing sign on the left of the highway is the turnoff to the Huron and Montezuma prospects. Turn off the highway to the left, onto dirt road. If you drive underneath the transmission lines, you have gone too far.

2.7 Take trail up to intersection with pipeline road. Park here for the first of several stops at the massive sulfide prospects.

STOP 2. Massive sulfide prospects. Old workings at this stop include the Victor-Swindler prospect at the south end of the mineralized zone and the Huron-Montezuma prospect at the north end (O'Hara, this volume). Less than 1,000 tons of ore were produced from the prospects that we will visit, but the deposits are extremely instructive for their patterns of alteration.

During the early 1980's this area was investigated extensively by a variety of American and Canadian companies. Their findings, including the documentation of aluminosilicate alteration, and quartz-magnetite-epidote alteration below one of the chert and rhyolite horizons, will be discussed at this series of stops. The first stop will concentrate on relations in the southern outcrops, where the quartz- magnetite-epidote assemblages affecting andesite protoliths is well displayed. After we finish at this stop, we will go to the north, near the Huron-Montezuma shaft

At the Huron-Montezuma prospect the effects of aluminosilicate alteration on rhyolite and quartz porphyry bodies will be emphasized, as will the complex structural setting of the volcanic rocks, which is well displayed in polished outcrops along the creek bottom. If time permits, we will then go up the hillside to the west to view some spectacular outcrops of andalusite-quartz-sillimanite rock.

Road Log from Huron-Victor-Swindler prospects to Mayer: 5.5 miles

Cumulative
mileage

0.0 Huron-Victor-Swindler prospects south of Iron King Mine. Turn south on Arizona Highway 69 toward Mayer.

0.8 Mount Elliott, elev. 6,980 ft, on the skyline at the right. Bold cliffs of Mount Elliott are composed of Crooks Canyon Granodiorite, an Early Proterozoic pre-tectonic leucocratic pluton (Anderson and Blacet, 1972a; DeWitt, 1989) that forms extensive outcrops in the southwestern part of the Prescott area. In the foreground are bouldery weathering outcrops of the Laramide stock at Poland Junction (fig. 1).

0.9 Roadcut exposes meta-andesite and metabasalt flows of the Iron King Volcanics.

1.1 Poland Junction. Road to Walker leads to the right and follows the route of a 1900's narrow gauge railroad bed. The Poland-Walker Tunnel cut through the crest of Eugene Ridge and connected the Walker district with the smelter at Humboldt (Lindgren, 1926). The drainage divide along the highway is capped by Quaternary to Tertiary gravel that locally conceals the metavolcanic strata. Ridges of ferruginous metachert and iron-formation protrude above the gravel, especially near the Boggs (Hurlbut, 1986) and Iron Queen mines to the left at about 10:00. Behind and to the right at 5:00 are the dumps of the Henrietta Mine.

View straight ahead in the far distance is of the New River Mountains. The jagged peaks are composed of ~1700 Ma metarhyolite similar to the Red Rock Rhyolite and other ash-flow tuff units in the Tonto Basin area (Wilson, 1939; Gastil, 1958; Conway, 1976; Karlstrom and Conway, 1986).

1.4 Big Bug Mesa on the right at 3:00 is capped by basalt flows of the Miocene and Pliocene Hickey Formation, which consists of fanglomerate, siltstone, lakebed sediments, and prominent mesa-capping basalt flows, and ranges in age from about 15 Ma to 11 Ma (McKee and Anderson, 1972; McKee and Elston, 1980; summarized in Reynolds and others, 1985).

1.9 Dredge tailings are visible on the right in the drainage of Big Bug Creek. The creek was placered extensively in the early 1940's (Wilson, 1961). Recorded production is more than 17,000 ounces of gold; estimated total production is 50,000 ounces of gold (Johnson, 1972), making the drainage of Big Bug Creek the third largest placer district in Arizona. From 1902 through 1968, Big Bug Creek was the second largest producer of placer gold in Arizona. Only the drainage of Lynx Creek produced more gold. Small-scale placer operations are currently active along the lower reaches of the creek, both above and below Mayer.

On the right at about 1:30 or 2:00, past the placer workings, are dumps of the Hackberry and Pentland mines. The mines are the southernmost massive sulfide deposits in the Big Bug district. The Hackberry produced slightly more than 20,000 tons of ore that, during its peak years of production, averaged 1.6% Cu, 2.3% Pb, 5.1% Zn, 3.6 oz/ton Ag, and 0.12 oz/ton Au. Behind and to the right at about 4:30 are the dumps of the Butternut mine, a small, gold-rich massive sulfide deposit that averaged about 0.17 oz/ton Au (DeWitt, this volume).

2.8 Dumps on the right at 3:00 are from the Upshot Mine, a small massive sulfide deposit that produced only a few hundred tons of ore. However, that ore averaged 7.6% Zn and 0.3 oz/ton Au (DeWitt, this volume).

4.1 Turnoff to the right leads to the main street of Mayer. We stay on Highway 69.

4.8 Stockpile of travertine on the right side of the highway. Roadcut is in travertine, which is quarried on both sides of the highway.

5.3 Bridge across Big Bug Creek. Town of Mayer on the right. Hills Motel and Restaurant on the right.

5.5 Intersection of Central Avenue in Mayer. Turn right, toward the Circle K store. We will assemble near the city park for lunch. Straight ahead is a smelter stack, which was completed just before one of the downturns in the silver market during the early 1900's, and was never used.

Day 1 - Afternoon: Mayer, Arizona to Bluebell Mine

or

Mayer to Texas Gulch Formation at Brady Butte

Road Log from Mayer to Texas Gulch Formation at Wolf Creek: 7.5 miles.

Cumulative
Mileage

0.0 Circle K Store in downtown Mayer. Turn right on Central; road swings gently to the right

0.3 Turn left on Miami, just past 2-story hotel on left

0.4 Stop sign. Turn right on Main

0.5 Turn left on Fairlan Street, just past Double D bar on left. Go straight ahead on Wicks Avenue past Mayer Christian Fellowship Church on left.

0.6 Stop sign; turn left on Jefferson

1.0 Crest of hill. Early Proterozoic metabasalt outcrops begin (fig. 2).

1.5 Fork in road; stay to right on main road.

1.8 Crest of small hill. Mayer Cemetery on right. Brady Butte at 12:00 on skyline is underlain by 1750 Ma pre-tectonic Brady Butte Granodiorite. Towers Mountain at 11:00 on skyline is underlain by Early Proterozoic gabbro-diorite body. Subdued topography that road crosses is metabasalt and meta-andesite

3.6 Road bends to left. Crossing contact, from dark weathering metabasalt to light weathering Texas Gulch Formation.

Figure 2 (below and two following pages). Geologic map of the Mayer area. Data from Anderson and Blacet (1972a, 1972b), DeWitt (1976, 1979, 1987, unpub. mapping, 1989), Blacet (1985), Anderson (1989), Jerome (1956), and Karlstrom (1989).

EXPLANATION

Qu	Quaternary units, undivided
Tvs	Tertiary volcanic and sedimentary rocks; dikes
TKg	Tertiary to Cretaceous granite to granodiorite
Xtg	Texas Gulch Formation
Xcb	Crazy Basin Quartz Monzonite
Xbm	Bumblebee Granodiorite
Xbs	Badger Spring Granodiorite
Xbb	Brady Butte Granodiorite
Xs	Pelitic metasedimentary rocks
Xgb	Gabbro
Xch	Metachert and iron-formation
Xr	Metarhyolite
Xd	Metadacite
Xt	Metatuff
Xb	Metabasalt and meta-andesite

Contact

Fault

Route of field trip

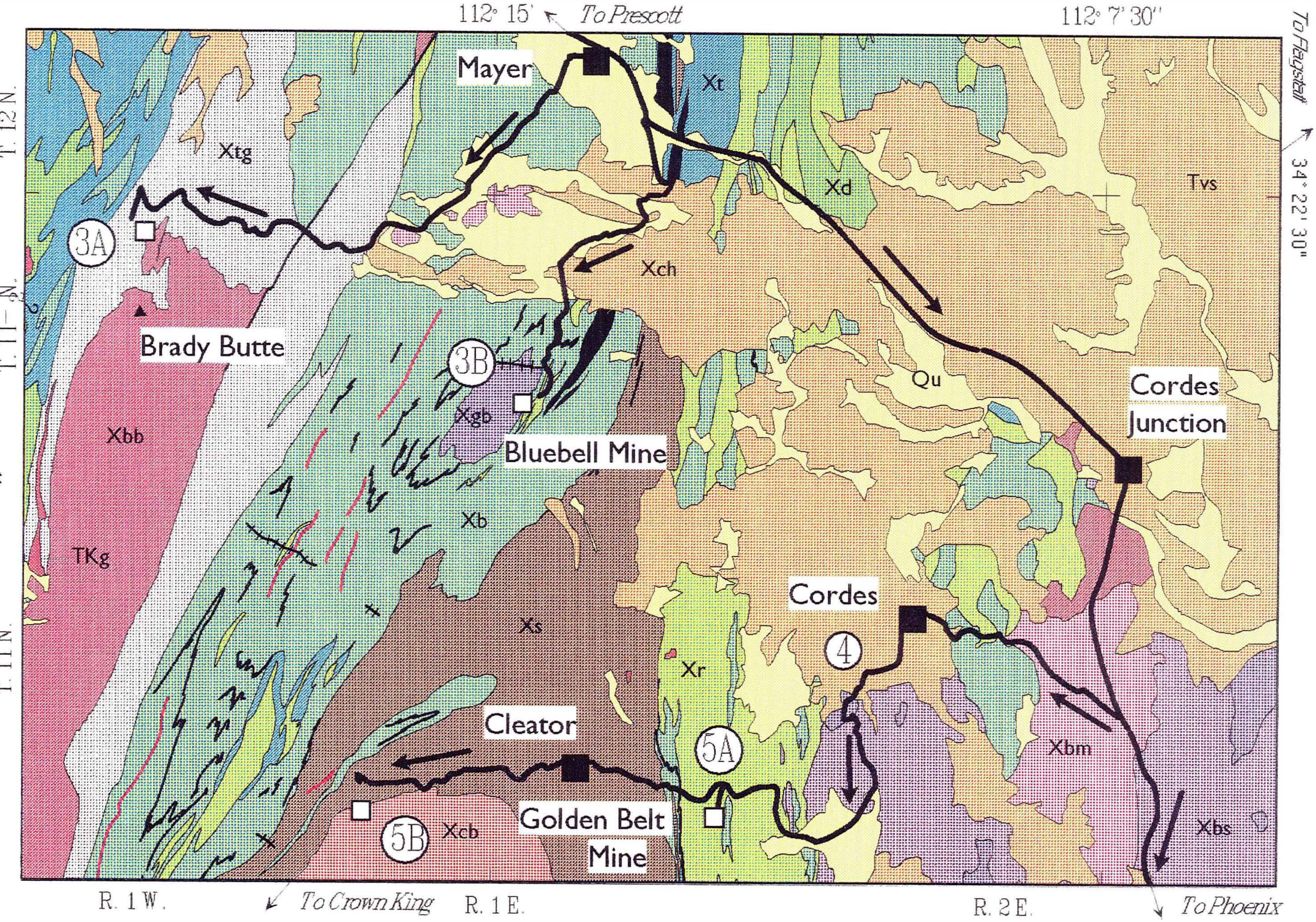
4 Stop number

0 1 2 3 mi

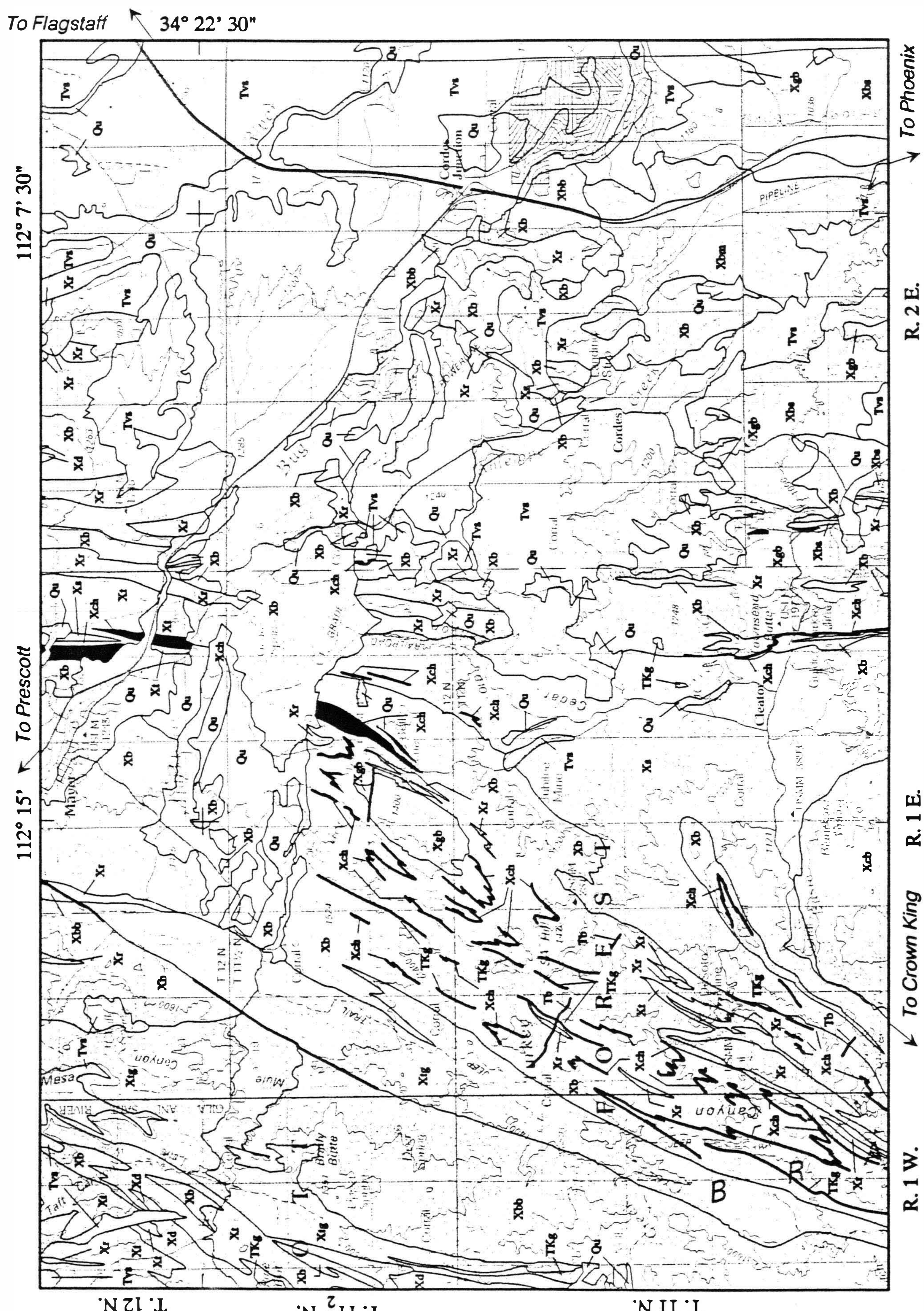
0 1 2 3 km

Scale: 1:100,000

Base from U.S. Geological Survey
Bradshaw Mountains, 1981



112° 15'
To Prescott
112° 7' 30"
To Flagstaff
34° 22' 30"
Mayer
Xt
Xtg
Xd
Tvs
3A
Xch
Brady Butte
3B
Qu
Cordes
Junction
Xgb
Xbb
Bluebell Mine
Xb
TKg
Cordes
Xs
4
Xr
Cleator
5A
Xbm
Golden Belt
Mine
5B
Xcb
Xbs
T. 12 N.
T. 11 N.
T. 11 N.
R. 1 W.
To Crown King
R. 1 E.
R. 2 E.
To Phoenix


To Flagstaff
34° 22' 30"
112° 7' 30"
112° 15'
To Prescott
To Phoenix
To Crown King
R. 2 E.
R. 1 E.
R. 1 W.
T. 12 N.
T. 11½ N.
T. 11 N.
PIPELINE
Cordes Junction
Cordes
Cleator
Mayer

4.5 Bullroad trail #202 to left; stay on main road. In Texas Gulch Formation; regional foliation dips east.

5.5 Top of ridge. Trail leads to left. Continue straight and descend into Mule Canyon.

5.7 Mule Canyon. In Texas Gulch Formation; regional foliation dips steeply west from this point to Wolf Creek.

6.1 Cattle guard. Beds in Texas Gulch Formation dip gently; foliation dips steeply west.

7.0 Ridge top. Descending into Wolf Creek. Brady Butte on left

7.4 Trail #304 to right. Stay on main road.

7.5 Crossing Wolf Creek. Turn left on trail just past the Creek. Park here.

STOP 3A. Texas Gulch Formation stratigraphy and structure to be discussed here. Features to be noted are the unconformable contact of the Texas Gulch Formation and the underlying Brady Butte Granodiorite (Blacet, 1966), the nature of the contact of the Texas Gulch Formation and older metavolcanic strata (O'Hara and others, 1978), and the polyphase folding of the Texas Gulch Formation (Karlstrom and O'Hara, 1984; Karlstrom , 1989).

Return to Mayer when finished, and then to Prescott for the evening.

Road Log from Mayer to Bluebell Mine: 5.7 miles

Cumulative
Mileage

0.0 Intersection of Arizona Highway 69. Turn right toward Phoenix.

0.1 Roadcut east of smelter stack begins in Tertiary fanglomerate, but quickly passes into highly foliated tuffaceous metasedimentary strata, quartz veins, iron-formation, tuffaceous rocks, and meta-andesite (fig. 2).

0.9 Black Canyon Mobile Home Sales area on right, ahead. Turn hard to the right before sales area onto paved road. Cross cattle guard and take immediate left onto gravel road.

1.3 Crossing beneath high tension power lines. Waste piles of the Bluebell mine are to the right of the road, below the circular house on the hillside. Ore from the mine was trammed overland a distance of three miles to an old railroad siding at the foot of the waste piles. Remains of the towers for the tramway are visible in places.

1.9 Road (#93) to Bluebell Mine to the right at top of small ridge. Driving in Tertiary Hickey Formation.

2.1 Cross cattle guard at crest of ridge

2.2 Y in road; take left fork. Bluebell Mine visible in saddle at 10:00. Brady Butte at 12:00. Big Bug Mesa at 1:00.

3.8 Top of small ridge. Y in road; take left fork

3.9 Trail leads to left; stay on main road

4.4 Cross Cedar Creek. Outcrops of Early Proterozoic metabasalt, metarhyolite, and iron-formation visible on both sides of road.

5.2 Saddle above Bluebell Mine.

5.4 Cuts on right are part of Bluebell Mine. Sericitized and hematite-stained metarhyolite now quarried for decorative facing stone.

5.7 Y in road. Take right fork to foundations of Bluebell shaft. Park vehicles here.

STOP 3B. Bluebell Mine. The Bluebell Mine was the largest producer of massive sulfide ore in the Mayer metallic mineral district, which also contains the DeSoto mine southwest of Mayer. The Bluebell produced about 1,100,000 tons of ore that averaged 3.13% Cu, 0.048 oz/ton Au, and 1.23 oz/ton Ag (DeWitt, this volume). Features to be discussed at this stop include stratigraphy of the mine area, structural features, especially isoclinal folds affecting all metavolcanic units, and alteration assemblages in footwall units of the ore deposit.

Return to Mayer when finished, and then to Prescott for the evening

Excerpts from "Base- and precious-metal concentrations of Early Proterozoic massive sulfide deposits in Arizona--crustal and thermochemical controls of ore deposition," by Ed DeWitt.

Base- and precious-metal concentrations of Early Proterozoic massive sulfide deposits in Arizona--crustal and thermochemical controls of ore deposition.

Ed DeWitt *M.S. 905, U.S. Geological Survey, Denver, Colorado 80225*

ABSTRACT

Of the 70 known Early Proterozoic massive sulfide deposits and prospects in Arizona, 48 have production data that are here summarized and that can be used to infer differences among the origins of the various deposits. Thirteen massive sulfide metallic mineral districts contain 48 mines and prospects that, from 1884 through 1978, produced 55.3 million tons of ore that contained 3.99 billion pounds of Cu, 237 million pounds of Pb, 1.0 billion pounds of zinc, 75.2 million ounces of Ag, and 2.0 million ounces of Au. Average ore grades were 3.6% Cu, 0.2% Pb, 0.9% Zn, 1.36 oz/ton Ag, and 0.037 oz/ton Au. Because Pb and Zn were produced sporadically, grades of any deposit that contained Pb and Zn are higher than the averages above, about 0.5% Pb and 3-10% Zn. Ag/Au values of all deposits averaged 37, but ranged from 8 to 462 for deposits producing more than 20,000 tons of ore. Precious metal concentrations ranged from less than 0.001 to 0.12 oz/ton for Au and from 0.009 to 3.56 oz/ton for Ag in deposits that produced more than 20,000 tons of ore.

Low-Au, low-Ag, high Ag/Au ore of the Hualapai and Old Dick districts contrasts markedly with the average for districts in the Prescott-Jerome area and these differences were likely caused by regional differences in the crust underlying western Arizona. Mojave-type crust, characterized by elevated $^{207}Pb/^{204}Pb$ and Th/U values compared to central Arizona, underlies western Arizona and was partially melted to form much of the metavolcanic strata that host massive sulfide deposits in the Hualapai and Old Dick districts. Apparently, Early Proterozoic Mojave-type crust is impoverished in precious metals compared to the crust underlying central Arizona.

Younger (post-1730 Ma and Phanerozoic) vein deposits in central and western Arizona that formed largely in plutonic rocks that intruded Mojave-type crust are characteristically Au-rich and have low Ag/Au values. This metallogenic signature is believed to be a crustal-scale phenomenon related to emplacement of voluminous plutons from 1690 to 1740 Ma that largely obliterated the metallogenic characteristics of the Early Proterozoic Mojave-type crust.

Low-Cu, high-Pb ore of the Big Bug district contained the highest precious metal concentrations, Au averaging 0.075 oz/ton and Ag averaging 2.65 oz/ton. Small deposits having metal ratios similar to the average for the Big Bug district are noted in the Old Dick, Verde, and Agua Fria districts, and indicate that local thermo-chemical controls of ore deposition, not regional factors, were important in the localization of these high-grade precious-metal deposits. Deposition of ore minerals at temperatures below 300° C from a sulfur-rich brine is the most likely cause of the enhanced precious-metal concentrations, not formation of the deposits in a setting distal from volcanism.

Low-Au, low-Ag ore, locally present in the Agua Fria and Verde districts, also contrasts markedly with the average for districts in the Prescott-Jerome area. A likely cause of this depletion in precious metals is deposition of ore minerals in these deposits from hydrothermal fluids having temperatures in excess of 300° C, a temperature too high for most chloride- and sulfide-complexes to transport large concentrations of gold and silver in solution. Deposits of this type appear to have formed within rhyolite flows and tuffs, not at the contact of felsic and more mafic rocks.

INTRODUCTION

Early Proterozoic massive sulfide deposits associated with submarine mafic to felsic metavolcanic rocks are present throughout central, west-central, and northwestern Arizona (Anderson and Guilbert, 1979; DeWitt, 1983, 1987; Keith and others, 1983, 1984; Eastoe and others, 1987; Donnelly and Conway, 1988; Lindberg, 1989). Production data for copper, lead, zinc, gold, and silver (Arizona Geological Survey, unpub. data) for most of the known deposits and prospects in thirteen metallic mineral districts (Welty and others, 1985) are here summarized. Nine of the thirteen districts have recorded production; only the Gray's Gulch and Bronco Creek districts north of Phoenix and the Pittsburg-Tonto and Pranty's Cabin districts south of Payson (fig. 1) lack data and are not discussed. These four districts produced a minimal amount of ore; omission of their totals does not materially affect the trends noted for the region as a whole. Production data for the remaining nine districts, which contain 48 mines for which metal data are available, allow trends in metal contents and ratios from mine to mine and district to district to be noted. Many of these features were noted by DeWitt (1983) and Lindberg (1989), but others were not.

Data used in this paper have been thoroughly checked for accuracy and completeness; however omissions are probably the most likely source of error. Small mines and deposits are particularly likely to have incomplete records of their production, as are many mines that operated in the late 1800's and earliest 1900's. Because of these drawbacks, relationships of metal contents and ratios and trends are most reliable for large mines and those with complete and verifiable records. Some published production data for massive sulfide deposits in Arizona are in disagreement with the data summarized here (examples are the Iron King mine in the Big Bug district- Gilmour and Still, 1968 and some of the notes in Donnelly and Conway, 1988); data summarized in this paper should supersede earlier summaries. Rigorous statistical treatment of the production data is not deemed appropriate, as ore types have been somewhat homogenized by the reporting of amounts of ore and metals on a yearly basis.

DISTRIBUTION, AGE, AND CHARACTERISTICS OF DEPOSITS

Metavolcanic rocks of basaltic to rhyolitic composition are host to numerous Early Proterozoic, syngenetic, massive sulfide deposits in central Arizona. Although most of the deposits are in the Prescott-Jerome region of central Arizona, mines and prospects are noted from the northwest part of the state (Hualapai district in the northern Hualapai Mountains) to the east-central part of the state (Pranty's Cabin district in the Sierra Ancha southeast of Payson). The deposits are contained within 1700-1780 Ma metavolcanic strata. All deposits in the Prescott-Jerome area (fig. 1) are hosted by 1740-1780 Ma mafic to felsic metavolcanic strata (Anderson and others, 1971; Anderson and Silver, 1976; Anderson, 1978, 1987, 1989a, 1989b; Donnelly and Hahn, 1981; Bowring and others, 1986; Karlstrom and others, 1987). Deposits in the western part of the state (Hualapai and Old Dick districts) are contained in mixed metavolcanic and metasedimentary strata that are about 1730 Ma (Silver, 1968; Bryant and Wooden, 1986; Chamberlain and Bowring, 1990; Wooden, unpub. data, 1990). Those deposits near Payson are associated with felsic to mafic metavolcanic strata that are 1700-1730 Ma (Gastil, 1958; Ludwig, 1973; Conway, 1976; Silver and others, 1986; Conway and Karlstrom, 1986; Karlstrom and others, 1990). Massive sulfide deposits are not associated with Early Proterozoic, predominantly subaerial, felsic metavolcanic rocks (Wilson, 1939; Conway, 1976; Conway and Silver, 1989) that are younger than 1700 Ma nor with the pelitic and psammitic Pinal Schist of southeastern Arizona.

Some deposits, such as the United Verde, Bruce and Old Dick, and to a lesser extent the Stoddard and Antler, have the classic features associated with submarine, volcanogenic deposits (Hutchinson, 1973; Franklin and others, 1981): stratabound nature, massive sulfide ore at the top of a major rhyolite body, zonal arrangement of metals within the deposit, and chloritic alteration pipe beneath the deposit. Others, such as the Iron King, Bluebell, Copper World, and Kay, appear to lack recognizable chlorite alteration pipes and metal zonation within the deposits, and instead possess extensive areas having sericite- and minor chlorite-rich rocks. Some, such as the Huron, Swindler, and Orizaba, have alteration pipes characterized by aluminosilicate-rich rocks and epidote (O'Hara, 1987, this volume; DeWitt, unpub. data, 1989).

Some deposits have been studied in detail, principally the Iron King mine in the Big Bug district (Gilmour and Still, 1968 and references cited therein), the Bruce mine in the Old Dick district (Baker and Clayton, 1968; Larson, 1984 and references cited therein) the United Verde mine in the Verde district (Anderson and Creasey, 1958; Lindberg, 1989; DeWitt and Waegli, 1989; Gustin, 1990), and the United Verde Extension mine in the Verde district (White, 1986a). Others, principally the Copper Queen mine in the Agua Fria district (Brook, 1974), the Antler and Copper World mines in the Hualapai district (Romslo, 1948; More, 1980), and the Copper Chief mine in the Verde district (Johnson, 1986b; Lindberg, 1986b), have been investigated in less detail. Many, however, have not been mapped or sampled since Lindgren's (1926) report on mines in the Prescott-Jerome region. This paper and previous summaries (Anderson and Guilbert, 1979; DeWitt, 1983; Lindberg, 1989) reveal trends in metal concentrations that are caused by first-order crustal differences and second-order thermo-chemical conditions of ore deposition. Obviously, additional work on most deposits is necessary before all are fully understood.

OVERALL DISTRICT SUMMARY

The 48 massive sulfide deposits in Arizona for which production data are available produced 55.3 million tons of ore that contained 3.99 billion pounds of copper, 237 million pounds of lead, 1.02 billion pounds of zinc, 75.2 million ounces of silver, and 2.06 million ounces of gold (table 1). From all districts, ore averaged 3.6% Cu, 0.2% Pb, 0.9% Zn, 1.35 oz/ton Ag, and 0.037 oz/ton Au. Averaged lead and zinc grades are artificially low, as most mines did not produce lead- and zinc-rich ore because they were penalized at the smelter for zinc. Lead, when produced, normally averaged less than 0.5% except for deposits in the Big Bug district. Zinc, when produced, averaged 3-10%. Copper, silver, and gold grades accurately reflect the metal concentrations of the deposits because these metals were always profitably extracted. Therefore, the combined Cu-Pb-Zn content of most deposits averaged about 7%, but was lead-poor. Silver/gold ratios averaged 37 but varied from 183 for the Old Dick district to 12 for the Zonia district.

Of the nine massive sulfide districts for which production data are available, the Verde district produced by far the most ore and metals (table 1). Sixty-nine percent of the ore, 93% of the copper, 74% of the silver, and 73% of the gold were produced from this district. The United Verde mine, the third largest massive sulfide deposit in

Excerpts from "Base- and precious-metal concentrations of Early Proterozoic massive sulfide deposits in Arizona--crustal and thermochemical controls of ore deposition," by Ed DeWitt.

Big Bug District

The Big Bug district is northwest of the Agua Fria district (figs. 1 and 5) and is characterized by massive sulfide deposits spatially associated with one metarhyolite tuff that is overlain and underlain by metabasalt (Lindgren, 1926; Creasey, 1950, 1952; Gilmour and Still, 1968; Anderson and Blacet, 1972b; Bouley and Hodder, 1976; Webb, 1979; Anderson and Guilbert, 1979; DeWitt, 1983, 1987; Anderson, 1986a, 1989a; O'Hara, 1986; O'Hara and Armstrong, 1986). The district has the lowest copper grade and the highest lead, silver, and gold grades (table 1). Although production from the district is highly biased by the Iron King mine (table 3), which accounted for 99% of the ore, 94% of the copper, and 99% of the precious metals, all the small deposits (fig. 5) have silver grades of 1-4 oz/ton and gold grades of 0.1-0.4 oz/ton. Likewise, except for the Butternut and Lone Pine, all copper grades for small mines are less than 2%. Therefore the district as a whole is copper-poor and lead-, silver-, and gold-rich. Zinc, when produced, was average compared to most districts. Cambrian, Pb-, and Au-rich massive sulfide deposits in western Tasmania bear a striking resemblance to those in the Big Bug district (Large and others, 1989).

The Cu-poor, Pb-, Ag-, and Au-rich deposit at the Iron King mine (Lindgren, 1926; Mills, 1941, 1944, 1946, 1947; Hendricks, 1947; Creasey, 1950, 1952; Kumke and Mills, 1950; Anderson and Creasey, 1958; Mitchell, 1964; Gilmour and Still, 1968; Lawrence and Dixon, 1986) is localized along altered metarhyolite units within a metabasaltic to andesitic flow sequence. Ore minerals are sphalerite-galena-pyrite-tennantite-arsenopyrite-chalcopyrite. Production data for the mine reveal moderate correlation of copper with gold (fig. 6) and copper with silver (fig. 7), but a much better correlation of lead with gold (fig. 6), especially for gold grades less than 0.1 oz/ton. Data points that lie to the lower right of the major positive correlation of gold and lead - those having high precious metal concentrations and low lead concentrations - come from pre-1940 production (fig. 8) in which oxidized(?), anomalously gold- and silver-rich ore having unusually low base-metal concentrations was mined. Elimination of those points from figs. 6 and 7 strengthens the positive correlation of precious metals, especially gold (fig. 8) with lead. Variations in Ag/Au are caused more by shifts in gold grade that shifts in silver grade (fig. 9), which remained quite constant from 1940 to 1970 (fig 10). Creasey (1952) and Gilmour and Still (1968) suggest that silver is present in tennantite, but metallurgical tests have not proven that association. Both authors state that gold appears to be associated with pyrite, galena, and sphalerite. However, the production data (fig. 6) show that much gold is spatially associated with galena. Neither precious metal correlates well with zinc, but importantly, high zinc grades do not indicate low precious metal concentrations (figs 6, 7, and 8).

The Hackberry mine (Lindgren, 1926), the second largest producer in the district, is also rich in lead, silver, and gold (table 3). The deposit is localized at the contact of metarhyolite and metabasalt is probably at the same stratigraphic position as the Iron King mine to the north. Pyrite-chalcopyrite-galena-sphalerite-tetrahedrite is the ore assemblage. Ag/Au for most of the lifetime of the mine is rather constant (fig. 11). Silver correlates very well with lead, but less well with zinc (fig. 11), and indicates that precious metals are mostly associated with galena. Lead and zinc, when produced, averaged 2.37% and 5.25%, respectively for the deposit.

Smaller mines in the district have the following notes. Totals for the Butternut are highly influenced by data for 1903, which account for half the total ore produced and much of the very high -grade material. Data for the Lone Pine include high-grade lead and silver ore for 1924, which may not be entirely representative of most ore from the deposit. The Boggs mine (Hurlbut, 1986) is one of the highest-grade deposits for precious metals in the area. The Huron and Victor-Swindler prospects (O'Hara, 1987a; this volume) are characterized by extensive alumino-silicate assemblages and development of quartz-epidote in the footwall of the massive sulfide deposits.

The Bell Ranch prospect (Swan and others, 1981; Swan, 1987; O'Hara, 1987b), located southeast of the Lone Pine mine, has produced no ore, but is similar in most regards to other mines in the Big Bug district. Gold- and silver-bearing pyrite, chalcopyrite, and arsenopyrite are present in and adjacent to metarhyolite. Very little massive sulfide ore is known. The Bell Ranch prospect may be a gold-rich end-member of the precious-metal-rich deposits in the Big Bug district.

In summary, for the Big Bug district, highest precious-metal grades are in deposits having the highest lead concentrations. The district as a whole is very lead-rich and has the highest silver and gold grades in the state. The Ag/Au of 35, which is the same as the state average, indicates that both precious metals are preferentially enriched in the district, and suggests that gold and silver are spatially associated with galena in the deposits.

Excerpts from "Base- and precious-metal concentrations of Early Proterozoic massive sulfide deposits in Arizona--crustal and thermochemical controls of ore deposition," by Ed DeWitt.

Table 1. Massive sulfide district production data, Arizona [Data from Arizona Geological Survey, unpub. data; Cu, copper; Pb, lead; Zn, zinc; Ag, silver; Au, gold; t, short tons; lb, pounds; oz, troy ounces; oz/t, troy ounces per short ton; no entry indicates no record of production for that element; 0.00 indicates that the grade of the element is less than 0.00999; 0.000 indicates that the grade of the element is less than 0.000999; Copper, silver, and gold amounts and grades accurately reflect metal concentrations and ratios in the massive sulfide deposits because these metals normally were produced throughout mining of the deposit; Lead and zinc amounts and grades, in most instances, do not accurately reflect concentrations and ratios in the deposits because lead and zinc seldom were produced throughout the lifetime of the deposit - see the text for ratios that are closer to actual].

DISTRICT	Ore (t)	Cu (lb)	Pb (lb)	Zn (lb)	Ag (oz)	Au (oz)	Cu (%)	Pb (%)	Zn (%)	Ag (oz/t)	Au (oz/t)	Ag/Au
Agua Fria	181,301	11,738,165	3,319	16,480	47,353	894	3.24	0.00	0.00	0.261	0.005	53
Big Bug	6,321,997	14,379,240	232,532,742	614,960,375	16,808,553	473,885	0.11	1.84	4.86	2.659	0.075	35
Hualapai	161,990	7,246,895	896,995	11,370,100	97,657	659	2.24	0.28	3.51	0.603	0.004	148
Kay	2,555	295,973	13,349		2,735	149	5.79	0.26		1.070	0.058	18
Mayer	1,401,870	83,675,564			1,624,804	65,064	2.98			1.159	0.046	25
New River	29,873	1,267,428			12,682	197	2.12			0.425	0.007	64
Old Dick	1,683,702	106,791,361	3,035,113	305,056,606	651,325	3,550	3.17	0.09	9.06	0.387	0.002	183
Verde	37,996,107	3,733,706,691	693,222	94,994,869	55,952,061	1,514,457	4.91	0.00	0.13	1.473	0.040	37
Zonia	7,519,678	30,317,238	801		4,019	340	0.20	0.00		0.001	0.000	12
TOTAL	55,299,073	3,989,418,555	237,175,541	1,026,398,430	75,201,189	2,059,195	3.61	0.21	0.93	1.360	0.037	37

Table 3. Massive sulfide deposit production data, Big Bug district [See headnote of table 1 for explanation].

DEPOSIT	Ore (t)	Cu (lb)	Pb (lb)	Zn (lb)	Ag (oz)	Au (oz)	Cu (%)	Pb (%)	Zn (%)	Ag (oz/t)	Au (oz/t)	Ag/Au
Boggs	582	17,920			2,047	233	1.54			3.517	0.400	9
Butternut	806	103,373			4,149	136	6.41			5.148	0.169	31
Hackberry	20,108	644,704	509,839	1,117,045	71,617	2,306	1.60	1.27	2.78	3.562	0.115	31
Huron	609	18,300			589	45	1.50			0.967	0.074	13
Iron King	6,298,235	13,482,716	232,022,815	613,843,330	16,726,396	470,892	0.11	1.84	4.87	2.656	0.075	36
Lone Pine	1,235	99,341	88		3,358	186	4.02	0.00		2.719	0.151	18
Swindler	271	7,151			201	40	1.32			0.742	0.148	5
Upshot	151	5,735			196	47	1.90			1.298	0.311	4
TOTAL	6,321,997	14,379,240	232,532,742	614,960,375	16,808,553	473,885	0.11	1.84	4.86	2.659	0.075	35

Excerpts from "Base- and precious-metal concentrations of Early Proterozoic massive sulfide deposits in Arizona—crustal and thermochemical controls of ore deposition," by Ed DeWitt.

Figure 2. Location map of mines in the Agua Fria district. Base from Bradshaw Mountains 1:100,000, 1981. Mine names in italics are massive sulfide deposits for which production data are not available. Mines having questionable locations are shown with a query (?).

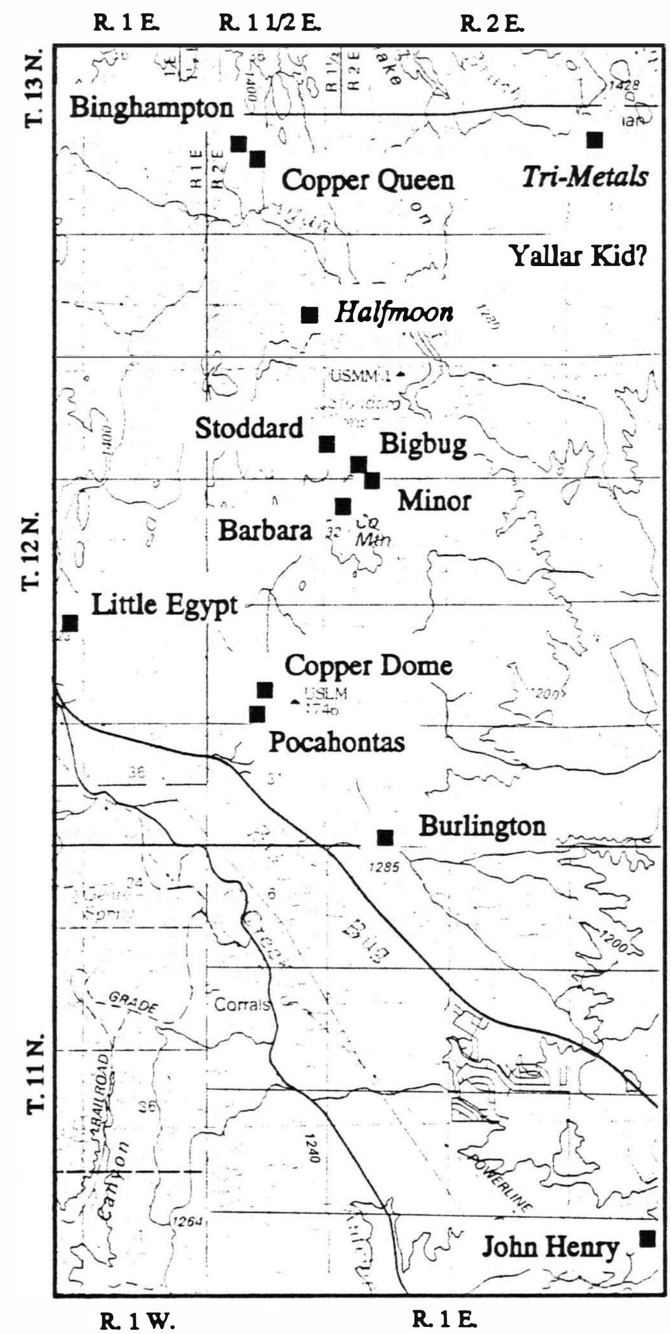
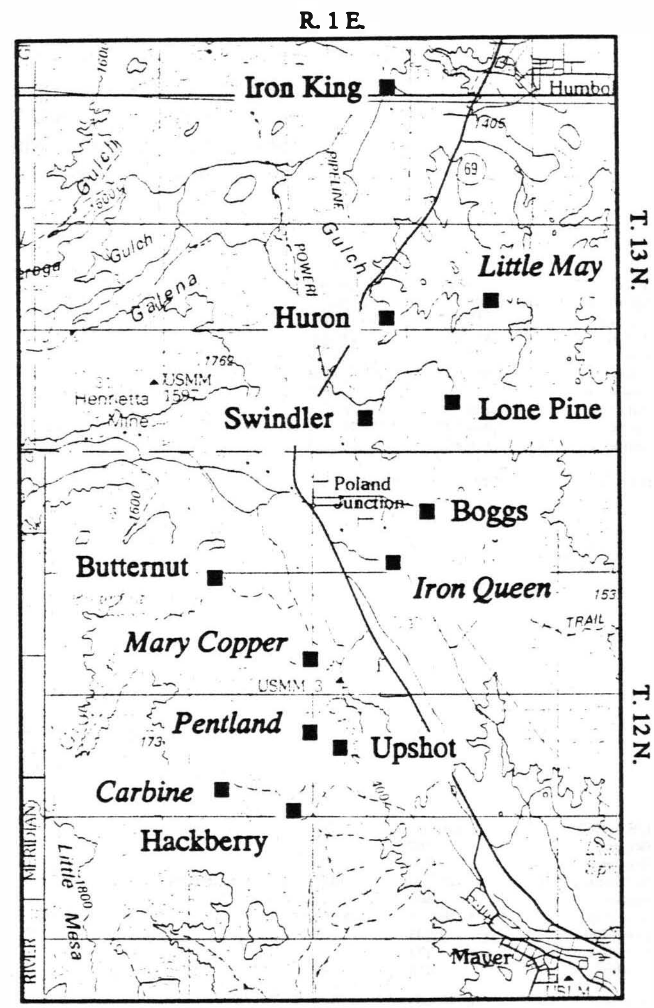


Figure 5. Location map of mines in the Big Bug district. Base from Bradshaw Mountains and Prescott 1:100,000, 1981. Mine names in italics are massive sulfide deposits for which production data are not available.



Excerpts from "Base- and precious-metal concentrations of Early Proterozoic massive sulfide deposits in Arizona--crustal and thermochemical controls of ore deposition," by Ed DeWitt.

Figure 8. Plot of year of production vs. gold, lead, zinc in the Iron King mine, 1936-1969. Symbols on the x-axis indicate no data for zinc.

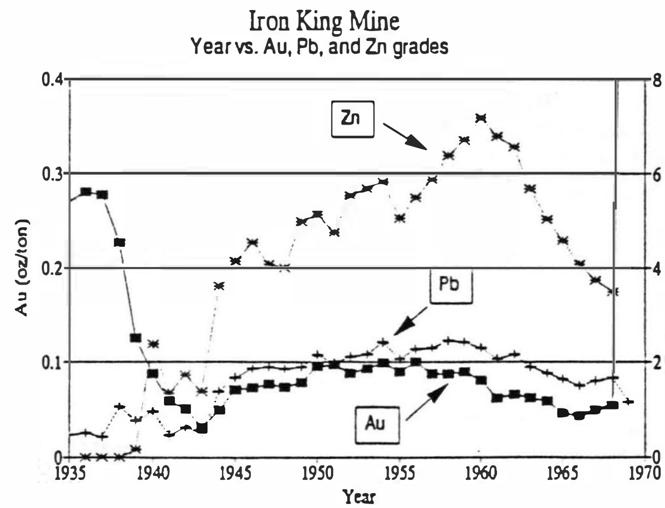


Figure 9. Plot of year of production vs. silver/gold, silver, gold*100 in the Iron King mine, 1936-1969.

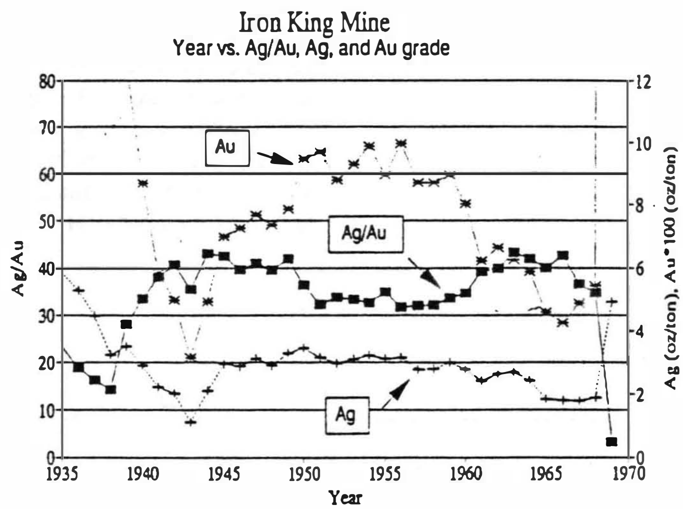
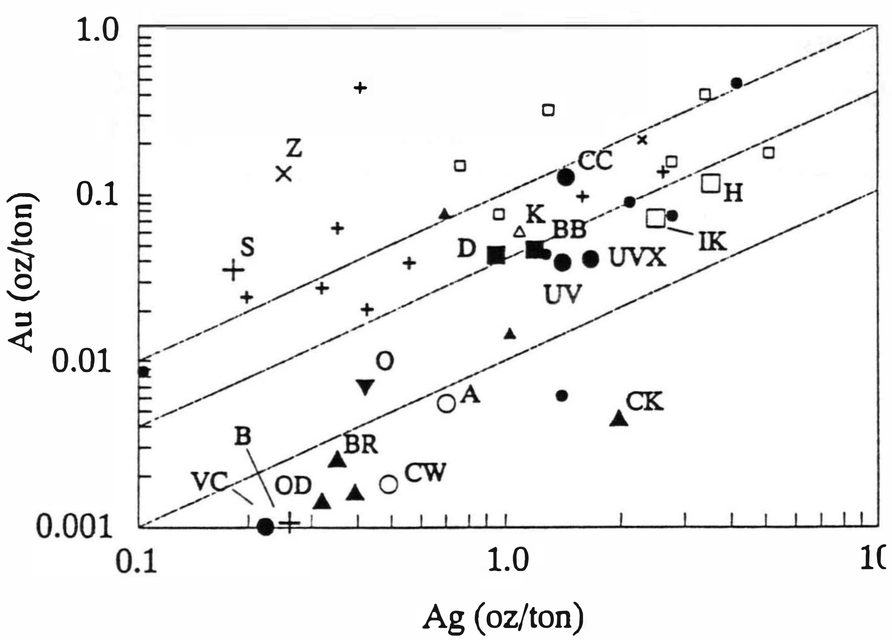
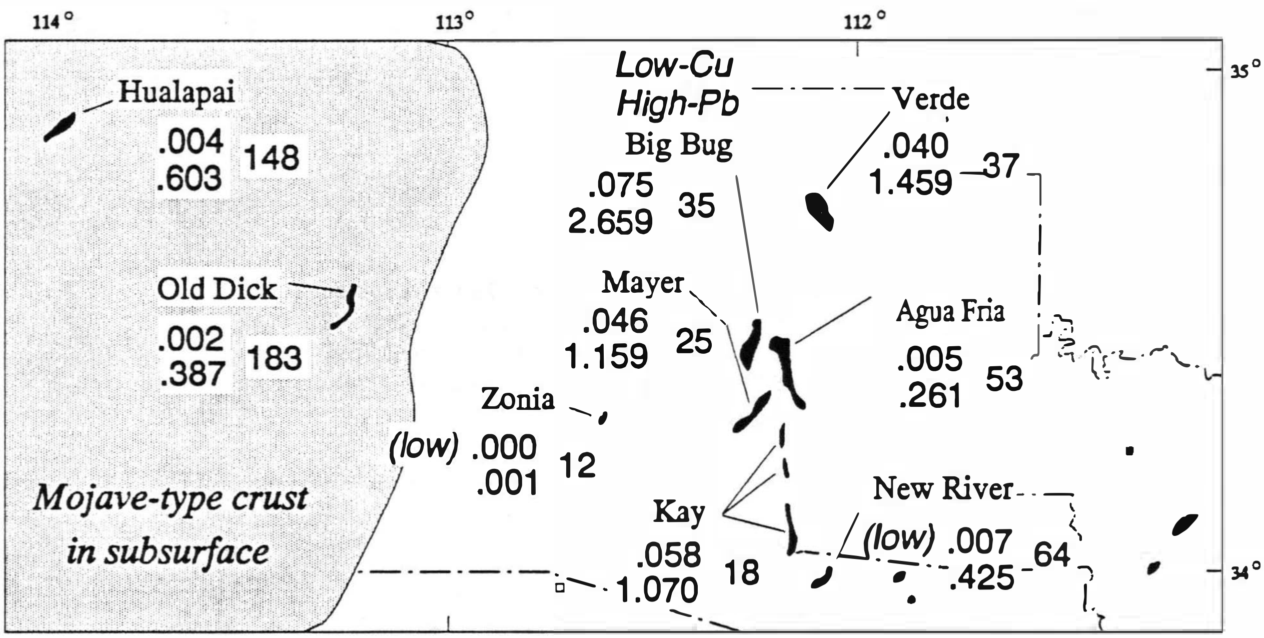


Figure 43. Plot of silver vs. gold for all massive sulfide deposits, Arizona. Symbols and mine names as in figure 42. Uppermost dashed, diagonal line is Ag/Au = 10; middle dashed, diagonal line is Ag/Au=40; lowest dashed, diagonal line is Ag/Au = 100.



Excerpts from "Base- and precious-metal concentrations of Early Proterozoic massive sulfide deposits in Arizona--crustal and thermochemical controls of ore deposition," by Ed DeWitt.

Figure 44. Massive sulfide metallic mineral districts and metal zonation patterns in central and northwestern Arizona. Location of Pittsburg-Tonto, Pranty's Cabin, Gray's Gulch, and Bronco Creek districts indicated, but district names deleted. Number beneath district name = Au (oz/ton); second number beneath district name = Ag (oz/ton); number to right of Au and Ag grades = Ag/Au; area in western Arizona underlain by Mojave-type crust shown by stipple pattern.



Excerpts from "Geology of Early Proterozoic gold mineralization, alteration assemblages, and geochemistry of the Huron-Victor-Swindler-Montezuma prospects, Yavapai County, Arizona," by P. F. O'Hara and R. C. Long.

Geology of early Proterozoic gold mineralization, alteration assemblages, and geochemistry of the Huron–Victor–Swindler–Montezuma prospects, Yavapai County, Arizona

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ABSTRACT

A series of early Proterozoic quartz porphyries of limited lateral extent are associated with hydrothermal alteration and stratabound gold mineralization within the Big Bug Group in central Arizona. These quartz porphyries mark the end of a volcanic cycle within the Iron King Formation and are probably the most highly fractionated rocks within the cycle. These quartz porphyries were emplaced along a series of potential growth faults which may have displaced the seawater – seafloor interface downward to the north. Deeper water to the north inhibited the formation of silicification and brecciation within the hydrothermal system because of pressure constraints on boiling and/or the change between lithostatic to hydrostatic pressure. Iron carbonate alteration in basal rocks of the next volcanic cycle immediately above the stratabound mineralization, suggested that the hydrothermal system continued activity long after the mineralizing event concluded.

INTRODUCTION

Metavolcanic and metasedimentary rocks of the Yavapai Series (Anderson and Creasey, 1958) crop out within the area described in this study (Figure 1). These rocks were originally subdivided into the Ash Creek Group and Alder Group (Anderson and Blacet, 1972). Isotopic data led Anderson and others (1971) to replace the name Alder Group with the Big Bug Group, which includes all the rocks of the Yavapai Series exposed in the Prescott–Jerome area.

The Big Bug Group is divided into three formations. From oldest to youngest they are: 1) Green Gulch Volcanics; 2) Spud Mountain 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).

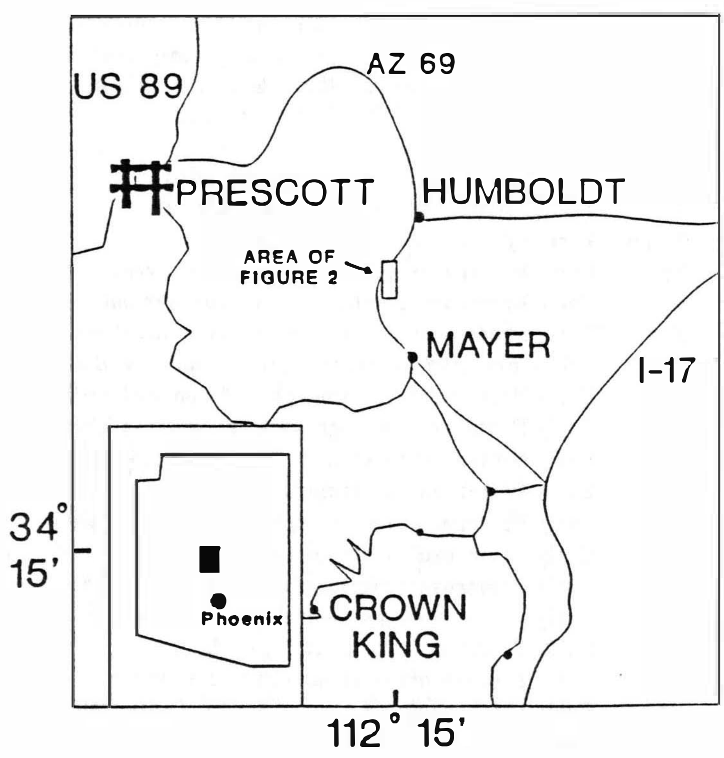


Figure 1. Location of the study area.

Excerpts from "Geology of Early Proterozoic gold mineralization, alteration assemblages, and geochemistry of the Huron-Victor-Swindler-Montezuma prospects, Yavapai County, Arizona," by P. F. O'Hara and R. C. Long.

REGIONAL GEOLOGY

The Iron King Formation are composed of a thick sequence of metamorphosed, pillowed and amygdaloidal andesitic and basaltic flows. Locally the Iron King Formation contain thin interbeds of metamorphosed rhyolitic tuff and flow units. The youngest members of the Iron King Formation are metatuffs of mixed andesitic to rhyolitic composition that crop out in the trough of an overturned syncline.

The Iron King Formation was informally subdivided into members (O'Hara, 1990) to facilitate mapping for industry. The area encompassing the Montezuma, Swindler, and Huron prospects is underlain by two members informally called the Boggs and Railroad members. Both of these members have been further subdivided for inclusion on a 1' = 500' map generated for a belt of rocks between Mayer and Iron King mine (O'Hara, 1990).

Isoclinal folding obscures the original stratigraphy (Anderson and Blacet, 1972; 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. Lack of marker horizons of adequate lateral extend hinders structural and stratigraphic analysis in the region.

Near the prospects, there is an extremely varied package of volcanic and sedimentary rocks (Figure 2). Metavolcanic units are complexly interlayered and indicate that rapid facies changes were characteristic of the protoliths, that potential growth structures existed to obscure the stratigraphic relations, and/or that structural repetition has taken place.

Figure 2 (below and facing page). Geologic map of the Huron-Montezuma area. Data from O'Hara (1990) and Anderson and Blacet (1972b, 1972c). All Early Proterozoic rock units are within the Iron King Volcanics. Irregular stipple pattern shows area of epidote-sericite + magnetite alteration. Even stipple pattern shows area of aluminosilicate alteration. Diagonal line pattern shows area of silicification. Small bodies of metachert and Iron-formation shown by thick, solid line (O'Hara, 1987). List of map units:

QTs	**Quaternary to Tertiary units, undivided**
Th	**Tertiary Hickey Formation fanglomerate**
TKgd	**Tertiary to Cretaceous granodiorite**
Xg	**Early Proterozoic gossan derived from pyrite-rich metavolcanic rocks**
Xc	**Early Proterozoic metachert and iron-formation**
Xvs	**Early Proterozoic metavolcanic and metasedimentary rocks; includes metamorphosed calcareous sediments, graywacke, andesitic volcanics, and dacite tuff**
Xcs	**Early Proterozoic metamorphosed iron-rich sediments; not chlorite-rich**
Xgw	**Early Proterozoic metagraywacke; contains felsic to intermediate metatuff and minor metachert**
Xt	**Early Proterozoic metamorphosed tuffaceous rhyolite and felsic tuff**
Xf	**Early Proterozoic metamorphosed felsic volcanics**
Xq	**Early Proterozoic metamorphosed quartz porphyry**
Xfc	**Early Proterozoic metamorphosed felsic volcanics; containchlorite and pyrite**
Xff	**Early Proterozoic metamorphosed fragmental felsic volcanics**
Xfq	**Early Proterozoic metamorphosed felsic volcanics and quartzporphyry.**
Xd	**Early Proterozoic metadacite porphyry**
Xap	**Early Proterozoic meta-andesite porphyry**
Xa	**Early Proterozoic metamorphosed andesitic volcanics andvolcaniclastic sediments**
Xb	**Early Proterozoic metamorphosed polymictic breccia**

EXPLANATION

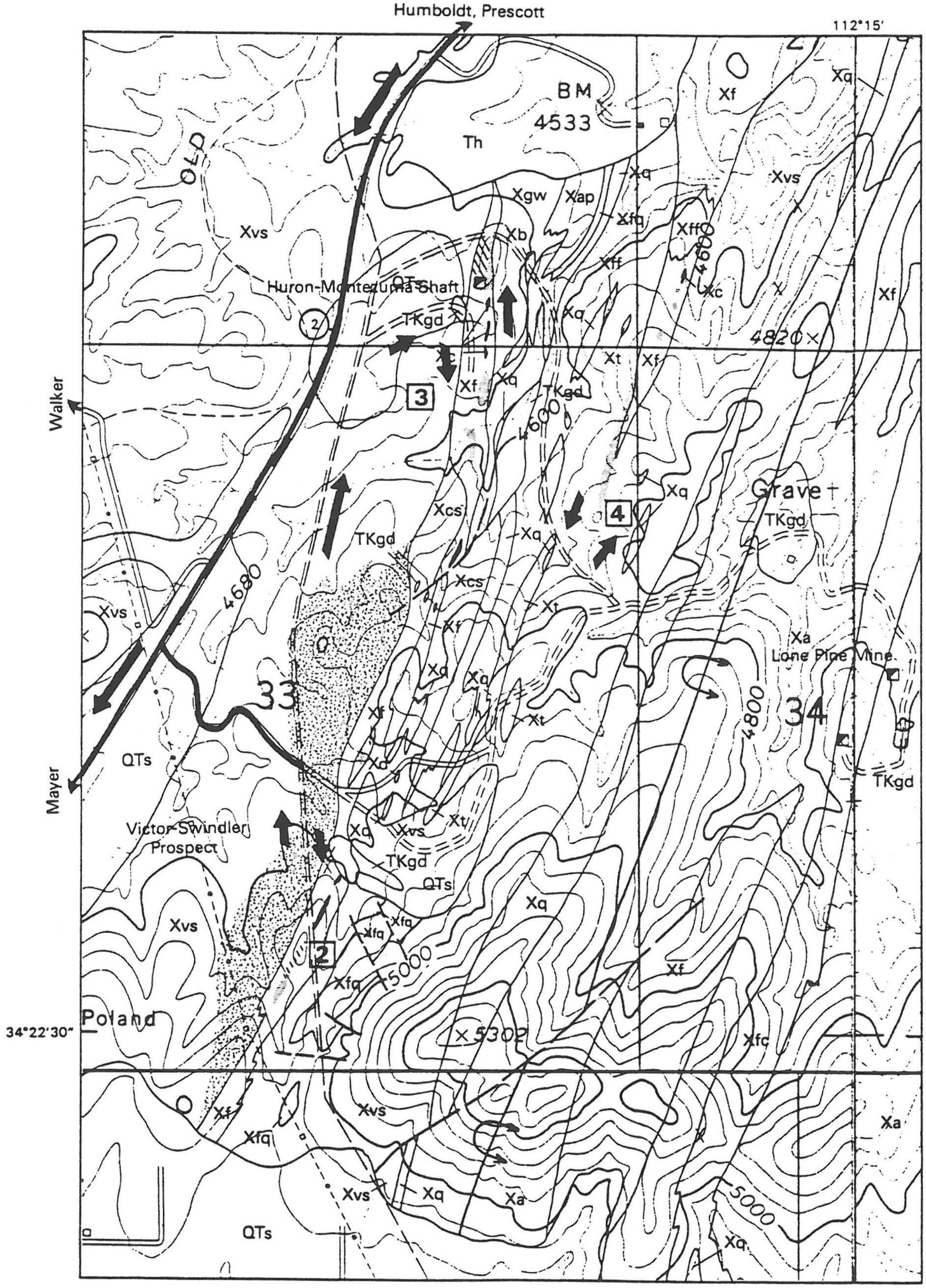
½ MILE 0

Scale 1:12,000

Route of field trip

Contact: dashed where inferred, dotted where concealed

Excerpts from "Geology of Early Proterozoic gold mineralization, alteration assemblages, and geochemistry of the Huron-Victor-Swindler-Montezuma prospects, Yavapai County, Arizona," by P. F. O'Hara and R. C. Long.



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HURON - VICTOR - SWINDLER - MONTEZUMA PROSPECTS

A series of quartz porphyry intrusions crop out at the top of a steeply dipping sequence of intermediate to felsic metavolcanic rocks and interlayered immature metasedimentary rocks. Rapid facies changes with sediment dominated rocks on the north side of each quartz porphyry, suggest that the quartz porphyries were emplaced along growth faults which facilitated hydrothermal flow and the formation of chemical sediments in the north flanking basins. This entire rock package is overlain by a complex mixture of metamorphosed calcareous sediments, graywacke, andesitic volcanic rocks and dacitic tuff (O'Hara, 1987).

The mineralized quartz porphyries contain very fine grained (<0.1mm in diameter) quartz phenocrysts as opposed to the coarse grained (>0.5mm in diameter) phenocrysts in unmineralized quartz porphyries lower in the section. The tops of the mineralized quartz porphyries are mound shaped in cross-section (map view because of the steep dip of the lithologies). Alteration and mineralization are associated with the fine grained quartz porphyries forming a series of complex hydrothermal-intrusive vent complexes at the seawater-seafloor interface (Figure 3).

ALTERATION

Gold mineralization and associated alteration assemblages are characteristically associated with small felsic volcanic centers in the Early Proterozoic metavolcanic belt of central Arizona (O'Hara, 1986). The felsic metavolcanic rocks are variably altered to assemblages rich in quartz and muscovite. In the vicinity of many mines and deposits, a general increase of aluminosilicate minerals takes place downward in the lower portion of the altered sequence. The aluminosilicate minerals are replaced upward by quartz+/-sericite assemblages or quartz dominant assemblages (Figure 3). In places, "exhalative" chert flanks the inferred volcanic-hydrothermal vent. In each of seven known or inferred hydrothermal systems near the Huron-Montezuma prospect, brecciation (either caused by hydrofracturing at depth or explosions onto the seafloor), pyrite enrichment, and concentration of gold can be documented. The location of highest gold grades varies laterally and vertically from system to system. Variations in the spatial distribution of gold are probably related to physio-chemical controls such as depth of the seawater-sediment interface, and temperature and composition of the hydrothermal fluids.

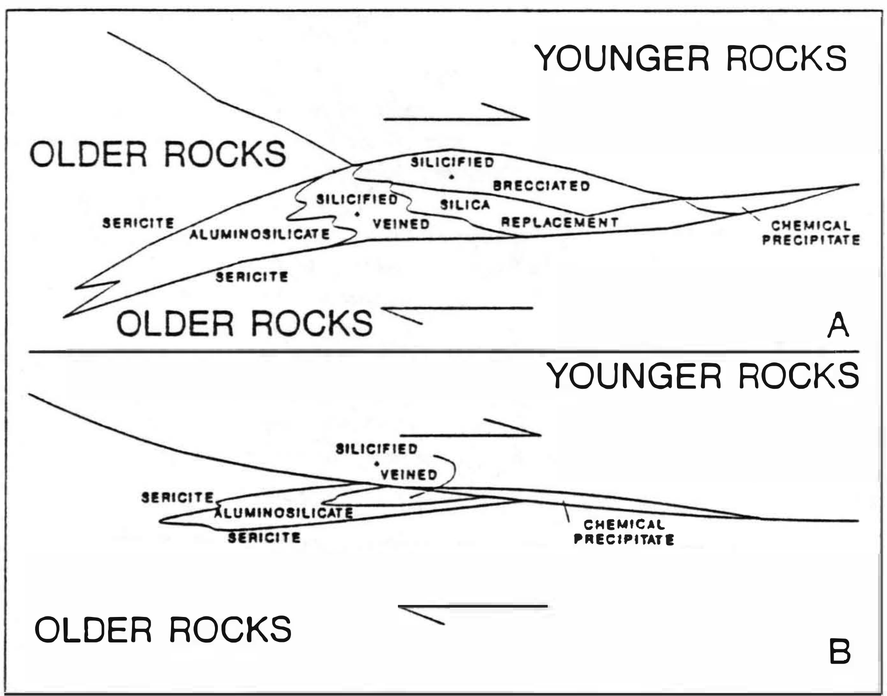


Figure 3a. Complete alteration sequence.

3b. Incomplete alteration sequence with silica replacement and silica breccia facies missing.

Excerpts from "Geology and alteration assemblages at the Bluebell Mine, an Early Proterozoic massive sulfide deposit, Yavapai County, Arizona," by Ed DeWitt.

Geology and alteration assemblages at the Bluebell Mine, an Early Proterozoic massive sulfide deposit, Yavapai County, Arizona

Ed DeWitt *M.S. 905, U.S. Geological Survey, Denver, CO 80225*

OBSERVATIONS

In many respects, the Early Proterozoic massive sulfide deposit at the Bluebell Mine near Mayer, Arizona, is typical of many small (<5 million-ton) orebodies hosted by 1.74-1.75-Ga metavolcanic rocks. The orebody is localized at the lower(?)contact of a hydrothermally altered rhyolite and underlying basalt and tuffaceous sedimentary rocks (Lindgren, 1926;; Anderson and Blacet, 1972b). The ore ranges from 20 to 80% pyrite and contains much lesser amounts of chalcopyrite and arsenopyrite, and minor amounts of sphalerite, galena, and tennantite(?) (Lindgren, 1926; DeWitt, 1976) The major gangue is a mixture of quartz, muscovite, and chlorite derived principally from hydrothermally altered rhyolite. No feeder pipe cutting through the footwall rocks has been recognized at the Bluebell (DeWitt, 1979); rather, the altered rocks appear to be spatially associated with the elongate metarhyolite. This alteration geometry and lack of a clear-cut pipe beneath or peripheral to the orebody is typical of other, small massive sulfide orebodies near Mayer, such as the DeSoto and Hackberry deposits

In detail, however, the alteration assemblage in ore-grade material collected from outcrops, old stopes, and waste piles, is more varied. Particularly noteworthy is the abundance of biotite-rich material containing abundant calcite, disseminated allanite and thin layers rich in tourmaline. Gangue in normal pyrite-rich to pyrite-poor ore may be either:

1) quartz-muscovite-chlorite-opaque material
2) quartz-calcite-opaque material
3) biotite-plagioclase-calcite-muscovite-opaque material
4) biotite-calcite-tourmaline-allanite
5) biotite-plagioclase-hornblende-allanite-opaque material
6) hornblende-biotite-calcite-plagioclase-opaque material

The presence of biotite-rich gangue that locally grades into biotitite is perceived as particularly important, as zones rich in tourmaline and allanite are much more common in the biotite-rich layers and biotitite that in any other layers. The biotite-, allanite-, and tourmaline-rich layers are interpreted to be either tuffaceous sedimentary horizons of unusual, possibly alkalic character, or layers formed from extreme hydrothermal alteration of diverse protoliths.

Because allanite characteristically is enriched in light rare-earth-elements, geochemical sampling programs may be able to determine stratigraphic intervals favorable for mineralized material by adding lanthanum, cerium, or yttrium to their otherwise standard list of elements. Likewise, if tourmaline is sufficiently concentrated in the biotite-rich layers, geochemical sampling programs emphasizing boron may prove effective in the search for concealed massive sulfide deposits in north-central Arizona.

Mayer District

Located southwest of the Agua Fria district, the Mayer district (figs. 1, 17), contains massive sulfide deposits in and at the contacts of metarhyolite flows with metabasalt and meta-andesite (Lindgren, 1926; Tenney, 1935; Blacet, 1968, 1985; Anderson and Blacet, 1972a, 1972b; DeWitt, 1976, 1978, 1979, 1987; Anderson and Guilbert, 1979; O'Hara, 1980; Vrba, 1980; Argenbright and Karlstrom, 1986; Anderson, 1989a). The district has average to very slightly low copper and silver grades and an average to slightly high gold grade (table 1). Two mines, the Bluebell and DeSoto (table 6), produced all the ore from the district and have very similar metal concentrations. Neither produced lead or zinc, and both contain only minor galena or sphalerite (Lindgren, 1926).

The Bluebell mine was the fifth largest massive sulfide deposit in the state in terms of tons of ore. The deposit is localized in and at the contact of underlying metabasalt and overlying metarhyolite (Lindgren, 1926; DeWitt, 1976, 1979). Both pyrite-rich and pyrite-poor ore is present. Ore minerals are pyrite-chalcopyrite-minor arsenopyrite-sphalerite-minor galena. Gold correlates well with silver (fig. 18), resulting in a constant Ag/Au of about 25 over much of the life of the mine. High gold and silver grades after 1920 are a result of mining small quantities of enriched ore (fig. 19). The prominent peak for 1905 data is a result of estimating pre-1905 production. Silver (and hence, gold) correlates well with copper (fig. 19).

The DeSoto mine (Lindgren, 1926; Blacet, 1968; DeWitt, 1976, 1979; Vrba, 1980) produced only one-fourth as much ore as the Bluebell, but shared most of its characteristics. Massive sulfide and stringer ore are at the contact of underlying metabasalt and overlying metarhyolite. Ore minerals are the same as at the Bluebell mine. Gold and silver are highly correlated (fig. 20). Ag/Au is constant over the lifetime of the mine. Silver (and hence, gold) is moderately well correlated with copper (fig. 21). A 1904 estimate accounts for half the ore produced at the DeSoto, but that estimate is in agreement with metal ratios for succeeding years.

Excerpts from "Geology and alteration assemblages at the Bluebell Mine, an Early Proterozoic massive sulfide deposit, Yavapai County, Arizona," by Ed DeWitt.

Table 6. Massive sulfide deposit production data, Mayer district [See headnote of table 1 for explanation].

DEPOSIT	Ore (t)	Cu (lb)	Pb (lb)	Zn (lb)	Ag (oz)	Au (oz)	Cu (%)	Pb (%)	Zn (%)	Ag (oz/t)	Au (oz/t)	Ag/Au
Bluebell	1,144,603	69,779,084			1,373,538	54,145	3.05			1.200	0.047	25
Desoto	257,267	13,896,480			251,266	10,919	2.70			0.977	0.042	23
TOTAL	1,401,870	83,675,564			1,624,804	65,064	2.98			1.159	0.046	25

Figure 18. Plot of year of production vs. silver, gold in the Bluebell mine, 1903-1930.

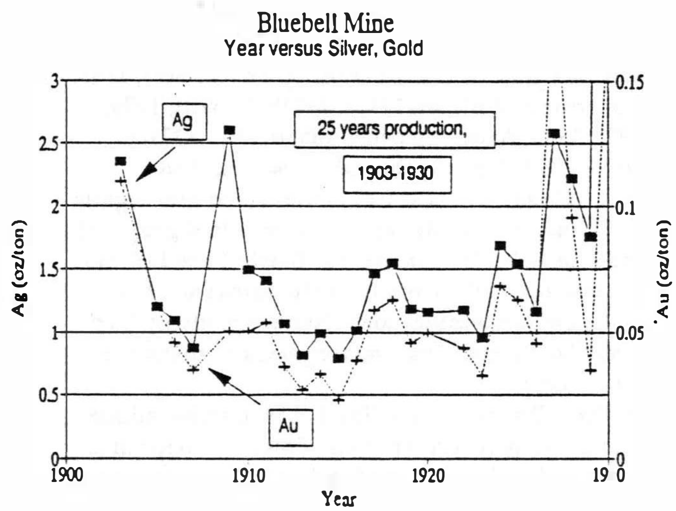
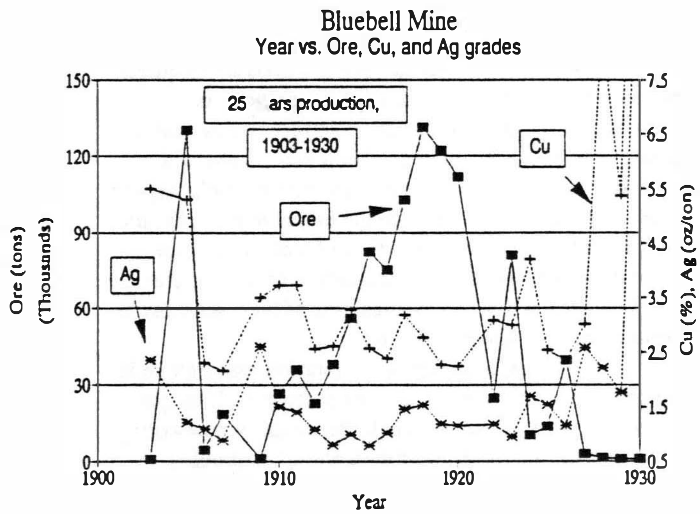
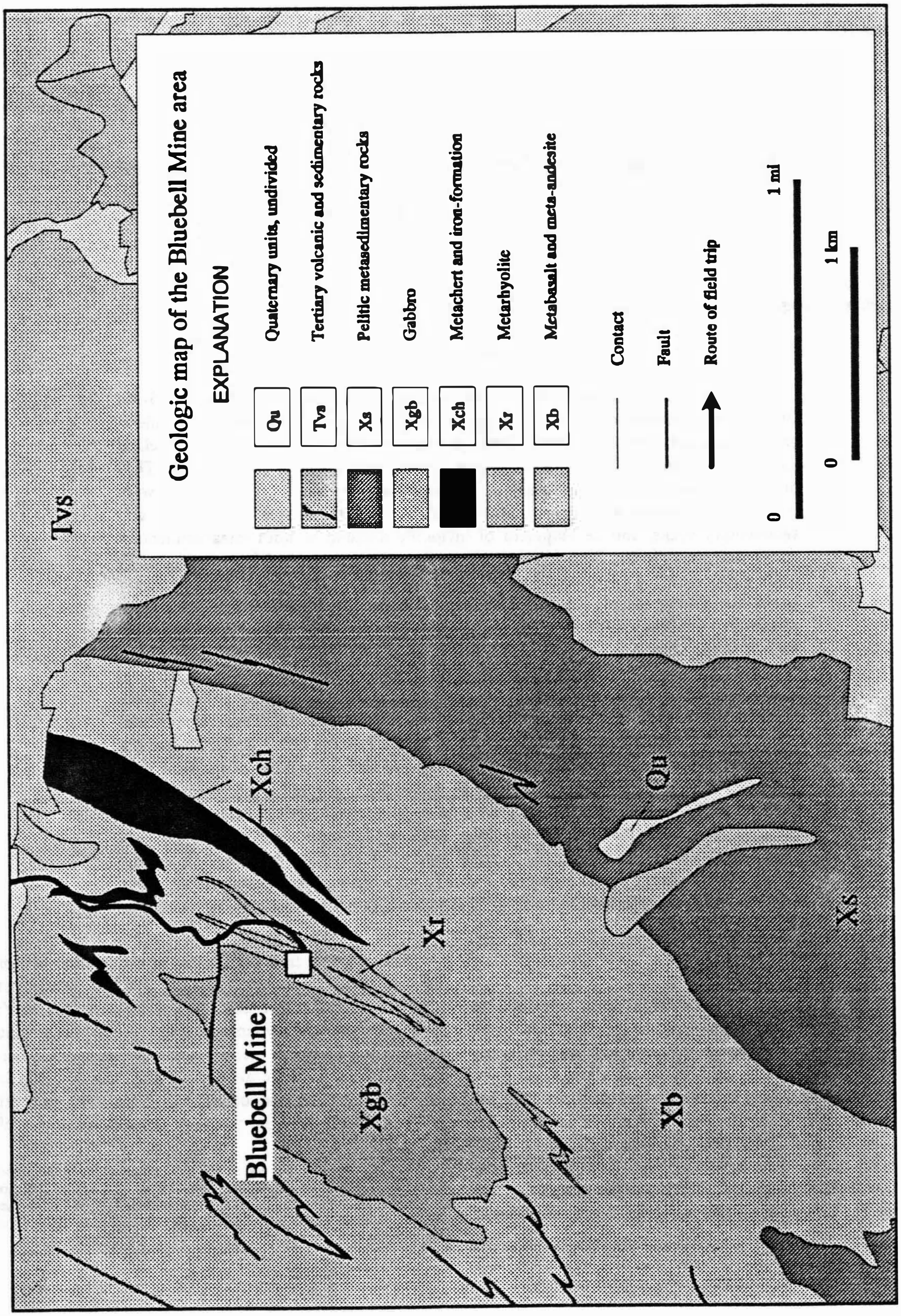


Figure 19. Plot of year of production vs. ore, copper, silver in the Bluebell mine, 1903-1930.



Excerpts from "Geology and alteration assemblages at the Bluebell Mine, an Early Proterozoic massive sulfide deposit, Yavapai County, Arizona," by Ed DeWitt.



Excerpts from "Early recumbent folding during Proterozoic orogeny in central Arizona," by K. E. Karlstrom. *Reprinted with permission from Grambling, J.A., and Tewskbury, B.J., eds, 1989, Proterozoic geology of the southern Rocky Mountains: Geological Society of America Special Paper 235, p. 155, 160, 162, and 163*

Early recumbent folding during Proterozoic orogeny in central Arizona

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ABSTRACT

Two generations of folds affected the folded unconformity between the 1,750-Ma Brady Butte Granodiorite and overlying Proterozoic Texas Gulch Formation metagraywackes and slates in the Brady Butte area of central Arizona. F_1 folds are isoclinal and were predominantly northwest-verging recumbent folds prior to F_2 folding. They occur at all scales, with macroscopic fold amplitudes exceeding 500 m. F_1 folds were temporally associated with transposition of bedding and mesoscopic thrusting in metasedimentary rocks, and development of mylonitic foliation in both metasedimentary rocks and granodiorite. Both style of structures and asymmetry of fabrics suggest F_1 folding accompanied northwest-directed thrusting. F_2 folds are open to tight and have northeast-striking, steeply dipping, axial plane foliation. F_2 folds are gently northeast plunging in the Brady Butte area, coaxial with F_1 folds, and the enveloping surface of F_2 folds is subhorizontal.

New structural data may have important regional implications. A subhorizontal enveloping surface for F_2 folds implies that stratigraphic units and the basal Texas Gulch Formation unconformity are repeated across strike in F_2 fold hinges. Thus, the metasedimentary rocks of the Crazy Basin area may correlate with the Texas Gulch Formation, and parts of the Spud Mountain Volcanics may correlate with parts of the Iron King Volcanics. However, transposition during F_2 and rotation of fold hingelines toward the subvertical F_2 finite stretching axis in areas of high shortening strain complicate structural geometry such that rootless intrafolial folds are common. Furthermore, F_2 folds affected an already transposed S_1 tectonic layering formed by recumbent folds and thrusts. The complex overprinting of F_1 and F_2 on a regional scale make stratigraphic interpretations tenuous until more detailed structural, geochronologic, and geochemical data are available.

INTRODUCTION

Early Proterozoic (1,800 to 1,600 Ma) rocks in Arizona are exposed in a northwest-trending band in the Transition Zone, between the Colorado Plateau and Basin and Range Provinces (Fig. 1). This band provides semi-continuous exposure for more than 500 km perpendicular to strike of the Proterozoic orogenic belt. The Transition Zone has been affected by Tertiary high-angle faults of moderately large displacement, but no post-Precambrian ductile deformation or large Tertiary extensional strains have been documented, so it is possible to study a cross section of Proterozoic crust that has been largely undisturbed since ca. 1,400 Ma.

This orogenic cross section can be divided into two major provinces (Fig. 1): an older (1,800 to 1,700 Ma) province to the northwest, underlain by oceanic volcanogenic rocks of the Yavapai Supergroup[1], and a younger (1,740 to 1,600 Ma) province to the southeast, underlain predominantly by continentally derived rocks of the Tonto Basin Supergroup and Diamond Rim Intrusive Suite (Conway and others, 1987; Karlstrom and others, 1987). Although the exact geometry and tectonic history of the

[1]This sequence of rocks was named the Yavapai Series by Anderson and others (1971). The chronostratigraphic term "Series" is replaced in this paper by the lithostratigraphic term "Supergroup" in accordance with recommendations of amendments to the U.S. Code of Stratigraphic Nomenclature (Henderson and others, 1980).

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cent volcanic rocks because of its position toward the center of the inferred regional anticline cored by the Brady Butte Granodiorite (Fig. 4), and based on correlation of the Texas Gulch Formation with slates exposed in the core of a major overturned anticline in the Green Gulch Volcanics (Krieger, 1965; Anderson, 1968). Blacet (1966) had documented that basal granodiorite-boulder conglomerate of the Texas Gulch Formation unconformably overlies a northern phase of the Brady Butte Granodiorite (bb in Fig. 3), which he considered at that time to be basement to the Yavapai Supergroup. He also showed that a southern granodiorite intrudes the Spud Mountain Volcanics, and he considered this to be a younger pluton. However, when U-Pb zircon dates showed that the two granodiorites were about the same age (1,750 ± 10 Ma), Anderson and others (1971) concluded that they were probably two phases of a single batholith and that the Texas Gulch Formation must be younger than the Spud Mountain Volcanics. Anderson and others (1971) no longer considered the Texas Gulch Formation to be part of their Yavapai Series (Fig. 4). The unconformity was apparently believed to represent considerable hiatus such that the Texas Gulch Formation did not belong within the 1,800 to 1,750 Ma interval specified for the Yavapai Series.

The structural interpretation of Anderson and his coworkers was that the regional folds are entirely upward-facing[3] and have subhorizontal plunges on a regional scale. They believed that the distribution of stratigraphic units in the Big Bug Group was controlled by a single generation of upright folds. The discovery, from isotopic data, that a unit toward the center of an anticline (Texas Gulch Formation) was younger than a unit farther out (Spud Mountain Volcanics) created problems reconciling structural and stratigraphic interpretations. They proposed that major ductile faults and shear zones entirely bound the Texas Gulch Formation (Fig. 4) and caused this younger unit to be downthrown along "piercement structures" in the core of the regional anticline (Anderson, 1967; Anderson and Blacet, 1972c). Gilmour and Still (1968) questioned the presence of these faults bounding the Texas Gulch Formation, as have other subsequent workers (DeWitt, 1976; O'Hara, 1980; and this chapter).

DeWitt (1976, 1979, 1980), working in the area of the Iron King Volcanics of Anderson and others (1971; Fig. 4), recognized problems with the structural interpretation of Anderson and others (1971). DeWitt reported a preponderance of steeply plunging minor folds and mineral and pebble lineations, and he reinterpreted the stratigraphy in terms of steeply plunging macroscopic folds. This prompted a discussion from Creasey (1980), who pointed out that areas outside DeWitt's study area, such as the Brady Butte area, had predominantly shallow-plunging folds and that it was these folds that controlled regional stratigraphy. This controversy can be reconciled with new structural data that show a much more complicated deformational geometry than envisioned by either worker, as discussed later.

O'Hara and others (1978) and O'Hara (1980) were the first workers to recognize that deformation in the rocks of the Texas Gulch Formation, and by inference older rocks, involved multiple fold generations and that distribution of stratigraphic units was more complex than could be explained by a pattern of macroscopic anticlines and synclines. They noted that Blacet's (1966) map pattern in the Brady Butte area (Fig. 3) suggested fold overprinting relationships (Blacet had interpreted this map pattern to be a topographic effect), and that two generations of mesoscopic folds could be seen in Mule Canyon, at the north end of the Brady Butte Granodiorite. This chapter documents the macroscopic and mesoscopic geometry of multiple fold generations in the Brady Butte area (see Fig. 3 for location), and reevaluates structural and stratigraphic interpretations of the Yavapai Supergroup of the Big Bug block in light of new structural data.

GEOLOGY OF A FOLDED UNCONFORMITY

The Brady Butte area (Fig. 5) is very important for understanding the structure of the Yavapai Supergroup. Most of the Yavapai Supergroup of the Bradshaw Mountains consists of lenticular and gradational volcanic units, many lacking primary layering. In contrast, the Brady Butte area contains a mappable unconformity, and metasediments of the Texas Gulch Formation preserve primary structures and fold overprinting relationships. The preservation of early structures may be due to the location of this area near the hinge of a macroscopic antiform cored by the massive Brady Butte Granodiorite (Fig. 3), where regional shortening strains were apparently lower than in adjacent areas.

The unconformity, seen at several locations (shown with dots in Fig. 5), is marked by basal conglomerate with boulders of granophyre, granodiorite, mafic volcanics, chert, and quartz in an arkosic matrix. This conglomerate is widespread but is not present everywhere at the contact (Fig. 5), suggesting that the conglomerates initially were lenticular debris flows or alluvial channels and/or that the contact has been tectonized. These basal boulder conglomerates reach a maximum thickness of about 10 m, with lenses of pebble conglomerate also occurring higher in the section. In areas where basal boulder conglomerate is absent, the unconformity is marked by pebble conglomerates or metasandstones. Below the contact is highly altered granodiorite in which feldspars have been converted, either partially or completely, to fine-grained muscovite and quartz. In places these altered rocks form a gradational zone between less altered granodiorite and basal conglomerate or arkose. These intensely altered granodiorites may represent regolithic material, as is suggested by their association with the unconformity. Alteration of feldspars may also have accompanied mylonitic deformation of the granodiorite (Knipe and Wintsch, 1985).

The importance of the unconformity from a structural viewpoint is that it is a marker horizon, across which younging is

[3]Shackleton (1958) defined fold "facing" as the younging direction seen in fold hinge areas. Combined with the concept of enveloping surface (Hobbs and others, 1976), facing is useful for reconstructing stratigraphy in isoclinally folded and transposed sequences. Folds can face up or down or in any compass direction.

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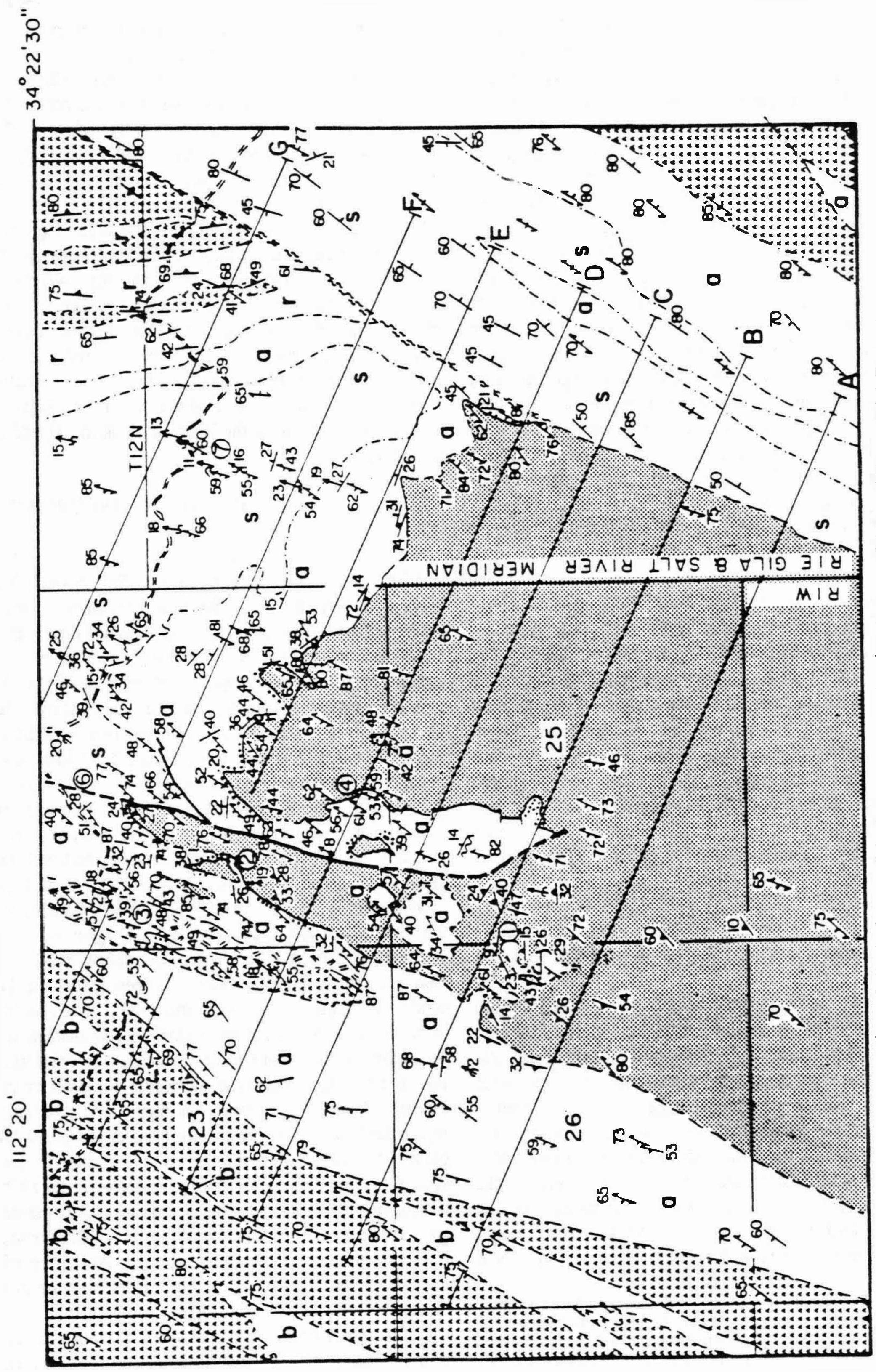

Figure 5. Geologic map of the Brady Butte area showing the trace of the basal Texas Gulch Formation unconformity. See Figure 3 for location.

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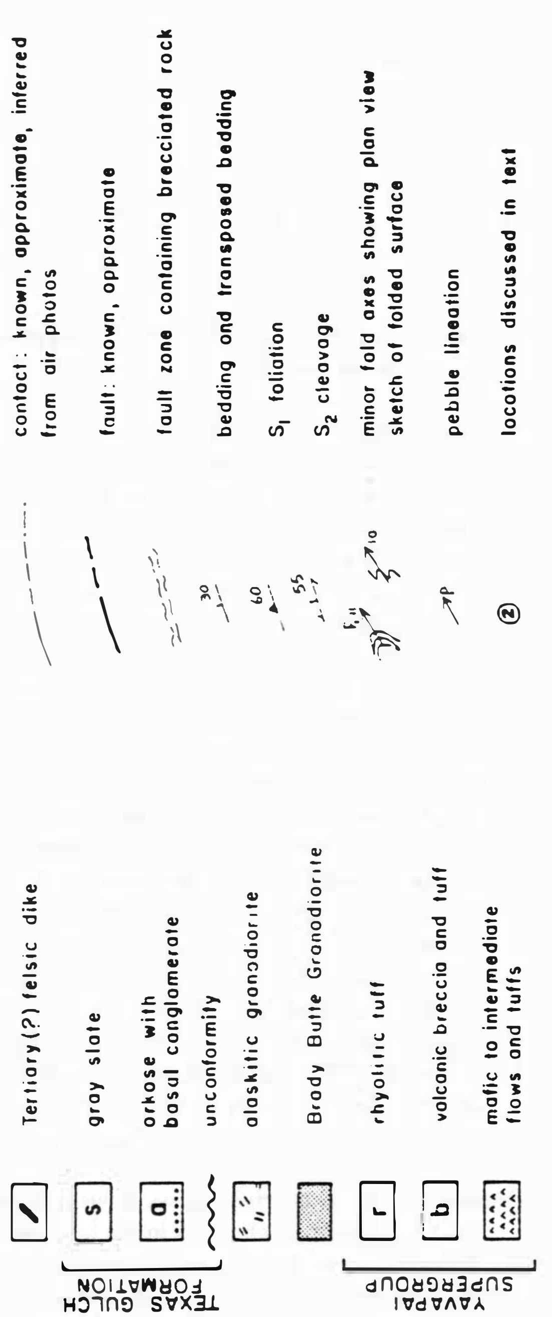
FIGURE 5 EXPLANATION



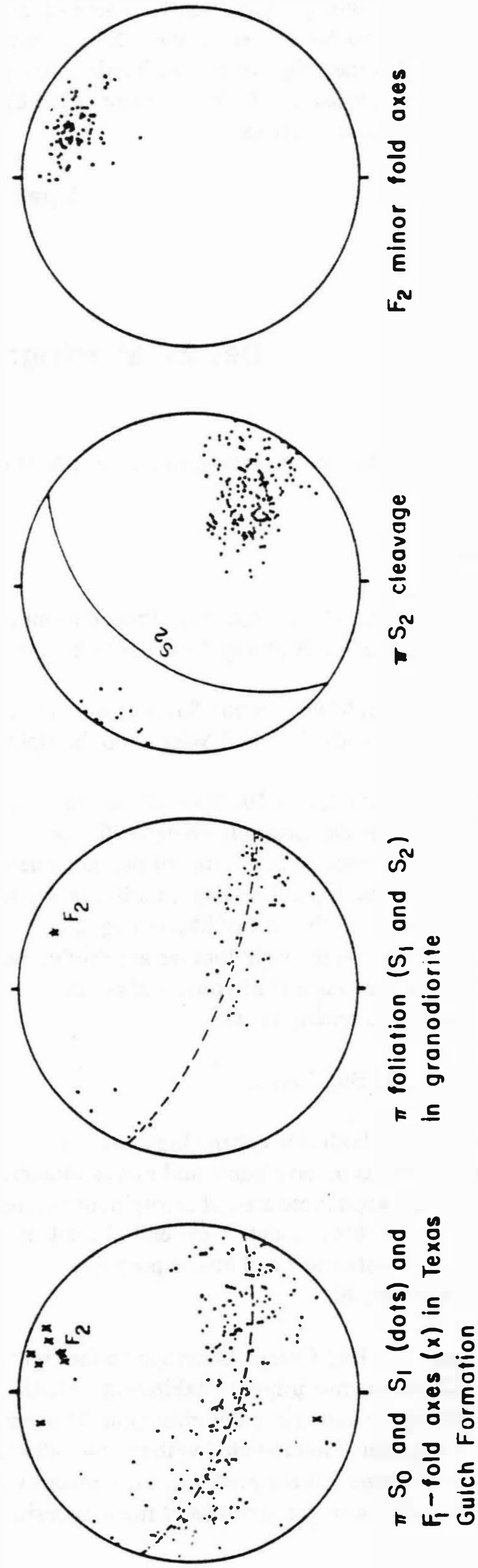


Figure 6. Lower-hemisphere equal-area projections of fabric elements in the Brady Butte area.

DAY 2

The second day of the field trip will be somewhat more diverse than the first. Our initial stop will be near the old town of Cordes, where we will have an overview of stratigraphy and structure in the southern part of the Bradshaw Mountains. During the morning, participants can choose between an ore deposits-related stop at the Golden Belt Mine, a middle Tertiary low-angle gold-rich vein deposit near Townsend Butte, or a structural stop west of Cleator in pelitic metasedimentary rocks adjacent to the 1.70 Ga Crazy Basin Quartz Monzonite. The ore deposit stop at the Golden Belt Mine will discuss the origin of middle Tertiary low-angle silver-rich vein systems. The stop west of Cleator will discuss the structural relationships of emplacement of the Crazy Basin Quartz Monzonite and the formation of regional fabrics in the surrounding country rocks.

Road Log and Field Trip Guide

By Ed DeWitt

Day 2 - Morning: Mayer, Arizona, to Cordes, Arizona

Road Log from Mayer, Arizona, to Cordes, Arizona: 15.7 miles.

Cumulative
Mileage

0.0 Circle K Store, Mayer, Arizona. Proceed south on Arizona State Highway 69 toward Phoenix.

0.7 Black Canyon Mobile Home Sales area on the right. Turnoff to the Bluebell Mine is on the right.

1.5 Outcrops on the left at 10:00 are ribs of ferruginous metachert that protrude above tuffaceous metavolcanic rocks. Some of the metachert and iron-formation define large, north-closing fold structures to the east of Mayer (fig. 2). Outcrops on the right that we are driving past are tuffaceous metarhyolite and pelitic metasedimentary rocks.

1.9 Crossing Big Bug Creek.

2.1 Outcrops on both sides of the highway are tuffaceous metavolcanic and metasedimentary rocks. Prominent lens of ferruginous metachert noted in this roadcut. Near end of roadcut metarhyolite tuff and quartz porphyry predominate.

2.3 Crossing Big Bug Creek. Outcrops on the right are tuffaceous metarhyolite exhibiting sericitic alteration and minor chloritization. Minor iron-formation is interbedded with the metarhyolite. Hills to the left are predominantly metarhyolite containing minor amounts of meta-andesite.

2.8 Crossing Big Bug Creek again. Small gold placer operation on the right side of the highway.

3.0 Roadcuts in hematite-stained and altered metarhyolite tuff. These altered rocks are the southern extension of extremely altered metavolcanic rocks in the Copper Mountain area to the north. Tertiary Hickey Formation covers the metavolcanic rocks on the right side of the highway (fig. 2).

3.6 Most of the roadcuts from here to the junction with Interstate Highway 17 are in Hickey Formation.

4.2 Forested, flat-topped peaks on the horizon at 11:30 to 12:00 are in the Pine Mountain area (Canney and others, 1967). The high plateau near Pine Mountain was one of the first areas in the Jerome-Prescott region to be designated a Primitive Area. Small belts of mafic metavolcanic rocks are preserved within a large granite to granodiorite complex whose description is similar to the tonalite of Cherry (DeWitt, 1989). Paleozoic strata overlie Proterozoic rocks, and all are covered by extensive basalt flows of the Hickey Formation.

5.0 Panoramic view to the right shows Towers Mountain on the far right., high peaks in the basin near Crown King to the left, and peaks in the Horsethief Basin area to the left of Crown King, at about 2:00 to 2:30. Much of the southern Bradshaw Mountains in the Horsethief Basin area is made up of the 1700 Ma Crazy Basin Quartz Monzonite (Karlstrom and Conway, 1986; DeWitt, 1989), the rock that forms the bouldery weathering topography noted even from this far away.

A Laramide stock at Crown King (Jaggar and Palache, 1905; DeWitt, 1976) and a northeast-striking system of granodiorite to rhyolite dikes and Laramide veins are host to the Tiger metallic mineral district, which is centered on Crown King. The district is one of the larger Laramide base- and precious-metal districts in the Bradshaw Mountains. Approximately 14 major mines and numerous smaller mines have produced more than 270,000 tons of zinc- and gold-rich ore. The stock has an evolved phase that contains breccia pipes and disseminated molybdenum. In all aspects, the district strongly resembles the Copper Basin district west of Prescott.

7.7 Cordes Junction and intersection with Interstate Highway 17 to Flagstaff and Phoenix. Turn right onto the entrance ramp for southbound I-17 to Phoenix. At 12:00 in the foreground are brown, granitic-weathering hills composed of Bumblebee Granodiorite.

8.6 Bridge over Big Bug Creek. First roadcuts are in a mixed variety of rocks including foliated granodiorite, metarhyolite, and some meta-andesite. Outcrops to the right on the ridge are predominantly metarhyolite. In the foreground is a plutonic rock described by Anderson (1972) as quartz diorite porphyry. Chemically and mineralogically the rock strongly resembles the Brady Butte Granodiorite, and is informally called the granodiorite of Big Bug Creek (DeWitt, 1989).

10.3 Crest of small divide. Panorama ahead shows gently dipping basalt flows on Black Mesa and Perry Mesa. In the distance are the New River Mountains. Outcrops on both sides of the highway are Bumblebee Granodiorite.

11.3 Exit 259 to Crown King and Horsethief Basin in the Bradshaw Mountains on the west and the Bloody Basin area in the New River Mountains on the east. Take exit ramp. At stop sign, turn right toward Crown King.

12.1 Cross pipeline. Driving through border phase of Bumblebee Granodiorite.

12.5 Cross contact of Bumblebee Granodiorite on east and metavolcanic rocks on west.

12.8 Trails lead to the right and left. Stay on main road. Towers Mountain at 9:00. Crown King in basin on skyline at 8:30. Horsethief Basin on skyline at 8:00.

14.0 Crossing small creek. Metavolcanic strata concealed by basalt flows and sedimentary rocks of the Hickey Formation (fig. 2).

14.5 Stop sign. Old town of Cordes. Turn left on #259 toward Cleator.

15.0 Cattle guard

15.7 Top of ridge. Take trail to left. New River Mountains at 10:00. Towers Mountain at 1:00.

STOP 4. Park vehicles as carefully as possible; try to make sure all are off the road, as this turn is sharp and hard to see around. At this stop we will discuss various interpretations of the geology of the southern Bradshaw Mountains, including to what degree the Shylock fault zone does or does not continue to the south from this point, and what role do high strain zones, such as the Shylock, play in the evolution of the Early Proterozoic deformation in the state.

After this stop, return to the main road, turn left, and continue toward Cleator and Crown King.

Road Log from Cordes, Arizona, to Golden Belt Mine: 4.3 miles

Cumulative
Mileage

0.0 Crest of ridge, 0.7 miles southwest of Cordes. Turn left onto main road toward Crown King.

0.2 Descending grade toward Townsend Butte and Golden Belt Mine. Contact of Badger Spring Granodiorite, a leucocratic, coarsely porphyritic (large phenocrysts of quartz), massive to strongly foliated intrusive that extends south toward the Black Canyon area.

0.9 Cattle guard

1.6 Y in road; stay to right on #259 toward Crown King.

2.5 Stop sign. Stay to right on #259.

3.0 Trail to left leads to Silver Cord Mine, a small, low-angle, high-grade silver vein famous for its specimens of wire silver.

3.4 Trail to right; stay on main road, which bends to the left.

3.8 Cattle guard and Prescott National Forest boundary. Golden Belt and Golden Turkey mines straight ahead. Dumps of an unnamed massive sulfide prospect in the Kay district, on the left at 9:00.

4.1 Crossing Turkey Creek

4.3 Turn left on road to Golden Belt Mine. Park cars on waste dump.

STOP 5A. Golden Belt and Golden Turkey Mines. These middle Tertiary, low-angle, precious-metal-rich deposits are in the Black Canyon metallic mineral district, which produced about 265,000 tons of ore from low-angle fractures and from veins adjacent to basalt dikes. Most of the production has come from the Golden Turkey and Golden Belt mines. Aspects of the geology to be discussed at this stop include the origin of the low-angle veins and their relationship to the overlying, flat, and undeformed cover of basalt flows and sedimentary rocks of the Hickey Formation.

When finished at the stop, return to Cordes and the Horesthief Basin interchange on I-17.

Approximate Road Log from Golden Belt Mine to stop 5B west of Cleator, Arizona: 4.5 miles

Cumulative
Mileage

0.0 Golden Belt Mine. Turn left onto road #259 toward Cleator. Driving through massive quartz porphyry metarhyolite.

0.4 Trail to left is old mining road that leads to south of Golden Belt Mine.

0.5 Ferruginous metachert crosses road.

0.7 St. Johns Mine on right. Driving through mixed meta-andesitic tuff and pelitic metasedimentary rocks. Crossing Cleator shear zone of Darrach (1988).

0.9 Contact of pelitic metasedimentary rocks that continue from here to Cleator, and to stop 5B west of Cleator.

1.8 Road to right follows bed of narrow gauge railroad that originally went to Bluebell siding and Mayer. Road now leads to Bluebell Mine through pelitic metasedimentary rocks.

1.9 Cleator, Arizona. Continue on main road, which follows bed of narrow gauge railroad that terminated at Crown King and serviced many of the Laramide vein deposits in the Crown King area. Continue through pelitic metasedimentary rocks to stop 5B. Road to the left, just past most buildings, is to the French Lily Mine.

2.9 Turnoff to the right leads to the DeSoto Mine, the southernmost massive sulfide deposit in the Mayer metallic mineral district (DeWitt, this volume). The DeSoto mine produced 300,000 tons of ore that averaged 3.6% Cu, 0.056 oz/ton Au, and 1.24 oz/ton Ag (DeWitt, 1976; this volume).

Spectacular, softball-size andalusite and golfball-size staurolite crystals are exposed in pelitic metasedimentary rocks along the road near the crest of the hill at 2:30 (DeWitt, 1976; Argenbright, 1986).

4.5 Bridge over Middleton Creek. Ore from the DeSoto Mine was trammed 1400 feet vertically to this point on the narrow gauge railroad. Some towers of the tram are visible from this point. Once across the bridge, turn to the left and park cars on the flat area off the roadway.

STOP 5B. Early Proterozoic pelitic metasedimentary rocks and 1.70 Ga Crazy Basin Quartz Monzonite. Stop will discuss relationships of intrusion of the Crazy Basin body and regional fabrics in the pelitic metasedimentary rocks.

When finished, return to Cordes and to the Horsethief Basin interchange on I-17.

Road Log from Horsethief Basin Interchange on I-17 to Sunset Point Rest Area on I-17: 6.8 miles

Cumulative
Mileage

0.0 Horesthief Basin Interchange (exit 259) on I-17. Turn right toward Phoenix.

0.4 Panoramic view of the central and southern Bradshaw Mountains on the right. Most of the high country visible from here at 3:00 is underlain by two phases of the Crazy Basin Quartz Monzonite (Anderson and Blacet, 1972c). The early, syntectonic phase is a fine- to medium-grained, equigranular, highly flow foliated to tectonically foliated two-mica granite (DeWitt, unpub. data, 1990). The late phase is late- to post-tectonic (in the interpretation of DeWitt, 1987) and is the coarse-grained, locally pegmatite-bearing two-mica granite that is locally flow foliated and boudinaged near Crazy Basin. Conway and others, (1989) interpret the late phase to be syntectonic. The late phase is responsible for much of the amphibolite facies metamorphism in the southern Bradshaw Mountains. No economic pegmatite deposits are associated with the granite, but tungsten veins in the Tussock metallic mineral district on the southwest side of the granite may be related to late quartz veins associated with the granite.

Much of the high country southwest of Horsethief Basin is underlain by the granodiorite of Lane Mountain (DeWitt, 1989), a pre-tectonic highly foliated leucocratic body that resembles the Brady Butte Granodiorite.

1.5 Roadcuts in hematite-stained Badger Spring Granodiorite.

2.1 View down and to the right through canyons cut into Tertiary fanglomerate is of Bland Hill, which is underlain by the 1.72 Ga quartz diorite of Bland (Jerome, 1956; Bowring and others, 1986)), a granodiorite similar in composition to the Bumblebee Granodiorite. The quartz diorite of Bland extends south along the Black Canyon schist belt and forms a major pluton in the western New River Mountains.

3.4 Exit 256 for the road to Badger Spring. This road provides access to the Richinbar mine on the east side of the Interstate, an Early Proterozoic? quartz vein at the eastern edge of Black Mesa. The mine is on the edge of an 800-ft-deep canyon formed by the Agua Fria River. Other mines in the Richinbar district are farther south along the highway near Black Canyon City. Roadcuts are in basalt flows of the Hickey Formation for the next 8 miles.

4.2 At 2:00 in the valley bottom is the old town of Bumble Bee. Bland Hill and the low country to the south of Bumble Bee is underlain by the quartz diorite of Bland. All of the pluton is extensively foliated, even those parts in the New River Mountains. The western margin is locally mylonitic (Jerome, 1956; Winn, 1982). Deformation of the quartz diorite took place at the same time as regional metamorphism and deformation of the metavolcanic and metasedimentary sequences. Much of the regional foliation and isoclinal folding in the Prescott region therefore took place between 1720 and 1700 Ma (Anderson, 1987; Karlstrom and Conway, 1986).

4.7 To the right at about 9:00 are iron-formation and ferruginous metachert lenses protruding above altered meta-andesite and metarhyolite in the Black Canyon schist belt. The Crazy Basin Quartz Monzonite forms the main mass of the Bradshaw Mountains west of the schist belt.

5.6 View back to the right at 4:00 is of many of the distinctive Early Proterozoic rock units in the Bradshaw Mountains. Highly foliated metarhyolite forms the light rocks in the Black Canyon schist belt, and is especially obvious on Townsend Butte, the conical peak on the north side of the road to Cleator and Crown King.

Meta-andesite and the quartz diorite of Bland are the dark rocks in the schist belt. Light rocks in the middle distance are pelitic metasedimentary rocks near Cleator. Mafic metavolcanic rocks are the dark band beyond the pelitic unit. The Brady Butte Granodiorite forms an impressive ridge extending south from Brady Butte, the conical peak directly over the top of Townsend Butte. On the horizon are the forested slopes of the high Bradshaw Mountains, underlain by metabasalt and gabbro that is well exposed on the slopes of Mount Union, the high peak just to the right of Brady Butte.

View to the right at 3:00 is of Bland Hill and the quartz diorite of Bland in the foreground and the DeSoto massive sulfide deposit on the ridge leading to Crown King in the background.

6.8 Turnoff to the Sunset Point Rest Area. Exit here for lunch.

We are on the western edge of Black Mesa, which is capped by basalt flows that are probably correlative with the Hickey Formation farther to the north. The youngest flows in the Hickey near Cordes Junction are about 11 Ma (McKee and Anderson, 1972). The top flow on Black Mesa is probably of this general age, and may have been derived from Joes Hills, a prominent shield volcano to the east across the canyon of the Agua Fria River. Middle Tertiary basalt sources are mostly northwest-trending feeder dikes (DeWitt, unpub. mapping, 1990).

After lunch, return to southbound I-17

toward Phoenix.

Day 2 - Afternoon: Sunset Point Rest Area on I-17 to southern New River Mountains

Road Log from Sunset Point Rest Area on I-17 to southern New River Mountains: 18.3 miles

Cumulative
Mileage

0.0 Sunset Point Rest Area on I-17. Return to Interstate 17 and continue south toward Phoenix.

0.2 On the left at 10:00 are high peaks of the New River Mountains. Except for the Tertiary basalt source on Squaw Mountain (fig. 3), all high peaks are underlain by ~1.7 Ga rhyolite, ash-flow tuff, columnar-jointed rhyolite, and subvolcanic granophyre related to the rhyolite (Maynard, 1986; DeWitt, 1987, unpub. mapping, 1990. This rhyolite sequence is very similar to 1700 Ma rhyolitic ash flows in the Tonto Basin area (Conway, 1976; Conway and others, 1983), and to the Red Rock Rhyolite in the Mazatzal Mountains (Wilson, 1939; Ludwig, 1973). Large rhyolite columns and miarolitic cavities in the rhyolite indicate that these rocks in the central part of the New River Mountains have not been strongly deformed or metamorphosed.

The same columnar rhyolite and ash-flow tuff, and older Early Proterozoic rocks, have been regionally deformed and metamorphosed along the eastern face of the New River Mountains, in and adjacent to the Moore Gulch shear zone (DeWitt, unpub. mapping, 1979; Maynard, 1986; Karlstrom and Conway, 1986). This shear zone is one of many zones of high strain in the Proterozoic terrane of central Arizona.

1.2 Roadcuts are in basalt flows. Interstate Highway 17 cuts down through the western side of Black Mesa and descends into the Black Canyon.

1.6 At 12:00 are highly foliated outcrops of the quartz diorite of Bland. From a distance the deformed pluton appears to be a metavolcanic or metasedimentary rock. Metavolcanic rocks crop out about one mile west of the Interstate.

2.0 Strongly fractured outcrops on the left are the quartz diorite of Bland. On the right are the striking outcrops of felsic metavolcanic rocks and iron-formation along the Black Canyon.

2.8 Exit 248 to Bumble Bee provides access to the Black Canyon and the steep eastern side of the Crazy Basin Quartz Monzonite. All outcrops along the highway are foliated plutonic rocks. Tertiary tuffaceous sedimentary rocks and lacustrine units are locally apparent beneath the basalt flows.

3.7 Deep roadcut in meta-andesite. Slump block of Tertiary basalt and sedimentary rocks to the left of the Interstate.

4.9 Town of Black Canyon City ahead. Dumps of the Kay mine, the largest massive sulfide deposit in the Kay district, are at 12:30, about four miles away. No large mines are located in the Kay district; only 2,500 tons of ore have been produced from the district. Most of the ore came from the Kay mine, which averaged 5.8% Cu, 0.3% Pb, 0.06 oz/ton Au, and 1.0 oz/ton Ag. Small mines and prospects in the Kay district extend north from the Kay mine to the Great Republic mine near Townsend Butte east of Cleator.

5.5 Roadcuts on the left expose Tertiary lacustrine deposits (fig. 3) that are cut by northwest-trending normal faults with minor offset. These faults are the northernmost indicators of Miocene extension so common farther south. One-quarter mile ahead, roadcut is in foliated quartz diorite of Bland.

6.9 Exit 244 to Black Canyon City. Black Canyon Greyhound Park on the right. Bold outcrops on the skyline to the right are the Crazy Basin Quartz Monzonite.

7.4 Prominent finger of rock at 9:00 is remnant of Tertiary basalt resting on lacustrine units. Depending on the sun angle, Tertiary basalt at 9:00 on the horizon can be seen extending three-fourths of the way up the crest of the New River Mountains. Inferred, northwest-trending feeder dike is beneath Squaw Mountain.

8.3 Bridge over the Agua Fria River, which has cut a deep canyon through the basalt on Black Mesa, to the left. Dump of the Kay mine on the right at about 2:30.

9.4 Exit 242 to Rock Springs and Black Canyon City. One-quarter mile farther south are roadcuts in Tertiary lake deposits. To the north, the Tertiary basalt and lake deposits have not been extensively faulted. In roadcuts to the south, however, are the first large normal faults to cut these rocks.

11.2 Roadcut in the northbound lane of I-17 is in slightly foliated quartz diorite of Bland. Small roadcuts in this lane are also in quartz diorite or a combination of quartz diorite and metarhyolite (fig. 3).

12.3 Crossing bridge over Little Squaw Creek. The crest of the New River Mountains is on the left. Early Proterozoic metabasalt and gabbro that are older than the ridge-capping 1.7-Ga rhyolite are exposed to the west of the Moore Gulch shear zone (fig. 3). The Orizaba mine, developed in meta-andesite and metatuff, contains the southernmost massive sulfide deposit in the Prescott-Jerome area. The mine produced about 30,000 tons of ore that, during copper- producing years, averaged 4.1% Cu, 0.42 oz/ton Ag, and 0.013 oz/ton Au. (DeWitt, this volume)

13.2 Bridge over Moore Gulch. Table Mesa two miles ahead. Roadcuts ahead are in lacustrine deposits and mudstone.

15.3 Normal faults exposed in roadcuts. Most lake deposits dip at low angles to the south, but some dip 40 degrees to the north and have been rotated by normal faults.

15.8 Exit 236, Table Mesa Road. Take exit and cross over the Interstate to the east. Follow gravel road into the southern part of the New River Mountains. Driving through Miocene lake bed deposits and terrace gravels.

16.7. Y in road. Stay to left. Right fork goes to Tee Ranch and is a private road. Just ahead is a fence and gate. Please be sure that the gate is shut after the last car goes through.

17.4 Outcrops are foliated, sericitized, and mineralized metarhyolite tuff that is equivalent to 1.7 Ga undeformed rhyolite and ash-flow tuff in central New River Mountains (Maynard, 1986; Anderson, 1989).

17.5. Cross New River. Drive through foliated metarhyolite for next 0.7 miles.

18.3 Large quarry on right in hematitic wacke and siltstone (fig. 3). Park in and around the quarry.

STOP 6. Southern New River Mountains. Stop here will review stratigraphy of the New River Mountains and discuss the extent and regional importance - or lack thereof - of the Moore Gulch shear zone. Undeformed and deformed equivalents of the rhyolite and ash flow tuff of the central New River Mountains will be visited, as will the older metasedimentary and metavolcanic strata to the east of the shear zone.

Figure 3 (below and two following pages). Geologic map of the New River Mountains area. Data from DeWitt (1987, unpub. mapping, 1990), Anderson (1989), Jerome (1956), Maynard (1986), Jagiello (1987), and Reynold (unpub. mapping, 1990).

EXPLANATION

Qu	Quaternary units, undivided
QTu	Quaternary and Tertiary units, undivided
Tvs	Tertiary volcanic and sedimentary rocks
YXg	Granite of Magazine Gulch
Xsv	Metasedimentary and metavolcanic rocks
Xps	Phyllite and slate
Xrhy	Rhyolite, metarhyolite, and ash-flow tuff
Xg	Granite to granodiorite
Xbl	Quartz Diorite of Bland
Xs	Pelitic metasedimentary rocks
Xgb	Gabbro
Xch	Metachert and iron-formation
Xgw	Metagraywacke and meta-andesite
Xvs	Metavolcanic and metasedimentary rocks
Xr	Metarhyolite
Xd	Metadacite and meta-andesite
Xb	Metabasalt and meta-andesite

Contact

Fault

Route of field trip

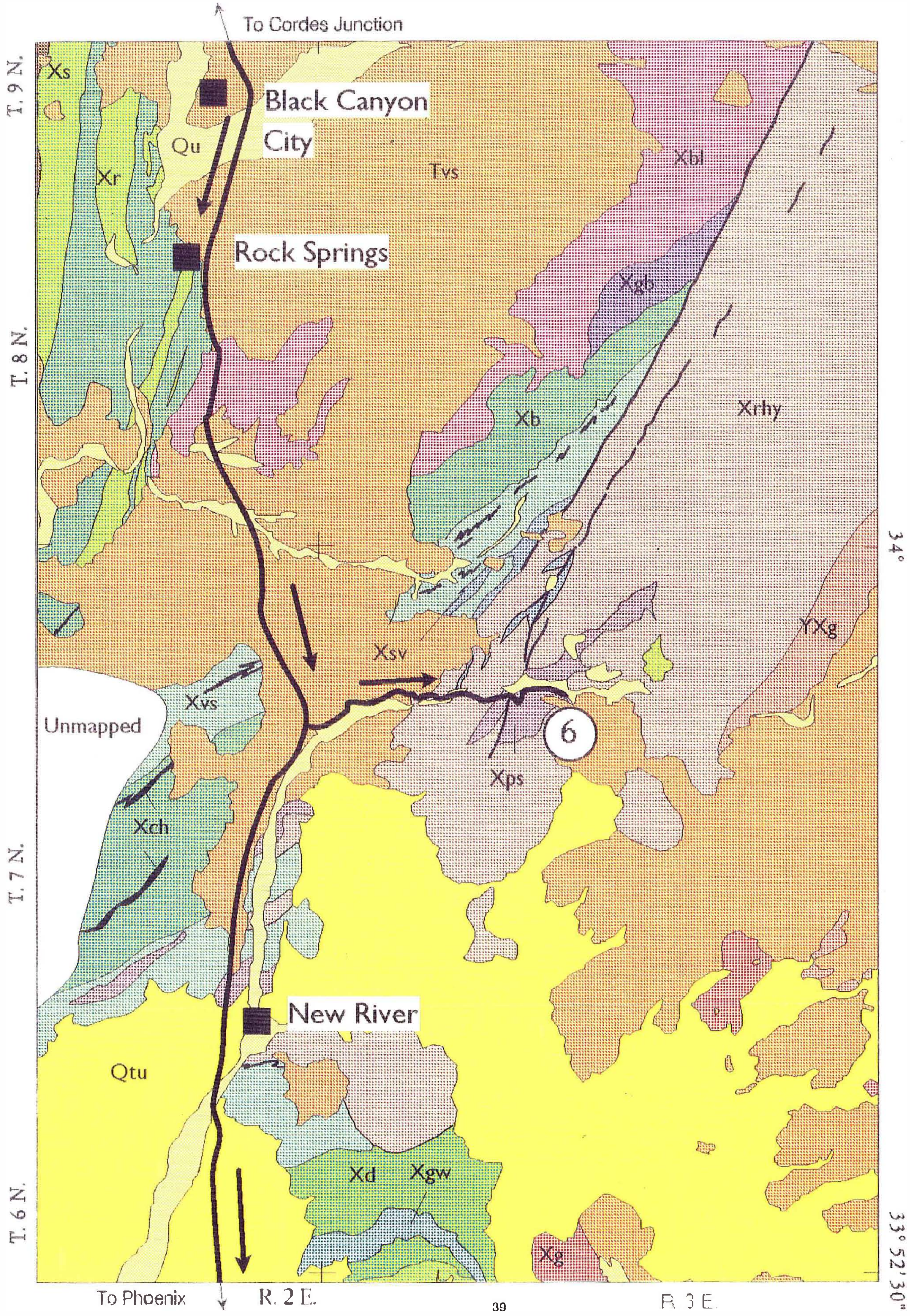
6 Stop number

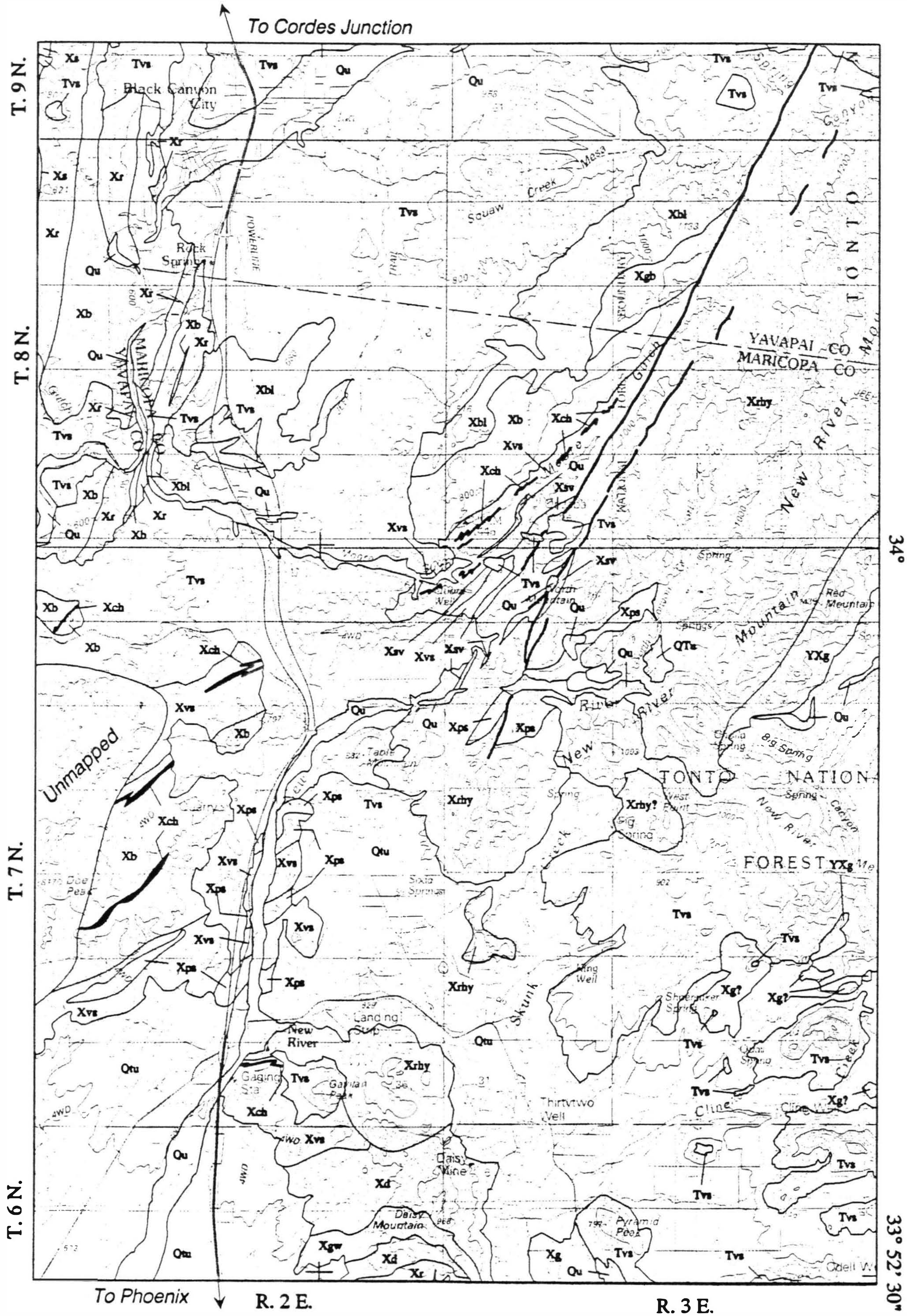
0 1 2 3 mi

0 1 2 3 km

Scale: 1:100,000

Base from U.S. Geological Survey Bradshaw Mountains, 1981, and Phoenix North, 1988


To Cordes Junction
Black Canyon City
Rock Springs
New River
Unmapped
Xs
Qu
Xr
Tvs
Xbl
Xgb
Xb
Xrhy
Xsv
Xvs
Xch
YXg
Xps
6
Qtu
Xd
Xgw
Xg
T. 9 N.
T. 8 N.
T. 7 N.
T. 6 N.
34°
33° 52' 30"
To Phoenix
R. 2 E.
R. 3 E.


To Cordes Junction
T. 9 N.
T. 8 N.
T. 7 N.
T. 6 N.
34°
33° 52' 30"
To Phoenix
R. 2 E.
R. 3 E.
Black Canyon City
Rock Springs
Squaw Creek Mesa
YAVAPAI CO
MARICOPA CO
MARICOPA CO
YAVAPAI CO
New River Mesa
Unmapped
New River
Table Mesa
Sixto Springs
Landing Strip
Gaging Sta
Gavilan Peak
Thirtytwo Well
Daisy Mine
Daisy Mountain
Pyramid Peak
Doe Peak
Skunk
Red Mountain
New River Mountain
Big Spring
TONTO NATIONAL FOREST
Cline
Xs
Tvs
Qu
Xr
Xb
Xbl
Xgb
Xch
Xvs
Xsv
Xps
Xrhy
Xrhy?
QTs
YXg
Qtu
Xg?
Xd
Xgw
Xg

At the end of this stop, the field trip is over. Return via the dirt road to the Table Mesa Exit on I-17. The road log continues south to New River.

Road Log from Table Mesa Exit on I-17 to New River: 4.3 miles

Cumulative
Mileage

0.0 Table Mesa Exit on I-17. Cross over I-17 and take southbound ramp toward Phoenix.

0.6 Roadcut in river gravel deposits. To the right, about 4 miles west, is Wild Burro Mesa, capped by middle Tertiary basalt and cut, to the south, by northwest-trending normal faults.

1.6 Outcrops on the right are Tertiary rhyolite tuff. Deep roadcut ahead is in felsic tuff and rhyolite cut by normal faults that dip to the north. Roadcut contains at least two normal faults that dip to the north at about 45 degrees.

2.2 Conical butte at 10:00 is Gavilan Peak, elev. 2,980 ft, which is a dacite dome (Jagiello, 1987), about 26 Ma (fig. 3)

2.3 Roadcuts in Early Proterozoic metarhyolite tuff that may be equivalent to rhyolite and ash flow tuff of the central New River Mountains (Anderson, 1989). Metarhyolite is overlain by Tertiary to Quaternary river gravels. Metarhyolite tuff is very sericitic and iron-stained. New River Mesa visible slightly behind and to the left at 8:00. The mesa is capped by 14 Ma basalt, but lower flows that are interbedded with lacustrine units and tuffaceous beds are as old as 22 Ma (Gomez, 1979).

3.0 Outcrops to the left beneath the veneer of river gravel are of sericitized metarhyolite and metamorphosed volcaniclastic rocks.

3.3 Outcrops and flat area to the right of the highway are composed of gray and purple slate and iron-stained sericitic metarhyolite tuff similar to that in the southern New River Mountains visited at stop 6. The gray and purple slate is very distinctive of 1.72-1.70-Ga metavolcanic rocks in the Cave Creek area north of Phoenix (Anderson, 1987; 1989) and the Slate Creek Divide area in the Mazatzal Mountains (Ludwig, 1973). Roadcuts are in gray slate that is interbedded with fine-grained metatuff and volcaniclastic metasedimentary rocks.

4.3 Exit 232 to the village of New River. On the left is Gavilan Peak. All the low country to the left is underlain by Early Proterozoic tuffaceous metavolcanic rocks. End of road log.

NOTES

Excerpts from "Geology of the Golden Belt Mine area, Black Canyon metallic mineral district, Arizona," by D. E. Wahl, Jr., and P. F. O'Hara.

Geology of the Golden Belt Mine Area, Black Canyon Metallic Mineral District, Arizona

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ABSTRACT

The Golden Belt mine and adjacent Golden Turkey mine lie at the northern limits of known mineralization associated with low-angle vein systems of the Black Canyon metallic mineral district. Both mines are developed on an east-northeast-trending vein system which dips approximately 15 to 22 degrees to the south-southeast. Black Canyon metallic mineral district veins typically are narrow, banded, brecciated, low-angle, quartz-rich systems which contain galena, chalcopyrite, pyrite and sphalarite as principal sulfide minerals. The less than 1-foot to 4-foot-thick veins cross cut foliated Early Proterozoic metamorphosed volcanic, volcaniclastic and sedimentary rocks. Wallrock alteration locally intensifies with depth, and includes argillization, iron staining, and minor development of quartz stockworks veining. Underground sampling and analysis of production records indicate that Golden Belt and Golden Turkey mines ore average grade was approximately 0.12 oz/ton gold and 3.00 oz/ton silver. Approximately 250,000 tons were mined from the interconnected Golden Belt and Golden Turkey mines. Much of this ore was mined from very shallow underground workings.

Two distinct types of mill tailings were also investigated

at the Golden Belt mine. The most extensive tailings pile contains approximately 45,000 tons of material believed to have been mined from the Golden Belt mine. A second, distinctly different tailings accumulation contains approximately 15,000 tons of material which is rumored to have originated at the Gladiator mine north of Crown King. Although both tailings piles are gold anomalous, they currently appear to be subeconomic due to difficulties in further recovery of metals from the piles.

INTRODUCTION

Wilson and others (1967) report that ore was located at the Golden Belt mine in 1873, and a 50 tpd mill was active in the early 1930's. Major reported developments in the Golden Belt mine include an 800 feet incline shaft and hundreds of feet of stopes and drifts (Wilson, et al., 1967). Underground workings of the Golden Belt mine connect with stopes and drifts of the Golden Turkey mine to the south. Recorded production for the two inter-connecting mines is approximately 129,500 lbs. of copper, 791,000 oz. of silver, 28,900 oz. of gold and 3,347,000 lbs. of lead from 243,300 tons of ore (Az. Geol. Survey, unpub. data 1990, calculated by Ed DeWitt). Much less ore was also produced from the Silver Cord and Gold Crown mines near the south end of the Black Canyon metallic mineral district.

Historic mining efforts at the Golden Belt and Golden Turkey mines were concentrated on a sulfide-bearing quartz vein system with an aggregate quartz vein thickness of less than 1 foot to local maxima of approximately 4 feet. Sheared, argillized, iron-

Excerpts from "Geology of the Golden Belt Mine area, Black Canyon metallic mineral district, Arizona," by D. E. Wahl, Jr., and P. F. O'Hara.

SURFACE INVESTIGATIONS

Minimal surface studies conducted on the 4 lode claims of the Golden Belt property indicate that narrow, low-angle, south-southeast-dipping quartz veins containing precious metals exist at several locations (Wahl, 1989). The best of 10 surface samples indicate that a 2-foot-thick, low-angle, quartz-iron oxide vein locally contains 0.342 oz/ton gold and 4.81 oz/ton silver. Surface vein development and alteration of felsic to intermediate schistose metavolcanic wallrocks are not as intense as that observed in Golden Belt stopes. Subvertical quartz segregations that parallel regional foliation are not mineralized.

UNDERGROUND EVALUATION

Underground workings of the Golden Belt mine were examined to determine the feasibility of a small open pit between the Golden Belt decline portal and Turkey Creek. The mineralized fracture-vein system exposed in Golden Belt workings lies at shallow depth and dips subparallel with the land surface toward Turkey Creek. Thus, the potentially mineralized fracture-vein system could be excavated with a relatively low stripping ratio.

Twenty-four samples were collected from Golden Belt underground workings to test the gold and silver grade of quartz veins and sheared, altered schist adjacent to the veins. Seven samples, averaged for their sample length, of select quartz-sulfide veins indicate 0.465 oz/ton gold and 3.11 oz/ton silver.

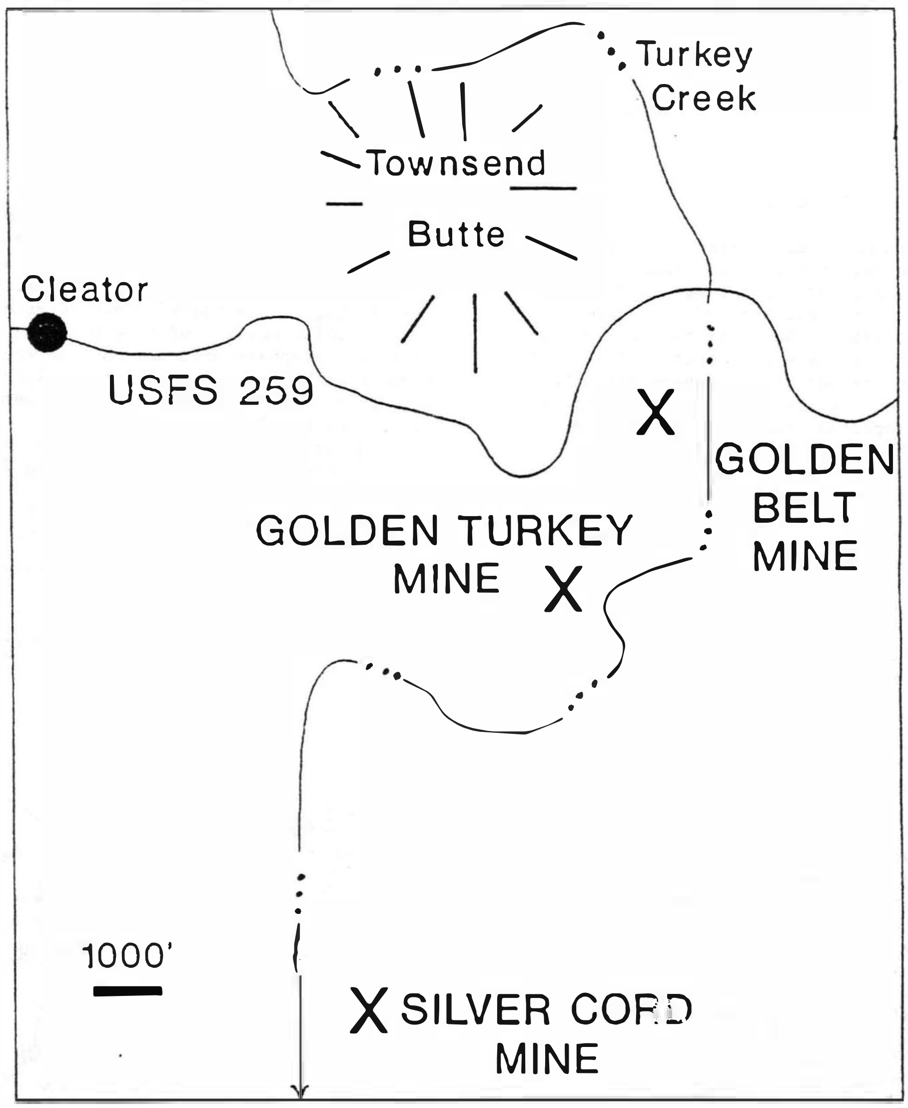
Vein thicknesses for those samples range from 0.5 to 4 feet. The highest grade assay (0.868 oz/ton gold and 10.31 oz/ton silver) came from a 3.5-foot-thick vein preserved in a small pillar within the main Golden Belt stope area. Not all Golden Belt workings could be reached due to caving and flooding.

Seventeen samples tested sheared, altered schist adjacent to the quartz-sulfide veins over widths of 2 to 6 feet. Averaged assay grade is 0.055 oz/ton gold and 0.36 oz/ton silver. Best values in the schist appear related to areas of highest iron staining and development of hairline quartz-lined fractures.

Averaged values for all Golden Belt underground samples is 0.120 oz/ton gold and 0.80 oz/ton silver. Averaged production ore grade of the Golden Belt and Golden Turkey mines is 0.12 oz/ton gold and 3.25 oz/ton silver. Samples collected by Wahl (1989) were all taken above water level. Flooded portions of the mine apparently are more silver rich, perhaps as a result of secondary enrichment at and below the water table. Material of approximately 0.12 oz/ton gold and >1.00 oz/ton silver appears to have been contained within a fairly continuous tabular slab 6 to 8 feet thick prior to undergound mining operations. Such a thickness of ore may well be economic under low stripping-ratio, open-pit mining conditions. Unfortunately, the Golden Belt vein and mineralized country rock have mostly been mined out. Old stope maps underestimate the extensive stopes within workings of the Golden Belt mine.

Excerpts from "Geology of the Golden Belt Mine area, Black Canyon metallic mineral district, Arizona," by D. E. Wahl, Jr., and P. F. O'Hara.

Figure 2. Location map of principal mines of Black Canyon metallic mineral district.



Excerpts from "Tectonic and magmatic contrasts across a two-province Proterozoic boundary in central Arizona," by C. M. Conway, K. E. Karlstrom, L. T. Silver, and C. T. Wrucke. *Reprinted with permission from Davis, G.H., and VandenDolder, E.M., eds., Geologic diversity of Arizona and its margins; excursions to choice areas: Arizona Bureau of Geology and Mineral Technology Special Paper 5, p. 158, 159, 160, 169, and 170*

Tectonic and Magmatic Contrasts Across a Two-Province Proterozoic Boundary in Central Arizona

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INTRODUCTION

One of the first major discoveries of the infant discipline of zircon geochronology was that the Early Proterozoic of Arizona comprised two age provinces with a boundary in the central part of the state (Silver, 1965, 1967, 1969). Rocks in the central to northwestern part of the state are about 1.70 to 1.78 Ga, whereas those in the central to southeastern part of the state are about 1.61 to 1.71 Ga. Since these results were first reported, the exact position and nature of the two-province boundary have been the subject of much debate and still elude geologists. It has become obvious that several iterations of field and geochronologic studies, each giving direction and raising questions for the next, are required for a understanding of the boundary and the Early Proterozoic history of Arizona in any detail. Because the two-province boundary in Arizona may extend northeastward into the mid-continent and perhaps farther and because the Transition Zone in Arizona offers superb outcrops across this boundary, Arizona may hold answers to questions regarding the Early Proterozoic crustal growth of the southern part of the North American craton. One of the major goals of this field trip is to examine the nature of the proposed boundary through stops and discussions of rocks in both provinces.

The controversy surrounding the nature of the boundary and the two provinces extends to the authors of this field guide. We cannot find agreement on definitions. It appears that the concept of a two-province boundary, at least on a local scale, is in question. Recently, the boundary has been viewed not as a simple line (e.g. a suture or shear zone), but as an area distributed over a distance of about 150 km NW-SE in the transition zone (Conway and Karlstrom, 1986; Karlstrom and Conway, 1986). In other words, the northern part of the boundary zone contains scattered examples of southern province rocks and the southern part of the boundary zone contains scattered areas of older rocks of the northern province.

Aside from isotopic age, two sets of criteria may be used to assign rocks to one province or the other -- broad lithologic characterization and deformational style. A fairly good correspondence exists between lithology and geochronology: "northern" province rocks are fundamentally submarine volcanic and volcaniclastic rocks and penecontemporaneous batholiths, most likely of oceanic or continental-margin arc derivation, and "southern" province rocks are fundamentally continental to possibly passive continental margin rocks, including rhyolite caldera suites and mature sandstones. The correspondence is not so good between structure and lithology, nor between structure and geochronology. "Northern" province rocks commonly have a ductile fabric and show evidence in several places of polyphase deformation, whereas "southern" province rocks generally are brittlely deformed in one stage at high crustal levels. These generalizations, however, do not hold up everywhere.

The Early Proterozoic terrane contains a number of major north- and northeast-trending faults or shear zones, along which the movement directions are not yet fully deciphered; minimum displacements in some cases are on the order of tens of kilometers. The signif-

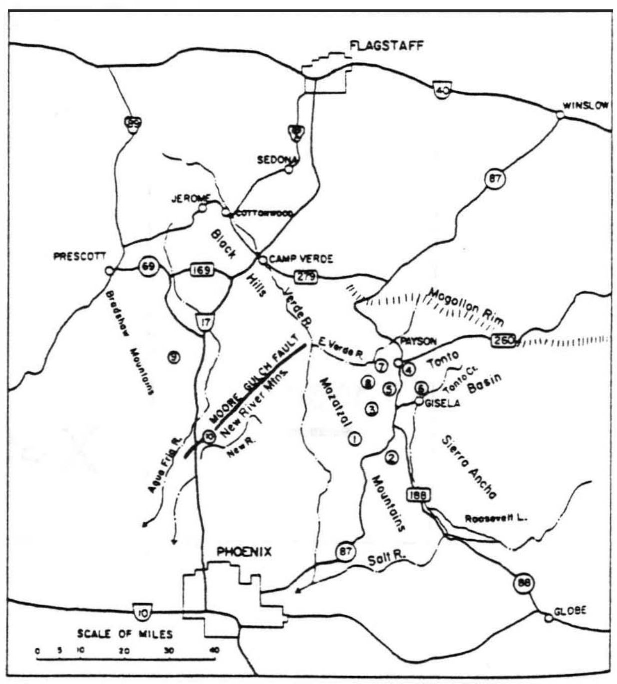

Figure 1. Index and highway map of region of field trip. Sites to be visited (1-10) are circled numbers.

Excerpts from "Tectonic and magmatic contrasts across a two-province Proterozoic boundary in central Arizona," by C. M. Conway, K. E. Karlstrom, L. T. Silver, and C. T. Wrucke. *Reprinted with permission from Davis, G.H., and VandenDolder, E.M., eds., Geologic diversity of Arizona and its margins; excursions to choice areas: Arizona Bureau of Geology and Mineral Technology Special Paper 5, p. 158, 159, 160, 169, and 170*

crustal origin and tectonic evolution. Other authors (Silver, Conway) hold a view that the "southern" province rocks are basically a coherent continental suite that has for its substrate cratonized "northern" province rocks, and that the faults separate blocks of similar crustal history. It may be that the ultimate resolution of the problems lies in middle ground.

This paper concentrates on the Early Proterozoic of central Arizona. We realize that accumulating data to the northwest and southeast add complexities to our interpretations, but they are beyond the scope of this discussion. We agree that one boundary in central Arizona is important yet not fully understood -- the Moore Gulch fault. In any further discussion of a boundary, unless specifically stated otherwise, we are referring only to the Moore Gulch fault.

TIMETABLE AND SITE DESCRIPTIONS

The route of the field trip and locations of sites to be visited are shown in Figure 1. Sites are also shown in other figures. In reading the site descriptions, one should refer to Figures 2 and 3 and subsequent text for geologic context of the units discussed.

TIME	SITE DESCRIPTIONS AND OBJECTIVES
Friday, Oct. 23, 1987	
7:00 a.m.	Leave Phoenix.
9:00 - Site 1 Mount Peeley	Superb exposures of rhyolite ash-flow tuff of the Red Rock Group lie on the southeast face of Mount Peeley. At this site, hike several hundred meters up the slope through one or more probable cooling units. Rhyolite in this exposure is typical of ash flows that are abundant in the upper part of the ca. 1700 Ma Tonto Basin Supergroup.
11:30 - Site 2 Slate Creek (lunch) (optional geologic stop)	Examine lithic sandstone and shale of the Alder Group and highly deformed rocks of the Slate Creek shear zone.
1:00 - Site 3 Barnhardt Canyon	Mazatzal Group stratigraphy and deformational style. Descend through the Mazatzal Group section - Mazatzal Peak Quartzite, Maverick Shale, and Deadman Quartzite - towards the core of an anticline. The Maverick contains abundant mesoscopic evidence for northwest-verging thrusts and folds.
5:00 - Site 4 Round Valley (optional stop)	Examine layered gabbro in the Gibson Creek batholith. Several square kilometers in this locality are underlain by two-pyroxene gabbro with cumulate texture and compositional layering. A gradation southeastward appears to exist from this orthopyroxene-rich gabbro into hornblende-rich gabbro and then into diorite.
6:30	Dinner at Payson.
7:30	Slides, maps, discussion - Swiss Village Lodge, Payson.
9:00 - Site 6 Gisela (lunch)	A number of geologic units are found in a small area at Gisela: diorite of the Gibson Creek batholith, pendants within the diorite, Payson Granite, Green Valley Hills Granophyre, rhyolite of the Red Rock Group, and a hybridized mafite porphyry. The mafite porphyry intrudes rhyolite of the Red Rock Group and is intruded by the Payson Granite. These are key relations that led to the hypothesis that a number of felsic volcanic and hypabyssal units in the region are cogenetic parts of caldera complexes. Pendants of stratified rock are the oldest known rocks in the Tonto Basin-Mazatzal Mountains region. The Agate Mountain thrust fault, probably of the same generation as the thrust faults in the Mazatzal Mountains, is also exposed at Gisela.
12:15 - Site 7 Snowstorm Mtn. (optional stop)	Layering (igneous lamination) in gabbro-diorite of the Gibson Creek batholith. Characterized by plagioclase- and amphibole-rich layers, these layered rocks contrast with the layered gabbro of Round Valley in having randomly oriented, highly acicular amphibole.
1:00 - Site 8 North Peak	Graywacke of the East Verde River Formation and a plug of granophyre are overlain in this area by the Deadman Quartzite of the Mazatzal Group. Recent mapping suggests that a fold in the graywacke and several units in the East Verde River Formation are overlain in angular unconformity by the Deadman Quartzite. The granophyre that intrudes the graywacke bears both granophyric and spherulitic textures and is thus similar to a sill of the Green Valley Hills Granophyre at King Ridge in Tonto Basin. This area is important and controversial. One question is whether the graywacke and granophyre are perhaps similar in age and were deformed together prior to erosion and deposition of the Deadman Quartzite, or whether the graywacke, if it is older than the Gibson Creek batholith, was folded and then intruded by high-level granophyre that is essentially the same age as the Deadman Quartzite.
4:30	Drive to Cottonwood.
6:00	Dinner, Camp Verde or Cottonwood.
7:30	Slides, maps, discussion - Best Western Cottonwood Inn, Cottonwood.
Sunday, Oct. 25	
8:00	Leave Cottonwood.
9:00 - Site 9 Crazy Basin	Northern terminus of the Crazy Basin Quartz Monzonite. Examine stratified rocks of the Yavapai Series and intrusive rocks of the Crazy Basin Quartz Monzonite, and consider the timing of various phases of deformation relative to metamorphism and plutonism. A new U-Pb zircon age of 1699 ± 5 Ma for the Crazy Basin

Excerpts from "Tectonic and magmatic contrasts across a two-province Proterozoic boundary in central Arizona," by C. M. Conway, K. E. Karlstrom, L. T. Silver, and C. T. Wrucke. *Reprinted with permission from Davis, G.H., and VandenDolder, E.M., eds., Geologic diversity of Arizona and its margins; excursions to choice areas: Arizona Bureau of Geology and Mineral Technology Special Paper 5, p. 158, 159, 160, 169, and 170*

Quartz Monzonite indicates that this batholith was crystallizing at about the same time that rhyolites and quartz arenites were being deposited in the terrane south of the Moore Gulch fault.

Site 9A — Margin of the Crazy Basin Quartz Monzonite. Examine cross-cutting relationships of numerous dikes of granite, aplite, pegmatite, and tourmaline-bearing quartz veins in pelitic rocks of the Yavapai Series. The variation in relative age and degree of deformation suggests that these various materials were injected during deformation.

Site 9B — Middleton Creek. Examine metamorphic rocks at the margin of the batholith. Staurolite-andalusite-garnet-biotite assemblages in pelitic rocks record P/T conditions of 3.7 kb and 500° C.

Site 9C — Aplite dike north of the Crazy Basin contact. An aplite dike (1700 Ma) intrudes Yavapai Series rocks just north of the Crazy Basin contact along the Desoto Road. This dike crosscuts an isoclinal fold in the Yavapai Series and is itself boudinaged and foliated, further evidence for syntectonic (specifically syn-F_2) intrusion of the batholith.

Site 9D — Cleator shear zone. The east side of the Crazy Basin Quartz Monzonite is bordered by the Shylock fault zone, a zone 1 to 3 km wide of vertical foliation and vertical stretching lineation. The vertical foliation and folds in the Shylock are overprinted in a wide zone by the Cleator shear zone and related asymmetrical folds, which exhibit evidence for sinistral strike-slip displacement.

12:00 - Site 10 Moore Gulch — Moore Gulch fault. Ductilely deformed rocks of the Yavapai Series crop out northwest of the fault, whereas rocks to the southeast include brittlely deformed equivalents of the Tonto Basin Supergroup. The fault in this locality has Tertiary movement, but the juxtaposition of diverse rock packages across the fault suggests major Precambrian movement.

OVERVIEW OF EARLY PROTEROZOIC GEOLOGY AND GEOCHRONOLOGY OF ARIZONA

The major stratigraphic and plutonic groups and structural features of the Early Proterozoic of central Arizona are shown in Figure 2. From the Moore Gulch fault to northwestern Arizona, U-Pb zircon ages range from about 1700 to 1775 Ma. The Yavapai Series of Anderson and others (1971) and most plutonic rocks in the Bradshaw Mountains and Black Hills are about 1720 to 1775 Ma (Anderson and others, 1971; L. T. Silver, unpublished data; S. A. Bowring, 1987, oral comm.).[1] Volumetrically less significant plutonic masses are about 1700 Ma, and a belt of volcanic rocks in the Bagdad area has volcanic rocks as young as 1709 Ma (Bryant and Wooden, 1986).

or continental-margin calc-alkaline arc affinity (Anderson, 1978, 1986; Condie, 1986; Vance, 1986). These volcanic rocks and associated penecontemporaneous batholiths are broadly similar to those of late Phanerozoic circum-Pacific magmatic arcs.

Quartzite in northern Chino Valley (Wilson, 1939; Krieger, 1965; Trevena, 1979) is an anomalous lithology in the terrane northwest of the Moore Gulch fault and probably belongs to the Mazatzal Group, a major unit in the generally 1700 Ma terrane southeast of the Moore Gulch fault. The Texas Gulch Formation, which rests unconformably on strata of the Yavapai Series and on the Brady Butte Granodiorite, has lithologic similarity to the Alder Group of the southeastern terrane, but may be older.

Plutons northwest of the Moore Gulch fault that are 1700 Ma are of special interest because they were apparently emplaced at the same time that rhyolite volcanism and quartz-arenite sedimentation were occurring south of the Moore Gulch fault. These are the Crazy Basin Quartz Monzonite (Site 9) in the southern Bradshaw Mountains (about 1680 Ma, Blacet and others, 1971; 1699 ± 5 Ma, Karlstrom and others, 1987), and a granite mass in the Arrastra Mountains southwest of Bagdad, previously included in the Signal Granite (Lucchitta and Suneson, 1982; Bryant and Wooden, 1986). This class of granites is distinct from the older calcic to calc-alkaline batholiths that are probably genetically related to volcanic belts of similar or slightly older age.

Southeast of the Moore Gulch fault in Arizona, most U-Pb zircon ages range from 1610 to 1710 Ma (Conway and Silver, 1987). In the Tonto Basin-Mazatzal Mountains region, numerous ages on rhyolite to rhyodacite flows in the Tonto Basin Supergroup are 1700 to 1710 Ma (Silver, 1967; Silver and others, 1986). Flows of this age are also found in the Redmond Formation of the Hess Canyon Group along the Salt River (Livingston, 1969a, 1969b; L. T. Silver, unpublished data) and in the Pinal Schist in southeastern Arizona (Silver, 1978). Widespread felsic hypabyssal units of the Diamond Rim Intrusive Suite in the Tonto Basin are 1692 to 1703 Ma (Silver and others, 1986), and felsic intrusive bodies in the southeastern part of the state are of similar age (Silver, 1978). There is an apparent gap between about 1692 and 1640 Ma. Granitic bodies ranging in age from 1610 to 1640 Ma occur at the town of Young in the northern Sierra Anchas (Conway, 1976), at Sunflower in the central Mazatzal Mountains (Silver, 1965), and at scattered localities in southeastern Arizona (Silver, 1978, unpublished data).

The Gibson Creek batholith and pendants of stratified rocks at Gisela appear to be lithologically anomalous geologic units in the southeastern terrane and are some 40 million years older than most other dated rocks southeast of the Moore Gulch fault. This batholith contrasts petrologically with the spatially associated 1700 Ma rocks and is similar to the batholiths of the northeastern terrane. The dominant subaqueous mafic volcanic rocks and turbidite graywacke of the East Verde River Formation are lithologically more like the strata of the Yavapai Series than the Tonto Basin Supergroup, and these units may also predate the Gibson Creek batholith.

The large felsic complexes of the Tonto Basin-Mazatzal Mountains-New River Mountains region, in-

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affected all of the Tonto Basin-Mazatzal Mountains area (Conway, 1976), but it is still unclear whether it may have also undergone earlier (pre-Tonto Basin Supergroup) penetrative deformation, as did the Yavapai Series and associated batholiths to the northwest. Similar questions regarding deformational and metamorphic history apply to the East Verde River Formation. The relationships at the northern end of the Mazatzal Mountains (Site 8) are thus of key importance because in this area folded graywackes of the East Verde River Formation are unconformably overlain by flat-lying Mazatzal Group rocks (Wrucke and Conway, in prep.)

YAVAPAI SERIES AND ASSOCIATED BATHOLITHS

Rocks northwest of the Moore Gulch fault include the Yavapai Series of Anderson and others (1971) and voluminous batholithic rocks. Strata of the Yavapai Series are crosscut by batholiths that are predominantly granodioritic and are probably temporally and genetically related to the volcanic rocks.

Figures 10 and 11 show lithologic subdivisions rather than the stratigraphic subdivisions of Anderson and others (1971) because structural complexity makes stratigraphic subdivisions highly controversial. Rocks in this region are geographically divided into three major areas by fault zones, the north-trending Shylock fault and the northeast-trending Chaparral fault. Anderson and coworkers proposed a statigraphy that roughly corresponded to this geographic subdivision. Their Ash Creek Group (oldest) is restricted to the area east of the Shylock fault, the Big Bug Group lies mainly between the Shylock and Chaparral faults, and the Green Gulch Volcanics of the Big Bug Group lies northwest of the Chaparral fault. The Texas Gulch Formation in the central block rests with unconformity on the 1750 Ma Brady Butte Granodiorite and on Big Bug Group volcanic rocks. This unit was considered by Anderson and others to be younger and not part of the Yavapai Series, although new structural interpretations suggest these slates and graywackes may correlate with graywackes and pelitic schists in the Big Bug Group around the Crazy Basin Quartz Monzonite. If so, the unconformity at the base of the Texas Gulch Formation [and possibly at the base of pelitic rocks in the Crazy Basin area (Site 9)] may represent a regional change from volcanism and plutonism in the arc to establishment of forearc or backarc sedimentary basins in the Yavapai Series.

Early deformation apparently predated 1740 Ma in the Ash Creek Group, and perhaps the in Big Bug Group. It was this deformation that may have been contemporaneous with collision of island-arc terranes and incipient development of continental crust. This early deformation, however, was followed by later deformation in the Big Bug Group, and it is this later deformation that is most pertinent to the discussion of the significance of the Moore Gulch fault as a tectonic boundary between diverse provinces.

The earliest deformation in the Big Bug Group is seen in the Brady Butte area. F_1 recumbent isoclinal folds in this area fold the pretectonic Brady Butte Granodiorite (1750 Ma) and the unconformably overlying Texas Gulch Formation. The unconformity between these two units is marked by boulders of granodiorite in basal conglomerate and is a mappable form surface that defines the recumbent folds (Karlstrom and Conway, area but become tighter to the southeast, where F_2 folds are highly attenuated and exhibit curved hinge lines believed to be related to hinge line rotation during progressive shortening. The northeast-trending vertical foliation that has an axial-plane orientation to the tight folds forms the dominant fabric of the Yavapai Series; it is interpreted to be a composite fabric consisting of transposed bedding, S_1 compositional layering, and S_2 cleavage. It can be traced eastward to the area of the Crazy Basin Quartz Monzonite (1699 Ma) and to the Shylock fault zone.

EMPLACEMENT AND DEFORMATION OF THE CRAZY BASIN QUARTZ MONZONITE

In the Crazy Basin area (Figure 11), the S_1/S_2 foliation is bent around the north terminus of the Crazy Basin Quartz Monzonite. This warping of foliation was interpreted by DeWitt (1979), O'Hara (1980), and Blacet (1985) to be related to post-tectonic intrusion of the batholith, but recent work by Argenbright and Karlstrom (1986) suggests that the pluton was syntectonic, in agreement with the early interpretations of Jagger and Palache (1905). A macroscopic anticline cored by volcanic rocks just north of the Crazy Basin Quartz Monzonite (Figure 11), believed to be an F_2 fold because of overprinting of earlier generation folds on its limbs, is crosscut by a dike of aplite that is the same age (1700 Ma) and of similar lithology (muscovite-bearing) as the batholith. By this evidence, folding (F_1 and F_2) was in part pre-1700 Ma. The aplite, however, is folded and contains a cleavage that has an axial-plane orientation to the large fold (Site 9C), indicating that the fold was tightened after injection of the aplite at 1700 Ma. Independent evidence that the Crazy Basin Quartz Monzonite crystallized during F_2 shortening comes from the eastern margin of the batholith. Here, stretching lineations in highly evolved phases of the granite are defined by aligned and boudinaged tourmaline needles. These lineations are steeply plunging, subparallel to the vertical L_2 stretching lineation in the Shylock fault zone.

F_2 folds and S_2 layering are refolded by F_3 folds in a wide zone close to the Shylock fault zone. F_3 folds have a consistent (sinistral) asymmetry. These folds and their northeast-trending axial-plane cleavage are believed to be the product of sinistral strike-slip displacement over a wide zone, but concentrated near the Cleator shear zone. The Cleator shear zone (Figure 12; Darrach and others, 1986) is a several-hundred-meter-wide mylonite zone with subhorizontal stretching lineation and abundant sinistral kinematic indicators. It overprints F_2 folds (Figure 12) but apparently moved while the Crazy Basin Quartz Monzonite was still partially liquid, as shown by sinistral vein arrays filled with granite in the east margin of the batholith. Sinistral kinematic indicators are also present in the west and north margins of the batholith, indicating that the entire batholith was involved in a wide zone of distributed sinistral shear. Shallowly plunging stretching lineations defined by tourmaline on the north and west of the batholith apparently reflect the strike-slip movement, just as similar lineations on the east margin reflect the dominance of vertical stretching during shortening.

The data suggest that F_2 shortening and F_3 sinistral strike slip were both contemporaneous with crystallization of the batholith at about 1700 Ma. These data are compatible with an overall trans-

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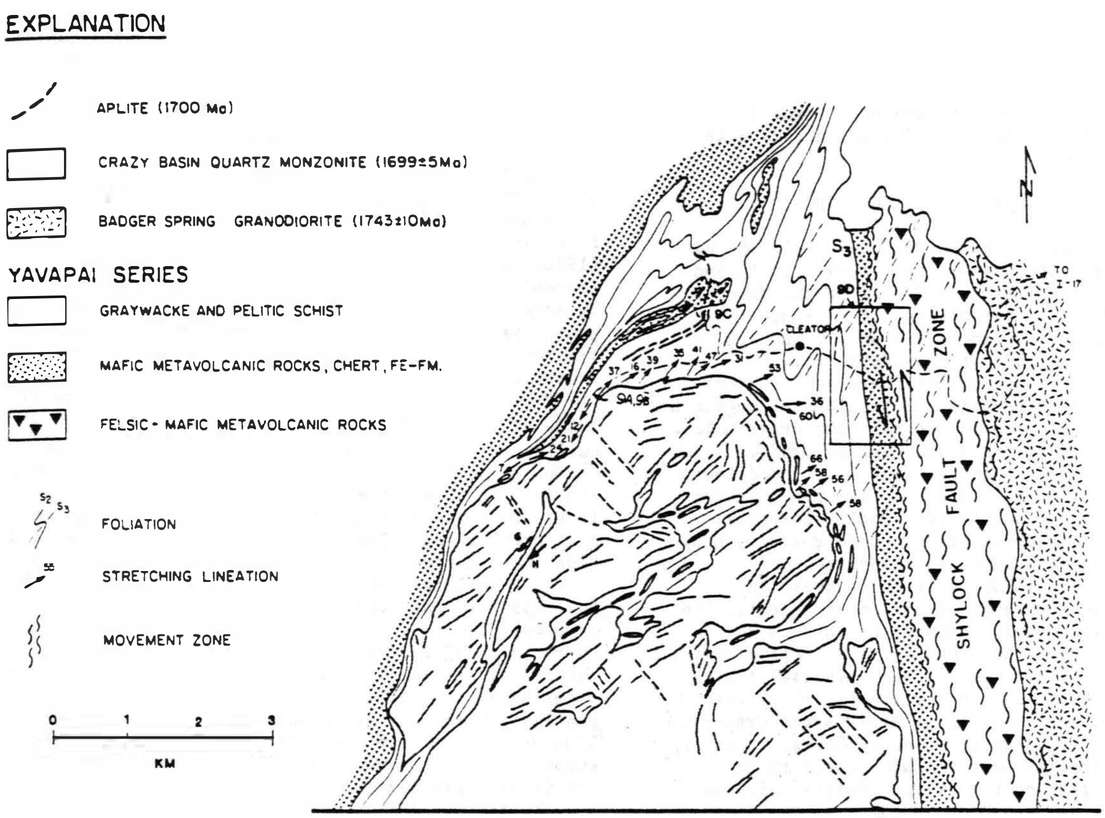

Figure 11. Generalized geologic map of the Crazy Basin Quartz Monzonite, showing locations of stops in Site 9 and area of detailed map of Cleator shear zone (Figure 12).

pressional shortening across the Shylock fault zone, with shortening and strike slip being partitioned into separate components, as is common during transpression (Sanderson and Marchini, 1984).

Well-developed foliation in the Crazy Basin Quartz Monzonite (Figure 11) also rules out the interpretation that the batholith is posttectonic, especially because the internal foliation crosscuts the margins of the granite and can be shown to be continuous with the regional foliation. Foliation in the granite is domainally developed, as in many deformed granites (Page and Bell, 1986) and is defined by shape-preferred orientation of feldspar, quartz, and phyllosilicate grains. The foliation is northeast trending and is closer in orientation to S_3 than S_2 (Figure 11).

the margin was at about 500°C and 3.7 kb, as shown by garnet-biotite geothermometry and garnet zoning profile (M. Williams, 1987, oral comm.). Porphyroblasts overgrow S_1/S_2 foliation and are themselves folded, boudinaged, and rotated, indicating syntectonic growth during S_2/S_3. Thus, plutonism, deformation, and metamorphism are all believed to have been broadly synchronous (1699 Ma) and to have taken place at depths of 12 to 15 km. This is compatible with the strongly peraluminous chemistry of the Crazy Basin Quartz Monzonite, which suggests crystallization depths of greater than 2.5 kb (Miller, 1985).

Excerpts from "Geology and structural relations in the southern New River Mountains and the significance of the Moore Gulch shear zone," by Ed DeWitt

Geology and structural relations in the southern New River Mountains and the significance of the Moore Gulch shear zone

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OBSERVATIONS

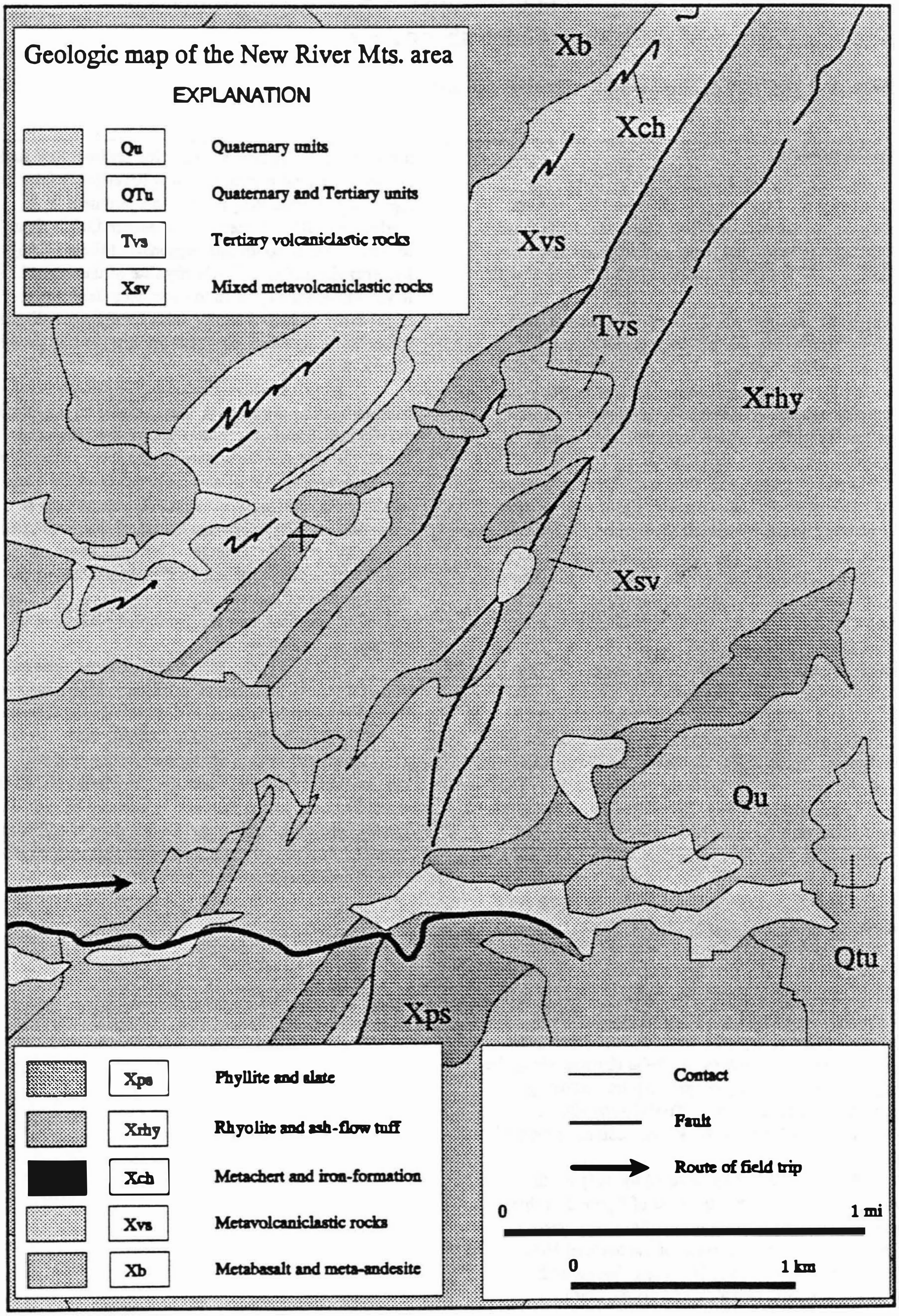
In the central and northern New River Mountains (fig. 3 of this volume and geologic map on following page), the Moore Gulch shear zone (Maynard, 1986) juxtaposes relatively unmetamorphosed and undeformed 1.7-Ga rhyolite on the east (unit Xrhy) with foliated, older (pre-1.72 Ga) metavolcanic rocks (units Xvs, Xb, Xch) on the west. In the central and eastern New River Mountains, the 1.7-Ga rhyolite displays spectacular welded tuff textures, and is intruded on the east by its subvolcanic-equivalent granophyre (DeWitt, 1987; unpub. mapping, 1990). Throughout the central and eastern New River Mountains the rhyolite and granophyre lack the distinctive northeast-striking regional fabric of most Early Proterozoic rocks in central Arizona. Pre-1.72-Ga metavolcanic strata west of the central part of the Moore Gulch shear zone are foliated metabasalt, thin beds of metarhyolite, metachert, iron-formation, and marble, and mixed metavolcaniclastic rocks (Maynard, 1986; DeWitt, unpub. mapping, 1990). The metabasalt is intruded by the pre-tectonic quartz diorite of Bland (Jerome, 1956), which is strongly deformed not only in proximity to the shear zone, but west, all the way to Black Canyon City (Winn, 1982; DeWitt, unpub. mapping, 1989). Bowring and others (1986) determined a U-Pb zircon age of 1.72 Ga for the quartz diorite, which indicates that the metavolcanic rocks on the west side of the shear zone are pre-1.72 Ga.

In the southern New River Mountains (geologic map on following pate), the Moore Gulch shear zone anastomoses and dies out into regionally foliated rocks. Importantly, the 1.7-Ga rhyolite of the central New River Mountains becomes more and more foliated to the west and south. Along the drainage of New River, the rhyolite passes from undeformed welded tuff and fragmental flows to rhyolite that has a regional cleavage, to foliated metarhyolite, and into strongly foliated quartz porphyry over a distance of less than one-half mile. Mixed metasedimentary and metavolcanic strata (unit Xsv) are interbedded with the 1.70-Ga rhyolite along the drainage of New River (geologic map on following page), indicating that the base(?) of the rhyolite is gradational downward into rock types common west of the shear zone.

South of the area shown on the map on the following page, but within the area of figure 3 of this volume, strongly foliated metarhyolite is exposed in roadcuts along I-17 to the north of the town of New River. There, the metarhyolite is interfolded with distinctive hematitic siltstone and wacke that is lithologically identical to hematitic sedimentary rocks in the south-central part of the New River Mountains (unit Xps, map on following page). In agreement with Anderson (1989), I interpret the Moore Gulch shear zone to die out to the south into regionally foliated Early Proterozoic rocks. 1.70-Ga rhyolite of the central New River Mountains appears to have been deposited on top of the suite of mixed metavolcanic and metasedimentary rocks (units Xvs and Xsv) that are intruded by the quartz diorite of Bland.

Near Brooklyn Peak, in the northern New River Mountains, the granophyre that intrudes its cogenetic, 1.7-Ga rhyolite in the central part of the range cuts across the trace of the Moore Gulch shear zone (DeWitt, unpub. mapping, 1990) and intrudes metabasalt and mixed metavolcaniclastic strata that are similar in composition to those exposed west of the shear zone in the central part of the range. I interpret these relations to indicate that displacement on the shear zone, in the northern part of the New River Mountains, had largely ceased by the time that the granophyre intruded the 1.7-Ga rhyolite ash-flow tuff

I interpret the Moore Gulch shear zone to be one of a family of zones of variable to high strain in the Early Proterozoic terrane of central Arizona (Shylock and Mountain Spring zones are others) that accommodated crustal shortening during regional deformation at 1.7 Ga. Because the Moore Gulch shear zone dies out to the south and is intruded by 1.7-Ga(?) granophyre to the north, the feature does not appear to be a crustal in scale as suggested by Karlstrom and Bowring (1988) and Karlstrom and others (1990), Excerpts from "Geology and structural relations in the southern New River Mountains and the significance of the Moore Gulch shear zone," by Ed DeWitt



Excerpts from "Gravity and magnetic evidence for an Early Proterozoic crustal boundary along the southern Shylock fault zone, central Arizona," by R. S. Leighty, D. M. Best, and K. E. Karlstrom.

Gravity and magnetic evidence for an Early Proterozoic crustal boundary along the southern Shylock fault zone, central Arizona

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ABSTRACT

East-west trending complete Bouguer and residual Bouguer gravity profiles across the southern Shylock fault zone (SFZ) show a prominent 20-30 mGal long-wavelength gradient, with lower gravity to the west. These data suggest that the crust to the west is either thicker or less dense than the crust to the east, or both. The residual Bouguer gravity gradient of the southern SFZ is also parallel to a 400-500 gamma east-to-west increase in the residual aeromagnetic field. The SFZ is located near the middle of the gravity and magnetic gradients, and we interpret it as a major regional crustal boundary.

Two-dimensional crustal models that use lateral density contrasts provide the best approximations of the observed long-wavelength gravity anomaly. Reasonable agreement between the calculated and observed anomalies is produced by using a slight (0.02-0.03 Mg/m^{-3}) east-to-west decrease in average density integrated over the entire crust, or by incorporating lower density (e.g., granitic) material, with a density contrast of -0.06 Mg/m-3, into the upper 10-15 km of the western block. A plausible but less likely model uses a small (<4 km) step to thicken the crust in the western block, with no lateral changes in density. The magnitude and wavelength of the gradient are not readily modelled in terms of individual granitoids exposed at the surface, such as the Crazy Basin Quartz Monzonite.

The distinct gravity and magnetic signatures of the southern SFZ contrast with those of the northern SFZ. None of the crustal models satisfactorily matches the relatively flat residual Bouguer gravity across the northern SFZ. A crustal model using little, if any, density and thickness contrasts fits this profile more adequately. The north-south trending residual magnetic anomaly also disappears across the northern SFZ. The relatively subdued residual aeromagnetic field across the northern SFZ area indicates that the magnetic character of rocks on either side of the northern SFZ is very similar.

The boundary along the southern SFZ between the western Big Bug block and the eastern Ash Creek block is of a different nature than that along the northern SFZ, which separates the Green Gulch and Ash Creek blocks. The southern SFZ appears to separate different crustal (or upper crustal) columns, whereas the northern SFZ does not.

INTRODUCTION

The Early Proterozoic orogenic belt in Arizona is segmented by north- and northeast-trending deformation zones, which have an enigmatic tectonic significance. These zones are tens of kilometers long, several kilometers wide, and appear to be crustal discontinuities. These deformation zones may be initial accretionary boundaries (i.e. sutures) (Karlstrom and Bowring, 1988), intraplate high strain zones during orogenic shortening (Bergh and Karlstrom, pers. comm.), and/or zones that accommodated differential uplift long after orogenic activity (Bowring and Karlstrom, 1990).

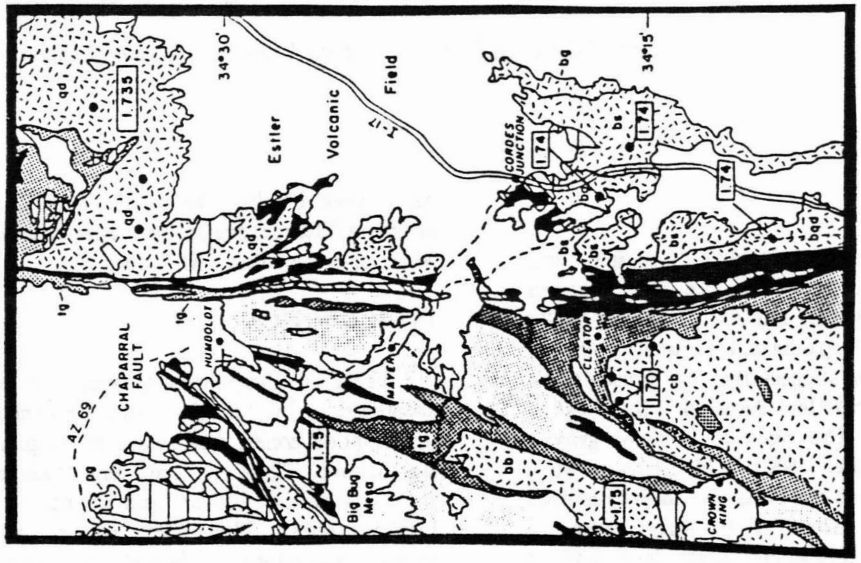
The purpose of this paper is to examine the gravity signature of one of these zones in central Arizona, the Shylock fault zone (Anderson and Creasey, 1958). This 60-km-long, 2-km-wide zone is characterized by sub-vertical foliation, steeply-plunging lineation, and transposition of rock units. The Shylock fault zone (SFZ) is overlapped at its north end by undeformed Cambrian Tapeats sandstone, indicating a Precambrian movement history.

New gravity data were collected along and across the zone and were added to existing data. This study will attempt to: (1) describe the complete and residual Bouguer anomaly maps, as well as the residual aeromagnetic anomaly map of the Bradshaw Mountain region, an area of twelve 7.5 minute quadrangles centered around Mayer (Fig. 1); (2) delineate relationships between short-wavelength (<50 km) anomalies and the surface distribution of Proterozoic and Phanerozoic rocks; and (3) model the longer-wavelength (>50 km) residual Bouguer anomalies across the SFZ in terms of different densities and/or thicknesses of crustal blocks across the fault zone.

Regional Geophysical Framework

Regional gravity maps of Arizona (Lysonski and others, 1980; Aiken and others, 1981) display a

Excerpts from "Gravity and magnetic evidence for an Early Proterozoic crustal boundary along the southern Shylock fault zone, central Arizona," by R. S. Leighty, D. M. Best, and K. E. Karlstrom.



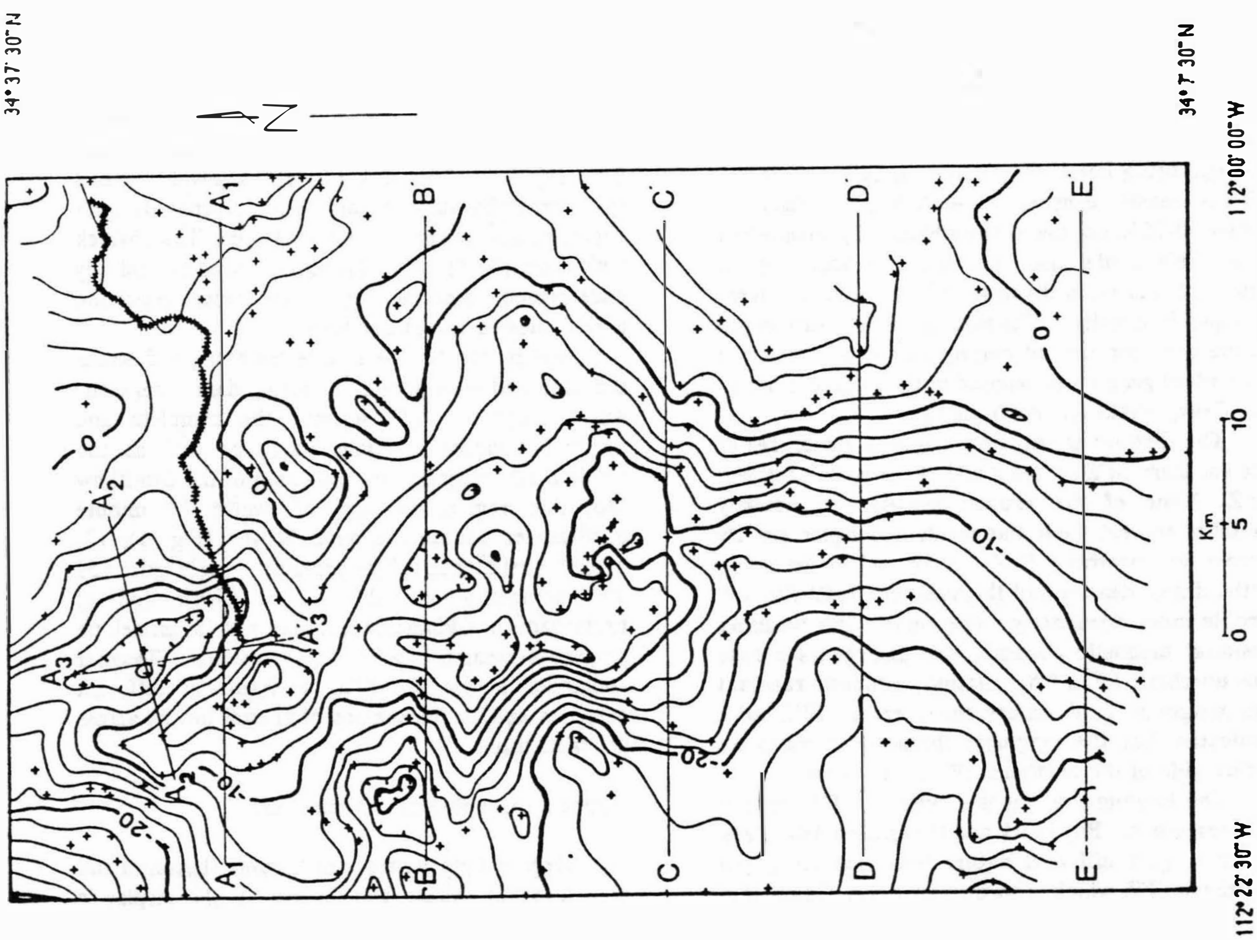


Figure 4B. Residual Bouguer anomaly map of the study area. Contour interval = 2 mGals.

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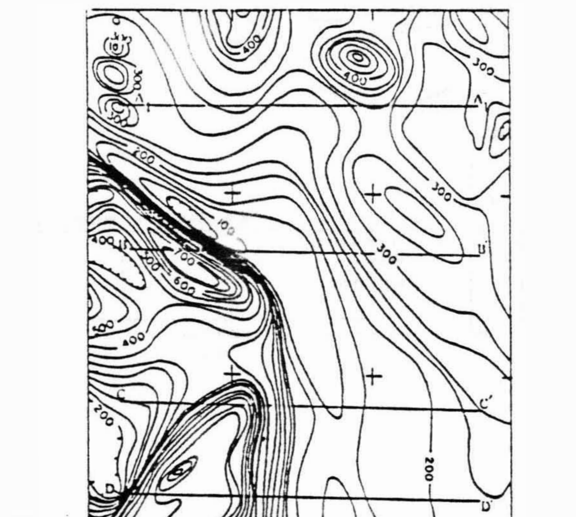


Figure 8. (A). Residual aeromagnetic anomaly map and profiles of the study area (from Sauck and Sumner, 1970); contour interval = 25 gammas. (B) Profiles correspond to those in Figures 4A and 4B.

of 2.67 Mg/m-3. In this survey, inner terrain corrections were calculated manually for all new stations due to the generally rugged nature of the field area, while outer terrain corrections (2.6 to 167 km) were computed using the digital elevation data base for Arizona. Corrections accounting for earth curvature were also applied. Using a digital topographic data base, the computer program RESID calculates the regional value of a gravity station and subtracts the variable thickness Bouguer slab effect from the free-air anomaly, resulting in residual Bouguer gravity values (Aiken and others, 1981).

Both the short- and long-wavelength residual Bouguer anomalies were interpreted using a standard two-dimensional modeling program based on Talwani and others (1959). Geologic maps from several sources (Anderson and Creasey, 1958; Anderson and Blacet, 1972a, 1972b, 1972c; Blacet,1985) control the shallow crustal models. Modeling of the deeper crust is weakly contrained by the crustal velocity structure of several seismic studies (Warren, 1969; Hauser and others, 1987; Hauser and Lundy, 1989).

Selection of specific densities for lithologic units used in two-dimensional computer modeling poses a problem due to variations in rock types, so averaged bulk density values were used (Table 1). Average densities for the crustal models may range from 2.70-2.76 Mg/m-3 for the upper and middle crust, to 2.90 Mg/m-3 and 3.30 Mg/m-3 for the lower crust and upper mantle, respectively. Because gravity modeling uses density contrasts, these average values can vary within reasonable limits. The aim in this survey is to describe possible lateral changes in the general density structure across the fault zone.

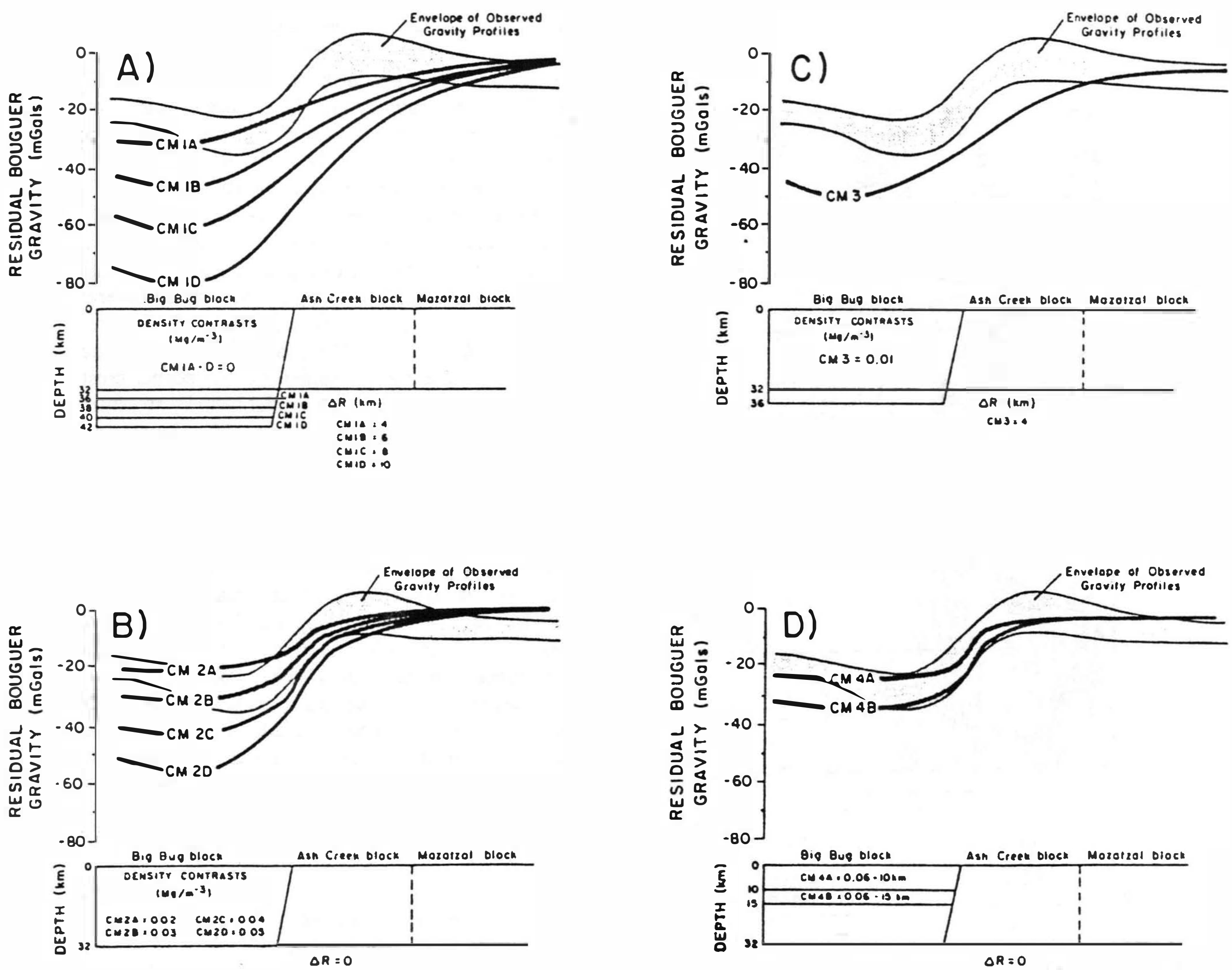
DESCRIPTION OF THE GRAVITY AND MAGNETIC FIELDS

Complete Bouguer Anomaly Map

The complete Bouguer anomaly map of the study area (Fig. 4A) represents a combination of effects produced by both shallow and deep sources. Gravity values range from -173 mGals to -126 mGals. Although a large gradient (~20 mGals over 15 km) dominates the southern portion of the area, the gravity field to the north is more convoluted. A detailed description of individual features on this map is not as critical as for the residual Bouguer map, but description of the profiles across this map are useful. Note that the major gradient in the southwest part of the map trends northeast and does not obviously correspond to the SFZ.

Figure 4A shows the location of profiles A1-A1', B-B', C-C', D-D', and E-E'. Each profile is 30 km long and is oriented east-west. The northernmost profile, A1-A1', crosses the quartz diorite of Cherry

Excerpts from "Gravity and magnetic evidence for an Early Proterozoic crustal boundary along the southern Shylock fault zone, central Arizona," by R. S. Leighty, D. M. Best, and K. E. Karlstrom.



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