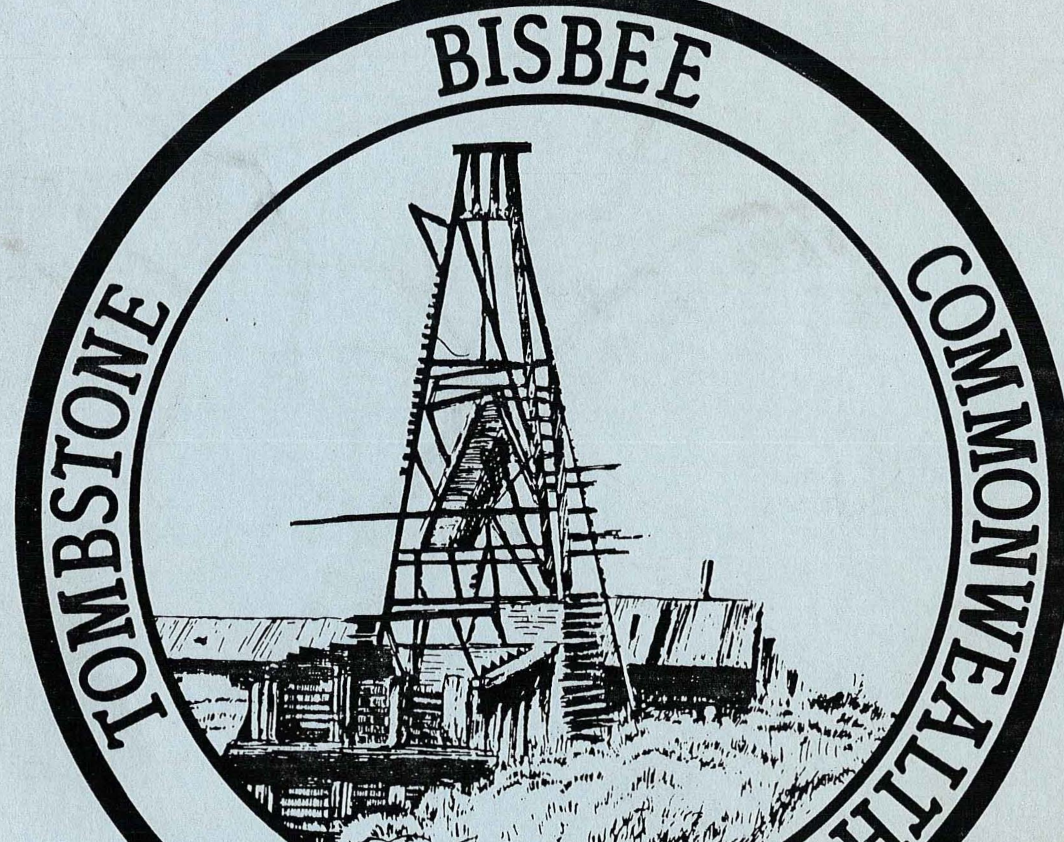

ARIZONA GEOLOGICAL SOCIETY
FALL FIELD TRIP 1988

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1988 Fall Field Trip

VISIT TO THE TOMBSTONE, BISBEE AND COMMONWEALTH DISTRICTS, ARIZONA

October 22 and 23, 1988

Hugo Dummett and Nora Colburn, Trip Leaders.

CONTENTS

ACKNOWLEDGEMENTS

We would like the thank the following for their very willing assistance with part or all of the field trip. As we observed during our preparations for the Spring Field Trip, these trips become a collective effort and it is to the credit of all members of the AGS, and some very important non-members, that these trips take place. Nora Colburn and I would like to thank the AGS for the opportunity to lead this year's trips - it has been fun! Now these are the persons whose names we gratefully acknowledge:

- Jim Babcock, mineralogist and owner of the Inn at Castle Rock for making sure that the field trip attendees would have a place to stay;

- Jim Briscoe, of JABA Inc. for arranging to provide the colored maps for the Tombstone area;

- Harald Drewes, of the USGS, for volunteering to join the field trip at fairly short notice;

- John T. Fitzgerald, of Tempe, for permission to use the sketch of his headframe on our guidebook cover;

- John Guilbert, of the University of Arizona, for filling in as a tour guide/expert for Tom Patton at the Commonwealth Mine;

- Stan Keith and Jan Wilt of Phoenix and Tucson, for the "Land of Cochise" road logs that we have gratefully used as a base for this trips logs;

- Jim Messegee, of Westland Minerals, for agreeing to let us visit the Commonwealth Mine;

- Roger Newell, of Newmont, for coming all the way to Arizona from Connecticut to renew an acquaintance with the AGS and his doctoral thesis area;

- Pat and Ron Palmer, of Tucson, for once again volunteering to feed the wolves on Saturday evening;

- Steve Reynolds, of the Arizona Geological Survey, for putting us in touch with relevant information and for publishing the 1988 Geology Map of Arizona just in time for the field trip;

- Morris Rutherford, of the Bisbee Elks Club, for making his BBQ facilities available to us for the Saturday evening affair;

- Pat Ryan, Don Ranta and Steve Eady, of Phelps Dodge, for making the Bisbee tour possible and to Steve for his short paper on that subject. We also take this opportunity to wish Steve a speedy recovery and "Get Well Soon!";

- Jim Sammons and Colin Podhaski, of Tucson, for helping with the BBQ, and to Jim for once again doing the guidebook cover and sweatshirts.

ITINERARY

Field Trip Leaders: Hugo Dummett and Nora Colburn.

Saturday, October 22, 1988

6:30 a.m. Registration in the parking lot at the El Con Mall.

7:00 a.m. Depart in Arizona Stagecoach buses for Tombstone.

8:00 a.m. Stop 1. East side of the Whetstone Mountains.

9:00 a.m. Stop 2. Overview of the Huachuca Mountains.

10:00 a.m. Stop 3. Overview of the Tombstone district.

10:15 a.m. to 1.00 p.m. Stop 4. Tour the Tombstone district with our guides Jim Briscoe and Roger Newell.

1:00 p.m. to 2:00 p.m. Lunch in Tombstone at the public park.

2:00 p.m. Depart from Tombstone.

2:30 p.m. Stop 5. Overview of Government Butte.

3:00 p.m. Stop 6. West end of Juniper Flat.

3:30 p.m. Arrive in Bisbee, check into hotels.

4:30 p.m. Field trippers reassemble in buses for trip to Bisbee Elks Park which is about five miles south of Bisbee.

Sunday, October 23, 1988.

8:15 a.m. Meet buses in Bisbee for short trip to Lavender Pit overlook.

8:30 a.m. to 11:00 a.m. Stop 7. Tour of Bisbee area with Phelps Dodge guides.

11:15 a.m. Leave Bisbee.

12:15 p.m. to 1:15 p.m. Lunch at Commonwealth Mine.

1:15 p.m. to 3:15 p.m. Stop 8. Tour the Commonwealth Mine with John Guilbert as our guide.

3:15 p.m. Leave Commonwealth Mine.

4:15 p.m. Stop 9. Overview of the northern Dragoons.

4:45 p.m. Leave for Tucson, arriving back at about 6:15 p.m.

INTRODUCTION

We will be visiting a number of mine localities in southeastern Arizona that have a fascinating history. Each of the districts has been through periods of production and shut down and it is interesting that each of these districts are now being re-evaluated because of the current price structure for precious metals and base metals.

This part of Arizona has been mapped and interpreted by a number of geologists. One of these geologists is Harald Drewes who will accompany this field trip and will comment on his current views of the structure of many of the ranges that we will see as part of the trip. Drewes has mapped this part of Arizona in detail and his "Tectonic Map of Southeast Arizona" (1980) and comprehensive summation "The Tectonics of Southeastern Arizona " (USGS Prof. Paper 1144, 1981) are landmark contributions to our understanding of the structural framework within which ore deposition took place.

Drewes recognizes three significant orogenic episodes in southeast Arizona, the Precambrian events, the Cordilleran (Laramide) orogeny (Lake Cretaceous to Early Tertiary) and the Mid-Tertiary extensional event.

Precambrian orogenesis began with the Mazatzal Revolution (1.5 - 1.7 Ga) that produced schists and gneisses. Near the close of this orogeny this area was cut by major northwest-trending dip slip and strike slip faults. These faults appear to have been important throughout the subsequent structural history of Arizona, so that Drewes proposes that the major mineral districts in the southeast, despite their younger age in some instances, occur within 1 km to 5 km of one of these NW-striking major faults (see his attached Fig. 2). Subsequent to the Mazatzal event, tectonism in Arizona during the Paleozoic and most of the Mesozoic was evidently limited to faulting with little folding or regional metamorphism.

The Cordilleran orogeny is defined by Drewes between 90 Ma and 53 Ma. The Cordilleran is subdivided into Piman and Helvetian phases which total about 12 million years during which time most of the major structural features were emplaced.

The Piman phase consisted of uplift, thrust faulting and folding. Regional uplift during the early Piman phase was followed by northeast-directed compression. This compression produced northwest-striking folds and large thrust faults that bounded plates of regional extent. Postulated transport for the Piman thrust faults is significant, ranging from 15 km to 100 km.

The individual thrust plates were further subdivided by a high-angle, northeast-trending fault into two portions, the northwest and southeast lobes, each of which has somewhat different internal characteristics. The southeast lobe contains two main thrust plates while the northwest lobe may contain three plates (see attached Fig. 3 of Drewes). Thrust faulting during the Piman phase was followed by the emplacement of epizonal, calc-alkaline plutons that are aligned along a northwest-trending zone from Tombstone to the Tucson Mountains.

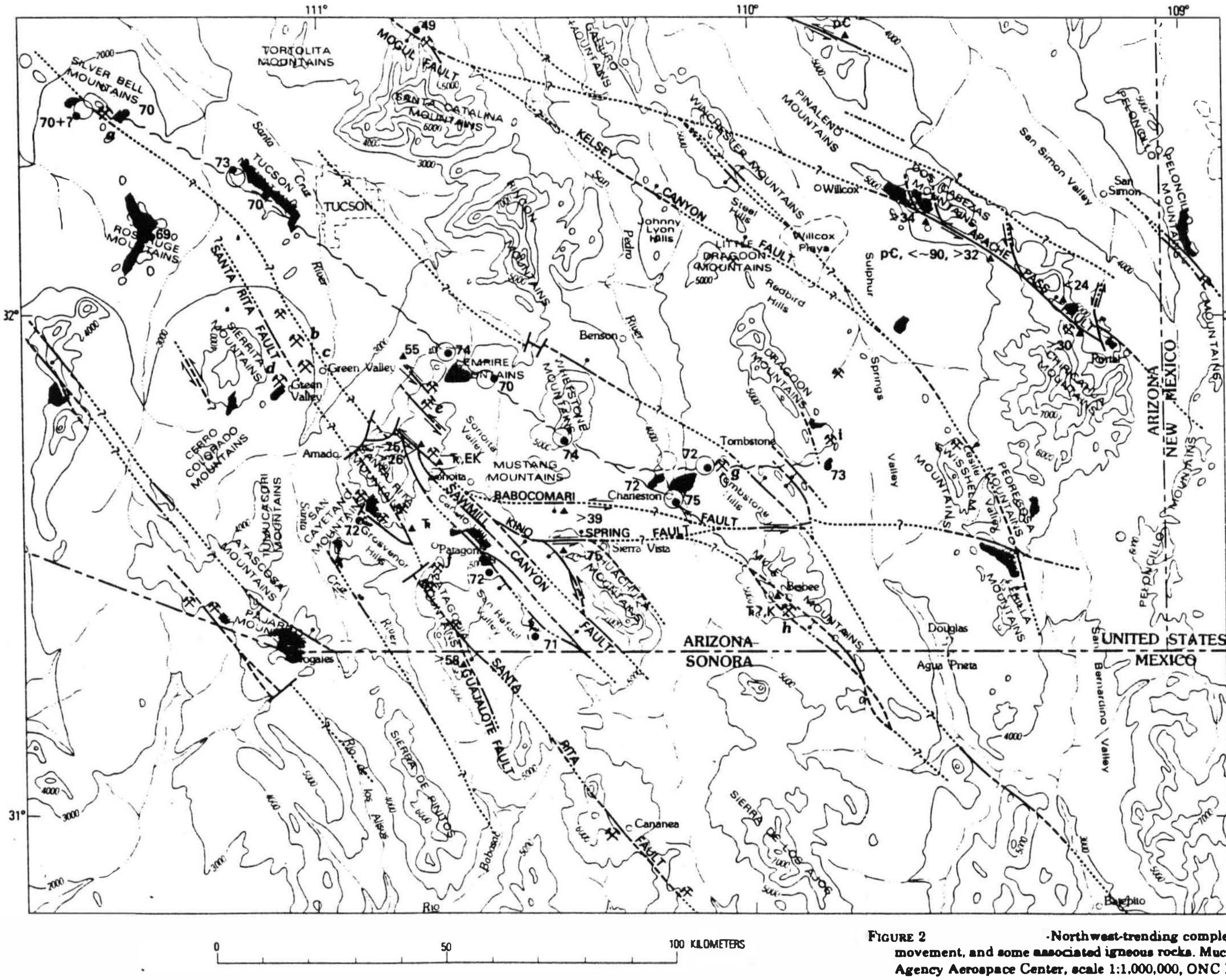
The Helvetian phase consisted of intrusive activity, strike-slip faulting and localized thrust faulting. The intrusives associated with this phase include stocks genetically associated with porphyry copper mineralization in the Sierrita Mountains. Left lateral motion on Precambrian northwest-striking faults was induced by compression which changed from N60°E to more directly eastward during Helvetian time.

The post-Cordilleran orogeny was a combination of high angle block faulting and crustal extension to produce detachment faults of a regional scale associated with metamorphic core complexes.

The three mining districts that we will be visiting are Tombstone, Bisbee and Commonwealth. The Tombstone district, although historically famous, is now once again the focus of re-examination by one of the major mining companies - currently this company is drilling in the area. The ores of the Tombstone area are somewhat typical carbonate replacement ores of copper, lead and zinc with important silver and gold credits. The mineralization is probably Laramide in age and occurs in Pennsylvanian-Permian and Cretaceous carbonates. Ore zones are localized within and adjacent to northeast and east striking faults.

At Bisbee we will re-visit the famous Lavender pit which hosts the only Jurassic age porphyry copper deposit in Arizona that was an important mine. We will also have described to us and visit Phelps Dodge's new Cochise orebody which is a recently delineated oxide porphyry copper deposit immediately adjacent, on the north, to the Lavender open pit.

The Commonwealth deposit is a Tertiary epithermal precious metals deposit in which gold and silver occur in east-striking quartz veins associated with chalcedony, amethyst, adularia and sericite. Like the Tombstone and Bisbee districts, Commonwealth is also being re-examined and drilled at the present time to determine the viability of mining the deposit.



EXPLANATION

VOLCANIC ROCKS OF THE SILVER BELL-CAT MOUNTAIN-SALERO SUITE

GRANODIORITE STOCK OF THE 70–74 M.Y. AGE GROUP—Dashed where inferred from geophysical data

FAULT—Dashed where inferred, dotted where extensively covered or intruded, queried where uncertain. Double headed arrows show evidence only of horizontal movement but without relative movement. Other arrows show sites of evidence for strike-slip movement. Bar and ball show site of evidence of vertical movement or of inferred vertical offset; ball on downthrown side

TRACE OF INFERRED FRACTURE IN BASEMENT ROCKS

70 SITE OF RADIOMETRICALLY DATED ROCK AND AGE IN MILLIONS OF YEARS

pC SITE OF GEOLOGICALLY OR RADIOMETRICALLY DATED ROCKS—Indicates age or age limits of some phase of movement (in millions of years or geologic age series)

MINING DISTRICTS—Large size and middle size (more than approximately $100 million, and $10–$100 million, respectively). *a*, Silver Bell; *b*, Pima-Mission; *c*, Twin Buttes; *d*, Esperanza-Sierrita; *e*, Rosemont; *f*, Red Mountain; *g*, Tombstone; *h*, Bisbee-Warren; *i*, Courtland-Gleason

FIGURE 2 ·Northwest-trending complex (or multiphased) faults, showing sites of inferred directions and ages of movement, and some associated igneous rocks. Much fault movement was pre-Cordilleran orogeny. Base from Defense Mapping Agency Aerospace Center, scale 1:1,000,000, ONC H-22, edition 8 (1969); contour interval 1,000 ft.

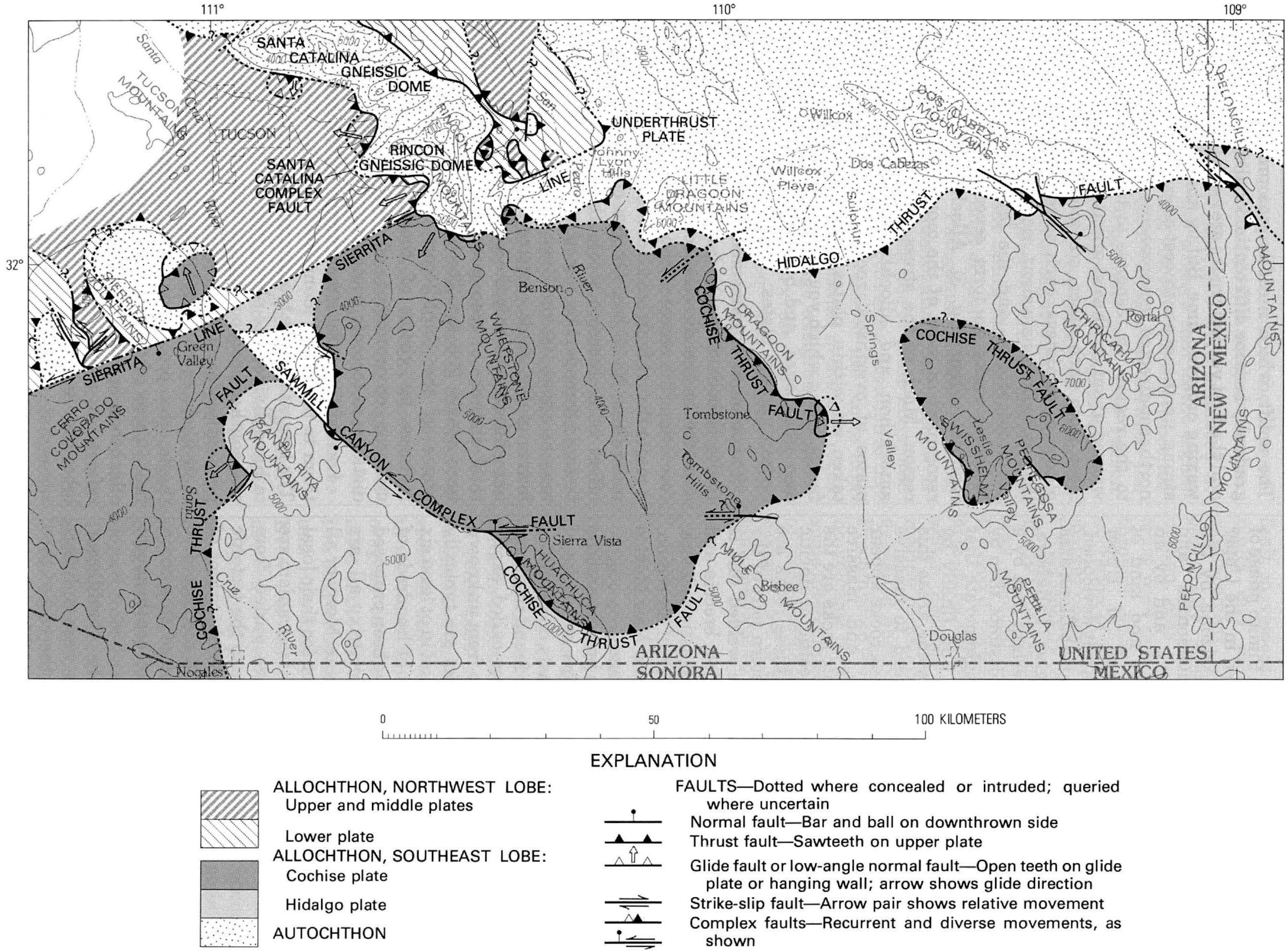


FIGURE 3.—Generalized map of major thrust faults of Cordilleran age, separating allochthons from each other and from the autochthon. Base from Defense Mapping Agency Aerospace Center, scale 1:1,000,000, ONC H-22, edition 8 (1969); contour interval 1,000 ft.

Qy	Young alluvium (Holocene to latest Pleistocene)—Deposits in present-day river and stream channels, flood plains, and playas
Q	Surficial deposits (Holocene to middle Pleistocene)—Alluvium in present-day valleys and piedmonts, eolian deposits, and local glacial deposits
Qo	Older surficial deposits (middle Pleistocene to latest Pliocene)—Alluvium with less abundant talus and eolian deposits
QTb	Basaltic rocks (Holocene to late Pliocene; 0 to 4 Ma)
QTv	Volcanic rocks (Quaternary to late Pliocene)—Rhyolitic to andesitic rocks associated with unit QTb
Tsy	Sedimentary rocks (Pliocene to middle Miocene)—Units deposited during and after late Tertiary normal faulting; sedimentary parts of the Bidahochi Formation, and the Bouse Formation, commonly capped by patches of Quaternary surficial deposits.
Tby	Basaltic rocks (Pliocene to late Miocene; 4 to 8 Ma)
	Volcanic rocks (Pliocene to middle Miocene; 4 to 15 Ma)—Rhyolitic to andesitic rocks associated with units Tby and Tb
Tb	Basaltic rocks (late to middle Miocene; 8 to 16 Ma)—Units, such as the Hickey Formation, erupted after most mid-Tertiary volcanism and tectonism
Tsm	Sedimentary rocks (middle Miocene to Oligocene; 15 to 38 Ma)—Deposited during mid-Tertiary orogenic activity in the Basin and Range Province and southwestern Transition Zone.
Tv	Volcanic rocks (middle Miocene to Oligocene; 15 to 38 Ma)—Silicic to mafic flows and pyroclastic rocks; includes some sub-volcanic intrusions
Tsv	Volcanic and sedimentary rocks (middle Miocene to Oligocene)
Ti	Subvolcanic intrusive rocks (middle Miocene to Oligocene)
Tg	Granitoid rocks (early Miocene to Oligocene; 18 to 38 Ma)
Tso	Sedimentary rocks (Oligocene to Eocene or locally Paleocene)—Units deposited on the Colorado Plateau and Transition Zone prior to or during the initial phases of mid-Tertiary volcanism; many units were deposited by drainages flowing north and east onto the Colorado Plateau; includes "rim gravels" and associated finer grained rocks along the Mogollon Rim; also includes Chuska Sandstone; some units, especially those in the Transition Zone, may overlap in age with unit Tsm.
TKgm	Granitic rocks (early Tertiary to Late Cretaceous; 45 to 75 Ma)—Commonly muscovite-garnet-bearing peraluminous granite and associated pegmatite.
TKg	Granitoid rocks (early Tertiary to Late Cretaceous; 55 to 85 Ma)—Generally metaluminous granite to diorite and subvolcanic porphyry.
Kv	Volcanic rocks (Late Cretaceous; early Tertiary near Safford)—Rhyolitic to andesitic volcanic rocks and locally associated sedimentary and subvolcanic intrusive rocks.
Kmv	Mesaverde Group (Late Cretaceous)—Yale Point Sandstone, Wepo Formation, and Toreva Formation
Ks	Sedimentary rocks (Cretaceous)—Dakota Sandstone, Mancos Shale, and related rocks near Show Low, Morenci (Pinkard Formation), and Deer Creek
KJs	Sedimentary rocks with local volcanic units (Cretaceous to Late Jurassic)—Bisbee Group (largely Early Cretaceous) and related rocks, Temporal, Bathtub, and Sand Wells Formations, rocks of Gu Achi, McCoy Mountains Formation, and Upper Cretaceous Fort Crittenden Formation and equivalent rocks.
Jm	Morrison Formation (Late Jurassic)—Locally mapped with San Rafael Group.
Js	San Rafael Group (Late to Middle Jurassic)—Bluff and Cow Springs Sandstones, Summerville Formation, Todilto Limestone, Entrada Sandstone, and Carmel Formation.
Jgc	Glen Canyon Group (Early Jurassic)—Navajo Sandstone, Kayenta and Moenave Formations, and Wingate Sandstone.
Jg	Granitoid rocks (Jurassic)—Granite to diorite, with local alkaline rocks; includes Triassic(?) granitoids in Trigo Mountains
Jsv	Sedimentary and volcanic rocks (Jurassic)—Sil Nakya, Ali Molina, and Pitoikam Formations, Cobre Ridge tuff, Rudollo Red Beds, Recreation Red Beds, Gardner Canyon Formation, and part of the Canelo Hills Volcanics in southern Arizona; Harquar formation and rocks of Slumgullion in western Arizona
Jv	Volcanic rocks (Jurassic, locally latest Triassic)—Mount Wrightson Formation, part of Canelo Hills Volcanics, Mulberry Wash Volcanics, Black Rock Volcanics, and equivalent rocks
JŦ	Sedimentary and volcanic rocks (Jurassic and Early Triassic)—Buckskin Formation, Vampire Formation, and Planet Volcanics in west-central Arizona
Ŧc	Chinle Formation (Late Triassic)—Shinarump Conglomerate Member (Ŧcs) mapped separately in most areas
Ŧm	Moenkopi Formation (Middle[?] and Early Triassic)
Mzo	Orocopia Schist (Jurassic protolith; Cretaceous metamorphism)
MzPz	Mesozoic and Paleozoic rocks—Structurally complex Jurassic, Triassic, and Paleozoic rocks in west-central Arizona
Pz	Paleozoic rocks, undifferentiated.
P	Sedimentary rocks (Permian)—Kaibab Limestone, Toroweap Formation, Coconino Sandstone, San Andres Formation, and Glorieta Sandstone on the Colorado Plateau; age-equivalent rocks in the Basin and Range Province and Transition Zone are included with unit PIP
PIP	Sedimentary rocks (Permian and Pennsylvanian)—Hermit Shale, Supai Group, Naco Group, De Chelly Sandstone, Cutler Group, Pakoon Limestone, Callville Limestone, and Queantoweap Sandstone.
MC	Sedimentary rocks (Mississippian to Cambrian)—Redwall Limestone, Temple Butte Limestone, and Tonto Group in northern Arizona; Escabrosa Limestone, Percha Shale, Martin Formation, El Paso Limestone, Abrigo Formation, and Bolsa Quartzite in southern Arizona.
Ys	Sedimentary rocks (Middle Proterozoic)—Grand Canyon Supergroup (locally Late Proterozoic), Apache Group, Troy Quartzite, and local basalt flows and diabase.
	Diabase (Middle Proterozoic; 1100 Ma).
Yg	Granitoid rocks (Middle Proterozoic; 1400 Ma).
YXg	Granitoid rocks (Middle or Early Proterozoic; 1400 Ma or 1650 to 1750 Ma)
Xg	Granitoid rocks (Early Proterozoic; 1650 to 1750 Ma)—Granite, granodiorite, tonalite, quartz diorite, diorite, and gabbro, commonly foliated
Xq	Quartzite (Early Proterozoic; 1700 Ma)—Mazatzal Group and similar rocks.
Xm	Metamorphic rocks (Early Proterozoic; 1650 to 1800 Ma)—Undifferentiated metasedimentary, metavolcanic, and gneissic rocks.
Xms	Metasedimentary rocks (Early Proterozoic; 1650 to 1800 Ma).
Xmv	Metavolcanic rocks (Early Proterozoic; 1650 to 1800 Ma).

MAP SYMBOLS

Contact

Fault

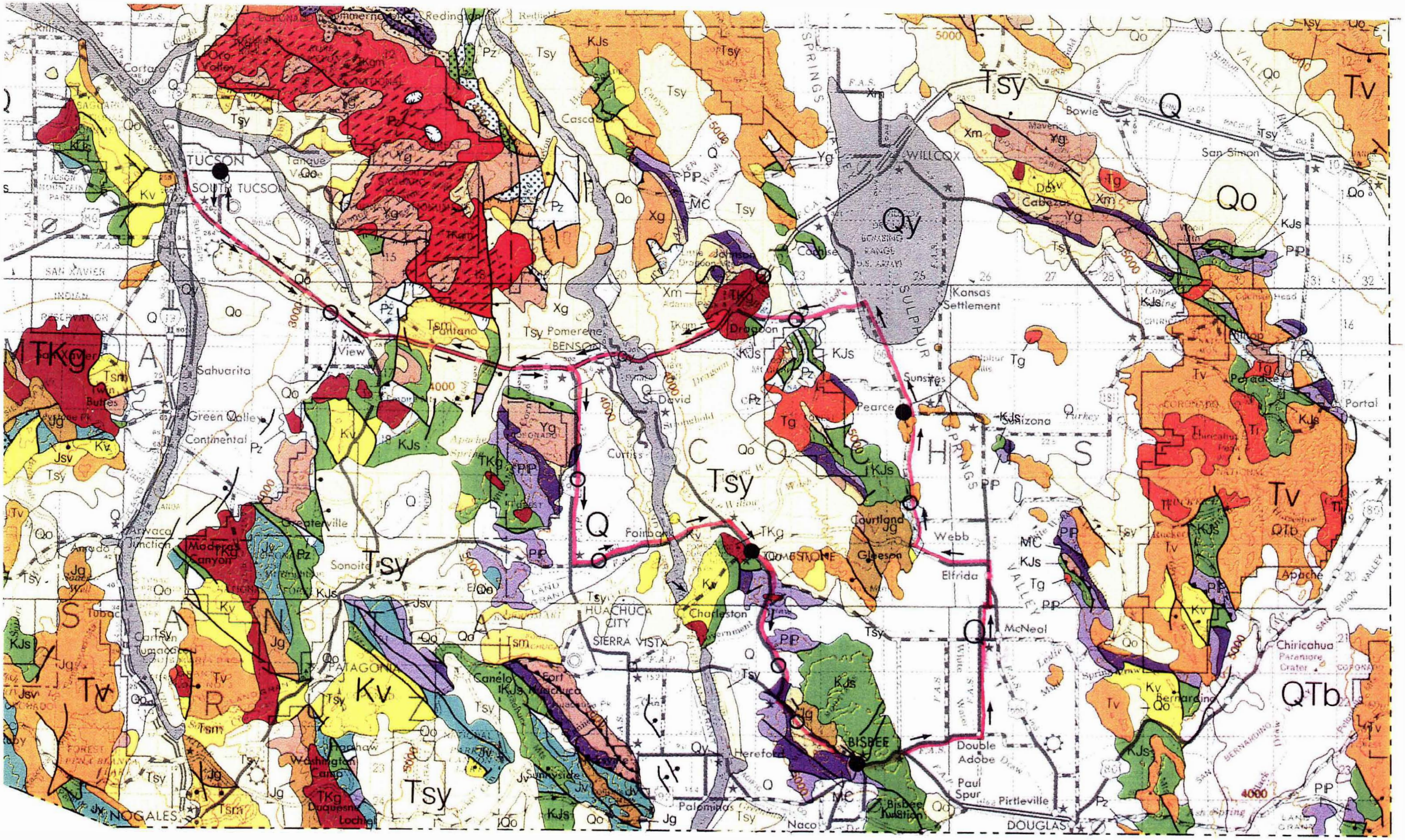
Low-angle normal fault

Detachment fault

Thrust or reverse fault

Middle Tertiary mylonitic fabric; lined pattern is approximately parallel to lineation.

Mesozoic to early Tertiary metamorphic fabric in Proterozoic to Mesozoic sedimentary rocks



1988 AGS FALL FIELD TRIP ROUTE MAP

● Major stops ○ Minor stops

DAY I
ROAD LOGS

ROADLOG - FROM TUCSON TO TOMBSTONE

Modified, with thanks, from the logs of Stanley B. Keith and Jan C. Wilt that were prepared for the "Land of Cochise" meetings in 1978. The field trip will assemble in the parking lot of the El Con shopping mall and proceed by buses south along Alvernon and Palo Verde and the log will commence at the Palo Verde on-ramp to the I-10.

0.0 Palo Verde entrance to Interstate 10. Start road log! **3.3**

3.3 Exit 268. Craycroft Road. **2.0**

5.3 Exit 270. Red and white checkered tank at 9:00 is over the facility formerly occupied by Anaconda for its exploration, metallurgical research and mining groups. Now occupied in part by Ceralox who specialize in "high purity aluminas". **0.8**

6.1 Water tank at 3:00 just as we pass over the ramp is at the site of a small community previously known as Galeyville. Exxon drilled a deep stratigraphic test into the Tucson basin about 2 miles south of here. The upper 7,277 ft is sand, gravel and clay, filling Basin and Range grabens formed after 12 Ma. From 7,277 to 9,000 ft the hole penetrated a volcanic section of tuff, andesite and rhyolite. Selected cuttings from a tuff at 7,940 to 7,960 ft yielded a K-Ar age of 23.4 Ma. Below the volcanic section from 9,000 to 9,500 ft reddish brown conglomerates were encountered. At 9,500 to 10,000 ft another volcanic unit was found which yielded K-Ar ages of 16.1 and 18.0 Ma. This was interpreted to be an intrusive dike or sill. From 10,000 to 12,000 ft more reddish brown conglomerates, slits and shales were drilled. At 12,000 ft was a quartz monzonite dated at 61 Ma by K-Ar and 120 Ma by Rb-Sr methods. Eberly and Stanley (1978) regard the section from 7,277 to 12,000 ft as deposited after the Eocene and before the Basin and Range faulting at about 13 Ma. **0.4**

6.5 At 3:00 are the Santa Rita Mountains. **1.1**

7.6 Milepost 272. At 10:00 is the large IBM General Products Division plant. As many of you no doubt know this plant is being phased out and reportedly IBM will only retain their

R&D staff in Tucson. Rumors are that a number of large computer tape manufacturers are considering purchase of all or part of the plant, e.g. the 3M Company. **1.0**

8.6 Exit 273. Rita Road. **1.0**

9.6 Milepost 274. I-10 traverses an aggradational surface on Plio-Pleistocene valley fill. The upper red clay-rich (argillic) horizons have been stripped away, exposing a thick caliche horizon. This stripping has occurred over most of the Tucson basin and demonstrates that the red soils are not of modern origin. **1.4**

11.0 Exit 275. Houghton Road and turn-off to Colossal cave and Pima County Fairgrounds. **1.1**

12.1 Milepost 276.5. Broad domal physiography of the Rincon Mountains is seen from 9:00 to 11:30.

The large rounded peak at 10:00 in the Rincon Mountains is Mica Mountain (8,666 ft). The conspicuous ridge trending west-south-west from Mica Mountain is Tanque Verde Ridge or the Tanque Verde Mountains. Cow Head Saddle separates Tanque Verde Ridge from Mica Mountain. The top of Tanque Verde Ridge gently plunges southwestward and generally marks the culmination of a large, antiformal foliation arch in mylonitic gneisses. Mica Mountain is separated from Rincon Peak (8,482 ft at 10:30) by Happy Valley Saddle. The small peak north of the cuesta-like peak and south of Rincon Peak is Wrong Mountain which hosts the Wrong Mountain quartz monzonite crops out extensively throughout the Rincon Mountains.

Layers of mylonite schist commonly separate layers of Wrong Mountain Quartz Monzonite from the darker layers of deformed Continental Granodiorite. These schistose lenses have been correlated with Pinal Schist by Drewes (1977).

Low foothills at 3:30 in middle distance are underlain by Paleozoic rocks. Colossal Cave, a local tourist attraction, is in the foothills at 9:30. Paleozoic rocks in the Agua Verde-Colossal Cave area are part of a series of deformed Phanerozoic rocks that also occur at Martinez ranch at the base of the Rincon Mountains in the Loma Alta area at the southern base of Tanque Verde Ridge, and in the Saguaro National Monument area just northeast of the nose of Tanque Verde ridge at 9:00. A large pediment in Rincon Valley between Loma Alta and Colossal Cave is cut on Precambrian Rincon Valley Granodiorite.

The Precambrian and Paleozoics are in the upper plate of the major, low-angle, Santa Catalina fault, which is located at the break in slope between the main Rincon massif and the foothill block. The Santa Catalina fault separates the unmetamorphosed, but highly deformed, upper plate rocks from lineated mylonites of the metamorphic core in the main Rincon Mountain mass. Inevitably these complicated geometric relationships have several interpretations. Davis (1975) analyzed fold geometries in Paleozoic and Mesozoic rocks of the upper plate and concluded that they represented a period of major gravitational sliding of the cover down the Santa Catalina fault surface in mid-Tertiary time. Drewes (1977) recognized this mid-Tertiary gravity-induced movement, but also suggested that the low-angle fault was older and represented former thrusts which were emplaced at about 73 Ma via regional north-east-southwest compression of Laramide age. These faults were reactivated in Oligocene time (25 Ma) during arching of the mylonite rocks of the metamorphic core. **1.5**

13.6 Milepost 278. Northern Santa Rita Mountains from 2:00 to 3:00. Mount Fagin at 2:00 consists of Late Cretaceous Salero Volcanics which unconformably overlie folded Bisbee Group. A defunct limestone quarry is the prominent scar on the hillside at 3:00. However there is an active limestone quarry that is lower on the slopes that is operated by Calcium Products of Arizona mostly for decorative and landscaping purposes. **1.3**

14.9 Exit 279. Vail and Wentworth roads to Colossal Cave and Saguaro National Monument. **2.1**

17.0 Exit 281. Arizona 83 south to Sonoita. The R.W. Webb Winery is the building at 10:00 when we first see the Exit 281 sign. The building at 11:00 houses Mountain States R&D International's assay and metallurgical research lab. **1.6**

18.6 Milepost 283. Northern Empire Mountains are at 1:30. The oldest rocks in the Empires are Precambrian Pinal schist and gneiss which occur immediately south of I-10 for about three miles. These units are mantled by outward dipping and overturned Cretaceous Bisbee Group. Further south, near Martinez Ranch, a Laramide quartz monzonite intrudes Pennsylvanian carbonates that are overlain by Bisbee Group sediments and slightly younger Salero volcanics. **2.0**

19.6 Milepost 284. Angular unconformity between Pliocene(?) valley fill and lower fanglomerate member of Oligocene Pantano Formation in roadcuts on either side of the highway. **0.4**

20.0 Bridge over Davidson Canyon. Roadcuts east of Davidson Canyon are in lower fanglomerate member of Pantano Formation with pronounced eastward dips. The Pantano Formation south of the Rincon Mountains generally exhibits a uniform, moderately east to northeast inclination throughout a thickness of over 10,000 ft. **0.7**

20.7 Milepost 285. Roadcut in Turkey Track Andesite flow that dips east at 45° at the top of the lower fanglomerate member. This volcanic unit takes its name from clusters of large (±1" long), elongate plagioclase phenocrysts. Roadcuts ahead are in the claystone member of the Pantano Formation. The lower half of the Pantano Formation is 28 Ma to 36 Ma on the basis of several radiometric dates (Keith & Wilt, 1978). Reddish clastics similar to Pantano Formation are widespread throughout southeastern Arizona. They may represent basinward facies shed from time-equivalent Oligocene ignimbrite piles. They may in some way be linked with the late Oligocene (28 to 22 Ma) activity in the metamorphic areas. They may also be linked to synclinal fold basins formed at the margins of mid-Tertiary basement uplifts, as in the Tortilla Mountains north of the Catalina Mountains. The 28 to 36 Ma dates of the Pantano Formation in this area are slightly older than the cooling ages (22 to 28 Ma) in the Rincon-Catalina metamorphic complex to the north.

Drewes (1977) suggested that parts of the Rincon Mountains were a structural basin through which the underlying metamorphic terrain was arched. Thus, the 22 to 28 Ma cooling ages of the metamorphic rocks represent the time of uplift and not necessarily the time of metamorphism, which is older by an unspecified amount. This metamorphism could have been Laramide in age, Precambrian (Mazatzal orogeny) in age, or a combination of both. For Drewes the profound lineation and accompanying metamorphic event of Laramide time would have been coincident with major low-angle thrusting during the Piman phase of the Laramide orogeny (Drewes, 1972, 1976a, 1978).

Others (Coney, 1978) suggest that the Pantano Formation is syntectonic with the development of extensive mid-Tertiary lineation and metamorphism. The lineation represents an extreme attenuation or thinning of the crust. This would have created a basin into which thick Pantano clastics were deposited. Rebound of the crust following the attenuation event would arch the metamorphic rocks through their Pantano cover. The Pantano Formation would then accumulate around the uplifted metamorphic terrain as large, gravity-slide blocks, which record a tectonic denudation of the dome during its arching from 22 to 28 Ma.

Gneiss clasts are conspicuous by their absence in the fanglomerate member of the Pantano Formation although every other pre-Tertiary rock is represented (Brennan, 1957; Finnel, 1970b). Imbrication directions as determined from aligned tabular clasts consistently indicate stream transport direction from the east and southeast. **0.4**

21.1 Roadcuts here and ahead are in upturned, nearly vertical, east-striking, mid-Cretaceous, Bisbee Group strata. These are in fault contact with the claystone member of the Pantano Formation to the west. This deformation in Bisbee Group strata is part of the east-west belt of the Late Cretaceous deformation which extends from the north end of the Whetstone Mountains through the north end of the Empire Mountains and disappears under pediment alluvium at the north end of the northern Santa Rita Mountains. This block of Bisbee Group also represents a north-trending, upthrown horst block bounded by normal faults that developed after deposition of the Pantano. Perhaps this horst is a part of the late Miocene-Pliocene Basin and Range faulting episode. **0.9**

22.0 Roadcuts in lower fanglomerate member of Pantano Formation, which is in fault contact with north-trending Bisbee horst to the west. This fault is well-exposed in the west-bound lane of I-10. Note the steep eastward dips in the fanglomerates. This tilting is at right angles to the east-west tectonic zone in the Bisbee Group horst. Deformation in the Bisbee and Pantano has been truncated by an extensive pediment, upon which rests a veneer of Plio-Pleistocene(?) gravels. **0.2**

22.2 Rhyolite tuff unit (29.4 Ma) within the lower fanglomerate member of the Pantano Formation is exposed in low roadcuts on either side of the highway and is better exposed in west-bound lane. **0.5**

22.7 Roadcuts in lower fanglomerate member. Fault within this member separates finer grained from coarser grained units. Turkey Track Andesite flow in roadcut on right is faulted against finer grained material. Note that the Turkey Track unit is completely faulted out in the roadcut on left side of highway. Numerous faults cut Pantano Formation in roadcuts ahead. **1.1**

23.6 Milepost 287. Quarry at 9:00 is in red colored sandy, argillaceous Pantano units that contain intercalated 1½" thick gypsum beds. These beds are overlain unconformably by a green-colored brecciated argillite(?). **0.2**

23.8 Fault(?) contact between claystone member (in roadcuts ahead) and fanglomerate member. The Turkey Track Andesite marker unit is faulted out here. Claystone member ahead is angularly overlain by Plio-Pleistocene(?) gravels. Farther east and northeast claystone member is overlain by upper fanglomerate member of Pantano Formation (Drewes, 1977). **1.0**

24.8 Cienega Creek bridge. Highway ascends onto a post-mid-Miocene aggradational surface on Plio-Pleistocene(?) gravels for the next several miles. **0.6**

25.4 Exit 289; Marsh Sta Road. **0.2**

25.6 Milepost 290. Whetstone Mountains (1:00) on skyline contain southwest-dipping Bisbee Group strata. A fuller description of the Whetstones is given later in this log. At 2:00 in the middle distance are relatively flat-lying conglomerates in upper fanglomerate member(?) of Pantano Formation. They may also be Miocene Nogales Formation which Drewes (1977) mapped south of the Rincon Mountains and north of I-10.

Total Wreck Ridge (3:30) in the northeastern Empire Mountains contains Concha Limestone and Rain Valley Formation. East of Total Wreck Ridge a thick (to 5,000 ft), southward-thinning, fanglomerate wedge of Glance Conglomerate represents a clastic wedge that was shed southward from an uplifted block exposing older Precambrian granite and Pinal Schist in Early Cretaceous time (Finnell, 1971; Bilodeau, 1978). South of the east-west tectonic belt (which I-10 is in), the southwest-dipping strata in the central Whetstone Mountains and southeast-dipping layers in the Empire Mountains form a broad, south-southwest-plunging syncline. **2.6**

28.2 Exit 292; Bell Road to Empirita ranch and vicinity. **0.4**

28.6 Low hills ahead and at 2:00 are in narrow, north-trending, Basin and Range horst block containing east-trending, north-dipping, overturned, tight folds of Bisbee Group strata with subordinate Pennsylvanian carbonates and Precambrian felsic gneisses. This is a relatively upthrown continuation of the east-trending, Late Cretaceous structural zone. **1.2**

29.8 Roadcuts here and ahead for next mile are in deformed, east-striking, nearly vertical, Bisbee Group overlain by flat-lying gravels veneering the pediment. At 9:00 steep, topographic scarps on the east side of the Rincons mark a large Basin and Range fault which is continuous with the east boundary of the horst block now being crossed by I-10. **0.8**

30.6 Milepost 295. Fault contact between late Miocene-Pliocene(?) basin-filling alluvium (post-Pantano Formation) and Bisbee Group. The fault is excellently exposed in roadcut on right. This fault strikes north, dips 70 to 75 degrees east, and is a continuation of the fault which marks the eastern boundary of the Rincon metamorphic range massif to the west. The Happy Valley block of eastern Rincon Mountain area has been dropped down a minimum of 5,000 ft to the east on this fault zone. It is significant that this faulting post-dates the metamorphic events and the low-angle fault phenomena which are associated with the development of the Rincon-Catalina-Tortolita metamorphic complex. Many people now interpret the age of this metamorphic complex to be of late Oligocene (22 to 28 Ma). This roadcut is an excellent example of Basin and Range faulting. which in southeast Arizona is generally younger than 14 Ma and possibly younger than 10 Ma Most of the Basin and Range faulting had terminated by about 5 Ma, although some has lingered to the present day.

The low rounded ridge ahead is underlain by valley fill. **1.2**

31.8 Entering Cochise County. El Paso Natural Gas compressor station on left. Happy Valley area at 8:30; Little Rincon Mountains at 9:00. Johnny Lyon Hills (10:00) are backed by the Winchester Mountains and the southern Galiuro Mountains in far distance. The Little Dragoon Mountains are at 11:30 with the "big" Dragoon Mountains at 12:00. **0.8**

32.6 Exit 297. Mescal-J Six Ranch road. Roads north from this exit lead to Happy Valley, an area of very complex structure related to the Rincon metamorphic complex to the west. **1.0**

33.6 Road continues across a mid-Pleistocene surface which now slopes toward San Pedro Valley and extends to the foot of the northern Whetstone Mountains at 2:30, where it merges with a Pliocene(?) pediment cut on 1,400 Ma(?) Precambrian granite. **1.2**

34.8 Exit 299. Skyline road. **0.8**

35.6 Milepost 300. The Johnny Lyon Hills (9:30 to 10:30) consist of an oblong, north-trending structural block which is separated from the southern Galiuro Mountains by the west-northwest-striking Antelope Tank fault zone at 9:30. The Antelope Tank fault zone was thought to be an element of the Texas lineament by Cooper and Silver (1964).

The east border of the Johnny Lyon Hills block is marked by a series of arcuate, north- to northwest-trending ridges which extend northward from Sheep Camp Ridge (10:00) and are backed by the Winchester Mountains at 9:45 on the skyline. These ridges consist of east- and northeast-dipping, younger Precambrian Apache Group and Paleozoic strata. These strata unconformably rest on 1,625 Ma Johnny Lyon Granodiorite and 1,680 Ma Pinal Schist; they form an extensive pediment west of the low ridges. Relationships of the older Precambrian rocks in the Johnny Lyon Hills allowed Silver and Deutsch (1963) to date what they regarded the Mazatzal orogeny of Wilson (1939). Pinal Schist was deformed into north-east-trending isoclines. This deformed terrain was intruded by the post-deformational, Johnny Lyon Granodiorite, bracketing the Mazatzal tectonic event between 1,680 and 1,625 Ma.

East-dipping Paleozoic and Apache Group strata, Pinal Schist and Johnny Lyon Granodiorite are truncated by several low-angle faults, which contain Paleozoic strata and some Apache Group strata in the upper plate. These plates are thought to be northeast-directed Laramide thrusts. These strata occupy the high area around Keith Peak (10:15), Sheep Camp Ridge and Javelina Hill (to the northeast behind Keith Peak).

The low-angle faults are intruded by Tertiary lamprophyre and rhyolite dikes (Cooper and Silver, 1964). **1.0**

36.6 Milepost 301. The southern Galiuro Mountains appear in the far distance behind the east end of the Little Rincons at 9:00. The southern Galiuro Mountains are mostly 28-22 Ma old ignimbrites which unconformably overlie pre-Tertiary rocks. See Creasey and Krieger (1978) for a discussion of volcanic stratigraphy in the northern Galiuro Mountains. **1.2**

37.8 Exit 302. Arizona 90 south to Fort Huachuca and Sierra Vista. The field trip will turn south here on Arizona 90.

To the east are badlands in flat-lying lake beds of the late Pliocene St. David Formation, which occur in a local basin within the complex San Pedro Valley graben system. Numerous age dates reported by Scarborough (1975) from tuffs interbedded with lake sediments below the fluvial member of the St. David Formation range from 2.5 Ma to 3.2 Ma. **0.1**

37.9 Milepost 291 (Arizona Highway 90). for next 0.9 miles road-cuts on both sides of the road are in flat-lying, red-brown, Holocene to Miocene, pediment-forming sands and gravels. **3.0**

40.9 Milepost 294. Northern end of the Whetstone Mountains are at 1:00 to 2:30. High ridges closest to the road at 1:30 are Precambrian Y biotite-chlorite granodiorite porphyry and quartz monzonite. The higher ridges on the skyline at 2:00 are Cambrian Bolsa and Abrigo quartzites, Mississippian Escabrosa limestone and Devonian Martin Formation. The Paleozoic overlies the Precambrian here unconformably and in places Drewes has mapped a thrust fault at this contact with transport from west to east. **3.0**

43.9 Milepost 297. Quarry on hillside at 2:30 is the site of the old Ricketts Mine which exploited a very thick white quartz vein for silica flux. The quartz vein occurs at the contact betweeen Precambrian Y alaskite and quartz monzonite. **1.9**

45.8 Rest Area. The prominent hill at 3:00 is capped by cliff-forming Cambrian Bolsa quartzite that dips to the west at about 20°. The Bolsa is intruded by a sill of fine-grained Cretaceous granodiorite that is the slope former. Pinal schist forms the lowermost slopes of the hill. Middle Canyon is at 3:30 and the low hills at

4:00 are Precambrian alaskite and schist. The Lone Star Mine produced 20,000 tons of fluorite between 1946 and 1967 from a vein in the Pinal Schist. The James Mine was a small mine that produced several hundred pounds of scheelite and wolframite concentrate from quartz veins in the alaskite. The hills in the foreground at 2:00 are capped by cliffs of west-dipping Bolsa quartzite. The prominent ridges on the skyline from 1:00 to 3:00 are Mississippian Escabrosa formation that strikes NNW and dips to the west at angles between 20° and 30°. It overlies Devonian Martin Formation and Cambrian Bolsa quartzite that forms the cliff halfway down the slope. The small foothill in the middle distance is also Bolsa quartzite overlying Pinal Schist. **3.6**

49.4 Hills in the middle distance at 3:00 are north-striking, west-dipping (±25°) Paleozoic units. The hills are capped by Pennsylvanian Horquilla limestone that conformably overlies Pennsylvanian Black Prince limestone, Mississippian Escabrosa limestone and Devonian Martin Limestone.

The high ridges on the skyline at 3:00 are made up of members of the Permian Scherrer formation. Two, north-striking thrust faults occur just below the ridge top. These thrusts enclose Scherrer formation and Permian Epitaph carbonate and overly Permian Colina limestone and Pennsylvanian Horquilla units which form the lower slopes (Wrucke, et al, Drewes, 1980). **2.5**

51.9 Milepost 305. At 4:00 the foothills are capped by Permian Horquilla limestone that overlies Black Prince limestone (Pennsylvanian) and Mississippian Escabrosa and Devonian Martin Formations. The dun-colored hills that form the skyline are Cretaceous Bisbee group sediments that have been intruded by a Laramide granodiorite porphyry. The highest part of the range is underlain by this toval stock.

East of the hills on the skyline is the Mine Canyon area in which Wrucke et al (1983) report a porphyry copper target near the Nevada and Mascot mines with a resource reserve of 32 million tons of 0.28% copper and 0.01% molybdenum. The mineralization occurs in a Laramide grandiorite and adjacent skarns in Permian carbonates.

The lower group of hills at 2:00 to 3:00 that are separated from the Whetstones by Mescal Creek are a block of Permian sediments that have been strongly faulted by east-west high-angle faults. The Mescal Creek drainage follows the trace of one of these structures - the Mescal Spring fault zone. The sharply pointed, conical hill at 3:00 (south of the fault) is capped by Scherrer Formation which overlies Permian Epitaph and Colina carbonates. The prominent cliff-former on the ridge line, south of the conical hill is Colina limestone, (Wrucke, et al, 1983). In this small range the middle member of the Epitaph Formation is gypsum-bearing and some of the beds here are up to 33 feet thick. This particular locality is on the east-facing slope of the conical hill at 3:00. **2.0**

53.9 Milepost 307 to 308.5. Community of Whetstone mostly on east side of the road. Directly ahead are the main ranges of the Huachucas. **1.4**

55.3 Junction of Arizona 90 with Arizona 82. Turn left towards Tombstone. For the next eight miles the road crosses Holocene to Miocene gravel of the San Pedro valley. As we face south we view the Huachuca Mtns. The foothills of the range are of the range are Precambrian granites overlain unconformably by Cambrian quartzines and Devonian and Mississippian Martin and Escabrosa Formations. At the foot of the range, striking NW and dipping NE is the Nicksville Fault (Drewes, 1983) that is down to the northeast. Exposures on the down-dropped side of this fault include small outcrops of Permian/Pennsylvanian carbonates and Bisbee Formation. **5.0**

58.3 Milepost 58 (Arizona 82). Low hills at 3:00 are Tertiary Bronco volcanics which are comprised of a lower andesite and an upper member that is predominantly quartz latite ($\pm$72 Ma). At 1:00 are the Tombstone Hills. **3.0**

61.3 Milepost 61. Road descends through cuts in pediment gravels adjacent to the San Pedro wash. **0.2**

61.5 Cross the San Pedro. **1.0**

62.5 Road ascends through roadcuts in valley gravels. **2.8**

65.3 Milepost 65. Prominent hills at 3:00 are Bronco volcanics. The highest hill on the right is "The Dome". **2.5**

67.8 Junction with U.S. 80. Turn right towards Tombstone (milepost 314 on U.S. 80). **1.3**

69.1 Road ascends through cuts in gravels (subhorizontal). **1.2**

70.3 Enter Tombstone. Boothill Graveyard on left. Road log will commence after Tombstone tour at Milepost 318 on south side of Tombstone.

ROADLOG - TOMBSTONE TO BISBEE

Modified from the log of Stanley B. Keith and Jan C. Wilt that was prepared for the "Land of Cochise" meetings in 1978. This road log commences at milepost 318 on the south side of Tombstone, driving southeast.

0.0 Milepost 318. Recommence road log driving southeast from Tombstone. For next mile, roadcuts are in Plio-Pleistocene alluvium overlying bedrock pediment cut on upturned Bisbee Group. The Tombstone Hills at 3:00 are separated from the Dragoon Mountains at 9:00 by a broad valley about 8 mi wide which marks the position of a northwest-trending Basin and Range graben of unknown depth. Note cut and fill aspect of coarse terrace alluvium which overlies finer-grained valley fill in roadcuts. Also note locally thick caliche layers in roadcuts. **1.4**

1.5 Roadcuts on right are in Bisbee Group within downthrown block north of east-striking Prompter fault. Ridge to south at 1:00 to 2:00 is north-dipping Horquilla Limestone in block south of Prompter fault which is intruded by 62 Ma rhyolite porphyry. **0.6**

2.0 Milepost 320. Hills at 9:00 to 10:00 are Miocene to Upper Oligocene andesites and dacites (Turkey Track equivalents ± 26 Ma). East of these hills the low-lying topography is underlain by the Jurassic Glesson quartz monzonite that hosts gold in quartz vein stockworks at Gold Camp currently being drill evaluated. **1.0**

3.0 Milepost 321. Hills to left are Horquilla and Earp formations with complicated bedding attitudes. Davis Road turn-off east to Gleeson. **1.0**

4.0 Roadcuts on right and left for next 0.2 miles are in Martin and Escabrosa units at top of the hill and in Colina Limestone near bottom of hill. These units are intruded in this area by a number of small bodies of Laramide age felsic porphyries (latîtes and dacites). Note fault and drag fold in roadcut on right at first road cut. Numerous small faults are exposed in the roadcuts that are not obvious in the outcropping section. **1.0**

5.0 Milepost 323. Intricate bedding attitudes in Paleozoic strata west of road indicate complicated structural history of Tombstone Hills. They were mapped and described by Gilluly

(1956) who argued for the presence of two orogenies. The first orogeny formed east-trending folds and reverse faults related to a north-south to north-northeast/south-southwest compression after deposition of the Bisbee Group and before deposition of the Bronco Volcanics.

The first orogeny was followed by widespread deformation, intrusion (72 Ma) and mineralization from a second orogeny. This orogeny caused north-trending folds, north-striking reverse faults, and strike-slip movement on east-west faults near and after 72 Ma. His second orogeny has been correlated by many workers with the Laramide.

Davis (1981) views the Tombstone Hills as a comparatively undeformed block in a large, northwest-trending, basement-cored uplift. Its structural margins are in the Dragoon Mountains to the northeast and the Huachuca Mountains to the southwest. Jones (1966) offered another interpretation; "that in Laramide time rising magmas; (a) broadly domed the area of the Tombstone Hills causing local compressional features of diverse trends but primarily causing normal faulting, (b) pushed up the Precambrian granite, (c) permitted access to the surface of various extrusive rocks, and (d) concluded their active rise by intruding some of the faults and then solidifying in the near surface rocks.

Prominent unnamed hill at 4:00 consists of Colina Limestone intruded by a conspicuous light colored 62 Ma old rhyolite. Note small, sharp kink fold in cliff-forming ledges of Colina Limestone above rhyolite intrusion. **1.0**

5.0 Between mileposts 323 and 324 look to the west for a view of the southern Tombstone Hills. The distinctive ridge is Colina Ridge and contains the type section of Permian Colina Limestone on the western slopes near the north end. Epitaph Gulch at the west end and the eastern slopes of the north end of Colina Ridge contain the type section of the Permian Epitaph Dolomite. Horquilla Peak (high peak at 10:00) contains the type section of the Pennsylvanian Horquilla Limestone.

Regionally the Horquilla disconformably overlies Black Prince Limestone and is gradational into the overlying Earp Formation. On Horquilla Peak the eroded Horquilla is 1,000 ft thick and consists of a series of thin-bedded, blue-gray limestones (pinkish gray on fresh fracture) with a few thicker beds which form ledges and a few reddish-weathering shaly limestones near the top.

The Earp Formation is 595 ft thick here (Gilluly and others, 1954). It generally forms gentle slopes and low areas because of the greater percentage of shales (particularly in the lower part) and clastics than in either the gradationally underlying Horquilla Limestone or the gradationally overlying Colina Limestone.

The Colina is 633 ft thick on Colina Ridge, but is 947 ft thick on the unnamed ridge extending southeast from Horquilla Peak from at 3:00 only a mile from Colina Ridge (Wilt, 1969). The variation in thickness is probably attributable to the varying downward extent of diagenetic dolomitization in the Epitaph (Patch, 1969), as the same bed can be traced from undolomitized Colina into dolomitized Epitaph. The Colina Limestone is dominantly a dark-gray, thick-bedded limestone that forms cliffs characterized by massive ledges and steep slopes only slightly less precipitous than the Escabrosa. On fresh fracture the limestones are very dark gray to black and have a fetid odor.

The lower contact of the Epitaph Dolomite is taken as the first massive dolomite above the transitional zone of partially dolomitized limestone at the top of the Colina. The lowest member is 200 ft of medium- to light-gray to yellow and buff, medium-bedded dolomite containing silica nodules weathering as knots on the surface. It is exposed as the dip slope on the east side of Colina ridge. The middle part of the Epitaph is exposed in the saddle at 3:00 and 4:00 between Colina Ridge and the low foreground hill. The middle part of the Epitaph consists of about 250 ft of poorly exposed, reddish, sandy limestone or limy sandstone containing shallow water indicators such as crossbedding, ripple marks and intraformational breccias, and a higher proportion of maroon shale and less dolomite. The upper part of the Epitaph, also exposed in the same hill, consists of over 100 ft of bluish-gray, thin-bedded limestone.

The Epitaph is unconformably overlain by Glance Conglomerate containing boulders and pebbles of dolomite, limestone, granite, rhyolite and quartzite with an angular discordance of about 15 degrees and with an erosion surface with relief exceeding 20 ft in 300 ft (Gilluly and other, 1954).

The large hill at 10:00 is Government Butte which is described after milepost 328. The Huachuca Mountains are on the skyline from 12:00 to 2:00. **1.0**

6.0 Milepost 324. Hill to left at 2:00 contains well-exposed, slope-forming Earp Formation in lower slopes. The Earp is in fault contact with Colina Limestone which is anticlinally folded. **1.0**

7.0 Milepost 325. Bridge over Government Draw. **1.0**

8.0 Milepost 328. From milepost 327 to milepost 329 Government Butte is the large hill on the east side of the road. At this point we will face north.

GOVERNMENT BUTTE

Introduction

Government Butte consists of upper Paleozoic strata, the type sections of which were measured in the Tombstone Hills. From this stop a controversial east-west structural zone is visible at the southern end of Government Butte. This structure is related to complex "Laramide" structural development here and in the southern Tombstone Hills.

Stratigraphy

The lower southern slopes of Government Butte from this view contain typical outcrops of Horquilla Limestone. At the west end of Government Butte (12:30) Horquilla Limestone forms alternating thin ledges and slopes; above this is a slope-forming unit with a few orange limestone ledges. This is the typical outcrop expression of the Earp Formation which contains the Pennsylvanian-Permian boundary. Above this slope interval are bluish-gray, thick ledges and slopes typical of the Colina Limestone. Colina Limestone comprises most of Government Butte, particularly on the north side.

The strata just described continue east through several east-striking faults mapped as high-angle reverse faults and thrust faults by Gilluly (1956), each with the north side slightly up. Consequently, the slope-forming Earp section is structurally higher in a topographic reentrant at 1:00. Farther east Earp Formation is again structurally lower and crops out at the southern base of Government Butte from 1:00 to 2:00.

Structural Geology and Tectonics

The southern slopes of Government Butte are on the complexly folded and faulted southern limb of a large, west-plunging, anticlinal fold which makes up the bulk of Government Butte. Numerous bedding plane "thrusts" may indicate flexural slip. Gilluly (1956) showed the southern edge of the butte to be marked by numerous east-striking, steeply north-dipping reverse faults.

The structures in Government Butte are part of a 25-mi-long (and possibly as much as 50-mi-long) east-west deformational belt, The Sawmill Canyon Complex Fault of Drewes (1980 & 1981.) The Government Butte block is separated from the flaylying Bisbee Group strata of the northern Mule Mountains by a complex, east-west structural zone of folding and reverse faulting, which passes through the notch at 2:45. This zone extends westward from Government Butte to the southern Charleston Hills (10:00), where east-west folds in the Bisbee Group are truncated by andesites of the Bronco Volcanics. From there the zone may continue west, concealed under alluvial cover, to the north end of the Huachuca Mountains at 9:00, where it may be represented by the Kino Spring fault zone and related structures. The age of this deformation is post-Bisbee Group (about 94 Ma) and pre-Bronco Volcanics (75(?) Ma), which is earlier than the Laramide.

To the east this zone extends through the Bisbee Group as a south-facing monocline. Interestingly, the Bisbee Group has flexed, but not faulted, over the trace of the east-west tectonic zone as it also has over the eastward projection of the Dividend fault (Hayes and Landis, 1964). The interbedded siltstones and shales of the Bisbee Group seem to be capable of absorbing strain by flexure rather than by the brittle rupture which is more common in the underlying Paleozoic section. This theme is persistently repeated throughout deformed Phanerozoic strata of south-eastern Arizona. **1.0**

11.0 Milepost 329. Hills from 9:00 to 11:00 are the Mule Mountains which here are composed of subhorizontal, Cretaceous Bisbee Group sediments. **1.5**

12.5 Hill at 9:00 is Devonian Martin Formation. **0.1**

12.6 Bridge. Outcrops in arroyo are Escabrosa Limestone. **0.4**

13.0 Milepost 331. Low hill at 3:00 is Horquilla Limestone. Juniper Flat granite (Jurassic) intrudes the Martin in low ridge at 12:00 to 2:00. Outcrops of the granite are next to the road on the west side. Low ridge to left is Cambrian Abrigo and Bolsa quartzite which are cut by granophyre dikes, presumably of Juniper Flat granite. **1.0**

14.0 Milepost 332. Roadcut in east- and northeast-striking fault slices of aphanitic dolomites of Martin Limestone, Juniper Flat Granite, and Percha Shale(?). Strike-slip, oblique-slip and dip-slip slickensides indicate a complicated movement history. Note brittle aspect of this deformation. **0.3**

14.3 Junction of U.S. 80 and Arizona 92. Hill at 3:00 is capped by crinoidal Escabrosa Limestone. Slope-former at base of hill is Martin Limestone, which contains aphanitic dolomite and sandstone and siltstone lenses. At the base of the Escabrosa cliff is a well-vegetated slope-forming unit that is probably olive-green mud-shales of Percha Formation. The yellowish-gray ledge below the presumed Percha Shale is probably a sandy dolomite in the upper Martin Limestone.

Both Martin and Escabrosa are cut by granophyre dike apophyses of Juniper Flat Granite. Note west-striking fault which offsets these Paleozoic strata.

Facing south at 12:00 Horquilla Limestone in hills to right (10:30 to 12:00). Mississippian and Pennsylvanian strata are well exposed in the long ridge from 8:30 to 11:45. The base of the northwest end of the ridge at 11:30 is massive crinoidal limestone in upper Escabrosa Limestone. At 10:00 is the basal siltstone-shale-micrite unit of Horquilla Limestone. The lower slope-forming unit of Horquilla Limestone rests unconformably on limestones of Black Prince Formation. Above the slope former, prominent fusulinid-bearing limestone ledges occupy the upper slopes of the ridge from 9:30 to 10:45. The top of the ridge is a sill-like intrusion of Juniper Flat Granite.

In the low ridge on right, west-dipping Bolsa Quartzite, overlain by Abrigo Formation is intruded by a prominent Juniper Flat Granite dike. These dikes are part of a prominent northwest-trending dike swarm which cuts Paleozoic rocks in Escabrosa Ridge to the southeast and in the unnamed low hill to the north. As mapped by Gilluly and by Hayes and Landis (1964), these dikes constitute a separate intrusive mass that is largely separated from the larger intrusion. The prominent massive cliffs of granite are also designated as Juniper Flat Granite by Gilluly and Hayes and Landis.

After the road junction, U.S. 80 swings to the southeast and follows a valley that is the trace of the Dividend Fault. This fault separates Juniper Flat granite, that is much of the area on the left of the road, from Precambrian Pinal schist, which is on the right of the road, the south side. The Pinal is unconformably overlain by Paleozoic sediments. **0.2**

14.5 Roadcut on right is southwest-dipping lower Abrigo Formation with numerous faults. **0.5**

15.0 Milepost 333. Roadcuts on left side of road are in middle carbonate member of the Cambrian Abrigo Formation.

15.2 Bridge across Banning Creek.

16.0 Milepost 334. Roadcuts are in southwest-dipping Bolsa Quartzite overlain conformably by Abrigo Formation. These are intruded at the southeast end of cut by a dike of Juniper Flat Granite.

From Milepost 334. Numerous roadcuts on the left of the road expose cobble-boulder colluvium which unconformably overlies Juniper Flat Granite and sheared Pinal Schist. The sheared schist may represent gouge related to the Dividend fault or deformation related to intrusion of the Juniper Flat Granite. For about 3 miles the highway nearly parallels the contact between Juniper Flat Granite and Pinal Schist. High ridge to left is Escabrosa Ridge. For the next four miles roadcuts are in locally mineralized and altered Juniper Flat Granite and sheared Pinal Schist. **5.0**

21.0 Milepost 339. As we top the ridge, Juniper Flat Granite crops out in immediate vicinity. Visible terrain to the southwest is mostly Pinal Schist intruded by dikes presumably related to the Juniper Flat Granite. Some of the ridge tops are capped by Bolsa Quartzite resting unconformably on Pinal Schist.

Mule Pass tunnel cuts through drainage divide. Tombstone Canyon drains eastward to Sulphur Springs Valley and Banning Creek drains northwest to San Pedro Valley. **0.6**

21.6 U.S. 80 Bisbee business loop intersects from the left. **0.2**

21.5 Bridge. Roadcuts ahead in Juniper Flat Granite. Turnoff to Bisbee and Tombstone Canyon on right. **0.1**

21.6 Roadcuts ahead will be in Pinal Schist for 0.8 mi. Note extremely deformed character of Pinal Schist, which is probably related to motions along Dividend fault. The Dividend fault is difficult to trace northwest of these roadcuts. Its projected trace has been a matter of considerable speculation. **0.8**

22.4 Pinal Schist with thermal alteration. Pinal Schist is here separated from Abrigo Formation by a northeast-striking fault strand of the Quarry fault. **0.4**

22.8 Bolsa Quartzite in roadcuts on both sides of road. Note numerous faults within the relatively competent Bolsa. The contrasting deformation styles in Bolsa Quartzite and Abrigo Formation illustrate the response to stress of rocks of differing ductilities.

The Bolsa Quartzite was named by Ransome (1904) from exposures in Bolsa Canyon on the southwest side of Escabrosa Ridge, although the best exposures are on Mount Martin. The Bolsa unconformably overlies Precambrian Pinal Schist and grades upward from a basal conglomerate to coarse-grained, cross-bedded quartzites. The upper layers of the 430 ft-thick Bolsa are thinner-bedded, more vitreous, fine-grained orthoquartzites. It is conformably overlain by the Late Cambrian Abrigo Formation. **0.1**

22.9 Abrigo Formation in roadcuts on both sides of highway. Note numerous kink folds in the comparatively incompetent strata of Abrigo Formation. Also note distinctive "graham cracker" texture and ribbed "tire track" aspect of carbonate beds within this part of the Abrigo.

The Cambrian Abrigo Formation was named by Ransome (1904) from exposures in Abrigo Canyon, 3 miles southwest of Bisbee. The Abrigo on Mount Martin is a 770 ft-thick sequence of dark greenish-yellow, thin-bedded, cherty-laminated limestones, which alternate with calcareous shale, and with some sandy limestone and sandstone in the upper part. **0.1**

23.0 Milepost 341. Covered area to left conceals Martin Limestone and much of the Abrigo Formation. Martin Limestone was named by Ransome (1904) from exposures on Mount Martin on Escabrosa Ridge south of the highway. **0.4**

23.4 Escabrosa Limestone on left. Escabrosa Limestone was named by Ransome (1904) for exposures on Escabrosa Ridge, south of the highway. It consists of about 700 ft of high cliff-forming, thick-bedded, nearly white to dark-gray, crinoidal, granular limestones (see Armstrong, this guidebook.)

Castle Rock, the conspicuous turreted crag which overlooks downtown Bisbee is down and to the right of the highway. Castle Rock is mainly composed of Escabrosa Limestone and Martin Limestone which are in fault contact with the Dividend fault to the north.

Excellent views overlooking Tombstone Canyon and Bisbee (to the right) for the next mile. **0.2**

23.6 Road to right to business section of Bisbee and the picturesque Brewery Gulch section. Bisbee, one of the more colorful mining towns in the American Southwest, was named for Judge DeWitt Bisbee of San Francisco, a shareholder and fatherin-law of one of the promoters in the Copper Queen Consolidated Mining Company. Judge Bisbee never visited the town which bore his name.

To the right is the Copper Queen mine; worthwhile mine tours are offered daily. Within the underground workings of the Copper Queen mine, some of the world's finest examples of secondary copper minerals have been found. The Warren district is particularly famous for its stalactitic and crystallized specimens of azurite and malachite. It is said that high school proms and Bisbee town council meetings were held in underground caverns adorned with spectacular malachite stalactites locally covered with crystallized rosettes of azurite. To the left just beyond the Copper Queen is a small amount of Martin Formation of Devonian age. **0.6**

24.2 Sacramento Hill, what is left of it, is on the right. Along this stretch of road are spectacular roadcuts of alteration related to porphyry copper mineralization in alkali granite of the Jurassic Sacramento stock. The surfaces of hills in this vicinity are covered by a bright red oxidized zone which follows the contours of the hills. This constitutes the classic oxidized zone present over many porphyry copper sulfide systems. Below the oxidized zone is hypogene (primary quartz-sericite-pyrite) alteration in the Sacramento stock. Note how the upper oxidized zone extends down into primary altered rock along fractures. The red iron oxide cap was the flag that initially drew many of the old prospectors into what are now major porphyry copper districts. **0.2**

24.4 Turn left from Lavender Pit overview on U.S. 80.

The Lavender Pit is one of the smaller open pit porphyry copper mines in the United States. To the right are the remains of Sacramento Hill. Across the pit one can see where the pit intersected old underground workings. The power house at 10:00 is at the head of major slumpage.

The Lavender Pit, which began stripping in 1954, included the Sacramento Pit, initiated in 1913 at what is now the northwest end of the pit. The Lavender Pit was named for Harrison Lavender, who became mine superintendent of the Copper Queen Mine in 1931, having started as a miner, and became general manager in 1937 for Phelps Dodge.

The head frames across the pit at 10:00 are the Campbell shafts. This mine was the main underground producer in the Warren district, extending 3,600 ft deep and supplying three-fourths of the total district production. The ore bodies consisted of rich lead-zinc-copper replacement bodies in Escabrosa, Martin and Abrigo formations.

Production data for the Warren mining district is as follows: 8,051,276,000 pounds of copper; 309,756,000 pounds of lead; 378,450,000 pounds of zinc; 2,726,000 ounces of gold; and 102,861,000 ounces of silver. Although the Warren district is popularly known as a copper camp, not so well known is the fact that the Warren district is by far the leading precious metal district in Arizona. It leads in both silver and gold production by a large margin.

The Warren mining district was named after George Warren, a prospector grubstaked by the army scout John Dunn, who had noticed rich ore in 1877 while camping in Mule Pass in pursuit of Apaches. Warren and Dunn owned the Copper Queen which merged with Phelps Dodge after 1880.

The upper benches of the southeast pit wall (9:30 to 11:30) are in maroon outcrops of Glance Conglomerte containing over 90% Pinal Schist-clasts. The Glance rests depositionally on the Jurassic Sacramento stock in the greenish brown outcrops of the lower benches (11:00 to 1:00). Glance Conglomerate here contains mineralized clasts of Pinal Schist. The southwest pit wall (12:00 to 2:30) is contact-altered Horquilla Limestone, Earp Formation and Colina Limestone (upper benches), which are overlain at 12:00 by Glance Conglomerate. The entire south wall of Lavender Pit has been downfaulted along the west-northwest-striking Dividend fault which traces through the center of the pit. The north wall of the pit is in upthrown Pinal Schist and is intruded by the Sacramento stock, named for Sacramento Hill at 3:00. Behind the ridge north or the road, Pinal Schist is overlain by Glance Conglomerate (50-200 ft thick). Thus 5,000 to 6,000 ft of Paleozoic section has been removed from the north block in Triassic-Jurassic time by activity along the Dividend fault. Bisbee is anomalous in that it is the only known Jurassic porphyry copper deposit in southeastern Arizona.

The Bolsa Quartzite, Abrigo, Martin, Escabrosa, Horquilla and Colina limestones were intruded by the Jurassic Sacramento stock along the Dividend fault. The initial stage of mineralization was intense silicification and pyritization of limestone, schist and porphyry. An estimated 500 million tons of pyrite were deposited during this stage. Additional intrusive activity formed dikes, sills and irregular bodies and at least two stages of intrusive breccia. Copper, followed by lead-zinc mineralization, is associated with this stage. Following renewed activity on the Dividend fault, the resulting pattern is that of a rimless spoked wheel cut in half at the Dividend fault. A hub of pervasive mineralization, centered on the one-mile diameter Sacramento stock, has replacement bodies in brecciated Abrigo and Martin formations along faults radiating out from this hub. The mineralized zones may range up to 2,000 ft vertically, 500 ft horizontally and extend to over 12,000 ft from the Sacramento stock. Final depths are in excess of 3,600 ft. Individual ore bodies ranged up to 1 million tons in size but about two-thirds of them were less than 25,000 tons.

Exhaustion of minable open pit reserves and the extremely high cost of underground mining, exploration and maintaining openings in the highly shattered altered rocks forced the final closing of the operation in 1975.

DAY 2
ROAD LOG

ROAD LOG - BISBEE TO I-10 (SECOND DAY)

Compiled by Nora Colburn Sept./Oct. 1988

South end of Tombstone Canyon road joins US 90 (south) 1.5 miles to junction. Scenic overlook to Lavender open-pit, on the southeast; dividend fault on the northwest: 0.6 miles to junction.

0.0 Circle-type intersection of US 80 and AZ 82, near junction with Bisbee-Warren Road. On the south and southeast edges of the loop are outcrops of Glance Conglomerate, the basal member of the Bisbee Group. HEAD EAST through Mule Gulch, towards Douglas. This route follows the SE extension of the Dividend Fault as it traverses the Lower Cretaceous Bisbee Group sediments, deposited at the northwestern end of the Chihuahua Trough. Several NE-striking normal faults offset these units down to the northwest.

1.9 Milepost 345. Within the Morita Formation, which overlies the Glance Conglomerate. High point to the N-NE is Grassy Hill, capped by the Cintura Formation. The youngest unit in the Bisbee Group, the Cintura Formation is near-shore and fluvial clastics, in part reddish-colored, and reaches 540 m in thickness. Lower down the massive, prominent limestone unit (up to 31 m thick of shoal and some reef facies) is within the Upper Member of the Mural Limestone. This Upper Member (about 82 m thick) pinches out to the north and south. So that the Mural Limestone here, near its type locality at Mural Hill, consists of two members. The Lower Member is about 131 meters of gray-green, slope-forming sandy limestone, sandstone, siltstone and shale, which overlies the uppermost prominent sandstone of the Morita Formation (up to 780 to 1260 m thick).

This general area is within the northern end of the Gold Hill mineral district, forming part of the Warren District. Of presumed Late Cretaceous age, this mineralization consisted of 1,600 oz. gold and 52,600 lbs. manganese, plus very minor silver, which was mined from 1901 to 1911.

4.4 to 4.7 Note that the Mural Limestone units and the underlying "redbeds" of the Morita Formation have fairly consistent 15-40° northeasterly dips. However steepening occurs (in some places to 80 or more degrees), as can be seen road crosses the southward extension of the Mule Fault and leaves the southern end of the Mule Mountains.

4.9 TAKE ELFRIDA TURN OFF and continue ENE on paved road for about 8 miles. Last outcrop was in Cintura Formation. Gravel road branching to north immediately after turn was completed, is sometimes called the 'High Lonesome' road.

5.5 Tavern on left, road descends slope into southern portion of the Sulphur Spring Valley; at 12:00 are the Perilla Mountains, located south of the Swisshelms and Pedregosa ranges.

6.5 Bald Knob extrusive rhyodacitic flows and pyroclastics (Oligocene-Miocene) at 11.50, located about 15 miles north of Douglas.

8.7 to 9.4 Arroyo on left, the extreme fine-grained nature of the soils may be indicative of playa-like conditions of deposition. In general view at 12:00 is the area of low-lying Cretaceous? andesitic volcanics and sediments between the Swisshelm Mountains on the north, the Perilla Mountains on the south and the Pedregosa Mountains toward the northeast.

10.0 Intersection with Frontier Road. It is asphalted all the way north to its intersection with Davis Road. 10.83 Cross N-S ranch road.

13.0 STOP SIGN. TURN LEFT/ NORTH on to Central Highway, leading to Mc Neal, Elfrida and Wilcox. Almost immediately road crosses arroyo of south-flowing Whitewater Draw; nearby houses and school form the community of Double Adobe.

13.3 to 15.1 Central Highway road continues northward, slightly west of the axis of the Sulphur Springs Valley. Light colored patch at 1:15 is granitoid mass (Upper Oligocene-Miocene), on the western side of Swisshelm Mountains which extend from 1:00 to 2:30, the Pedregosa and Perilla ranges extend southward to about 4:15. Two "double" peaks can be seen at 10:30 AND 11:30, these are Hay Mtn., Signal Hill and Outlaw Mtn. and Sugarloaf Hill formed in the Tertiary rhyolitic volcanics and Jurassic granite/quartz monzonite of the southern Dragoon range. From 9:45 and back are the eastern slopes of the Mule Mountains, consisting almost entirely of the upper units of Bisbee Group.

17.2 Chili factory.

19.2 Bagby Road on west. Whitish granitoid patch in Swisshelms now at 2:00. The darker, brownish layer overlying lighter-colored rocks mark the contact of at least one thrust plane, separating older units (Precambrian granites or Paleozoic sediments) above from lower younger units (sediments of the Bisbee Group).

21.1 Ranch on left. Squaretop Hills can be seen at 1:00; distant mountains at 12:30 are the Dos Cabezas; the "double" peaks of the southern Dragoons begin to overlap part of the Tombstone Hills at about 9:45. Brown Peak may be at 10:45 or 11:00.

22.4 STOP SIGN. Intersection with Davis Road, Elfrida is 6 miles to the north-northeast; McNeal is 2 miles east. Patch of light-colored rocks in Swisshelms at 2:15; the southern end of the Dragoon Mountains begins with knob at 9:40 to peaks west of Courtland at 10:00 to 10:45.

24.7 At 1:15 are the isolated Squaretop Hills, composed of Tertiary rhyodacitic volcanics.

25.0 to 25.5 Road makes jog to east, then north again.

26.0 Approaching Elfrida; good views of the southern Dragoon Mountains and scattered hills from 8:50 to 10:45; at 11.00 reddish slope marks the western edge of the Courtland mining and townsite area.

27.8 Cross 12th Street at southern edge of Elfrida.

28.4 STOP SIGN at intersection, continue NORTH on US 666.

29.3 MP 25. Approaching turn off to Gleeson road, a sharp left, shortly after posted 55 speed limit sign.

29.7 TURN LEFT - WEST on to GLEESON ROAD.

29.8 Sign: "Courtland - 7, Gleeson - 11 miles, Tombstone -27 miles." Mule Mountains at 9:15 - 11:00, scattered hills to 12:20 and northern portion of Southern Dragoons, with isolated peak at 2:10. The isolated 'cone-shaped' hill at 11:30 is Sugarloaf Hill, composed of quartz latite (74.50 ± 2.90, K-Ar/bio, from welded tuff (Reynolds and others, 1986). At the eastern base of the Sugarloaf quartz latite is a patch of Q-T basalt.

33.8 Road intersection from south; Cochise Packers. Visible toward the NW from road mileage 33.8 to 35.6 are the three northwest-trending ridges, formed from single to multiple fault slices. This is the Courtland-Gleeson area. The southern gray-colored ridge at 12:45 - 1:15 is a mixture of Escabroas and Horquilla limestones, and Earp Formation positioned on top of Copper Belle monzonite porphyry. The middle ridge is less well defined but is notable for reddish coloration of the Bolsa quartzite, with Browns Peak at the southern end. This is Turquoise Ridge has Cretaceous rhyolite along its eastern base, and the Cambrian sediments above some Precambrian Pinal schist, intruded by Triassic monzonite. The easternmost ridge at 1:45 - 2:00 a eastward-dipping jumble of both Lower and Upper Paleozoic sediments above Triassic monzonite, the Copper Belle in this case.

35.6 Ranch road from SE. Road begins to curve to NW; ranch road, cattle guard and another ranch road at cumulative mileage: 36.0.

36.5 Cattle guard. Sugarloaf Hill now at 10:00.

37.0 PAVEMENT ENDS, graded dirt road begins.

37.4 Dirt joins at angle from south. Nearing intersection to Courtland. Sign: "Gleeson -4 miles, Tombstone - 15 miles" ahead.

37.5 TURN NORTH/RIGHT ON TO ROAD TO COURTLAND (4 miles) and PEARCE (12 miles). An additional mileage log will start at this point.

37.6 (0.0) ON ROAD TO COURTLAND. Limestone hills at 9:00. This is the southern edge of the Turquoise Mining District. Mineralization is associated with the Jurassic monzonite porphyries. Production was primarily silver and copper; 1,049,00 oz Ag; 21,600 oz gold; 50,397,000 lbs. Cu; 5,747,000 lbs. lead, plus some 78,500 lbs. manganese, mined from 1902 to 1978. Additional, probably high-grade silver and copper was mined from 1883 to 1900. The Turquoise granite/quartz monzonite is named for a pale green-blue turquoise found in certain localities.

37.7-37.8 (0.1 - 0.2) Cross dip in wash. Road off to right at angle; some dumps are visible, as are scattered outcrops of carbonates.

38.0 (0.4) Cross under powerline.

38.1 (0.5) Cross cattle guard, powerline angles off into valley. Sugarloaf quartz latite knob at 9:00, with Abrigo to Horquilla fragments.

38.49 (0.89) Road off to right. Browns Hill at 10:00.

39.1 (1.5) Dirt road off to left.

39.6 - 39.8 (2.0 - 2.2) Cross a series of dips and washes; several roads go off in various directions.

40.1 (2.5) Bottom of dip.

40.3 (2.7) Cattle guard; south fork of Y-intersection on right leads to Elfrida (7 miles). Abandoned mining town of Courtland, which once had a population of 1,000 people, -1 mile ahead; Gleeson 4 miles back. Limestone hill at 12:00; cross wash.

40.4 (2.8) North branch of Y-intersection. Purple hills at 9:30 - 1:00; haulage railroad grade visible on eastern slope, as well as reddish alteration.

40.6 (3.0) Outcrops along road; Triassic Copper Belle monzonite feldspar porphyry.

40.7 (3.1) Ruin with cobbled-walls on right at 1:00. Still in monzonite porphyry; major workings and main part of town off at 9:00 - 12:00.

41.0 (3.4) Abandoned building at 1:00.

41.1 (3.5) Road junctions, take RIGHT fork; left branch goes around hills, now in limestone outcrops/hills.

41.2 (3.6) Tight right curve; limestone on right, may be Martin or Escabrosa. Mine workings now behind, occasional glimpses of Suphur Spring Valley ahead.

41.3 (3.7) Side road; rubbly, blocky limestone outcrop behind ruin.

41.4 (3.8) Concrete building foundation.

41.4 - 41.7 (3.8 - 4.1) Another curve to left; buildings plus tailings at 1:00. Mines in this immediate area include Mary, Silverton, and King Plomo. Bedrock along left side of road, showing steep bedding and Fe-oxide stained, altered marly limestone/siltstone, and black shale. Area from about 41.6; 4.0 miles, also has scattered dumps and mine workings. At 41.7; 4.1 = Small shaft and dump on right side of road. This may be the Germania mine, which Keith, 1973 describes as having a "blanket-like" copper carbonates and oxides in a thrust fault breccia, with

Bolsa quartzite in the upper plate and Carboniferous limestone in the lower. Other mines in this area are the April Fool and Maid of Sunshine.

About 41.75 (4.15) Small dump; road off to left, just before road curves right/east and uphill to U-curve to north.

42.0 (4.4) Ruin at 8:00; old road off to right; jumbled appearing limestone outcrop indicate road is possibly crossing over a thrust fault zone. Now out of Courtland. Occasional view Squaretop, Pearce hills beyond.

42.2 (4.6) Cattle guard; Sulphur Hills at 1:00.

42.6 (5.0) Milepost sign; in sandy wash, road narrows.

42.7 (5.1) Road intersects from right.

42.8 (5.2) Road intersects from left. Low-lying outcrops of Cretaceous Bisbee Group nearer to mountain front.

43.0 (5.4) Ranch road off to left. Central Dragoon Mountains from 8:30 to 11:00.

43.4 (5.8) Cross sandy washes. Middlemarch Pass at 8:30 - 9:00, Cochise Stronghold at 10:30 - 11:00.

43.7 (6.1) Hill immediately on right is probably one capped by andesite (33.90 ± 0.60, K-Ar, WR: Reynolds and others, 1986) over Sugarloaf quartz latite. Good view of Dragoon Mountains; north of Middlemarch Pass are the jagged peaks of Stronghold area at 10:00 - 11:30.

44.0 (6.4) Major sand wash.

44.1 (6.5) Ranch road on left.

44.3 (6.7) Ranch road; Pearce Hills and Squaretop Hills cross Sulphur Spring Valley from 12:00 to 3:00, visible when road rises on top of drainage divides.

44.7 (7.1) Ridge of Stronghold intrusive at 9:00.

45.2 - 45.5 (7.6 - 7.9) Cross several sandy washes.

45.8 (8.2) Ranch road from west.

46.2 (8.6) Cattle guard. Good view of Chiricahua Mountains at 3:00, Dos Cabezas Mountains at 1:30. Prominent ridge in Dragoon Mountains from 9.30-10.00; because of the overlaping thrust sheets the entire Phanerozoic sequence is telescoped and thinned. The lower slopes on this east side include Bisbee Group and non-Bisbee Group Cretaceous sediments and volcanics, both intruded by sill-like Oligocene rhyolitic dikes. From 11:00 to 2:30 the predominantly volcanic Pearce, Sulphur and Squaretop Hills show easterly dips.

47.3 (9.7) From 11:00 to 3:00 Pearce, Sulphur and Squaretop Hills; at 9:30 view of southeast side of Stronghold granite weathered spires.

48.1 (10.5) and 49.0 (11.4) Cross dips.

49.7 (12.1) Southernmost tuffaceous volcanics of Pearce Hills area. Mine dump ahead at 11:45; approaching Pearce and Commonwealth Mine.

49.8 (12.2) Cattle guard, small mine workings now at 1:00 on southwest side of hill; town of Pearce at 11:30.

50.5 (12.9) Now entering outskirts of Pearce.

50.9 (13.3) Road to right.

51.1 (13.5) CROSSROADS IN PEARCE. At general store is intersection of Middlemarch road from west; on right road goes to Commonwealth Mine and US 666 at 1 mile (junction is at MP 45.6); road north also continues 1.1 miles to US 666 (junction is at MP 47).

FIELD TRIP STOP WILL BE AT THE COMMONWEALTH MINE. TURN RIGHT. The next few entries assume travel direction is north out of Pearce.

51.6 (14.0) Cattle guard. Sulphur Hill and the more distant Pat Hills at 2:00-2:45, with the Dos Cabezas Mountains beyond at 1:00; Dragoon Mountains extend from 11:00 back and from 11:30 to 12:15 are the Red Bird, Gunnison and Steele Hills. Stronghold canyon is at 9:30.

52.2 (14.6) STOP SIGN. Pearce road intersects US 666 at MP 47. New cumulative mileage log will begin at this junction, HEAD NORTH.

Milepost 47 (0.0) JUNCTION OF US 666 (North) and Courtland-Pearce Road.

Milepost 47.9 (0.9) Arizona Sunsites Sign.

Milepost 48 (1.0) Treasure Road.

Milepost 49 (2.0) Be prepared for SHARP LEFT TURN AT IRONWOOD ROAD.

Milepost 49.1 (2.1) TURN LEFT/WEST on to Ironwood Road, a gravel road; COCHISE STRONGHOLD -10 miles.

2.2 Granitic spires at 11:15; at 12:00 white limestone unit visible on slope above NE extension of Stronghold granite.

6.8 COCHISE ROAD intersection. Forest Road 84 straight ahead to Cochise Stronghold (4 miles); graded road to north leads to Dragoon road (Willcox 27 miles).

7.3 (8.3) A series of cattle guards.

8.9 Cattle guard; power line off to south. Broken Arrow Baptist Camp road to right.

9.2 Camp buildings can be seen at 1:00, at base of granitic knob. Cross gravel wash.

9.3 (10.9) A series of cattle guards as road passes in and out of private land holdings; also repeated crossings of a rocky stream bottom.

11.1 Entrance to camp/picnic area as road diverges granite boulder. 203.7; fee area

0.0 Reset mileage as pass boulder on way out.

4.4 TURN NORTH/LEFT on to COCHISE ROAD.

0.0 Begin new cumulative mileage.

0.57 Ranch road.

1.05 Eastland Road.

2.1 Abandoned windmill; ranch house.

2.2 Better view of north end of main Dragoon Mountains; Mount Glen at 9:45-10:00.

3.2 - 3.3 Triple A Ranch entrance on west (pistacho orchards); power plant stack and building can be seen at 1:00 near AZ 666; Dos Cabezas main mass at 2:00, Gunnison Hills at 11:00.

4.0 Richland Road from east.

4.6 Ranch road both ways. When not hidden from view Red Bird Hills at 12:00 with Steele Hills beyond.

5.2 Steele Hills ? at 11:00 - 11:30.

6.1 STOP SIGN. TURN WEST/LEFT at intersection of Dragoon Road with Cochise Road to the south and the Yucca Ridge Ranch road to the north.

0.0 Begin new cumulative mileage.

0.3 Road parallels various power lines. Good view SW into Middlemarch area; Mount Glenn peak at 11:00; broad pass at 12:00 separates the Dragoon Mountains from the Gunnison Hills to the north.

0.7 - 2.25 Several roads from south; distinctive carbonate layering (Late Paleozoic units on the east side) in hills at 1:30.

2.8 Cattle guard. Golden Rule mine road. Actively mined from 1883 to 1957, the Golden Rule (Old Terrible, Manzoro, Santa Lucia) mine produced about 10,500 oz. gold; 16,300 oz. silver and 218,000 lbs. lead, plus 3,000 lbs. copper. Galena, pyrite and oxidized zinc ore is found in coarse, vuggy quartz and/or calcite veins. Host is Paleozoic limestone, and in the case of the Golden Rule it Cambrian Abrigo Formation. Mineralization is associated with trust-fault breccias and/or small rhyolitic porphyry plugs. A NE-striking basaltic dike, which cuts mineralized veins in the Abrigo, has been dated at 74.10 ± 2.00, k-Ar/W.R. (Reynolds and other, 1986).

3.8 - 4.0 Pass area. To the south thrust plates are dominant structures, in part repeating stratigraphic packages. While in the Gunnison Hills to the north, low-angle faults are not exposed and normal faults are more obvious. Cretaceous Glance conglomerate occurs in both mountain ranges. A large mass of Pinal Schist is located of the pass area and off to the west. Overall dips are toward the SE. Dragoon wash is visible, marked by the trees are at 2:00-3:00. Texas Canyon stock is at 1:00 -2:15, with the Little Dragoon Mountains beyond; Johnson Peak is at 1.00. The notable ridge formed by the Texas Canyon intrusive is composed of a finer-grained, aplitic "border" or "cap" phase which may be a true granite in places.

4.6 Road curves; Johnson Peak at 2:00.

5.8 Truck access road from south. This is the general vicinity of the Four Ranch.

6.15 Sign on south, locates site of historic Butterfield Stage Station.

6.6 At 2:00 town of Dragoon, behind tree-lined wash.

7.15 Cross cattle guard, at east side of town of Dragoon.

7.3 Road curves away from corner of Main and Black Prince.

7.4 Cross railroad tracks, continue straight. Off to the north at 7.41 is Johnson Road, which meets I-10 at "The Thing". To the north the Proterozoic Pinal schist is represented by conglomeratic and arkosic units, rather than the more common silver-gray phyllite. The street in Dragoon called the "Black Prince" is named after a mine in the Dragoon (Golden Rule) mining district. The mine also provided a name for one the carbonate ore/skarn units: the Late? Carboniferous Black Prince limestone. This unit has a restricted depositional area. Around the early part of the 20th century, tungsten production from placers north of Dragoon was second only to the Boulder Canyon deposists of Colorado.

9.6 Cottonwood trees; within Texas Canyon quartz monzonite.

9.95 Road to north leads to Amerind Foundation, formerly the Fulton Ranch.

10.4 Triangle T Guest Ranch turn off to north. Now in Texas Canyon stock, and typical exfoliation-rounded boulder forms. Near this area was the site of the October, 1861 signing of a significant treaty between the Chiricahua Apaches and the U.S. Army.

10.85 Cross wash.

10.9 - 11.0 Cattle guard; entrance to and underpass to I-10 at about MP 318.9.

ENTER INTERSTATE HIGHWAY
(Road log to be read as heading west toward Tucson)

Milepost 316.5 Cochise Stronghold, west side of Dragoon Mountains at 9:00; Tombstone Hills at 9:30-10:30. Road still in Texas Canyon plutons. Huachuca Mountains at 10:00-11:00, and at 11:00-1:30 are the Whetstone Mountains.

Milepost 316 (218.4) ROAD CURVES

Milepost 313.2 Exit 312 to Sybil Road.

Milepost 310.7 Some distance stratigraphically below the top, St.David's/Benson formation, is typified by badlands erosion into fine-grained silts and sands, lacustrine, below erosional terrace surface (Pleistocene). The number of terrace levels varies along the San Pedro depending upon local post-Pliocene geological events. This may be one of the higher terrace with 2 to 3 more to cut through before reaching the present flood-plain.

Milepost 309.8 Cross Adams Peak Wash.

Milepost 306.2 Cross center of bridge over San Pedro River

REFERENCES

Drewes, Harald, 1980, Tectonic Map of Southeast Arizona, U.S.G.S. Map I-1109, 1:125,000 2 sheets.

Gilluly, James, 1956, General Geology of Central Cochise County, Arizona, U.S.G.S. Prof. Paper 281, 109 pages.

James, H. L., 1978, "Once Upon a Time There Was a Town", the Ghosts of Southeastern Arizona, in J. F. Callender, Jan C. Wilt, and R. E. Clemons, Editors, Land of Cochise, Southeastern Arizona, New Mexico Geol. Soc., 29th Field Trip Guidebook, p. 365 -371.

Keith, Stanley B., 1978, Supplemental Road Log No. 3, Tucson to Lordsburg via Interstate 10, in J. F. Callender, Jan C. Wilt, and R. E. Clemons, Editors, Land of Cochise, Southeastern Arizona, New Mexico Geol. Soc., 29th Field Trip Guidebook, p. 112 - 124.

Keith, Stanley B., Don E. Gest, Ed DeWitt, Netta Wooode Toll, and Beverly A. Everson, 1983, Metallic Mineral Districts and Production in Arizona, Ariz. Bur. Geol. and Min. Tech., Geol. Surv. Br., Bull. 194, 58 pages, plus map.

Keith, Stanton B., 1973, Index of Mining Properties in Cochise County, Arizona, Ariz. Bur. Mines, Bull. 187; 98 pages.

Reynolds, S. J., F. P. Florence, J. W. Welty, M. S. Roddy, D. A. Currier, A. V. Anderson, and S. B. Keith, 1986, Compilation of Radiometric Age Determinations in Arizona, Ariz. Bur. Geol. and. Min. Tech., Bull. 197; 258 pages, plus maps.

Schreiber, Joseph F., Jr., and Robert W. Scott, 1987, Lower Cretaceous Coral-Algal-Rudist Patch Reefs in Southeastern Arizona, in George H. Davis and Evelyn M. VandenDolder, Editors, Geologic Diversity of Arizona and Its Margins: Excursions to Choice Areas, Geol. Soc. Amer. Annual Mtg, Phoenix, Field-Trip Guidebook, Ariz. Bur. Geol. & Min. Tech. Special Paper 5; p. 280-292.

FIELD GUIDE NOTES

The Tombstone Mining District
Part of the Laramide Tombstone Caldera Complex
Cochise County, Arizona

October 17, 1988

A Summary Updated From a Private Report
by James A. Briscoe and Thomas E. Waldrip, Jr.
November, 1982

The Tombstone District, then in Arizona territory, was discovered by Ed Schiefflin, son of California 49er's, in 1877. Tombstone, though isolated and subject to marauding Indians and outlaws in its early days, was affected by world events through their effect on silver prices. Coincident with Schiefflin's discovery of rich silver mineralization at Tombstone, silver prices began a decline from which they would not see the same price of silver as in the year of Schiefflin's discovery for almost 86 years. During the 34 year period from 1877 to 1915, when most of the ore was produced at Tombstone, declining silver prices, financial panics, and the removal of the United States currency from the silver standard had immeasurably more effect on the mines than the Earp-Clanton feud, Apaches, bandits, and underground waters. In 1911, silver prices of approximately $0.55 per ounce (less than one-half of that in effect when Schiefflin discovered Tombstone) brought the demise of efforts to unwater the mines and the bankruptcy of the Development Corporation of American and its Tombstone Consolidated Mines subsidiary. The Phelps Dodge Corporation operated the mines in a desultory fashion under its subsidiary, the Bunker Hill Mining Company, from 1914 through 1933, when the Tombstone Development Corporation, was formed. Higher gold prices instituted by Roosevelt in 1932, stimulated some development for a few years, as did manganese and copper production during World War II. However, production never came close to the halcyon years, between 1877 and 1910. The Tombstone Development Company properties have been operated and explored only sporadically from the end of World War II to the present time. In the period 1980 to 1985, Tombstone Exploration, Inc. (T.E.I.) operated the Contention Pit and heap leach from ore along the Contention vein zone. A significant but undocumented amount of gold and silver was recovered. In 1985, T.E.I. filed for bankruptcy. At the time of this field trip (October 22, 1988), PBR Minerals, Inc. is working toward re-opening the Contention Mine. Further, Santa Fe Pacific Mining is doing deep drill testing of the lower Paleozoic sediments in the central part of the Tombstone Basin.

Tombstone has primarily been a silver camp, though significant gold and subordinate lead, copper, zinc and manganese has also been produced. Production has come mainly from mineralized vein fractures, cutting folded, Lower Cretaceous sediments of the Bisbee group within the Tombstone Basin. Ninety-five percent or more of the production is from zero to 600 feet below the surface and is primarily from oxide ore minerals.

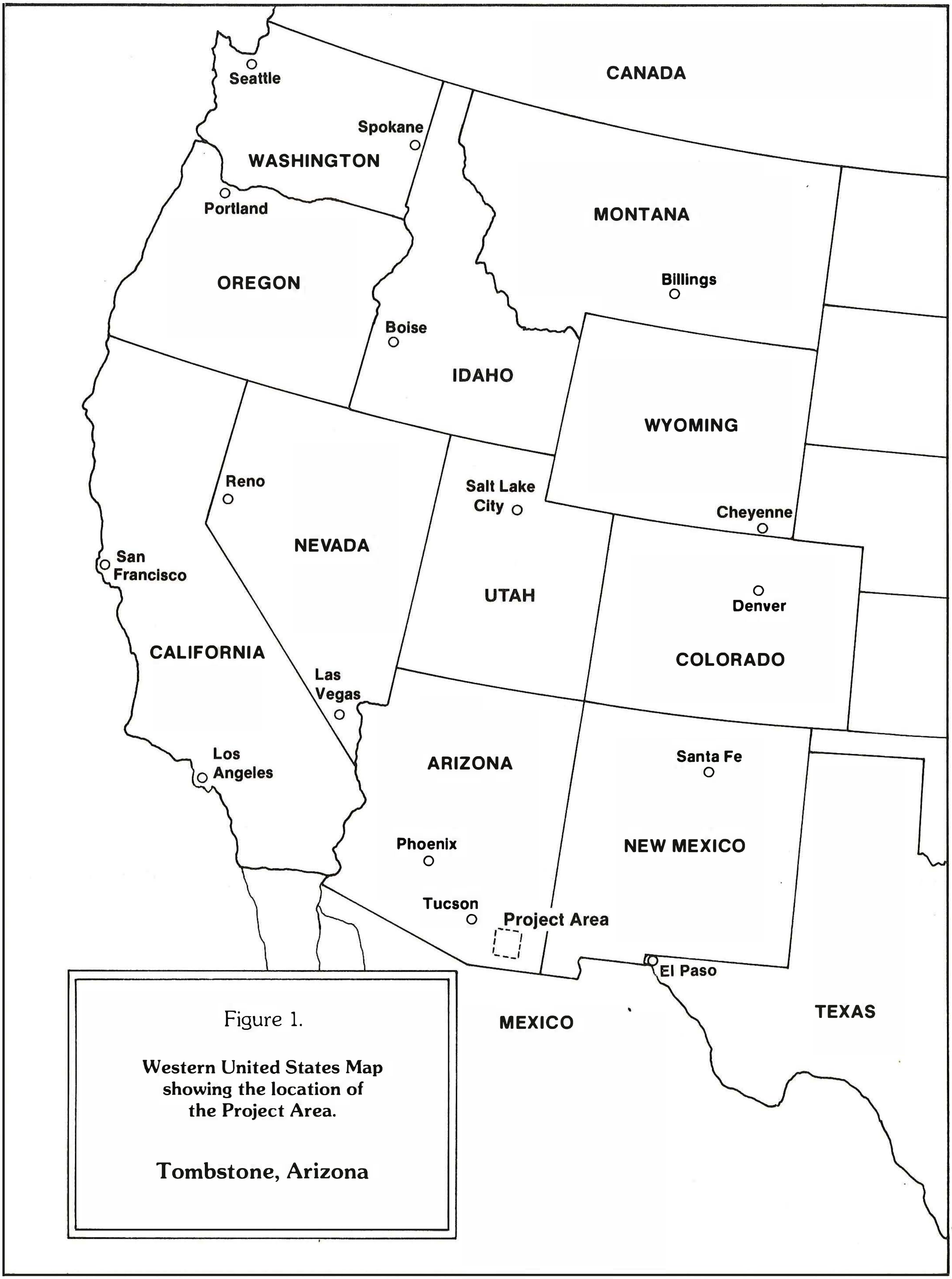


Figure 1.

Western United States Map showing the location of the Project Area.

Tombstone, Arizona

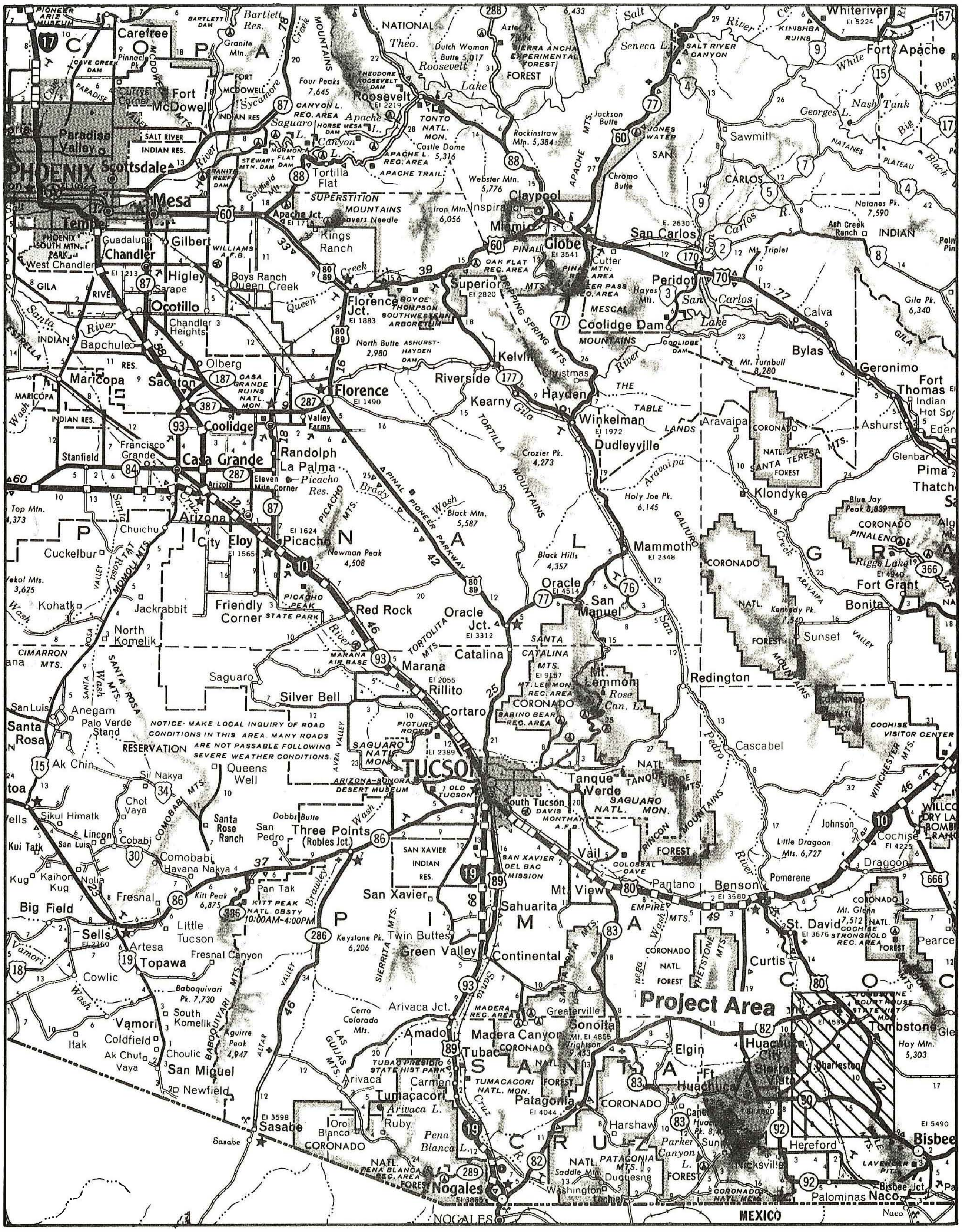
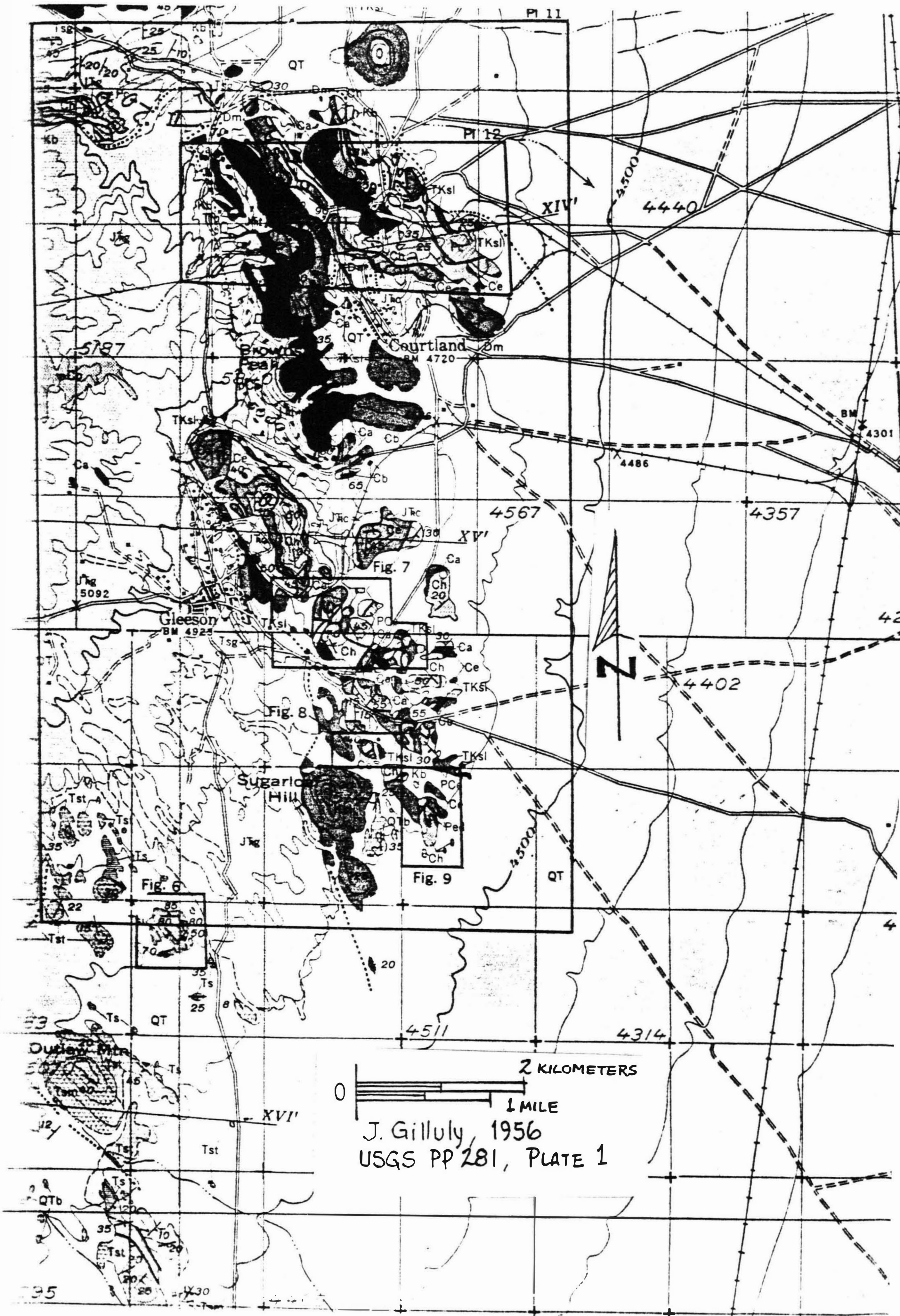
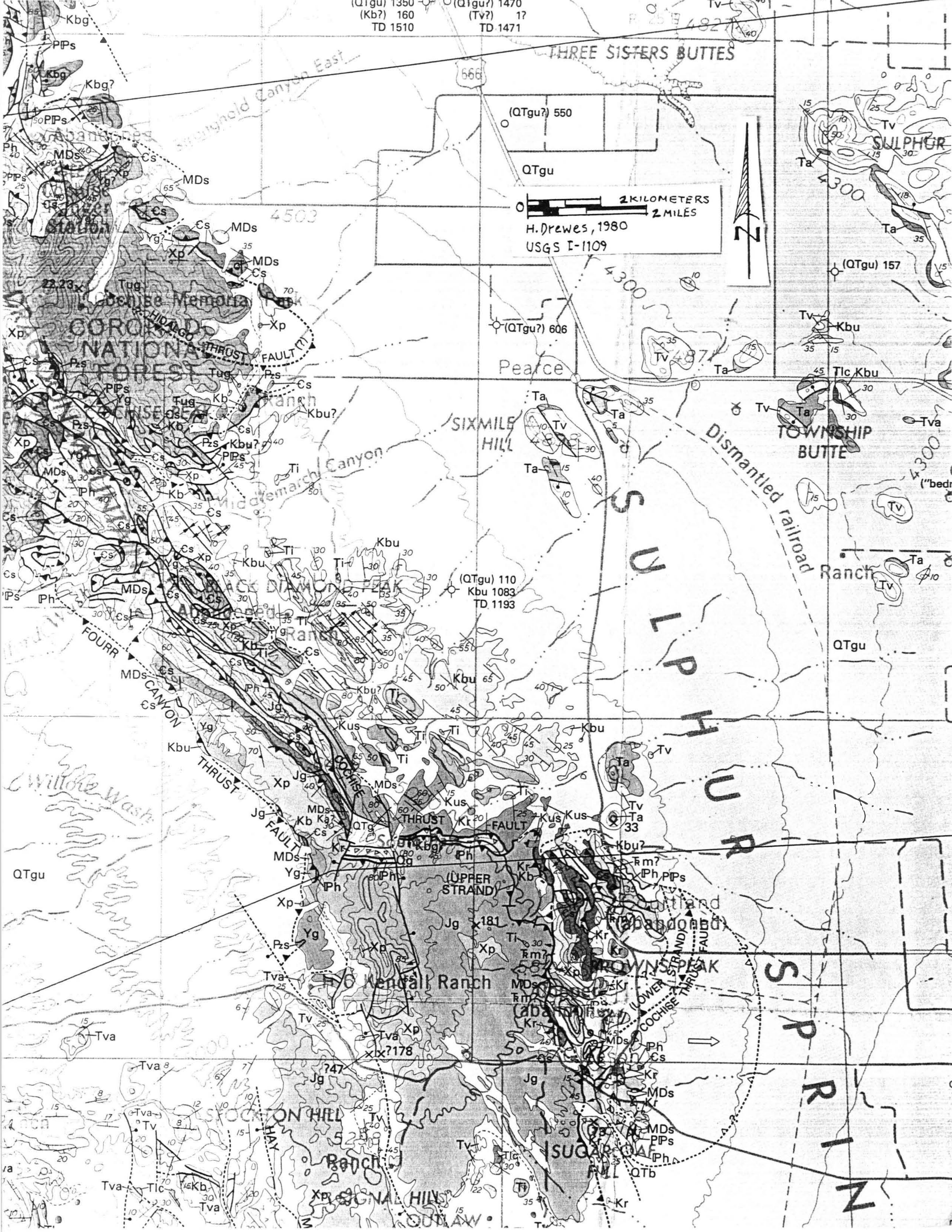


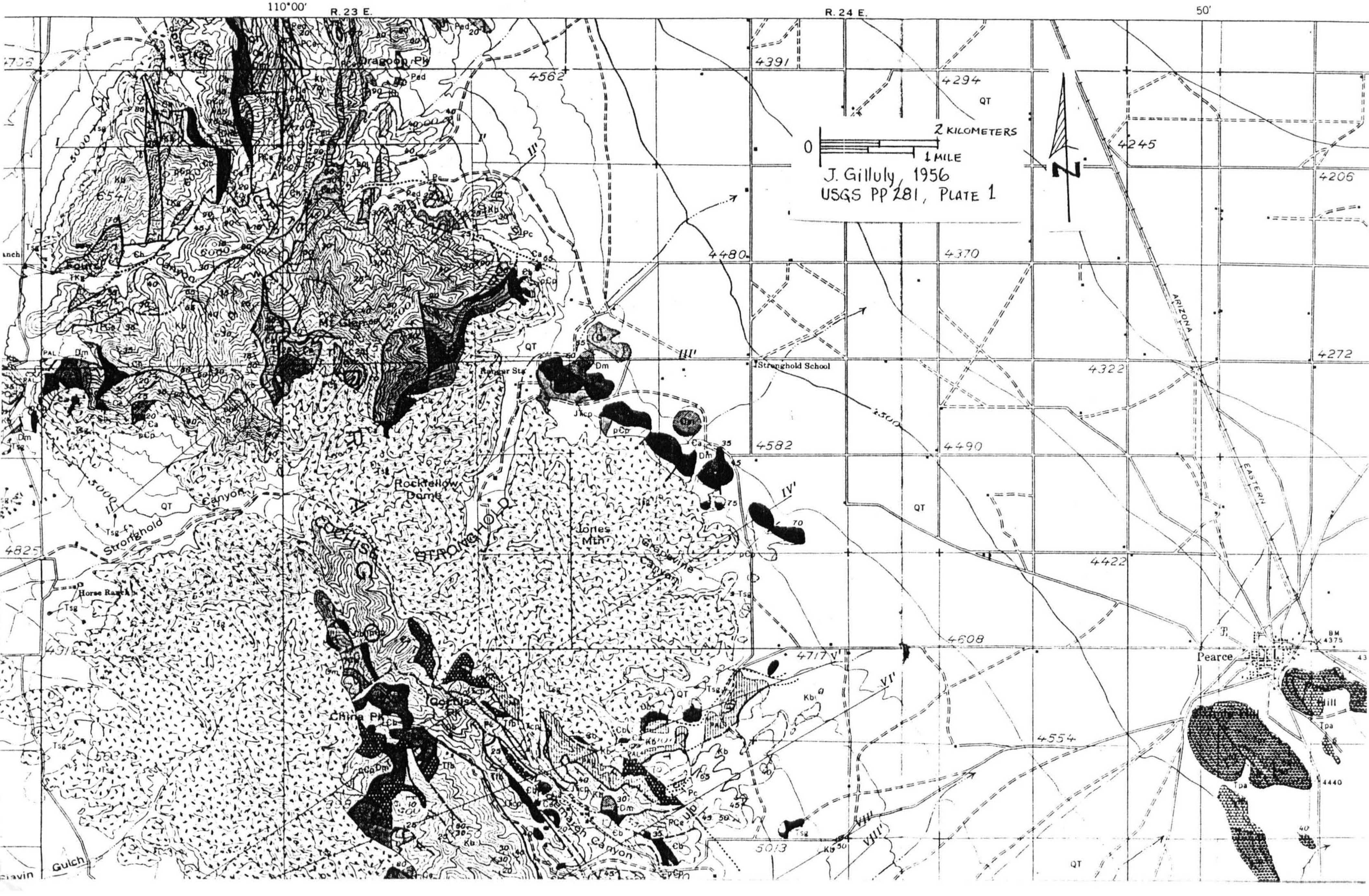
Figure 2. Highway map showing the location of the Project Area in relation to Tucson and Phoenix, Arizona

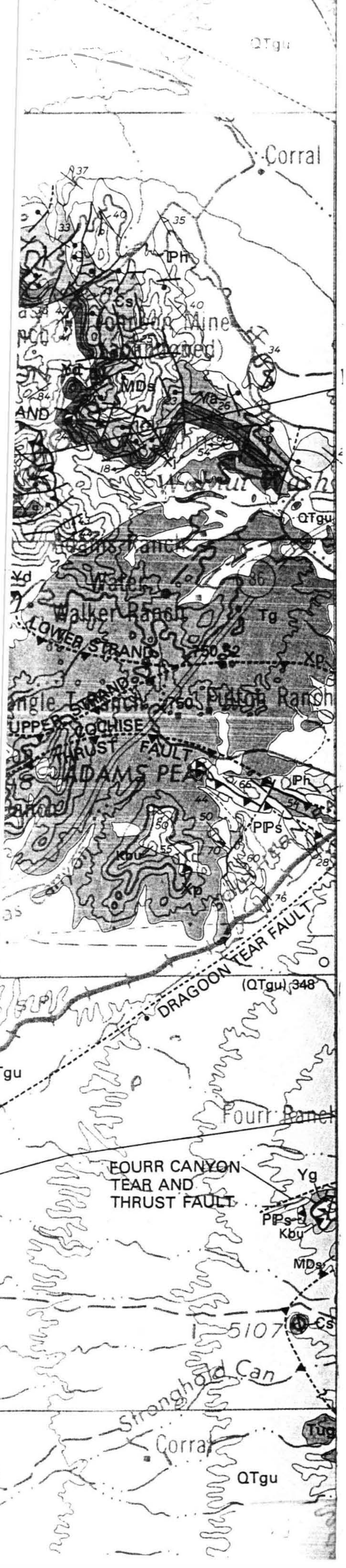
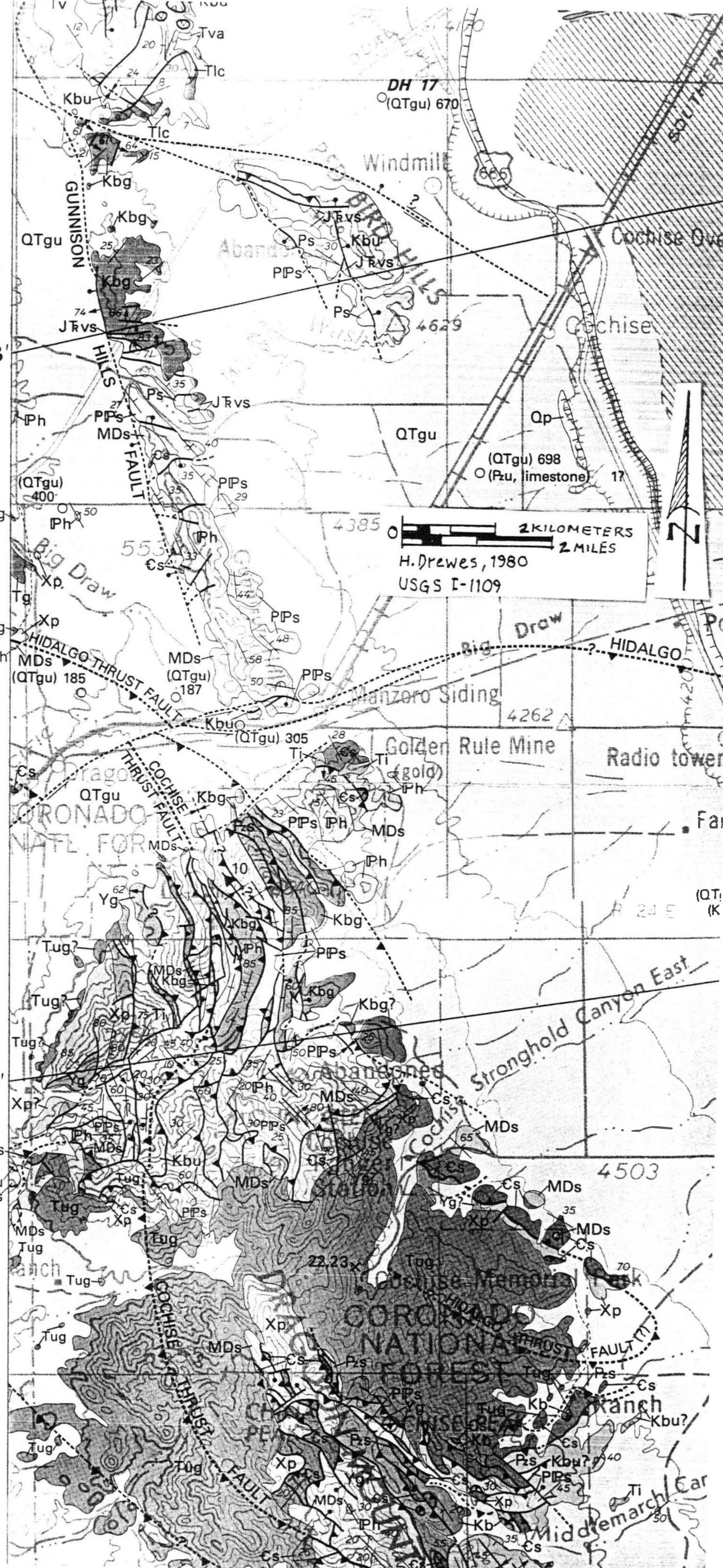


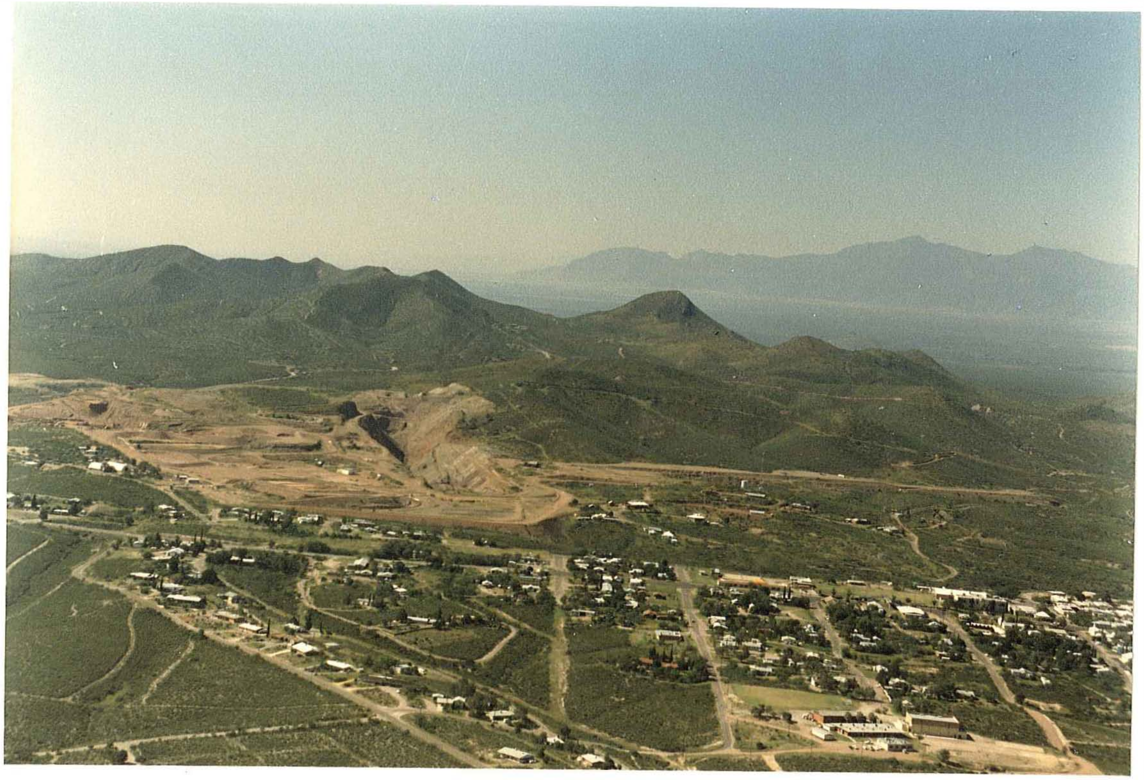
J. Gilluly, 1956
USGS PP 281, Plate 1



2 KILOMETERS
2 MILES
H. Drewes, 1980
USGS I-1109
THREE SISTERS BUTTES
Middle March Canyon East
Coronado National Forest
HIDALGO THRUST FAULT (?)
Pearce
SIXMILE HILL
Middlemarch Canyon
Dismantled railroad
TOWNSHIP BUTTE
SULPHUR
SULPHUR SPRIN
BLACK DIAMOND PEAK
Abandoned Ranch
FOURR CANYON THRUST FAULT
COCHISE THRUST FAULT
(UPPER STRAND)
(LOWER STRAND)
Courtland (abandoned)
BROWNS PEAK
Gleeson (abandoned)
Kendall Ranch
STOCKTON HILL
SUGAR LOAF HILL
SIGNAL HILL
OUTLAW
Willow Wash
(QTgu?) 550
(QTgu?) 606
(QTgu) 157
(QTgu) 110
Kbu 1083
TD 1193
(QTgu) 1350
(Kb?) 160
TD 1510
(QTgu?) 1470
(Tv?) 1?
TD 1471
4300
4503
666


110°00'
R. 23 E.
R. 24 E.
50'
2 KILOMETERS
0
1 MILE
J. Gilluly, 1956
USGS PP 281, Plate 1
N
ARIZONA
EASTERN
Pearce
Stronghold School
Ranger Sta
Dragoon Pk
Rockfellow Dome
Jones Mtn
Grapevine Canyon
Stronghold Canyon
COCHISE STRONGHOLD
China Pk
Cochise Pk
Horse Ranch
Gulch
Hill
4391
4294
4245
4206
4562
4480
4370
4272
4322
4582
4490
4422
4825
4608
4717
4554
5013
4440
QT


Corral
Walker Ranch
LOWER STRAND
UPPER STRAND
COCHISE
THRUST FAULT
ADAMS PEAK
DRAGOON TEAR FAULT
(QTgu) 348
Fourr Ranch
FOURR CANYON
TEAR AND
THRUST FAULT
5107
Stronghold Can
Corral
QTgu

DH 17
(QTgu) 670
Windmill
GUNNISON
HILLS
FAULT
BIRD HILLS
4629
Cochise
B'
(QTgu) 698
(Pzu, limestone)
2 KILOMETERS
2 MILES
H. Drewes, 1980
USGS I-1109
Big Draw
HIDALGO THRUST FAULT
HIDALGO
(QTgu) 185
(QTgu) 187
Manzoro Siding
4262
(QTgu) 305
Golden Rule Mine
(gold)
Radio tower
COCHISE THRUST FAULT
CORONADO
NATL FOR
Stronghold Canyon East
C'
4503
Cochise Memorial Park
CORONADO NATIONAL FOREST
HIDALGO THRUST FAULT (?)
COCHISE THRUST FAULT
Ranch
Middlemarch Can



Frontispiece - Tombstone Looking South

This view of Tombstone looks almost due south towards the Mexican-American border, with the Huachuca Mountains and Miller Peak on the right hand horizon. At the foot of the Huachucas, at the right edge of this photograph, lies Ft. Huachuca and the bedroom community of Sierra Vista. The San Pedro River flows northward, closely parallelling the trend of the Huachucas. The Tombstone Basin occupies the center of this photo, with the T.E.I. Contention open pit lying just south of the boundaries of the Tombstone village. The pit is cut along the Contention-Tranquility fault zone, the north end of the pit lying approximately over the location of the Pump Shaft. Trending east-westerly a short distance south of the Contention Pit is the Prompter Fault zone, behind which are up-thrown Paleozoic sediments. The high escarpment at approximately one o'clock from the Contention Pit, is Military Hill - a hog-back consisting of Bolsa quartzite. Its steep west escarpment marks the Military Hill Fault, which is the eastern margin of the Tombstone caldera. Stratigraphic throw along the Military Hill Fault is approximately 5,000 feet, with Bisbee Group Sediments overlain by intra-caldera Uncle Sam Tuff lying to the west. More than 95% of the production of the Tombstone District has come from the Contention Pit area, and to the east along the flanks of the Empire Anticline and associated drag folds. Total production from the central Tombstone District includes approximately 260 thousand ounces of gold, 32.5 million ounces of silver, 651 million pounds of lead, 2.5 million pounds of copper, and 1 million pounds of zinc.

Abrigo and Martin at Bisbee may be similar to those suspected beneath Tombstone. This deep potential is presently being tested by Santa Fe Pacific Mining, who is drilling diamond drill holes as deeply as 3,000 feet.

Multiple porphyry copper centers are thought to occur associated with Laramide granodioritic to quartz monzonitic plutons, within the caldera complex. One such center, confirmed by deep drilling by ASARCO in 1973-74, occurs at the Robbers Roost, where intense phyllic alteration and breccia pipe emplacement are exposed by erosion. Here too, the hydrothermal system is superimposed on the Paleozoic sedimentary sequence, hidden beneath the Uncle Sam quartz latite tuffs, Silver Bell type andesites, and rhyolites of the Bronco volcanics. Silver, lead, zinc, mantos and copper replacement bodies are to be expected in this environment rather than ore grade igneous hosted copper porphyrys.

SUMMARY OF TOTAL RECORDED PRODUCTION AT TOMBSTONE
1879 TO 1937
CALCULATED TO CURRENT VALUES - $400 GOLD, $10 SILVER, $1.00 COPPER, $.50 LEAD, $.40 ZINC

SOURCE & YEAR	TOTAL VALUE OF PRODUCTION IN YEAR PRODUCED	CALCULATED OUNCES OF GOLD PRODUCED	VALUE AT $400/OZ.	CALCULATED OUNCES OF SILVER PRODUCED	VALUE AT $10/OZ.	CALCULATED POUNDS OF LEAD PRODUCED	VALUE AT $.50/LB.	CALCULATED POUNDS OF COPPER PRODUCED	VALUE AT $1.00/LB.	CALCULATED POUNDS OF ZINC PRODUCED	VALUE AT $.40/LB.	TOTAL CURRENT VALUE OF PRODUCTION
J. B. TENNEY												
1879 TO 1907	28400000	192356	76942400	24338159	243381590	31805070	15902535	NRP*	NRP	NRP	NRP	336226525
MINERAL RESOURCES OF THE UNITED STATES												
1908 TO 1934	8138571	57971	23188400	6659692	66596920	23767829	11883915	2358495	2358495	1058234	423294	104451023
TOMBSTONE DEVELOPMENT TOMBSTONE MINING CO'S.												
1935 TO 1936	564437	6375	2550000	390305	3903050	3197305	1598653	157536	157536	NRP	NRP	8209239
TOMBSTONE EXTENSION												
1930 TO 1937	374972	1083	433056	1080491	10804907	6335734	3167867	NRP	NRP	NRP	NRP	14405829
TOTAL	37477980	257785	103113856	32468647	324686467	65105938	32552969	2516031	2516031	1058234	423294	463292616
AVERAGE/TON**		0.21	82.22	25.89	258.90	51.91	25.96	2.01	2.01	0.84	0.34	369.42

*NO RECORDED PRODUCTION

**TOTAL TONNAGE ASSUMED TO BE - 1254097

James A. Briscoe & Associates, Inc.
Tucson, Arizona

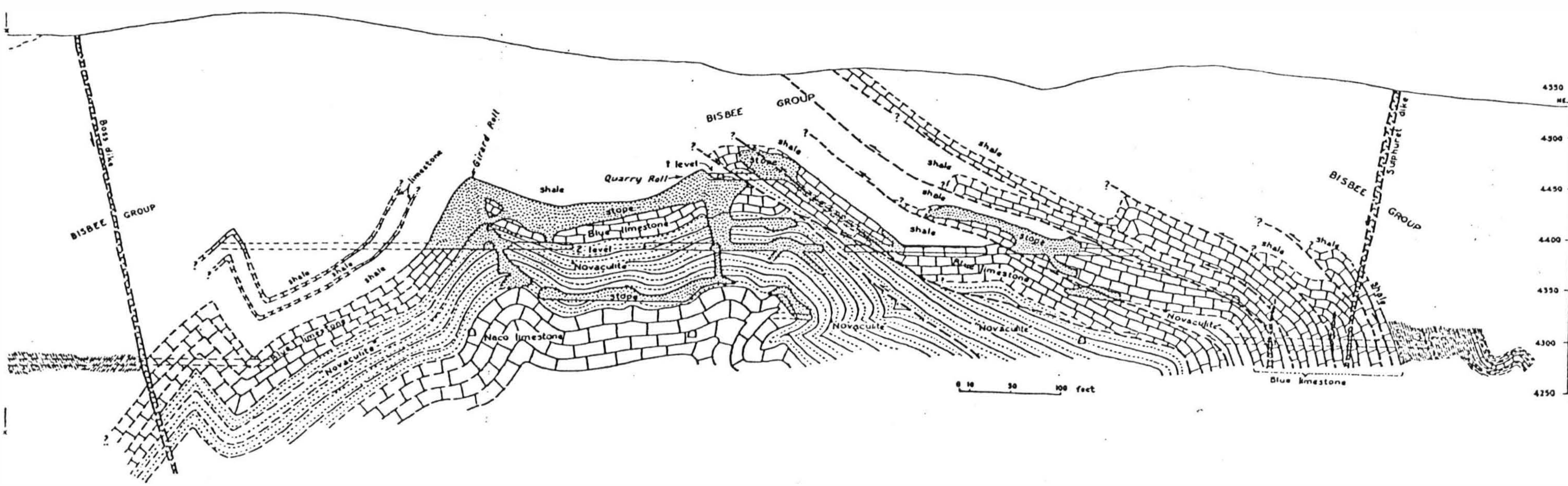


Plate XXIV, A.—Section along West Side fissure, looking northwest (northeast half; joins Plate XXIV, B at line X-X).

Explanation

Geology

QTgu — OLDER OR UNDIFFERENTIATED SURFICAL DEPOSITS (HOLOCENE TO OLIGOCENE):—Gravel, sand, and silt (Pleistocene and Pliocene—Mainly alluvium of basins; includes some colluvium and landslide deposits. Generally light-pinkish gray, weakly indurated, and with poorly rounded clasts; locally well indurated. Thickness several meters to hundreds of meters.

QTb — Basalt (Pleistocene to Pliocene)—Lava flows, pyroclastic rocks, and some intercalated gravel. Thickness several meters to a few hundred meters in most places. Radiometrically dated at 0.25, 1.0, and 3.2 m.y. old

Tva — Extensive andesite and dacite (Miocene and Upper Oligocene)—Lava flows, pyroclastic rocks, some intercalated epiclastic rocks, and dikes. Mostly gray, fine-grained, porphyritic rocks; includes some very coarse feldspar porphyry andesite (Turkey track porphyry, an informal term of Cooper, 1961). Thickness mostly several meters to several tens of meters. Dated at 24, 25, 27, 33, and 39 m.y.

Tv — Extrusive rhyolite and rhyodacite (Miocene and Upper Oligocene—Lava flows, welded tuff, pyroclastic rocks, and some intercalated epiclastic rocks. Light-gray to grayish-pink, vitric to fine-grained, porphyritic. Commonly a few tens to a few thousand of meters thick. Dated at 23, 24, 25, 26, 26, 26, and 27 m.y. An additional date of 47 m.y., if substantiated, may indicate the presence of Eocene rocks in the lower member of the S O Volcanics of Cochise Co.

Tlc — Lower conglomerate, gravel, and sand (Oligocene and Eocene?)—Alluvium; commonly grayish-red deposits of small, well rounded, nonvolcanic clasts. Mostly several meters to a few tens of meters thick.

Tlv — UPPER CORDILLERAN (LARAMIDE) IGNEOUS ROCKS (LOWER PALEOCENE):—Lower volcanic rocks—Rhyolite to andesite lava flows, pyroclastic rocks, and some intercalated epiclastic rocks. Dated at 57 m.y. Possibly younger age to east.

TKp — MAIN CORDILLERAN (LARAMIDE) IGNEOUS ROCKS:—Porphyritic and aplitic intrusive rocks (Paleocene and Upper Cretaceous)—Mostly latitic porphyry to dacitic porphyry in small stocks and plugs and aplitic bodies not associated with other granitoid stocks. Dated at 61, 63, 63, 64, and 65 m.y.

Kib — Fluidized intrusive breccia—exact age unknown, but penetrates, and thus younger than Uncle Sam porphyry.

Kr — Rhyodacite tuff and welded tuff —Includes parts of Salero Formation, Sugarloaf Quartz Latite, and Bronco Volcanics, and all of Red Bay Rhyolite, Cat Mountain Rhyolite of Brown (1939) and Uncle Sam Prophyry. Includes local intrusive bodies and locally contains fragments of exotic rocks. Thickness commonly several tens of meters to several hundreds of meters. Dated at 66(?), 70, 72, 73, and 73 m.y. The Uncle Sam, in the Tombstone area, is dated 72 m.y.

Ka — Andesitic to dacitic volcanic breccia.—Includes parts of Salero Formation, Sugarloaf Quartz Latite, and Bronco Volcanics, and all of Demetrie Volcanics and Silverbell Formation of Courtright (1958). Commonly contains large blocks of exotic rocks and locally includes some sedimentary rocks and intrusive rocks. Several tens of meters to several hundreds of meters thick in most places.

Klq — Lower quartz monzonite and graodiorite—Includes some quartz diorite; appears in small stocks. Locally associated with mineralization. Dated at 70, 71, 72, 73, 74, 74, 74, and 76 m.y. The Schieffiin granodorite at Tombstone is 72 m.y.

Kb — BISBEE FORMATION OR GROUP, UNDIFFERENTIATED (LOWER CRETACEOUS):—Upper part of Bisbee Formation or Group, undifferentiated, and related rocks.—Includes upper part of Bisbee Formation, Mural Limestone, Morita, Cintura, Willow Canyon, Apache Canyon, Shellenberger Canyon and Turney Ranch Formations (not listed in stratigraphic sequence) of the Bisbee Group, Amole Arkose of Bryant and Kinnison (1954), and Angelic Arkose. Consists of brownish- to reddish-arkose, gray siltstone, sandstone, conglomerate, and some fossiliferous gray limestone. Commonly several hundred meters thick

Jg — GRANITE AND QUARTZ MONZONITE (JURASSIC)—Stocks of pinkish-gray coarse-grained rock. Locally associated with mineralization. Dated at 140, 148, 149, 149, 150, 153, 160, 161, 167, 178, 185 m.y.

PIPs — Sedimentary rocks (Lower Permian and Upper Pennsylvanian)—consists of Epitaph Dolomite (Lower Permian), Colina Limestone (Lower Permian), and Earp Formation (Lower Permian and Upper Pennsylvanian), undifferentiated. Epitaph Dolomite is a dark- to light-gray slightly cherty dolomite, limestone, marl, siltstone, and gypsum, 120-280 meters thick. Colina Limestone is a medium gray, thick-bedded, sparsely cherty, and sparsely fossiliferous limestone 120-280 meters thick. Earp Formation is a pale-red siltstone, mudstone, shale, and limestone, 120-240 metersthick.

IPh — Horquilla Limestone (Upper and Middle Pennsylvanian)—Light-pinkish-gray, thick- to thin-bedded, cherty, fossiliferous limestone and intercalated pale-brown to pale-reddish-gray siltstone that increases in abundance upward. Typically 300-490 meters thick.

MDs — SEDIMENTARY ROCKS (MISSISSIPPIAN AND DEVONIAN)—Consists mainly of Escabrosa Limestone (Mississippian)—locally (Armstrong and Silberman, 1974) called Escabrosa Group—and Martin Formation (Upper Devonian), undifferentiated. In part of the Chiricahua Mountains also includes Paradise Formation (Upper Mississippian) and Portal Formation of Sabins, 1957a (Upper Devonian). In the Little Dragoon Mountains and some adjacent hills also includes Black Prince Limestone, whose fauna and correlation show strongest affinities with Mississippian rocks but which may include some Pennsylvanian rocks. Escabrosa Limestone is a medium-gray, massive to thick-bedded, commonly crinoidal, cherty, fossiliferous limestone 90-310 meters thick. Martin Formation is thick- to thin-bedded, gray to brown dolomite, gray sparsely fossiliferous, and some siltstone and sandstone, 90-120 meters thick. Paradise Formation is a brown, fossiliferous, shaly limestone. Portal Formation is a black shale and limestone 6-105 meters thick. Black Prince Limestone is pinkish-gray limestone with a basal shale and chert conglomerate, as much as 52 meters thick.

O€s — SEDIMENTARY ROCKS (LOWER ORDOVICIAN TO MIDDLE CAMBRIAN):—El Paso Limestone (Lower Ordovician and Upper Cambrian), Abrigo Formation (Upper and Middle Cambrian), and Bolsa Quartz (Middle Cambrian), undifferentiated.—El Paso Limestone is a gray, thin-bedded cherty limestone and dolomite 90 meters to about 220 meters thick. Abrigo Formation is a brown, thin-bedded fossiliferous limestone, sandstone, quartzite, and shale, 210-240 meters thick. Bolsa Quartzite is a brown to white or purplish-gray, thick-bedded, coarse-grained quartzite and sandstone with a basal conglomerate, 90-180 meters thick. To the east, equivalents of part of the Abrigo Formation and Bolsa Quartzite are known as the Coronado Sandstone.

€s — Sedimentary rocks (Upper and Middle Cambrian)—Abrigo Formation (Upper and Middle Cambrian), and Bolsa Quartzite (Middle Cambrian), undifferentiated.

Yg — GRANITOID ROCKS (PRECAMBRIAN Y):—Mainly granodiorite and quartz monsonite, unfoliated to foliated, in part metamorphosed. Generally in stocks, which ahve been little studied.

Xp — PINAL SCHIST (PRECAMBRIAN X)—Chlorite schist, phyllite, and some metavolcanic rocks, metavolcanic rocks, metaquartzite, metaquartzite conglomerate, and gneiss. One metavolcanic rock dated at 1715 m.y.

CONTACT—Dotted where concealed.

MARKER HORIZON—Dotted where concealed.

DIKES—Showing dip.

70 — FAULTS—Showing dip. Dotted where concealed or intruded; ball and bar on downthrown side.

45 — Normal

45 — Reverse

Strike-slip—Arrow couple shows relative displacement. Single arrow shows movement of active block.

Major thrust fault—Sawteeth on upper plate.

Thrust fault—Sawteeth on upper plate.

Anticline.

Syncline.

30 — Inclined strike and dip of beds.

EXOTIC-BLOCK BRECCIA—Rock contains chip or block inclusions of rock different from those of host or other blocks nearby. Typically of volcanic-tectonic or sedimentary-tectonic origin; excludes Tertiary megabreccia deposits.

o (QTgu) 157 — Site of well or generalized site of several wells, showing unit penetrated, if known, and depth of well, in feet. 100 feet equals 30.5 meters.

72x — COLLECTION SITE—Radiogenically dated rock showing age in millions of years. Query before symbol where precise location uncertain.

Roads and Highways

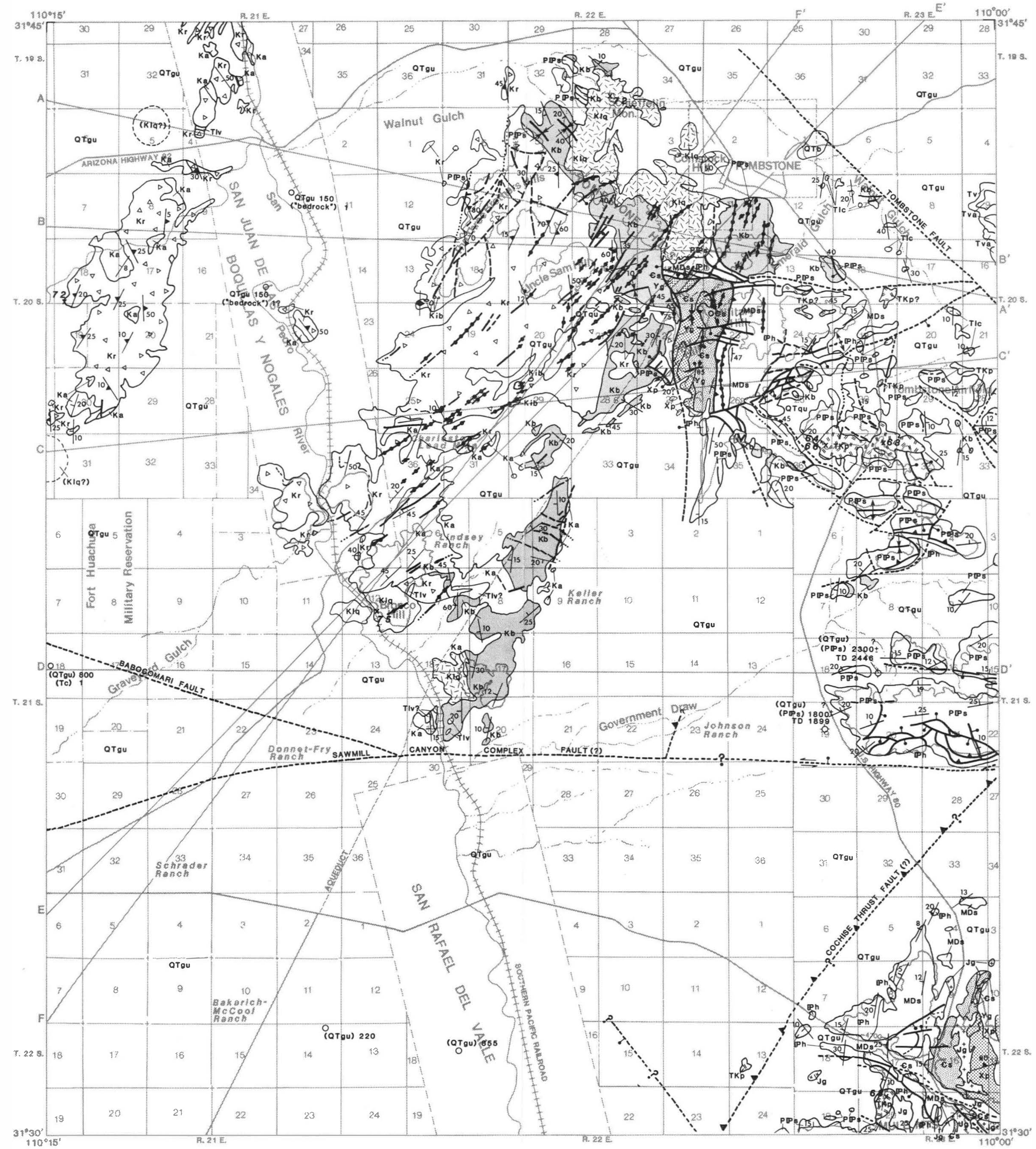
Dry wash

Southern Pacific Railroad

Government Reservation Boundary

Aqueduct

A—A′ Cross section line



Tombstone Development Company, Inc.
Tombstone, Arizona

1 0 1 2 3 Miles

N

Geology adopted from Drewes, Harold, 1980, and Newell, R.A., 1973.

Figure 3. Generalized geological and structural map on screened topographic base.

By James A. Briscoe
James A. Briscoe and Associates
Tucson, Arizona

Explanation

Land Status

Public Domain - Mineral and Surface owned by Federal Government.

State Domain - Mineral and Surface owned by State of Arizona.

Public Domain Mineral and Surface. Mineral owned by Federal Government; Surface owned by State of Arizona.

Fee Simple - Mineral and Surface privately owned.

Fee Simple Surface and Public Domain Mineral Private Surface ownership Mineral owned by Federal Government.

Spanish Land Grants - Fee Simple. Mineral and Surface privately owned; Reservation of Gold, Silver and Mercury to Federal Government.

Military Reservation - Restricted Mineral Entry. Not open to Mining.

Water & Power Resource Service & Various other Withdrawals - Not open to Mineral Entry or Mining.

Mineral and Surface owned by Federal Government. Mineral Rights privately claimed.

Mineral and Surface owned by State of Arizona. Mineral leases, prospecting permits or applications privately held.

Public Domain Mineral and State of Arizona Surface. Mineral rights privately claimed.

Public Domain Mineral and Fee Simple Surface. Mineral rights privately claimed.

Tombstone Development Company, Inc. Lands

Public Domain Mineral and Surface. Mineral rights claimed by Tombstone Development Company, Inc.

Mineral and Surface owned by State of Arizona. Prospecting permits or applications held by Tombstone Development Company.

Public Domain Mineral and Surface owned by State of Arizona. Mineral rights claimed by Tombstone Development Company, Inc.

Patented Mining Claims owned by Tombstone Development Company, Inc.

Public Domain Mineral and Fee Simple Surface. Mineral rights claimed by Tombstone Development Company, Inc.

Fee Simple Surface and State of Arizona Mineral. Prospecting Permit held by Tombstone Development Company, Inc.

Roads and Highways

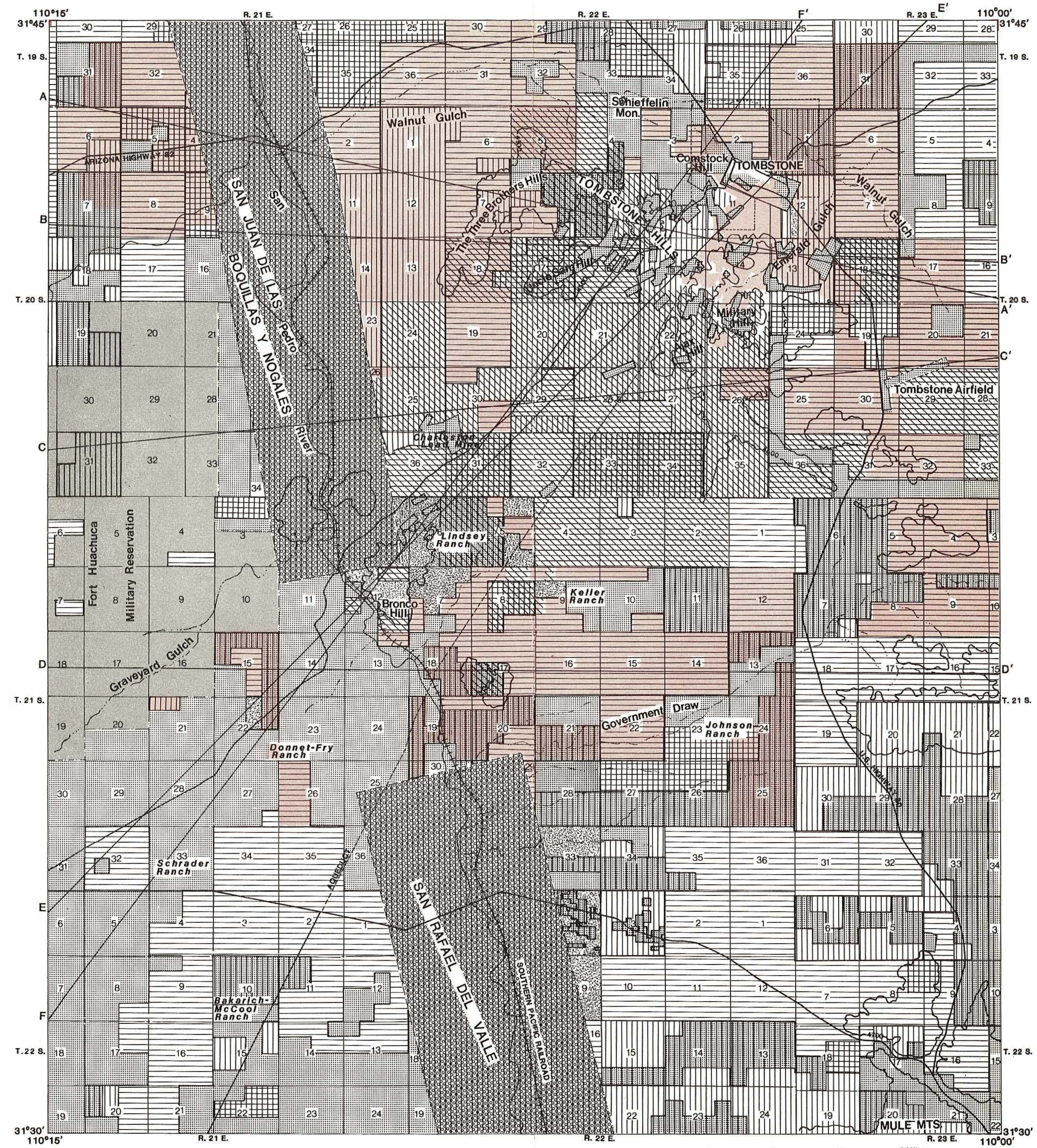
Dry wash

Southern Pacific Railroad

Government Reservation Boundary

Aqueduct

Cross section line



Tombstone Development Company, Inc.

Tombstone, Arizona

Land Status Map, Tombstone
15 min. Quadrangle

By Thomas E. Waldrip, Jr.
James A. Briscoe and Associates
Tucson, Arizona

Figure 5. Property map showing ownership of major holdings of mineral rights in the Tombstone area. Red overprint shows state, federal and private land and lands with mineral rights held by the Tombstone Development Company as of October 15, 1981.

Explanation

Geology

QTgu OLDER OR UNDIFFERENTIATED SURFICAL DEPOSITS (HOLOCENE TO OLIGOCENE):—Gravel, sand, and silt (Pleistocene and Pliocene—Mainly alluvium of basins; includes some colluvium and landslide deposits. Generally light pinkish gray, weakly indurated, and with poorly rounded clasts; locally well indurated. Thickness several meters to hundreds of meters

QTb Basalt (Pleistocene to Pliocene)—Lava flows, pyroclastic rocks, and some intercalated gravel. Thickness several meters to a few hundred meters in most places. Radiometrically dated at 0.25, 1.0, and 3.2m.y. old

Tva Extensive andesite and dacite (Miocene and Upper Oligocene)—Lava flows, pyroclastic rocks, some intercalated epiclastic rocks, and dikes. Mostly gray, fine-grained, porphyritic rocks; includes some very coarse feldspar porphyry andesite (Turkey track porphyry, an informal term of Cooper, 1961). Thickness mostly several meters to several tens of meters. Dated at 24, 25, 27, 33, and 39 m.y.

Tv Extrusive rhyolite and rhyodacite (Miocene and Upper Oligocene—Lava flows, welded tuff, pyroclastic rocks, and some intercalated epiclastic rocks Light-gray to grayish-pink, vitric to fine-grained, porphyritic. Commonly a few tens to a few thousand of meters thick. Dated at 23, 24, 25, 26, 26, 26, and 27 m.y. An additional date of 47 m.y., if substantiated, may indicate the presence of Eocene rocks in the lower member of the S O Volcanics of Cochise Co.

Tlc Lower conglomerate, gravel, and sand (Oligocene and Eocene?)—Alluvium; commonly grayish-red deposits of small, well rounded, nonvolcanic clasts. Mostly several meters to a few tens of meters thick.

Tlv UPPER CORDILLERAN (LARAMIDE) IGNEOUS ROCKS (LOWER PALEOCENE):—Lower volcanic rocks—Rhyolite to andesite lava flows, pyroclastic rocks, and some intercalated epiclastic rocks. Dated at 57 m.y. Possibly younger age to east.

TKg MAIN CORDILLERAN (LARAMIDE) IGNEOUS ROCKS:—Porphyritic and aplitic intrusive rocks (Paleocene and Upper Cretaceous)—Mostly latitic porphyry to dacitic porphyry in small stocks and plugs and aplitic bodies not associated with other granitoid stocks. Dated at 61, 63, 63, 64, and 65 m.y.

Kib Fluidized intrusive breccia - exact age unknown, but penetrates, and thus younger than Uncle Sam porphyry

Kr Rhyodacite tuff and welded tuff.—Includes parts of Salero Formation, Sugarloaf Quartz Latite, and Bronco Volcanics, and all of Red Bay Rhyolite, Cat Mountain Rhyolite of Brown (1939) and Uncle Sam Prophyry. Includes local intrusive bodies and locally contains fragments of exotic rocks. Thickness commonly several tens of meters to several hundreds of meters. Dated at 66(?), 70, 72, 73, and 73 m.y. The Uncle Sam, in the Tombstone area, is dated 72m.y.

Ka Andesitic to dacitic volcanic breccia.—Includes parts of Solero Formation, Sugarloaf Quartz Latite, and Bronco Volcanics, and all of Demetrie Volcanics and Silverbell Formation of Courtright (1958). Commonly contains large blocks of exotic rocks and locally includes some sedimentary rocks and intrusive rocks. Several tens of meters to several hundreds of meters thick in most places.

Klg Lower quartz monzonite and graodiorite—Includes some quartz diorite; appears in small stocks. Locally associated with mineralization. Dated at 70, 71, 72, 73, 74, 74, 74, and 76 m.y. The Schieffin granodorite at Tombstone is 72 m.y.

Kb BISBEE FORMATION OR GROUP, UNDIFFERENTIATED (LOWER CRETACEOUS):—Upper part of Bisbee Formation or Group, undifferentiated, and related rocks.—Includes upper part of Bisbee Formation, Mural Limestone, Morita, Cintura, Willow Canyon, Apache Canyon, Shellenberger Canyon and Tumey Ranch Formations (not listed in stratigraphic sequence) of the Bisbee Group, Amole Arkose of Bryant and Kinnison (1954), and Angelic Arkose. Consists of brownish- to reddish-arkose, gray siltstone, sandstone, conglomerate, and some fossiliferous gray limestone. Commonly several hundred meters thick

Jg GRANITE AND QUARTZ MONZONITE (JURASSIC)—Stocks of pinkish-gray coarse-grained rock. Locally associated with mineralization. Dated at 140, 148, 149, 149, 150, 153, 160, 161, 167, 178, 185m.y.

PIPs Sedimentary rocks (Lower Permian and Upper Pennsylvanian)—consists of Epitaph Dolomite (Lower Permian), Colina Limestone (Lower Permian), and Earp Formation (Lower Permian and Upper Pennsylvanian), undifferentiated. Epitaph Dolomite is a dark- to light-gray slightly cherty dolomite, limestone, marl, siltstone, and gypsum, 120-280 meters thick. Colina Limestone is a medium gray, thick-bedded, sparsely cherty, and sparsely fossiliferous limestone 120-280 meters thick. Earp Formation is a pale-red siltstone, mudstone, shale, and limestone, 120-240 meters thick.

IPh Horquilla Limestone (Upper and Middle Pennsylvanian)—Light-pinkish-gray, thick- to thin-bedded, cherty, fossiliferous limestone and intercalated pale-brown to pale-reddish-gray siltstone that increases in abundance upward. Typically 300-490 meters thick.

MDs SEDIMENTARY ROCKS (MISSISSIPPIAN AND DEVONIAN)—Consists mainly of Escabrosa Limestone (Mississippian)—locally (Armstrong and Silberman, 1974) called Escabrosa Group—and Martin Formation (Upper Devonian), undifferentiated. In part of the Chiricahua Mountains also includes Paradise Formation (Upper Mississippian) and Portal Formation of Sabins, 1957a (Upper Devonian). In the Little Dragoon Mountains and some adjacent hills also includes Black Prince Limestone, whose fauna and correlation show strongest affinities with Mississippian rocks but which may include some Pennsylvanian rocks. Escabrosa Limestone is a medium-gray, massive to thick-bedded, commonly crinoidal, cherty, fossiliferous limestone 90-310 meters thick. Martin Formation is thick- to thin-bedded, gray to brown dolomite, gray sparsely fossiliferous, and some siltstone and sandstone, 90-120 meters thick. Paradise Formation is a brown, fossiliferous, shaly limestone. Portal Formation is a black shale and limestone 6-105 meters thick. Black Prince Limestone is pinkish-gray limestone with a basal shale and chert conglomerate, as much as 52 meters thick.

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Cs Sedimentary rocks (Upper and Middle Cambrian)—Abrigo Formation (Upper and Middle Cambrian), and Bolsa Quartzite (Middle Cambrian), undifferentiated.

Yg GRANITOID ROCKS (PRECAMBRIAN Y):—Mainly granodiorite and quartz monsonite, unfoliated to foliated, in part metamorphosed. Generally in stocks, which ahve been little studied.

Xp PINAL SCHIST (PRECAMBRIAN X)—Chlorite schist, phyllite, and some metavolcanic rocks, metavolcanic rocks, metaquartzite, metaquartzite conglomerate, and gneiss. One metavolcanic rock dated at 1715 m.y.

CONTACT—Dotted where concealed.

MARKER HORIZON—Dotted where concealed.

DIKES—Showing dip.

70 FAULTS—Showing dip. Dotted where concealed or intruded; ball and bar on downthrown side

45 Normal

45 Reverse

Strike-slip—Arrow couple shows relative displacement. Single arrow shows movement of active block.

Major thrust fault—Sawteeth on upper plate.

Thrust fault—Sawteeth on upper plate.

Anticline.

Syncline.

30 Inclined strike and dip of beds.

EXOTIC-BLOCK BRECCIA—Rock contains chip or block inclusions of rock different from those of host or other blocks nearby. Typically of volcanic-tectonic or sedimentary-tectonic origin; excludes Tertiary megabreccia deposits.

(QTgu) 157 Site of well or generalized site of several wells, showing unit penetrated, if known, and depth of well, in feet. 100 feet equals 30.5 meters.

72x COLLECTION SITE—Radiogenically dated rock showing age in millions of years. Query before symbol where precise location uncertain.

Roads and Highways

Dry wash

Southern Pacific Railroad

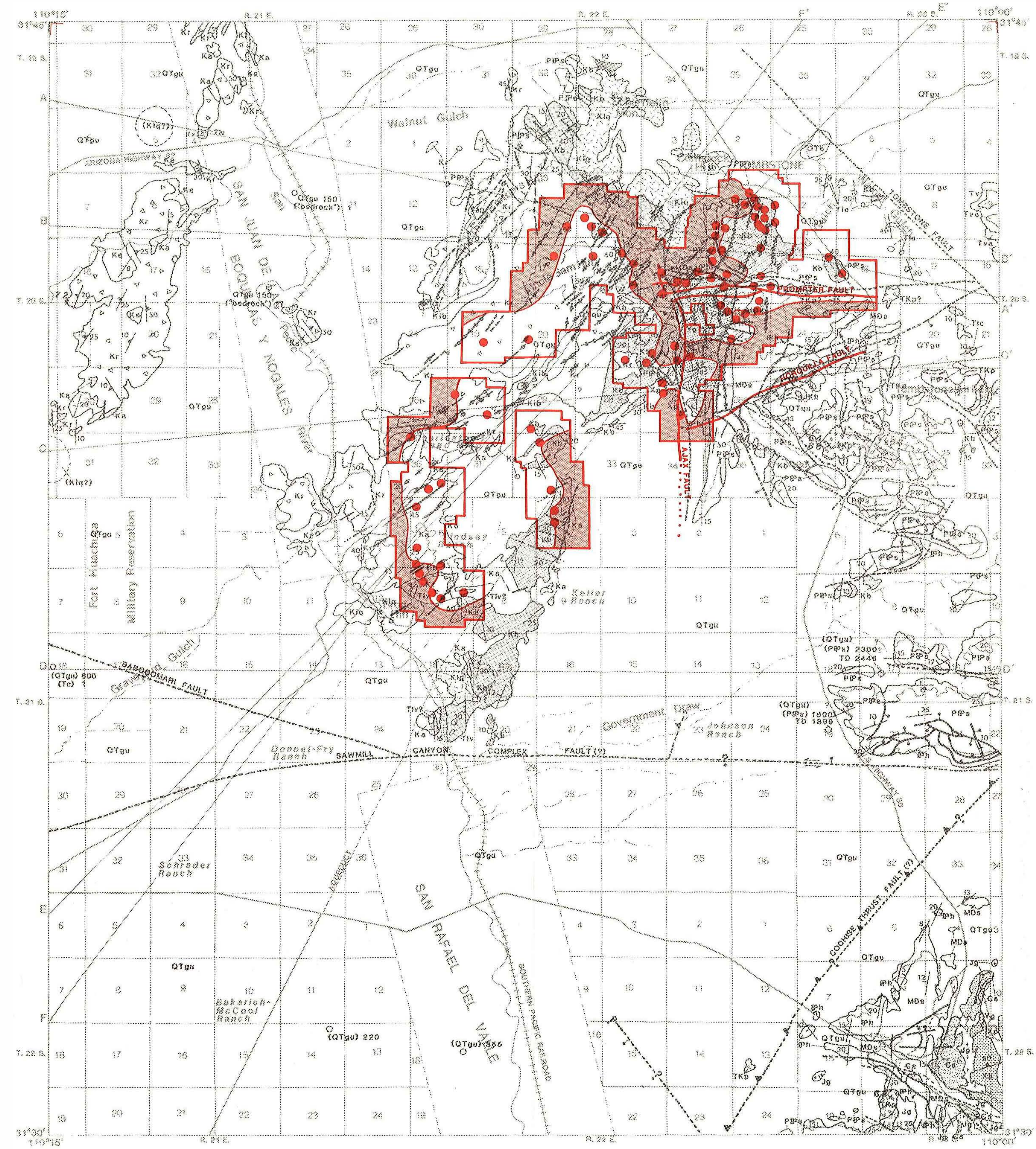
Government Reservation Boundary

Aqueduct

A—A' Cross section line

Dump sample location

Silver



Tombstone Development Company, Inc.
Tombstone, Arizona

Geology adopted from Drewes, Harold, 1980, and Newell, R.A., 1973.

By James A. Briscoe

James A. Briscoe and Associates
Tucson, Arizona

Figure 6. Dump sample location map showing area of influence boundaries and the Ajax, Prompter, and Horquilla faults, from Newell, R.A., 1973.

Distribution pattern for high silver ratios in dump samples (in red).

1 0 1 2 3 Miles

N

Explanation

Geology

QTgu — OLDER OR UNDIFFERENTIATED SURFICAL DEPOSITS (HOLOCENE TO OLIGOCENE):—Gravel, sand, and silt (Pleistocene and Pliocene—Mainly alluvium of basins; includes some colluvium and landslide deposits. Generally light-pinkish gray, weakly indurated, and with poorly rounded clasts; locally well indurated. Thickness several meters to hundreds of meters.

QTb — Basalt (Pleistocene to Pliocene)—Lava flows, pyroclastic rocks, and some intercalated gravel. Thickness several meters to a few hundred meters in most places. Radiometrically dated at 0.25, 1.0, and 3.2 m.y. old

Tva — Extensive andesite and dacite (Miocene and Upper Oligocene)—Lava flows, pyroclastic rocks, some intercalated epiclastic rocks, and dikes. Mostly gray, fine-grained, porphyritic rocks; includes some very coarse feldspar porphyry andesite (Turkey track porphyry, an informal term of Cooper, 1961). Thickness mostly several meters to several tens of meters. Dated at 24, 25, 27, 33, and 39 m.y.

Tv — Extrusive rhyolite and rhyodacite (Miocene and Upper Oligocene—Lava flows, welded tuff, pyroclastic rocks, and some intercalated epiclastic rocks. Light-gray to grayish-pink, vitric to fine-grained, porphyritic. Commonly a few tens to a few thousand of meters thick. Dated at 23, 24, 25, 26, 26, 26, and 27 m.y. An additional date of 47 m.y., if substantiated, may indicate the presence of Eocene rocks in the lower member of the S O Volcanics of Cochise Co.

Tlc — Lower conglomerate, gravel, and sand (Oligocene and Eocene?)—Alluvium; commonly grayish-red deposits of small, well rounded, nonvolcanic clasts. Mostly several meters to a few tens of meters thick.

Tlv — UPPER CORDILLERAN (LARAMIDE) IGNEOUS ROCKS (LOWER PALEOCENE):—Lower volcanic rocks—Rhyolite to andesite lava flows, pyroclastic rocks, and some intercalated epiclastic rocks. Dated at 57 m.y. Possibly younger age to east.

TKg — MAIN CORDILLERAN (LARAMIDE) IGNEOUS ROCKS:—Porphyritic and aplitic intrusive rocks (Paleocene and Upper Cretaceous)—Mostly latitic porphyry to dacitic porphyry in small stocks and plugs and aplitic bodies not associated with other granitoid stocks. Dated at 61, 63, 63, 64, and 65 m.y.

Kib — Fluidized intrusive breccia – exact age unknown, but penetrates, and thus younger than Uncle Sam porphyry.

Kr — Rhyodacite tuff and welded tuff. –Includes parts of Salero Formation, Sugarloaf Quartz Latite, and Bronco Volcanics, and all of Red Bay Rhyolite, Cat Mountain Rhyolite of Brown (1939) and Uncle Sam Prophyry. Includes local intrusive bodies and locally contains fragments of exotic rocks. Thickness commonly several tens of meters to several hundreds of meters. Dated at 66(?), 70, 72, 73, and 73 m.y. The Uncle Sam, in the Tombstone area, is dated 72 m.y.

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MARKER HORIZON—Dotted where concealed.

DIKES—Showing dip.

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Roads and Highways

Dry wash

Southern Pacific Railroad

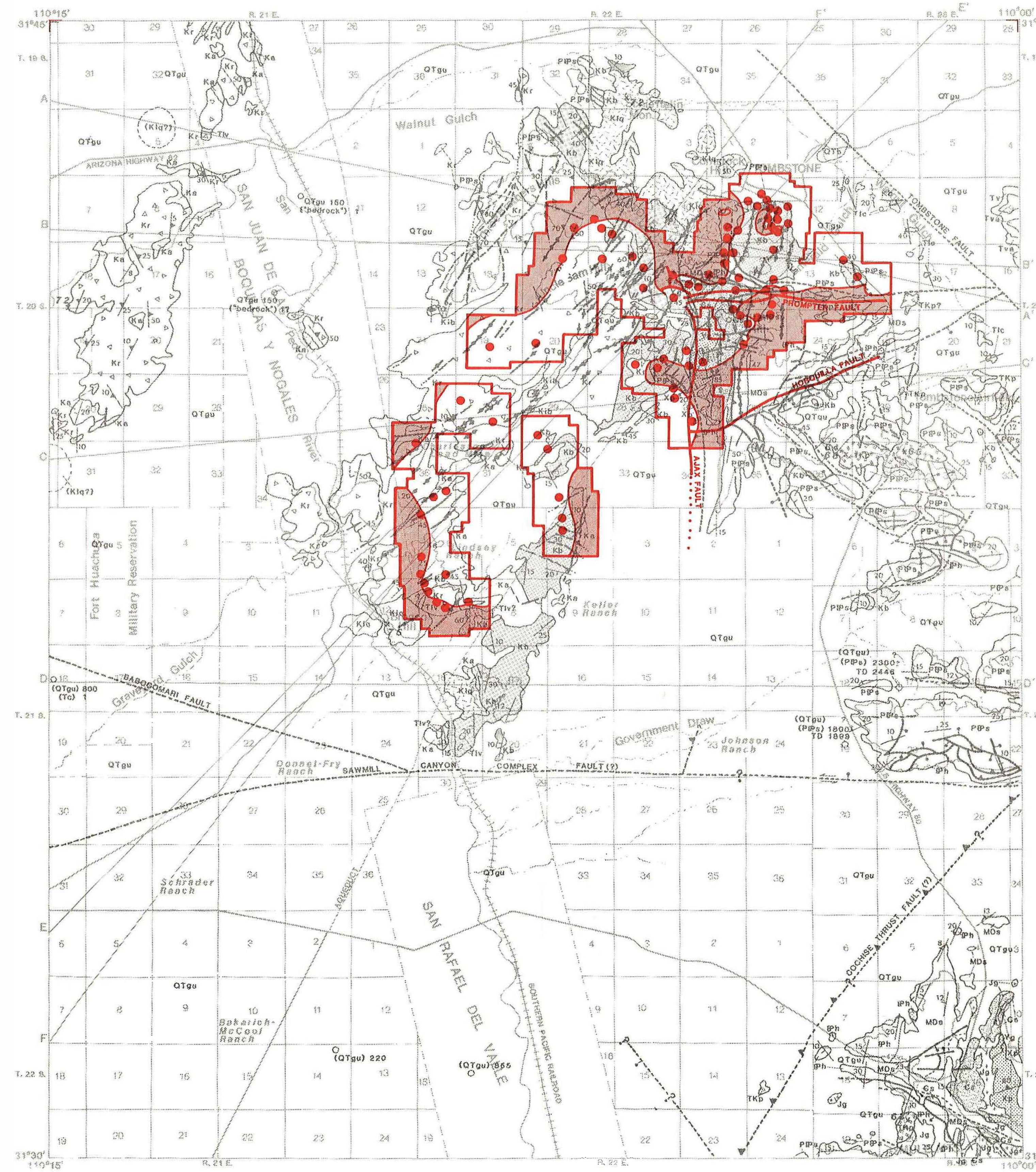
Government Reservation Boundary

Aqueduct

A—A' Cross section line

Dump sample location

Zinc



Tombstone Development Company, Inc.
Tombstone, Arizona

1 0 1 2 3 Miles

N

Geology adopted from Drewes, Harold, 1980, and Newell, R.A., 1973.

By James A. Briscoe
James A. Briscoe and Associates
Tucson, Arizona

Figure 7. Dump sample location map showing area of influence boundaries and the Ajax, Prompter, and Horquilla faults, from Newell, R.A., 1973.

Distribution pattern for high zinc ratio in dump samples (in red).

Explanation

Geology

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Roads and Highways

Dry wash

Southern Pacific Railroad

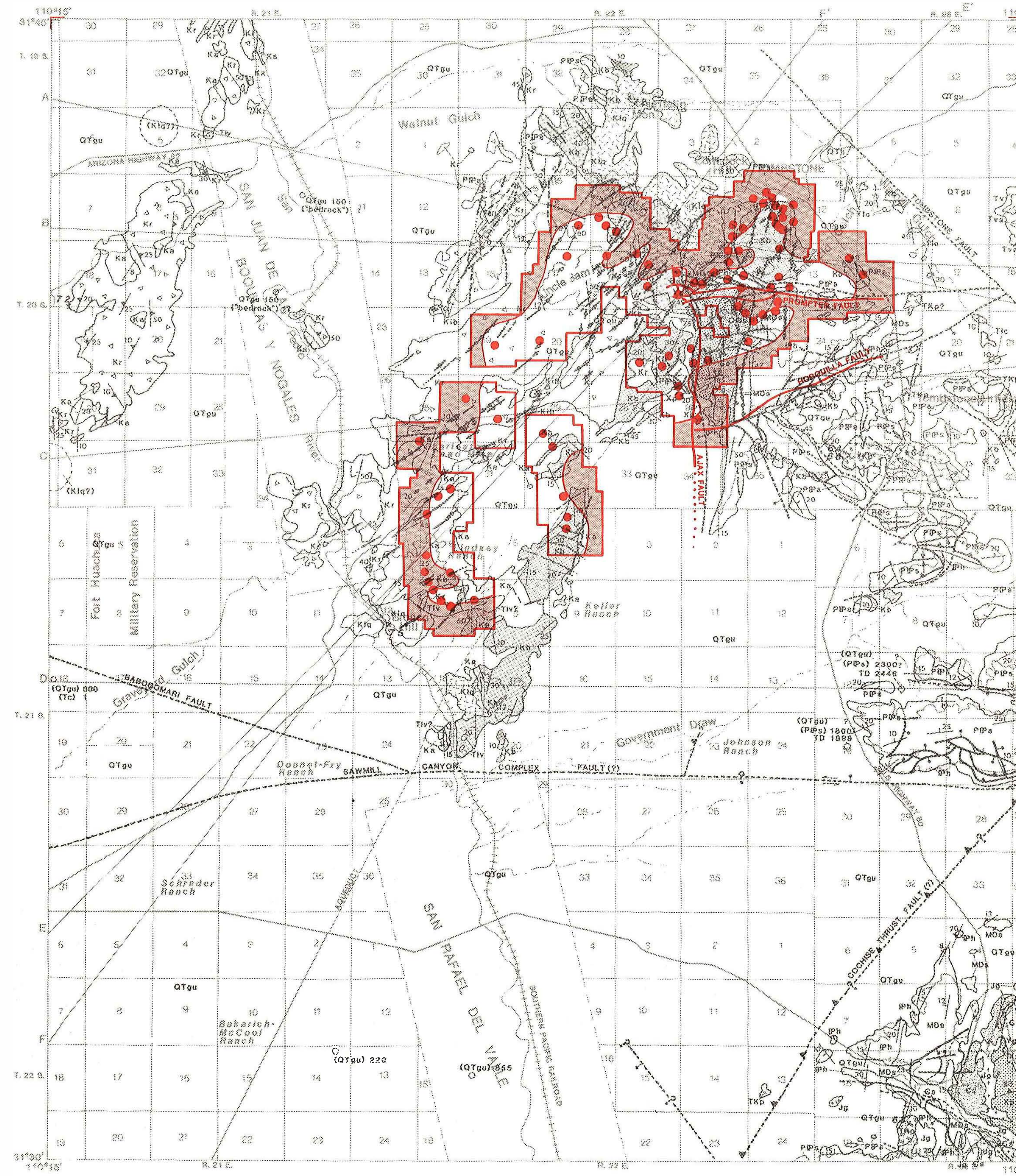
Government Reservation Boundary

Aqueduct

A—A' Cross section line

Dump sample location

Lead



Tombstone Development Company, Inc.
Tombstone, Arizona

1 0 1 2 3 Miles

N

Geology adopted from Drewes, Harold, 1980, and Newell, R.A., 1973.

By James A. Briscoe
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Klg — Lower quartz monzonite and gradiorite—Includes some quartz diorite; appears in small stocks. Locally associated with mineralization. Dated at 70, 71, 72, 73, 74, 74, 74, and 76 m.y. The Schiefflin granodorite at Tombstone is 72 m.y.

Kb — BISBEE FORMATION OR GROUP, UNDIFFERENTIATED (LOWER CRETACEOUS):—Upper part of Bisbee Formation or Group, undifferentiated, and related rocks.—Includes upper part of Bisbee Formation, Mural Limestone, Morita, Cintura, Willow Canyon, Apache Canyon, Shellenberger Canyon and Turney Ranch Formations (not listed in stratigraphic sequence) of the Bisbee Group, Amole Arkose of Bryant and Kinnison (1954), and Angelic Arkose. Consists of brownish- to reddish-arkose, gray siltstone, sandstone, conglomerate, and some fossiliferous gray limestone. Commonly several hundred meters thick

Jg — GRANITE AND QUARTZ MONZONITE (JURASSIC)—Stocks of pinkish-gray coarse-grained rock. Locally associated with mineralization. Dated at 140, 148, 149, 149, 150, 153, 160, 161, 167, 178, 185 m.y.

PIPe — Sedimentary rocks (Lower Permian and Upper Pennsylvanian)—consists of Epitaph Dolomite (Lower Permian), Colina Limestone (Lower Permian), and Earp Formation (Lower Permian and Upper Pennsylvanian), undifferentiated. Epitaph Dolomite is a dark- to light-gray slightly cherty dolomite, limestone, marl, siltstone, and gypsum, 120-280 meters thick. Colina Limestone is a medium gray, thick-bedded, sparsely cherty, and sparsely fossiliferous limestone 120-280 meters thick. Earp Formation is a pale-red siltstone, mudstone, shale, and limestone, 120-240 meters thick.

IPh — Horquilla Limestone (Upper and Middle Pennsylvanian)—Light-pinkish-gray, thick- to thin-bedded, cherty, fossiliferous limestone and intercalated pale-brown to pale-reddish-gray siltstone that increases in abundance upward. Typically 300-490 meters thick.

MDs — SEDIMENTARY ROCKS (MISSISSIPPIAN AND DEVONIAN)—Consists mainly of Escabrosa Limestone (Mississippian)—locally (Armstrong and Silberman, 1974) called Escabrosa Group—and Martin Formation (Upper Devonian), undifferentiated. In part of the Chiricahua Mountains also includes Paradise Formation (Upper Mississippian) and Portal Formation of Sabins, 1957a (Upper Devonian). In the Little Dragoon Mountains and some adjacent hills also includes Black Prince Limestone, whose fauna and correlation show strongest affinities with Mississippian rocks but which may include some Pennsylvanian rocks. Escabrosa Limestone is a medium-gray, massive to thick-bedded, commonly crinoidal, cherty, fossiliferous limestone 90-310 meters thick. Martin Formation is thick- to thin-bedded, gray to brown dolomite, gray sparsely fossiliferous, and some siltstone and sandstone, 90-120 meters thick. Paradise Formation is a brown, fossiliferous, shaly limestone. Portal Formation is a black shale and limestone 6-105 meters thick. Black Prince Limestone is pinkish-gray limestone with a basal shale and chert conglomerate, as much as 52 meters thick.

OCs — SEDIMENTARY ROCKS (LOWER ORDOVICIAN TO MIDDLE CAMBRIAN):—El Paso Limestone (Lower Ordovician and Upper Cambrian), Abrigo Formation (Upper and Middle Cambrian), and Bolsa Quartz (Middle Cambrian), undifferentiated.—El Paso Limestone is a gray, thin-bedded cherty limestone and dolomite 90 meters to about 220 meters thick. Abrigo Formation is a brown, thin-bedded fossiliferous limestone, sandstone, quartzite, and shale, 210-240 meters thick. Bolsa Quartzite is a brown to white or purplish-gray, thick-bedded, coarse grained quartzite and sandstone with a basal conglomerate, 90-180 meters thick. To the east, equivalents of part of the Abrigo Formation and Bolsa Quartzite are known as the Coronado Sandstone.

Cs — Sedimentary rocks (Upper and Middle Cambrian)—Abrigo Formation (Upper and Middle Cambrian), and Bolsa Quartzite (Middle Cambrian), undifferentiated.

Yg — GRANITOID ROCKS (PRECAMBRIAN Y):—Mainly granodiorite and quartz monsonite, unfoliated to foliated, in part metamorphosed. Generally in stocks, which ahve been little studied.

Xp — PINAL SCHIST (PRECAMBRIAN X)—Chlorite schist, phyllite, and some metavolcanic rocks, metavolcanic rocks, metaquartzite, metaquartzite conglomerate, and gneiss. One metavolcanic rock dated at 1715 m.y.

CONTACT—Dotted where concealed.

MARKER HORIZON—Dotted where concealed.

DIKES—Showing dip

70 — FAULTS—Showing dip. Dotted where concealed or intruded; ball and bar on downthrown side.

45 — Normal

45 — Reverse

Strike-slip—Arrow couple shows relative displacement. Single arrow shows movement of active block.

Major thrust fault—Sawteeth on upper plate.

Thrust fault—Sawteeth on upper plate.

Anticline.

Syncline.

30 — Inclined strike and dip of beds.

EXOTIC-BLOCK BRECCIA—Rock contains chip or block inclusions of rock different from those of host or other blocks nearby. Typically of volcanic-tectonic or sedimentary-tectonic origin; excludes Tertiarymegabreccia deposits.

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72x — COLLECTION SITE—Radiogenically dated rock showing age in millions of years. Query before symbol where precise location uncertain.

Roads and Highways

Dry wash

Southern Pacific Railroad

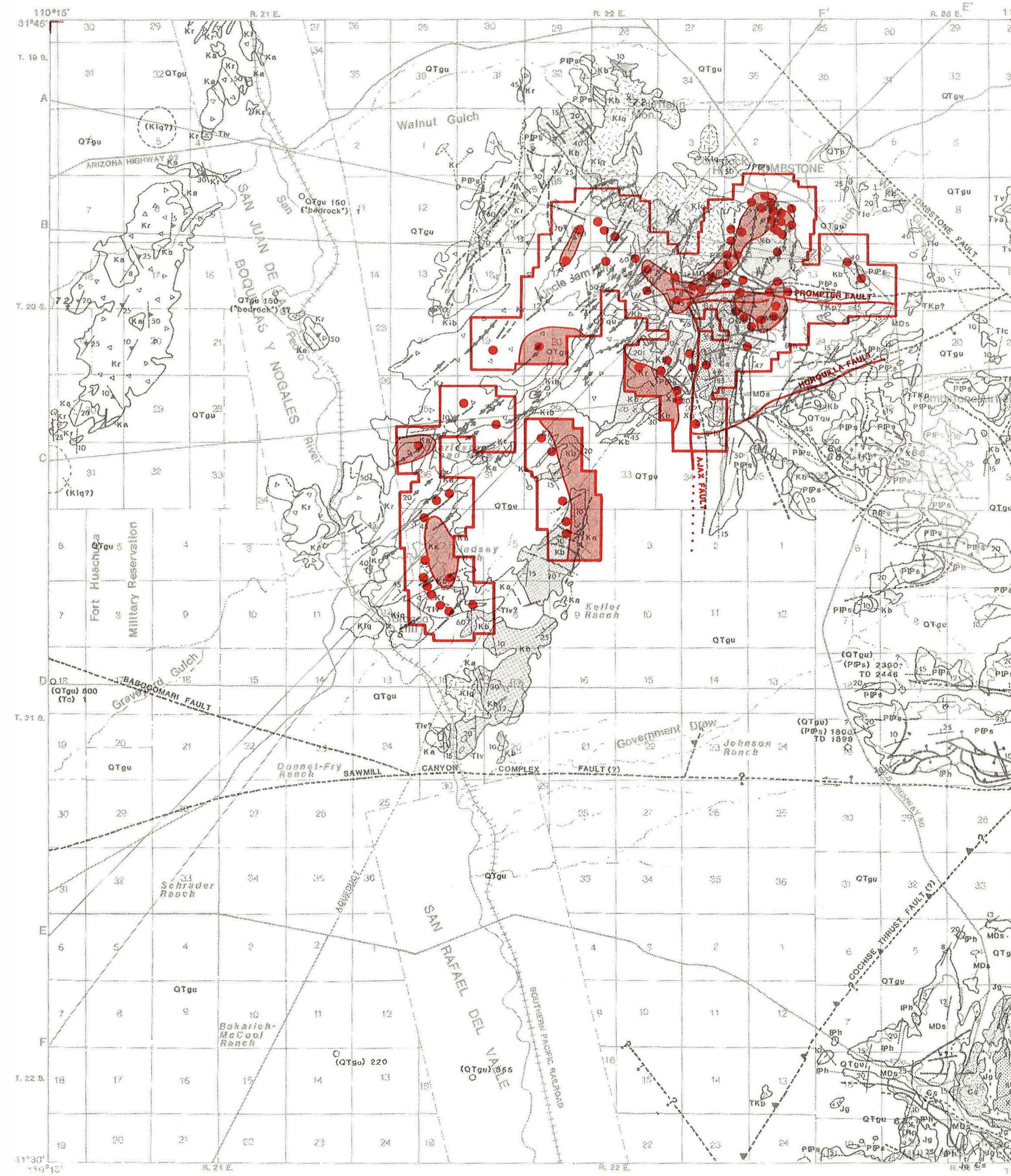
Government Reservation Boundary

Aqueduct

A——A' Cross section line

Dump sample location

Copper



Tombstone Development Company, Inc.
Tombstone, Arizona

1 0 1 2 3 Miles

N

Geology adopted from Drewes, Harold, 1980, and Newell, R.A., 1973.

By James A. Briscoe
James A. Briscoe and Associates
Tucson, Arizona

Figure 9. Dump sample location map showing area of influence boundaries and the Ajax, Prompter, and Horquilla faults, from Newell, R.A., 1973.

Distribution pattern for high copper ratios in dump samples (in red).

Explanation

Geology

QTgu — OLDER OR UNDIFFERENTIATED SURFICAL DEPOSITS (HOLOCENE TO OLIGOCENE):—Gravel, sand, and silt (Pleistocene and Pliocene—Mainly alluvium of basins; includes some colluvium and landslide deposits. Generally light-pinkish gray, weakly indurated, and with poorly rounded clasts; locally well indurated. Thickness several meters to hundreds of meters.

QTb — Basalt (Pleistocene to Pliocene)—Lava flows, pyroclastic rocks, and some intercalated gravel. Thickness several meters to a few hundred meters in most places. Radiometrically dated at 0.25, 1.0, and 3.2 m.y. old

Tva — Extensive andesite and dacite (Miocene and Upper Oligocene)—Lava flows, pyroclastic rocks, some intercalated epiclastic rocks, and dikes. Mostly gray, fine-grained, porphyritic rocks; includes some very coarse feldspar porphyry andesite (Turkey track porphyry, an informal term of Cooper, 1961). Thickness mostly several meters to several tens of meters. Dated at 24, 25, 27, 33, and 39 m.y

Tv — Extrusive rhyolite and rhyodacite (Miocene and Upper Oligocene—Lava flows, welded tuff, pyroclastic rocks, and some intercalated epiclastic rocks. Light-gray to grayish-pink, vitric to fine-grained, porphyritic. Commonly a few tens to a few thousand of meters thick. Dated at 23, 24, 25, 26, 26, 26, and 27 m.y. An additional date of 47 m.y., if substantiated, may indicate the presence of Eocene rocks in the lower member of the S O Volcanics of Cochise Co.

Tlc — Lower conglomerate, gravel, and sand (Oligocene and Eocene?)—Alluvium; commonly grayish-red deposits of small, well rounded, nonvolcanic clasts. Mostly several meters to a few tens of meters thick.

Tlv — UPPER CORDILLERAN (LARAMIDE) IGNEOUS ROCKS (LOWER PALEOCENE):—Lower volcanic rocks Rhyolite to andesite lava flows, pyroclastic rocks, and some intercalated epiclastic rocks. Dated at 57 m.y. Possibly younger age to east.

TKp — MAIN CORDILLERAN (LARAMIDE) IGNEOUS ROCKS:—Porphyritic and aplitic intrusive rocks (Paleocene and Upper Cretaceous)—Mostly latitic porphyry to dacitic porphyry in small stocks and plugs and aplitic bodies not associated with other granitoid stocks. Dated at 61, 63, 63, 64, and 65 m.y.

Kib — Fluidized intrusive breccia – exact age unknown, but penetrates, and thus younger than Uncle Sam porphyry.

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Roads and Highways

Dry wash

Southern Pacific Railroad

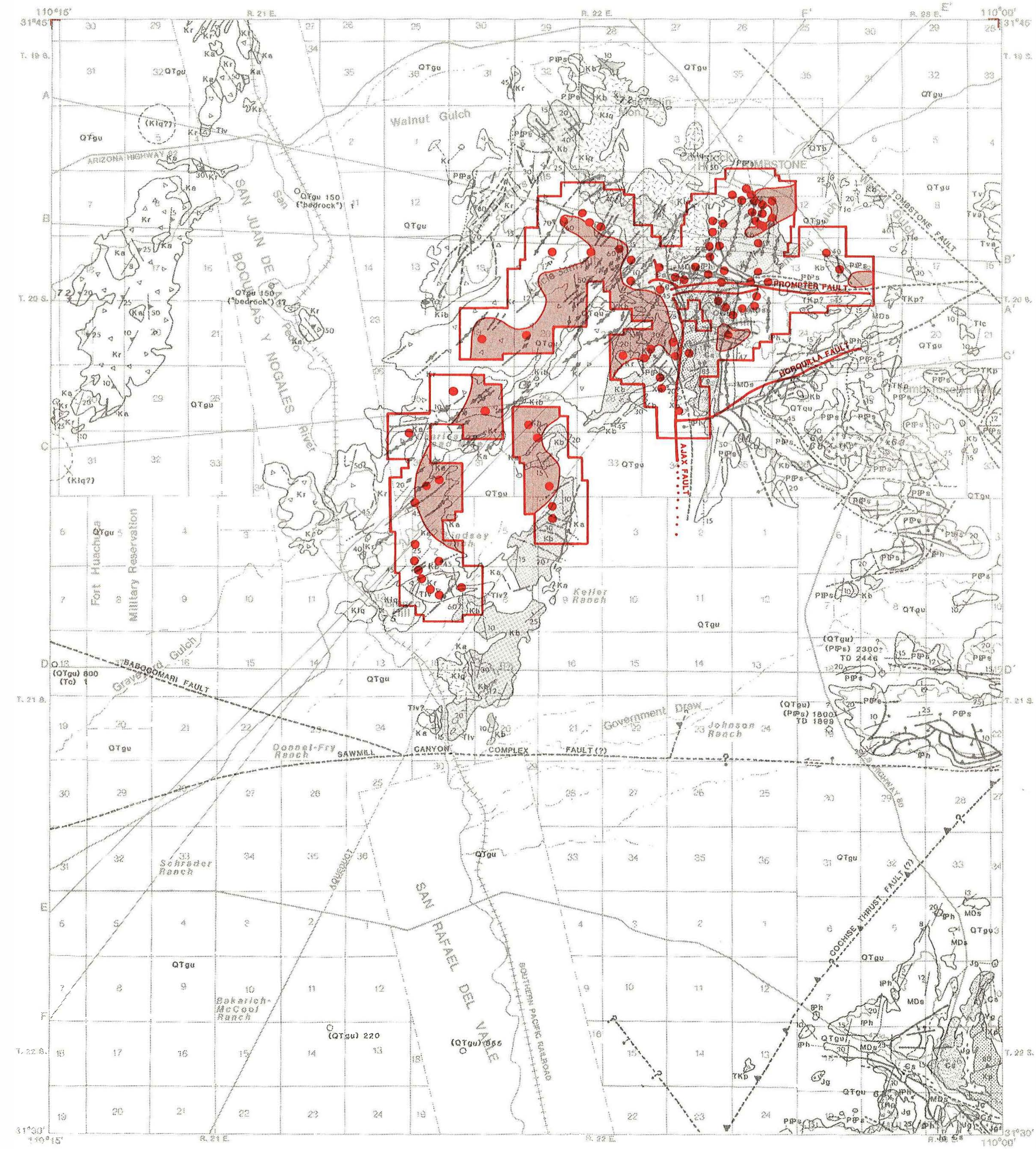
Government Reservation Boundary

Aqueduct

A——A' Cross section line

Dump sample location

Molybdenum



Tombstone Development Company, Inc.
Tombstone, Arizona

Geology adopted from Drewes, Harold, 1980, and Newell, R.A., 1973.

By James A. Briscoe
James A. Briscoe and Associates
Tucson, Arizona

Figure 10. Dump sample location map showing area of influence boundaries and the Ajax, Prompter, and Horquilla faults, from Newell, R.A., 1973.

Distribution pattern for high molybdenum ratios in dump samples (in red).

Explanation

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Roads and Highways

Dry wash

Southern Pacific Railroad

Government Reservation Boundary

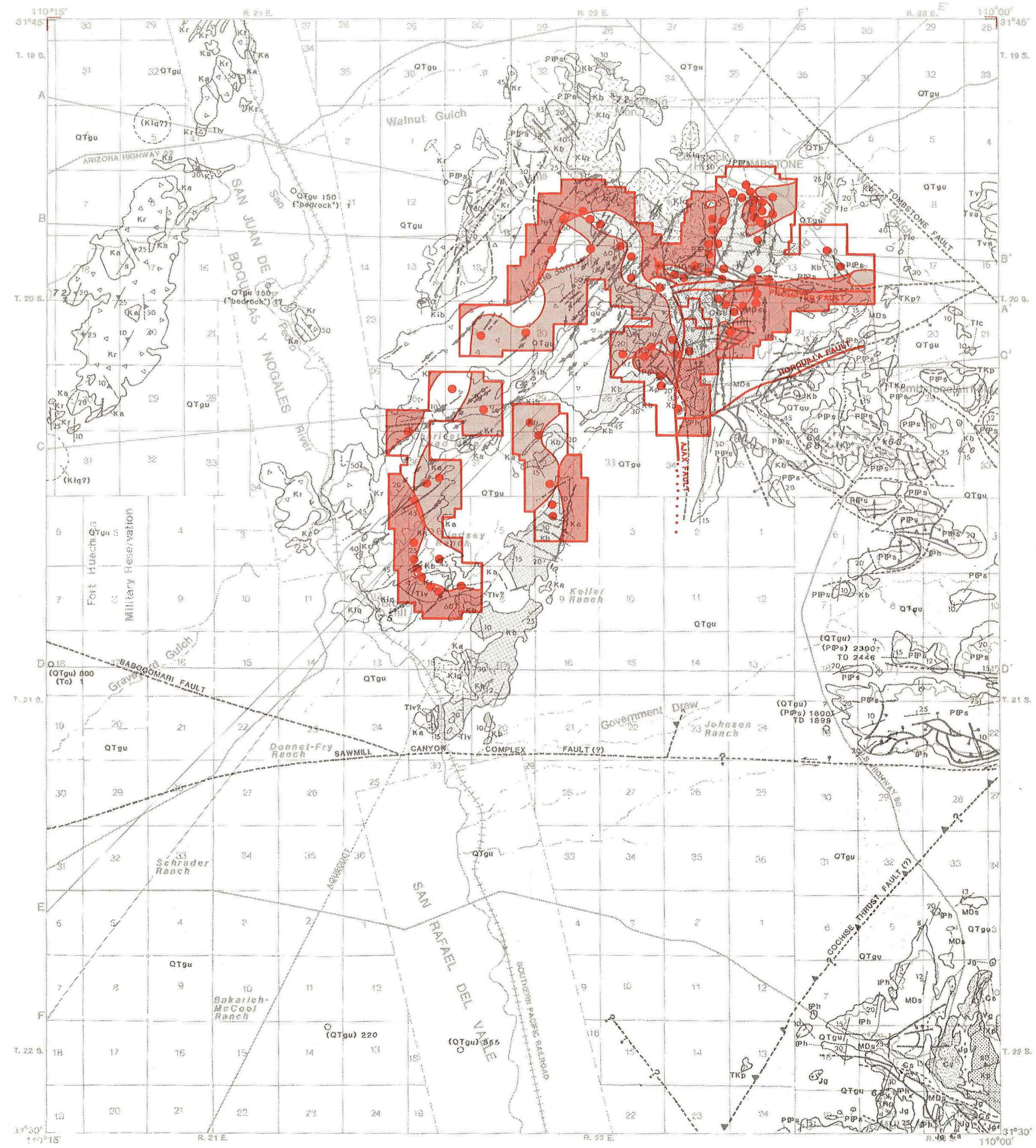
Aqueduct

A—A' Cross section line

Dump sample location

Molybdenum

Zinc



Tombstone Development Company, Inc.
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Kr — Rhyodacite tuff and welded tuff. - Includes parts of Salero Formation, Sugarloaf Quartz Latite, and Bronco Volcanics, and all of Red Bay Rhyolite, Cat Mountain Rhyolite of Brown (1939) and Uncle Sam Prophyry. Includes local intrusive bodies and locally contains fragments of exotic rocks. Thickness commonly several tens of meters to several hundreds of meters. Dated at 66(?), 70, 72, 73, and 73 m.y. The Uncle Sam, in the Tombstone area, is dated 72 m.y.

Ka — Andesitic to dacitic volcanic breccia.—Includes parts of Solero Formation, Sugarloaf Quartz Latite, and Bronco Volcanics, and all of Demetrie Volcanics and Silverbell Formation of Courtright (1958). Commonly contains large blocks of exotic rocks and locally includes some sedimentary rocks and intrusive rocks. Several tens of meters to several hundreds of meters thick in most places.

Klg — Lower quartz monzonite and graodiorite—Includes some quartz diorite; appears in small stocks. Locally associated with mineralization. Dated at 70, 71, 72, 73, 74, 74, 74, and 76 m.y. The Schiefflin granodorite at Tombstone is 72 m.y.

Kb — BISBEE FORMATION OR GROUP, UNDIFFERENTIATED (LOWER CRETACEOUS):—Upper part of Bisbee Formation or Group, undifferentiated, and related rocks.—Includes upper part of Bisbee Formation, Mural Limestone, Morita, Cintura, Willow Canyon, Apache Canyon, Shellenberger Canyon and Turney Ranch Formations (not listed in stratigraphic sequence) of the Bisbee Group, Amole Arkose of Bryant and Kinnison (1954), and Angelic Arkose. Consists of brownish- to reddish arkose, gray siltstone, sandstone, conglomerate, and some fossiliferous gray limestone. Commonly several hundred meters thick

Jg — GRANITE AND QUARTZ MONZONITE (JURASSIC)—Stocks of pinkish-gray coarse-grained rock. Locally associated with mineralization. Dated at 140, 148, 149, 149, 150, 153, 160, 161, 167, 178, 185 m.y.

PPe — Sedimentary rocks (Lower Permian and Upper Pennsylvanian)—consists of Epitaph Dolomite (Lower Permian), Colina Limestone (Lower Permian), and Earp Formation (Lower Pennian and Upper Pennsylvanian), undifferentiated. Epitaph Dolomite is a dark- to light-gray slightly cherty dolomite, limestone, marl, siltstone, and gypsum, 120-280 meters thick. Colina Limestone is a medium gray, thick-bedded, sparsely cherty, and sparsely fossiliferous limestone 120-280 meters thick. Earp Formation is a pale-red siltstone, mudstone, shale, and limestone, 120-240 meters thick.

Ph — Horquilla Limestone (Upper and Middle Pennsylvanian)—Light-pinkish-gray, thick- to thin-bedded, cherty, fossiliferous limestone and intercalated pale-brown to pale-reddish-gray siltstone that increases in abundance upward. Typically 300-490 meters thick.

MDs — SEDIMENTARY ROCKS (MISSISSIPPIAN AND DEVONIAN)—Consists mainly of Escabrosa Limestone (Mississippian)—locally (Armstrong and Silberman, 1974) called Escabrosa Group—and Martin Formation (Upper Devonian), undifferentiated. In part of the Chiricahua Mountains also includes Paradise Formation (Upper Mississippian) and Portal Formation of Sabins, 1957a (Upper Devonian). In the Little Dragoon Mountains and some adjacent hills also includes Black Prince Limestone, whose fauna and correlation show strongest affinities with Mississippian rocks but which may include some Pennsylvanian rocks. Escabrosa Limestone is a medium-gray, massive to thick-bedded, commonly crinoidal, cherty, fossiliferous limestone 90-310 meters thick. Martin Formation is thick- to thin-bedded, gray to brown dolomite, gray sparsely fossiliferous, and some siltstone and sandstone, 90-120 meters thick. Paradise Formation is a brown, fossiliferous, shaly limestone. Portal Formation is a black shale and limestone 6-105 meters thick. Black Prince Limestone is pinkish-gray limestone with a basal shale and chert conglomerate, as much as 52 meters thick.

OCs — SEDIMENTARY ROCKS (LOWER ORDOVICIAN TO MIDDLE CAMBRIAN):—El Paso Limestone (Lower Ordovician and Upper Cambrian), Abrigo Formation (Upper and Middle Cambrian), and Bolsa Quartz (Middle Cambrian), undifferentiated.—El Paso Limestone is a gray, thin-bedded cherty limestone and dolomite 90 meters to about 220 meters thick. Abrigo Formation is a brown, thin-bedded fossiliferous limestone, sandstone, quartzite, and shale, 210-240 meters thick. Bolsa Quartzite is a brown to white or purplish-gray, thick-bedded, coarse-grained quartzite and sandstone with a basal conglomerate, 90-180 meters thick. To the east, equivalents of part of the Abrigo Formation and Bolsa Quartzite are known as the Coronado Sandstone.

Cs — Sedimentary rocks (Upper and Middle Cambrian)—Abrigo Formation (Upper and Middle Cambrian), and Bolsa Quartzite (Middle Cambrian), undifferentiated.

Yg — GRANITOID ROCKS (PRECAMBRIAN Y):—Mainly granodiorite and quartz monsonite, unfoliated to foliated, in part metamorphosed. Generally in stocks, whichahve been little studied.

Xp — PINAL SCHIST (PRECAMBRIAN X)—Chlorite schist, phyllite, and some metavolcanic rocks, metavolcanic rocks, metaquartzite, metaquartzite conglomerate, and gneiss. One metavolcanic rock dated at 1715 m.y.

CONTACT—Dotted where concealed.

MARKER HORIZON—Dotted where concealed.

DIKES—Showing dip.

70 — FAULTS—Showing dip. Dotted where concealed or intruded; ball and bar on downthrown side.

45 — Normal

45 — Reverse

Strike-slip—Arrow couple shows relative displacement. Single arrow shows movement of active block.

Major thrust fault—Sawteeth on upper plate.

Thrust fault—Sawteeth on upper plate.

Anticline.

Syncline.

30 — Inclined strike and dip of beds.

EXOTIC-BLOCK BRECCIA—Rock contains chip or block inclusions of rock different from those of host or other blocks nearby. Typically of volcanic-tectonic or sedimentary-tectonic origin; excludes Tertiary megabreccia deposits.

(QTgu) 157 — Site of well or generalized site of several wells, showing unit penetrated, if known, and depth of well, in feet. 100 feet equals 30.5 meters.

72x — COLLECTION SITE—Radiogenically dated rock showing age in millions of years. Query before symbol where precise location uncertain.

Roads and Highways

Dry wash

Southern Pacific Railroad

Government Reservation Boundary

Aqueduct

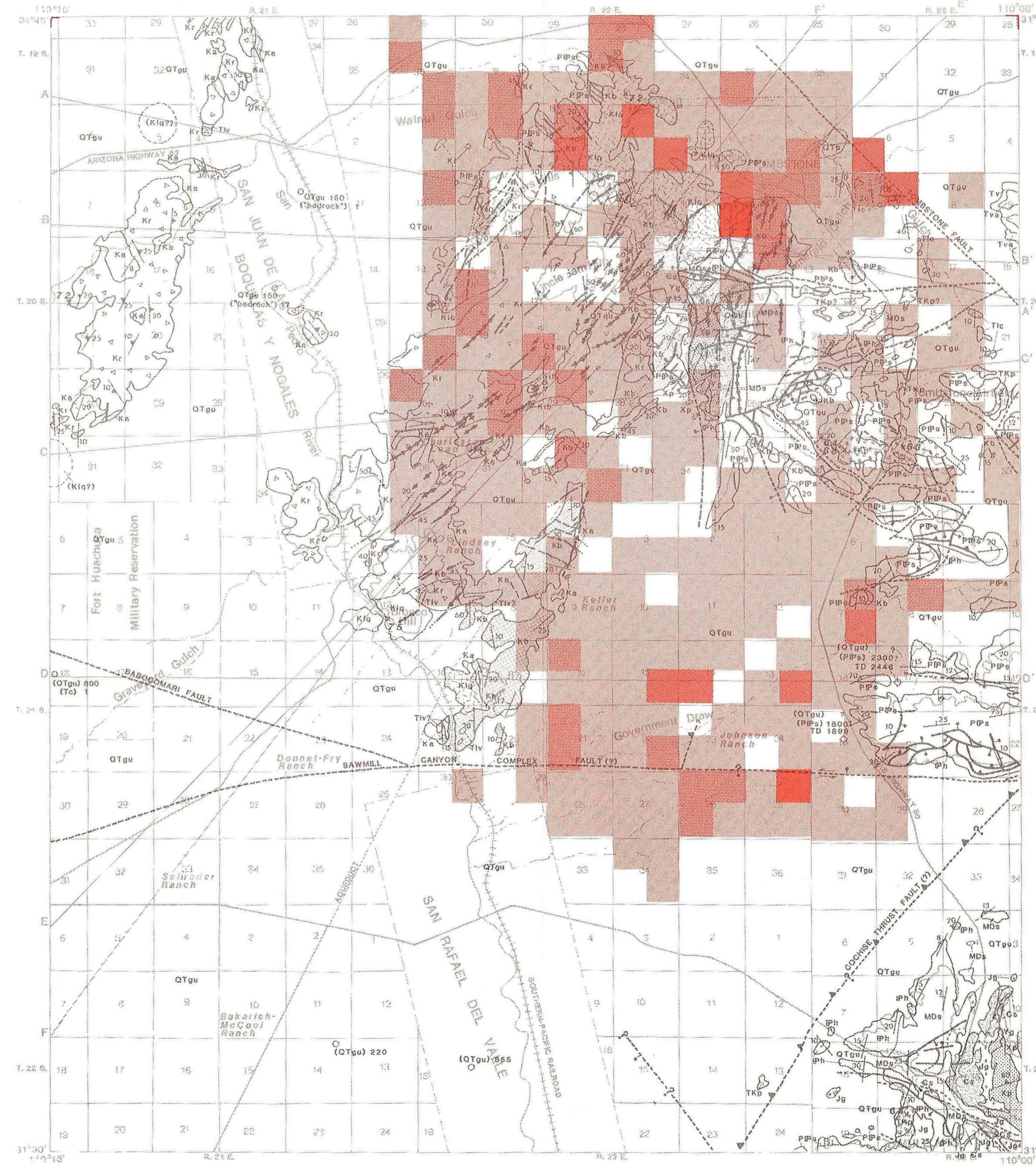
A———A' Cross section line

≤ 1 ppm

1.1 - 2 ppm

2.1 - 3 ppm

≥ 3 ppm



Tombstone Development Company, Inc.
Tombstone, Arizona

1 0 1 2 3 Miles

N

Geology adopted from Drewes, Harold, 1980, and Newell, R.A., 1973.

Figure 12. Distribution pattern of silver in mesquite trees (in red), from Newell, R.A., 1973.

By James A. Briscoe
James A. Briscoe and Associates
Tucson, Arizona

Explanation

Geology

QTgu — OLDER OR UNDIFFERENTIATED SURFICAL DEPOSITS (HOLOCENE TO OLIGOCENE):—Gravel, sand, and silt (Pleistocene and Pliocene—Mainly alluvium of basins; includes some colluvium and landslide deposits. Generally light-pinkish gray, weakly indurated, and with poorly rounded clasts; locally well indurated. Thickness several meters to hundreds of meters.

QTb — Basalt (Pleistocene to Pliocene)—Lava flows, pyroclastic rocks, and some intercalated gravel. Thickness several meters to a few hundred meters in most places. Radiometrically dated at 0.25, 1.0, and 3.2 m.y. old

Tva — Extensive andesite and dacite (Miocene and Upper Oligocene)—Lava flows, pyroclastic rocks, some intercalated epiclastic rocks, and dikes. Mostly gray, fine-grained, porphyritic rocks; includes some very coarse feldspar porphyry andesite (Turkey track porphyry, an informal term of Cooper, 1961). Thickness mostly several meters to several tens of meters. Dated at 24, 25, 27, 33, and 39 m.y.

Tv — Extrusive rhyolite and rhyodacite (Miocene and Upper Oligocene—Lava flows, welded tuff, pyroclastic rocks, and some intercalated epiclastic rocks. Light-gray to grayish-pink, vitric to fine-grained, porphyritic. Commonly a few tens to a few thousand of meters thick. Dated at 23, 24, 25, 26, 26, 26, and 27 m.y. An additional date of 47 m.y., if substantiated, may indicate the presence of Eocene rocks in the lower member of the S O Volcanics of Cochise Co.

Tlc — Lower conglomerate, gravel, and sand (Olligocene and Eocene?)—Alluvium; commonly grayish-red deposits of small, well rounded, nonvolcanic clasts. Mostly several meters to a few tens of meters thick.

Tlv — UPPER CORDILLERAN (LARAMIDE) IGNEOUS ROCKS (LOWER PALEOCENE):—Lower volcanic rocks—Rhyolite to andesite lava flows, pyroclastic rocks, and some intercalated epiclastic rocks. Dated at 57 m.y. Possibly younger age to east.

TKg — MAIN CORDILLERAN (LARAMIDE) IGNEOUS ROCKS:—Porphyritic and aplitic intrusive rocks (Paleocene and Upper Cretaceous)—Mostly latitic porphyry to dacitic porphyry in small stocks and plugs and aplitic bodies not associated with other granitoid stocks. Dated at 61, 63, 63, 64, and 65 m.y.

Kib — Fluidized intrusive breccia – exact age unknown, but penetrates, and thus younger than Uncle Sam porphyry.

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Jg — GRANITE AND QUARTZ MONZONITE (JURASSIC)—Stocks of pinkish-gray coarse-grained rock. Locally associated with mineralization. Dated at 140, 148, 149, 149, 150, 153, 160, 161, 167, 178, 185 m.y.

PIPs — Sedimentary rocks (Lower Permian and Upper Pennsylvanian)—consists of Epitaph Dolomite (Lower Permian), Colina Limestone (Lower Permian), and Earp Formation (Lower Permian and Upper Pennsylvanian), undifferentiated. Epitaph Dolomite is a dark- to light-gray slightly cherty dolomite, limestone, marl, siltstone, and gypsum, 120-280 meters thick. Colina Limestone is a medium gray, thick-bedded, sparsely cherty, and sparsely fossiliferous limestone 120-280 meters thick. Earp Formation is a pale-red siltstone, mudstone, shale, and limestone, 120-240 meters thick.

IPh — Horquilla Limestone (Upper and Middle Pennsylvanian)—Light-pinkish-gray, thick- to thin-bedded, cherty, fossiliferous limestone and intercalated pale-brown to pale-reddish-gray siltstone that increases in abundance upward. Typically 300-490 meters thick.

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MARKER HORIZON—Dotted where concealed.

DIKES—Showing dip.

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45 — Normal

45 — Reverse

Strike-slip—Arrow couple shows relative displacement. Single arrow shows movement of active block.

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Anticline.

Syncline.

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72x — COLLECTION SITE—Radiogenically dated rock showing age in millions of years. Query before symbol where precise location uncertain.

Roads and Highways

Dry wash

Southern Pacific Railroad

Government Reservation Boundary

Aqueduct

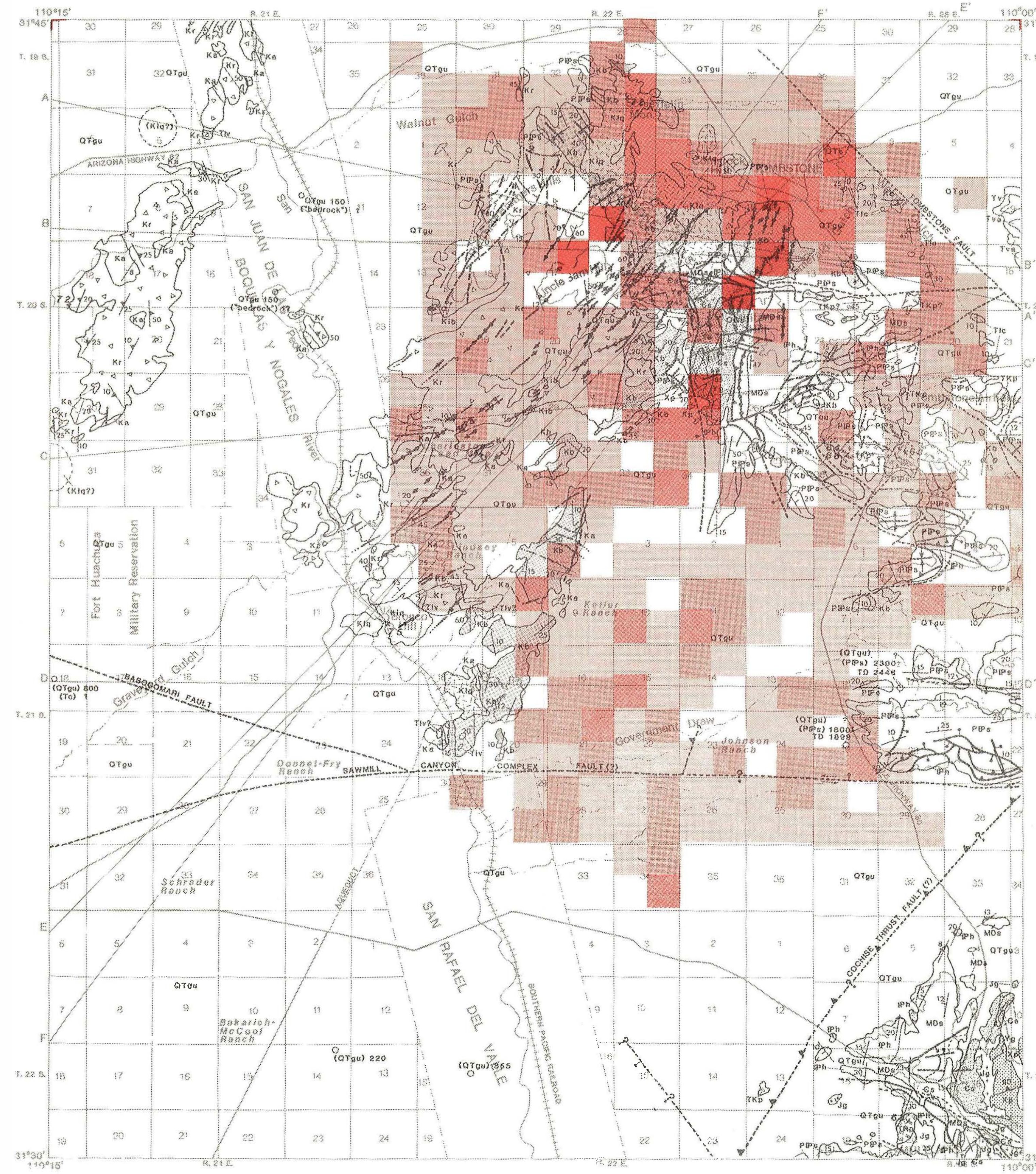
A— —A' Cross section line

≤ 400 ppm

401 - 600 ppm

601 - 800 ppm

≥ 800 ppm



Tombstone Development Company, Inc.
Tombstone, Arizona

1 0 1 2 3 Miles

N

Geology adopted from Drewes, Harold, 1980, and Newell, R.A., 1973.

Figure 13. Distribution pattern of zinc in mesquite trees (in red), from Newell, R.A., 1973.

By James A. Briscoe
James A. Briscoe and Associates
Tucson, Arizona

Explanation

Geology

QTgu — OLDER OR UNDIFFERENTIATED SURFICAL DEPOSITS (HOLOCENE TO OLIGOCENE):—Gravel, sand, and silt (Pleistocene and Pliocene—Mainly alluvium of basins; includes some colluvium and landslide deposits. Generally light-pinkish gray, weakly indurated, and with poorly rounded clasts; locally well indurated. Thickness several meters to hundreds of meters.

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DIKES—Showing dip

70

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45

Normal

45

Reverse

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Roads and Highways

Dry wash

Southern Pacific Railroad

Government Reservation Boundary

Aqueduct

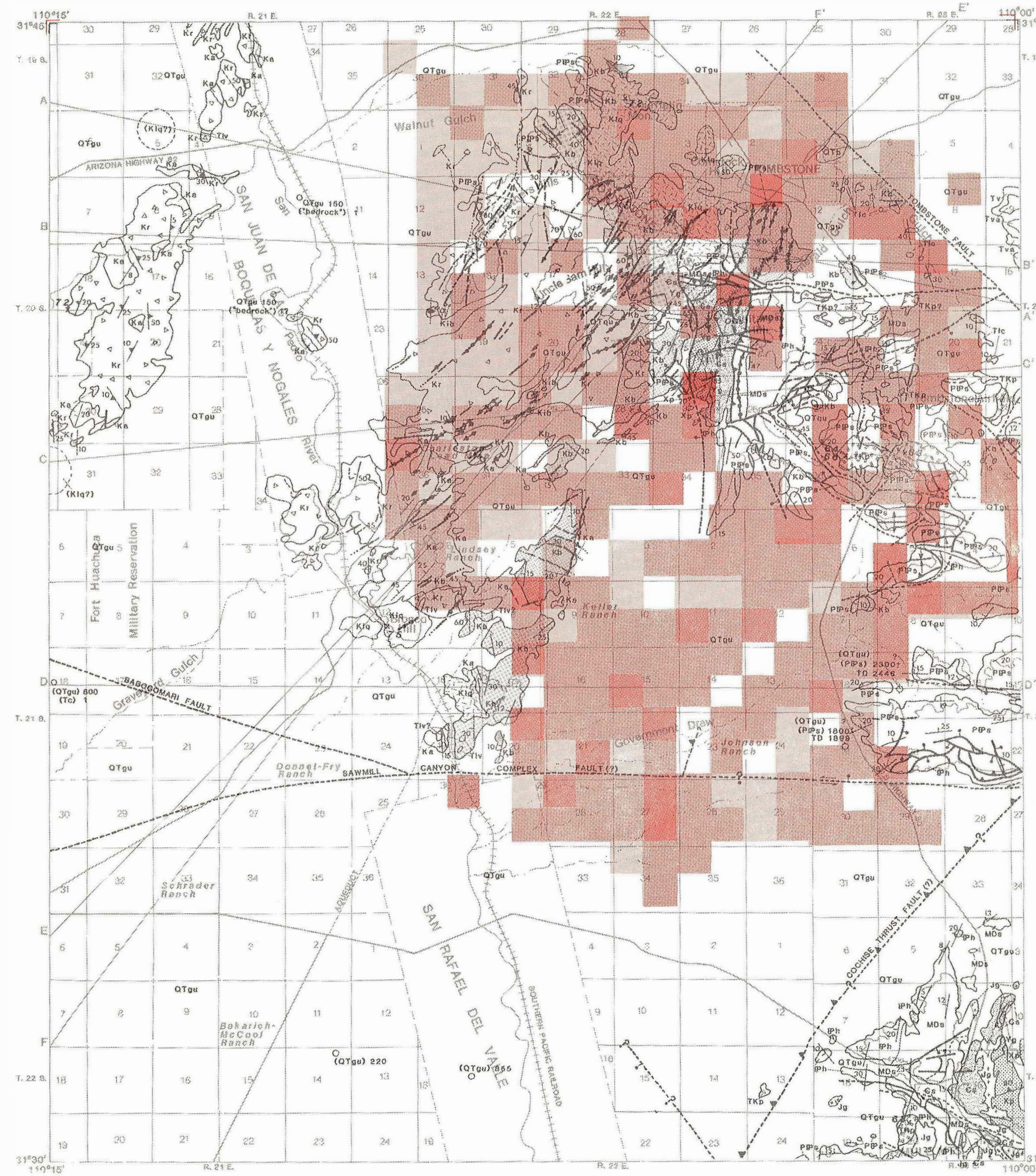
A——A' Cross section line

≤ 100 ppm

101 - 150 ppm

151 - 200 ppm

≥ 200 ppm



Tombstone Development Company, Inc.
Tombstone, Arizona

Geology adopted from Drewes, Harold, 1980, and Newell, R.A., 1973.

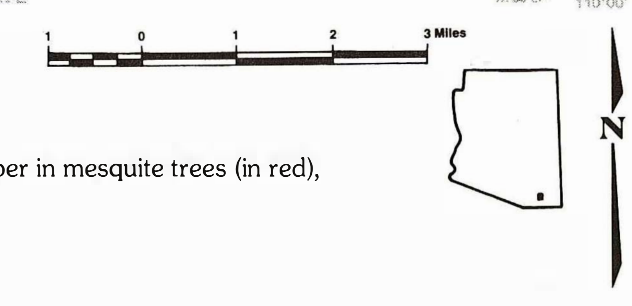


Figure 14. Distribution pattern of copper in mesquite trees (in red), from Newell, R.A., 1973.

By James A. Briscoe
James A. Briscoe and Associates
Tucson, Arizona

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TKg — MAIN CORDILLERAN (LARAMIDE) IGNEOUS ROCKS:—Porphyritic and aplitic intrusive rocks (Paleocene and Upper Cretaceous)—Mostly latitic porphyry to dacitic porphyry in small stocks and plugs and aplitic bodies not associated with other granitoid stocks. Dated at 61, 63, 63, 64, and 65 m.y.

Kib — Fluidized intrusive breccia –exact age unknown, but penetrates, and thus younger than Uncle Sam porphyry.

Kr — Rhyodacite tuff and welded tuff. –Includes parts of Salero Formation, Sugarloaf Quartz Latite, and Bronco Volcanics, and all of Red Bay Rhyolite, Cat Mountain Rhyolite of Brown (1939) and Uncle Sam Prophyry. Includes local intrusive bodies and locally contains fragments of exotic rocks. Thickness commonly several tens of meters to several hundreds of meters. Dated at 66(?), 70, 72, 73, and 73 m.y. The Uncle Sam, in the Tombstone area, is dated 72 m.y.

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Klg — Lower quartz monzonite and graodiorite—Includes some quartz diorite; appears in small stocks. Locally associated with mineralization. Dated at 70, 71, 72, 73, 74, 74, 74, and 76 m.y. The Schiefflin granodorite at Tombstone is 72 m.y.

Kb — BISBEE FORMATION OR GROUP, UNDIFFERENTIATED (LOWER CRETACEOUS):—Upper part of Bisbee Formation or Group, undifferentiated, and related rocks.—Includes upper part of Bisbee Formation, Mural Limestone, Morita, Cintura, Willow Canyon, Apache Canyon, Shellenberger Canyon and Turney Ranch Formations (not listed in stratigraphic sequence) of the Bisbee Group, Amole Arkose of Bryant and Kinnison (1954), and Angelic Arkose. Consists of brownish- to reddish-arkose, gray siltstone, sandstone, conglomerate, and some fossiliferous gray limestone. Commonly several hundred meters thick

Jg — GRANITE AND QUARTZ MONZONITE (JURASSIC)—Stocks of pinkish-gray coarse-grained rock. Locally associated with mineralization. Dated at 140, 148, 149, 149, 150, 153, 160, 161, 167, 178, 185m.y.

PlPs — Sedimentary rocks (Lower Permian and Upper Pennsylvanian)—consists of Epitaph Dolomite (Lower Permian), Colina Limestone (Lower Permian), and Earp Formation (Lower Permian and Upper Pennsylvanian), undifferentiated. Epitaph Dolomite is a dark- to light-gray slightly cherty dolomite, limestone, marl, siltstone, and gypsum, 120-280 meters thick. Colina Limestone is a medium gray, thick-bedded, sparsely cherty, and sparsely fossiliferous limestone 120-280 meters thick. Earp Formation is a pale-red siltstone, mudstone, shale, and limestone, 120-240 meters thick.

lPh — Horquilla Limestone (Upper and Middle Pennsylvanian)—Light-pinkish-gray, thick- to thin-bedded, cherty, fossiliferous limestone and intercalated pale-brown to pale-reddish-gray siltstone that increases in abundance upward. Typically 300-490 meters thick.

MDs — SEDIMENTARY ROCKS (MISSISSIPPIAN AND DEVONIAN)—Consists mainly of Escabrosa Limestone (Mississippian)—locally (Armstrong and Silberman, 1974) called Escabrosa Group—and Martin Formation (Upper Devonian), undifferentiated. In part of the Chiricahua Mountains also includes Paradise Formation (Upper Mississippian) and Portal Formation of Sabins, 1957a (Upper Devonian). In the Little Dragoon Mountains and some adjacent hills also includes Black Prince Limestone, whose fauna and correlation show strongest affinities with Mississippian rocks but which may include some Pennsylvanian rocks. Escabrosa Limestone is a medium-gray, massive to thick-bedded, commonly crinoidal, cherty, fossiliferous limestone 90-310 meters thick. Martin Formation is thick- to thin-bedded, gray to brown dolomite, gray sparsely fossiliferous, and some siltstone and sandstone, 90-120 meters thick. Paradise Formation is a brown, fossiliferous, shaly limestone. Portal Formation is a black shale and limestone 6-105 meters thick. Black Prince Limestone is pinkish-gray limestone with a basal shale and chert conglomerate, as much as 52 meters thick.

O€s — SEDIMENTARY ROCKS (LOWER ORDOVICIAN TO MIDDLE CAMBRIAN):—El Paso Limestone (Lower Ordovician and Upper Cambrian), Abrigo Formation (Upper and Middle Cambrian), and Bolsa Quartz (Middle Cambrian), undifferentiated.—El Paso Limestone is a gray, thin-bedded cherty limestone and dolomite 90 meters to about 220 meters thick. Abrigo Formation is a brown, thin-bedded fossiliferous limestone, sandstone, quartzite, and shale, 210-240 meters thick. Bolsa Quartzite is a brown to white or purplish-gray, thick-bedded, coarse-grained quartzite and sandstone with a basal conglomerate, 90-180 meters thick. To the east, equivalents of part of the Abrigo Formation and Bolsa Quartzite are known as the Coronado Sandstone.

€s — Sedimentary rocks (Upper and Middle Cambrian)—Abrigo Formation (Upper and Middle Cambrian), and Bolsa Quartzite (Middle Cambrian), undifferentiated.

Yg — GRANITOID ROCKS (PRECAMBRIAN Y):—Mainly granodiorite and quartz monsonite, unfoliated to foliated, in part metamorphosed. Generally in stocks, which ahve been little studied.

Xp — PINAL SCHIST (PRECAMBRIAN X)—Chlorite schist, phyllite, and some metavolcanic rocks, metavolcanic rocks, metaquartzite, metaquartzite conglomerate, and gneiss. One metavolcanic rock dated at 1715 m.y.

CONTACT—Dotted where concealed.

MARKER HORIZON—Dotted where concealed.

DIKES—Showing dip.

70 — FAULTS—Showing dip. Dotted where concealed or intruded; ball and bar on downthrown side.

45 — Normal

45 — Reverse

Strike-slip—Arrow couple shows relative displacement. Single arrow shows movement of active block.

Major thrust fault—Sawteeth on upper plate.

Thrust fault—Sawteeth on upper plate

Anticline.

Syncline.

30 — Inclined strike and dip of beds.

EXOTIC-BLOCK BRECCIA—Rock contains chip or block inclusions of rock different from those of host or other blocks nearby. Typically of volcanic-tectonic or sedimentary-tectonic origin; excludes Tertiary megabreccia deposits.

(QTgu) 157 — Site of well or generalized site of several wells, showing unit penetrated, if known, and depth of well, in feet. 100 feet equals 30.5 meters.

72x — COLLECTION SITE—Radiogenically dated rock showing age in millions of years. Query before symbol where precise location uncertain

Roads and Highways

Dry wash

Southern Pacific Railroad

Government Reservation Boundary

Aqueduct

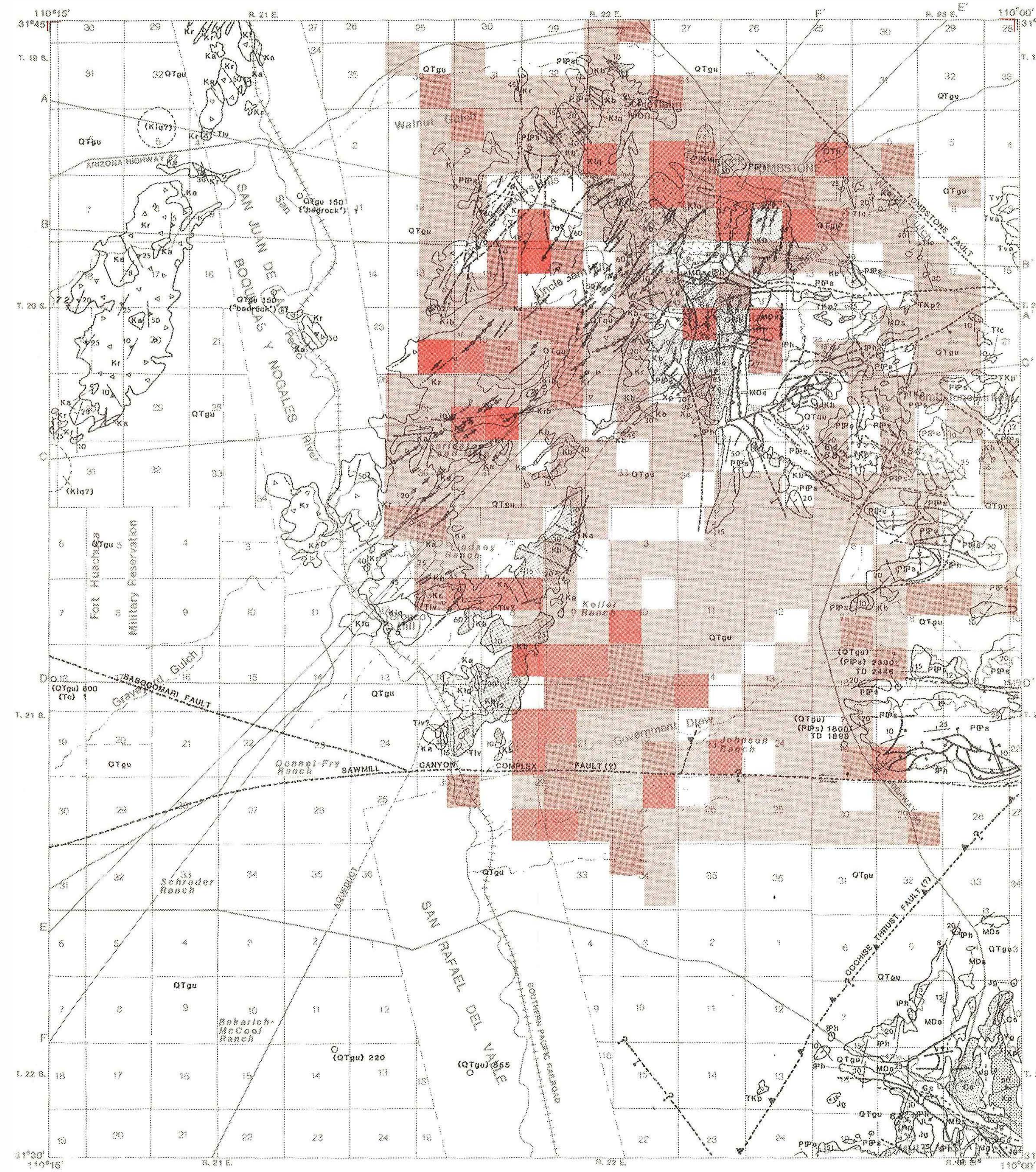
A——A' Cross section line

≤ 5 ppm

5.1 - 9 ppm

9.1 - 14 ppm

≥ 14 ppm



1 0 1 2 3 Miles

N

Tombstone Development Company, Inc.
Tombstone, Arizona

Geology adopted from Drewes, Harold, 1980, and Newell, R.A., 1973.

Figure 15. Distribution pattern of molybdenum in mesquite trees (in red), from Newell, R.A., 1973.

By James A. Briscoe
James A. Briscoe and Associates
Tucson, Arizona

Explanation

Geology

QTgu — OLDER OR UNDIFFERENTIATED SURFICAL DEPOSITS (HOLOCENE TO OLIGOCENE):—Gravel, sand, and silt (Pleistocene and Pliocene—Mainly alluvium of basins; includes some colluvium and landslide deposits. Generally light pinkish gray, weakly indurated, and with poorly rounded clasts; locally well indurated. Thickness several meters to hundreds of meters.

QTb — Basalt (Pleistocene to Pliocene)—Lava flows, pyroclastic rocks, and some intercalated gravel. Thickness several meters to a few hundred meters in most places. Radiometrically dated at 0.25, 1.0, and 3.2 m.y. old

Tva — Extensive andesite and dacite (Miocene and Upper Oligocene)—Lava flows, pyroclastic rocks, some intercalated epiclastic rocks, and dikes. Mostly gray, fine-grained, porphyritic rocks; includes some very coarse feldspar porphyry andesite (Turkey track porphyry, an informal term of Cooper, 1961). Thickness mostly several meters to several tens of meters. Dated at 24, 25, 27, 33, and39 m.y.

Tv — Extrusive rhyolite and rhyodacite (Miocene and Upper Oligocene—Lava flows, welded tuff, pyroclastic rocks, and some intercalated epiclastic rocks. Light-gray to grayish-pink, vitric to fine-grained, porphyritic. Commonly a few tens to a few thousand of meters thick. Dated at 23, 24, 25, 26, 26, 26, and 27 m.y. An additional date of 47 m.y., if substantiated, may indicate the presence of Eocene rocks in the lower member of the S O Volcanics of Cochise Co.

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Roads and Highways

Dry wash

Southern Pacific Railroad

Government Reservation Boundary

Aqueduct

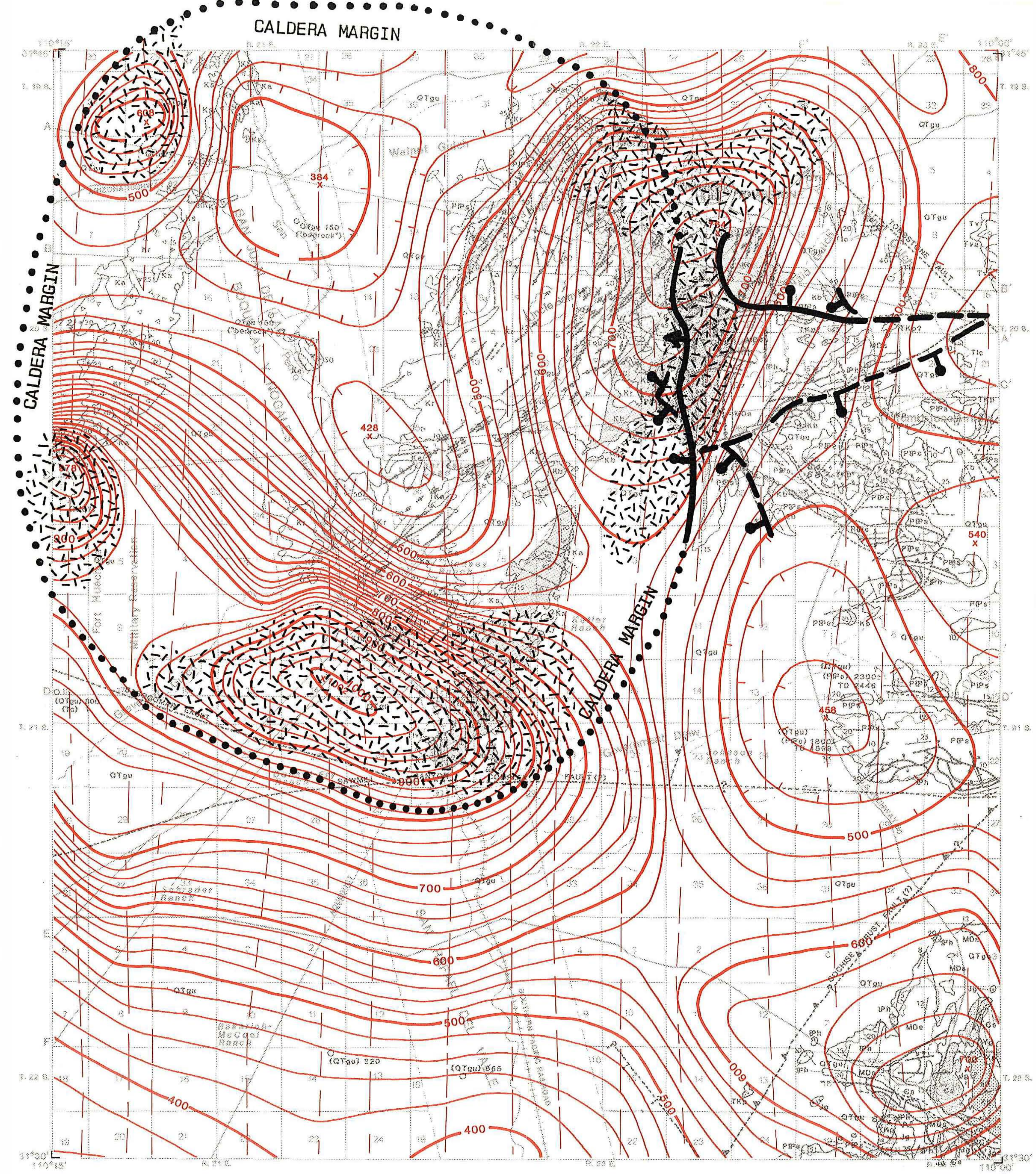
A——A' Cross section line

Flight line

Index contour line

Contour line

Contour interval: 25 gammas



Tombstone Development Company, Inc.
Tombstone, Arizona

Geology adopted from Drewes, Harold, 1980, and Newell, R.A., 1973.

By James A. Briscoe
James A. Briscoe and Associates
Tucson, Arizona

Figure 16. Aeromagnetic map of the Tombstone area.

From *Residual Aeromagnetic map of Southeastern Arizona*, Sauck, W.A., and Sumner, J.S., 1970. From Andreason, G.E., Mitchell, C.M., and Tyson, N.S., 1965

1 0 1 2 3 Miles

N

Explanation

Geology

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MARKER HORIZON—Dotted where concealed.

DIKES—Showing dip.

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FAULTS—Showing dip. Dotted where concealed or intruded; ball and bar on downthrown side.

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Roads and Highways

Dry wash

Southern Pacific Railroad

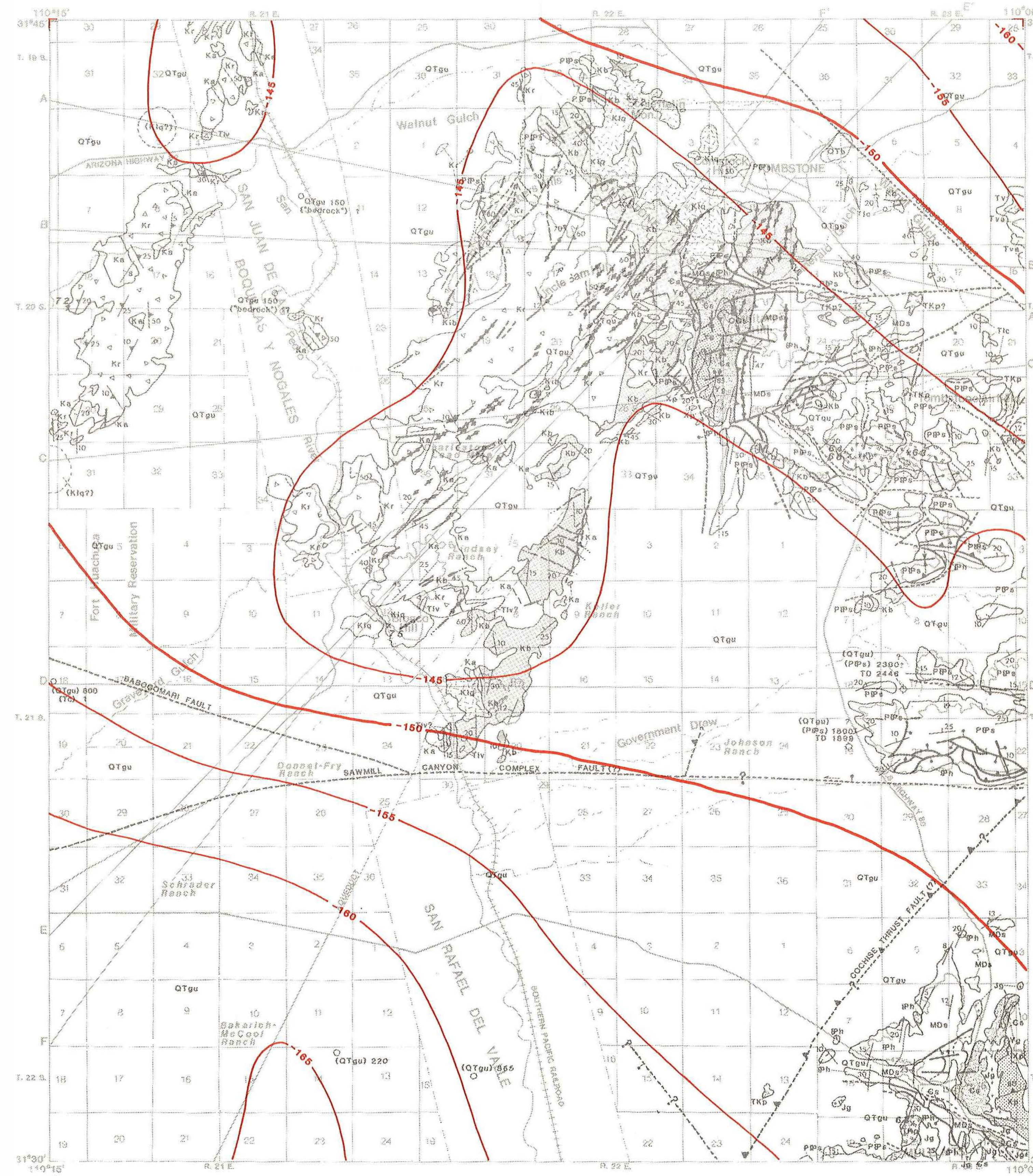
Government Reservation Boundary

Aqueduct

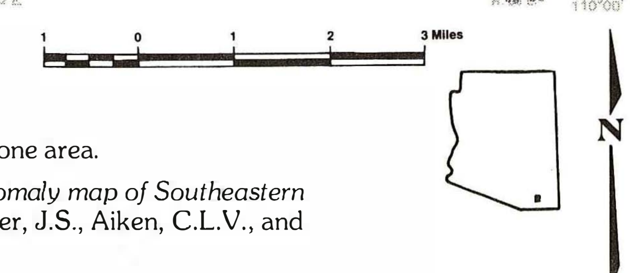
A—A' Cross section line

-150 Gravity contour line

Contour interval: 5 milligals



Tombstone Development Company, Inc.
Tombstone, Arizona

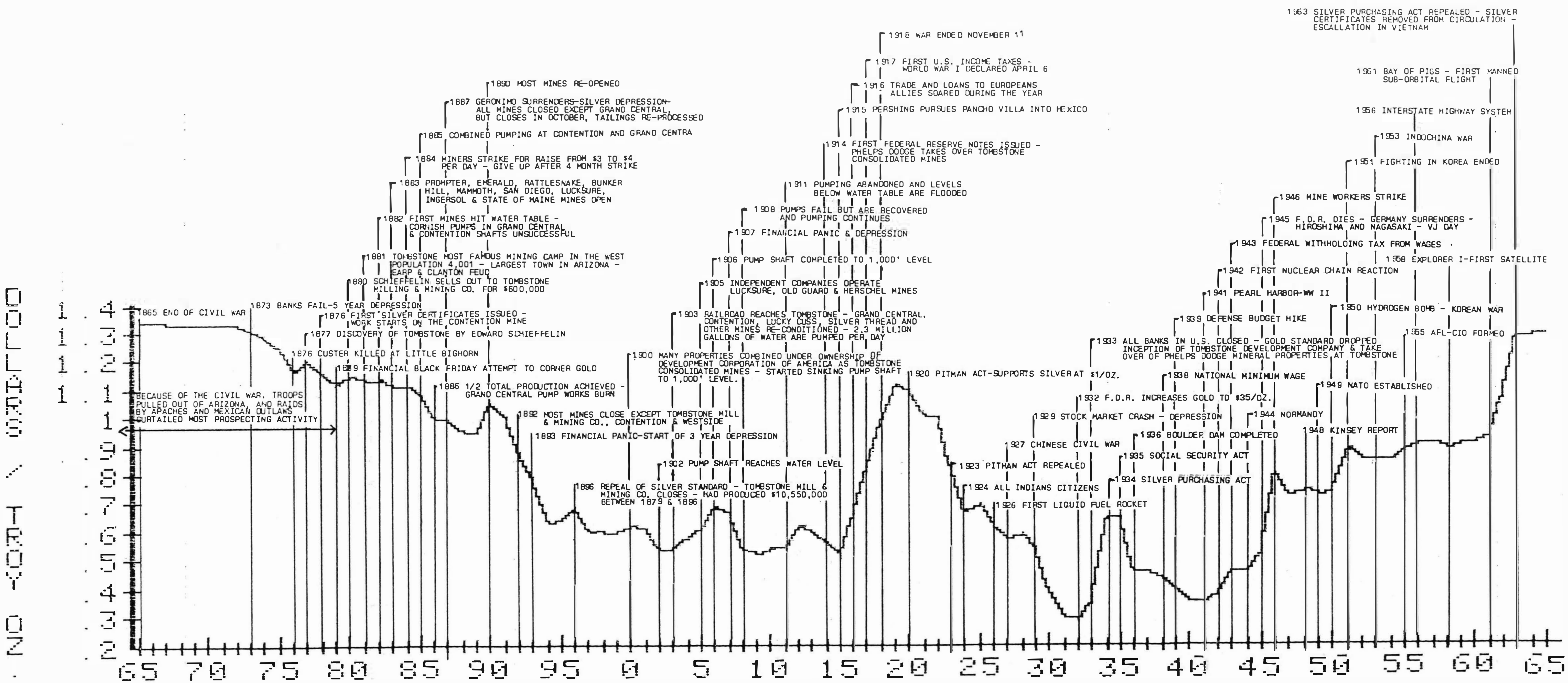


Geology adopted from Drewes, Harold, 1980, and Newell, R.A., 1973.

Figure 17. Gravity map of the Tombstone area.

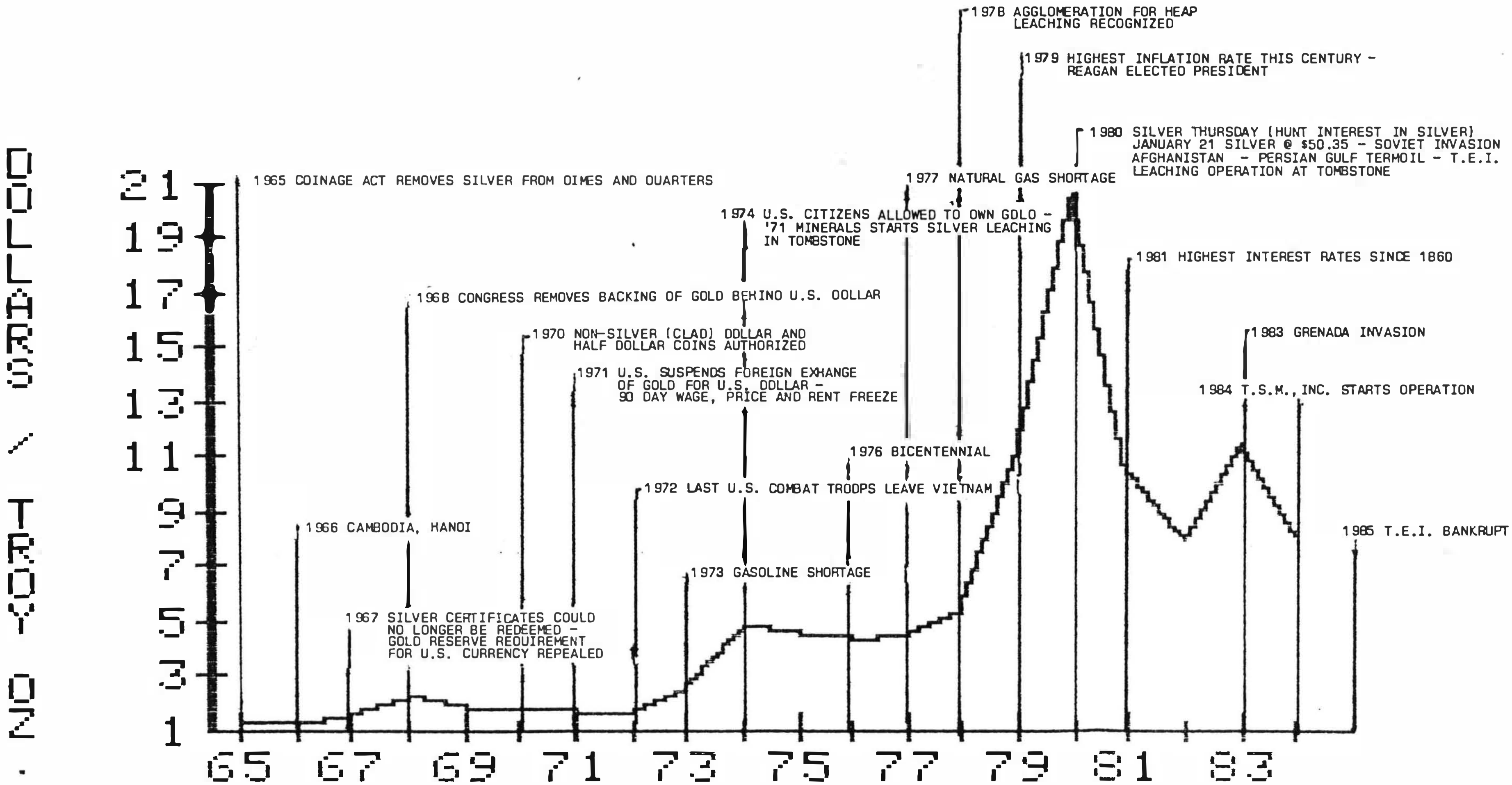
From *Bouguer Gravity Anomaly map of Southeastern Arizona*, West, E.E., Sumner, J.S., Aiken, C.L.V., and Conley, J.N., 1973.

By James A. Briscoe
James A. Briscoe and Associates
Tucson, Arizona



100 YEAR SILVER PRICE CHART

AVERAGE ANNUAL SILVER PRICE
YEARS: 1865 THROUGH 1965



RECENT SILVER PRICE CHART

AVERAGE ANNUAL SILVER PRICE

YEARS: 1965 THROUGH 1984

BIBLIOGRAPHY AND REFERENCES

Andreasen, G. E., Mitchell, C. M., and Tyson, N. S., 1965, Aeromagnetic map of Tombstone and vicinity, Cochise and Santa Cruz Counties, Arizona: U. S. Geol. Survey Open File Rept., June 11.

Austin, W. L., 1883, Silver milling at Charleston, Arizona: Eng. Mining Jour., v. 35, Jan. 27, P. 44-46.

Blake, W. P., 1882a, The geology and veins of Tombstone, Arizona: Am. Inst. Min. Metall. Eng. Trans., v. 10, p. 334-345.

---------- 1882b, The geology and veins of Tombstone Arizona--I: Eng. Mining Jour., v. 33, Mar. 18, p. 145-146.

---------- 1882c, The geology and veins of Tombstone, Arizona--II: Eng. Mining Jour., v. 33, Mar. 25, p. 157.

---------- 1882d, Porphyry dike, Tombstone District, Arizona: Eng. Mining Jour., v. 34, July 15, p. 29-30.

---------- 1904a, Mining in the southwest: Eng. Mining Jour., v. 77, Jan. 7, p. 35-37.

---------- 1904b, Tombstone and its mines: Am. Inst. Min. Metall. Eng. Trans., v. 34, p. 668-670.

Blanchard, Roland, 1968, Interpretation of Leached Outcrops, Nevada Bureau of Mines Bull. 66, Mackay School of Mines, University of Nevada, Reno.

Briscoe, James A., 1973, Interum geologic report on the Tombstone Mining District, Cochise County, with particular emphasis on the State of Maine Mine area: Private report to Sierra Mineral Management Co., 71 p.

Briscoe, James A. and Waldrip, Thomas E. Jr., 1982, A Summary of the Tombstone Development Company Lands in the Tombstone Caldera Complex, Cochise County, Arizona - A Geologic Appraisal and Estimate of Mineral Potential, unpublished report to the Tombstone Development Company, Grand Island, Nebraska.

Butler, B. S., and Wilson, E. D., 1937, Structural control of the ore depsits at Tombstone, Arizona (abs.): Econ. Geology, v. 32, p. 196-197.

---------- 1938, Some Arizona ore deposits: Ariz. Bur. Mines Bull. 145, p. 104-110.

---------- 1942, Ore deposits at Tombstone, Arizona, in Newhouse, W. H., ed., Ore deposits as related to structural features: New York, Hafner Publ. Co., p. 201-203.

Butler, B. S., Wilson, E. D., and Rasor, C. A., 1938, Geology and ore deposits of the Tombstone District, Arizona: Ariz. Bur. Mines Geol. Ser. No. 10, Bull. No. 143, 114 p.

Chapman, Thomas G., 1924, The Metallurgy of Chloride Ore from the State of Maine Mine in the Tombstone Mining District, M.Sc. Thesis, University of Arizona, 47 pages.

Church, J. A., 1887a, Concentration and smelting at Tombstone, Arizona: Am. Inst. Min. Metall. Eng. Trans., v. 15, p. 601-613.

---------- 1887b, Concentration and smelting at Tombstone, Arizona: Eng. Mining Jour., v. 43, April 16, p. 274-276.

---------- 1902, Tombstone, Arizona, mining district: Eng. Mining Jour., v. 73, April 26, p. 584.

---------- 1903, The Tombstone, Arizona, mining district: Am. Inst. Min. Metall. Eng. Trans., v. 33, p. 3-37.

Clark, F. W., 1914, Water analysis (from the 1000-foot level, Contention mine, Tombstone, Arizona): U. S. Geol. Survey Water-Supply Paper 364, p. 39.

Comstock, T. B., 1900, The geology and vein-phenomena of Arizona: Am. Inst. Min. Metall. Eng. Trans., v. 30, p. 1038-1101.

Creasey, S. C., and Kistler, R. W., 1962, Age of some copper-bearing porphyries and other igneous rocks in southeastern Arizona: U. S. Geol. Survey Prof. Paper 450-D, p. D1-D5.

Damon, P. E., and Bikerman, M., 1964, Potassium-argon dating of post-Laramide plutonic and volcanic rocks within the Basin and Range province of southeastern Arizona and adjacent areas: Ariz. Geol. Soc. Digest, v. 7, p. 63-78.

Damon, P. E., and Mauger, R. L., 1966, Epeirogeny-orogeny viewed from the Basin and Range province: Am. Inst. Min. Metall. Eng. Trans., v. 235, p. 99-112.

Development Company of America, 1911, Annual report: Eng. Mining Jour., v. 92, July 8, p. 61.

Drewes, Harald, 1980, Tectonic map of southeast Arizona: U. S. Geol. Survey miscellaneous investigation series, Map I-1109, 2 sheets, scale 1:125,000.

---------- 1971, Mesozoic stratigraphy of the Santa Rita Mountains, southeast of Tucson, Arizona: U. S. Geol. Survey Prof. Paper 658-C, 81 p.

Dumble, E. T., 1902, Notes on the geology of southeastern Arizona: Am. Inst. Min. Metall. Eng. Trans., v. 31, p. 696-715.

Dunning, C. H., 1959, Rocks to riches: Phoenix, Arizona, Southwest Publ. Co., Inc., 406 p.

Engineering and Mining Journal, 1878, General mining news: Eng. Mining Jour., v. 26, Oct. 19, p. 279-280.

---------- 1879, General mining news: Eng. Mining Jour., v. 27, May 31, p. 392.

---------- 1879, General mining news: Eng. Mining Jour., v. 27, June 28, p. 468.

---------- 1879, General mining news: Eng. Mining Jour., v. 28, Aug. 16, p. 112.

---------- 1879, Answers to some inquiries concerning Arizona and Nevada mines: Eng. Mining Jour., v. 28, Nov. 1, p. 311-312.

---------- 1879, Tombstone mining district, Arizona: Eng. Mining Jour., v. 28, Nov. 8, p. 340.

Engineering and Mining Journal, 1879, Tombstone district, Arizona: Eng. Mining Jour., v. 28, Nov. 29, p. 393.

---------- 1880, General mining news: Eng. Mining Jour., v. 29, Mar. 20, p. 204.

---------- 1880, General mining news: Eng. Mining Jour., v. 29. Mar. 27, p. 221.

---------- 1880, General mining news: Eng. Mining Jour., v. 29, April 3, p. 238.

---------- 1881, General mining news: Eng. Mining Jour., v. 31, April 9, p. 252.

---------- 1881, Tombstone, Arizona: Eng. Mining Jour., v. 31, May 7, p. 316-317.

---------- 1882, General mining news: Eng. Mining Jour., v. 33, Mar. 18, p. 147.

---------- 1882, Official statement and reports--Tombstone Mill and Mining Co., Tombstone, Arizona: Eng. Mining Jour., v. 33, May 6, p. 234.

---------- 1882, General mining news: Eng. Mining Jour., v. 34, July 22, p. 46-47.

---------- 1883, The Tombstone Mill and Mining Co., Tombstone, Arizona: Eng. Mining Jour., v. 35, May 12, p. 267-269.

---------- 1883, The present condition of the mines of the Tombstone Mill and Mining Co.: Eng. Mining Jour., v. 36, Oct. 13, p. 229-230.

---------- 1883, General mining news: Eng. Mining Jour., v. 36, Nov. 24, p. 328.

---------- 1883, General mining news: Eng. Mining Jour., v. 36, Dec. 29, p. 400.

---------- 1902, The mining revival at Tombstone: Eng. Mining Jour., v. 73, Mar. 1, p. 314-315.

---------- 1904, General mining news: Eng. Mining Jour., v. 77, Feb. 25, p. 334-338.

---------- 1904, General mining news: Eng. Mining Jour., v. 77, April 14, p. 618-621.

---------- 1904, The Tombstone mines, Arizona: Eng. Mining Jour., v. 77, June 9, p. 919-920.

---------- 1982, Featured this month: Pelletizing Aids Tombstone Leaching Operating: Eng. Mining Jour., v. 182, No. 1, January, 1981, p. 94-95.

Escapule, C. Bailey Jr., 1981, Geological Report on the Grace Claim Group, Cochise County, Arizona for Tombstone Silver Mines, Inc., unpublished private report.

Farnham, L. L., Stewart, L. A., and Delong, C. W., 1961, Manganese deposits of eastern Arizona: U. S. Bur. Mines I. C. 7990, 178 p.

Genth, J. A., 1887, Hessite from the Westside mine, Arizona: Am. Philos, Soc., v. 24, p. 36.

Gilluly, James, 1945, Emplacement of Uncle Sam porphyry, Tombstone district, Arizona: Am. Jour. Sci., v. 243, P. 643-666.

---------- 1956, General geology of central Cochise County, Arizona: U. S. Geol. Survey Prof. Paper 281, 169 p.

---------- 1963, The tectonic evolution of the western United States: Geol. Soc. London Quart. Jour., v. 119, p. 133-174.

Gilluly, James, Cooper, J. R., and Williams, J. S., 1954, Late Paleozoic stratigraphy of central Cochise County, Arizona: U. S. Geol. Survey Prof. Paper 266, 49 p.

Goodale, C. W., 1889, The occurrence and treatment of the argentiferous manganese ores of the Tombstone district, Arizona: Am. Inst. Min. Metall. Eng. Trans., v. 17, p. 767-777.

---------- 1890, Addition to the occurrence and treatment of the argentiferous manganese ores of Tombstone district, Arizona: Am. Inst. Min. Metall. Eng. Trans., v. 38, p. 910-912.

Graves, Arthur J., 1984, Geological and Preliminary Valuation Report on the State of Maine Area, Cochise County, Arizona, private report to Tombstone Silver Mines, Inc.

---------- 1985, private report to Tombstone Silver Mines, Inc. on exploration and drilling programs starting in June, 1984.

Hayes, P. T., 1970, Cretaceous paleogeography of southeastern Arizona and adjacent areas: U. S. Geol. Survey Prof. Paper 658-B, 42 p.

Hayes, P. T., Simons, F. S., and Raup, R. E., 1965, Lower Mesozoic extrusive rocks in southeastern Arizona--the Canelo Hills volcanics: U. S. Geol. Survey Bull. 1194-M, p. M1-M9.

Hewett, D. F., 1972, Maganite, hausmannite, braunite: features, modes of origin: Econ. Geology, v. 67, p. 83-102.

Hewett, D. F., and Pardee, J. T., 1933, Manganese in western hydrothermal ore deposits, in Ore deposits of the western states (lindgren volume): Am. Inst. Min. Metall. Eng., p. 680-681.

Hewett, D. F., and Radtke, A. S., 1967, Silver bearing black calcite in western mining districts: Econ. Geology, v. 62, p. 1-21.

Hewett, D. F., and Rove, O. N., 1930, Occurrence and relations of alabandite: Econ. Geology, v. 25, p. 36-56.

Hillebrand, W. F., 1886, Emmonsite, a ferric tellurite (Tombstone, Arizona): Colo. Sci. Soc. Proc., v. 2, p 20-23.

---------- 1889, Analyses of three descloisites from new localities: Am. Jour. Sci., v. 37, p. 434-439.

Hollyday, E. F., 1963, A geohydraulic analysis of mine dewatering and water development, Tombstone, Cochise County, Arizona: M.Sc. thesis, Univ. of Arizona., 90 p.

Huff, L. C., 1970, A geochemical study of alluvium-covered copper deposits in Pima County, Arizona: U. S. Geol. Survey Bull. 1312-C, p. C1-C31.

Jensen, Mead L. & Bateman, Alan M., 1981, Economic Mineral Deposits, John Wiley & Sons, New York.

Keith, S. B., 1973, Index of mining properties in Cochise County, Arizona: Ariz. Bur. Mines Bull. 187, 98 p.

Keith, Stanley B., Gest, Don E., et al., 1983, Metallic Mineral Districts and Production in Arizona, Arizona Bureau of Geology and Mineral Technology, Geological Survey Branch, University of Arizona, Tucson, Arizona.

Lakes, Arthur, 1904, Ore in anticlinals, as at Bendigo, Austrilia, and Tombstone, Arizona: Min. Sci. Press, v. 88, p. 193.

Lee, L. C., 1967, The economic geology of portions of the Tombstone-Charleston district, Cochise County, Arizona, in light of 1967 silver economics: M.Sc. thesis (unpub.), Univ. of Arizona, 99 p.

Lingren, Waldemar, 1933, Mineral Deposits 4th Edition, McGraw-Hill Book Company, Inc., New York & London.

Luepke, Gretchen, 1971, A re-examination of the type section of the Scherrer Formation (Permian) in Cochise County, Arizona: Ariz. Geol. Soc. Digest, v. IX, p. 245-257.

Moses, A. J., 1893, Ettringite from Tombstone, Arizona, and a formula for ettringite: Am. Jour. Sci., 3rd ser. 45, p. 489-492.

Moses, A. J., and Laquer, L. M. I., 1892, Alabandite from Tombstone: Columbia Univ. School of Mines Quart., v. 13, p. 236-239.

Needham, A. B., and Storms, W. R., 1956, Investigation of Tombstone district manganese deposits, Cochise County, Arizona: U. S. Bur. Mines RI 5188, 34 p.

Newell, Roger A., 1974, Exploration geology and geochemistry of the Tombstone-Charleston Area, Cochise County, Arizona: PhD. dissertation (unpubl.), Stanford University, 205 p.

Newhouse, W. H., ed., 1942, Ore deposits as related to structural features: Princeton, N. J., Princeton Univ. Press, 280 p.

Oetking, Philip, 1967, Map No. 2, Geological Highway Map of the Southern Rocky Mountain Region, The American Association of Petroleum Geologists, P. O. Box 979, Tulsa, Oklahoma.

Park, Charles F. Jr., & MacDiarmid, Roy A., 1975, Ore Deposits, 3rd Edition, W. H. Freeman and Company, San Francisco.

Patch, Susan, 1969, Petrology and stratigraphy of the Epitaph Dolomite (Permian) in the Tombstone Hills, Cochise County, Arizona: M.Sc. thesis (unpubl.), Univ. of Arizona, 42 p.

---------- 1973, Petrology and stratigraphy of the Epitaph Dolomite (Permian) in the Tombstone Hills, Cochise County, Arizona: Jour. Sed. Petrol., v. 43, no. 1, p. 107-117.

Penrose, R. A. F., 1890, The manganiferous silver ores of Arizona--Tombstone: Geol. Survey of Arkansas Ann. Rept., v. 1, p. 465-468.

Ransome, F. L., 1904, Geology and ore deposits of the Bisbee quadrangle, Arizona: U. S. Geol. Survey Prof. Paper 21, 167 p.

---------- 1920, Deposits of manganese ore in Arizona--Bisbee and Tombstone district, Cochise County: U. S. Geol. Survey Bull. 710, p. 96-103, 113-119.

Rasor, C. A., 1937, Mineralogy and petrography of the Tombstone mining district, Arizona: PhD. dissertation (unpubl.), Univ. of Arizona., 115 p.

---------- 1938, Bromeyrite from Tombstone, Arizona: Am. Mineral., v. 23, p. 157-159.

---------- 1939, Manganese mineralization at Tombstone, Arizona: Econ. Geology, v. 34, p. 790-803.

Romslo, T. M., and Ravitz, S. F., 1947, Arizona manganese-silver ores: U. S. Bur. Mines RI 4097, 13 p.

Sarle, C. J. & Mellgren, V.G., 1928, Report on the Mellgren Mines, Tombstone Mining District, Cochise County, Arizona, unpublished private report.

Schmitt, H., 1966, The porphyry copper deposits in their regional setting, in Titley, S. R., and Hicks, C. L., eds., Geology of the porphyry copper deposits, southwestern North America: Tucson, Arizona, Univ. of Arizona Press, p. 17-33.

Sillitoe, Richard H., 1973, The Tops and Bottoms of Porphyry Copper Deposits, Economic Geology, v. 68, No. 6, p. 799-813.

Sillitoe, Richard H., & Bonham, Harold F. Jr., 1985, Volcanic Land Forms and Ore Deposits, Economic Geology, v. 79, No. 6, p. 1286-1298.

Staunton, W. F., 1910, The pumping problems at the Tombstone mine: Eng. Mining Jour., Jan. 15, p. 174.

---------- 1918, Effects of an earthquake in a mine at Tombstone, Arizona: Seismol. Soc. America Bull., v. 8, p. 25-27.

Tenney, J. B., 1938, Geology and ore deposits of the Tombstone district, Arizona (rev.): Econ. Geology, v. 33, p. 675-678.

Timmins, W. G., 1981, Geological Report on the Grace Claim Group, Cochise County, Arizona for Artex Resources, Inc., private unpublished report.

Walker, E. W., 1909, Pumping plant at the Tombstone Consolidated: Eng. Mining Jour., v. 88, no. 4, p. 160-162.

Wallace, D. E., and Cooper, L. R., 1970, Dispersion of naturally occurring ions in groundwater from various rock types in a portion of the San Pedro River basin, Arizona: Jour. Hydrology, v. 10, p. 391-405.

West, E. E., Sumner, J. S., Aiken, C. L. V., and Conley, J. N., 1974, Bouger gravity anomaly map of southeastern Arizona, from a geophysical and geological investigation of potentially favorable areas for petroleum exploration in southeastern Arizona; Laboratory of Geophysics, Department of Geosciences, University of Arizona; Arizona Oil & gas Conservation Commission, Report of Investigations 3, 44 p.

Wilson, E. D., and Butler, G. M., 1930, Manganese ore deposits in Arizona: Ariz. Bur. Mines Bull. 127, p. 47-55.

Wilson, E. D., Cunningham, J. B., and Butler, G. M., 1934, Arizona lode gold mines and gold mining: Ariz. Bur. Mines Bull. 137, p. 122-124.

Wilt, J. C., 1969, Petrology and stratigraphy of Colina Limestone (Permian) in Cochise County, Arizona: M.Sc. thesis (unpubl.), University of Arizona, 117 p.

WARREN MINING DISTRICT

C.S. Eady 10/88

Bisbee is located in the Warren mining district of Cochise County, Arizona. It is situated on the Southern end of the Mule Mountains, a block-faulted basin and range feature intruded by the Juniper Flat granite. Smaller mineralized stocks which are genetically related to the Juniper Flat granite have introduced copper and other metals in the district.

Active mining began in late 1877 and continued essentially uninterrupted until mid-1975. During that period millions of tons of ore and waste were removed from two open pits and nearly 2000 miles of underground workings.

Copper was the most important metal produced in the district; however, lead, zinc, silver, gold and manganese were also economically important. In fact more lead, zinc, silver and gold were produced from Bisbee than in any other district in Arizona. Metal production through May 1975 is listed below.

Copper	Zinc	Lead
100 billion pounds	355 million pounds	324 million pounds

Silver	Gold	Manganese
100 million ounces	2.7 million ounces	11 million pounds

Since 1980 the district has been under evaluation to determine the potential for undiscovered underground and open-pitable copper, gold and silver deposits. Between 1981 and 1984, gold and silver ores were mined from several underground mines. Approximately 35,000 ounces of gold were produced from this effort. The potential for underground base and precious metals is far from exhausted; however, current economic constraints associated with dewatering the mines and underground mining prohibits production of these deposits.

Last year, Phelps Dodge Corporation announced the discovery of the Cochise copper deposit located north of the Lavender Pit and the Dividend Fault. The Cochise deposit is a supergene enriched chalcocite blanket typical of most porphyry copper deposits. Drilling of the deposit has recently been completed and engineering studies coupled with economic analyses are currently being conducted.

GEOLOGY

The basement rock in the district is the Precambrian Pinal Schist which has been unconformably overlain by both Paleozoic limestones and Mesozoic arenaceous rocks. The Pinal Schist and the Paleozoic sections are intruded by the Jurassic (180 mya) Juniper Flat granite and its correlative, the Sacramento stock. The Sacramento stock is divided into two different units, the older quartz porphyry and the younger quartz-feldspar porphyry. The older quartz porphyry predates the younger quartz-feldspar porphyry by approximately 2 million years. The majority of mineralization in the district is related to the younger porphyry.

There are at least three other intrusive rocks found in the district, however, their relationships to mineralization in the district, if any, have not been determined.

Some time after emplacement of the younger porphyry, numerous episodes of faulting and additional mineralization took place. Two dominant sets of faults occur in the district. The oldest faults trend NW-SE. These faults may be offset by younger faults trending roughly orthogonal to the trend of the older faults. One major faulting event splits the district in half along the NW-SE trending Dividend Fault. The north side of the Dividend Fault was uplifted by as much as 5000 feet. Subsequent erosion has removed all of the Paleozoic rocks and any contained orebodies from the upthrown side of the district. Through natural leaching and enrichment processes on the upthrown side, a chalcocite blanket was formed in the granite porphries, the breccias and the Pinal Schist. Later the entire district was covered by Cretaceous seas which deposited the thousands of feet of sandstones, siltstones and limestones which make up the Bisbee Group.

MINERALIZATION

Mineralization occurred in at least four different stages in the Warren district. Major orebodies are generally located at the intersections of NW-SE and NE-SW trending faults in Paleozoic limestones. Breccias were often formed at the fault intersections providing channels for mineralizing fluids. Sulfide mineralization both filled voids and replaced limestone fragments in the breccias. Some limestone horizons were also replaced by sulfides forming "bedded" deposits clearly associated with the breccias.

The morphology of a typical breccia orebody resembles an elongated cigar-shaped mass plunging in the direction of the fault intersection. A core of silica and pyrite forms the majority of the orebody and is surrounded by a concentric zone of copper sulfides which in turn have intermittent peripheral zones of lead and zinc sulfides. An episode of gold and silver mineralization is superimposed on all three zones.

PARAGENESIS OF BRECCIA ORE BODIES

Faulting

Breciation
No Mineralization

Early Hydrothermal
Mostly Barren
Minor Cu, Pb,Zu

Time →

Faulting

Main Stage Barren
Silica - Pyrite -
Hematite

Faulting

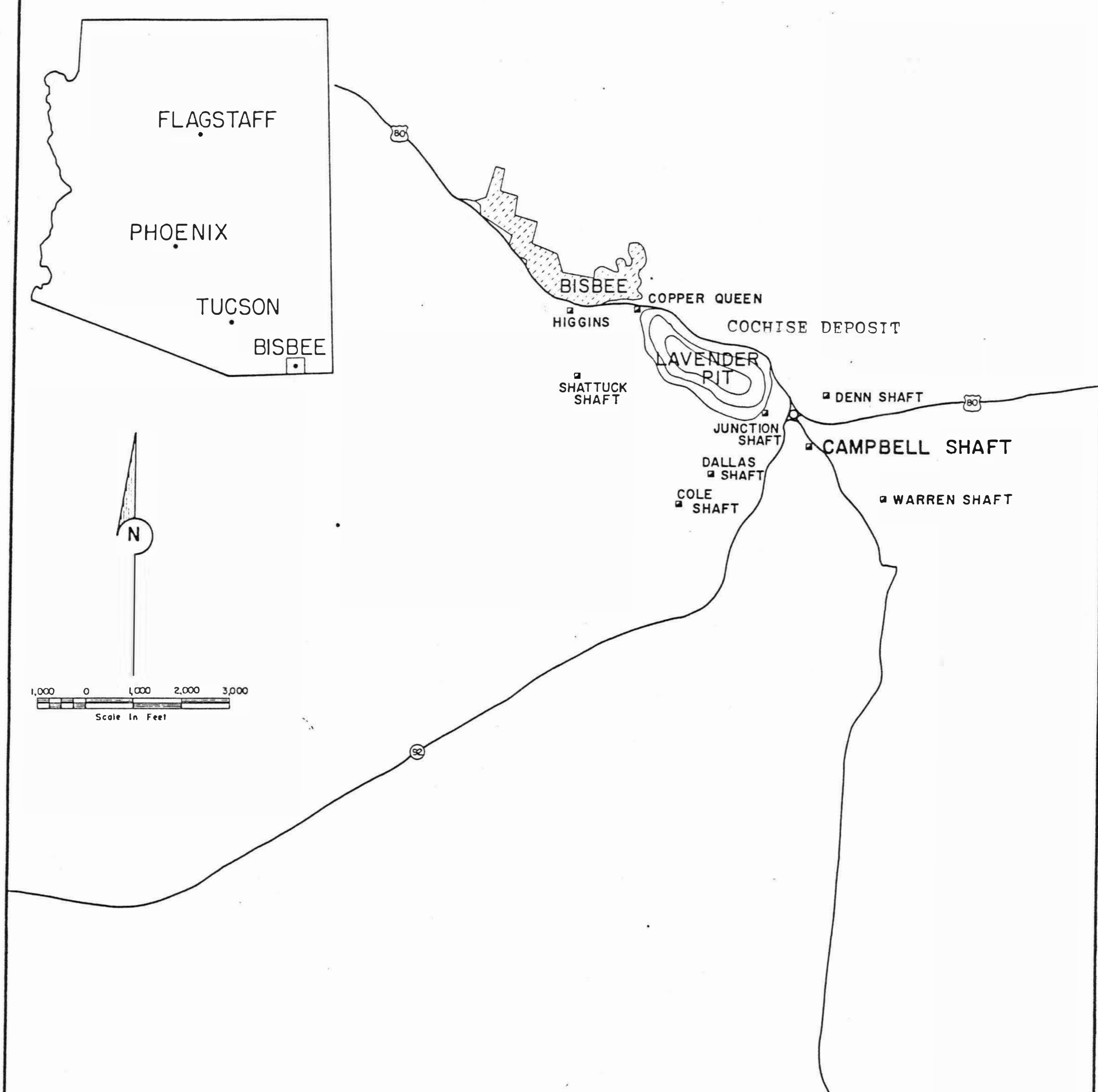
Main Mineralizing
Major Cu, Pb,Zu
Minor Au-Ag

Faulting

Precious Metal
Mineralization

Faulting

Leaching
Enrichment

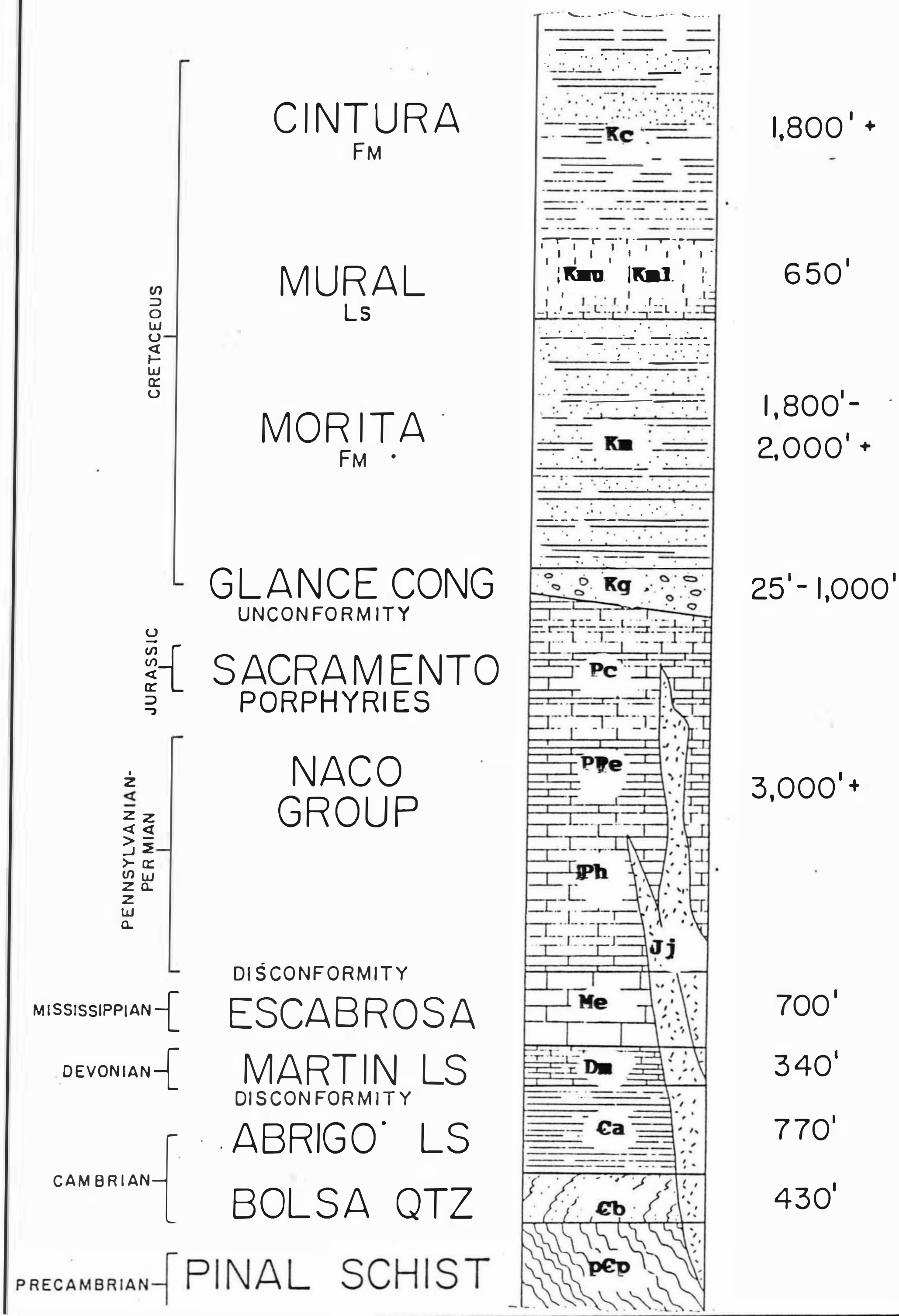


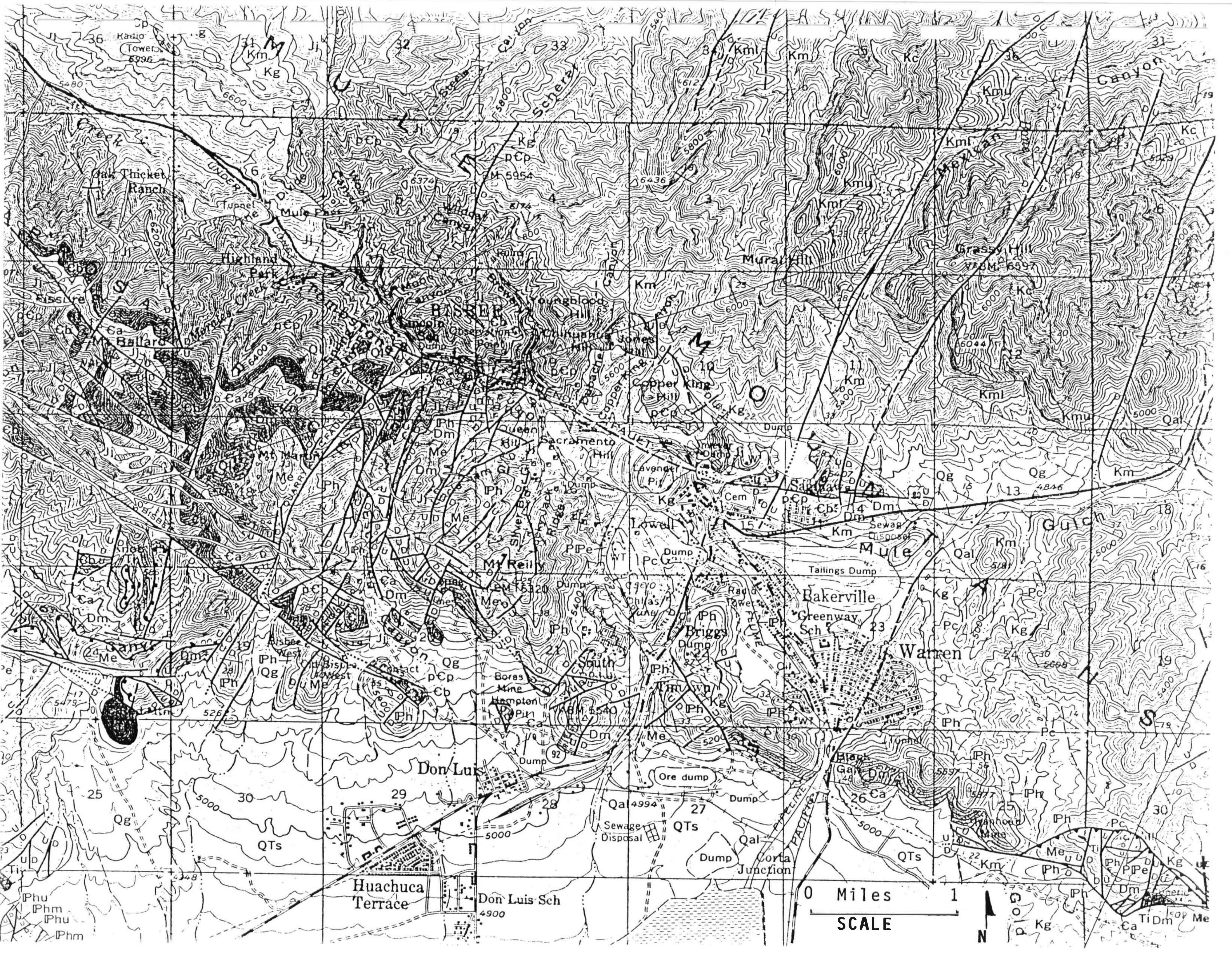
LOCATION MAP

WARREN MINING DISTRICT

GENERALIZED STRATIGRAPHIC SECTION

WARREN MINING DISTRICT





Radio Tower
Oak Thicket Ranch
Highland Park
Mule Pass
Tunnel
Mt Ballard
Mt Martin
Bisbee
Youngblood Hill
Chihuahua Hill
Sacramento Hill
Queen Hill
Copper King Hill
Lavender Pit
Mural Hill
Grassy Hill
Mexican Canyon
Lowell
Mt Reilly
Tailings Dump
Bakerville
Greenway Sch
Warren
Mule Gulch
Briggs
South
Bisbee West
Old Bisbee Lowest
Boras Mine
Hampton Pit
Don Luis
Huachuca Terrace
Don Luis Sch
Ore dump
Sewage Disposal
Dump
Corta Junction
QTs
0 Miles 1
SCALE
N

View towards the west looking up Tombstone Canyon at Bisbee. The Lavender Pit that we will visit is in the left foreground and the contact between grey, unoxidized copper ore and overlying, red, oxidized ore is readily apparent. Phelps Dodge's new Cochise deposit, that we will also visit, underlies the red hill to the right of the Lavender Pit - note the drill road. Juniper Flat granite outcrops are prominent on the skyline above and to the right of Bisbee.

FIELD GUIDE-NOTES
to the
COMMONWEALTH MINE,
Pearce, Cochise County, Arizona

Prepared for the 1988 Field Trip,
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INTRODUCTION

It is a little-known fact that R.A.F. Penrose, he who was to become the greatest benefactor of the Geological Society of America in its history and one of the founders of the Society of Economic Geologists, visited the Pearce area in 1893. Recently graduated from Harvard (in 1886), he was seeking to make his fortune. Optimist that he was, and already philanthropically inclined, he renamed the prospect at Pearce "The Commonwealth", and acquired it in 1895. It proved to be the basis of a career that included co-founding the Utah Copper Corporation that was to become Kennecott. He sold his interest in the Commonwealth at a huge profit in 1903 and went onward to the benefit of us all.

The mine itself is a 'little-known fact'. Oddly, the Commonwealth, along with the Great American, Ash Creek, Stein's Pass, and other epithermal mines and prospects in southeastern Arizona, has never been included on maps and inventories by USGS scientists, in spite of excellent exposures of classic volcanic-hosted epithermal mineralization that occur there. There are only two publications of any consequence on the Commonwealth, namely M.S. theses by Lewis A. Smith (1927) and Kim K. Howell (1977), both at the University of Arizona. The Advanced Ore Deposits class at The University of Arizona is currently engaged in a comprehensive study of the district, with the cooperation of Warren Hinks and Westland Minerals Corporation, that will result in a 1989 paper.

PRODUCTION

Smith (1927) reported that production from the Commonwealth to that date had been 940,000 tons at an average grade of $11.71 per ton. The price of silver in 1927 was $0.65 per ounce, close to the average for the 1895-1927 period, so the average grade was about 18 ounces per ton (560 ppm). The value then was $10,407,000, about half of which was profit. At today's $6.50 per ounce, gross modern revenue would be over $100 million from the 17 million ounces of silver extracted. Gold apparently ran about 0.1 oz. per ton (3 ppm), so some of the $11.71 historic value (about $2 at $20.00 gold) resulted therefrom.

The mine closed in depression times, and has been sporadically and trivially operated, mainly by leasors, since then. Stamp-milled amalgamation and younger cyanidation tailings piles north of Pearce Hill (Figure 2) have recently been reprocessed.

The mine reached the 8th level about 500 feet deep down dip from the "D" Shaft near the east end of the main hill. A major collapse of some 500,000 tons of hangingwall volcanics in 1905 resulted in the slot at the surface and the dangerous glory hole at the east ead of the main hill near "D" Shaft.

Modern exploration -- mostly shallow drilling without known benefit of modern lithologic-structural mapping until now -- has not revealed significant new ore. Westland Minerals seeks new extensions of the Main Vein and intercepts of disseminated values that would permit bulk mining methods. About 20 reverse circulation rotary holes are planned for completion before year's end.

GEOLOGY

The Commonwealth Mine (Figure 1) is a classic vest-pocket-size epithermal volcanic-hosted bonanza precious metal silver-gold deposit in Bisbee Group sediments (?) and, almost totally, Mid-Tertiary felsic volcanics. Bisbee Group sediments outcrop at the base of the Pearce Hill and to the east near Huddy Hill. The Pearce volcanics that make up the whole of the Pearce Hill surface include andesite flows described by Drewes (1980) as Eocene or Oligocene mainly greenish-gray propylitized pyroxene, amphibole, and feldspar porphyritic flows and pyroclastics, and younger extrusive vitric and crystal rhyolitic and rhyodacitic flows, welded tuffs, and pyroclastics with sparse volcaniclastic sedimentary units. These younger units are coeval with the main Chiricahua volcanic event at 25±2 my. Excellent petrographic description and stratigraphy is provided by Howell (1977), who distinguished several easily recognized subtypes on the Pearce Hill.

The principal veins (Figure 2) are the east-west North Vein that dips 40-50° S and the N70°W Main Vein that dips 60-80° S. The North Vein can be traced along surface through the silicified, heavily veined area east of D Shaft; the Main Vein runs through the collapsed zone and the glory hole and on to the southeast. They comprise massive to banded and comb quartz in normal faults with associated steep sheeted zones. Clear quartz and amethyst predominate, but values lay in greenish, oily chalcedonic veins and veinlets.The vein structures contained high grade ore shoots that were originally sulfide-sulfosalt (proustite, tetrahedrite, chalcopyrite, galena) but were silver halides (embolite, bromyrite) and native gold, oxidized and locally redistributed by supergene processes, when mined. Smith (1927) described several subhorizontal enrichment bands that he related to old proto-Wilcox-Playa lake levels. The primary system was undoubtedly a near-surface hot-spring environment.

Alteration consisted of ubiquitous silicification, with propylitization in andesite and potassic alteration in all rocks at upper levels and near the veins that 'upgraded' rhyodacites and latites to trachyte-rhyolite compositions.

BE CAREFUL -- OPEN SHAFTS, STEEP SLOPES, LOOSE ROCK !!!

FIELD TRIP TARGETS

We will park at D Shaft if the bus can make it or at the base of the hill on the north side east of the Thetford mill if it cannot. In either case, proceed to the D shaft where maps and sections will be posted. There are excellent specimens of classic epithermal textures on dumps, in outcrop, almost everywhere. It is especially worthwhile to roam the hill west of D Shaft and east along the North Vein to see "exploration outcrops" of undisturbed surface.

Two maps will be provided, one 1:1200 (1"=100 feet) by Tom Patton, courtesy of Tom Patton and Westland Minerals, one 1:920 (1"= 85 feet) by Kim Howell. Use them to establish your own traverse, which should include a trip through the caved area to see the contact in the west wall of rhyolite breccia (TCP)-First Flow (KKH) beneath and Upper Andesite (TCP)-Second Flow (KKH) above. The veins and workings are exposed here too. Waxy green mineraloid like Vaseline is embolite; earthy green is montmorillonite. Bisbee Group outcrops at the west end near the Thetford mill building. (NOTE: fragments of specularite-diopside-pyrite-chalcopyrite skarn here are from the Black Diamond in the Dragoons, not the Commonwealth. Custom milling was done here.) Work along eastward past the glory hole, with splendid samples of comb quartz, amethyst, etc. As you proceed east with Huddy Hill to the near east-northeast and Metat Hill to the near east-southeast you pass over outcrops of Upper Andesite-Second Flow that have been extensively potassically altered to trachyte-rhyolite. The new drill-hole location stakes in general bracket and define the trace of the Main Vein. Don't miss the strong veining that webs between the North and Main Veins out to the east along the ridge before you get to Huddy Hill. All the while imagine yourself in the shallow roots of a hot-spring system -- sulfur-depositing springs were active a few miles east (hence the Sulphur Springs Valley name) until the 1887 Bavispe Sonora earthquake.

REFERENCES

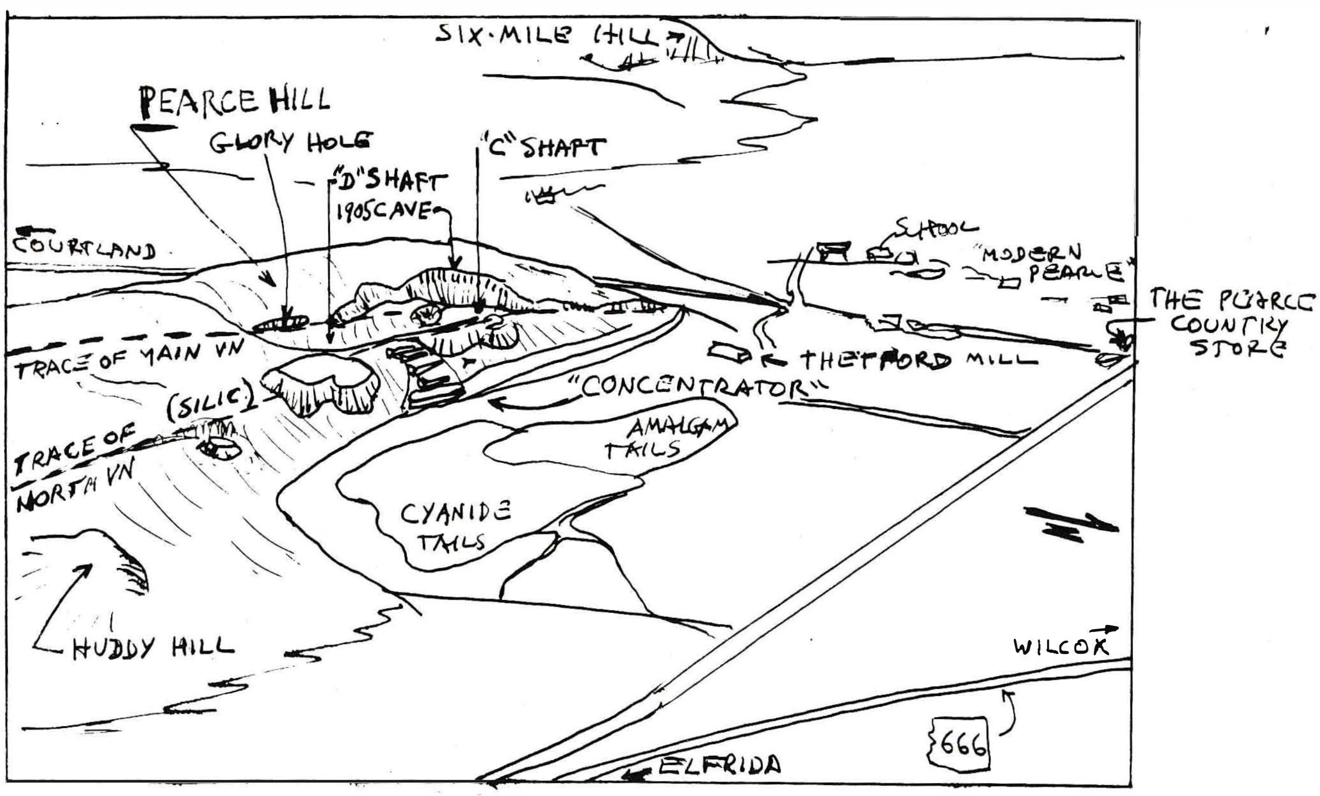
Drewes, Harald, 1980. Tectonic Map of Southeast Arizona, Map I-1109, USGS.

Howell, Kim K, 1977. Geology and Alteration of the Commonwealth Mine, Cochise County, Arizona. Unpub. M.S. Thesis, University of Arizona, 225 p.

Smith, Lewis A., 1927. The Geology of the Commonwealth Mine. Unpub. M.S. Thesis, University of Arizona, 73 p.

Figure 1 (above). Oblique aerial photo toward the southwest showing Huddy Hill (lower left), the old concentator foundations downhill from the Main Vein cave zone on Pearce Hill, and Six-Mile Hill (right center, upper margin) The old Pearce store is at the upper right margin.

Figure 2 (below). An overlay sketch map showing pertinent geography-geology and culture.



BACKGROUND MATERIALS

THE TOMBSTONE MINING DISTRICT HISTORY, GEOLOGY AND ORE DEPOSITS

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INTRODUCTION

The Tombstone mining district, located in a small group of hills 6 mi north of the San Pedro River and 65 mi southeast of Tucson, Arizona, was one of the rich "bonanza" silver districts of the late 1800's. Mining commenced in 1878, escalated rapidly until 1882, and then slowly declined until the last mine closed in the late 1930's. The total production from 1878-1957 amounted to approximately one million tons of ore worth about $39,000,000; of that total value, half was derived from the production during the seven-year period 1879-1886 (Wilson, 1962).

The district has been described in the literature by Blake (1882), Church (1903), Ransome (1920), Butler and others (1938), Gilluly (1956) and Newell (1974). Of these works, that by Butler and others was the most extensive and detailed. The accompanying geologic map and section (figs. 4, 5) are from their publication and have been reproduced without modification.

HISTORY

Ed Schieffelin discovered silver chlorides and lead carbonates in a quartz vein in the southwestern part of what became the Tombstone mining district in the late summer of 1877. On the third of September, 1877, he recorded his "Tumbstone Mine" and "Graveyard" claims in Tucson, County of Pima, Arizona Territory (Devere, 1960). After recording his claims, it took Schieffelin almost a year before he could raise sufficient money and convince his brother Al, and Richard Gird, a mining engineer, to join him in developing his discovery. The vein proved to be small and poorly mineralized, so while the disgruntled Al Schieffelin and Richard Gird attempted to mine, the ever-optimistic Ed Schieffelin prospected further to the north and east, and in two successive days, discovered the large, rich lodes of the Lucky Cuss and Toughnut silver deposits (Butler and others, 1938).

With the discovery of the Lucky Cuss and Toughnut lodes, the Tombstone silver boom was born. In rapid succession, the lodes of the Goodenough, Grand Central, Contention, Vizna, Empire and Tranquility mines were discovered. A town, named after Schieffelin's original claim, the Tombstone (fig. 1), was established and mills were built on the San Pedro River at what became the towns of Charleston, Contention and Fairbank. The "Arizona Weekly Star" of November 2, 1879, reported that Tombstones' petition for incorporation had been granted by the Pima County Board of Supervisors. The town boasted a population of 1000-1500, while Charleston, a mill town on the San Pedro River claimed 600-800 inhabitants (Devere, 1960).

The silver-lead ores were high grade, near surface and easily extractable. The only problem was the lack of local water for milling; therefore mills were built along the San Pedro River and ore was transported the 9 mi at a cost of $3.50 per ton (Blake, 1882). That problem was solved in 1881 when water was encountered at a depth of 520 ft in the Sulphuret mine. With water, the future for mining seemed bright, but the water that was thought to be the mines' savior, turned into their executioner. In 1886, the pumps at the Grand Central mine burned, leaving only the Contention mine pumps to handle the water. Those pumps were inadequate, forcing the suspension of all mining below the water table. From 1886-1901, mining was at a low ebb, being carried on largely by lessees.

In 1901, the Grand Central Company, the Tombstone Mill and Mining Company and the Contention Company were joined to form the Tombstone Consolidated Mines Company. With the joining of the three companies, the majority of the larger mines in the district were consolidated and the decision was made to once again pump the water and develop the deeper ores. The company sunk the four compartment Boom shaft, constructed a new 125 ton per day cyanide mill and reconditioned the old levels in the Grand Central, Contention, Empire, Lucky Cuss, Silver Thread, Toughnut and West Side mines. By 1906, the Boom shaft had reached the 1000-ft level and water was being pumped at the rate of 3000 gpm (fig. 2).

The deeper ores were only partially oxidized, so in the same year the cyanide mill was converted and expanded. Using stamps, slime cones, Wilfley tables and cyanide tanks, the mill operated at a capacity of 225 tons per day (Butler and others, 1938). Independent mines reopened and mining at Tombstone regained some of its old vigor. Silver was selling for 67 cents per ounce, lead at 5.6 cents per pound and gold at the fixed price of $20.67 per ounce.

In June 1909 water again dealt Tombstone mining a serious blow. Due to defective fuel for the boilers, the steam pumps on the 1000-ft level (fig. 3) of the Boom shaft seized and stopped. Eight large steam sinking-pumps were installed, but they were incapable of handling the water and it rose to the 900-ft level. As the water rose the overtaxed boilers ruptured

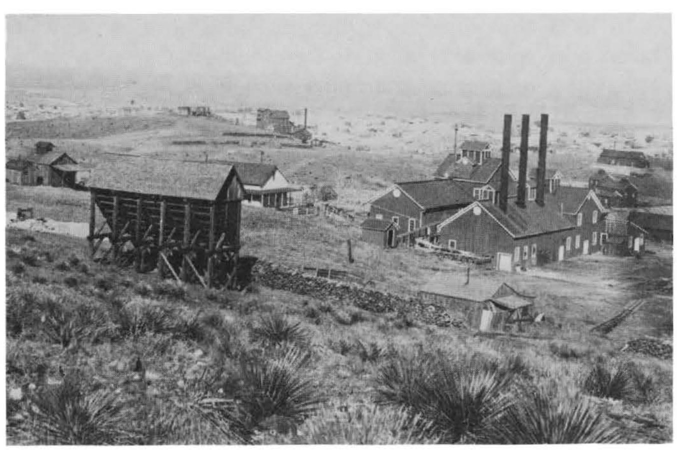


Figure 1. Grand Central mine surface plant in 1884, with the town of Tombstone in the background (Macia-Devere collection).

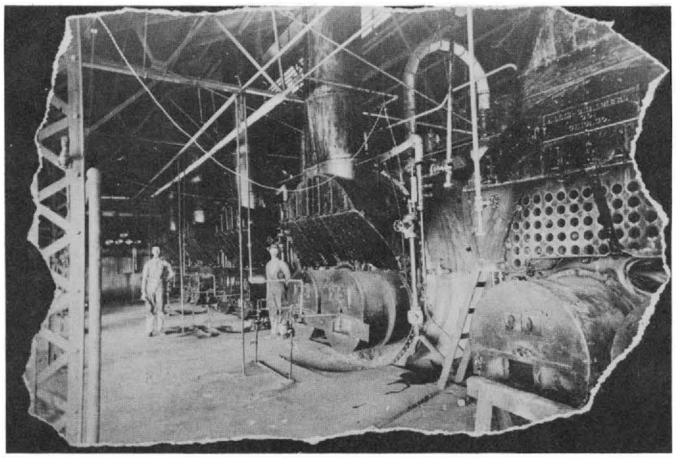


Figure 2. Surface boilers for the steam pumps in the Boom shaft near Tombstone about 1904 (Macia-Devere collection).

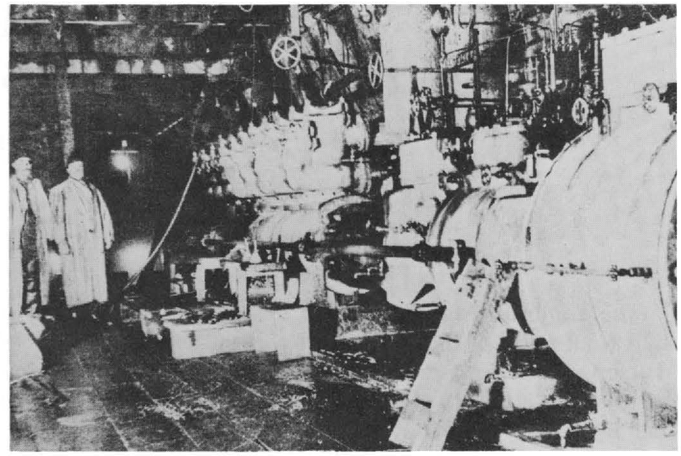


Figure 3. Steam pumps on the 1,000-ft level of the Boom shaft near Tombstone about 1906 (Macia-Devere collection).

almost simultaneously, stopping all pumping. In 1910, a 4,000 cubic-foot compressor was installed and the sinking pumps were run by air. With the air pumps and the installation of new boilers, the submerged pumps were finally recovered and development on the 1,000-ft level was resumed by the end of the year (Butler and others, 1938).

The cost of defeating the water, pumping 3,500 gpm, the decreasing silver price and the lack of sufficiently large, high-grade orebodies at depth, finally took their toll. On January 11, 1911, pumping stopped and the pumps on the 600, 700, 800 and 1,000-ft levels of the Boom shaft were allowed to flood (Butler and others, 1938). With the flooding of the lower levels, mining by the Tombstone Consolidated Mines Company ceased, though lessees continued to work the dumps and search for ore above the water table.

In 1914, Phelps Dodge Corporation, one of the principal creditors of Tombstone Consolidated Mines Company, acquired all the company's holdings and started mining under the name of Bunker Hill Mines Company. That company made no attempt to recover the lost pumps or reopen the lower workings. Rather, they concentrated on mining the shallower, lower grade manganese-silver ores in the southern and western part of the district. They mined until 1918, when they turned their operations over to lessees.

In 1933, the properties of Bunker Hill Mines Company were taken over by the Tombstone Development Company, which attempted to operate the mines via lessees; their operations continued sporadically into the late 1930's.

The Tombstone Extension, a lead-carbonate vein mine located in the eastern part of the district, opened in 1930. During 1932-33, the mine was the largest lead producer in Arizona (Asarco files). That mine was turned over to lessees in the mid-1930's and closed in the late 1930's.

Since the Second World War, the Anaconda Company and Newmont Mining Corporation have both examined the district in some detail; however, neither company was successful in discovering sufficient ore to justify reopening the mines.

Two mining operations are being conducted in the district at present. The Escapule Brothers, Charles and Louis, are leaching the dumps from the State of Maine mine and plan to commence mining and leaching of low-grade underground ores in the near future. The other operation is that of Sierra Minerals, which has during the last few years, been reworking the old mine dumps and recovering silver and gold via a cyanide leach process. The large dump east of Tombstone is the site of their current operation.

REGIONAL GEOLOGIC SETTING

The Tombstone mining district lies along the axis and just west of the deepest part of the Sonoran geosyncline. It also lies within a belt of north-northwest trending mountain ranges that are separated by broad alluvial-filled valleys and extend from the Colorado Plateau in central Arizona, to Sonora, Mexico. The region is underlain by a relatively thick blanket of Paleozoic and Mesozoic sediments.

GEOLOGY

Rocks of the Tombstone mining district consist of schist, granite, limestone, dolomite, shale, sandstone and conglomerate of Precambrian through Mesozoic age, and younger granodiorite, tuff, rhyolite sills, plugs and dikes, andesite dikes, valley fill and a basalt plug.

Precambrian rocks, Pinal Schist and granite, are exposed in a north-south elongate window in younger sediments and volcanic rocks in the south-central part of the district (fig. 4).

Overlying Precambrian rocks are 440 ft of Cambrian Bolsa Quartzite (Ransome, 1916) and 844 ft of Cambrian Abrigo Limestone (Gilluly, 1956). Devonian Martin Limestone, 230 ft of alternating limestone and shale, unconformably overlies the Abrigo Limestone (Gilluly, 1956). The Mississippian is represented by 786 ft of Escabrosa Limestone and dolomite (Gilluly, 1956).

The Pennsylvanian-Permian Naco Group, first described by Ransome during his early work in the Bisbee district, 20 mi to the southeast (Ransome, 1904), is well exposed in the Tombstone Hills. Due to the excellent exposures, Gilluly and his co-workers (Gilluly, 1956) were able to subdivide the Naco into 999 ft of Horquilla Limestone, 584 ft of limestone, sandstone and shale in the Earp Formation, 633 ft of Colina Limestone and 783 ft of limestone and dolomite in the Epitaph Dolomite.

Unconformably above the Naco Group is the Cretaceous Bisbee Formation (Gilluly, 1956). The Bisbee Formation at Tombstone is not to be confused with the Bisbee Group

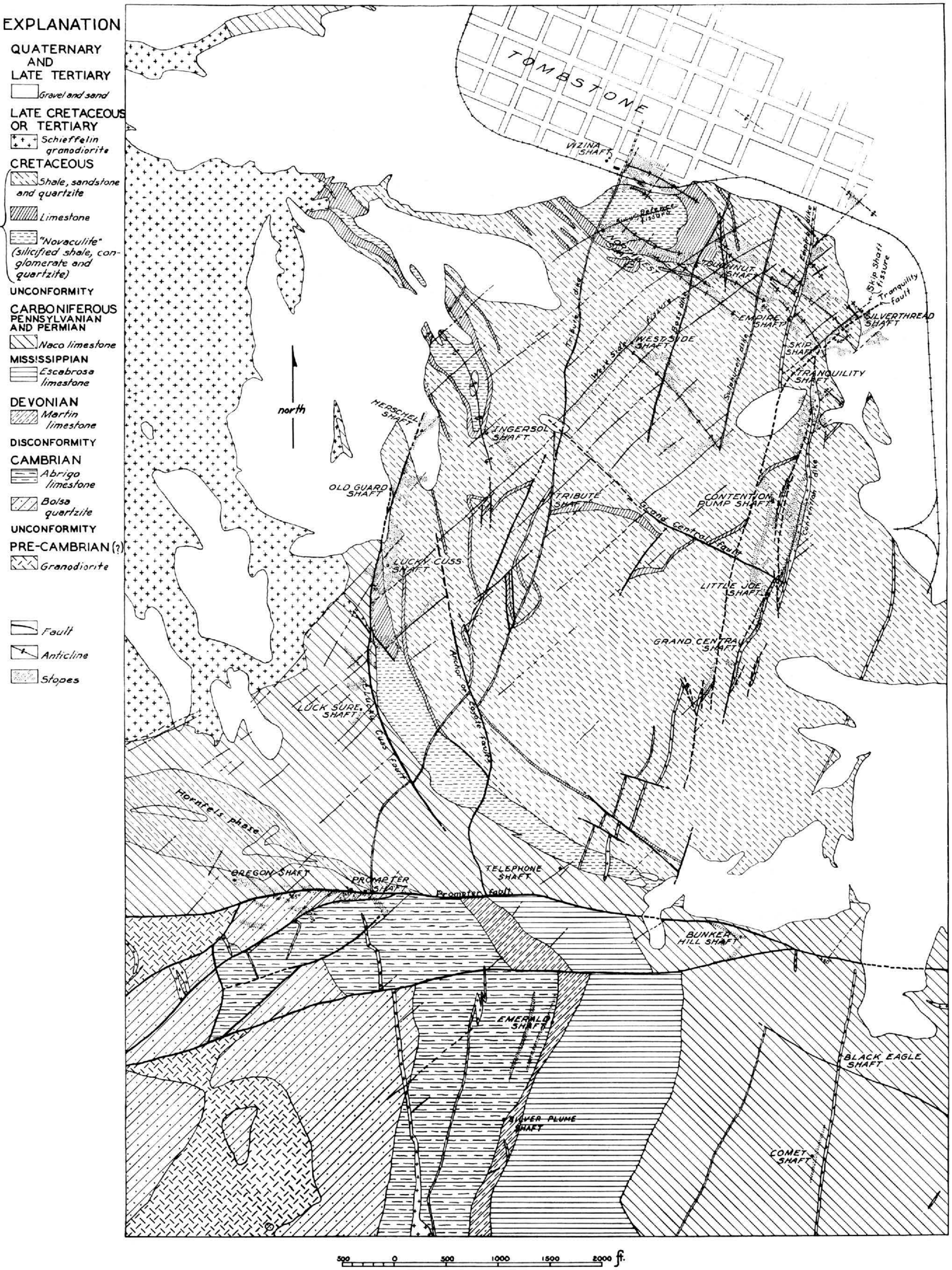


Figure 4. Geologic map of Tombstone district, Arizona (from Butler and others, 1938).

(Ransome, 1904) in the Mule Mountains to the southeast, as the Glance Conglomerate, Morita Formation, Mural Limestone and Cintura Formation do not occur, but their stratigraphic equivalents may be present. It has been suggested that Cretaceous beds at Tombstone are all younger than the Mural Limestone and "possibly even post-Cintura Formation" (Stoyanow, 1949, p. 30). However, Reeside has noted that "although the fossils of the Blue limestone (in the Bisbee Formation) at Tombstone are not precisely identifiable, they resemble those of the Mural closely" (Gilluly, 1956, p. 77). While there is little doubt of the Cretaceous age of the Bisbee Formation at Tombstone, direct correlation of stratigraphic units of the Bisbee Group, as they occur in their type locality, cannot be made. The formation exposed at Tombstone is a much faulted and metamorphosed sequence of sandstone, shale and limestone that is 3,079 ft thick (Gilluly, 1956). Of considerable importance as far as mineral deposition is concerned is the lower 128 ft of the formation, which consists of the "Novaculite" unit which contains 60 ft of basal shale and limey sandstone with localized limestone conglomerate, the "Blue limestone" which is 34 ft thick, 24 ft of shale and a 10-ft thick bed of limestone (Gilluly, 1956).

Late Cretaceous igneous rocks, the Schieffelin Granodiorite and the Uncle Sam quartz latite tuffs (Butler and others, 1938), are exposed in the western and southern part of the district, and dikes of granodiorite are found throughout its central part. The granodiorite is a holocrystalline rock with a hypidiomorphic granular texture. It is light gray to grayish-pink and medium-grained, consisting of 35-40% plagioclase, 15-20% orthoclase, 5-10% quartz, 5-10% green hornblende, 3-5% biotite and 1-5% augite with minor amounts of clinozoisite, zircon, magnetite, sphene and apatite (Newell, 1974).

Newell (1974) describes the Uncle Sam quartz latite tuff as a hypocrystalline rock that is slightly welded and contains ash-phenoclasts that are embayed and set in a devitrified matrix. The light yellowish-brown to gray-brown lithic tuff, with moderately well-defined flow structures, contains 40-50% plagioclase, 20-25% quartz, 15-20% orthoclase, and 1-5% biotite with traces of magnetite and apatite.

The tuffs have been dated at 71.9±2.4 m.y. (Newell, 1974), whereas the granodiorite is 72 m.y. old (Creasey and Kistler, 1962). The close relationship of the two rock types, both spatially and temporally, and the tendency for the tuff to be less mafic and more siliceous than the granodiorite, suggest that they are differentiates from the same magma.

The granodiorite and tuffs are cut by dikes of hornblende andesite that are bluish gray to light olive-gray in color. They consist of medium to coarse-grained hornblende phenocrysts and fine-grained plagioclase in a microcrystalline groundmass (Newell, 1974).

Rhyolite porphyry, dated at 63 m.y. (Creasey and Kistler, 1962) occurs as sills, plugs and dikes south and east of the main part of the district. The rock is pinkish gray and made up of medium- to fine-grained phenocrysts in devitrified groundmass. The texture is hypocrystalline, being typically porphyritic aphanitic.

To the north and east of the district, the pediment of the Tombstone Hills is covered by Gila Conglomerate. The rock unit, which is probably a fanglomerate, is several hundreds of feet thick, contains boulders up to 3 ft in diameter, as well as cobbles and pebbles, all of which are set in a fine sand matrix. The unit is generally poorly sorted, becoming finer grained and vaguely bedded in its upper part.

The youngest rock in the area is a basalt plug which intrudes the Gila Conglomerate on the east side of Walnut Gulch, north of the central part of the district. The elliptically shaped plug is dark gray to greenish black in color, being made up of fine-grained olivine, diopside and enstatite that occur in the interstices between felted plagioclase laths (Newell, 1974).

STRUCTURE

The Tombstone mining district is structurally complex. Several periods of faulting, with movement along the same structure, sometimes in different directions, has complicated the unravelling of the tectonic history.

Two structural features predominate: the Ajax Hill horst and the Tombstone basin (Butler and others, 1938). The Ajax Hill horse, located mostly south and east of Figure 4, is a 6 mi^2 area that is bounded on the west by the north-south trending Ajax Hill fault, on the north by the east-west trending Prompter reverse fault, and on the south by the northeast-southwest trending Horquilla Peak fault (Gilluly, 1956). To the east, the boundary is concealed by alluvium. Displacement along the boundary faults has been significant; the Ajax Hill fault has brought rocks of the Bisbee Formation, on the west, into contact with Bolsa Quartzite, on the east; the Prompter fault separates the northern Naco Group limestones from southern Pinal Schist; while the Horquilla Peak fault has brought upper Naco Group limestones on the south to rest against the Abrigo Limestone on the north.

North of the Ajax Hill horst is the Tombstone basin, which is shown by the large area of Cretaceous sediments on Figure 4. The basin is a broad synclinal warp, the axis of which trends east-west and plunges gently to the east. The syncline is complicated by a series of smaller west-northwest trending, anticlinal and synclinal folds that were called "rolls" by the early miners. To the west the broad syncline and its associated tighter folds abut and are truncated by the Schieffelin Granodiorite which is clearly younger than the folding.

Prior to the intrusion of the Schieffelin Granodiorite the Tombstone basin was subject to east-west and north-south faulting. Following the intrusion of the granodiorite, dikes of similar composition were emplaced along many of the pre-existing faults. The basin was then faulted along north-northeast trends, and there was renewed movement along the east-west and north-south faults which brought about the development of a series of northeast tension fractures. Thereafter, the faults and the tension fractures were mineralized, with the tension fractures becoming the northeast fissure veins. Following mineralization, the basin was again disrupted by faulting along west-northwest and north-northwest trends. Movement along the newly created and pre-existing faults tilted the basin to the north and northeast.

METAMORPHISM

The intrusion of the Schieffelin Granodiorite and its accompanying dikes metamorphosed the rocks in the Tombstone mining district prior to mineralization. Shale and sandstone of the Bisbee Formation were converted to hornfels and quartzite which fractured well and helped develop the long continuous tension fractures during the many periods of faulting. Limestone of the Bisbee Formation and upper Naco Group were recrystallized, while the "Novaculite," the basal member of the Bisbee Formation, altered to a jasperoid.

ORE DEPOSITION

The hornfelsic shales played a dual role: they fractured well, thus providing excellent, confined channel ways for ascending mineralizing solutions; and, because they were unshattered and competent except in the immediate vicinity of the fissure veins, they formed impermeable caps under which the solutions could spread and replace favorable limestone horizons. Since the Bisbee Formation is mostly shale and sandstone that altered to hornfels and quartzite, much of the ore was confined to fissure veins and faults. However, the largest orebodies occurred as limestone replacement deposits. Favorable horizons for replacement deposits were the "10-foot limestone," the "Blue limestone" and the "Novaculite," of the lower Bisbee Formation and the uppermost beds of the Naco Group.

The most favorable loci for ore deposition were where a northeast fissure vein, dike or premineral fault cut a favorable horizon that had been folded by one of the west-northwest-trending anticlinal flexures. In most cases, the "10-foot" and "Blue" limestones were more tightly folded and fractured than were the underlying Naco limestones. These features, together with the fact that the "10-foot" and "Blue" limestones were capped and bottomed by impermeable hornfelsic shales, made them the most receptive hosts in the district. Fracturing and permeability are the greatest where the bends are the sharpest. The folds are not symmetrical, and the sharpest bends may or may not be at the crest of a fold. In some folds, slip along beds produced permeable zones on the limb of the fold, and mineralization often extended for some distance down a limb.

The Silver Thread fold has a flat crest that bends sharply into a nearly vertical northeast limb. The bend has intensely fractured the "Novaculite," and it is continuously mineralized for 600 ft between a dike and a northeast fissure vein. The "Blue limestone" on the same roll was replaced by sulfides for 400 to 500 ft from the dike (Butler and others, 1938). The "Blue limestone," where it is cut by a large fissure vein along the Sulphuret fold, produced an orebody that was stoped for 300 ft; the stope varies in width from 25 to 100 ft and from 3 to 8 ft in height. The ore averaged $70 per ton when it was mined in 1904-05 (Butler and others, 1938). Figure 5, taken along the West Side fissure between the Boss and Sulphuret dikes is a good example of the complexity of folding and localization of replacement ores within the district.

Several ore shoots occur in the fisure veins. The Skip-Shaft fissure was mineralized for about 900 ft along strike and for more than 600 ft below the surface. Stratigraphically, the fissure made ore from the Naco Group to about 400 ft above the "Blue limestone" in the Bisbee Formation. The fissure was most productive along its intersection with the "Blue limestone," where the limestone was replaced for some distance away from the fissure. Maps of the old workings indicate the fissure was stoped over a width of several feet regardless of the rock type. The Arizona Queen fissure on the surface is a shear zone 4 to 5 ft wide. Like the Skip-Shaft fissure, the Arizona Queen has been most productive where it crossed the "Blue limestone." However, in the altered shales the fissure was well mineralized over a width of 10 to 12 ft, reaching a maximum width of 20 ft (Butler and others, 1938).

In addition to the replacement and fissure vein deposits, several orebodies were formed within the larger faults. These deposits generally occurred at the intersections of faults and fissure veins, particularly where a fissure vein hooked into and paralleled the fault for some distance before continuing in a northeasterly direction. Orebodies so formed were usually irregular, erratic and pipelike in shape. The Prompter fault contained irregular pipelike and tabular orebodies from the surface to the water level, where mining stopped. In one stope on the third level of the Prompter mine, approximately 180 ft below the surface, the entire fault zone, a width of 30 ft, was ore (Buchard, 1884).

The bulk of the Tombstone ores have been silver chlorides and lead, zinc and copper carbonates, with the majority occurring above the water table that stands at 4,120 ft above sea level, 450 to 600 ft below the surface. At some time in the past, the water table must have been lower, as oxidized ores have been mined from below the water table in the Grand Central, Lucky Cuss, Bunker Hill and Emerald mines.

There appear to have been at least two phases of mineralization: an earlier iron, lead, zinc, copper sulfide phase that was rich in silver and contained significant gold and a later manganese-silver phase. The ore related to the sulfide phase of mineralization contains little manganese and occurred as masses of pyrite, galena, tetrahedrite and sphalerite with minor amounts of chalcopyrite. The galena is later than the other sulfides as it replaces them, but it does not appear to be associated with the later manganese-silver mineralization. Galena and tetrahedrite are both argentiferous as is some of the pyrite. A sample of massive pyrite from the Sulphuret mine assayed 4.18 ounces per ton silver (Butler and others, 1938).

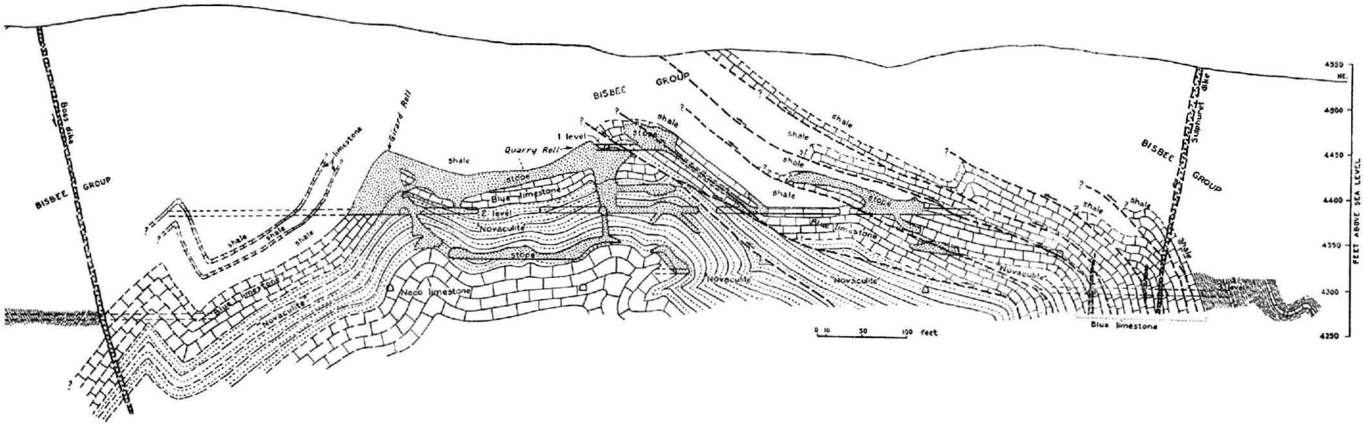


Figure 5. Cross-section along West Side fissure, looking northwest (from Butler and others, 1938).

The sulfide ore oxidized to limonite and cerussite that contained considerable bromyrite and cerargyrite with minor amounts of smithsonite, malachite, native gold and silver. In a few phases, chalcocite and argentite were found with the oxides.

The later manganese-silver ores occur mostly in the southern and western parts of the district principally in orebodies associated with the Prompter and Lucky Cuss faults. Most of the manganese occurs as psilomelane; however, a mass of alabandite was mined from the 350-ft level of the Lucky Cuss mine. The alabandite occurred in a replacement deposit in crystalline Naco limestone adjacent to the Lucky Cuss fault and was surrounded by pyrite, galena and sphalerite, which it in part replaced (Butler and others, 1938). The manganese ore generally contained less silver and lead and more copper than the oxidized sulfide ores, with the silver content usually being less than 20 ounces per ton. Typical manganese ore from the Dry Hill mine assayed 17 ounces per ton silver, 0.04 ounces per ton gold and 0.17% copper (Butler and others, 1938). However, some of the manganese ores from the Prompter mine averaged 35 ounces per ton silver from production in 1883 (Buchard, 1884). Ransome (1920) concluded that there was little doubt that the manganese-silver deposits occurred, at least in part, due to the reaction between the carbonate host rocks and the oxidizing sulfide deposits. However, the much lower silver and lead, and the higher copper content of the manganese-rich ores compared to the low-manganese sulfide ores suggests a separate, distinct phase of mineralization.

Silver was the most economically important metal produced, but gold and lead were also significant. The silver to gold ratio for ores produced was 6:1 in dollar value. The district has produced 45,000,000 pounds of lead (Keith, 1973, p. 13), an average of approximately 45 pounds of lead per ton of ore mined.

REFERENCES

Blake, W. P., 1882, The geology and veins of Tombstone, Arizona: Am. Inst. Min. Eng. Trans., v. 10, p. 334-345.

Buchard, H. C., 1884, Production of gold and silver in the United States, 1883: U.S. Dep. of Treasury, Doc. 604, p. 38-50.

Butler, B. S., Wilson, E. D., and Rasor, C. A., 1938, Geology and ore deposits of the Tombstone district, Arizona: Arizona Bur. of Mines Bull. 143, 114 p.

Church, J. A., 1903. The Tombstone Arizona mining district: Am. Inst. Min. Eng. Trans., v. 33, p. 3-37.

Creasey, S. C., and Kistler, R. W., 1962, Age of some copper-bearing porphyries and other igneous rocks in southeastern Arizona: U.S. Geol. Survey Prof. Paper 450-D, p. 1-5.

Devere, J. M., 1960, The Tombstone bonanza, 1878-1886: Arizona Pioneers Hist. Quart., v. 1, p. 16-20.

Gilluly, James, 1956, General geology of central Cochise County, Arizona: U.S. Geol. Survey Prof. Paper 281, 169 p.

Keith, S. B., 1973, Index of mining properties in Cochise County, Arizona: Arizona Bur. of Mines Bull. 187, 98 p.

Newell, R. A., 1974, Exploration geology and geochemistry of the Tombstone-Charleston area, Cochise County, Arizona [Ph.D. dissertation]: Stanford, Calif., Stanford Univ., 205 p.

Ransome, F. L., 1904, Geology and ore deposits of the Bisbee quadrangle, Arizona: U.S. Geol. Survey Prof. Paper 21, 167 p.

————, 1916, Some Paleozoic sections in Arizona and their correlation: U.S. Geol. Survey Prof. Paper 98-K, p. 133-166.

————, 1920, Deposits of manganese ore in Arizona: U.S. Geol. Survey Bull. 710, p. 96-103, p. 113-119.

Stoyanow, A. A., 1949, Lower Cretaceous stratigraphy in southeastern Arizona: Geol. Soc. of America Memoir 38, 169 p.

Wilson, E. D., 1962, A resume of the geology of Arizona: Arizona Bur. of Mines, Bull. 171, 109 p.

[Devere, B.J., 1978, The Tombstone mining district, history, geology, and ore deposits, in Callender, J.F., and others, eds., Land of Cochise (southeastern Arizona): New Mexico Geological Society Fall Field Conference, 29th, November 9-11, 1978, Guidebook, p. 315-320.]

◈ ◈ ◈ GEOLOGY AND ORE DEPOSITS OF THE WARREN MINING DISTRICT

BY DONALD G. BRYANT AND HARRY E. METZ

INTRODUCTION

The Warren mining district is in the Mule Mountains of Cochise County in the southeastern corner of Arizona and is about 6 miles north of the Mexican International Boundary. The producing area, as it is now known, comprises about 3 square miles at a mean altitude of about 5,000 feet above sea level. A concentrator of 18,000 tons-per-day capacity is located in Lowell, and the smelting works are at Douglas 25 miles to the east. The mine area is connected with the smelter by the Southern Pacific Railroad and U.S. Highway 80.

The earliest published geologic study of the district was by Ransome in 1902 (8, 9). These excellent publications are constantly used today as the authoritative geologic source of information for the Warren mining district. Since 1904 a number of papers have been published and are cited in the bibliography; however, particularly noteworthy are the ones of Bonillas, Tenney, and Feuchere in 1916 (1) and a number of papers by Trischka (13), former chief geologist of the Copper Queen Branch, Phelps Dodge Corp., the last of which was in 1938.

Copper ore was discovered in the Warren mining district in 1877 by Jack Dunn, a member of a government scouting party, while he was searching for water in Mule Gulch. The first mining claim was the Rucker, and it was located by Dunn, Lt. Rucker, and T. D. Byrne on August 2, 1877. The Halero claim was located in December 1877 and was later relocated as the Copper Queen, destined to become one of the major producers of the district.

The first smelter was erected in 1878 to treat lead ore. It was unsuccessful and in 1881 was replaced by a copper smelter. On the recommendation of Dr. James Douglas, the Phelps Dodge interests entered the district with the purchase of the Atlanta claim for $40,000. After ore was discovered on the Atlanta, Phelps Dodge bought out the Copper Queen, which adjoined it, and in 1885 began large-scale mining operations that have continued to date.

In 1899 a syndicate of mining men in Red Jacket, Michigan, organized as Lake Superior and Western Development Co., purchased a group of mining claims in the Warren district, of which the Irish Mag claim was one. Ore was discovered in the Irish Mag claim on the 750-foot level in 1900, and serious production began in 1902 by a newly organized company, the Calumet and Arizona Mining Co. The Calumet and Arizona Mining Co. and the Copper Queen Consolidated Mining Co., which later became Phelps Dodge Corp., became the two largest producing companies in the district. A third company, the Shattuck Denn Mining Co., although considerably smaller than these two, was also important. In the fall of 1931, the Phelps Dodge Corp. and the Calumet and Arizona Mining Co. merged, and the active holdings of the Shattuck Denn Mining Co. were purchased in 1947, making complete the consolidation of the mining operation in the Warren mining district under one mining company—the Phelps Dodge Corp.

GENERAL GEOLOGY AND REGIONAL SETTING

Generally speaking, the Mule Mountains in which the deposits are located are divided into two geologic tracts by the northwest-southeast-trending Tomb-Stone Canyon, the site of the town of Bisbee. On the southwest side of the canyon the exposures are principally Paleozoic rocks with a few windows showing the Precambrian Pinal Schist. On the northeast, except for the strip adjacent to the canyon, the rocks are Cretaceous in age. The exposures in the strip on the northeast side of the canyon consist principally of Juniper Flat Granite. As exposed, this granite extends from Mule Pass down the canyon for about 5 miles and has a maximum width of nearly 2 miles. The northeastern side of the granite passes under the Cretaceous beds, and consequently this dimension of the intrusive is unknown. On the southwest side of the canyon there is a strip of Precambrian Pinal Schist overlain to the south by Paleozoic rocks. These rocks are transected with northwest-southeast-trending dikes of granite and rhyolite believed to be apophyses of the Juniper

Photograph by Paradise Aerial Photo Service

FIGURE 1.—Aerial view of Bisbee and Warren looking westerly up Tombstone Canyon.

Flat Granite. The Paleozoic beds have a gentle to moderate dip away from, and more or less normal to, the southwestern side and ends of the Juniper Flat Granite, suggesting northwest-southeast anticlinal doming related to its emplacement. The production area of the Warren mining district consists of about 3 square miles situated on the southeastern end of the anticlinal dome. The nearest ore of consequence is about 1¼ miles from the southern end of the granite mass. The relative ages of the granite intrusive and ore deposition imply a genetic relation between the two.

About 2 miles east of the Juniper Flat Granite is the stocklike mass of Sacramento Quartz Porphyry, which manifests itself as the focus of mineralization in the district. Although very irregular in outline, it may be described as about a mile in diameter. A major fault of east trend, the Dividend, splits the stock. On the north or footwall side the fault wall is Pinal Schist; on the south or hanging wall it is Paleozoic sediments. Displacement on the Dividend fault is normal and is about 2,000 feet at the old Glory Hole in Bisbee and about 5,000 feet 2½ miles eastward at the Saginaw shaft. Remnants of Cambrian Bolsa quartzite on the footwall and the Paleozoic sediments on the hanging wall make these displacement figures fairly reliable. On the west, the Dividend fault is lost where it passes into the Pinal Schist near Bisbee. There has been speculation that the southwesterly contact of the Juniper Flat Granite is the Dividend fault because it is fairly straight and regular and the alignment is about right for the projected strike. Also, there has been speculation that the Quarry fault, the major limiting fault on the west side of the Bisbee district, is the continuation of the Dividend curving to the southwest. Evidence for verifying either of these concepts is lacking. Eastward the Dividend fault is lost in the alluvium of Mule Gulch.

There is a marked change in the strike of the Dividend fault where it passes through the Sacramento stock. Westward from the stock, it has a strike of N. 70° W ±., which conforms more or less to the lineation of the other geologic features in the vicinity of Tombstone Canyon. Eastward, it assumes a more nearly east-west strike for nearly 2 miles until it is lost in the alluvium. In the Sacramento stock where this change in strike occurs, the fault apparently splits westward into a number of branches, which leave the main break on an east-west-trending strike and curve southward as horsetails. The most conspicuous strand of this horsetail in the Lavender pit workings has been designated as the Lavender Pit fault. It dips southward about 70°, conforming to the Dividend fault. Displacement is normal and is believed to be about 500 feet. The Lavender Pit fault is probably one of the faults noted in the early mining of the limestone replacements, which dropped the ore-bearing horizons in the Irish Mag and Spray mines about 500 feet with respect to the ore horizons to the northwest. Also, this displacement plus the cumulative displacement of the other branches could account for some of the wide discrepancy of movement on the Dividend fault between its east and west ends.

South of the Dividend fault the Paleozoic rocks of the productive area have been cut by a great number of northeast fractures. These have been separated into fault zones and have been indicated on the majority of the geologic maps of the Bisbee area as single fault planes. They have a strike that is complementary to the Dividend fault, roughly N. 20° E., and dip steeply to the west. Individually, even the strongest fractures lack persistency in strike and dip. It is common for breaks containing as much as a number of inches of gouge and resembling a plane of major dislocation to fade out and become lost within a few feet both on strike and dip. Displacement on individual fractures is insignificant. However, collectively, across a zone that might be as much as 1,000 feet wide, the cumulative displacement may be considerable—500 feet or more. In all, there have been more than 20 fault zones identified, most of northeast trend. Ore occurrence is intimately associated with these northeast fractures. The major fracture zone in the Junction area is in Mexican Canyon. It is a zone possibly 1,000 feet wide, which has an overall displacement of from 400 to 500 feet. Ore has occurred intermittently in this zone for a vertical extent of more than 2,000 feet. The Mexican Canyon fault, which so conspicuously displaces the Cretaceous Mural Limestone in the hills north of the Dividend fault, has a strike that projects into this ore zone. This relation has been used as evidence of a post-Cretaceous age for the mineralization. It has been reasoned that the ore-zone fractures and the fault which displaced the Cretaceous beds were one. Other evidence, which will be enumerated later, places the age so overwhelmingly in the pre-Cretaceous that this cannot be the case and can be explained by recurrent faulting.

About 8,000 feet south of the Dividend fault is the first of another system of faults that is more or less parallel to the Dividend and limits the productive area on the south. The zone of breaking, referred to as the Don Luis block in some of the earlier literature, is about 3,000 feet wide. Generally, displacement is normal, and the downthrown side is on the north for the northernmost breaks and on the south for the southern breaks. In the northern section, the Paleozoic rocks are dropped in stages on each break until the Precambrian Pinal Schist is exposed. Progressing southward this condition is reversed until Paleozoic rocks on the south are abutted against Precambrian Pinal Schist on the north.

ROCK DESCRIPTIONS

Precambrian Metamorphic Rocks

The oldest rock in the Warren mining district is the Precambrian Pinal Schist, a quartz sericite schist. This rock is probably the result of regional metamorphism of thin-bedded clastic sediments. Bedding, when detectable in the field, is very steep. Neither the top nor the bottom of the schist has been found; consequently, the thickness of these sediments is indeterminate. In thin section, essential constituents are quartz and very fine grained aggregates of sericete with accessory tourmaline and rare red garnets.

Paleozoic Sedimentary Rocks

The Bolsa Quartzite, deposited with angular unconformity on the nearly level plane of eroded Pinal Schist, is of Middle Cambrian age. The Bolsa Quartzite is 430 feet thick, as measured by Ransome (8) at the Mount Martin type section. The basal beds of the Bolsa consist of quartzite conglomerate, which grades upward into a pebbly grit, commonly crossbedded. The upper part of the Bolsa is argillaceous and calcareous and grades into the overlying Abrigo Limestone.

The Abrigo Limestone of Middle and Late Cambrian age is 770 feet thick at the Mount Martin type section (8). The lower contact of the Abrigo with the Bolsa is conformable and is arbitrarily set at the top of the uppermost quartzite bed in the transitional zone. The lower half of the Abrigo is characteristically shaly, and the upper half is distinctly crystalline. The crystalline upper half of the Abrigo is divisible into two mapping units. The lower unit of 170 feet is a distinctive series of remarkably evenly bedded crystalline limestone beds, averaging 2 inches thick, separated by wavy greenish laminae. The upper unit of 220 feet consists of massive—6 inches to 2 feet—sandy limestone with some crossbedding, terminated by a quartzite bed. This quartzite, known in the district as the Parting Quartzite, is composed of equigranular, well-rounded, white quartz grains cemented by silica. The thickness is very irregular and ranges from 0 to 16 feet.

Rocks of Ordovician through Middle Devonian age have not been recognized in the Warren mining district.

The Upper Devonian Martin Limestone, unconformably overlying the Cambrian Abrigo Limestone, is from 300 to 375 feet thick. The lower part of the Martin consists characteristically of black shaly limestone. The upper part of the formation is thick bedded and consists of very fine grained black crystalline limestone.

Conformably overlying the Martin Limestone without a well-defined contact is the Escabrosa Limestone of Early and middle Mississippian age. The Escabrosa Limestone seems to thin to the southeast. Measurements of the thickness of the Escabrosa in the Warren mining district range from 600 to 800 feet. The Escabrosa is predominantly a very thick bedded, light-gray to white, coarse granular crinoidal limestone with subordinate dark-gray aphanitic beds. About 250 feet above the base of the Escabrosa are the "lower" chert beds, which are about 50 feet thick. The distinctive chert beds are 1 to 8 inches thick, dark gray to black, finely crystalline, and are interbedded with dark-gray aphanitic limestone. The contact of the Escabrosa with the overlying Horquilla Limestone of Pennsylvanian age is not well defined but is considered to be at the top of the Escabrosa cliff. This contact is marked neither by erosion, stratigraphic break, nor by marked lithologic change, although faunal assemblages indicate that the Upper Mississippian is absent. Of possible significance during recent work in the Naco Hills, only 5½ miles southwest of the Warren district, is the discovery of 144 feet of shaly limestone lying conformably between the Escabrosa and the Horquilla Limestones. This shaly limestone is very similar to the Late Mississippian Paradise Formation described by Hernon (5, p. 653–696) and Stoyanow (11, p. 508–511).

The Pennsylvanian Naco Formation, named and measured by Ransome (8), is about 3,000 feet thick in the Warren mining district. Gilluly, Cooper, and Williams (4, p. 15–42) raised the Naco Formation to the Naco Group and divided the group into six new formations. Only the lower three of these formations are present in the district. These formations are the Pennsylvanian Horquilla Limestone, about 1,000 feet thick; the Pennsylvanian-Permian Earp Formation, about 460 feet thick; and about 250 feet of the lower part of the Permian Colina Limestone.

In the mining area, the Earp and Colina are exposed from the southerly wall of the Lavender pit to the Dallas shaft in a small downdropped fault block.

The Horquilla Limestone, of Middle to Middle-Late Pennsylvanian age, is a predominantly thin-bedded (6 inches to 2 feet thick) blue-gray limestone with a few thicker beds as much as 6 or even 8 feet thick and subordinate granular crinoidal beds. Near the top of the Horquilla, shale beds become increasingly numerous. The base of the overlying Earp Formation is placed where the shale is predominant.

The Earp Formation, of Middle-Late Pennsylvanian to Permian age, consists predominantly of clastic sediments in the lower part and massive limestone and conspicuous orange dolomite toward the top. The uppermost of these dolomite beds is considered the top of the Earp Formation. The incompetent clastic beds in the Earp, lying between the massive limestone of the Naco and Colina, are especially susceptible to intense faulting in the Warren district, making the estimated thickness of 460 feet completely unreliable.

Conformably overlying the Earp is the Permian Colina Limestone. The Colina Limestone is a black, fossiliferous, massive limestone and is about 250 feet thick.

No younger Paleozoic rocks have been recognized in the Warren mining district.

Mesozoic Sedimentary Rocks

In the Warren mining district, Mesozoic sedimentary rocks consist of an accumulation of predominantly clastic rocks about 5,000 feet thick of Lower Cretaceous age. It is probable that Jurassic and Triassic sediments were never deposited in the district. The Cretaceous beds were first described in 1902 by Dumble and designated as the Bisbee Group. Ransome (8) retained the name of Bisbee Group and divided it into four formations—the Glance Conglomerate, the Morita Formation, the Mural Limestone, and the Cintura Formation.

The basal member of the Cretaceous Bisbee Group is the Glance Conglomerate, which ranges from 0 to more than 3,000 feet thick. The Glance Conglomerate consists of bedded angular to imperfectly rounded pebbles and boulders imbedded in a reddish fine-grained matrix. These pebbles and boulders have been derived from all the pre-Cretaceous rocks of the Warren mining district. The terrain upon which the Glance Conglomerate was deposited is characterized by radical differences in relief. North of the Dividend fault, which is the northern boundary of the ore-producing area, the Glance Conglomerate was deposited on a surface of low relief cut principally on Pinal Schist with a few remnants of Bolsa Quartzite and Juniper Flat Granite. Ransome (8) believed that this surface is probably equivlent to the Precambrian surface upon which the Bolsa Quartzite was deposited. In this area, the Glance is from 0 to 75 feet thick and consists predominantly of schist fragments. South of the Dividend fault, the relief of the pre-Cretaceous surface was characterized by very deep canyons and low hills in Paleozoic limestone. This concept of extreme relief was recently verified by diamond drilling at an area about 7 miles southwest of Bisbee. One hole collared and advanced 2,725 feet in the Naco Limestone, but less than a mile away another hole cored Glance Conglomerate with predominant limestone boulders through its entire length of 2,210 feet. Between the two holes there is no recognizable post-Glance faulting. Only in the upper part of the Glance south of the Dividend fault does schist detritus become common. The explanation of the origin of this extreme contrast of lithology and thickness of the Glance Conglomerate depends on the Dividend fault. First, pre-Glance movement of several thousand feet on the Dividend fault elevated the northern block higher than the southern block. Then subaerial erosion stripped the Paleozoic sediments and intrusive igneous rocks from the northern block and dumped this debris onto the complexly faulted southern block. With rapid submergence, as evidenced by the variable size and angularity of the fragments, the seas covered the area except for the higher schist terrain. Erosion of the north block continued until the irregularities of the sea bottom were leveled by deposition of Glance with predominant schist boulders. With complete submergence of the area, deposition of the Glance Conglomerate ended with a gradual change of lithology to the fine clastic material of the conformably overlying Morita Formation.

The Morita Formation is 1,800 feet thick and consists of alternating shale and sandstone. It becomes increasingly calcareous toward the top and grades into the overlying Mural Limestone.

The Mural Limestone is 650 feet thick and is divided into two mappable units. The lower 300 feet consists of thin-bedded impure limestone, and the upper 350 feet is a thick-bedded very fossiliferous limestone. In the predominantly clastic Bisbee Group, this upper member is distinctive, as it forms a white cliff in much of the district.

The Cintura Formation consists of 1,800 feet of alternating shale and sandstone, which conformably overlies the Mural Limestone. The original thickness is unknown because the top is an erosion surface.

Cenozoic Rocks

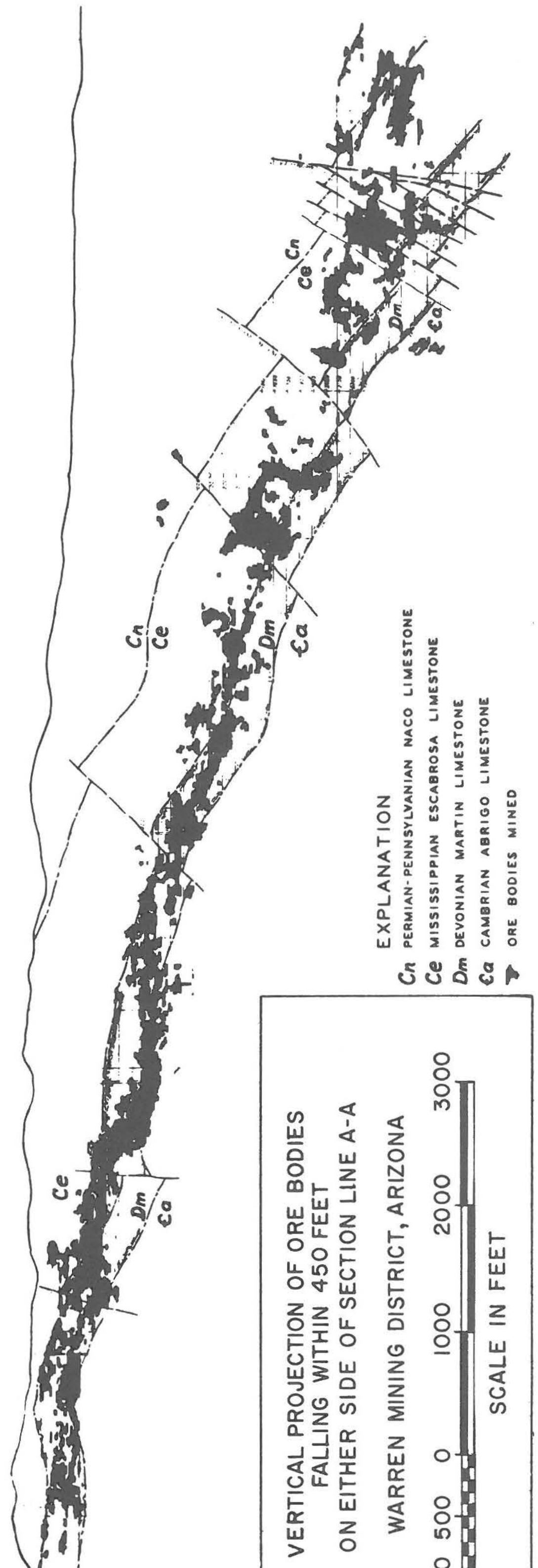
The only other sedimentary rocks in the district are Quaternary and Recent fluviatile deposits and a few very local landslide deposits. These fluviatile rocks consist of coarse angular to subrounded detritus and are rarely bedded.

Post-Paleozoic—Pre-Cretaceous Igneous Rocks

In the Warren mining district, the important igneous rocks were intruded during the post-Paleozoic–pre-Cretaceous interval. Although these intrusives differ in form, size, texture, and geologic environment, the similarities of granite composition and age indicate a probable comagmatic origin. The intrusive rocks are grouped into two geologic classifications on the basis of the extent of hydrothermal activity. Northwest of Bisbee the first group, including the Juniper Flat Granite and the Escabrosa Ridge dikes, is not appreciably altered. The second group, which includes the Sacramento stock and the "underground" porphyries, is intensely altered and intimately associated with mineralization.

The Juniper Flat Granite forms a northwest-trending elongated stock located in the central part of the Mule Mountains and is resistant to erosion and forms topographic highs, cliffs, and steep slopes. In general, the Juniper Flat Granite has typical granitoid texture, but a distinct porphyritic phase is present locally, particularly on Juniper Flat. The coarse-grained variety of Juniper Flat Granite is composed of quartz, orthoclase, plagioclase, and biotite. The finer grained porphyritic rock, although megascopically similar to the coarse variety, is distinctly different when studied under the microscope. Microscopically, the porphyritic phase consists of orthoclase and quartz with minor amounts of plagioclase and biotite. Associated with the Juniper Flat Granite are numerous dikes, irregular intrusive bodies, and sills intruding all the pre-Cretaceous rocks. These intrusives are especially well developed along Escabrosa Ridge as a northwest-striking interlaced network parallel to the elongation of the Juniper Flat Granite. Megascopically, the minor intrusive rocks consist of irregular, embayed, and idiomorphic quartz and flesh-tinted orthoclase phenocrysts imbedded in an aphanitic groundmass. Under the microscope, the groundmass is a microgranitic aggregate of quartz, orthoclase, and muscovite. Ransome (8) referred to these intrusives as granite porphyries, but modern usage requires the groundmass of granite porphyries to be megascopically crystalline or phaneritic (12, p. 9). Since the groundmass is aphanitic, rhyolite porphyry is believed to be better terminology.

The most important intrusive body of the altered group is the Sacramento stock. This stock, which is about a mile in diameter, appears to be the center of mineralization, as indicated by peripheral distribution of the ore bodies shown in figure 2. Geologic mapping during recent open-pit operations indicates that the stock is an intrusive complex rather than a single intrusion. Identifiable are: 1. an intensely silicified pyritized quartz porphyry more or less in the center and believed to be the earliest intrusive; 2. a breccia consisting of an intensely silicified mixture of schist, quartzite, limestone, and quartz porphyry fragments, more or less confined to the southerly side of the stock, which is designated as intrusion(?) breccia and is believed to have been formed during the emplacement of the early quartz porphyry; 3. a sericitized slightly pyritized feldspar quartz porphyry, which is more or less in the easterly part of the stock but is also prevalent in the mineralized area as dikes and sills and is designated as "underground" porphyry; and 4. a breccia consisting of a heterogeneous agglomeration of rounded fragments of schist, quartzite, limestone, both types of porphyry, and low-grade siliceous sulfide, which is designated as intrusive breccia and is quite prevalent as large irregular masses within the stock



Cn
Ce
Ce
Dm
Ca
Cn
Ce
Dm
Ca
Ce
Dm
Ca
VERTICAL PROJECTION OF ORE BODIES
FALLING WITHIN 450 FEET
ON EITHER SIDE OF SECTION LINE A-A
WARREN MINING DISTRICT, ARIZONA
1000 500 0 1000 2000 3000
SCALE IN FEET
EXPLANATION
Cn PERMIAN-PENNSYLVANIAN NACO LIMESTONE
Ce MISSISSIPPIAN ESCABROSA LIMESTONE
Dm DEVONIAN MARTIN LIMESTONE
Ca CAMBRIAN ABRIGO LIMESTONE
ORE BODIES MINED

FIGURE 2a.

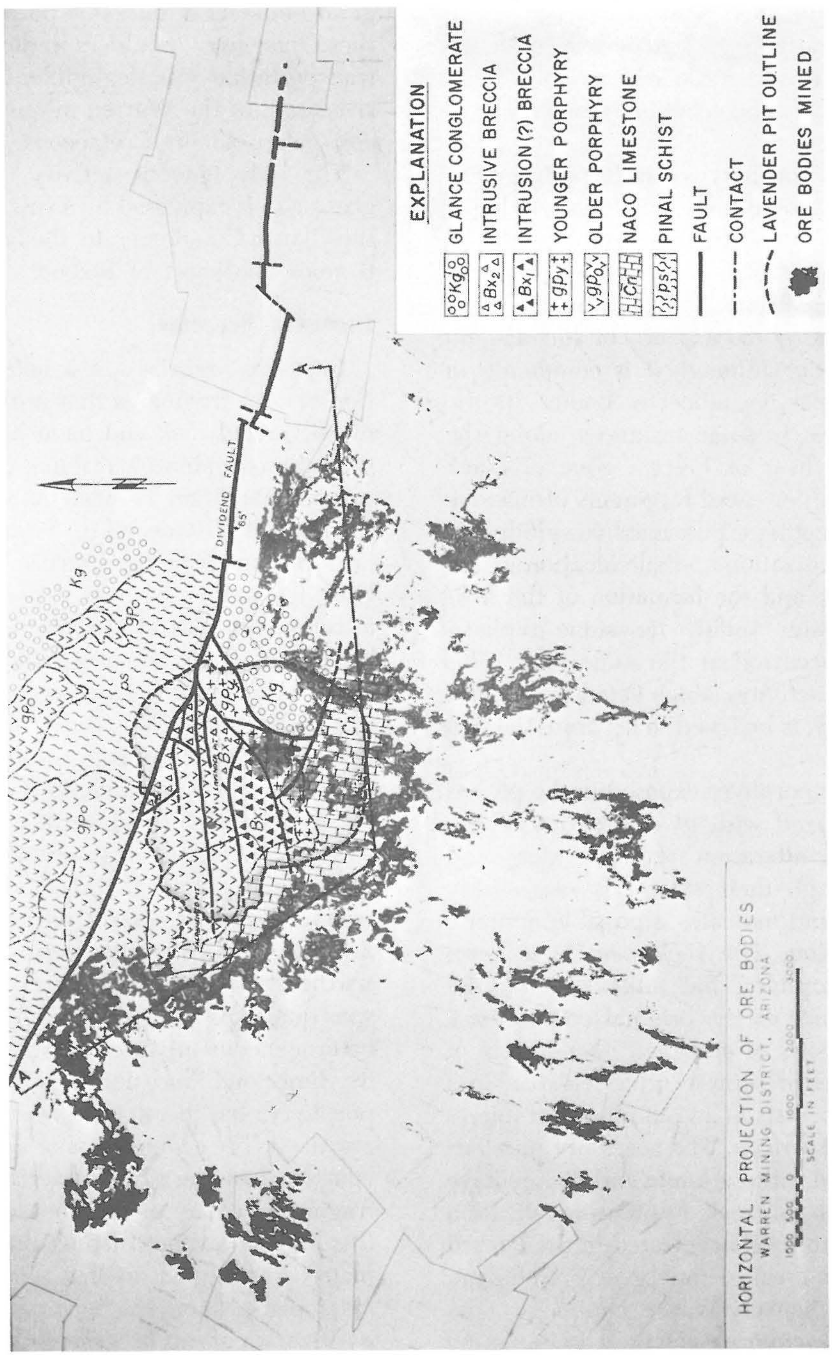

EXPLANATION
GLANCE CONGLOMERATE
INTRUSIVE BRECCIA
INTRUSION (?) BRECCIA
YOUNGER PORPHYRY
OLDER PORPHYRY
NACO LIMESTONE
PINAL SCHIST
FAULT
CONTACT
LAVENDER PIT OUTLINE
ORE BODIES MINED
DIVIDEND FAULT
HORIZONTAL PROJECTION OF ORE BODIES
WARREN MINING DISTRICT, ARIZONA
SCALE IN FEET

FIGURE 2b.

area and in the mineralized limestone as small irregular bodies.

The quartz porphyry of the Sacramento stock has been thoroughly altered, silicified, and pyritized so that the character of the original rock is indeterminable. The altered rock consists of anhedral grains of quartz, intergranular pyrophyllite, and scattered, large, rounded, and embayed phenocrysts of quartz, commonly termed quartz "eyes." Accessory minerals include dickite, alunite, and rutile with minor zircon, apatite, and bastite. The sulfide content is more than 15 percent, mostly pyrite.

The feldspar quartz porphyry is a rather soft, greenish-gray, thoroughly altered rock with scattered disseminated pyrite. In the stock area it is on the south and easterly contacts of the stock and occurs in the mineralized limestone area as irregular dikes and sills. The porphyry is distinctive by the absence of silicification and intense pyritization, although it is commonly in contact with large massive siliceous bodies in the undergound exposures. In some instances, along the porphyry contact, a shear or breccia zone of black mylonitic material with oriented fragments of massive pyrite is present, indicating a post-massive sulfide age for this porphyry. Pyritization and silicification of the early quartz porphyry and the formation of the low-grade, siliceous, massive sulfide limestone replacements undoubtedly occurred at the same time. This surge of mineralizing activity, which acted on one but not the other porphyry, is believed to separate the two intrusions in time.

The feldspar quartz porphyry exposed in the pit has been intensely sericitized without destruction of the original texture. The alteration of the undergound intrusive rocks, through their extent, is remarkably uniform in intensity and indicates a possible deuteric origin of the alteration. The rock may have been quartz monzonite porphyry, but alteration has destroyed all the evidence of the original composition. The altered rock consists of embayed phenocrysts of quartz, pseudomorphs of sericite after feldspar, and chloritic biotite phenocrysts in a groundmass of microcrystalline quartz and sericite. The accessory minerals are zircon, apatite, and rutile. Alunite and dickite have not been recognized in this rock. Pyrite mineralization is slight and appears to be concentrated in the altered biotite phenocrysts. In areas of supergene enrichment, the altered biotite phenocrysts are completely destroyed, probably by action of downward-circulating water.

Age of Granitic Intrusions

The Juniper Flat Granite intrudes the Precambrian Pinal Schist and the Pennsylvanian Horquilla Limestone (4, p. 54). The Cretaceous Glance Conglomerate rests directly on an erosional surface of Juniper Flat Granite. Thus, the age of the Juniper Flat Granite is definitely post-Paleozoic–pre-Cretaceous. The Sacramento intrusive complex intrudes the Pinal Schist and all the Paleozoic rocks up to and including the Permian Colina Limestone. The Sacramento stock-Glance Conglomerate contact has been exposed recently by stripping operations in the Lavender pit. The Glance Conglomerate is deposited on an erosional surface carved on porphyry and contains numerous large angular boulders of the same porphyry. The condition of these porphyry boulders indicates that distance of transportation was negligible. Thus, the major intrusive rocks of the Warren mining district are definitely post-paleozoic–pre-Cretaceous.

The only igneous activity of definite post-Cretaceous age is expressed by a few andesitic dikes cutting the Glance Conglomerate, the largest of which is about 6 miles southeast of Bisbee.

Intrusive Breccias

Intrusive breccias are a heterogeneous agglomeration of rock fragments that are embedded in a matrix of pulverized rock and have been transported, sometimes for considerable distances, and emplaced in their present condition in what appear to be pre-existing fractures. At Bisbee, all the underlying formations may be represented in the breccia, but none of the overlying formations have ever been identified in it. The intrusive breccias of the Warren mining district have been divided into two mappable units, which are designated as intrusion(?) breccia and intrusive breccia.

The intrusion(?) breccia has been so designated because of its close association with the early quartz porphyry of the Sacramento complex and the possibility of its being formed in the emplacement process of this porphyry. It is in the southerly part of the intrusive complex near the Gardner shaft. Here, it is in contact with the quartz porphyry on the north and limestone on the south with a finger that extends northeast beween the quartz porphyry and the feldspar quartz porphyry. (See fig. 3.) It is composed of a heterogeneous mixture of fragments of schist, quartzite, limestone, and porphyry, which, like the quartz porphyry, has been intensely altered, silicified, and pyritized. The groundmass or matrix is pluverized rock composed of the same material as the enclosed rock fragments. Many of the contacts of the fragments in this breccia are not distinct but are gradational from matrix to fragment as if a semidigestive process had taken place. There has been pervasive silicification and pyritization of this breccia to about the same degree as in the quartz porphyry. However, there are more small massive sulfide bodies in the breccia. Overall sulfide content is probably about the same.

The intrusion(?) breccia is the so-called contact breccia described in earlier publications (1). It was believed at that time that this breccia was volcanic explosion debris intruded by the older quartz porphyry. Subsequent work both in underground and open-pit operations has established that the breccia

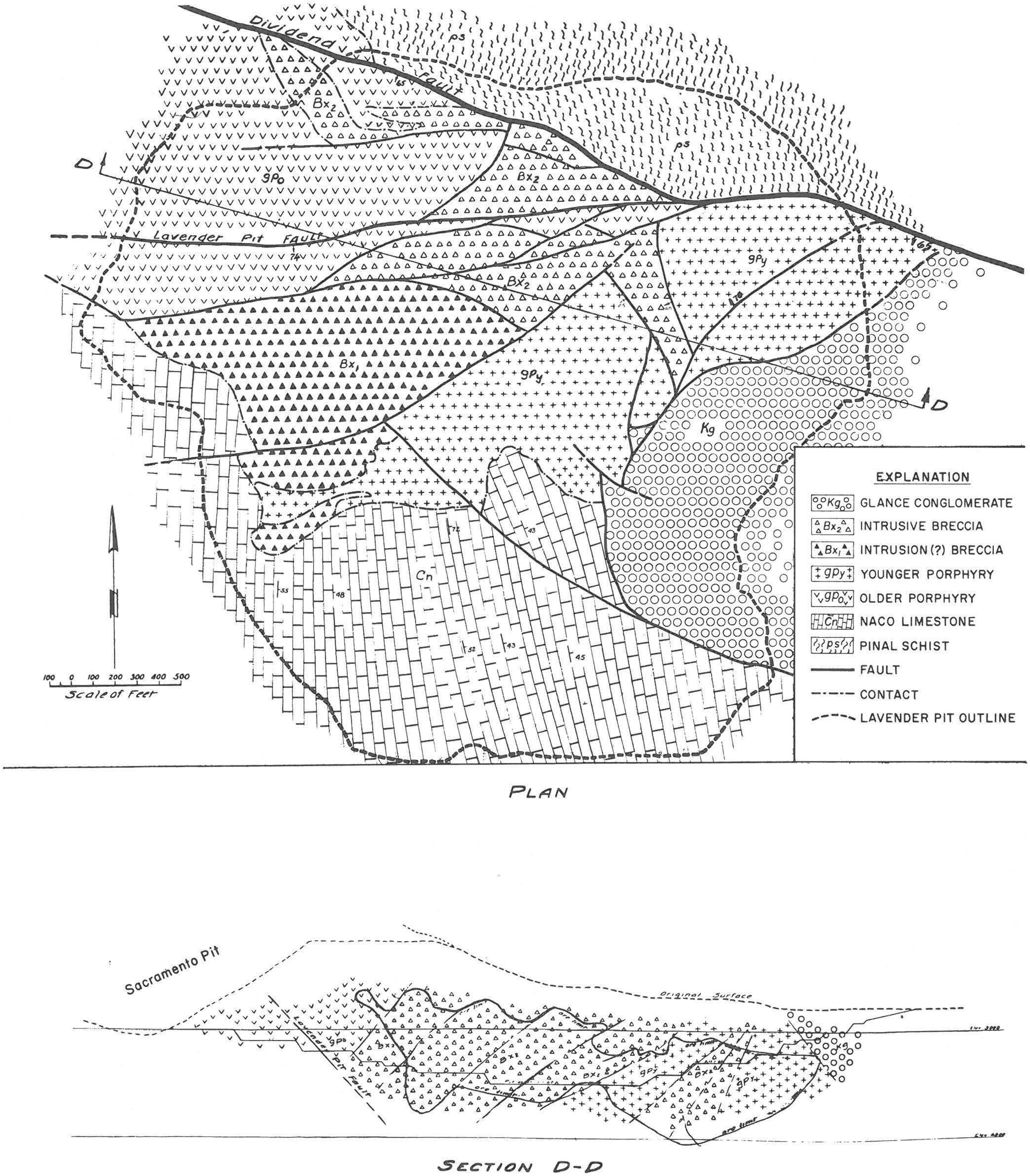


FIGURE 3.—Geologic plan and section of the Lavender pit.

was formed either during or after, but not before, the intrusion of the breccia.

The intense silicification and pyritization of the Sacramento stock and the intrusion of later units into it have obscured the character of the intrusion(?) breccia. The areal restriction of this unit to the southerly contact of the older porphyry and the presence of contorted swirling flow structure seem to indicate that the unit is an intrusion breccia that has been dragged or pushed from depths by the forcible intrusion of magma. There are other features that are more compatible to the designation of the unit as an intrusive breccia. These conflicting features are the lack of igneous matrix, extreme heterogeneity of included fragments, and the rounding of fragments. In addition, the presence of broken, separated, and transported fragments of ptygmatic silica bands, which were formed during the stage of intense silicification, indicates that the breccia was still active after emplacement of the porphyry. The intrusion(?) breccia is a very complex unusual rock, and much more research will be needed to resolve the history.

The other unit, designated as intrusive breccia, is later, cuts the Permian rocks, and is widely distributed in the Bisbee district. The size of the intrusive breccia bodies ranges from dikes and sills of less than an inch wide to irregular masses with dimensions of several hundred feet. Because of the strong influence of preexisting structures, the resulting shapes of intrusive breccia masses are very irregular. Commonly, intrusive breccia material will travel along a fracture as a dike, then intrude along a bedding plane or move into a fracture intersection to produce an intrusive breccia pipe. The extreme mobility of this material is indicated by the ease with which it changes controlling structures to form an intricate network even in tightly fractured rock. In areas of very intense fracturing, complete engulfment with removal and (or) reworking of the broken ground results in large irregular intrusive breccia masses. The contacts with the intruded rocks are usually knife-sharp and smooth as if irregularities and projections of the walls have been scoured.

The characteristic internal structure of the intrusive breccias is turbulent with random distribution and orientation of fragments. Only adjacent to the walls and peripheral to the larger fragments are flow structures observed. Adjacent to the walls the flow structures are indicated by rude parallelism of the fragments. Careful study of sliced oriented specimens containing these flow structures indicates that the direction of flow is not necessarily vertical but may vary from horizontal to vertical. No definite subsidence or downward movement of fragments has been observed. In thin masses less than 1 or 2 feet thick, this parallelism persists from wall to wall, but in the thicker bodies, the central areas indicate turbulence during transportation.

Fragments of all the pre-Cretaceous rock types are found in the intrusive breccias. Included as fragments are the following rock types: Pinal Schist, all the Paleozoic sediments, silicified and altered early quartz porphyry, intrusion(?) breccia, silicified pyrite and silica of the early barren stage, and the later feldspar porphyry. Notably absent are exotic fragments of rock types not known in the district.

These fragments vary greatly in size and shape, depending on the original competency of the rock type, the distance traveled, and (or) the turbulence during transportation. The sizes range from large blocks measured in tens of feet to microscopic rock flour of the matrix. These larger fragments probably did not travel far but were merely suspended as the finer intrusive breccia material was emplaced. That these large blocks are truly unsupported in three dimensions, except by the breccia-forming mechanism, has been demonstrated many times during the mapping of the Lavender open-pit mine. Fragments of quartzite, silicified porphyry, and schist are commonly large and well rounded or spherical. The presence of comminuted rock in the matrix indicates that the rounding was accomplished by attrition and abrasion rather than corrosion. The largest well-rounded boulder observed is an ellipitical boulder of Bolsa Quartzite measuring 7 feet along the minor axis and 11 feet along the major axis. Generally, the rounded fragments range in size from 3 feet to less than 1 mm in diameter. As the name "intrusive breccia" implies, these fragments have been transported upward into the higher formations of the stratigraphic column. The distances traveled may vary from a few inches to several thousand feet. For instance, in an exposure of intrusive breccia cutting the Pennsylvanian Horquilla Limestone, the presence of Pinal Schist fragments indicates a minimum upward displacement of 3,000 feet.

Under the microscope, the matrix of the intrusive breccias is composed of fine-grained rock fragments usually cemented by calcite and (or) silica and heavily impregnated by pyrite and copper sulfides. These cementing materials are later than the emplacement of the breccia and are associated with the subsequent stage of ore mineralization. The composition of the matrix is extremely heterogeneous, and usually all the pre-copper mineralization rock types are present. The matrix maintains this heterogeneity even in exposures of breccia in which the large fragments are predominantly of the immediate wall rocks. Major parts of the large intrusive breccia of the Sacramento complex in the north-central area of the Lavender pit are made up of porphyry fragments. Both early quartz porphyry and later feldspar porphyry are present. The other part of this breccia consists of mixtures of fragments of both porphyries, Pinal Schist, Bolsa Quartzite, intrusion(?) breccia, and siliceous pyrite and silica of the early barren stage.

The determination of the alteration undergone by the fragments during transportation is very difficult for several reasons. First, in most instances, these breccias are closely associated with ore, and, therefore, the ore alteration is superimposed upon any previous alteration. Also, the extent of alteration of the fragment at its point of origin is unknown. In addition, the products of alteration occurring during transportation and emplacement are subject to removal by abrasion. In the few exposures of intrusive breccia that seem to be unassociated with mineralization, the alteration of fragments is very weak or nonexistent. Limestone may show slight peripheral recrystallization, and porphyry fragments are slightly bleached along the periphery. In some instances a thin skin of talcose or chloritic alteration has been observed on the surface of the fragments. These same difficulties arise when alteration of the intruded rocks is investigated.

The origin of breccias containing transported fragments has been discussed exhaustively and adequately in several recent articles (2, 3, 6, 7). Rather than reviewing these discussions, distinctive features of the Bisbee intrusive breccias, which should be considered in any discussion of origin, are enumerated:

1. The complete lack of appreciable subsidence.
2. Transportation and abrasion of fragments upward for thousands of feet.
3. Lack of any indication of explosive violence.
4. Extreme fluidity or nonviscuous behavior of the breccia mass.
5. Sharp contacts with nonbrecciated wall rocks.
6. Chemical nonreactivity of the transporting medium.
7. The absence of igneous material in the matrix except as fragments and comminuted rock powder.
8. The presence of spherical boulders.
9. The absence of exotic boulders.

THE LAVENDER PIT ORE BODY

The low-grade disseminated mineralization of the Lavender pit ore body is of the hypogene and supergene type. The localization of the ore body in the Sacramento intrusive complex was controlled by the "horsetailing" of the Dividend fault. This "horsetailing" in its earlier phases was probably also responsible for the emplacement of the various units of the Sacramento complex. The ore body is restricted to the south or downthrown side of the Dividend fault. As has been true of nearly all the so-called "porphyry" copper deposits, detailed mapping has proven that spatial and temporal distribution of ore and rock types are not simple.

Oxidation, leaching, and redeposition of the copper between Permian and Cretaceous times developed a chalcocite blanket. This blanket dips easterly and is from 50 to 400 feet thick. The upper surface of the blanket is irregular and undulates conformably to the erosion surface upon which the Cretaceous Glance Conglomerate was deposited. The oxidation-leaching process has thoroughly removed the copper from the oxide capping, and no mixed oxide-sulfide ores are present in the area now being mined. There is very abrupt transition from oxide capping to sulfide ore.

The distribution of ore can be summarized in four types segregated on the basis of the host rock and environments. These are: 1. the intrusive breccia; 2. the intrusion(?) breccia; 3. the argillized younger feldspar porphyry; and 4. the intensely sheared and broken siliceous older quartz porphyry. In each of these rocks the ore is distinctly different. At present, no correlation between grade of ore and intensity of alteration is apparent because the alteration appears to be spatially controlled by rock types.

In the intrusive breccias, which are concentrated more or less in the interior of the intrusive complex (fig. 3), the ore occurs as supergene replacement of hypogene sulfide minerals, principally of copper, which are disseminated in the matrix and in the fragments along fractures. The ore mineral in this supergene zone is "sooty" chalococite with local covellite. In polished section, microscopic cores of primary sulfide—including chalcopyrite, bornite, and sphalerite—have often been observed in the chalcocite grains. With depth, below the main supergene zone, the supergene chalococite becomes subservient to the unreplaced hypogene copper minerals as to preponderance in the ore. The grade of the intrusive breccia ore is high compared to the average grade of the Lavender pit ore body, but the ore-grade material is distributed very erratically.

The copper ore in the intrusion(?) breccia on the southerly margin of the pit consists of sporadic, relatively small, irregular lenses of very rich chalcopyrite and bornite, which grade outward into more typical disseminated "porphyry" ore. These ore bodies are the same as the "ore plums" mined by underground-mining methods in the "contact breccia" early in the history of the Bisbee district and described by Bonillas and others (1). There is very little evidence of supergene enrichment, indicating that the "tough" slightly fractured intrusion(?) breccia did not permit percolation of the meteoric solutions.

Most of the ore in the younger quartz feldspar porphyry is localized in the eastern end of the pit adjacent to the intrusive breccia. This area is characterized by intense argillization that may be related to the supergene process. The ore consists of disseminated shattered grains of pyrite, which have been replaced by sooty chalococite more typical of the classical concept of "porphyry" copper ore bodies. In the younger porphyry, the ore is erratically distributed and is generally low grade except adjacent to zones of intense fracturing.

Least productive of the Sacramento intrusive complex is the older quartz porphyry. It is a hard, tough, thoroughly silicified rock that is very resistant to fracturing and erosion. The prominent topographic feature of Sacramento Hill resulted from the resistant characteristics of this rock. It contains 15 to 18 percent sulfide minerals, practically all pyrite that was from the early barren stage of mineralization. Because of the very impervious characteristics of the silicified quartz porphyry, the action of supergene solutions has been superficial. Except for a small area of intense fracturing in the southwestern part of the Lavender pit where hypogene solutions have deposited a few high-grade "plums," this formation is largely noneconomic.

The ore of all the formations of the Sacramento complex is very erratic. Even in the ore area, there is seldom a bank shot that does not contain ore, leach ore, and waste. Careful selective mining is necessary and is made possible with truck haulage and blast-hole control samples. As a shovel advances along a face, loaded trucks are dispatched according to the blast hole that broke the material.

From a metallurgical standpoint, the ore of the Sacramento complex is difficult to treat. Except where there is hypogene copper mineralization or supergene mineralization influenced by the presence of hypogene copper minerals, concentration is difficult because of the incomplete replacement of the pyrite grains by chalcocite. The pyrite grains have been shattered, resulting in numerous "hairline" fractures, the faces of which are each coated with a film of chalcocite. Concentrates in the range of 12 percent copper are the general average from this ore.

LIMESTONE REPLACEMENT ORE DEPOSITS

Before the Lavender pit was opened, the majority of the copper production in the Warren mining district was from underground-mining methods from limestone replacement deposits. A horizontal projection of the ore bodies (fig. 2) shows a semicircular arrangement around the Sacramento stock with offshoots radiating outward like the spokes of a wheel. This arrangement is the result of ore-body concentrations in fracture and fault zones. The semicircular arrangement is in the shattered zone around the stock, probably the result of its emplacement, and the "spokes" reflect the fracture or fault system mentioned earlier.

Copper ore has been found in all the Paleozoic limestone; however, the most productive formations have been the upper half of the Abrigo Limestone, all of the Martin Limestone, and the lower half of the Escabrosa Limestone, a total thickness of about 1,000 feet (fig. 2). The favorable formations are brittle and tend to shatter when subjected to diastrophic stresses, whereas the other formations above and below tend to yield, resulting in a fold or failure along a single break.

The limestone replacement ore bodies consist of a variety of occurrences and shapes. The feature common to all is that the host rock must have undergone intense fracturing or brecciating prior to the surge of copper solutions. Composition of the host rock is also a factor; however, this property appears to be secondary to ground preparation. The upper horizons of the Abrigo Limestone are particularly brittle, and the resulting ore bodies are cigar-shaped deposits along the intersection of a particular bed and fracture or fracture zone. The vertical dimensions of these deposits are small in comparison to the horizontal dimensions. The Martin Limestone is rather uniformly friable but ranges in chemical composition from very shaly impure limestone to highly dolomitic limestone to fairly pure limestone. The beds are massive and fine grained. As a result of the chemical variance in a fairly thick horizon of uniform brittleness, the ore bodies still show influence of the attitudes of the beds but are typically more football-shaped—that is, the vertical dimension is greater with respect to the horizontal than in the Abrigo deposits. The long axis again is the intersection of the favorable limestone horizon and a fracture. The productive horizon of the Escabrosa is a fairly pure, massive, crinoidal limestone with a series of thin chert beds toward the top. Deposits in this formation appear to depend on more powerful disruptions, such as intersecting fracture systems, brecciation, accompanying igneous intrusion, and particularly strong fracture zones. These deposits are typically pipelike with the vertical dimension much greater than the horizontal. The chert beds that add to the brittleness of this formation are particularly remunerative.

The type of limestone in which the deposits occur also influences the ground condition for mining purposes. Replacements occurring in the shaly Abrigo and Martin Limestones usually require some type of timber-support method of mining because of the poor bond between beds due to the residual altered shale. Replacements in the pure massive limestone beds of the Escabrosa and parts of the Martin are usually massive uniform deposits permitting open-type mining methods.

Certain formations are more productive in one part of the Warren mining district than in another. In the Cole-Dallas area, the Abrigo Limestone is the most favorable. Practically all the ore in this area is found in the Abrigo with only scattered ore bodies in the lower Martin and none at all in the Escabrosa. In the White Tailed Deer-Congdon area, the favorable horizon is the Abrigo at the south transgressing into the Martin northward. In the Queen-Irish Mag-Lowell area, the Martin was the most productive horizon, and in the Junction-Briggs zone (fig. 4) the Escabrosa is the favorable limestone. Stratigraphically below each of these productive formations are large bodies of low-grade siliceous pyrite. This is believed to be the key to the area segregation of the favorable formation. The early surge of low-grade siliceous pyrite reacted progressively with the limestone from the depths, forcing the later copper solutions to the reactive beds above. Below the large ore bodies of the Junction-Denn area (fig. 4) there are immense areas of very low-grade siliceous pyrite in the Martin, Abrigo, and Bolsa, which are believed to have formed during the very early surge of mineralizing solution. The later copper-bearing solutions were forced to pass through these formations, which had already been neutralized, to the

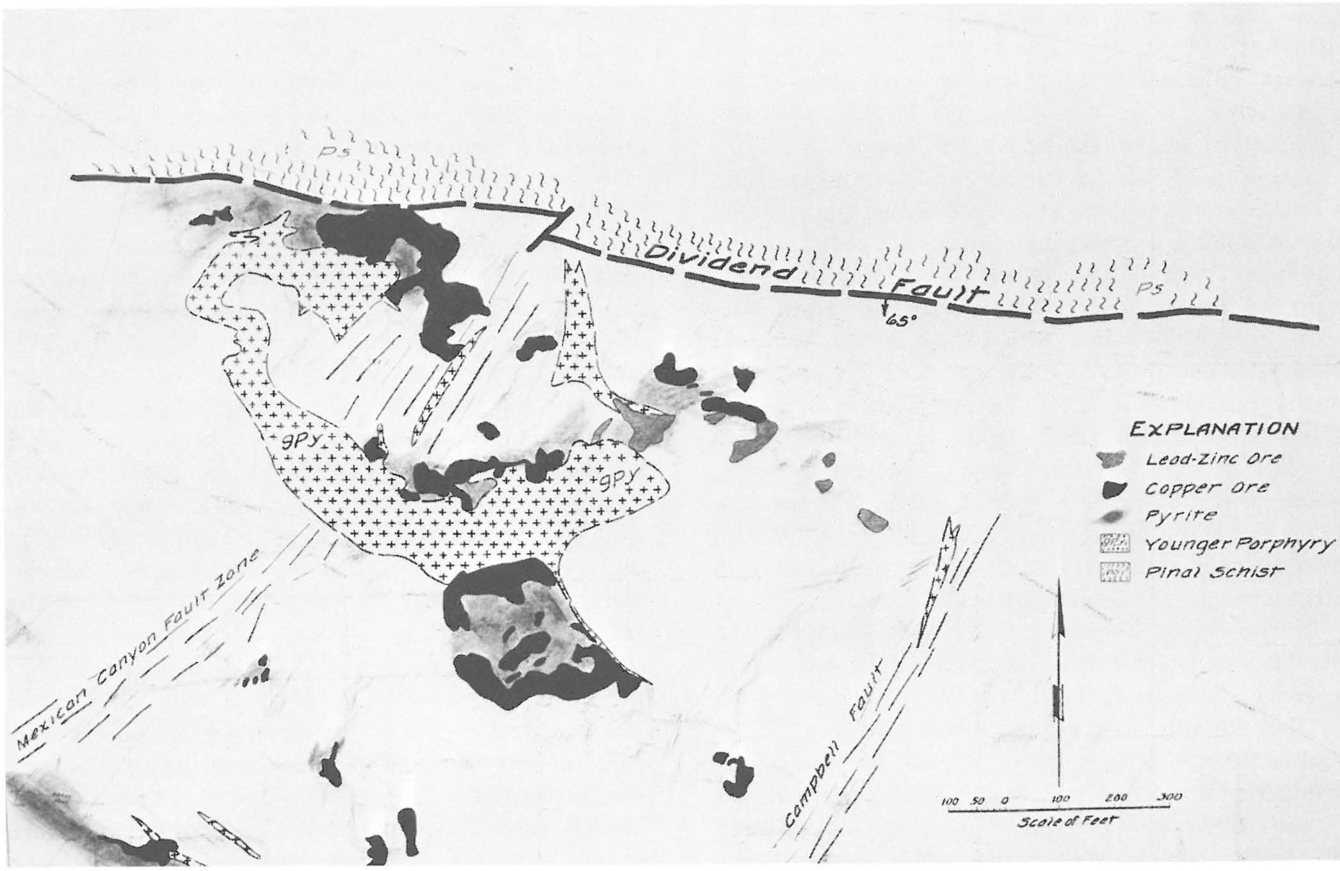


FIGURE 4.—Ore bodies in the Denn-Side-line, and Mountain Maid areas; 2,433-foot level, Junction mine.

reactive beds above. Below the large ore bodies of the Cole-Dallas area is a similar situation; the lower Abrigo and Bolsa have been completely mineralized with silica and pyrite, forcing the copper solution to the formation above. The Shattuck, Irish Mag-Lowell, and Oliver zones bottomed in similar mineralization. In the instance of the lower Campbell ore body, the early siliceous pyritization was incomplete, and Abrigo ore is being found below the large Escabrosa-Martin ore bodies.

This same reasoning is believed to apply to the ore occurrences on a smaller scale. Practically without exception, the copper ore bodies are closely associated with larger low-grade bodies of siliceous pyrite. In arrangement, they are commonly peripheral to the siliceous pyrite but with scattered ore bodies within the mass. There is a tendency for a greater concentration of ore along the footwall or keel of the sulfide masses. It is believed that, following fracturing or brecciation, the early siliceous pyrite, following paths of least resistance, replaced the center of the fractured or breccia zone. Then subsequent copper solutions along the same channels preferred the surrounding limestone to the siliceous pyrite; however, fracturing of the pyrite mass permitted some penetration, and scattered ore bodies formed in and around the mass. Occasionally, post-siliceous pyrite faulting brecciated considerable parts of the siliceous pyrite, which were later permeated by the copper solution depositing copper minerals in the interstices and partially replacing the earlier sulfide. This is the sulfide breccia type of ore.

Much of the ore, particularly in the Briggs, Junction, and Campbell areas, is closely associated with porphyry dikes and sills. Commonly, the ore will occur along the porphyry in contact with it but practically always replacing limestone. Except for the main stock area, it is very rare for the porphyry to contain sufficient ore minerals to become economic. Irregularities in the contact, such as embayments or abrupt changes in the dip or strike ore, are particularly favorable to ore occurrence. This association of porphyry and ore is structural. Fractures that formed the channels for the introduction and emplacement of the porphyry likewise served as plumbing for the hydrothermal solutions. Delimiting the underground porphyry masses is one of the most fruitful methods of prospecting.

Closely associated with the limestone replacement bodies are the "underground" intrusive breccias. In form they are protuberant, pinching and swelling between the limestone beds or along joints and fractures. At times the breccia may be the wall of the ore body, or it may pass through it as a waste dike or sill. Also, the breccia may be the host rock for the copper minerals with practically complete replacement. This close association of ore and intrusive breccia is believed to be structural. The presence of the intrusive breccia indicates deep persistent fracturing, which provided not only the plumbing for the intrusive breccias but also for the later ore solutions.

Size of individual ore bodies is quite variable—from a few thousand tons to, in exceptional instances, more than a million. Possibly two-thirds of the production has been from ore bodies of 25,000 tons or less.

In the ore zones, intermittent lenses of ore may be found over quite a long range, both horizontally and vertically. The Denn-Side-line ore zone has been productive for more than 2,000 feet vertically in an area of about 2,000 by 500 feet horizontally, with elongation parallel to the Dividend fault. The Baras-Home-Reindeer ore zone has a vertical extent of more than 1,000 feet and a horizontal of about 300 by 1,200 feet. As mentioned earlier, these zones commonly bottom in large low-grade bodies of pyrite and silica.

Practically all the mining in the early history of the district was from "oxide" ore bodies. The oxide ores were so prevalent at the time of Ransome's study (8, 9) that he was skeptical of the importance of the deeper primary sulfide zones. A small amount of the production even today is from this type or ore. In general, these oxide ore bodies, by simply substituting the oxidation products for the sulfide minerals, are the same geologically as the sulfide ore bodies discussed earlier. Normally, there is a relatively large mass of ferruginous silica with peripheral ore bodies consisting of the usual copper oxide minerals. Within the ferruginous silica mass, smaller ore bodies also may occur. The ferruginous silica is synonymous to the low-grade pyrite of the primary bodies and the copper oxides to the primary copper minerals. Normally, in the oxidation process there was very little transportation of the copper. Any upgrading of the original sulfide ore was due to removal by leaching of the soluble oxidation products, resulting in a light gangue with the same amount of copper present, often as a richer ore mineral. The oxide copper minerals that occur in these ore bodies are malachite, azurite, delafossite, cuprite, native copper, and chalococite. An ore body may contain predominantly any one of these minerals, or they may occur together in various combinations. Often one mineral will predominate in one section of an ore body and another mineral elsewhere. Many other oxide minerals of copper occur in the Bisbee district, but normally they are of insufficient quantities to be important as an ore mineral.

GEOLOGIC HISTORY

The first event in the legible geologic history of the Bisbee district was the deposition of a thick series of arenaceous sediments now represented by the early Precambrian Pinal Schist. Subsequently, these rocks were tightly folded along a generally northeasterly axis and mildly metamorphosed to quartz sericite schist. Between the time of early Precambrian low-grade metamorphism and the advent of the Middle Cambrian seas, erosional forces produced a surface of remarkable smoothness. The Paleozoic marine seas did not reach the Bisbee district until Middle Cambrian time when the Bolsa Quartzite was deposited as the sandy strand deposits of an encroaching sea. The seas gradually deepened, and the finer grained strata of the Upper Cambrian Abrigo Limestone were deposited. No break or sedimentation occurred between the Middle and Upper Cambrian strata. With continued subsidence, the clay and fine sandy sediments of the lower Abrigo gave way to the more calcareous deposits that constitute most of the Abrigo Limestone. The seas withdrew before the end of Cambrian time, leaving a sand bed (now quartzite) at the top of the Abrigo as a record of regression. No deposition occurred during the interval between the beginning of the Ordovician and Late Devonian periods. The absence of appreciable erosion of the Cambrian deposits suggests that the area was near sea level during this hiatus. During Late Devonian time, a shallow sea, as evidenced by the fine clastic and limy deposits of the Martin Limestone, again flooded the area of the Bisbee district. The lowermost Mississippian beds are absent, and the area was probably emergent, but regressive or transgressive clastic deposits indicative of this emergence have not been recognized. During Early Mississippian time, the area was again flooded, and the Escabrosa Limestone was deposited. The purity of this limestone and abundance of fossils indicate that the Escabrosa seas were shallow and clear. Although the Late Mississippian and earliest Pennsylvanian sediments have not been recognized in this district, evidence of emergence is lacking. Of importance to the deciphering of this Mississippian-Pennsylvanian interval is the nearby presence of predominantly clastic calcareous sediments possibly correlative to the Paradise Formation and of Late Mississippian age. The area was submerged in Early Pennsylvanian, and deposition of the Naco Group, predominantly fossiliferous limestone, continued until late in the Permian period.

Between the last of the Paleozoic sediments and the first recognizable Mesozoic strata of Cretaceous age is a period of at least 70 million years. The major deformation, igneous intrusion, and ore mineralization of the Bisbee district occurred during this interval. The deformation, possibly initiated by intrusion of the Juniper Flat Granite, commenced with extensive shattering and faulting with dominant northeasterly and southwesterly trends. Following the fracturing, the Sacramento quartz porphyry stock and associated intrusion(?) breccia were intruded along the Dividend fault, a major northwest structure. After intrusion of the Sacramento stock, the surrounding limestone and probably the porphyry itself were intensely pyritized and silicified by hydrothermal solutions. In the limestone, this mineralization produced large massive bodies of siliceous pyrite with only minor or trace amounts of copper. Probably the intense silicification of the quartz porphyry stock and introduction of pyrite may be attributed to this period of hydrothermal activity. The amount of early barren pyrite introduced at this stage is conservatively estimated at more than 500 million tons. Following this intense mineralization (sericitic), feldspar quartz porphyry intruded the limestone of the district adjacent to the Sacramento quartz porphyry and throughout the district as dikes, sills, and irregular bodies. The intrusive breccias containing fragments of all the pre-ore rock were then injected into the Sacramento stock and the limestone as structurally controlled irregular bodies or dikes along fractures and into the beds as sills. After emplacement of the intrusive breccias, copper mineralization probably transported by hydrothermal solutions was initiated. The deposition of the copper ore was localized along many of the same structures that controlled the position of the porphyries, pyrite, silica mineralization, and intrusive breccias, indicating that the major ingress channelways were probably open continually. Following the initial stage of copper mineralization—which deposited chalcopyrite, bornite, chalcocite, and pyrite—the solutions then deposited sphalerite, galena, pyrite, and chalcopyrite peripheral to the preceding individual copper ore bodies and to the copper area. The stage of lead-zinc mineralization terminated the major magmatic activity in the Bisbee district.

The next events in the geologic history of the Bisbee district were erosion, oxidation along fractures to variable depths, and the supergene enrichment of the ore bodies by chalcocite. The depth of oxidation is extremely variable and is directly related to differences in the strength and permeability of the controlling fractures. The chalcocite of the Lavender pit blanket was produced during the pre-Cretaceous period because evidence for superimposed oxidation or enrichment is absent. In addition, the top of the chalcocite blanket is more or less parallel to the irregular erosion surface upon which the overlying Cretaceous sediments were deposited.

Before the deposition of the Cretaceous sediments, rejuvenation of the Dividend fault dropped the southern block several thousands of feet with reference to the northern side. On the southern side the extremely rough topography was not leveled by erosion but was preserved and covered by the angular material of the Glance Conglomerate produced by the erosion of the block north of the Dividend fault. On completion of the leveling by "cutting and back filling," the area was covered by the shallow Cretaceous seas, and deposition of the Morita Formation began.

At the close of the Mesozoic Era, southeastern Arizona was subjected to the intense Laramide compression with attendant thrust faulting of the Laramide orogeny. During this time, however, the Bisbee district acted as a single unit or block and was singularly unaffected. Within the district, minor movement on the Dividend fault occurred during this time and displaced the Cretaceous sediments. Outside the district at the northern and southern end of the Mule Mountains, the major Laramide structures thrust the Paleozoic and Mesozoic beds on top of the Mesozoic formations.

Then, probably in Pliocene time, the country was cut by normal faults of the basin-and-range type, forming the major topographic features of today. During the basin-and-range development, the entire Mule Mountains were tilted to the northeast about 15°. Following this uplift and tilting, uninterrupted erosion has stripped the Cretaceous rocks from the Bisbee district and unveiled one of the major copper camps of the Southwest.

SELECTED BIBLIOGRAPHY

1. Bonillas, Y. S., Tenney, J. B., and Feuchere, L., 1917, Geology of the Warren mining district: Am. Inst. Mining Metall. Petroleum Engineers Trans., v. 55, p. 284–355.
2. Brynner, Leonid, 1961, Breccia and pebble columns associated with epigenetic ore deposits: Econ. Geology, v. 55, p. 488–508.
3. Gates, Olcott, 1959, Breccia pipes in the Shoshone Range, Nevada: Econ. Geology, v. 54, p. 790–815.
4. Gilluly, James, Cooper, J. R., and Williams, J. S., 1954, Late Paleozoic stratigraphy of central Cochise County, Arizona: U.S. Geol. Survey Prof. Paper 266, 49 p.
5. Hernon, R. M., 1935, The Paradise Formation and its fauna: Jour. Paleontology, v. 9, p. 653–696.
6. Johnson, W. P., 1961, Geology and origin of mineralized breccia pipes in Copper Basin, Arizona: Econ. Geology, v. 56, p. 916–940.
7. Perry, V. D., 1961, Significance of mineralized breccia pipes: Am. Inst. Mining Metall. Petroleum Engineers Trans., v. 220, p. 216–226.
8. Ransome, F. L., 1904, Geology and ore deposits of the Bisbee quadrangle, Arizona: U.S. Geol. Survey Prof. Paper 21, 168 p.
9. ——— 1904, Description of the Bisbee quadrangle, Arizona: U.S. Geol. Survey Folio 112.
10. ——— 1932, General geology and summary of ore deposits, *in* Ore deposits of the Southwest: 16th Int. Geol. Cong. Guidebook 14, p. 1–23.
11. Stoyanow, A. A., 1936, Correlation of Arizona Paleozoic formations: Geol. Soc. America Bull., v. 47, p. 459–540.
12. Travis, R. B., 1955, Classification of rocks: Colorado School Mines Quart., v. 50, no. 1, 98 p.
13. Trischka, Carl, 1938, Bisbee district: Arizona Bur. Mines Bull. 145, p. 32–41.

[Bryant, D.G., and Metz, H.E., 1966, Geology and ore deposits of the Warren mining district, in Titley, S.R., and Hicks, C.L., eds., Geology of the porphyry copper deposits, southwestern North America: Tucson, Ariz., The University of Arizona Press, p. 189-203.]

GEOLOGICAL REPORT

ON THE

COMMONWEALTH MINE,

COCHISE COUNTY, ARIZONA

for

Alpine Resources, Ltd.
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by

Thomas C. Patton

May 15, 1984

REGISTERED GEOLOGIST
CERTIFICATE NO.
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ARIZONA, U.S.A.

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ILLUSTRATIONS

(Plates are in pocket)

THOMAS C. PATTON
CONSULTING GEOLOGIST

GEOLOGICAL REPORT ON THE COMMONWEALTH MINE COCHISE COUNTY, ARIZONA

SUMMARY

The Commonwealth Mine in Cochise County, Arizona is a bonanza-type epithermal silver-gold deposit which produced 12.9 million ounces of silver and 122,000 ounces of gold during the period 1895-1942. The Tertiary rocks around the Commonwealth Mine (probable age 20-40 m.y.) originally formed a conformable sequence which were subsequently fractured, mineralized, and complexly faulted. This study has shown that

1) Huddy Hill is probably a faulted segment of Pearce Hill due to right-lateral offset along the Main and North veins.

2) The North vein is later and lower grade than the Main vein and probably cuts if off at depth.

3) The best chance for a bulk-tonnage silver-gold deposit occurs in the footwall portion of the Main vein. The entire wedge of rocks between the Main and North veins is prospective, but areas outside this zone are not prospective.

4) The area on the west end of Pearce Hill has potential for significant tonnages of high grade gold and silver ore.

In my opinion, the Thetford property has potential for 5 million tons of open pit ore averaging 3 oz/ton silver and 0.02 oz/ton gold. The 22 hole reverse circulation drilling program recommended in the West and East zones (Plate 1) is intended to outline the extent of the anticipated orebody. Following the successful completion of this program, an additional 20 to 40 close-spaced holes will be necessary to delineate fully 5 million tons of proven ore reserves.

INTRODUCTION

The Commonwealth Mine in Cochise County, Arizona is a bonanza-type epithermal silver-gold deposit which produced 12.9 million ounces of silver and 122,000 ounces of gold during the period 1895-1942. My preliminary report of February 25, 1983 reviewed the early history and results of previous exploration programs at the Commonwealth Mine and called attention to its potential as a bulk-tonnage open pit producer of silver and gold. Alpine Resources, Inc. of Grass Valley, California subsequently acquired the center of the district from Carl Thetford on May 30, 1983 and leased contiguous claims from L.A. Gaylen on July 1, 1983.

The purpose of this study was to

1) Prepare a geologic map of the area on the new topographic base (1" = 100') flown by McClain Aerial Mapping and Surveying, Inc.

2) Compile and interpret all previous exploration data.

3) Lay out a drilling program to evaluate previously identified mineralization on the east and west ends of Pearce Hill.

I have attempted to include all information which will be useful in the on-going evaluation of the Commonwealth property. To avoid repetition of data covered in my earlier report, a copy is included in the Appendices for reference.

LOCATION

The Commonwealth Mine is in central Cochise County (T18S, R25E, secs. 4,5) about twenty-five miles south of Wilcox and 70 miles east of Tucson (Fig. 1). The old mine workings are located on Pearce Hill, one of several low hills which rise abruptly above the Sulphur Springs Valley (Fig. 2). The property is less than a half mile south of U.S. Highway 666 and 2 miles south of the retirement village of Sunsites.

LAND STATUS

A claim map compiled in 1981 by E. Grover Heinrichs and Associates is shown in Figure 3. To the best of my knowledge, the claims are accurately located, although a detailed land take-off would be necessary to be sure. The mineral survey monument which marks the common corners of patented claims Commonwealth, Silver Crown, and One and All is plotted on Plate 1.

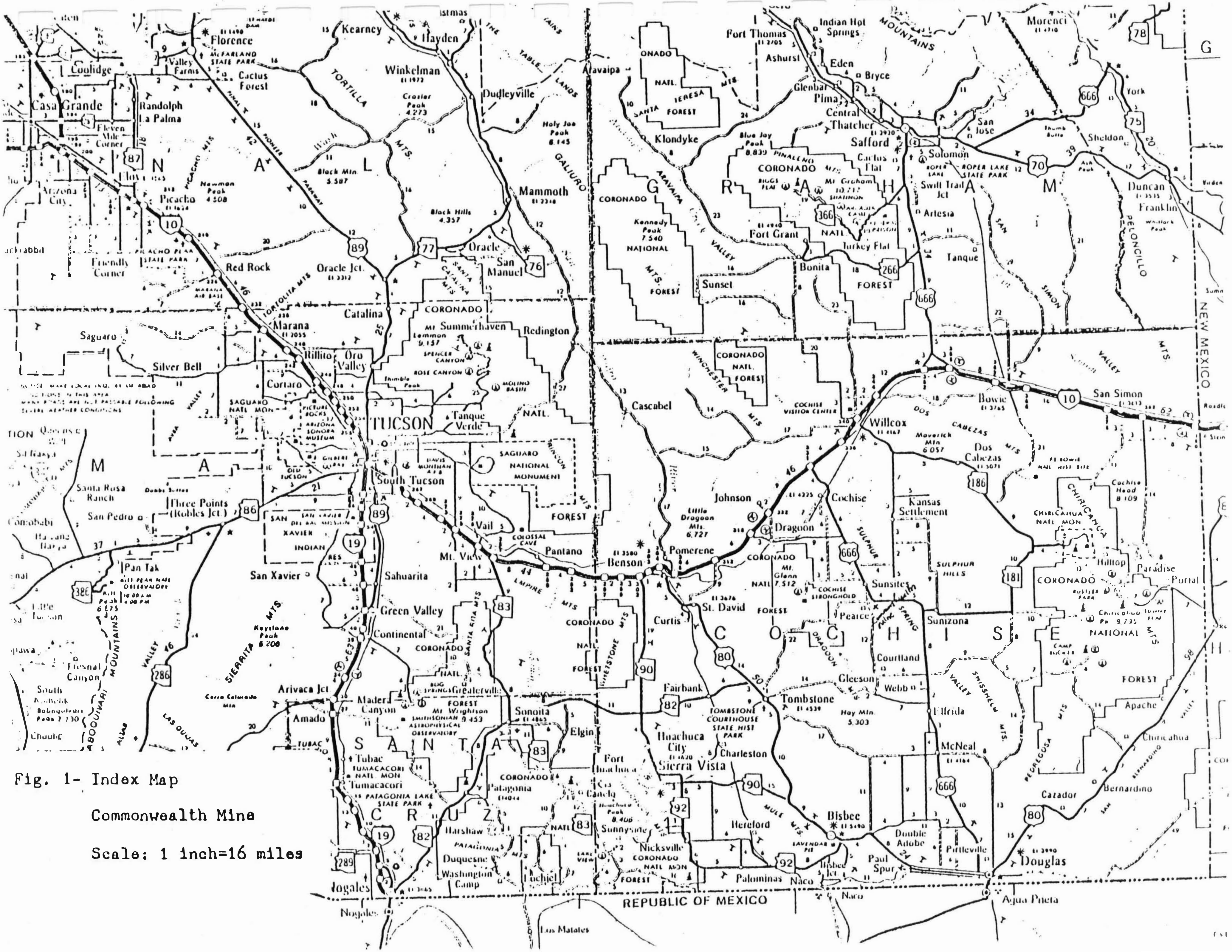

Fig. 1- Index Map

Commonwealth Mine

Scale: 1 inch=16 miles

Alpine Resources, Inc. currently has under lease 21 patented claims, 77 unpatented claims and 2 patented millsites distributed as follows:

1. From Carl Thetford

   a. Patented Claims- 88% interest in 7 claims, 142.3 acres (Sulphur Springs Valley, Ocean Wave, Silver Wave, North Bell, One and All, Commonwealth, Silver Crown).

   b. Patented Millsites- 10 acres (Ocean Wave Millsite, One and All Millsite).

   c. Unpatented Lode Claims (17)
      Lyle 1 thru 6- BLM Nos. 50140 thru 50145
      Pan 8 thru 15- BLM Nos. 50146 thru 50153
      Mamie V thru VII- BLM Nos. 128288 thru 128290

   d. Unpatented placer claims (4)
      Mamie I thru IV- BLM Nos. 50136 thru 50139

2. From L.A. Galyen

   a. Patented Lode Claims (4)
      Arthur, Rainbow, Hornspoon, Silver Thread

   b. Unpatented Claims (74)
      Pan 1 thru 7- BLM Nos. 38050 thru 38056
      Pan 16 thru 78- BLM Nos. 38057 thru 38119
      Ayn Rand 1 thru 4- BLM Nos. 38120 thru 38123

   c. Unpatented Placer Claims (3)
      Bill B 1 thru 3- BLM Nos. 38047 thru 38049

   d. Patented Fee Acreage, Surface and Minerals- 320 acres in sec. 4 (80 acres); sec. 9(240 acres)

   e. Patented Fee Acreage, Surface only- about 550 acres in sec. 4 (390 acres); sec. 9 (120 acres); sec. 16 (40 acres).

Fig. 2. View looking south toward Commonwealth Mine. Caved area along Main vein is visible in center of Pearce Hill. Note old Pearce townsite at right base of Pearce Hill near center of photo.
1= Metat Hill 2= Huddy Hill 3= Pearce Hill 4= Sixmile Hill 5= Dragoon Mountains
6= Swisshelm Mountains

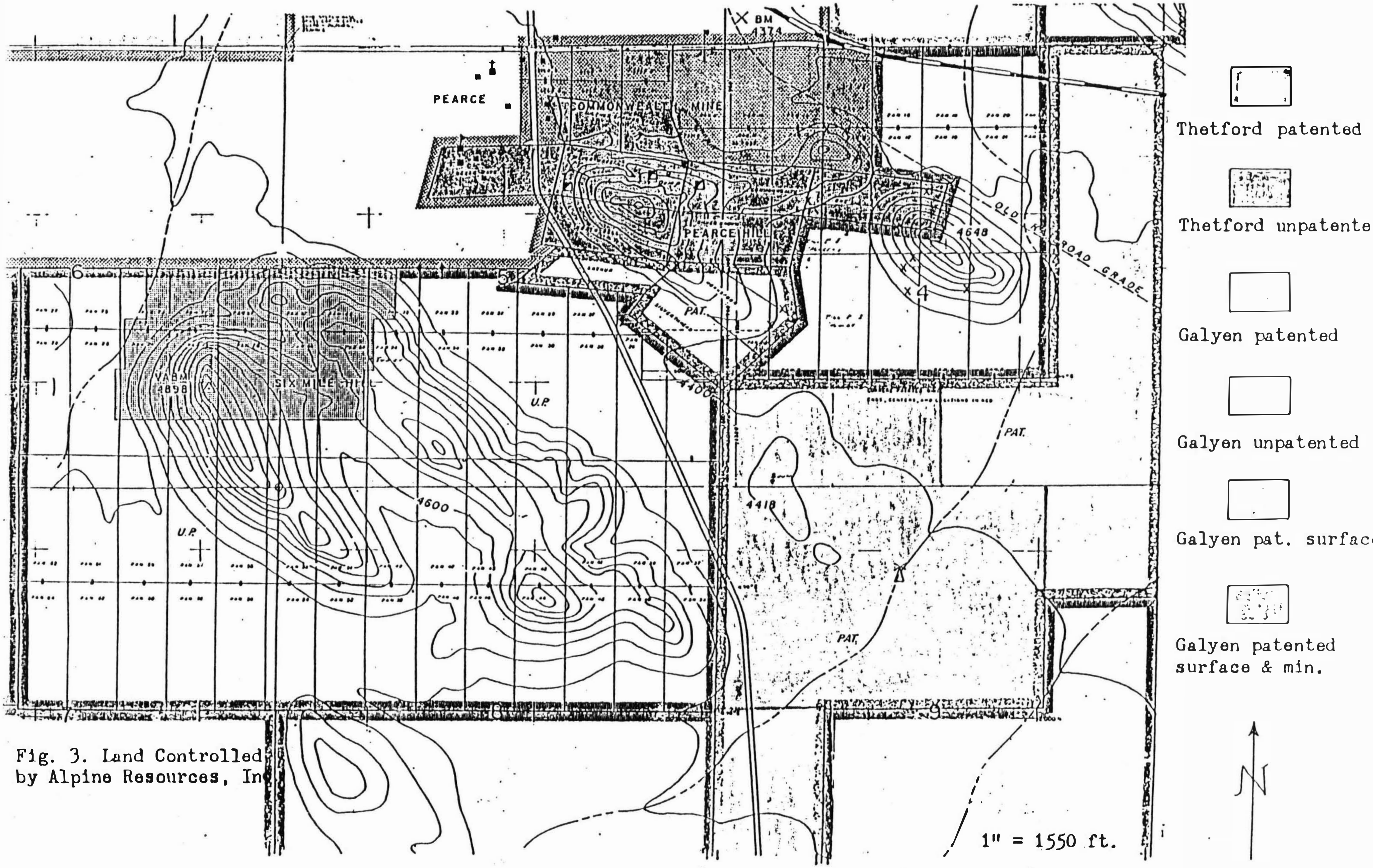

Fig. 3. Land Controlled by Alpine Resources, Inc

Thetford's Mamie V, VI and VII lode claims in the SW¼ of section 4, T18S, R25E appear to be in conflict with Galyen's Pan claims. However, as long as both blocks are under lease, no problem exists. Bureau of Land Management records dated March 7, 1984 show that 1983 assessment work has been filed for all unpatented claims under lease to Alpine Resources, Inc. The only claims in the Pearce Hill-Sixmile Hill area not controlled by Alpine Resources are the Ramon 1 thru 6 claims on the north end of Sixmile Hill owned by Manuel R. Hernandez.

SCOPE OF INVESTIGATION

I spent 7 days at the property mapping the surface geology, locating drill holes, and doing a limited amount of underground work. The following points should be emphasized:

1. Geologic mapping. Data were plotted on orthophotos with topography and subsequently transferred to the topographic base shown in Plate 1. Rock names used in this report are descriptive field terms based on the hand lens examination of hand specimens. A petrographic study of the rocks in the Commonwealth Mine area was made by Howell (1977) and should be consulted for more detailed information. The geologic map reflects subsurface drilling information, especially in areas of sparse outcrop.

2. Drill hole locations. Holes drilled by Platoro (CS-1 thru CS-5) were surveyed as part of this study. Bethex surveyed all of their drill holes and these coordinates correspond very closely with actual collar locations. The holes drilled by Western States Minerals Corporation apparently were not surveyed. The only record of their locations is a copy of a Bethex drill map with the holes sketched in. I found several discrepancies between these locations and their actual positions on the ground. The Western States drill holes shown on Plate 1 are actual field locations except in cases where the collar could not be found.

3. I mapped the Huddy tunnel and checked the mapping of Howell (1977) on the 3rd, 5th, 6th, and 7th levels accessible from C shaft. The Brockman shaft is open but the ladder is in such poor condition that I did not attempt to go down.

4. The vein locations shown in the cross sections on Plate 2 were taken from the level maps of Smith (1927) and Howell (1977) which were reduced to 1" = 100'. Information shown on the drill holes in the cross sections was taken from available data ranging from detailed (Bethex) to sketchy (Western States and Platoro). All assays and some drill logs are included in the Appendices.

5. For details relating to production statistics and the history of mining and exploration at the Commonwealth Mine, please refer to my report of February 25, 1984.

GEOLOGY

The Pearce Hills and other low hills in the Sulphur Springs Valley between the Willcox Playa and the Swisshelm Mountains are composed of middle Tertiary flows, welded tuffs, and pyroclastic rocks which were extruded over a platform of Cretaceous and older sediments. The Tectonic Map of Southeast Arizona by Drewes (1980) shows that these tilted volcanic blocks strike northwest, dip northeast at 10°-40°, and are separated by a series of northwesterly trending Basin and Range faults. Drewes' map strongly suggests that the Pearce Hills are a northwestern continuation of the Swisshelm Mountains, a theory that appears to be supported by regional gravity and magnetic data. Although Tertiary rocks in the vicinity of Pearce have not been dated, an Oligocene-Miocene age (20-40 m.y.) is probable based on correlation with similar rocks in the Swisshelm and Chiricahua Mountains (Drewes, 1980). The rock units shown on Plates 1 and 2 are discussed in the following paragraphs.

Bisbee Formation (Kb). The oldest rocks in the mine area are well sorted sandstones and mudstones of late Early Cretaceous age that are referred to as Bisbee Formation following the terminology proposed by Hayes (1970b). In several nearby mountain ranges, Bisbee sediments can be divided into four units of formation rank: Glance Conglomerate, Morita Formation, Mural Limestone and Cintura Formation (ascending order), which collectively form the Bisbee Group. However, at Pearce the absence of Mural Limestone, which is the only distinctive unit within the Bisbee sediments, prevents correlation of these rocks with any of the units listed above. In my opinion, the Bisbee Formation in the Commonwealth Mine area probably is correlative with the Morita Formation of Hayes (1970a) in the Mule and Huachuca Mountains.

Because the Bisbee Formation is soft and easily eroded, outcrops are limited to a few small exposures along the north side of Pearce Hill near the footwall of the North Vein (Plate 1). However, Bisbee sediments are exposed in several underground workings on the north side of Pearce Hill (especially in the adit to the third level), and in numerous drill holes. As the cross sections in Plate 2 show, Bisbee sediments form the footwall of the North vein and underlie the entire area north of the North vein, including the cyanide tailings and Thetford mill. Bisbee sediments also occur at the extreme western end of Pearce Hill south of the Main vein in the Brockman-Mominier shaft area (See Plate 2, cross section D-D').

Where I observed Bisbee Formation along the North and Main vein, it is a clean, fine to medium-grained sandstone with abundant silicification, fracturing and iron staining. Drill logs indicate that the formation also contains siltstones and sandy,calcareous mudstones which do not crop out.

Lower Andesite (Ta; Tf_1 of Howell, 1977; Earlier andesite of Smith, 1927). The lower andesite is identifiable largely on the basis of its stratigraphic position between underlying Bisbee Formation and overlying rhyolite breccia, and to a lesser degree because of observable differences with the Upper andesite. Although numerous textural variations make generalizations hazardous, the following features are typical of Lower andesite: 1) low-profile, dense, smooth, and well-fractured outcrops 2) stubby plagioclase phenocrysts set in a light gray to black aphanitic matrix 3) autobrecciated fragments present but subordinate 4) generally weak to nonmagnetic. Lower andesite crops out on the west end of Pearce Hill (Plate 1; Fig. 4), where drill holes show that it unconformably overlies Bisbee Formation (Plate 2, section D-D'). A few outcrops and abundant float also occur on the west side of Huddy Hill, which is presumably the faulted offset of the Pearce Hill outcrop. Several outcrops of andesite occur along the Main vein near its point of intersection with the North vein (Plate 1). The rock is so shattered, silicified and iron-stained that positive identification is impossible, but in my opinion, it is lower andesite.

Rhyolite Breccia (Trb; Ta_1 of Howell, 1977; Earlier breccia of Smith, 1927). This rock is a distinctive rhyolite crystal lithic tuff (Fig. 5) with phenocrysts of square quartz, potassium feldspar and minor biotite; and fragments of andesite and locally minor Bisbee formation. It forms massive, easily recognizable outcrops on Pearce and Huddy Hills (Plate 1). Faulted slices of rhyolite breccia also form bold outcrops along the Main and North veins in the center of the area of previous mining. Smith (1927, p. 26) believed that the rhyolite breccia extending from C shaft eastward to Huddy Hill was later than the breccia on Pearce Hill. He based this conclusion on differences in color and fragment size and composition.

I believe that the rhyolite breccia is all part of the same crystal lithic tuff unit, with the differences noted by Smith attributable to alteration and silicification along the Main and North Vein systems. Relatively unaltered rhyolite breccia occurs on Pearce and Huddy Hills (Plate 1; Fig. 5a). The rock is white to light brown with sharply outlined fragments of andesite and minor Bisbee formation. The same rock occurs in fault slices along the Main and North veins but its appearance has been altered by silicification, quartz veining, and iron staining (Fig. 5b).

Upper Andesite (Tau; Tf_2 of Howell, 1977; Middle andesite of Smith,1927). This rock type is the most areally extensive at the Commonwealth Mine,

Fig. 4. Contact between lower andesite (Ta) and rhyolite breccia (Trb) in caved area near No. 1 shaft at northwest end of Pearce Hill (Plate 1). Contact strikes N20W, dips 40° NE.

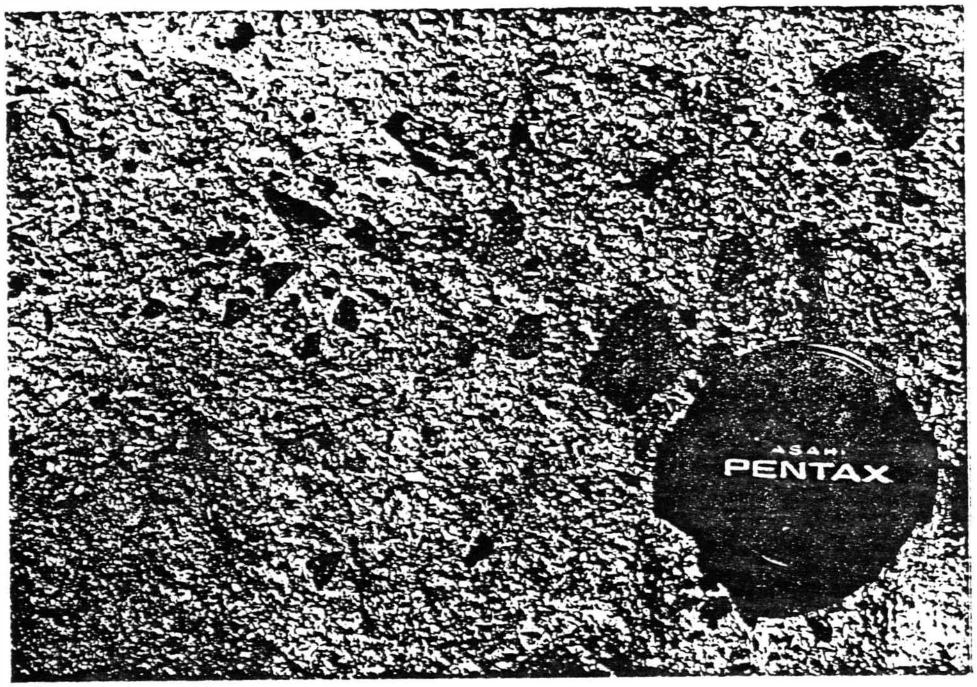

Fig. 5a. Unaltered rhyolite breccia on dump of Commonwealth Ext. 2 shaft, southeast end of Pearce Hill. Note andesite fragments in rhyolite matrix.

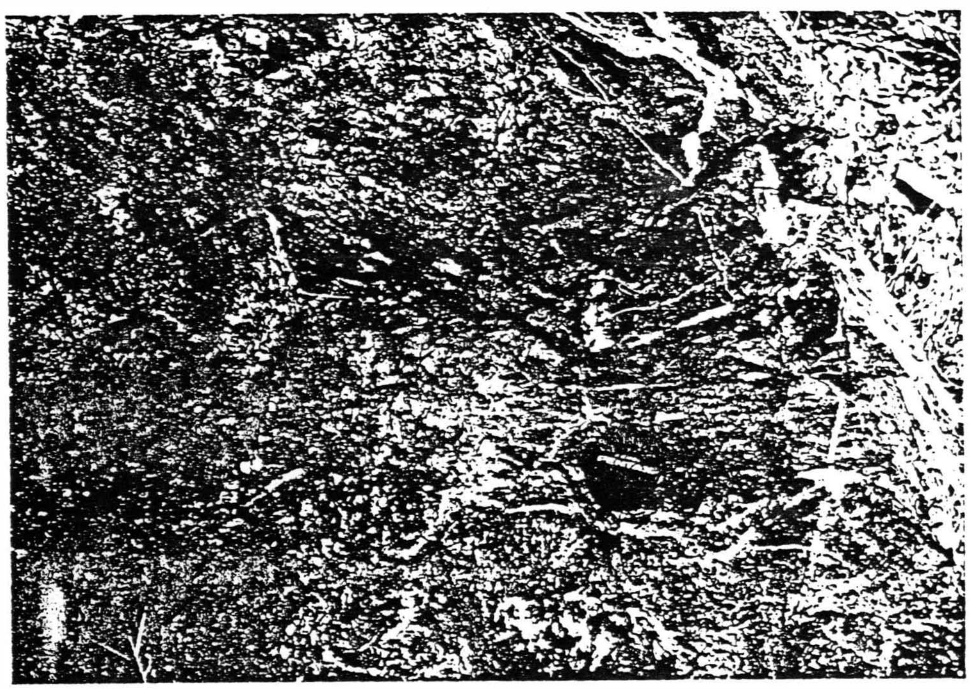

Fig. 5b. Altered rhyolite breccia exposed in cliff 150 feet east of C shaft. Easily recognizable texture shown in Fig. 5a is obscured by quartz veining and iron staining, but is still visible.

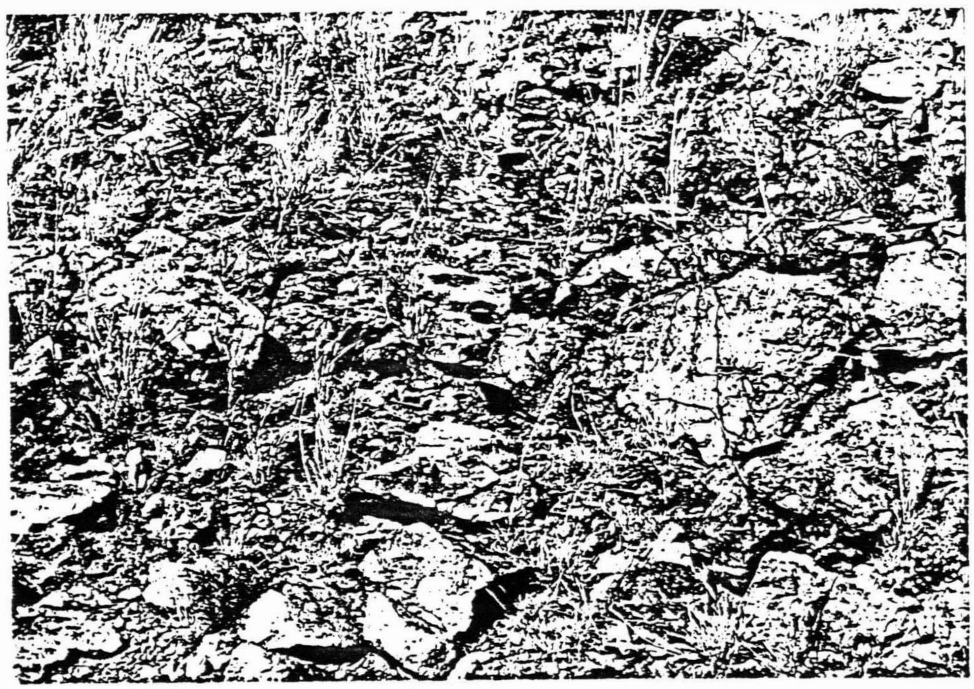

Fig. 6. Upper andesite on southeast end of Pearce Hill showing typical rubbly appearance.

covering the entire southern and eastern parts of Pearce Hill and the extreme eastern side of Huddy Hill. The Upper andesite typically forms light gray to brown, scabby, rubbly weathering outcrops (Fig. 6); has a light to dark brown, fine-grained matrix with plagioclase laths; is commonly weakly magnetic; has easily recognizable hornblende crystals and/or breccia fragments. A vesicular basalt noted on Plate 1 at the north end of Metat Hill may be a scoriaceous flow top of the upper andesite as noted by Howell (1977, p. 38). The eastern extent of the Upper andesite is based largely on drill hole information and examination of dump material.

Arkosic Sandstone (Tss; Tw3 of Howell, 1977). Outcrops of this easily eroded unit are sparse, and the distribution shown on Plate 1 is based in part on drill hole and dump information and in part on speculation that the valley between Pearce and Metat Hills is caused by the weathering of this friable arkosic sandstone.

The rock is fairly distinctive, with rounded fragments of limestone, Bisbee Formation and andesite set in an arkosic sandstone matrix. Along the North vein south of Huddy Hill, the sandstone has been silicified and superficially resembles the rhyolite breccia (Trb). The contacts of this unit are not exposed, and the distribution shown on Plate 1 is based on examination of float. The arkosic sandstone is probably an intervolcanic sedimentary unit laid down between volcanic eruptions.

Ash Flow Tuff (Taf; Ta3 of Howell, 1977). This unit caps Metat Hill (Plate 1) and is similar to rocks in the Sixmile Hill area. It is not mineralized and was only briefly examined. The rock is a dense, welded tuff with flattened pumice fragments, quartz phenocrysts and local vitrophyric textures (Fig. 7).

STRUCTURE

A discussion of the regional structure in Southeastern Arizona is beyond the scope of this report. The subject has been reviewed in detail by Drewes (1980,1981) and should be consulted by the interested reader. It is important to note that Tertiary volcanism, mineralization, and Basin and Range orogeny in the Commonwealth Mine area were synchronous events that combined to produce the complex series of veins and faults visible today on Pearce Hill. The following interpretation of these intertwined events is based on the field evidence as I see it, and almost certainly will require modification as additional information becomes available.

The Tertiary rocks around the Commonwealth Mine originally formed a conformable sequence which were subsequently fractured, mineralized and complexly faulted. The individual events leading to the present day

Fig. 7. Typical outcrop of ash flow tuff (Taf) exposed near top of Huddy Hill.

relationships are summarized below:

1. The Tertiary volcanic rocks described above (Lower andesite, rhyolite breccia, Upper andesite, arkosic sandstone, and ash flow tuff) were poured out on a platform of Bisbee Formation sediments during Oligocene-Miocene time. These rocks appear to represent a conformable sequence, because no angular unconformities have been noted. The contacts between individual volcanic units are faulted in places (for instance in the Huddy tunnel where gouge separates rhyolite breccia from Upper andesite). However, I don't believe these faults have had substantial movement, and probably reflect minor adjustments in response to later post-mineral faulting.

2. This package of relatively flat-lying Tertiary volcanic rocks was subsequently fractured and faulted along what is now the Main vein. Fault movement was predominately strike-slip and resulted in apparent right lateral offset of 600-800 feet along the Main vein (Plate 1). The absence of tectonically brecciated vein material along the Main vein suggests that mineralization post-dated at least some of this movement. Several smaller subsidiary structures with no apparent movement were also mineralized at this time (J. Pearce- Ext. No. 2-Brockman vein system; Huddy Hill vein system). It is possible, although purely conjectural, that the Huddy Hill vein-fracture system is the offset portion of the Main vein. Northeastward tilting of the volcanic sequence had probably begun at this time.

Fault offset along the Main vein is well illustrated in section C-C'. The offset is not apparent in sections A-A' and B-B' because faulting has juxtaposed Upper andesite on either side of the vein.

3. Possibly in response to a shift in the stress field, recurrent fracturing and lower grade mineralization took place along the North vein. The wedge of rocks between the Main and North veins was intensely fractured, silicified, and cut by quartz stringers. The bonanza orebodies of the Commonwealth Mine occurred near the intersection of these veins.

4. Major faulting occurred along North vein during the waning stages of mineralization, with apparent strike-slip displacement of about 3000 feet (Plate 1). The fault may have had a significant dip-slip component, but movement was primarily right lateral strike-slip. Conspicuous tectonic brecciation (quartz fragments recemented by silica) along the North vein is strong evidence for this faulting. Movement took place on a least two splays of the North vein (Plate 1) and resulted in several wedges of rhyolite breccia and lower andesite aligned parallel to the fault. The cross sections in Plate 2 suggest that movement along the North vein cut off the Main vein at depth but additional drilling would be necessary to confirm this.

5. Basin and Range faulting and subsequent erosion cut the volcanic sequence into the individual fault blocks that we see today. The Brockman fault mapped by Smith (1927) at the western edge of Pearce Hill is presumably one of these post-mineral Basin and Range faults.

These events have resulted in a generally conformable sequence of rocks south of the Main vein and a faulted sequence of the same rocks on Huddy Hill. Silver-gold mineralization of economic significance is restricted to the pie-shaped wedge of sediments between the North and Main veins; and along the Main vein at the western edge of Pearce Hill.

MINERALIZATION

The Commonwealth Mine is typical of Tertiary epithermal precious metal systems found throughout the western United States. Silver and gold mineralization occurs within a series of quartz veins localized along and between the Main and North veins (Plate 1). The veins exhibit classical epithermal features, including drusy quartz-lined vugs, crustification, comb and cockade textures. Historical production came from supergene-enriched ores of silver (cerargyrite, embolite argentite, native silver) and native gold (Smith, 1927). Gangue minerals include quartz, black and white calcite, adularia, montmorillonite, and sericite. Iron oxides are abundant along fractures in the mineralized zone, but the original sulfide content of the system was low. Minor copper oxides are found on some dumps, most notably in the vicinity of the J. Pearce shaft.

Two distinctive types of quartz veins have been recognized:

1. Main vein. Quartz is clear to yellow-green, exhibits crustification and cockade textures, and has late amethystine quartz crystals projecting from vein walls to form prominent comb structures. High grade silver-gold mineralization is associated with these veins.

2. North vein (Figs. 8,9). Quartz is massive, white, and delicately banded with abundant amethyst and some cockade textures. This type of quartz for the most part is associated with low grade silver mineralization and appears to be a lower temperature variety than the quartz in the Main vein.

K.D. Cornelius determined that the trace of the Main and North veins at their point of intersection strikes N55W and plunges southeast at 30° (Plate 1). This calculation assumed an average attitude of N70W/SW70° on the Main vein and N88W/45°SW on the North vein. The trace of this critical intersection projects very close to the North Shaft where high grade mineralization has been found on the dump.

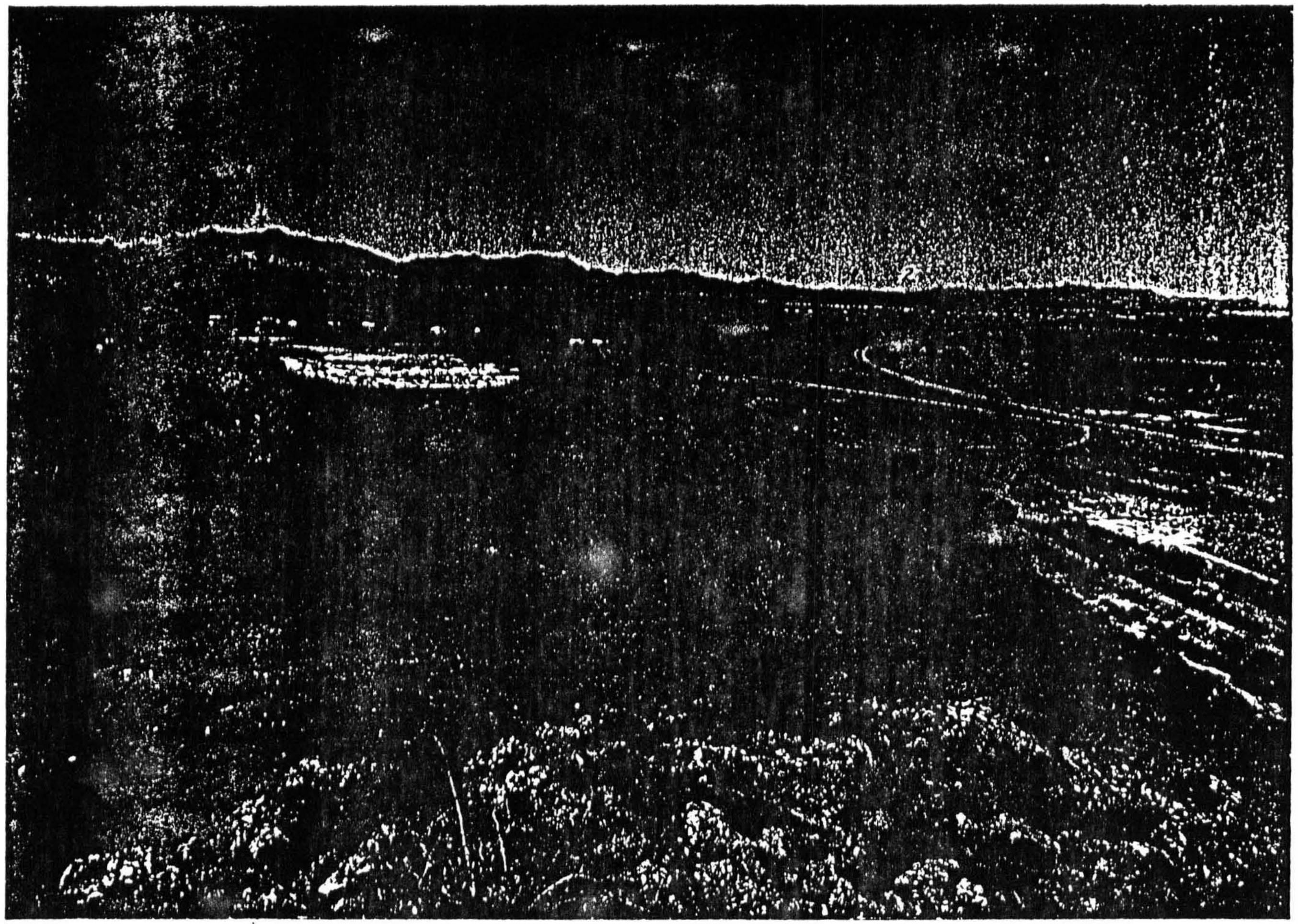

Figure 8. Huddy Hill as viewed from Metat Hill. The contacts between Upper andesite (Tau) and rhyolite breccia (Trb) are marked by distinct color changes. Note the easterly continuation of the North vein as shown on photo. Rocks in foreground are welded ash flow tuffs (Taf) which cap Metat Hill. A portion of the old railroad bed which connected Pearce with Cochise and Douglas is visible on the extreme right.

1= Cochise Stronghold 2= town of Sunsites

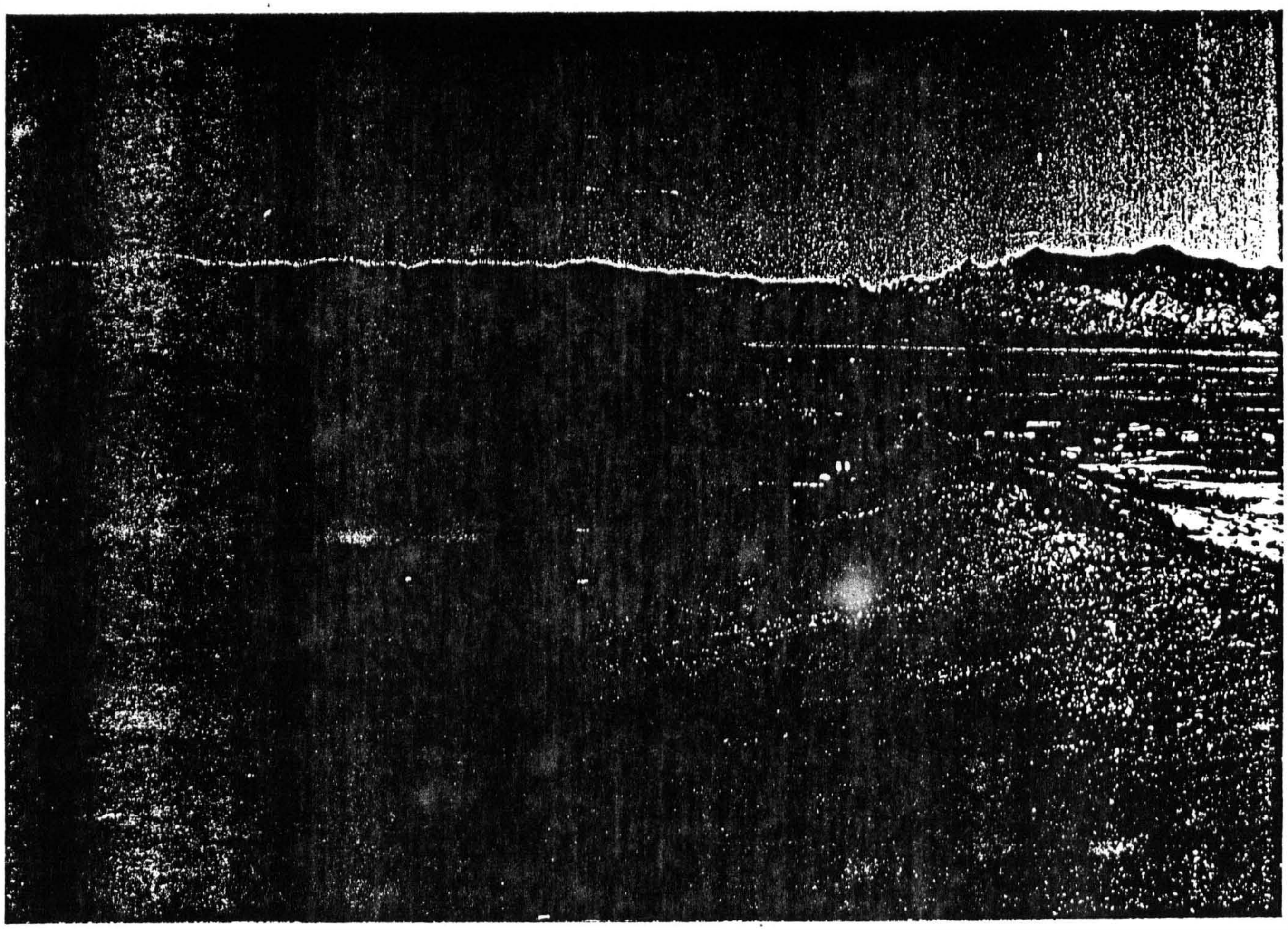

Fig. 9. Pearce Hill as seen looking due west from Metat Hill. Drill roads show general area tested for eastern continuation of Main vein. Caved areas on north side of hill are over principal mined out bonanza orebodies. Tanks shown below D shaft mark site of abortive 1982 attempt to leach dump material. Dragoon Mountains in background.
1-5 = Platoro holes CS-1 thru CS-5 (approximate locations)
D= D shaft dump N= North shaft dump CE= Commonwealth Ext. No. 1 dump
NV= Bold outcrop of North vein

INTERPRETATION OF SAMPLING AND DRILLING RESULTS

The Commonwealth Mine represents a difficult exploration problem. The majority of the old mine workings are inaccessible, assays tend to be erratic on a small scale, and caving has obscured many key relationships along the surface trace of the mineralized zone. However, enough data have been accumulated through this investigation and previous drilling programs to make some generalizations about what is known at this time and where to look (and where not to look) for more ore. Fortunately drill cuttings and core from all previous programs are stored on the property (Fig. 10) and are available for re-logging or check assays.

Rock chip and dump sampling. A limited amount of rock chip and dump sampling during the mapping program (Tables 1,2) showed 2 unexpectedly high values and raise questions about geological relationships:

1. A dump sample from North shaft (Fig. 9) assayed 0.068 oz/ton gold and 15.94 oz/ton silver. This rock shows the best looking mineralization I have seen on the property, with yellow-green crustified quartz, cockade textures and late combs of amethystine quartz. Several fragments have specks of a dark gray metallic mineral which appears to be argentite. I am convinced that this mineralization came from the eastern continuation of the Main vein. However, the trend of the Main vein beyond the last point where its location is known with certainty (Plate 1; Plate 2, cross section A-A') is problematic. Either the Main vein bends sharply, as I have suggested on Plate 1, or is faulted to account for its position at North shaft. In any case, this mineralization is 600 feet from the nearest drill hole and represents an excellent opportunity to expand ore reserves eastward along the Main vein.

2. A dump sample from the Mominier shaft at the extreme west end of the property (Fig. 11) ran 8.12 oz/ton silver and 0.70 oz/ton gold (ave. of 2 assays- see Table 2). This high grade material, in conjunction with the high gold values intersected in holes WC-7 and WC-14, raises questions about the grade, extent, and ore controls in this area which can only be answered by drilling. The high grade assays reported from holes WC-7 and WC-14 by Western States Minerals Corporation were confirmed by check assays run during this study (See Patton- Appendix A).

Bulk dump sampling program. The B, C, and D shaft dumps were bulk sampled with a backhoe. Sample locations are shown on Plate 1, values are reported in Table 3, and details of the entire program are in Appendix A. This work showed that the dumps comprise about 50,000 tons of material with a weighted average of 1.66 oz/ton silver and 0.021 oz/ton gold. It should be noted that the alluvial material near the Thetford mill (samples D-21 thru D-23) averages 1.90 oz/ton silver and 0.033 oz/ton gold.

Fig. 10. View from Pearce Hill toward core storage shed (1) and office (2) of Alpine Resources, Inc.

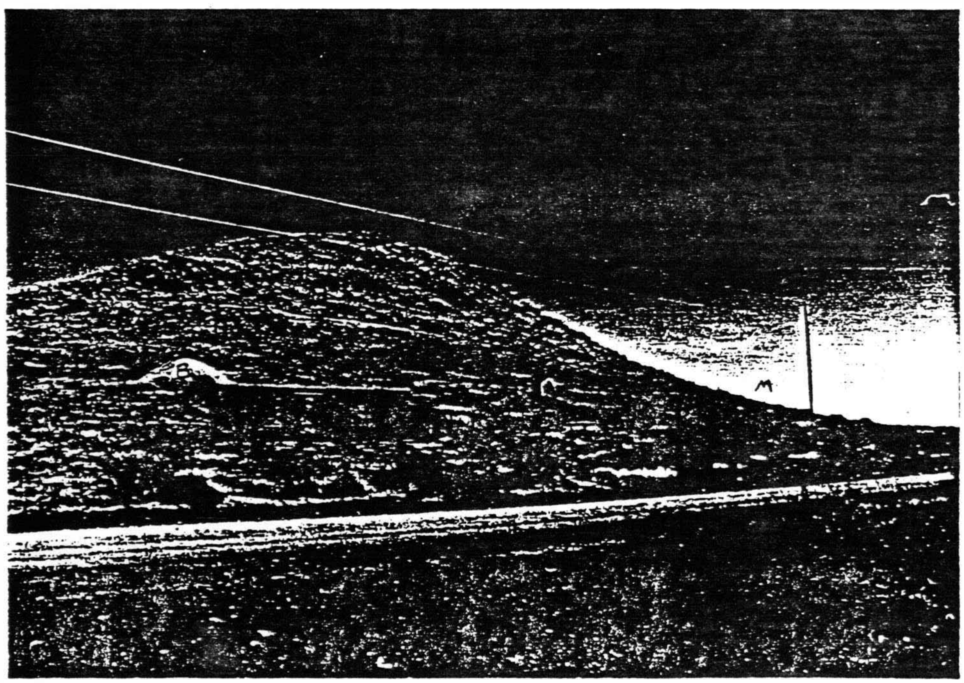

Fig. 11. Western end of Pearce Hill viewed from east. Note approximate positions of holes WC-7 and WC-14.

Ta= Lower andesite Trb= rhyolite breccia

B= Brockman shaft dump M= Mominier shaft dump

Tailings. The large cyanide tailings pond (Plate 1; Figure 12) is not included in the Alpine Resources contract with Carl Thetford. However, in case the tailings become available in the future, it should be noted that about 350,000 to 450,000 tons of tailings remain which average approximately 1.8-2.0 oz/ton silver and less than .01 oz/ton gold. Detailed sampling would be necessary to determine exact tonnages and grades.

Previous drilling programs. All available assays and drill logs from holes drilled by Platoro, Bethlehem Copper, Western States Minerals Corporation and Stephens-Heinrichs are included in Appendices B thru E, respectively. Mineralized intercepts from most of the holes are summarized on Plate 2 cross sections.

1. Platoro Mines drilled 5 holes during 1975 (CS 1-5), 4 of which intersected thick zones of well-mineralized andesite in the footwall of the Main vein (Plate 2, section B-B'). Smith (1927, p. 5) noted that in 1901 the method of mining was changed from stulls to square sets to accomodate the widening of stopes to 60 feet in order to mine the footwall zone of the main vein. This zone offers the best bulk tonnage potential on the property, but has not been tested since the initial holes by Platoro.

2. The Bethlehem Copper drilling program did not accomplish its objectives. They attempted to extend the mineralization delineated by Platoro to the east with the following results:

a) Angle holes 76-1 thru 3 ended in old stopes without testing the footwall zone.

b) Vertical holes 76-6, 8, 9, and 10 were drilled in the hanging wall of the Main vein (Plate 2, cross sections A-A', B-B') and hit spotty zones of low grade silver.

c) Hole 76-7 did test the footwall zone and hit thick zones of silver mineralization. The assay values are suspect because sampling was done on 10 foot intervals. Hole 76-11 tested the zone north of the best area (cross section A-A') and still hit 65 feet of mineralization which averaged 2.27 oz/ton silver. All other holes were drilled outside of the prospective area. Thus only 2 holes out of 16 tested the key target area, and both hit zones of good mineralization.

3. Western States Minerals Corporation drilled 13 percussion holes in 1978. Nine of these holes were drilled in low-potential areas. Holes WC-7 and WC-14 hit high grade gold on the western end of Pearce Hill (Plate 2, section D-D'). Holes WC-5 and WC-11 (Plate 2, section C-C') hit significant zones of silver mineralization in the prospective area between the North and Main veins.

Fig. 12. Commonwealth mine cyanide tailings as seen from D shaft. Tailings are currently being shipped to the Phelps Dodge smelter at Animas, New Mexico, about 55 airline miles east of Pearce.

4. John A. Stephens and Grover Heinrichs drilled zones north and south of Metat Hill (See Appendix E) with totally negative results. Rapid reconnaissance of the Sixmile Hill area, also drilled by Stephens and later by Santa Fe, shows a few low temperature amethystine quartz veins of the North vein type which are not prospective for bulk silver-gold deposits. No additional work is warranted in either of these areas.

Key target areas. All work performed during the course of this and previous studies has focused attention on 1) the zone between the Main and North veins 2) the western end of Pearce Hill. Previous drilling has shown that holes placed north of the North vein or south of the Main vein will result in failure.

The zone between the North and Main veins has the best chance of hosting a bulk tonnage deposit. The entire wedge of rocks between these faults is silicified and cut by quartz stringers. Although the andesite (Tau) appears to fracture better than the massive rhyolite breccia (Trb), both rock types are good hosts for mineralization (See Plate 2). It is probable that mineralized zones will progressively decrease in thickness with increasing distance away from the North/Main vein intersection. However, drilling will be necessary to confirm this. It is also possible that ore shoots may occur at depth along the trace of the North/Main vein intersection shown in Plate 1.

RECOMMENDED DRILLING PROGRAM

All holes listed below are shown on Plate 1 and are numbered in relative order of priority.

West end of Pearce Hill. Seven holes, average depth 300-400 feet per hole. This drilling will not block out ore reserves but will establish whether the zone has any significant tonnage potential. The interval in WC-14 between 355-380 feet is the only high gold-low silver zone that I am aware of in the area. As shown in Plate 2 on section D-D', mineralization may be related to a number of steeply dipping quartz veins. This drilling should also determine whether it is worthwhile to explore west of the Brockman fault for a possible faulted segment of the Main vein.

1. Test updip portion of mineralized intercept in WC-7.
2. Test updip portion of WC-7 in Discovery stope area.
3. Test western extension of Main vein.
4. Test footwall of Main vein in Discovery stope area (this zone could be a sleeper).
5. Test hanging wall of Main vein, area stoped near Brockman shaft.
6. Test updip portion of mineralization hit in WC-14.
7. Test for gold in area of high values found on Mominier shaft dump.

East end of Pearce Hill. Fifteen holes, average depth 400 feet per hole. This drilling will in part offset previously identified mineralization and will also test its continuity to the east and west. The successful completion of these holes could delineate up to 1 million tons of proven and probable ore (500 ft. long x 250 ft. deep x 100 ft. wide) and at least an additional 1 million tons of possible ore. Hole placement will be critical to insure that the footwall of the Main vein is intersected.

1. Test footwall between CS-1 and CS-3.
2. Test footwall between CS-4 and CS-5
3. Test footwall west of CS-5
4. Test footwall southeast of CS-3 near No. 8 shaft.
5,6. Collar in hanging wall, test footwall at depth.
7,8. Test eastern continuation of footwall mineralization.
9,10,11. Test western continuation of footwall mineralization (See cross section C-C')
12. Test footwall mineralization near C shaft.
13,14,15. Test area for high grade silver/gold mineralization present on North shaft dump.

All holes should be drilled with a reverse circulation rig to prevent possible downhole contamination and to get through the old workings which are sure to be intersected.

I want to emphasize that the 22 drill holes discussed above will outline the expected target area but will not be adequate to fully delineate 5 million tons of proven ore. Following successful completion of this program, an additional 20-40 holes will be necessary to drill out the orebody.

Based on the results of my study, past production records, and previous drilling, the Commonwealth mine has an excellent chance to contain at least 5 million tons of open pit silver ore. The project represents an attractive, low risk exploration opportunity to identify a major open pit silver mine.

TABLE 1

SAMPLE DESCRIPTIONS (Locations Shown on Plate 1)

1-25-84-1.	Southeast side of Pearce Hill. Upper andesite cut by vuggy, open-space quartz veins. Veins trend N35W, dip 55° NE.
1-25-84-2.	Pit 400 feet west of Pearce shaft. Quartz vein stockwork, minor calcite, cutting upper andesite (N60W/90°).
1-25-84-3.	Vein material exposed between upper and lower J. Pearce shafts. Minor quartz veining and brown calcite cut upper andesite. Minor copper oxide.
1-26-84-4.	Dump sample from Mominier shaft. Cretaceous Bisbee sandstone, with abundant iron oxide and quartz veining.
1-26-84-5.	Dump sample from Brockman shaft. Same as 1-26-84-4.
2-10-84-6.	Rock chip sample about 200 south of No. 9 shaft in area of intensely silicified andesite. Banded silica with abundant amethyst.
2-10-84-7.	Rock chip sample from cat trench about 300 feet north of No. 9 shaft. Fragments of quartz in earthy red-brown clay matrix, which is probably altered Cretaceous Bisbee formation.
2-10-84-8.	Rock chip sample from trench on southeastern flank of Huddy Hill. Andesite cut by numerous quartz stringers of North vein type. Abundant tectonic breccia with quartz fragments.
2-10-84-9.	Rock chip sample from zone of intensely silicified andesite on southeastern flank of Huddy Hill. Veins trend N10-40W, with steep dips.
2-10-84-10.	Dump sample from shaft on southeastern flank of Huddy Hill. Silicified andesite cut by numerous quartz veins.
2-10-84-11.	Dump sample from shaft sunk on N60W/70NE- trending shear zone, southeastern flank of Huddy Hill. Andesite cut by quartz veins.
2-10-84-12.	Dump sample from prospect on northwestern flank of Metat Hill. Welded ash-flow tuffs with brick red hematite along fractures.
3-1-84-13.	Rock chip sample from face of southeast drift in Huddy tunnel. Andesite cut by quartz veins.
3-1-84-14.	Rock chip sample from pit on southeastern flank of Metat Hill. Silicified welded tuff with disseminated amethyst in matrix.

Sample Descriptions (con't)

3-23-84-15. Rock chip sample from caved area 150 feet southwest of D shaft. Silicified rhyolite breccia with iron oxide on fractures.

CD 76-7. Dump sample. Andesite with iron oxide, quartz veining, amethyst, minor copper oxide.

CD Ext. 1. Commonwealth Ext. 1 dump. Arkose, both silicified and fresh.

CD-3. Lemmon shaft dump.

TABLE 2

COPPER STATE ANALYTICAL LAB., INC.

DNYANENDRA A. SHAH
ARIZONA REG. NO. 8888

REGISTERED ASSAYER
P. O. BOX 7517
TUCSON, ARIZONA 85725

710 E. EVANS BLVD.
PHONE 602-884-5811
884-5812

JOB# 002815
RECEIVED 1/31/84
REPORTED 2/6/84
INVOICE# C 3105

.c: ARI Operating Co. - Tucson, AZ

SAMPLE NUMBER	Au opt	Ag opt	RECHECK Au opt				
1-25-84-1	<.001	0.10					
1-25-84-2	<.001	0.12					
1-25-84-3	0.012	4.92					
1-25-84-4	0.685	8.12	0.720				
1-25-84-5	0.018	1.18					
2-10-84-6	0.002	0.08					
2-10-84-7	0.001	0.42					
2-10-84-8	0.006	1.28					
2-10-84-9	0.002	0.08					
2-10-84-10	0.003	0.38					
2-10-84-11	0.003	1.92					
2-10-84-12	<0.001	< 0.05					
3-1-84-13	0.004	0.14					
3-1-84-14	0.002	0.07					
3-23-84-15	0.003	1.98					

REGISTERED ASSAYER CERTIFICATE NO. 8888 Dnyanendra Ambalal Shah DATE SIGNED Arizona U.S.A.

...-84

1 ppm = 0.0001%   1 troy oz./ton = 34.286 ppm   1 ppm = 0.0292 troy oz./ton

* Gold and Silver reported in troy oz. per 2,000 lb. ton.

TO:

DATE: 9/28/83

REPORT NO: 398

ASSAY REPORT

CEC CONTROL NO.	CLIENT SAMPLE NO.	DESCRIPTION	ASSAY Au T.Oz/T	Ag T.Oz/T					
4628	CD-76-7	No. 8 shaft dump	0.010	2.16					
4629	CD EXT-1	Commonwealth Ext.No.1 dump	TR	0.27					
4630	CD-3	Lemmon shaft dump	TR	1.23	sw¼ sw¼ sec.4, T13S,R25E				
3047		N. shaft dump	0.068	15.94					

CERTIFIED BY:

P.O. BOX 38448

Cimetta Engineering &

TABLE 3

TO: ARI Operating
83-420
Commonwealth Dump Testing

DATE: 11/4/83

REPORT NO: 437-1

ASSAY REPORT

CEC CONTROL NO.	CLIENT SAMPLE NO.	DESCRIPTION	ASSAY Au T.Oz/T	Ag T.Oz/T					
5057	CMD-1	C shaft, backhoe cut	0.025	4.63					
5058	CMD-2	C shaft, backhoe cut	0.013	1.76					
5059	CMD-3	C shaft, backhoe cut	0.029	1.25					
5060	CMD-4	C shaft, backhoe cut	0.008	1.37					
5061	CMD-5	C shaft, backhoe cut	0.016	1.30					
5062	CMD-6	C shaft, backhoe cut	0.017	1.91					
5063	CMD-7	C shaft, backhoe cut	0.021	2.63					
5064	CMD-8	C shaft, backhoe cut	0.011	1.68					
5065	CMD-9	D shaft ext., backhoe cut	TR	1.86					
5066	CMD-10	D shaft, backhoe cut	0.020	1.37					
5067	CMD-11	D shaft, backhoe cut	0.009	0.44					
5068	CMD-12	D shaft, backhoe cut	0.010	0.75					
5069	CMD-13	D shaft, backhoe cut	0.016	1.10					

APPROVED BY:

P.O. BOX 36446
TUCSON ARIZONA 85740

Cimetta Engineering & Construction Co., Inc.

(602) 297-7231

TO: ARI Operating
83-420
Commonwealth Dump Testing

DATE: 11/4/83

REPORT NO: 437-2

ASSAY REPORT

CEC CONTROL NO.	CLIENT SAMPLE NO.	DESCRIPTION	ASSAY Au T.Oz/T	Ag T.Oz/T			Au T.oz/t	Ag T.oz/t	CEC Control No.
5070	CMD-14	D shaft, backhoe cut	0.048	1.89					
5071	CMD-15	D shaft, backhoe cut	0.045	1.70					
5072	CMD-16	B shaft area, grab sample	0.023	1.12					
5073	CMD-17	B shaft area, grab sample	0.431	9.09	Duplicate	Sample 17R	0.315	5.55	5240
5074	CMD-18	B shaft area, grab sample	0.023	1.29					
5075	CMD-19	B shaft area, grab sample	0.019	2.26					
5076	CMD-20	near ¼ cor. sec. 5-6, grab sample	0.004	0.11					
5077	CMD-21	alluvial material, backhoe cut	0.035	2.08					
5078	CMD-22	alluvial material, backhoe cut	0.038	2.17					
5079	CMD-23	alluvial material, backhoe cut	0.027	1.46					
5080	CMD-24	grab sample, vein material, at CMD-22	0.158	15.32					
5241	CMD-25	grab sample, NW of D shaft	0.01	0.39					

APPROVED BY: [signature]

P.O. BOX 36446
TUCSON ARIZONA 85740

Cimetta Engineering & Construction Co., Inc.

(602) 297-7231

REFERENCES CITED

Drewes, H. D., 1980, Tectonic map of southeast Arizona: U.S. Geological Survey, Map I-1109.

__________, 1981, Tectonics of southeastern Arizona: U.S. Geol. Survey Prof. Paper 1144, 96 p.

Hayes, P. T., 1970a, Mesozoic stratigraphy of the Mule and Huachuca Mountains, Arizona: U.S. Geol. Survey Prof. Paper 658-A, 27 p.

__________, 1970b, Cretaceous paleogeography of southeastern Arizona and adjacent areas: U.S. Geol. Survey Prof. Paper 658-B, 42 p.

Howell, K. K., 1977, Geology and alteration of the Commonwealth mine, Cochise County, Arizona: M.S. Thesis, Univ. Arizona, 225 p.

Smith, L. A., 1927, The geology of the Commonwealth Mine: M.S. Thesis, Univ. Arizona, 73 p.