Field Guide for a Transect from Florence to Miami, Arizona

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Guidebook for the Arizona Geological Society Spring Field Trip

April 20-21, 1996

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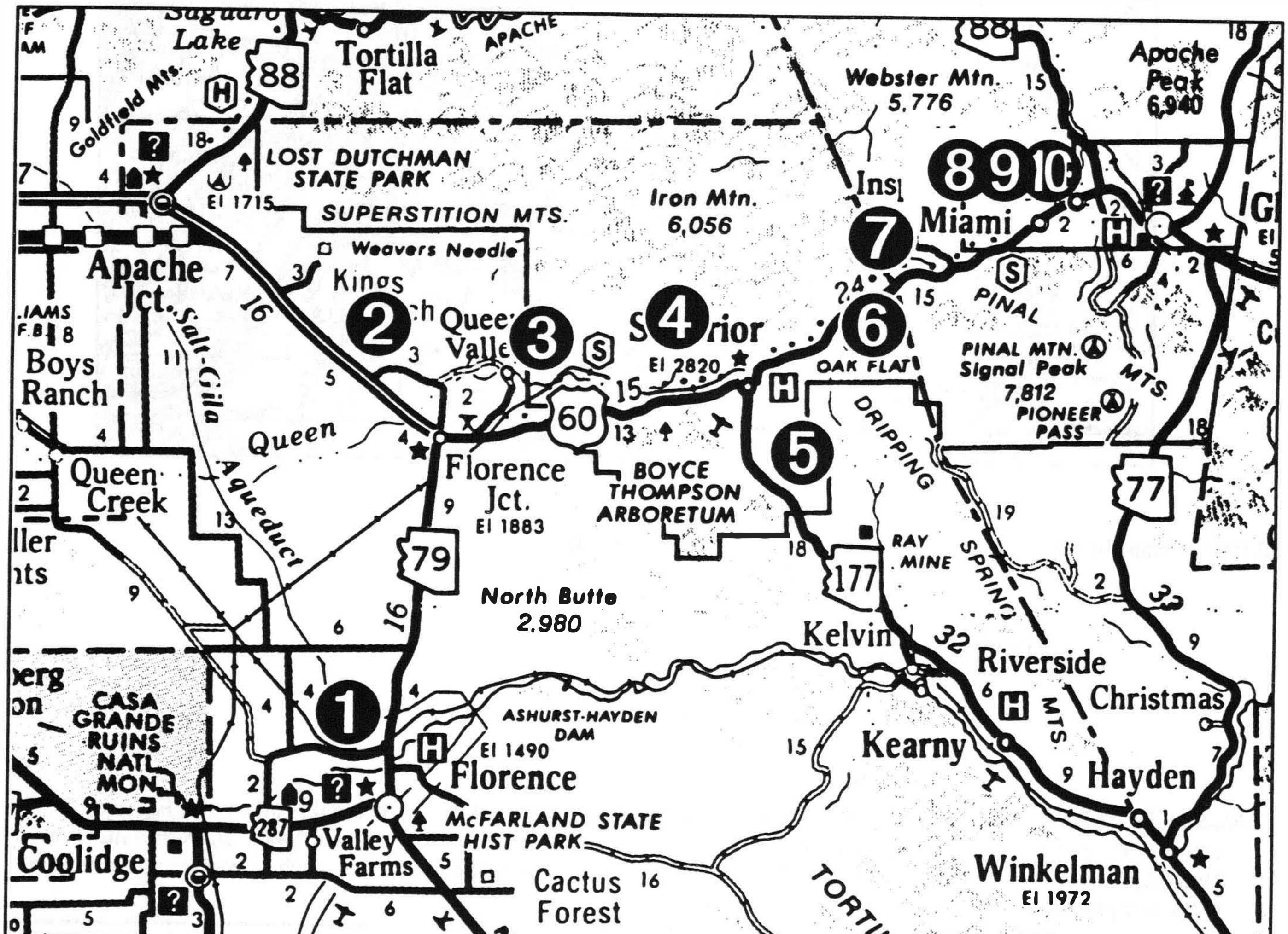
INTRODUCTION

Welcome to the Spring 1996 Arizona Geological Society Field trip. This trip will follow a traverse from Florence to Miami, looking at surface exposures and cross sections along this transect to review the effects of mid-Tertiary extension., especially with respect to the abundant mineralization in the area. Figure 1 is a location map showing the trip route and the location of stops described in this guide, and Figure 2 shows the location of cross sections. Most of the stops will be to survey the terrane covered by one or more cross sections included in this guide. The major theme of this field trip is the nature of the pre early Miocene-extension geology of this transect.

Figure 1. Map showing field trip route and location of stops



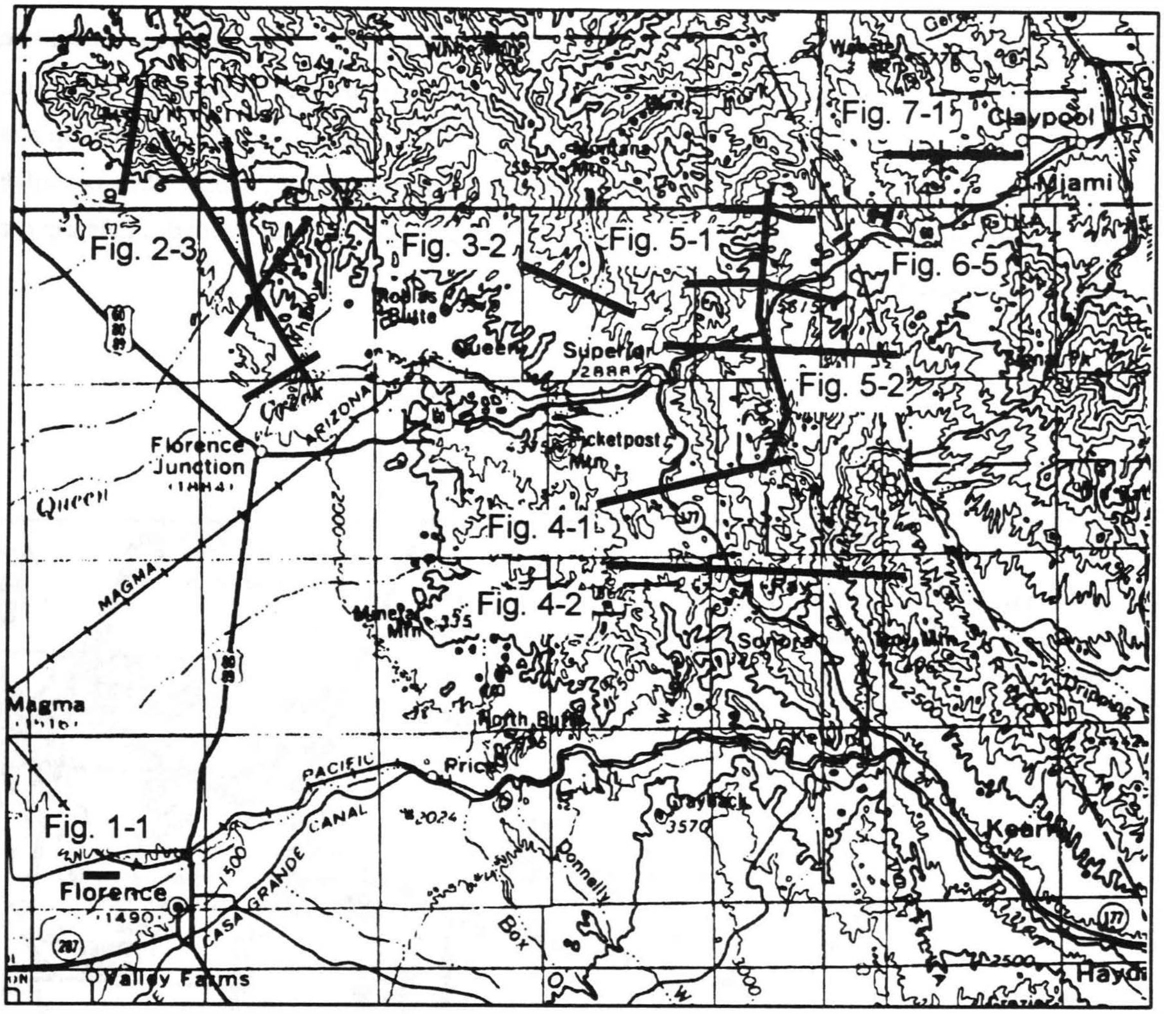


Figure 2. Map showing location of cross sections included in this guide

ROAD LOG

Day One

Meet at the BHP/Magma office north of Florence at 8:30 AM, Saturday, April 20. To get to this office take Highway 79 (old 89) to the north bank of the Gila River just north of Florence and turn west on Hunt Highway. Drive two miles on Hunt Highway to BHP/Magma building at base of "F" Mountain. Consolidate vehicles as much as possible; we can leave extra cars parked in the lot here until Sunday evening.

Stop 1. BHP/Magma Florence deposit geology. See page 9 for more discussion of geology and cross sections.

mp ..... Δ .... Σ	(mile post, incremental distance, aggregate distance)
136.1 0	Turn left (north) on State Highway 79, and head towards Florence Junction.
146.1 . 10 10	Mineral Mountain is prominent peak on skyline to east
150.7 . 4.6 ..... 14.6	Florence Junction; turn left and head west on U. S. 60 towards Apache Junction
.... 4 .... 18.6	Turn right onto El Camino Viejo road, and park in first parking area on left, just after cattle guard

Stop 2. The purpose of this stop is to view the spectacular southern scarp of the Superstition Mountains, and point out how these rocks are separated from the slightly older lava field of the Whitlow Canyon area (see page 15 for cross sections and more information). To the north, the north-dipping topographic margin of the Superstition Cauldron is delineated by the prominent contact between the layered and vertically jointed intracauldron Superstition Tuff, and the massive, cliff-forming, pre-caldera, lava domes at the mouths of Monument Canyon, and Hieroglyphic Canyon, and at the Dacite Cliffs (which are composed of crystal-poor rhyolite). The cauldron margin runs eastward to Miners Needle where it apparently turns abruptly to the north, along the northward extension of a major fault (Elephant Butte fault) which will be the focus of Stop ~~4~~3. In the foreground, dark colored hills are composed of the tuff of Comet Peak, probable outflow sheet of the Superstition Tuff. The depositional contact between this and the older lava flows of the Whitlow Canyon area is visible along first major ridge to the northeast.

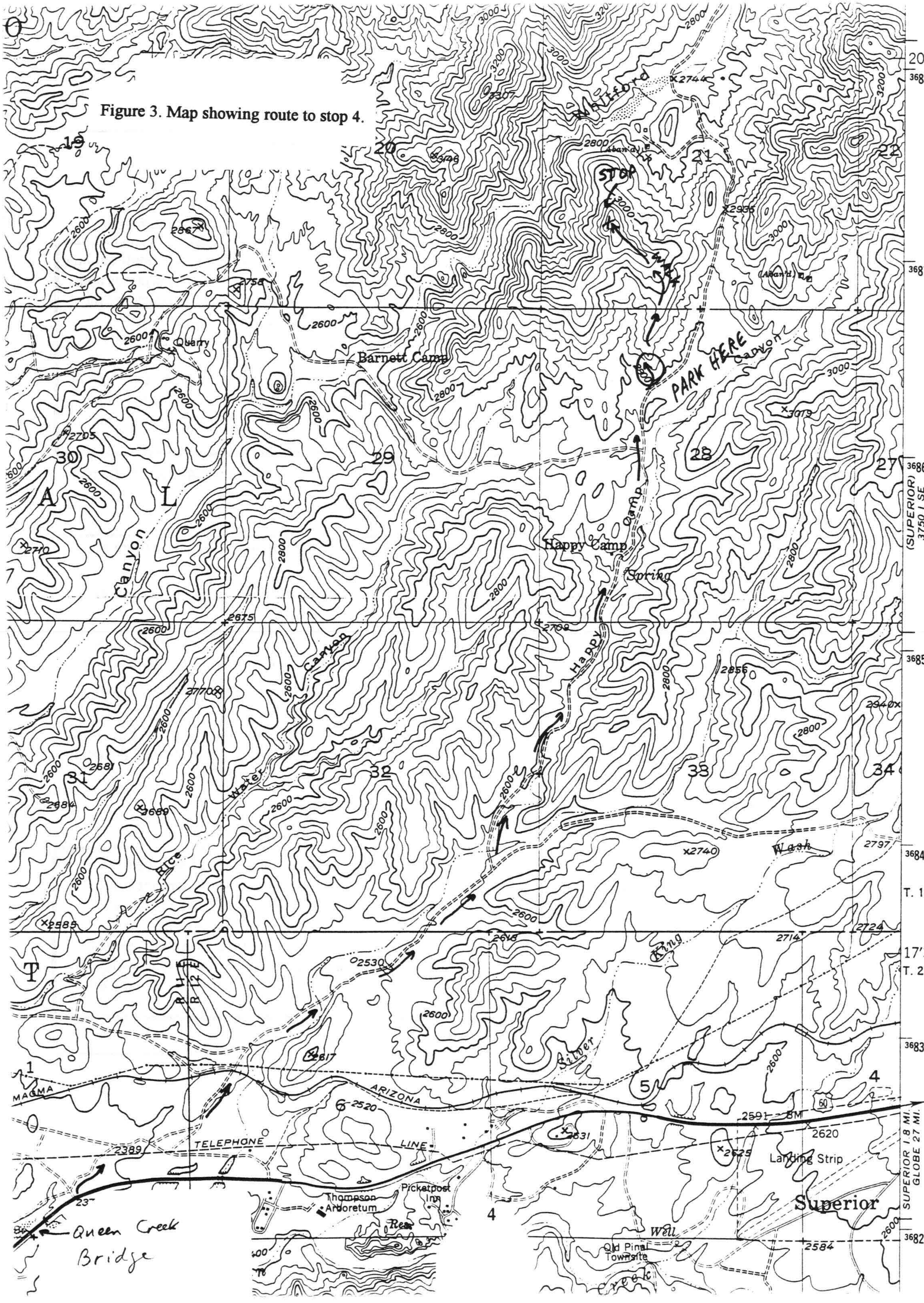
.... Return to vehicles and continue east on El Camino Viejo, towards Queen Valley and Whitlow Ranch Dam.

mp ..... Δ .... Σ	(mile post, incremental distance, aggregate distance)
.... 1.5 ..... 20.1	outcrops of Comet Peak tuff on right (north) side of road; outcrops between here and mile 6 are all Comet Peak tuff
.... 2.3 ..... 22.4	Turn left (north) on Silver King Road just before crossing Queen Creek; road heads up Queen Creek on the north side of the creek.
.... 2 .... 24.4	Cross poorly exposed contact of unit of Queen Valley overlying Comet Peak tuff. The unit of Queen Valley consist of tuffaceous sandstone and conglomerate, derived from underlying volcanic units.
.... 0.8 ..... 25.2	Queen Valley golf course on right, developed area on left; continue straight towards Whitlow Ranch Dam
.... 0.7 ..... 25.9	Take right at fork, continuing along the base of the Whitlow Ranch Dam; the west branch of the Elephant Butte fault, which here places unit of Queen Valley in the hanging wall on Comet Peak tuff is well exposed on the north side of the road at this intersection
.... 0.6 ..... 26.5	Turn left on paved access road leading to parking area on top of the dam
.... 0.3 ..... 26.8	Park in area at the top of the Whitlow Ranch Dam

Stop 3. The purpose of this stop is to view geology of the Whitlow Canyon area, examine the tuff of Comet Peak (probable outflow facies of the Superstition Tuff) and discuss the age, geometry, and kinematics of the Elephant Butte fault, whose trace is visible just to the west of this point. To the north, Elephant Butte fault strikes parallel to a line connecting Weavers Needle, Miners Needle, and Buzzards Roost. From this vantage point, all of these pinnacles are visible. Miners Needle, which barely protrudes above the peaks in the foreground, can be identified by a characteristic window near its crest. Near Buzzards Roost, the fault turns abruptly to the south and runs down the prominent valley occupied by Elephant Butte Road, and in this area it appears to be plugged by a young lamproitic intrusion. Cross-section E-E' (Page 21) runs normal to strike just to the north of here.

mp ..... Δ .... Σ	(mile post, incremental distance, aggregate distance)
.... 0.3 ..... 27.1	return to vehicles and retrace route to base of dam, and turn left towards Florence Junction
.... 0.5 ..... 27.6	leave outcrops of unit of Queen Valley, onto old alluvium.

Figure 3. Map showing route to stop 4.



.... 1.2 ..... 28.8 pass graded dirt road on left, Magma-Arizona railroad tracks next to road on left; continue on paved road

214.3 . 1.8 ..... 30.6 Queen Valley Road ends at U.S. 60; turn left on U.S. 60 and continue east towards Superior

214.9 . 0.6 ..... 31.2 Weaver's Needle visible to north-prominent spire formed by felsic lava flow on top of Superstition tuffs

216.9 . 2 .... 33.2 Dromedary Peak to south, underlain by welded tuff probably related to Superstition caldera

218.2 . 1.3 ..... 34.5 From here to just before Gonzalez Pass, road cuts expose a shiny, dark gray phyllite marker unit in the Pinal Schist

218.6 . 0.4 ..... 34.9 Gonzalez pass

219.2 . 0.6 ..... 35.5 View ahead to town of Superior; cliffs forming backdrop are Pinal Schist at base, overlain by Apache Group and Paleozoic strata through Pennsylvanian Naco Limestone, overlain by Apache Leap Tuff. Picketpost Mountain visible ahead to left (1 o'clock) is a felsic volcanic center consisting of lava flows, pyroclastic rocks, and a feeder intrusion visible by the prominent conical, upward-diverging fractures on the east side of the north face [Peterson, 1966]. Biotite from the youngest volcanic unit yielded a K-Ar date of 18.4±0.5 Ma [Shafiqullah et al., 1980]

220.6 . 1.4 ..... 36.3 last road cut in Pinal Schist; fine grained phyllite here contrasts with coarse hornfels seen at stop 5; foliation is steep

221.9 . 1.3 ..... 37.6 Tertiary basalt cut by minor faults in road cut

222.2 . 0.3 ..... 37.9 Queen Creek bridge

222.3 . 0.1 ..... 38 **Turn left (north) off U.S. 60** just east of Queen Creek Bridge, cross cattle Guard, take right fork on FS 8. See Figure 3 for topographic map of route to stop 4.

.... 0.1 ..... 38.1 Sign post for FS 8

.... 0.7 ..... 38.8 railroad crossing; good basin-fill conglomerate and sandstone outcrops in railroad cut to northeast

.... 0.3 ..... 39.1 Basin-fill conglomerate outcrops along wash to E of road, apparent dip is horizontal, strata dip gently towards the road

.... 0.5 ..... 39.6 Cottonwood trees in wash; basalt lava interbedded in conglomeratic basin fill crosses the canyon here, probably forcing water in stream bed to surface

.... 0.3 ..... 39.9 **Turn left at fork**, onto FS 650, and start up Happy Camp Canyon

.... 0.9 ..... 40.8 cattle guard

.... 0.2 ..... 41 pass left turn to Happy Camp

.... 0.3 ..... 41.3 road crosses onto outcrop of tuff that underlies conglomerate here

.... 0.1 ..... 41.4 pass left turn to Barnett Camp in Whitford Canyon

.... 0.1 ..... 41.5 road crosses onto outcrop of diabase, with typical red ochre soil cover

.... 0.1 ..... 41.6 road to left, park here.

Stop 4. This stop is for an overview of the structural geology of the northernmost part of the Concentrator fault (See page 25 for discussion and cross section). Climb the hill to the north of the parking area, following the ridge north and northwest to the summit, from which a series of tilted sections of Apache Group strata in the hanging wall of the Concentrator fault can be seen. The hike is in diabase intruding Dripping Spring Quartzite and Mescal Limestone until the summit, which is in Mescal Limestone.

.... Return to vehicles and retrace route to U. S. 60

mp ..... Δ .... Σ (mile post, incremental distance, aggregate distance)

222.3 . ... 45.1 **Turn left (east)** on U.S. 60

223.1 . 0.6 ..... 45.7 Boyce Thompson Arboretum; base of Tertiary section on Pinal Schist crosses highway here; road cuts in Tertiary volcanic rocks next 1.7 miles.

223.5 . 0.4 ..... 46.1 roadside marker (south side) *"Picketpost Mountain-- A landmark and lookout point during Indian Wars, site of outpost of Camp Pinal which was located at head of Stoneman Grade to the east. Soldiers protected Pinal City and the Silver King Mine from Apache raiders. It was the home of Col. William Boyce Thompson, mining magnate and founder of the Southwest Arboretum a the foot of the mountain"* Col. Thompson's house is the tile-roofed building at about 2 o'clock.

224.8 . 1.3 ..... 47.4 last Tertiary basalt outcrops in road cuts

224.9 . 0.1 ..... 47.5 perlite quarry to south of Highway

225.9 . 1 .... 48.5 **Exit U.S. 60** to get on Arizona 177 and head south towards the Ray mine and Kearny; turn right (south) at the intersection at the top of the ramp.

165.2 . 2.7 ..... 51.2 road cut in conglomerate basin fill of Superior basin, tuff in upper part, cut by fault. (mile posts are now for State Highway 177)

162.7 . 2.5 ..... 53.7 **Turn left** onto dirt road; outcrops of Tertiary basalt

.... 53.7 gate in fence (last one through please close)

.... 0.1 ..... 53.8 Cross splay of Concentrator fault, with Tertiary basalt in the hanging wall and Proterozoic diabase in the footwall. A sliver of Martin(?) Formation separates these where the road crosses the fault. This fault zone is characterized by slivers of Apache Group and Paleozoic strata for about a mile along strike where it crosses State Highway 177.

.... 0.05 ... 53.85 Cross contact (not exposed) of diabase against Pinal Schist.

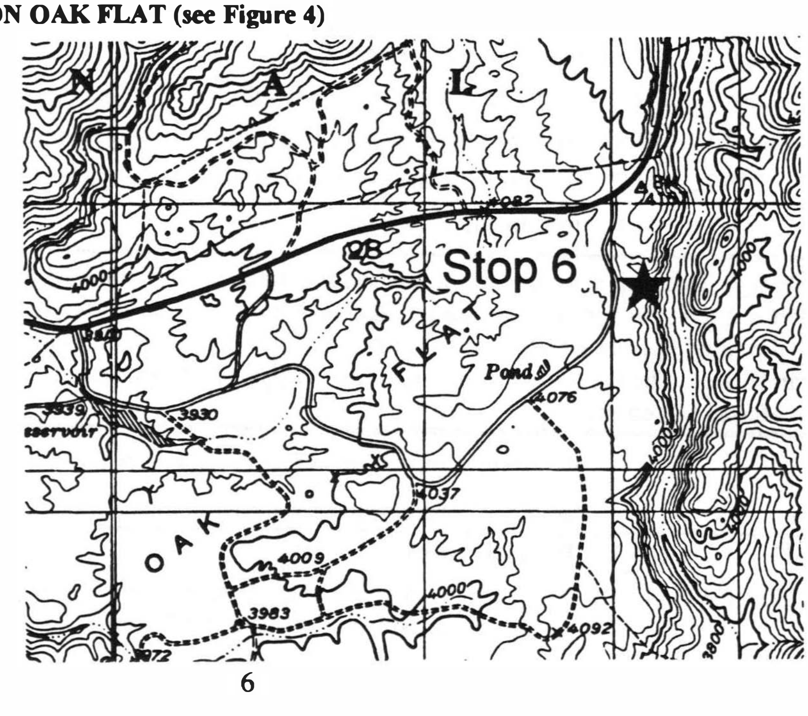
.... 0.15 ... 54 Park on east side of low hill of Pinal Schist

Stop 5. Climb the low hill next to the parking area to survey the terrane along the central part of the cross sections described on page 25 and discuss the sections. Then walk north and to the east into the major wash to look at an intrusive contact between Proterozoic Madera diorite and Pinal Schist. Note that the Pinal Schist in this area contain 2-4 mm muscovite grains (much coarser grained than is typical in the region), and that the schist is not fissile. This hornfels facies of the schist is identical to that observed near contacts with other early to middle Proterozoic diorite to granite intrusions in the southern part of the Picketpost Mountain Quadrangle. On the east side of the wash, just before it curves to the west is an outcrop with a beautifully exposed intrusive contact of Madera diorite into Pinal Schist. The diorite and schist are interleaved on a meter scale, and the diorite is locally weakly foliated. This contact had previously been mapped as one of a number of thrust faults that we now believe are mostly normal faults, or in this case intrusive contacts.

.... End day 1; return to Arizona 177, and head for town.

MEET SUNDAY MORNING 8:30 AM, ON OAK FLAT (see Figure 4)

Figure 4. Map showing route to Stop 6.



Day Two

mp..... Δ .... Σ	(mile post, incremental distance, aggregate distance)
230.9	From Superior head east on U.S. 60 up Queen Creek Canyon, or from Miami head west up Bloody Tanks Wash on U.S. 60 to Oak Flat, mile post 230.9. Watch for the "Magma Mine, Oak Flat Recreation Area" sign. Turn south off U.S. route 60, take the first left, and drive about one mile in an easterly direction to near the west edge of Devil's Canyon, for an overlook of Devil's Canyon fault and hole A-4. We will convene here at **8:30 am**. See Figure 4 for route to stop.

Stop 6. Geology beneath the Apache Leap tuff on Oak Flat. See cross sections and discussion, page 31. Buried beneath about 4000 feet of Tertiary strata is a copper deposit with and estimated minimum geologic resource of 200 million tons of 0.9% copper [Sell, 1995]. Drilling to define this deposit provides a good picture of the Tertiary faults and unconformities beneath the Apache Leap tuff.

230.9 0	Return to vehicles retrace route to U.S. 60, and **turn right**, heading towards Miami. Reset odometer.
232.7 . 1.8 ..... 1.8	road on right to Asarco's Superior East Project, continue on U. S. 60 towards Miami
238.9 . 6.2 8	**Turn left (north)** onto road to Pinto Valley mine and Cactus-Carlota project.
....	Drive about 3 miles on this road, around the tailings pond. Just before the main gate to the Pinto Valley Mine, turn left and follow the road about .75 mile down a steep hill into Pinto Creek Valley, and park at the bottom of the hill. If the road down hill is too rough, we will park at the top and walk down to inspect outcrops.

Stop 7. Geology of Cactus-Carlota deposit. See cross sections and discussion on page 41. After reviewing the geologic setting and discussing the sections here, we will look at outcrops of the Cactus breccia and exposures of the underlying low-angle normal fault in cuts along the road.

....	Retrace rout to U. S. 60, **turn left (east)** and continue towards Miami. Outcrops along the road are the Laramide Schultze Granite in the headwaters of Bloody Tanks Wash. Reset odometer

mp..... Δ .... Σ	(mile post, incremental distance, aggregate distance)
240.2 . 1.3 ..... 1.3	Fault gouge in low road cuts to the north; lower Ox Hide pit to the north. This is the Schultze fault, which bounds the Lower Ox Hide deposit on the west. The fault strikes northerly and dips 25-30 degrees east
240.5 . 0.3 ..... 1.6	pendant of Precambrian Pinal schist in Schultze granite.
240.8 . 0.3 ..... 1.9	Steeply dipping joints or hydrofractures in granite
241.2 . 0.4 ..... 2.3	Moderately dipping joint(?) surfaces in granite on the south site do the highway and steeply dipping joint surfaces ahead (on the horizon) on the north side of the road
241.9 . 0.7 3	Contact of Schultze Granite and Pinal Schist; may be the eastward continuation of the east-dipping Barney fault system. The contact is not exposed, but granite near it is crushed and may be the edge of a fault zone.
242 .... 0.1 ..... 3.1	Bluebird mine road on left (north); the mine is located behind the large leach heaps. We will leave the Cyprus Miami complex here after stop 9.
243 .... 1 .... 4.1	Road on left; Carlotta Copper Company office on the right as the U.S. 60 enters Miami. *Note this intersection—we will return here for stop 10.* Cross the Miami fault, a NE-trending, 50-60 degree east dipping normal fault, with post-20 Ma conglomerate in the hanging wall and Pinal Schist in the footwall. The Van Dyke shaft is on the skyline at 10 o'clock, and the Miami #5 shaft is at 11 o'clock. Tailings ahead on the edge of Miami are from 50 year old Miami Copper company block cave and are being reclaimed by BHP/Magma through hydraulic mining from inside of the pile.

244.9 . 1.9 ..... 6 Traffic light; **turn left** to Cyprus Miami Mining Company Main Gate. The former International Smelting Company smelter, now operated by Cyprus, is on the hill above the road.

We will have to check in; hard hats, safety glasses, and long pants are required in the mine area. Consolidate vehicles to reduce congestion in the mine area. Follow the lead car for stops here.

Stop 8. North side of the Thornton-Joe Bush (TJ) pit. View to south. Cross section on page 58 passes from west to east approximately through the center of the pit. Outcrop here is Pinal Schist, covered by Apache Leap tuff to the north and west. The south pit wall is granite porphyry of the Schultze granite. The Miami fault runs diagonally across the view to the east beyond the pit and the old Miami block cave which is now being leached. The Barney fault is the tall exposure in the distance at 2 o'clock.

Stop 9. East side of the Bluebird-Live Oak pit (BL), looking west. Standing on granite and granite porphyry (Schultze granite), with Pinal Schist in the lower part of the western wall of the pit. The schist is overlain by Tertiary conglomerate dipping 30-40° to the southwest into the pit wall. The Barney fault, on the highest bench at 2 o'clock, dips 60 east. The Barney fault breaks into a series of sigmoid fault strands and lensoid slivers behind the Pearl Harbor day slide directly across the pit. One of the fault splays can be seen emerging from the south side of the landslide. The Barney fault probably also causes the slow degradation of the pit wall to the south of the landslide. The "S" fault dips 37 north at the south wall of the pit and has several possible explanations. It is most likely that it is the faulted extension of the Williamson fault, which crops out west of the Barney fault.

.... Return to U.S. 60 through the Bluebird gate. **Turn left**, and proceed 1 mile east to the road intersection across the street from the Carlota Copper company.

.... **Turn left (north)**, then **turn right** at the "T" intersection, and park at the exposure of the Miami fault in the road cut.

Stop 10. Miami fault. This fault has apparently displaced the base of the Tertiary conglomerate (Gila) as much as 3500 feet in a vertical sense. There are several copper deposits (Van Dyke, Miami East) in the hanging wall of the fault, but none have proven to be economic to date.

.... Return to vehicles and retrace route to U.S. 60

End of Trip! Have a safe journey home.

Geology and Project Overview of the BHP Florence (Poston Butte) Porphyry Copper Deposit, Pinal County, Arizona

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BHP

Property History and Status

The Florence (Poston Butte) deposit is located two miles northwest of the Town of Florence in Pinal County, Arizona. From 1969 through 1975, Conoco geologists delineated an extensive, low grade porphyry copper resource near Poston Butte based on 605,857 feet of exploration and development drilling including 659 rotary drill holes and 396 diamond drill holes (Nason, Shaw, and Aveson, 1983). In 1974, Conoco mined 50,000 tons of ore from a single-level, underground, mine for metallurgical, mining, and geological testing. The mine was accessible via two 700-foot deep shafts and more than a mile of drifts and cross cuts; this pilot mine is now flooded. The Poston Butte operation as envisioned by Conoco included: 1) an oxide open pit mine delivering ore to vat and leaching facilities followed by solvent-extraction and electrowinning (SX-EW) treatment of solutions, and 2) open pit mining of the underlying sulfide material with ore delivered to a concentrator followed by smelting and refining to produce copper cathode (Magma, 1994). Conoco invested over $27 million in this project. The relatively large capital investment cost ($504 million), however, as well as low copper prices in the mid-1970s forced this project into dormancy.

Magma Copper Company acquired the property in July 1992 from Conoco and began a pre-feasibility study in 1993 focusing on the most appropriate mining method for developing the oxide resource. The conclusions of this study were that because of the deposit's relatively low grade (0.34% total copper, 0.24% acid soluble copper) and overburden depth (350 feet), an in-situ solution mining technique followed by SX-EW is the only economic way to extract the 368,160'000 tons of copper oxide ore. The lithologic, mineralogical, and structural features are all favorable to solution mining because of the low gangue acid-consuming host rock, the presence of acid-soluble chrysocolla along fractures and in argillized feldspars, and the intense fracturing of the rock allowing solution migration.

Currently, BHP Copper (BHP purchased Magma in January 1996) is completing a feasibility study begun in 1995. During this phase, 52 pump, observation, and monitor wells were drilled for materials property testing to provide hydrologic data for the Aquifer Protection Permit Application and to characterize the aquifer in the hydrology computer model; the APP Application was submitted to the Arizona Department of Environmental Quality in February 1996. Archaeologists completed a reconnaissance survey of 350 acres and will soon begin clearing sites for infrastructure development. A 38-hole diamond drill program was conducted to confirm ore reserves in the deeper, western portion of the deposit, and to gather material for geological and metallurgical tests. Construction is planned to begin in 1997 with production of 75MM lbs/year cathode beginning in January 1998. Figure 1 shows the Florence site location and planned facilities.

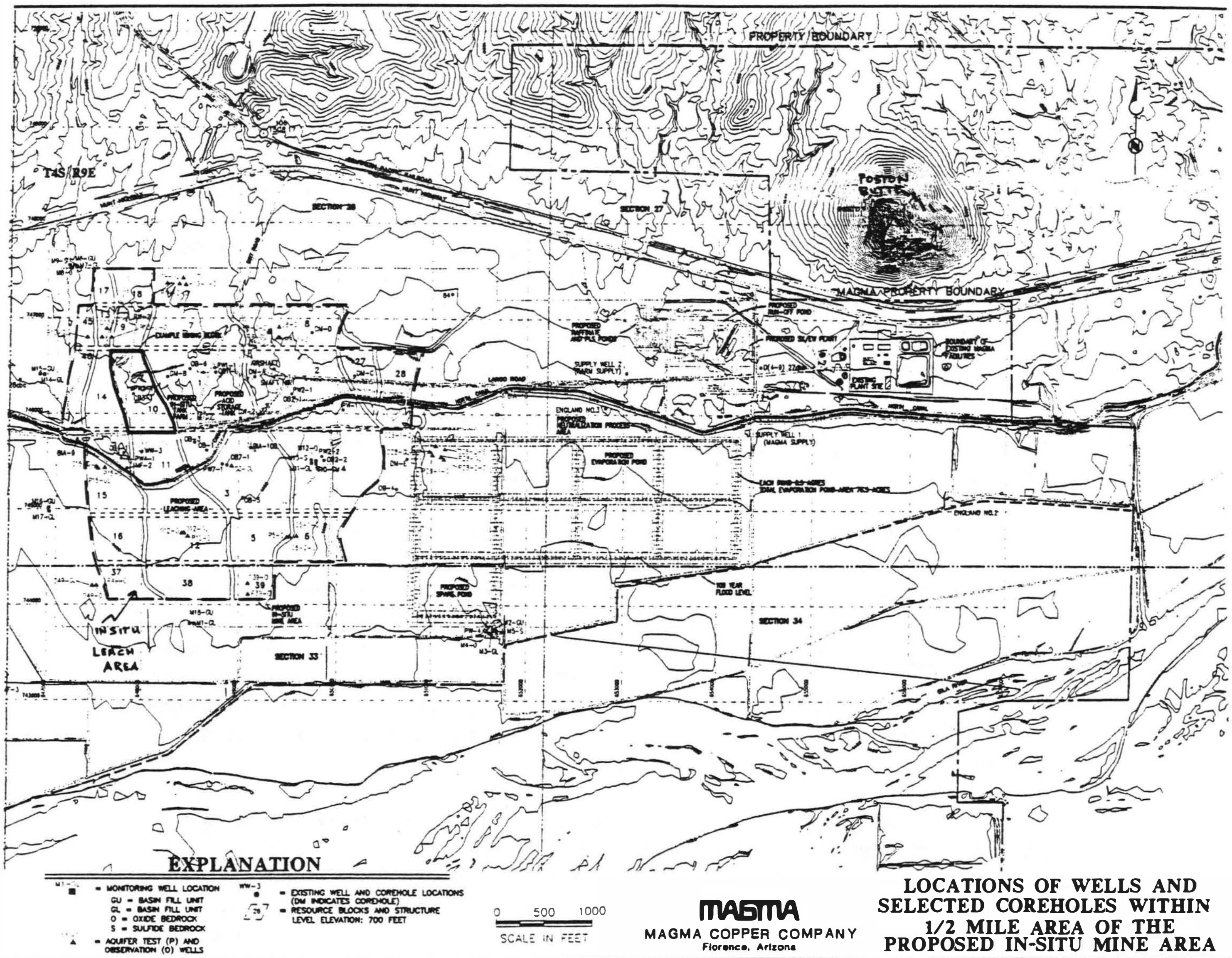

Figure 1. Location of BHP Florence site and planned in-situ copper oxide mine facilities.

Deposit Geology Overview

Lithology

For a detailed discussion of the geology of the Poston Butte deposit, the reader is referred to Nason et al., 1983. East and west of the Florence deposit, the Precambrian metamorphic and igneous basement was intruded by Precambrian diabase and Laramide igneous rocks. These rocks are cut by Tertiary basalt, andesite, trachy andesite, and latite dikes. Tertiary and Quaternary fanglomerate, alluvium, and basalt unconformably overlie the Precambrian and Laramide rocks.

At the Florence deposit, Precambrian Pinal Schist has been encountered in drill core and crops out 3.5 miles north of the deposit. A Precambrian quartz monzonite and quartz monzonite porphyry batholith (correlative with the Oracle Granite) intruded the Pinal Schist and is the host for approximately 90 percent of the mineralization. The quartz monzonite porphyry contains large (1-2 cm) subhedral, locally perthitic orthoclase phenocrysts in a coarse-grained matrix of quartz, plagioclase, and biotite with minor magnetite, sphene, apatite, and rutile; locally, the texture becomes equigranular. Aplite dikes and metasomatized xenoliths are commonly associated with the quartz monzonite. Olive-black, fine-grained Precambrian diabase dikes crosscut the monzonite and are frequent hosts for mineralization.

The Laramide intrusive rocks are represented at Florence by three, closely related varieties of granodiorite porphyry dated at about 62 $\pm$ 1 m.y. The principal variety (Type I) hosts 20 percent of the deposit and is a light gray, medium- to fine-grained rock containing quartz, plagioclase, and biotite phenocrysts in a quartz and orthoclase matrix. Type II is more mafic and finer-grained but is coeval with Type I. The Type III variety crosscuts the other two varieties and forms barren, greenish gray dikes containing only quartz and plagioclase phenocrysts. In general, the granodiorite porphyry is less fractured and mineralized than the intensely fractured quartz monzonite.

Tertiary andesite and quartz latite (55-60 m.y.) and younger, barren trachy andesite cross cut quartz monzonite and frequently intrude along the same structural zones used by the Precambrian diabase or Tertiary granodiorite porphyry. One andesite dike intruded along the Party Line fault, a major mid-Tertiary, post-mineralization structure. Presumably, there were Precambrian and Paleozoic sedimentary or Mesozoic sedimentary and volcanic rocks in the region at one time, but they have been completely eroded down to a peneplain surface primarily of Precambrian quartz monzonite (porphyry). Overlying this surface are basin-fill units approximately 350 feet deep consisting of moderately consolidated fanglomerate with a coarse, calcareous arkose matrix and completely unconsolidated sand, silt, clay, and gravel lenses. Flat-lying basalt flows and dikes (5.8 $\pm$ 0.14 m.y.K-Ar) were encountered by drilling in the poorly indurated conglomeratic unit.

Alteration

Hydrothermal alteration accompanied the intrusion and cooling of the Tertiary granodiorite porphyry stocks and dikes into the quartz monzonite. Although alteration in the granodiorite porphyry is primarily veinlet-controlled, alteration in quartz monzonite is by turns pervasive, selectively pervasive, and veinlet-controlled. Potassic alteration (quartz-orthoclase-biotite-sericite) is the dominant alteration assemblage. Salmon-colored, secondary orthoclase replaces primary orthoclase phenocrysts, rims quartz ± biotite veins, and occurs as pervasive orthoclase flooding. Shreddy, secondary, brown biotite replaces plagioclase and matrix feldspars, and occurs in biotite-sulfide veinlets.

A sericitic (quartz-sericite-pyrite) alteration zone surrounds the potassic zone and is especially evident in the deep portions of the sulfide ore body. Fine-grained sericite selectively replaces plagioclase, orthoclase, and biotite, and forms thin alteration selvages along quartz ± sulfide veins. Propylitic (calcite-chlorite-epidote) alteration is visible in mafic dike rocks and is reported in exploration holes fringing the deposit. One of the most noticeable features in the oxide ore zone is a late-stage argillic alteration assemblage consisting of montmorillonite-kaolinite-sericite ± illite ± halloysite. The conversion of sericite to clay minerals in plagioclase phenocrysts and along fracture surfaces is selectively pervasive. X-ray analyses from recent BHP core holes indicates the clay is primarily a mixture of calcium-montmorillonite and kaolinite. These clay-altered plagioclase crystals were favorable loci for remobilized copper silicates produced by natural in-situ leaching.

Mineralization

The main sulfide minerals include chalcopyrite, pyrite, and molybdenite with minor chalcocite and covellite. Trace bornite, galena, and sphalerite are occasionally noted. Molybdenite occurs as discrete grains or as a film on fracture surfaces; the average molybdenum grade is .008 percent. Pyrite is usually subordinate to chalcopyrite (1:1 to 1:3 ratio) and both are found in veinlets and as disseminated grains; they commonly occur in quartz ± biotite veins rimmed by orthoclase and sericite. Supergene chalcocite coats pyrite and chalcocite and dusts fracture surfaces. The supergene chalcocite blanket is very thin and irregular; in most instances, the transition from the leachable copper silicates and oxides to the sulfide zone is quite abrupt.

Mineralization in the oxide zone consists of chrysocolla, "copper wad", cuprite, native copper, and trace azurite and brochantite. Approximately 40 to 50 percent of the chrysocolla occurs as veins and fracture fillings, while the remainder occurs as extremely fine-grained chrysocolla adsorbed onto the surface of clay-altered plagioclase phenocrysts. The "copper wad" appears to be an amorphous mix of manganese, iron, and copper oxides that occurs as dendrites, spots, and irregular coatings on fracture surfaces. Cuprite is smeared along hematite/goethite-coated fracture surfaces; the chalcotrichite variety of cuprite is also present on fractures or vugs, sometimes intergrown with native copper crystals. The thickness of the oxidized zone ranges from 100 to 1,200 feet with an average thickness of 400 feet.

In general, the grade of oxide ore is very similar to that of the primary sulfide ore. This is attributed to the low overall sulfide content and the low pyrite:chalcopyrite ratio (Nason et al., 1983). An extensive leached cap 150-350 feet thick in the western center of the deposit indicates that the original pyrite to chalcopyrite ratio was higher in local areas. Locally, the oxide grade is twice as high as the underlying sulfide ore.

Structure

Because the Florence deposit is almost entirely covered by 350 feet of overburden material, Conoco originally interpreted the structure based on exploration and development drill holes, their underground mine maps, and regional geology and geophysics. In 1995, Magma Copper developed a technique to refine structural interpretations of buried deposits by employing an acoustic borehole televiewer logging tool in selected NX, HX, and six-inch diameter holes on the west side of the deposit. This downhole tool provides dip angles and dip azimuths for digitized fractures visible on a digital display, and was used in conjunction with detailed fracture-angle and fracture-mineralogy notes recorded and compiled by geotechnicians. The goal was to study the vertical distribution of common ore and gangue minerals, to determine predominant structural trends, and to identify preferred fracture orientations for copper-bearing structures. These data will be incorporated into the geology and hydrology models and production well-field design. Although the structural compilation is on-going, preliminary observations from more than 22,000 fractures in 12 oriented core holes indicates a preferred strike range of N-S to N40E dipping 50-60 degrees west or northwest. Copper-bearing fractures are somewhat randomly distributed, but copper oxides most commonly occur on fractures striking NS to N30E and dipping 50-60 degrees west or northwest.

The local and regional structure has been previously described by Balla (1972) and Nason et al. (1983). These authors suggest that the oldest structural trend affecting the Florence deposit is the N70E-trending Ray Lineament, a pre-Laramide zone of crustal weakness traced east-northeast from Sacaton through Walker Butte, Florence and on to Ray. Laramide intrusions at these deposits are emplaced and elongated in a east-northeast direction presumably at the intersections of conjugate fault sets. At Florence, the Type I and Type III granodiorite intrusions are both elongated in a northeast to east-northeast direction; northwest-trending en echelon Precambrian diabase dikes suggest a conjugate structural direction.

Within the deposit area, the pre-Laramide and Laramide northeast-trending fracture patterns are recorded on Conoco's underground maps and in oriented drill core completed by Magma. Conoco reported that most copper-bearing fractures underground trended northeast. Another dominant set of fractures trends north-south to north-northwest and dips westerly; these fractures have been attributed to the Basin and Range extensional tectonics. The most apparent structural trends now visible in the Florence area are the major horst-and-graben structures related to mid-Tertiary normal faulting (Figure 2). The Florence deposit lies within a horst block bounded both east and west by deeply buried, fault-controlled depressions or grabens. The relatively narrow depressions trend north-south to north-northwest and are filled with as much as 1,300 vertical feet of fanglomerate and unconsolidated alluvial material. Copper grades exceeding 0.4 percent were encountered in quartz monzonite in deep drill holes beneath these paleodepressions.

The major post-mineralization structures intersected in drill core are the Party Line and Sidewinder faults (Figure 3). The Party Line fault is a fault zone 50 to 100 feet thick trending N34W, 45-50W with a maximum offset of 1,000 feet. The Party Line fault bounds the eastern portion of the ore body and has a strike length in excess of 3,600 feet; the footwall east of this fault is completely barren. Bounding the western edge of the deposit is the Sidewinder fault which can also be traced for thousands of feet. The offset along this thick fault zone is approximately 250 feet; the hanging wall has been intensely fractured. The Sidewinder fault is responsible for creating a north-northwest trending paleovalley within the deposit; this depression is as much as 200 feet deep and has been traced over a strike length of 2,500 feet.

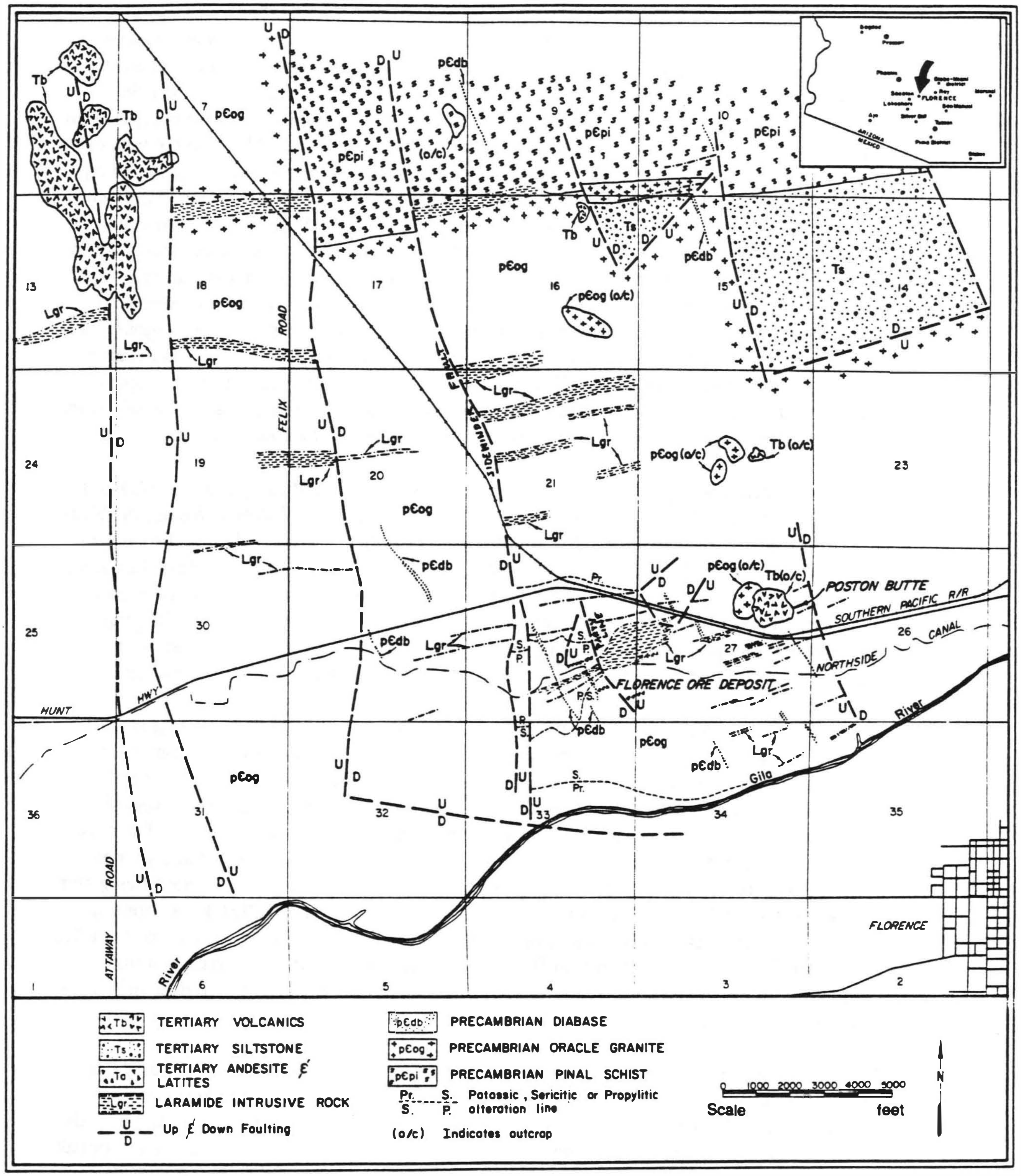

Figure 2. Generalized, sub-surface geology map of Poston Butte area from Nason, Shaw, Aveson, 1983.

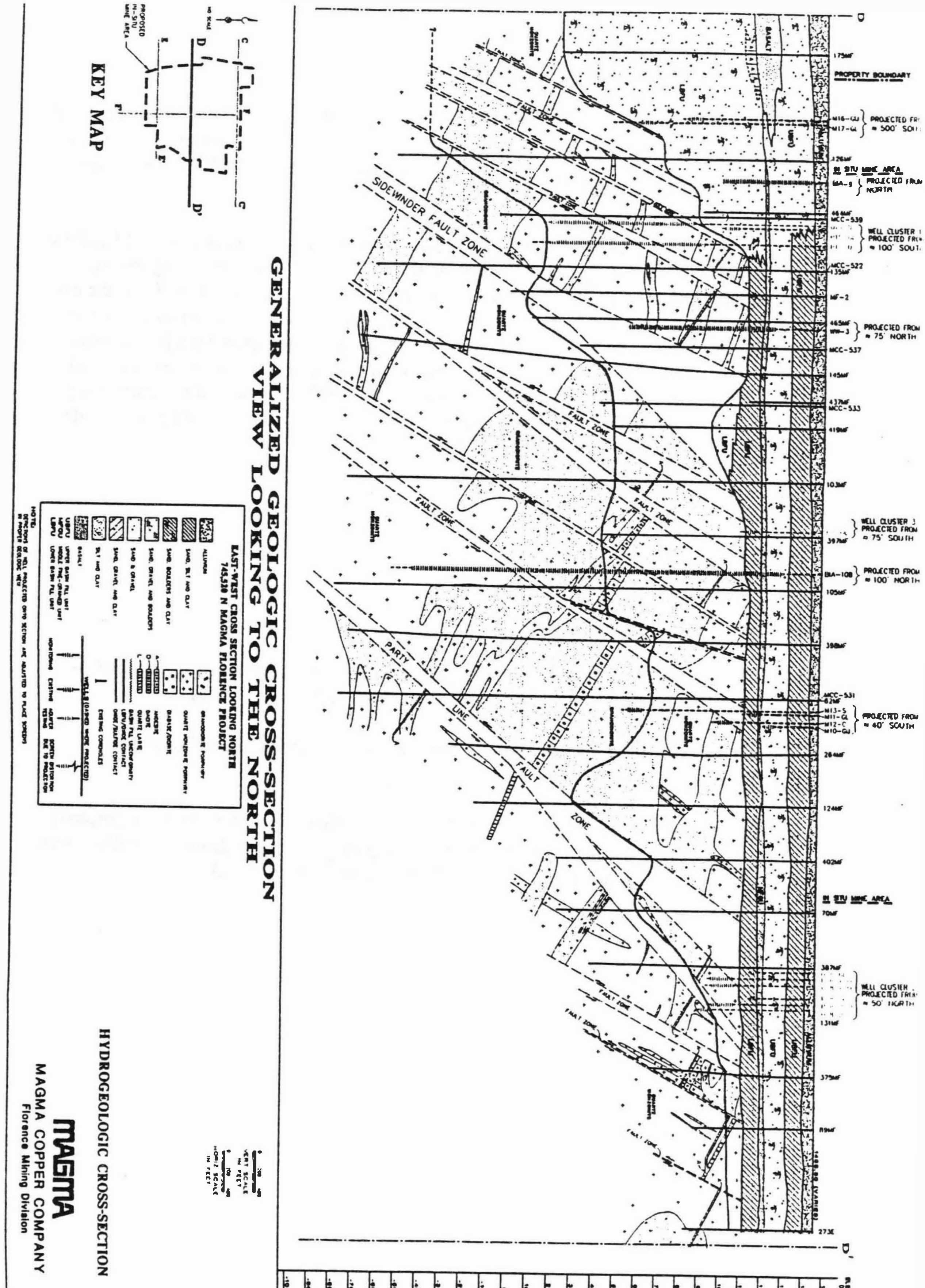

Figure 3. East-west cross section (745520N) through center of Florence deposit.

Several other north-northwest trending faults have been postulated between the Party Line and Sidewinder faults and west of the Sidewinder fault. Recent borehole televiewer data indicate the presence of significant eastward and southerly dipping structures which will be incorporated into future geologic models for Florence.

Conoco drilling intersected tilted Whitetail Conglomerate (basal consolidated fanglomerate) with dips of 40 to 60 degrees in some downthrown blocks. North of the deposit, however, the same conglomerate units show little or no tilting. Along the Party Line fault, the oxide-sulfide boundary does show significant offset. Over the majority of the deposit, however, the oxide-sulfide interface is fairly horizontal and mimics the eroded, post-fault paleotopography of the top of bedrock. Rotation, if it occurred, took place pre-oxidation or within specific fault blocks before the latest age of faulting (Nason et al., 1983). Additional structure analyses combined with alteration studies may provide more conclusive data regarding the possibility of rotation or tilting of the Florence ore body.

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Overview of Superstition Mountains and Whitlow Canyon Area

by Charles A. Ferguson, Arizona Geological Survey

The Superstition Cauldron's southern topographic margin is spectacularly exposed at a number of localities along the range's steep south-facing escarpment. A cauldron is the inferred remains of a caldera after its geomorphic expression has been largely modified by later geologic processes. Directly to the south lies a broad valley underlain by Proterozoic basement (see cross-sections A-A', B-B', C-C', pages 17-19), which marks the boundary between the Superstition Mountains on the north and the Whitlow Canyon Area on the south. The valley represents the highly fractured, easily eroded, and therefore valley-forming rim of the cauldron. The intracauldron Superstition Tuff, referred to previously as the Siphon Draw Member of the Superstition Tuff (Stuckless and Sheridan, 1971), has been subdivided into five informal members (Skotnicki and Ferguson, 1995; Ferguson and Skotnicki, 1995), whose boundaries are readily visible along the range's steep south-facing escarpment. These units comprise a remarkably undisturbed, flat-lying structural block bounded to the south, east, north, and northwest by moderately to severely tilted volcanic rocks. In most areas these tilted rocks are older than the Superstition Tuff, but directly to the north Superstition Tuff is also involved in the tilting. Current and future detailed mapping projects in collaboration with $^{40}Ar/^{39}Ar$ sanidine dating of principal units should help constrain more precisely the timing and spatial distribution of tilting in the area.

The Whitlow Canyon Area consists of a greater than 1 km thick sequence of pre-Superstition Tuff lava flows that have been tilted between 10 and 30 degrees to the east. The lavas are overlain in the Florence Junction area by the Superstition Tuff's nearest preserved outflow sheet which, because it is isolated from the main mass within the cauldron, has been provisionally named tuff of Comet Peak (Ferguson and Skotnicki, 1995). The Elephant Butte fault transects the Whitlow Canyon Area. This major, west-side-down, dip-slip, normal fault is probably continuous to the south with the concealed and inferred range-bounding fault east of Mineral Mountain. The pre-Superstition Tuff volcanic rocks of the Whitlow Canyon area are weakly extended (22%). A strike-normal distance of 7.45 km along cross-section D-D' restores to about 6.1 km, and most of this extension occurs across the Elephant Butte fault.

The Tertiary volcanic stratigraphic sequence to the east of Elephant Butte fault includes all of the widespread units found in areas to the west plus a few others that are restricted to the east side of the fault, one of which is quite thick along the fault. It is as if the fault were originally east-side-down and acted as a barrier to the westward flow of lavas. In fact, there are a number of other splays of the main fault in the Buzzards Roost area that appear to have accommodated motion in both directions at different times during emplacement of the lavas. To the north, the Elephant Butte fault may coincide with the eastern margin of the Superstition Cauldron. The "Superstition Tuff" to the east of the fault can not be assigned, based on field observation alone, to any of the members found to the west. Farther south, in the Comet Peak area (cross-section E-E'), an abandoned eastern strand of the fault was apparently exposed as a west-facing scarp (erosional?) during emplacement of the tuff of Comet Peak.

Cross section E-E' shows over 1 km of Tertiary volcaniclastic rocks interbedded with at least 3 basalt flows in a hanging-wall basin to the Elephant Butte fault. Although the dip of these rocks is very gentle in the Queen Valley area, the cross-section depicts geometry that is well exposed just to the south, where the dip decrease up-section from nearly 40° to horizontal. Based on the lack of offset of a high-angle intrusive contact in the Pinal Schist to the north of Whitlow Ranch Dam, west-side-down offset along the Elephant Butte fault is interpreted to be predominantly dip-slip.

Regionally, the Elephant Butte fault represents the westernmost fault of a series of major faults with similar geometry (but not necessarily kinematics) in the Mineral Mountain area. It also represents the approximate eastern limit of pre-Tertiary deformation of the Middle Proterozoic Apache Group. This deformation is expressed by local, open to close folding of Mescal Limestone (see east end cross-section D-D'), a broad, north-trending, anticlinal warp of the Apache Group cored by Pinal Schist (see cross-section B-B'). A widespread angular discordance between bedding of the Apache Group and the basal Tertiary unconformity may be a result of broad folding of the Apache Group or a pre-volcanic phase of Basin and Range style tilting.

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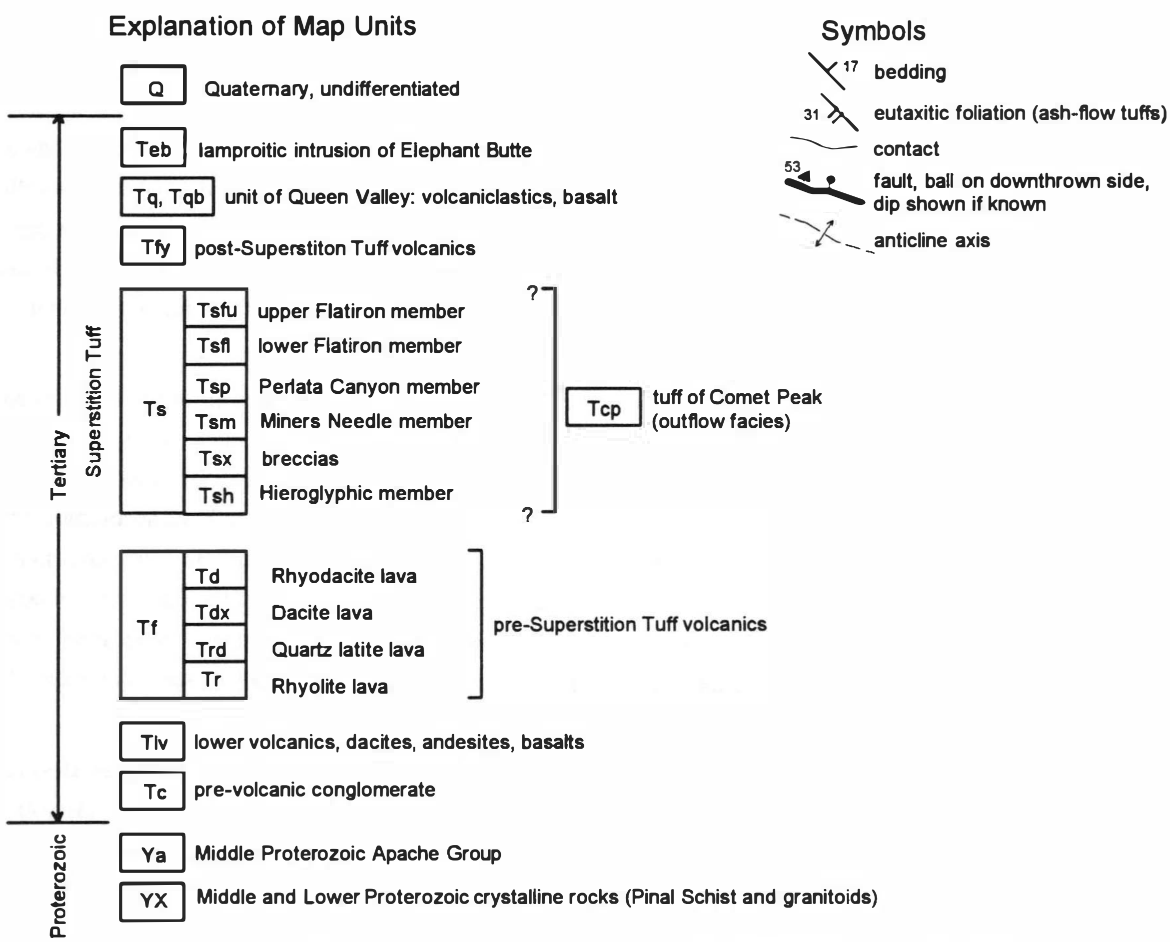
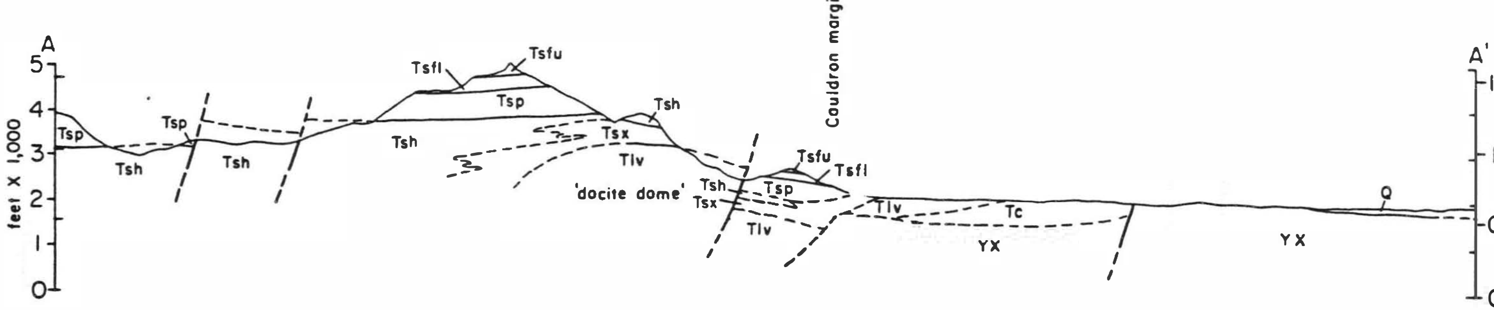
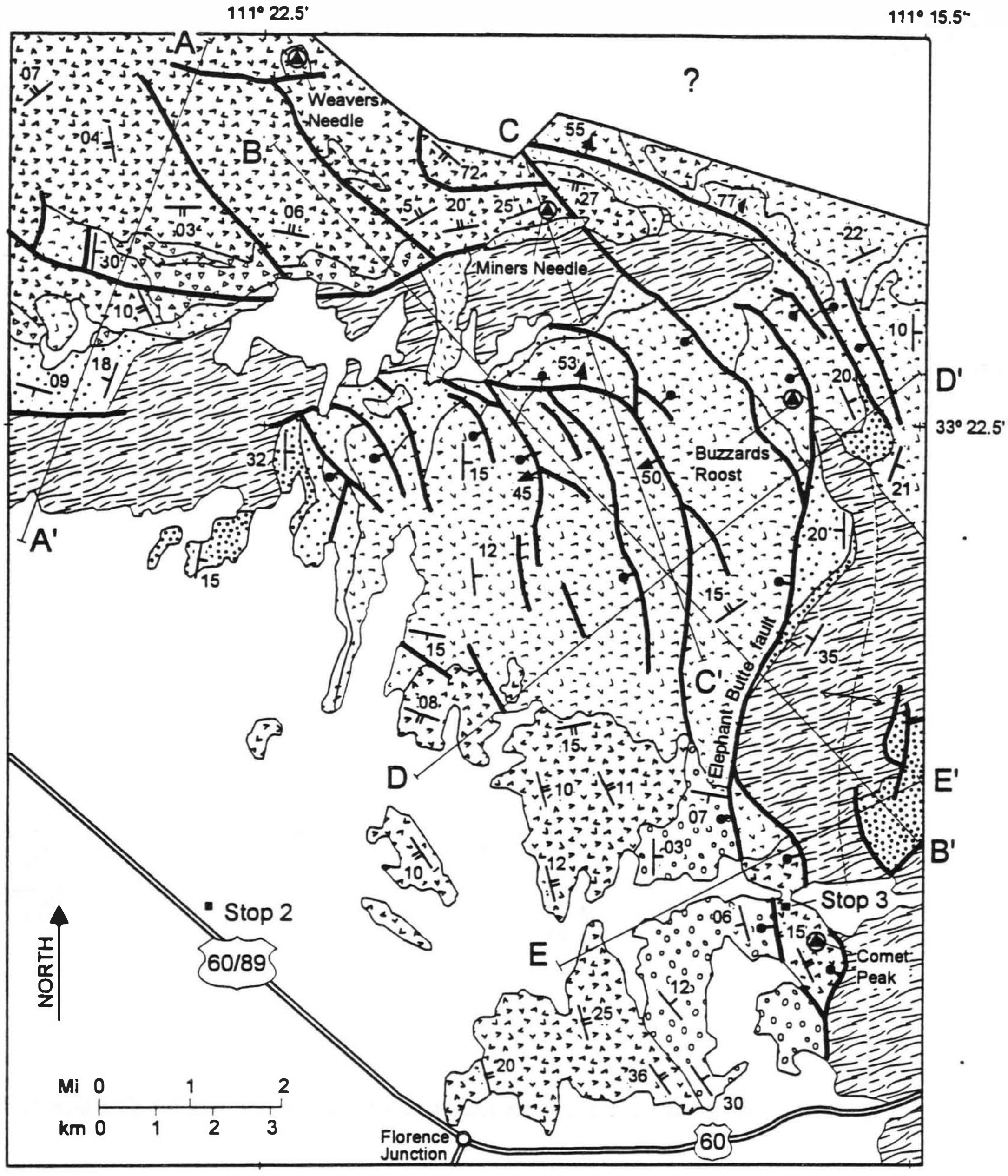


Figure 3.1. Explanation for generalized geologic map of southern Superstition Mountains and Whitlow Canyon area (Figure 3.2), and for cross sections in Figure 3.3





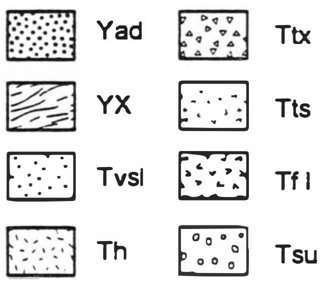


Figure 2.2. Generalized geologic map of southern Superstition Mountains and Whitlow Canyon Area, showing location of sections A-E, and Stops 2 and 3. Yad=Apache Group, YX=crystalline basement, Tvsl=lower volcanics and pre-volcanic conglomerate, Th=hypabyssal rocks (pre and post-Superstition Tuff), Ttx=cauldron breccias, Tts=lavas (pre and post-Superstition Tuff, Tfl=Superstition Tuff (and equivalents), Tsu=unit of Queen Valley.

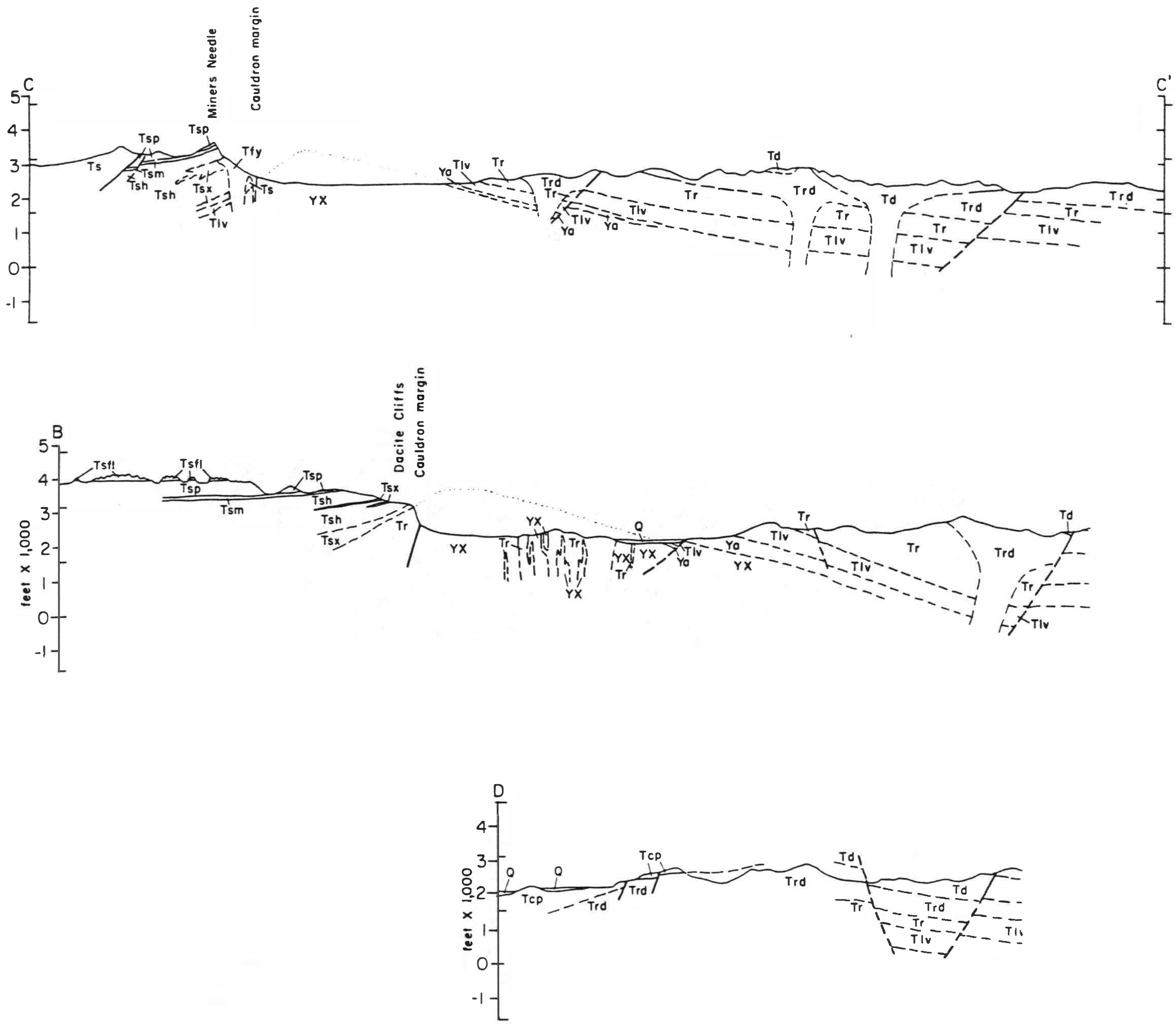


Figure 2.3. Cross sections of the southern Superstition Mountains and Whitlow Canyon area (left)

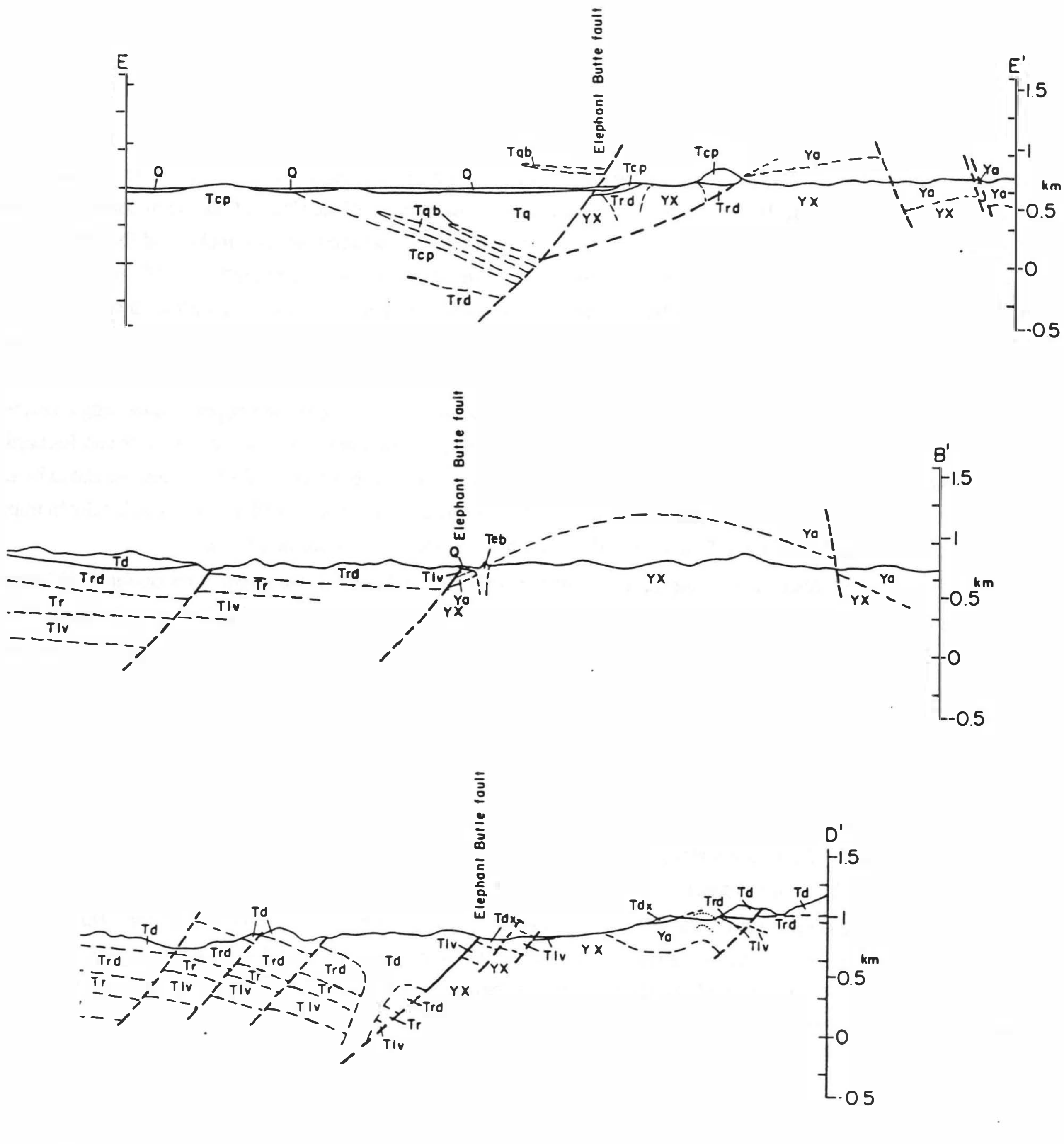


Figure 2.3. Cross sections of the southern Superstition Mountains and Whitlow Canyon area (right)

Normal faulting in the Whitford Canyon area northwest of Superior, Pinal County, Arizona

Jon E. Spencer and Stephen M. Richard, Arizona Geological Survey

The Concentrator fault is a major west-dipping normal fault that extends along the east side of the town of Superior [Peterson, 1969]. This fault extends southward toward the San Pedro River valley where it is linked to an extensive system of normal faults [Dickinson, 1991]. In the Superior area the footwall block of the Concentrator fault consists of a sequence of middle Proterozoic Apache Group strata and associated diabase, Paleozoic sedimentary rocks, and the Miocene Apache Leap Tuff. This sequence dips gently to moderately eastward and forms the prominent bluffs east of town. To the north early Proterozoic Pinal Schist is exposed beneath the Apache Group. Exposures of the hanging wall block consist of Miocene conglomerate in the area around Superior. The mill and smelter and a few homes are built on this conglomerate, but most of the town is on overlying, unfaulted Quaternary alluvium.

The concentrator fault extends northwestward from Superior to the west edge of the Superior quadrangle (Peterson, 1969) where it continues into upper Whitford Canyon in the Picketpost Mountain quadrangle (Spencer and Richard, 1995). The Apache Group and associated diabase are exposed in the hanging-wall block of the fault and are truncated by the fault to the north. The fault extends into an area where Pinal Schist forms both hanging-wall and footwall blocks in upper Whitford Canyon and Spencer and Richard (1995) were not able to follow its trace in this area.

The hanging-wall block of the Concentrator fault forms the footwall block of the Roblas Canyon fault. Where exposed, the Roblas Canyon fault juxtaposes moderately east-tilted Apache Group and diabase and Paleozoic strata with underlying Pinal Schist. The Roblas Canyon fault projects southeastward toward the town of Superior but is buried by Miocene conglomerate. Most likely it is a branch of the Concentrator fault.

The west-dipping Concentrator fault north of Superior and the Roblas Canyon fault separate three east-tilted fault blocks. To estimate total displacement on the two faults, a cross section was drawn across the faults (azimuth 106°) perpendicular to the north to east-northeast strike of beds. Restoration of faults to realign bedded units indicates that an area now 10.3 km wide was originally 5.2±1.0 km wide. Displacement on the Roblas Canyon fault is slightly greater than on the Concentrator fault. Restoration along a cross section oriented at less than 90° to the strike of beds would require greater displacement, so the 5 km of extension determined here is a minimum.

In general, there is no evidence for significant Laramide deformation in the area around Superior. Tertiary volcanic and sedimentary rocks were deposited across a surface of gently dipping Paleozoic and middle Proterozoic strata that was not significantly affected by Laramide or older faulting or folding. Laramide mineralization at Superior was apparently not localized by Laramide or older Mesozoic structures.

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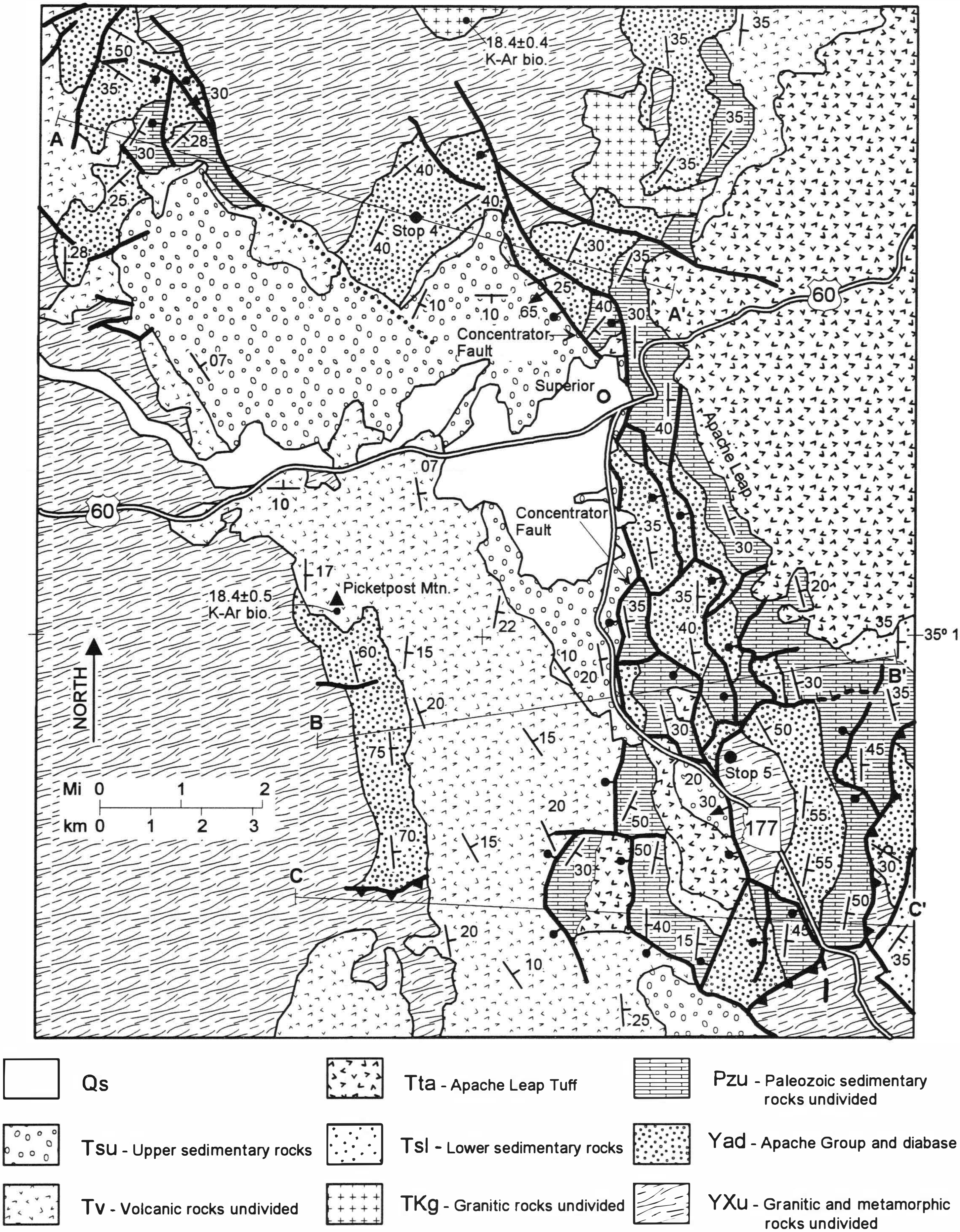

Figure 3.1 Generalized geologic map of Teapot Mountain-Picketpost Mountain area. Cross sections for stops 4 and 5 are located on this figure.

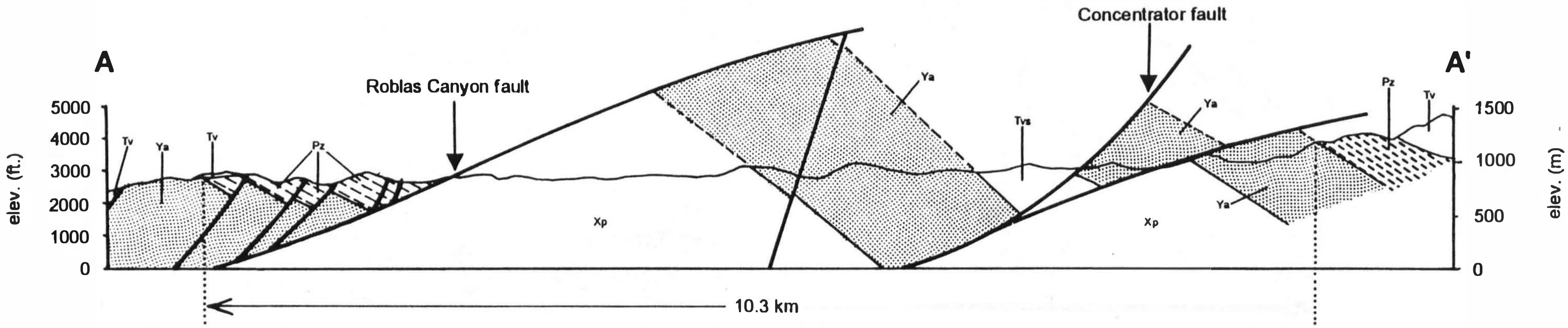

Figure 3.2

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Cross sections of Teapot Mountain Quadrangle, Pinal County, Arizona

Stephen M. Richard and Jon E. Spencer

Two cross sections were constructed across the Teapot Mountain quad and parts of the adjacent Mineral Mountain and Sonora quadrangles. The sections were drawn perpendicular to the average strike to tilted upper Proterozoic, Paleozoic and Tertiary strata along the section line, based on the assumption that this is a good estimate of the regional extension direction. To the extent that this assumption is valid, displacement along Tertiary normal faults in the section will be entirely within the section, and the sections can be reconstructed to their pre-extension geometry by realigning originally horizontal marker horizons in the section. The cross sections were reconstructed in two steps in order to determine that the sections are balanced, i.e. that area in the cross section is conserved (at least approximately) during the extension event.

The first step was to reconstruct the base of the Apache Leap tuff, or the base of Tertiary strata where the Apache Leap tuff is absent, to a horizontal datum. This assumes very little relief on the topographic surface blanketed by the Apache Leap tuff in the line of the cross section. In light of the abundant evidence for pre-Apache Leap faulting, this assumption is probably not entirely valid, but serves as a simple starting point. The apparent displacement that occurred after deposition of the Apache Leap tuff is generally small, except for the poorly understood fault system between the Dripping Spring Mountains and Teapot Mountain (section B-B'). The magnitude of extension indicated by post-Apache Leap faults is small relative to the pre-Apache Leap deformation (see below). The several thousand feet of present structural relief on the pre-Apache Leap unconformity is probably significantly larger than that resulting from the pre-tuff landscape, and is interpreted to be largely the result of faulting.

The second step in the reconstruction is to restore the Apache Group and overlying Paleozoic strata to horizontal. These strata in the north central part of the Teapot Mountain Quad, along section B-B' can reasonably be assumed to have been originally contiguous. In the longer section C-C', some interpretation had to be made as to the relationship of Apache group strata in the steeply east-tilted section south of Picketpost Mountain (west end of cross section) and the gently west-dipping section in the Dripping Spring Mountains (east end of cross section) to those in the Teapot Mountain Quadrangle. This interpretation hinges on the relationship between thrust faults in the central and western part of this section line. As discussed below ("Thrust faults" section), our working hypothesis is that these thrust faults are all parts of a single fault, and Apache Group and Paleozoic strata in Section C-C' are all in the footwall of this structure, thus reconstructing to a horizontal layer cake.

Magnitude of extension

Extension was calculated by measuring the map (horizontal) distance between material points in the cross sections in their present and reconstructed positions. The area of the sections can be divided into four extension domains: 1) the Sleeping Buffalo domain west of the Concentrator fault system; 2) the central domain, tilted Paleozoic strata between the Concentrator fault and the Teapot Mountain tilt block; 3) the Teapot Mountain block, bounded on the east by the Devil's Canyon fault system; and 4) the Dripping Spring Mountains, east of the Devil's Canyon fault. Section B-B' crosses domains 1 and 2, and section C-C' crosses all 4 domains.

	extension (%)					length change (km)				
domain	1	2	3	4	total	1	2	3	4	total
B-B'										
pre Tal	153%	85%			111%	3.0	2.7			5.7
present	3%	7%			5%	0.1	0.4			0.6
total					**122%**					**6.3**
C-C'										
pre Tal	58%	36%	50%	3%	30%	1.5	1.4	1.3	0.2	4.3
present	6%	5%	0%	-5%	1%	0.2	0.3	0.0	-0.3	0.2
total					**32%**					**4.5**

Table 1. Extension summary for cross sections.

Extension values measured from the reconstructed sections are summarized in Table 1. The relative extension, and absolute magnitude of extension across section B-B' is significantly greater than that for section C-C', even though B-B' does not include extension on the Devil's Canyon fault. This change in extension (1.8 km difference, section lines approximately 5 km apart) would produce about 20° of relative rotation (change in hanging wall strike) if accommodated by a scissors-like displacement increase. Alternatively displacement may have been significantly underestimated on faults beneath the Sleeping Buffalo basin in section B-B' (domain 1), in which case the Apache Group strata south of Picketpost Mountain would reconstruct to the hanging wall of the Walnut Canyon fault and the Mineral Mountain thrust would have to be a structurally higher thrust. A third possibility is that pre-Apache Leap normal faults in section B-B' may be significantly more gently dipping.

Discussion of Section lines

The present dip of faults was determined where possible by drawing structure contours on the fault surface based on its outcrop trace. These constructions generally indicate that normal faults older than the Apache Leap tuff cut across bedding at angles of 45 to 80°, while faults younger than the Apache Leap tuff cut across the tuff at angles of 60 to 85°, suggesting that the older faults initiated at generally lower dip. The geometry of the abundant diabase sills in the Apache group has only been shown in some detail near surface outcrops. In the more interpretive subsurface parts of the sections, and in the reconstructions, the Apache Group and diabase are shown as a single unit.

In section B-B', a buried fault beneath the Sleeping Buffalo basin has been inferred in the section line; this fault does not change the estimated extension, but results in a thinner Tertiary section in the basin. Pre-Apache Leap faults were cut at a high angle (60-75°) by post Apache Leap tuff normal faults.

Several interpretations made in section C-C' should be mentioned:

- Reverse-drag bending of fault blocks above listric normal faults has been inferred in two places. Near the east end of the section in the Mineral Mountain quadrangle, Apache Leap tuff crops out at a lower elevation than would be projected from the base of the Tertiary section to the east. This relationship suggests post-Apache Leap bending of this fault block during displacement on the southern continuation of the Concentrator fault, which bounds the eastern side of the Sleeping Buffalo Basin. The increase in dip of Paleozoic strata eastward across the stack of fault blocks in the central part of the section line is attributed in small part (~15°) to post-Apache Leap reverse drag on the young fault bounding the eastern side of the Teapot Mountain basin.
- The Livingston and School reverse faults on the north side of the Ray Mine and north of there along Mineral Creek are interpreted as anti-listric (steepening downward) reverse faults related to post-Apache Leap bending of the crust between the east-dipping Teapot Mountain block and west-dipping Dripping Spring block.
- The dip of Naco Formation strata decreases eastward across the fault block in the headwaters of White Canyon. Similar decrease of eastward dip, and even reversal to westward dip, is observed in Tertiary strata south of these Naco Formation outcrops progressively closer to the southern Concentrator/ northern Copper Butte, post-Apache Leap fault system. This geometry is interpreted to be related to normal drag along these faults,

shown in the cross sections to be accommodated at depth by an array of splays from the normal fault, which die out upward into folded strata in the Naco Formation.

- Dilation of the section related to intrusion of voluminous hypabyssal rhyolite in the western part of the section has not been reconstructed, but may account for ~1000' feet of additional extension.
- Post Apache Leap normal faults in this section intersect the pre-Apache Leap faults at angles of 25 to 40°.
- The age and kinematics of faults in the Dripping Spring Mountains at the eastern end of the section line are not known.

Thrust faults

The working hypothesis used to reconstruct Tertiary deformation is that the thrust(?) fault placing Pinal Schist on Apache group strata in the Mineral Mountain quadrangle (Mineral Mountain thrust), the Walnut Canyon thrust, and the Emperor fault in the Ray Mine are all part of a single Laramide fault system that trended WNW across the Mineral Mountain area, and curved to a more north south trend along the eastern side of the Dripping Spring Mountains, possible connecting southward with faults along the east side of the Santa Catalina Mountains. The transport direction on this fault system is not well constrained. The northward decrease in stratigraphic separation along the Walnut Canyon thrust, suggestive of a displacement component to the north, may represent the tip of a thrust fault. The axis of the major fold in Apache Group strata along Walnut Canyon appears to plunge to the southeast, suggesting an east to northeast vergence for this structure when untilted. The Mineral Mountain and Emperor thrusts are presently sub-horizontal, but cut up section in footwall Apache Group strata to the east. The Walnut Canyon thrust is presently moderately to steeply dipping, but is nearly concordant with bedding in the Naco Formation. The Mineral Mountain and Emperor thrusts represent deeper parts of the fault zone, where it was cutting up section at 30 to 40° across Apache Group strata, and the Walnut Canyon thrust represents a structurally high part of the fault where it paralleled bedding in the footwall.

No similar structure is present along strike in the Dripping Spring Mountains. Thus, the strike of the thrust fault must have changed from WNW to more north-south in the vicinity of the Ray Mine. The absence of similar Laramide thrust structures to the north between Superior and Globe, and presence of Laramide thrust faults to the south on the east side of Santa Catalina Mountains [e.g. Bykerk-Kauffman and Janecke, 1987] suggests that the thrust system curved to the south along the Gila River. This thrust fault would have broken the earth's surface west of and above the present Dripping Spring Mountains.

This hypothesis implies that Apache group strata south of Picketpost Mountain, in the Teapot Mountain quad and in the Dripping Spring Mountains are all in the footwall of this fault, and should reconstruct to a subhorizontal layer-cake before the onset of middle Tertiary extension. The large expanse of Pinal Schist, Oracle Granite, and Laramide igneous rocks from this thrust fault system south to the vicinity of the Gila River represents the hanging wall of this thrust system, which had its cover of Paleozoic and upper Proterozoic strata stripped in early Tertiary time.

Some of the rock mapped as Pinal Schist structurally above the Apache Group and Paleozoic strata on the Teapot Mountain quadrangle [Creasy et al., 1983] and Mineral Mountain Quadrangle [Theodore et al., 1978] is probably sedimentary breccia and rock avalanche deposits transported from the hanging wall of this thrust system onto its footwall during deposition of the Whitetail conglomerate (Oligocene-early Miocene). Whitetail conglomerate north of Copper Butte, along Walnut Canyon, contains abundant monolithologic breccia derived from Pinal Schist.

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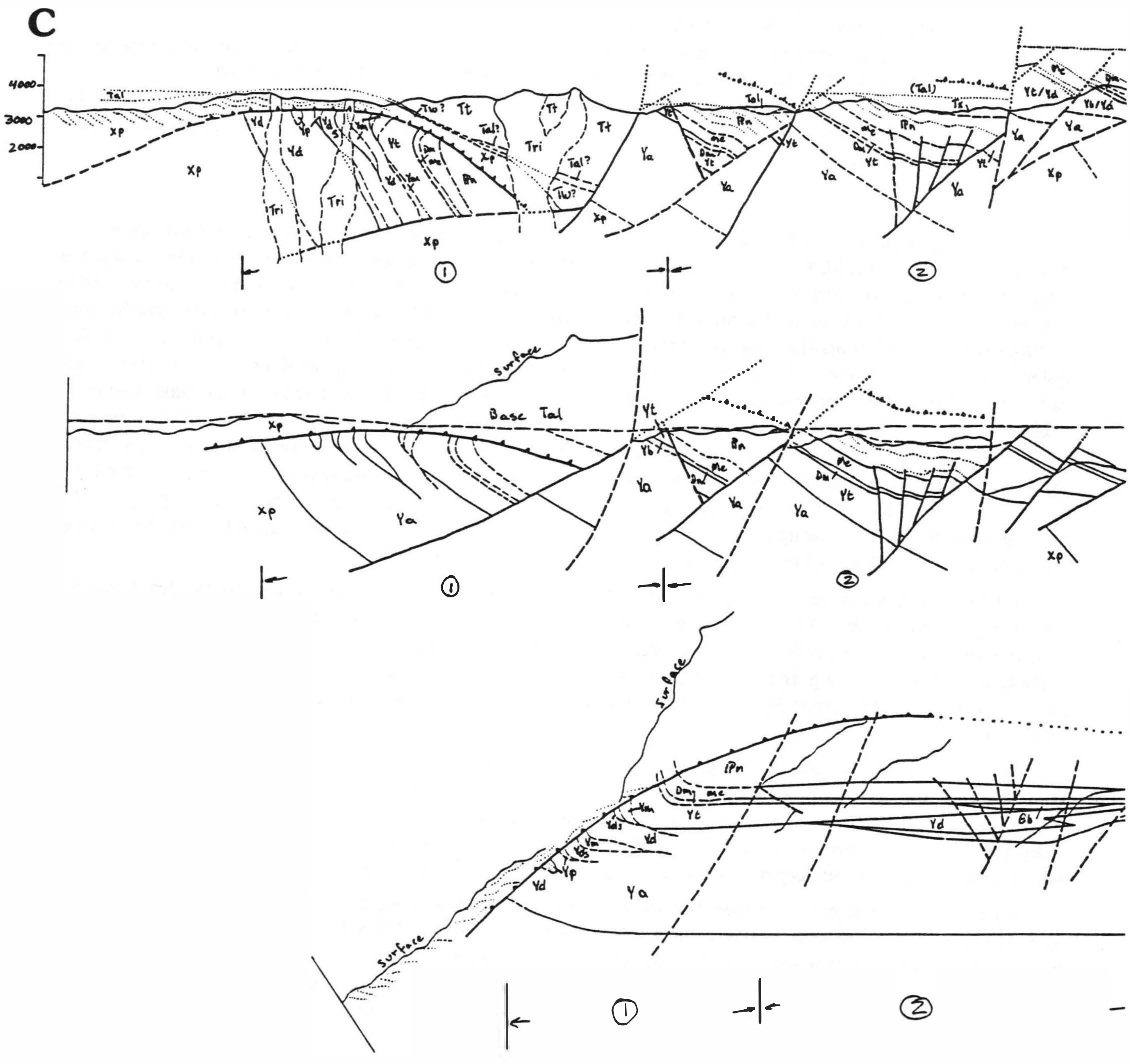

Figure 4-1. Cross section C-C', Sleeping Buffalo-Teapot Mountain-Scott Mountain. Location of section line shown in Figure 3-1. Abbreviations: Tr-Tertiary rhyolite lavas; Tt-Tertiary tuff and tuffaceous sediments; Tal-Apache Leap Tuff; Tw-Whitetail Conglomerate; Pn-Naco Formation; Me-Escabrosa Limestone; Dm-Martin Formation; Dmu undivided Martin and Escabrosa formations; Yt-Troy Quartzite; Yd-Late Proterozoic diabase, locally includes basalt lava and other formations of Apache Group; Ya-Apache Group undivided; Ym-Mescal Limestone; Yds-Dripping Spring Quartzite; Yp-Pioneer Formation; Xp-Pinal Schist.

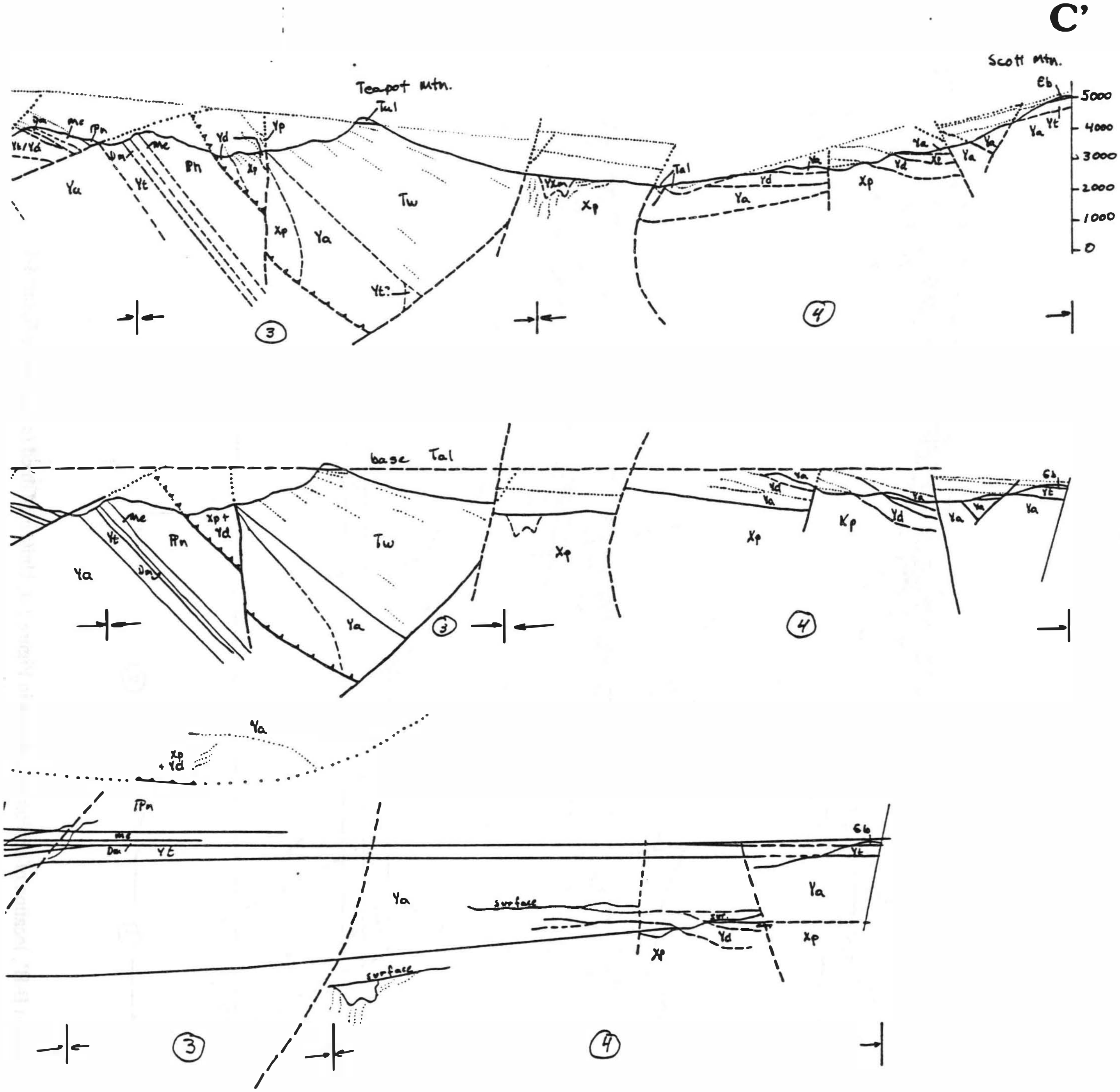
C'
Scott Mtn.
Teapot Mtn.
5000
4000
3000
2000
1000
0
Tw
Xp
Ya
Yt
Yd
Yp
base Tal
Xp + Yd
surface

Fig. 4.1 (right)

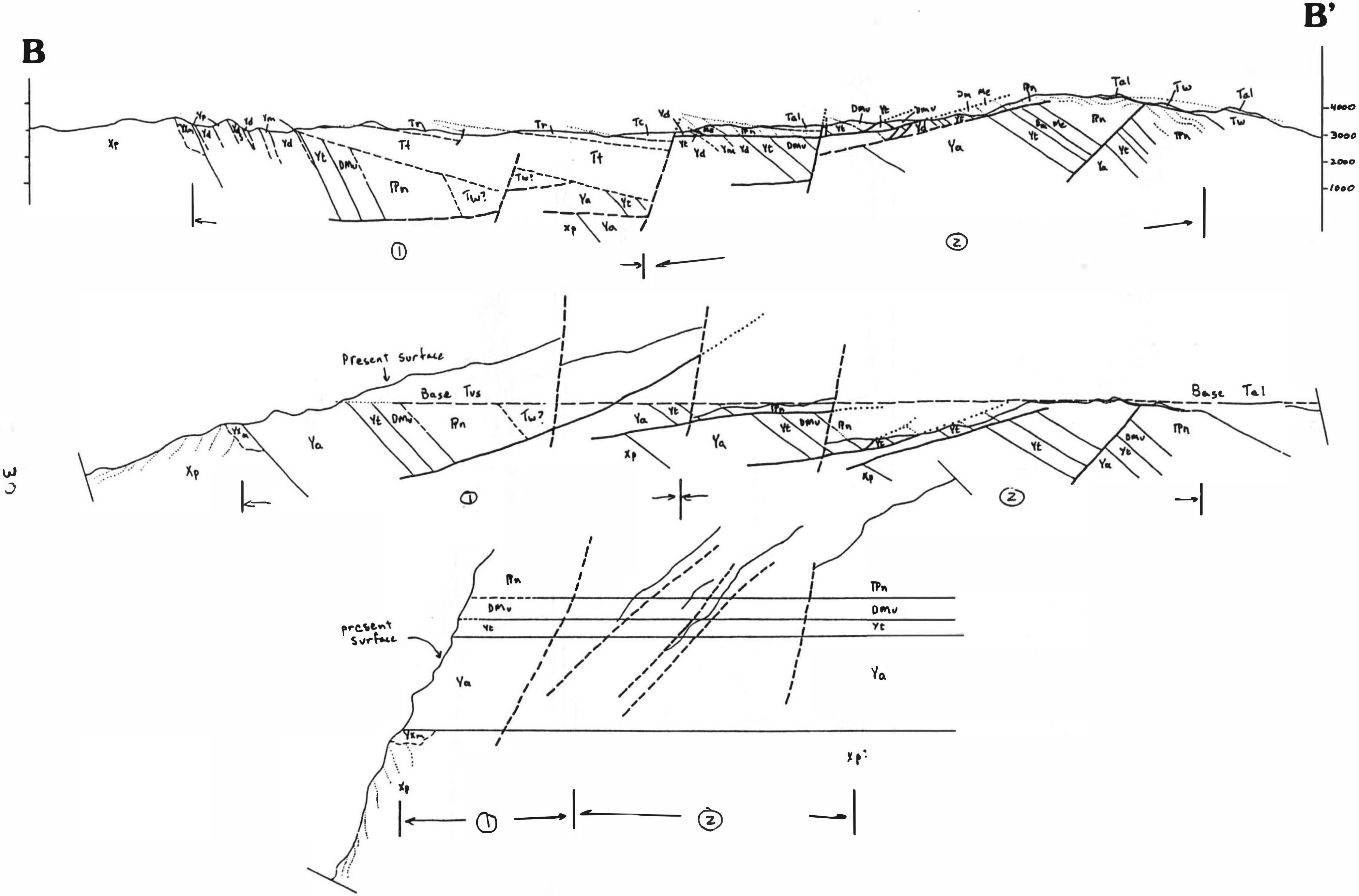

Figure 4.2. Cross section B-B', location of section line shown in Figure 3-1. Units explained in caption to figure 4-1.

TECTONICS UNDER THE APACHE LEAP TUFF,

The up and down interpretation by drill hole data, Pinal County, Arizona.
by James D. Sell

(Arizona Geological Society Spring Field Trip, 1996).

ABSTRACT:
A bevy of drill holes now permits a preliminary interpretation of the tectonic adjustments of the earth's crust, along with mapping around the Apache Leap Tuff plateau, east of Superior, Arizona, that has indicated a complex history of fault movement, erosion, and deposition, of units from the Precambrian time through the present.

The outcropping units and their tectonic displacements have been clearly discussed by Hammer, Webster, and Lamb (1962), for the zone west of the Apache Leap enscarpment. A more detailed discussion was presented by Hammer and Peterson, 1968, for the units in and around the Magma mine.

Peterson's, 1962, 1969, publications, also discussed and mapped the faulting, erosional contacts, intrusion along faulting by the Precambrain diabase, and the continued faulting after the diabase implacement, the pre-Paleozoic erosion surface, and the pre-Whitetail conglomerate erosion surface, to indicated a very tectonic active district from Precambrian time to the present.

The drill holes now available for interprepation has extended our knowledge of the tectonic history under the Apache Leap plateau, east of Superior. Figure 1 (derived from Figure 6, Sell, J.D., 1995), contains the drill holes used in the construction of four lines across the plateau. Line 1, northern, extends eastward from the west edge through drill holes DCA-1A and A-1 to Pinal Schist in Powers Gulch. The central Line 2 extends from the west side at Silver King eastward through drill holes M-1A, DCA-3A, AI-1, and LB-4 to the Schultze Granite intrusive. The southern Line 3 extents from the Concentator Fault eastward through Magma Shaft # 6, then drill holes A-4, AOF-1, and MS-1 to the Pinal Schist on the flanks of the Pinal Mountains. The north-south Line 4 extends southward from DCA-1A (Line 1), through M-1A (Line 2), hole A-7, A-4 (Line 3) , holes A-3, MJ-1, and DC-1 and off the plateau to the southwest into Pennsylvanian Naco Formation.

<u>Northern Line 1</u>:
On the west, the line 1 starts in Pinal Schist, then up through the Precambrian Apache Group, across the Martin and Escabrosa limestone, with cover by the Whitetail Conglomerate, the Earlier Volcanics, and the Apache Leap Tuff. The section from the west to hole DCA-1A is located on the Haunted Canyon quadrangle (Peterson, D.W., 1960). Note that the Precambrian Troy Quartzite and/or Cambrian Bolsa Quartzite has been eroded from the sequence, as well as the Naco Limestone and perhaps part of the Escabrosa, by pre-Paleozoic and pre-Tertiary erosion, before being covered by Tertiary units. Drill hole DCA-1A penetrated the Tertiary volcanic series, the Whitetail Conglomerate, then the Naco, Escabrosa, and Martin limestones of Paleozoic age, and terminated in Precambrian Troy Quartzite. As drill hole DCA-1A found, the

Naco Limestone is found below the Whitetail Conglomerate to the east as far as the Devils Canyon Fault in the down-dropped block. Further east in drill hole A-l, only the Apache Leap Tuff, a brecciated block of Pinal Schist and in-place Pinal Schist was found. The movement on the Devils Canyon fault was in early Tertiary, of pre-Whitetail time, as assuming a plus thousand feet thickness of Naco Limestone, found regionally, and only finding some 329 feet in hole DCA-1A, it suggests that erosion was active on the west side of the fault, prior to the start of the Whitetail Conglomerate deposition. The debris for the Whitetail is of the total Paleozoic and Precambrian sedimentary, plus diabase, and Pinal Schist sections. No Whitetail nor Earlier Volcanics were found in the eastern drill hole, and the Tertiary Apache Leap Tuff was deposited on Precambrian Pinal Schist breccia. Total movement on the Devils Canyon Fault is probably in excess of 8000 feet along Line 1, west side down.

<u>Central Line 2:</u>

On the west, Line 2 starts in the Silver King quartz diorite of Laramide age (Balla, 1972), extends eastward through the Precambrian Pinal Schist, the Precambrian Apache Group sequence, and over the Paleozoic Bolsa Quartzite, Martin and Escabrosa limestones which are covered by the Tertiary Earlier Volcanics. Both the Naco Limestone and the Whitetail Conglomerate are missing in this section. Further east, the drill hole M-1A cored through the Apache Leap Tuff, Earlier Volcanics, and the Whitetail Conglomerate before intersecting the Permian Supai red beds and terminated in Pennsylvanian Naco Formation. This discovery of Permian Supai is of importance as no Permian units were known in this part of Arizona. The last Permian red beds are seen north of the Salt River. Permian is known in eastern Arizona. Obviously, the pre-Whitetail erosion was active to erode out all the Naco on the escarpment side of the plateau. Eastward, across the Devils Canyon Fault, a thick section of Tertiary Apache Leap Tuff, Earlier Volcanics, and Whitetail Conglomerate were preserved, with the Whitetail resting on Precambrian Pinal Schist, and further east on Laramide quartz monzonite. Peterson, 1968, indicates several hundred feet of displacement in the Apache Leap Tuff in this area, across the Devils Canyon Fault, where gray unit is adjacent to white unit. Thus, movement along the Devils Canyon Fault continued after the cooling of the units. Of course it is unknown how much Pinal Schist has been removed on the east side, but it must have been a substantial amount as no Apache Group is known to the east as far as Pinal Mountain, and again, a mininum of 8000 feet of total displacement must be on the Devils Canyon Fault..

Continuing eastward, drill hole DCA-3A cut the three Tertiary units and in the lower part of the Whitetail Conglomerate two slide blocks were cored with conglomerate below each slide block. The first block contained Pinal Schist intruded by Tertiary Schultze Granite, with the second block containing Tertiary quartz monzonite. The coring then returned brecciated quartz monzonite bottomed by a flattish fault, then into Pinal Schist intruded by quartz monzonite. It is believed the "bedrock" brecciated quartz monzonite was emplaced from the southeast, and probably also the quartz monzonite slide block up in the Whitetail. The upper slide block of Pinal Schist intruded by Schultze Granite was probably emplaced from the east. The Rawhide Canyon Fault cuts the Whitetail Conglomerate above the slide blocks, and early movement on this fault may have cut-away a toe to the uplifted block further east, and initiated the slide block movement. Further east the drill hole LB-4 cut a minor thickness of Apache Leap Tuff and a smell of Earlier Volcanics before entering the Laramide Schultze Granite which it bottomed in at considerable depth.

Southern Line 3:

On the west, Line 3 starts in Quaternary Gila Conglomerate, crosses the Concentrator Fault, then through a block of Apache Group, and Paleozoic sediments (Including the Escabrosa Limestone), crosses the Main Fault and back into Apache Group and up through Escabrosa Limestone at the Whitetail Conglomerate contact, as the line goes eastward. Further east, Magma # 6 Shaft was started in Apache Leap Tuff, then penetrated Whitetail Conglomerate, the Naco, Escabrosa, and Martin limestones, and Cambrian Bolsa Quartzite and bottomed in Precambrian Apache Group sediments cut by diabase. The westerly-trending Queen Creek is south of the section, and was influenced by the east-west faults in the area, and was active in helping to erode the Naco Limestone along the trend. This portion also shows the thin outcropping of Whitetail Conglomerate overlapping Escabrosa Limestone. Of the Whitetail outcrops mapped on the west side of the plateau, the two in this area are the lowest in elevation, indicating a major drainage to the west during Whitetail time.

A length of ten thousand feet east of Magma's No. 9 Shaft has sparce data, before drill hole A-4 is located. As shown in the Line 3 section, several north-trending faults are projected to the section, based on the mapping by Peterson, 1969, between Shaft No. 9 and A-4. Drill hole A-4 was started on the edge of Devils Canyon and penetrated Apache Leap Tuff, Earlier Volcanics, Whitetail Conglomerate, a thin piece of Mississippian Escabrosa Limestone, then cut a dipping fault, then into Precambrian Pinal Schist intruded by a Laramide age quartz monzonite. The fault is the Devils Canyon Fault projected from the surface. Near the base of the Whitetail, a slide block of brecciated Escabrosa Limesone was noted, with Whitetail between it and the in-place Escabroa below. It is believed that the brecciated Escabrosa was emplaced from the west, and that the thin (85-foot thickness) of in-place Escabrosa is in the upper two-thirds of the Mississippian section. Again, substantial erosion removed all the Naco Limestone from this area, and probably the upper part of the Mississippian. The projected faults may have been active in pre and early Whitetail time in order to strip the Naco and emplace the block of brecciated Escabrosa. To the east the section passes the Rawhide Canyon Fault and to drill hole AOF-1. The drill hole penetrated the Apache Leap Tuff and considerable Whitetail Conglomerate, under which was found Precambrian Pinal Schist intruded by diabase.

Further east is drill hole MS-1, which terminated in Apache Leap Tuff. Geophysical interpretation suggests some 2000 feet of Tuff underlain by a similar thickness of Whitetail Conglomerate before bedrock of Precambrian Pinal Schist may be found. Eastward, after passing a fault mapped on the east side of the Apache Leap Tuff, the Precambrian Pinal Schist intruded by Precambrian diabase of the Pinal Mountains, is found.

North-South Section, Line 4:

The line 4 ties the previous three section and is located west of the Devils Canyon Fault. On the north it starts at drill hole DCA-1A, which penetrated the Apache Leap Tuff, the Earlier Volcanics, the Whitetail Conglomerate and the bed-rock units of Naco, Escabrosa, and Martin limestones and bottomed in Precambrian Troy Quartzite. The next drill hole south is M-1A which penetrated the three Tertiary units, then into the Permian Supai red-beds and bottomed in Pennsylvanian Naco Formation. Within the upper portion of the Whitetail was a slide block of brecciated Tertiary quartz monzonite emplaced from the southeast. Assuming a regional thickness of Naco to be a thousand feet thick, then it is obvious that pre-Whitetail erosion eroded some thickness of Supai red-beds and much of the Naco between holes DCA-1A and M-1A.

Continuing south to drill hole A-7, where Apache Leap Tuff, a thinner sequence of Earlier Volcanics, an increase thickness of Whitetail was cored before the bedrock units of Permian Supai red-beds and Pennsylvanian Naco was encountered as the hole was terminated. The finding of Supai in the two holes over 3000-feet apart suggests the preservation of a considerable block before being covered by Whitetail. In hole A-7, a brecciated slide block of Tertiary Schultze Granite was found in the upper portion of the Whitetail.

Going south to drill hole A-4, it is projected that the east-west Conley Spring Fault passes between holes A-7 and A-4, and probably terminates eastward at the north-south Devils Canyon Fault. As discussed under Line 3, a block of brecciated Mississippian Escabrosa Limestone was found near the base of the Whitetail in hole A-4. In-place Escabrosa Limestone was found below the Whitetail. As expressed on Line 4, movement on the Conley Spring Fault must have been of considerable and varied activity. First, the south side must have been higher than the north side in order to strip the Supai, Naco and part of the Escabrosa from the south side, Then at a later date and pre-Whitetail time, the south side was dropped, but still above the projected Escabrosa on the north side. At the western escarpment, the Conley Spring Fault displaces Apache Leap Tuff five hundred feet, south side down. This is about the same displacement and same sense of displacement of the projected Whitetail-Supai contact on the north with the Whitetail-Escabrosa contact on the south. Thus, the large displacement suggested to bring the Escabrosa up on the south at pre-Whitetail time in order to erode the Supai and Naco on the south and preserve them on the north is an earlier displacement on the Conley Spring Fault. As Peterson's, 1962. mapping indicated, the east-west faults around Queen Creek, including the Magma fault, has had movement on them from Precambrian time on until Whitetail time, and it is not unreasonable to assume that such structures extend to the east.

Continuing south to drill hole A-3. Hole A-3 penetrated Apache Leap Tuff and into Whitetail Conglomerate. Near the bottom of the hole, a brecciated slide block of Precambrian diabase was found, with additional Whitetail below, in which the hole was bottomed. As the section indicates, the Earlier Volcanics do not extend as far south as drill hole A-3, and it is probable that in several hundred feet of additional drilling, the Escabrosa Limestone would be intercepted.

Further south is drill hole MJ-1. Starting in Apache Leap Tuff, the hole cut through Whitetail

Conglomerate, and around sea level, the hole penetrated the Naco, Escabrosa, and bottomed in Martin Limestone, some 1500 feet above the bottom of hole A-3! A Paleozoic high extends southward through drill hole DC-1, which ended in Naco, and to the outcropping Naco further south. This bed-rock high extends from the vicinity of the Belmont-Grand Pacific mines on the west, eastward to the Devils Canyon Fault. Peterson, 1969, indicates this high, as a window of Naco within the Apache Leap Tuff. As suggested in the section, the Precambrian Apache Group sediments and intruded diabase, was at a sufficient elevation to shed the brecciated block of diabase found in hole A-3.

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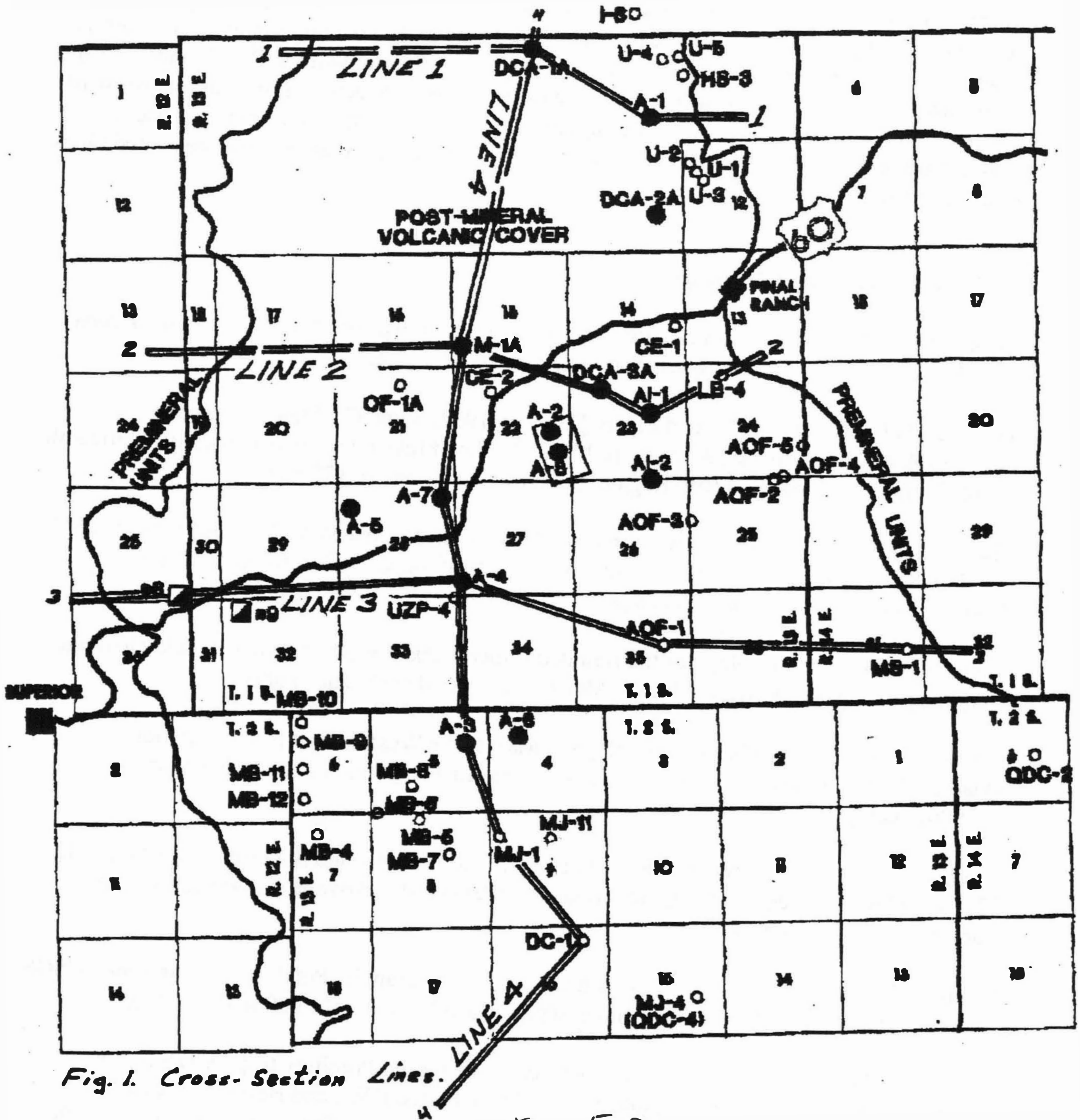


Fig. 1. Cross-Section Lines.

Fig 5-0

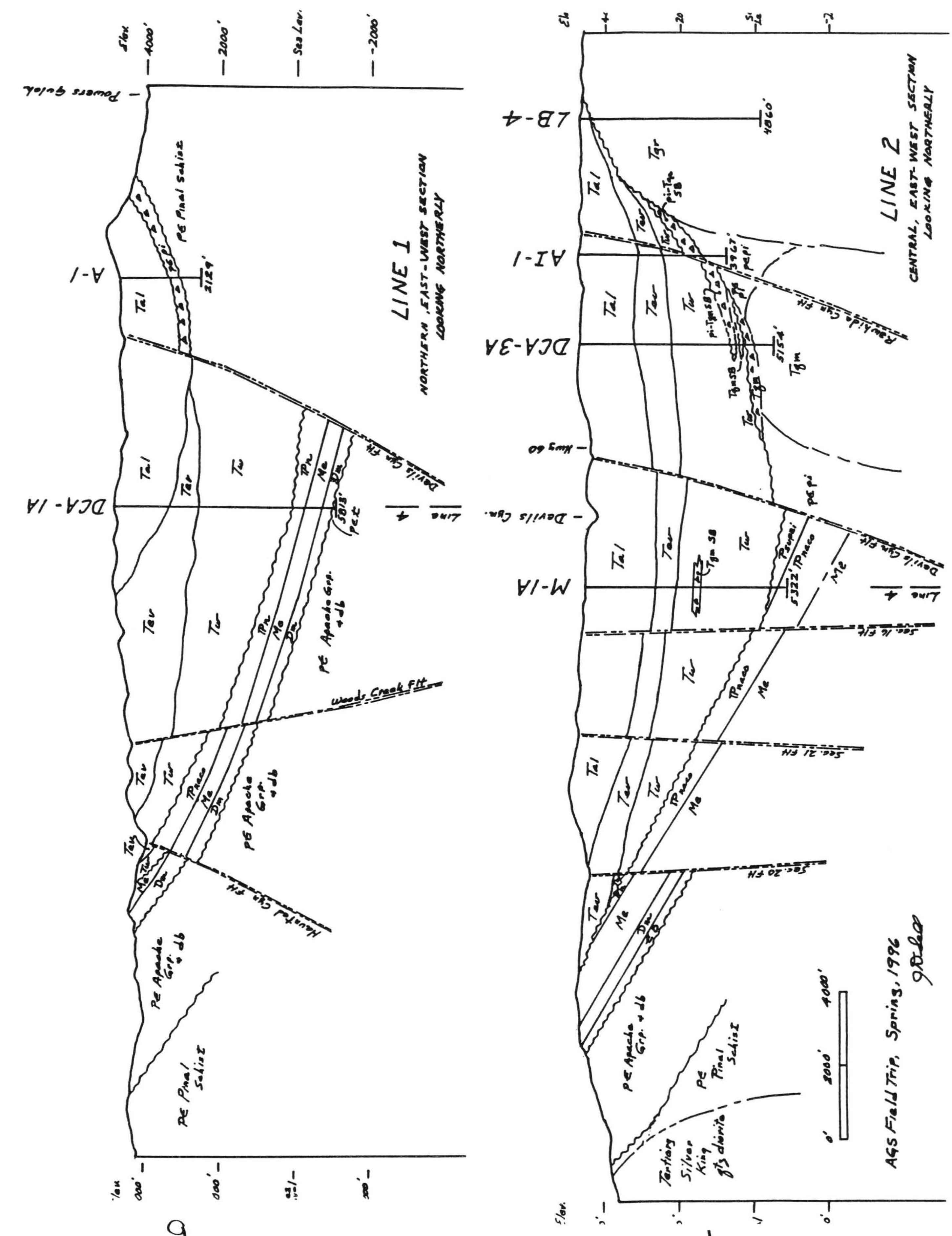
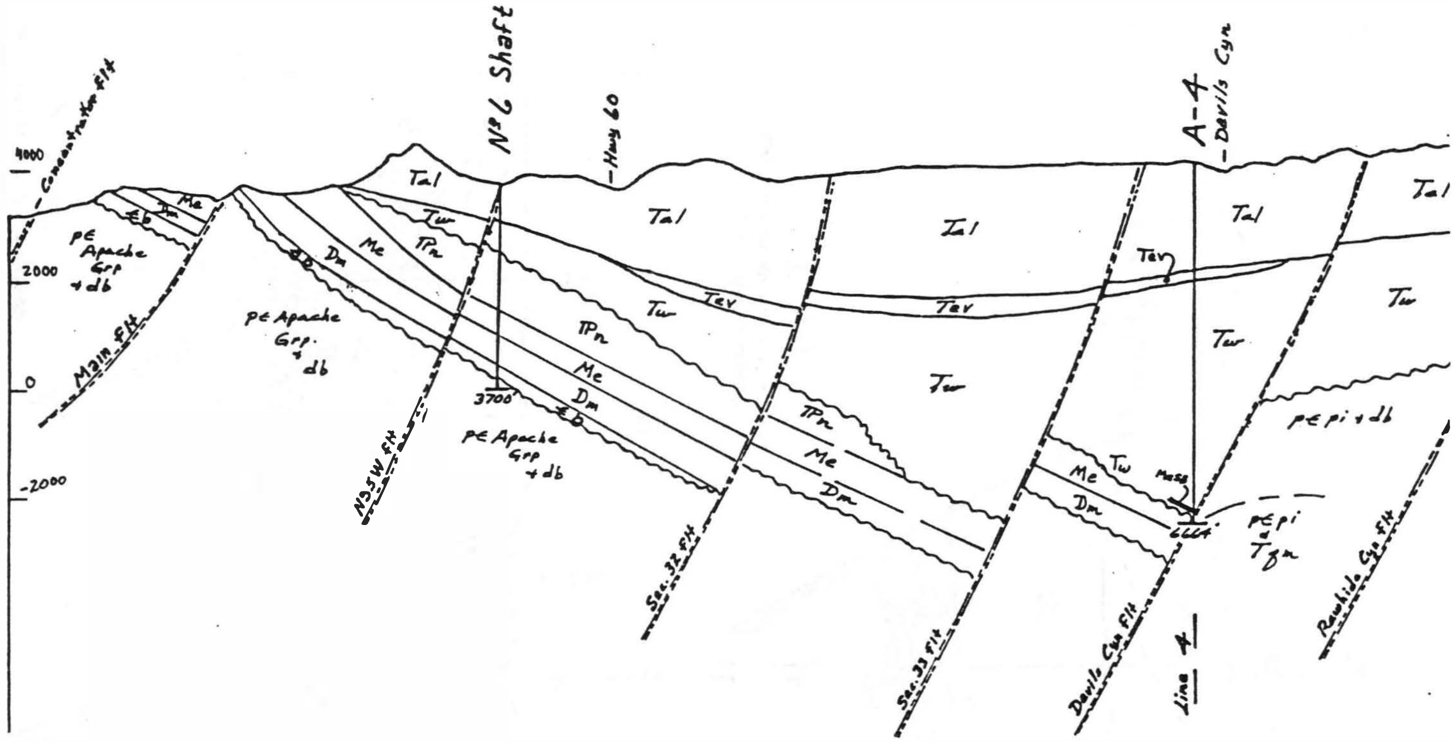
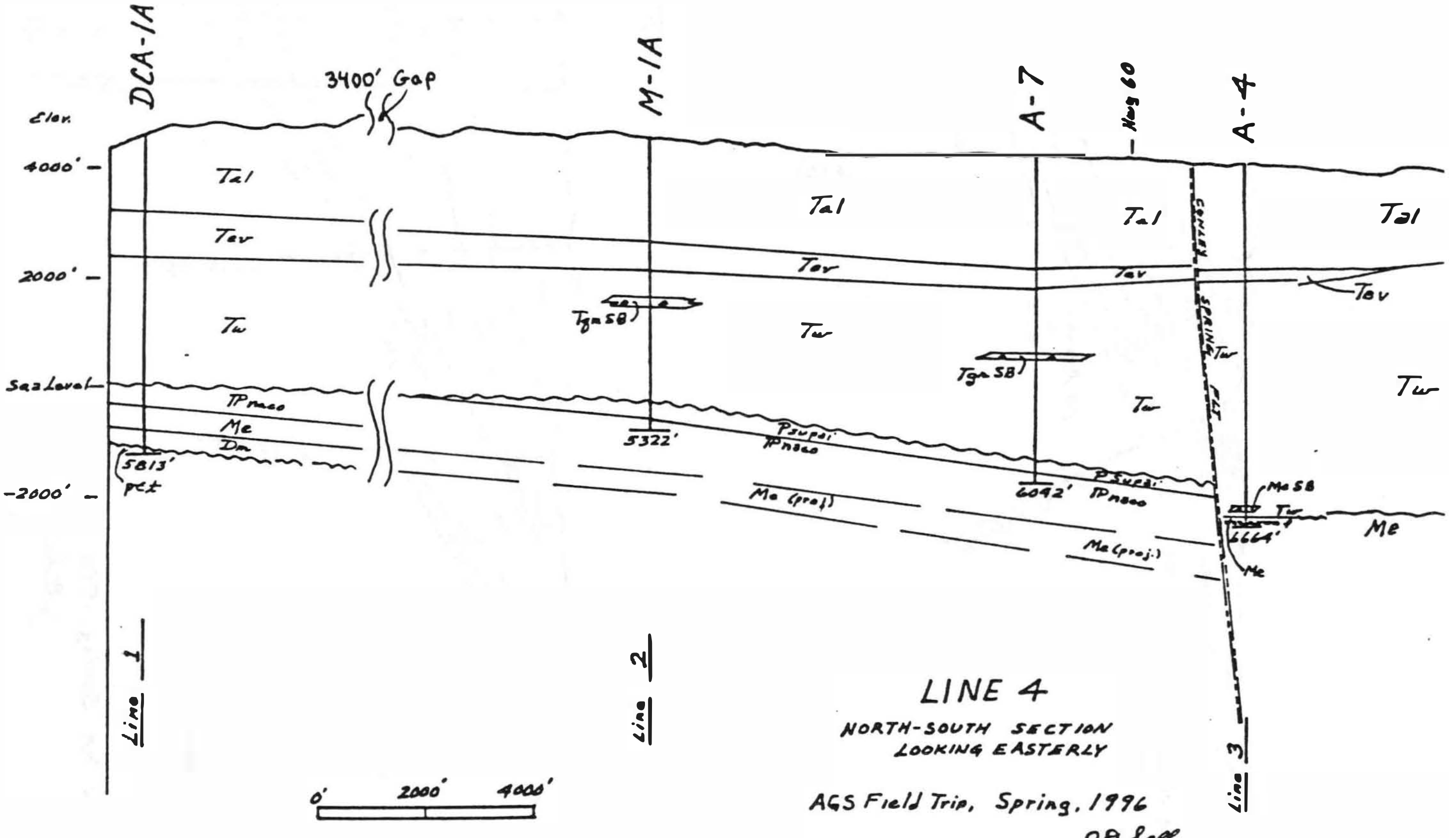

LINE 1
NORTHERN, EAST-WEST SECTION
LOOKING NORTHERLY
LINE 2
CENTRAL, EAST-WEST SECTION
LOOKING NORTHERLY
AGS Field Trip, Spring, 1996

Fig. 5-2

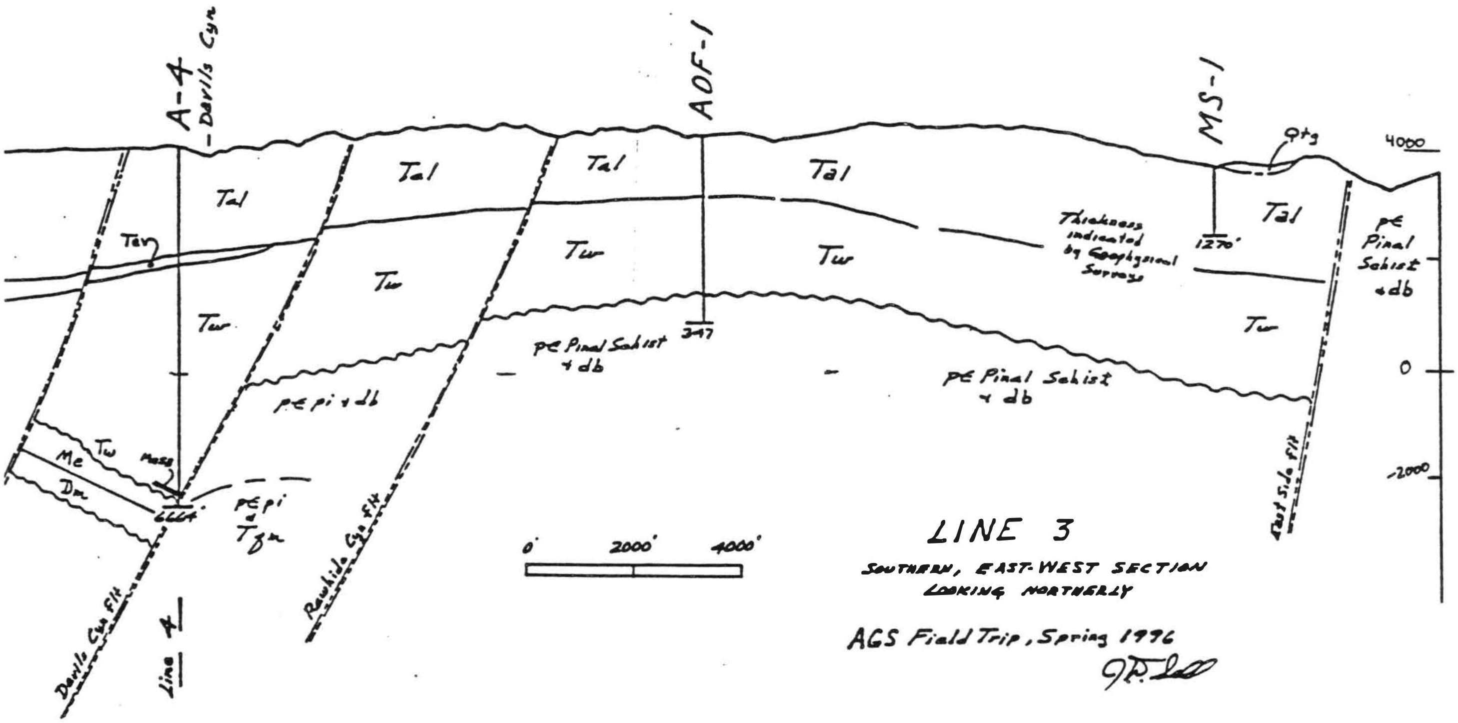


No 6 Shaft
Hwy 60
A-4
Davils Cyn
Concentrator flt
Main flt
pЄ Apache Grp + db
N35W flt
Sec. 32 flt
Sec. 33 flt
Davils Cyn flt
Rawhide Cyn flt
Line 4
Tal
Tw
Tev
TPn
Me
Dm
Єb
pЄpi + db
pЄpi Tgn
3700'
6664'
4000
2000
0
-2000



DCA-1A
3400' Gap
M-1A
A-7
Hwy 60
A-4
Elev.
4000'
2000'
Sea Level
-2000'
Tal
Tev
Tw
Tgn SB
TPnaco
Me
Dm
Psupai
5813'
pЄt
5322'
6042'
6664'
Me (proj.)
Me SB
Line 1
Line 2
Line 3
LINE 4
NORTH-SOUTH SECTION
LOOKING EASTERLY
0' 2000' 4000'
AGS Field Trip, Spring, 1996

Fig 5-3 (left)


A-4
Devils Cyn
ADF-1
MS-1
Qts
4000
Tal
Tev
Tw
Thickness indicated by Geophysical Surveys
1270'
pЄ Pinal Schist + db
347
pЄ pi + db
0
-2000
Me
Dm
6664'
pЄpi Tgm
0' 2000' 4000'
LINE 3
SOUTHERN, EAST-WEST SECTION
LOOKING NORTHERLY
AGS Field Trip, Spring 1996
Devils Cyn Flt
Line 4
Rawhide Cyn Flt
East Side Flt

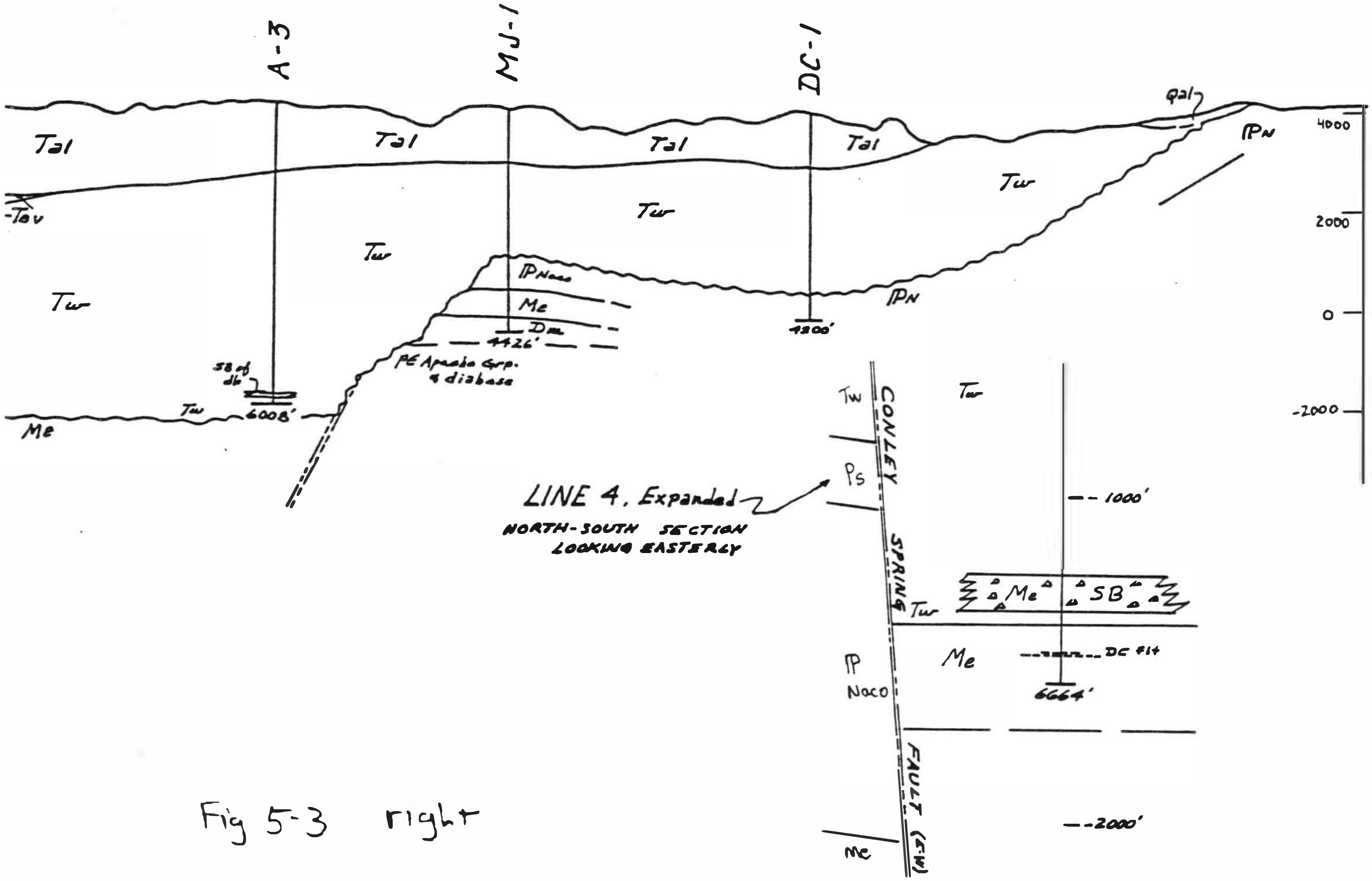

A-3
MJ-1
DC-1
Qal
Tal
Tev
Tw
IPN
IPNaco
Me
Dm
4426'
4200'
pЄ Apache Grp. + diabase
SB of db
6008'
4000
2000
0
-2000
LINE 4, Expanded
NORTH-SOUTH SECTION
LOOKING EASTERLY
CONLEY SPRING FAULT (EW)
Ps
SB
DC Flt
IP Naco
6664'
1000'
-2000'

Fig 5-3 right

Notes for the Arizona Geological Society Spring 1996 Field Trip

Tertiary Tectonics and Copper Mineralization
A transect from Casa Grande to Globe, Arizona

The Carlota Copper Project
Globe-Miami Mining District

The Carlota Copper Project is at the western end of the Globe-Miami Mining District, about 2 miles southwest of BHP Copper's Pinto Valley operation and 4 miles northeast of ASARCO's Superior East Project. The Carlota Copper Project comprises four copper deposits--the Carlota, Cactus, Eder North, and Eder South--with a combined mineable reserve of some 106 million tons grading 0.45 percent copper. The project will be exclusively a mine-for-leach operation, with copper recovery via SX-EW methods. Construction is scheduled to start during the fall of 1996.

The following pages present a description of the geology and mineralization of these four related deposits and include selected cross sections and other illustrations. A summary of some of the more relevant observations related to Tertiary tectonics and copper mineralization of the Carlota Project are summarized below:

Faults

Kelly Fault - This normal fault strikes west-northwest and defines the southwestern margin of the Carlota Graben. The Kelly Fault has at least 2,000 feet of dip slip (down to the northeast and right lateral offset). This fault zone is up to a hundred feet wide and generally dips some 65 to 75 degrees to the north. Significant movement along this fault is post-Apache Leap Dacite (17 my) and post-Carlota/Cactus mineralization, but possibly pre-Gila (5-8 my). The Kelly Fault is paralleled by the North Fault, which has much less offset and defines the northern extent of the Carlota Graben.

Cactus Fault - This low-angle normal fault is "scoop" shaped and was once likely very extensive but is now preserved only within the Carlota Graben. Displacement along this fault is probably at least 10,000 feet, but is uncertain due to a lack of offset marker beds, etc. Movement direction is likely upper block to the west based on the clast composition of the Cactus Breccia which suggests it may have been derived from the east. The Cactus Breccia is a subaerial rockfall avalanche deposit which is preserved almost exclusively within the Carlota Graben and is always underlain by the Cactus Fault.

Bundy Fault - This high-angle fault trends northeast and separates Precambrian-age diabase from Pinal Schist in the area south of the Kelly Fault. Displacement is likely at least 1,000 feet with probably a majority dip-slip component. There are no good constraints on age movements along this fault, except that it is cut off by the Kelly Fault.

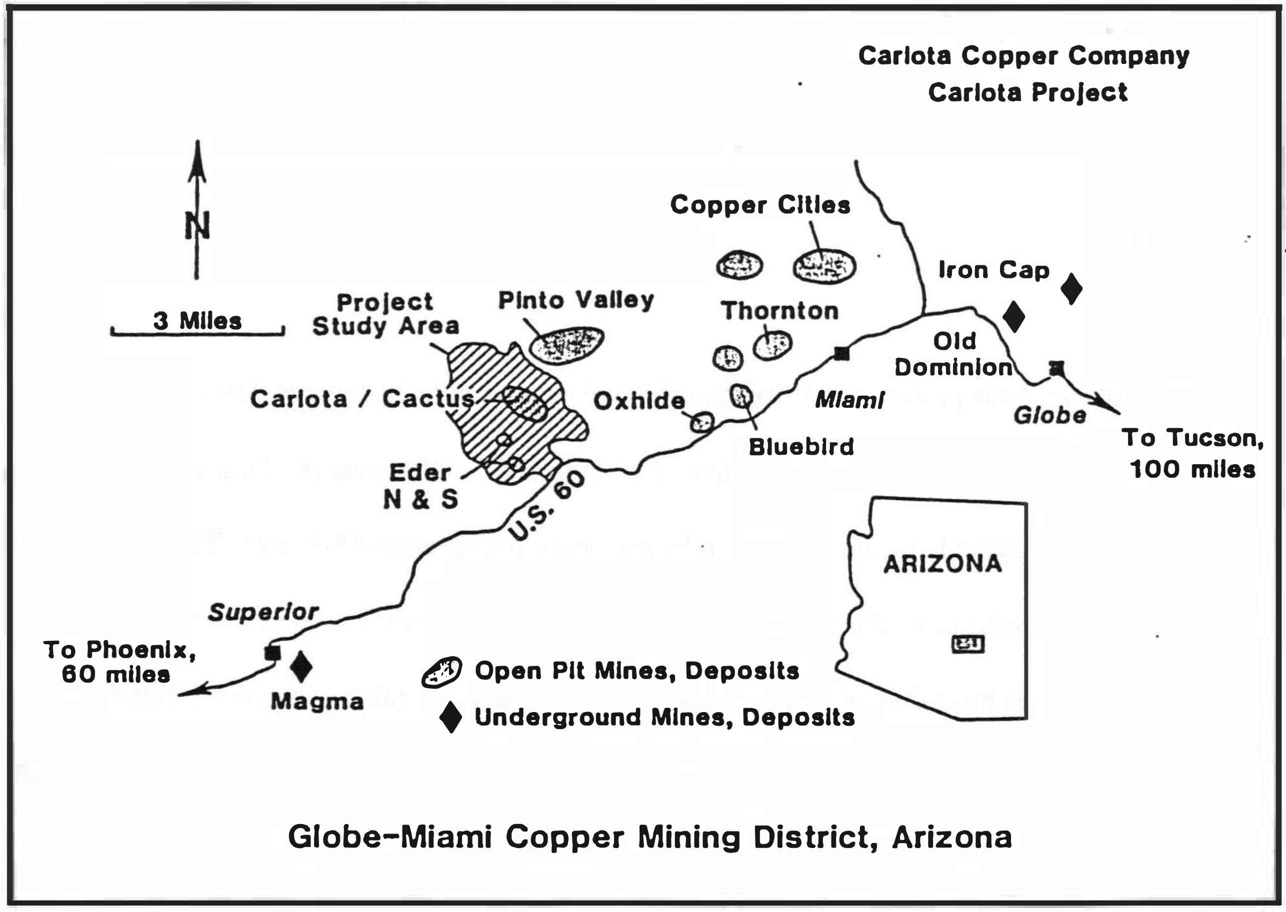
Mineralization

Mineralization at the Carlota/Cactus deposit is exotic in origin and post dates the derivation of the Cactus Breccia, the initial movement along the Cactus and Kelly Faults and, at least to some extent, the Apache Leap Dacite (17 my). Because of the general relationship of mineralization type (sulfide vs oxide) and distribution to the current water table, at least some redistribution (and mineralization?) is still taking place.

At the Eder North and South deposits, dating of the mineralized episode(s) is less constrained, but generally appears to be pre-Apache Leap Dacite.

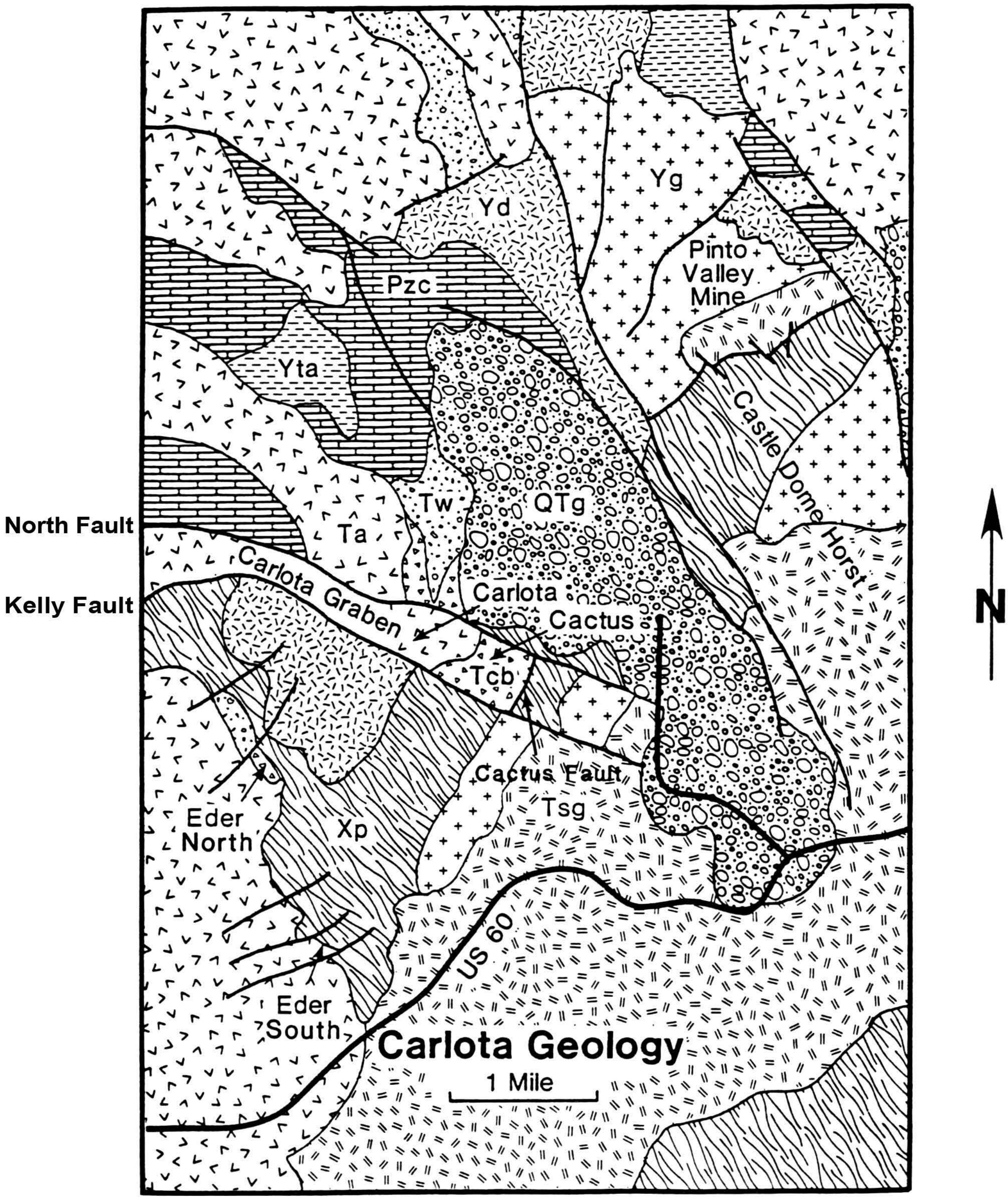
Tilting

Regional tilting in the project area is expressed in the approximate 25 degrees down to the west dip of the Apache Leap Dacite in the area of the Eder North and South deposits. This tilting episode is obviously post Apache Leap and appears to be pre-Gila Conglomerate (5-8 my). The westward tilt has affected mineralization at both the Eder South and Cactus deposits. The eastern portion of the Cactus deposit has been tilted upward and where above the water table,, chalcocite mineralization has been oxidized to malachite. In addition, some supergene enrichment has taken place at and slightly below the water table. The Apache Leap Dacite in this area also has a westerly dip with a dip reversal along a hinge line along the north projection of the Bundy Fault. A somewhat similar situation has affected mineralization at the Eder South deposit. Where protected from weathering by the overlying dacite, mineralization dips westward conformable to the dip of the dacite. To the east where the dacite has been eroded, weathering and remobilization of copper has taken place, and mineralization in this areas has a flat, non-dipping base (see cross section).



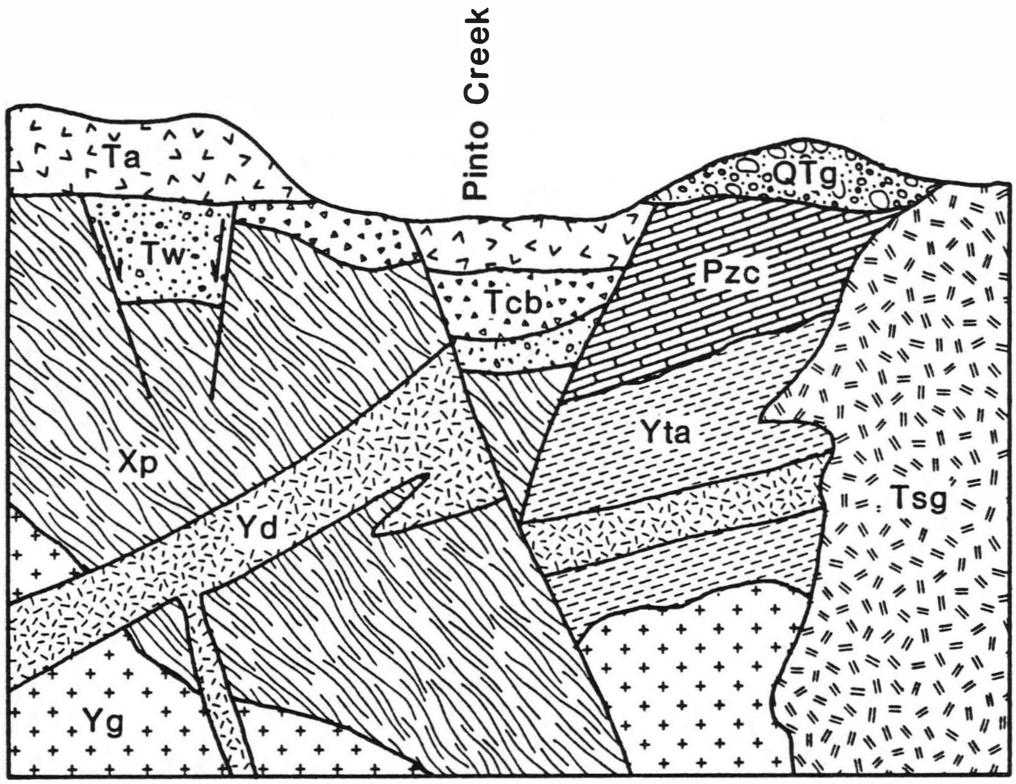
Carlota Copper Company
Carlota Project
N
3 Miles
Copper Cities
Iron Cap
Project
Study Area
Pinto Valley
Thornton
Old
Dominion
Carlota / Cactus
Oxhide
Miami
Globe
Bluebird
To Tucson,
100 miles
Eder
N & S
U.S. 60
ARIZONA
Superior
To Phoenix,
60 miles
Magma
Open Pit Mines, Deposits
Underground Mines, Deposits
Globe-Miami Copper Mining District, Arizona

Fig 6-1



Carlota Copper Company
Carlota Project
Fig. 6-2

Carlota Copper Company
Carlota Project



Schematic Geologic Section

Quaternary	Qtg	Gila Conglomerate
Tertiary	Ta	Apache Leap Tuff
	Tcb	Cactus Breccia
	Tw	Whitetail Conglomerate
	Tsg	Schultze Granite
Paleozoic	Pzc	Sedimentary (Carbonate) Rocks, Undiff.
Middle Proterozoic	Yd	Diabase
	Yta	Troy Quartzite, Apache Group
	Yg	Granitic Rocks, Undiff.
Early Proterozoic	Xp	Pinal Schist

Fig 6-3

Fig 6-4a

Carlota / Cactus Geology

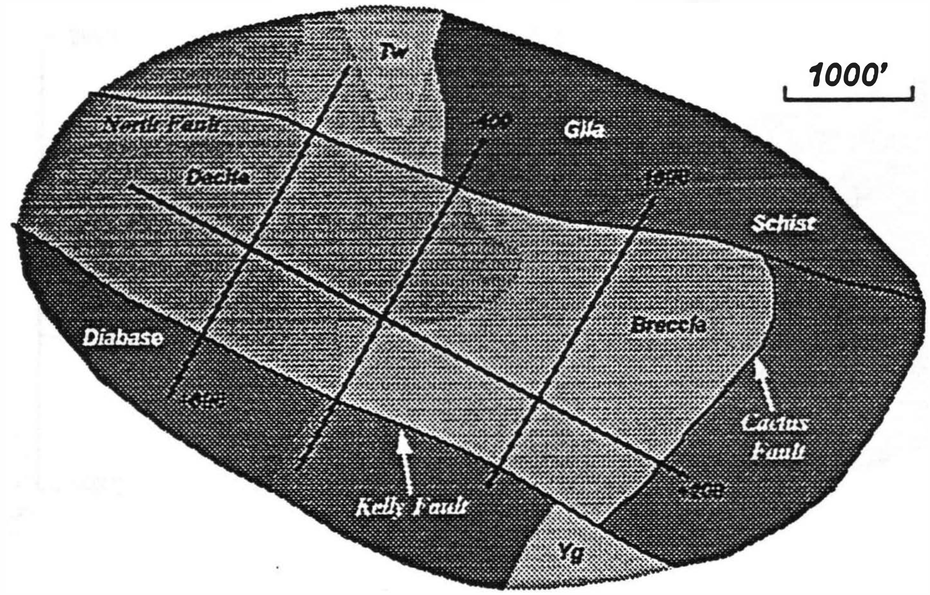
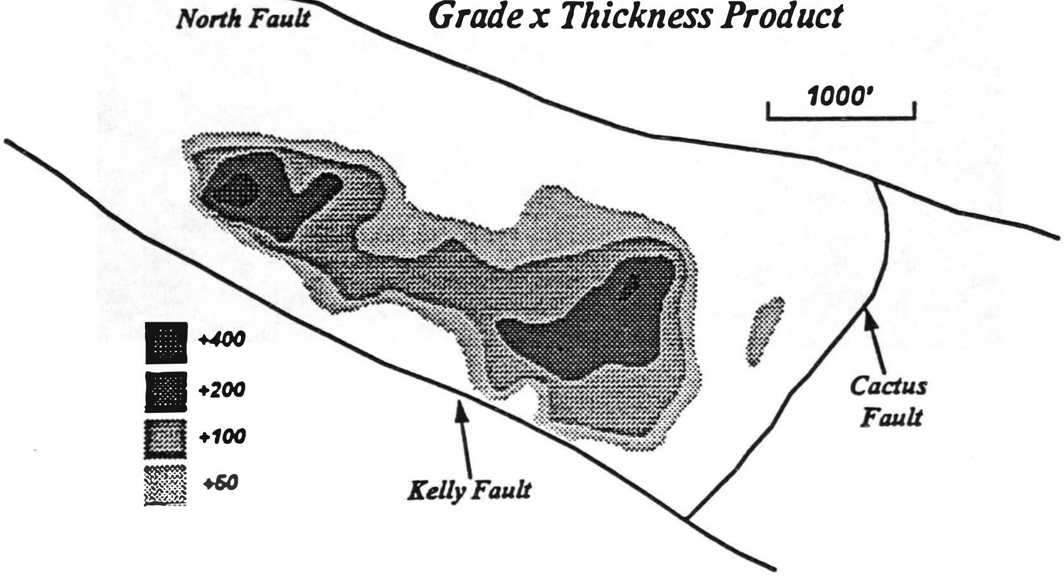


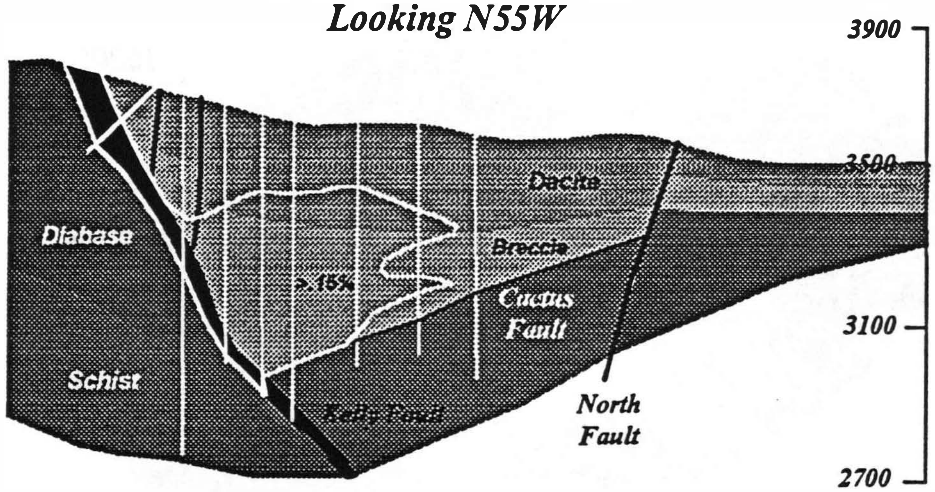
Fig 6-4b

Carlota / Cactus Deposit
Grade x Thickness Product



a.

Cross Section - Line 600
Looking N55W



b.

Cross Section - Line -400
Looking N55W

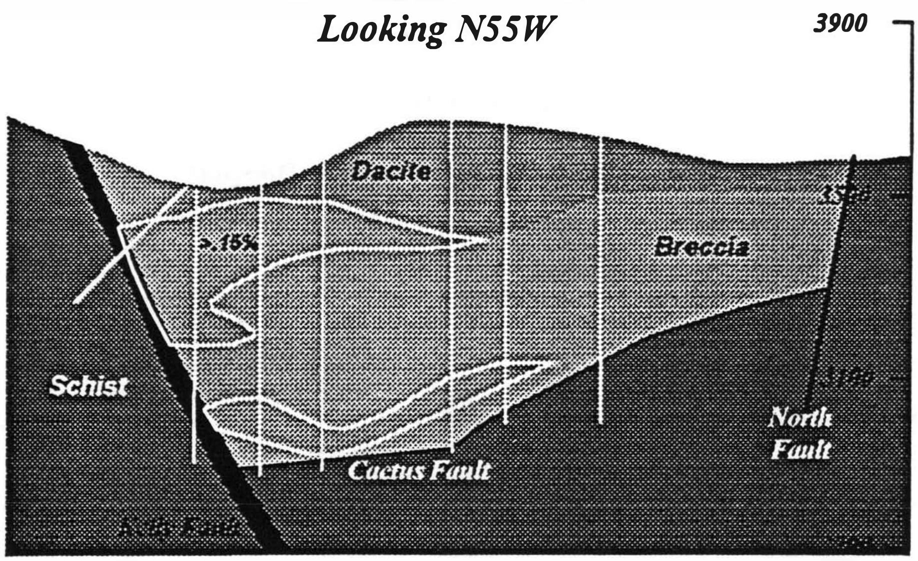
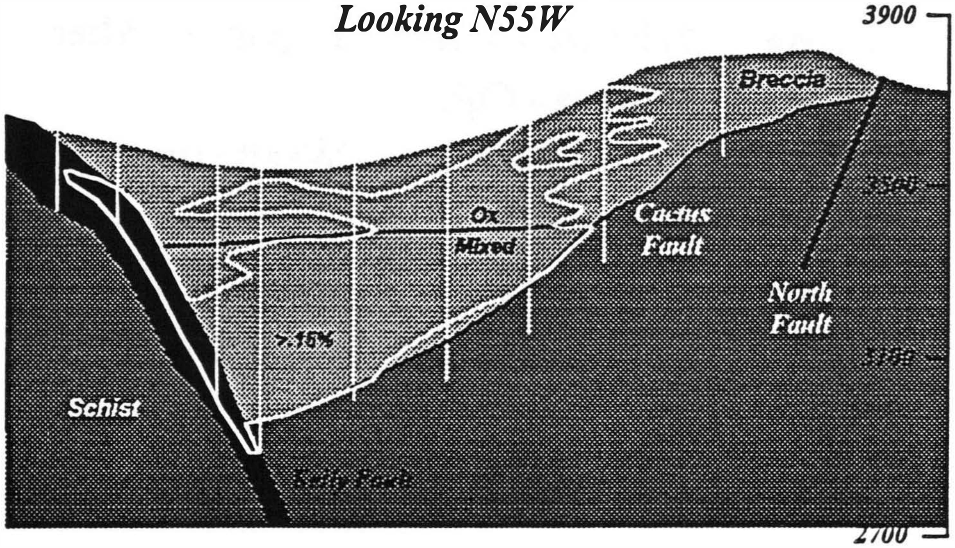


Fig 6-5

Cross Section - Line -1600
Looking N55W

c.



Long Section - Line 200
Looking N35E

d.

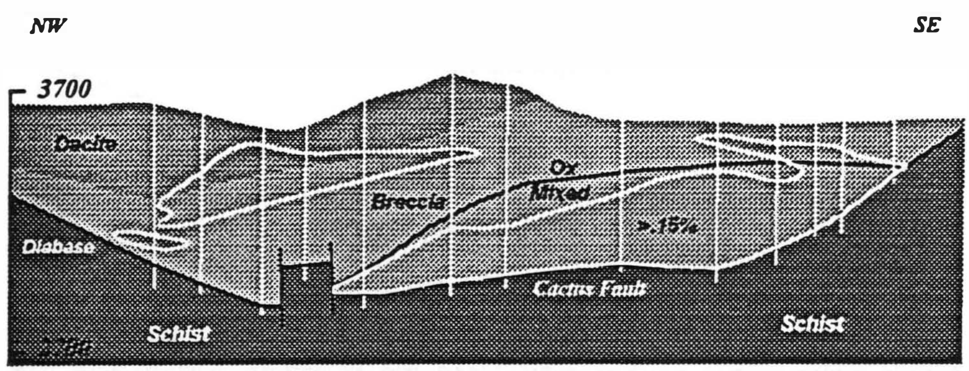


Fig 6-5 con't.

Proposed Genesis

Time	Geology	Mineralization
60 Ma	Schultze Granite	Hypogene, Alter.
30-35 Ma	Whitetail Cgl.	
20-30 Ma	Cactus Breccia	Weathering, Oxid.
20 Ma	A.L. Dacite	
10-20 Ma	Horst/Graben	Oxide/Sulfide
0-10 Ma	Tilting, Uplift	Supergene Enrich.

Long Section - Line 200
Looking N35E

NW *SE*

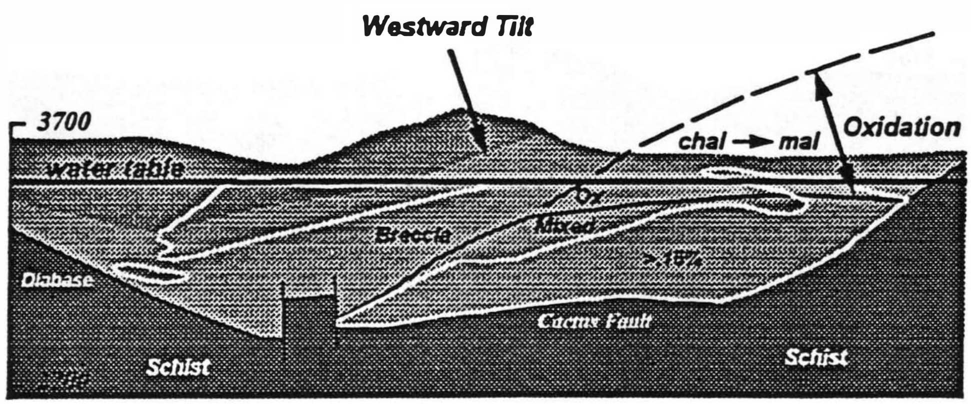
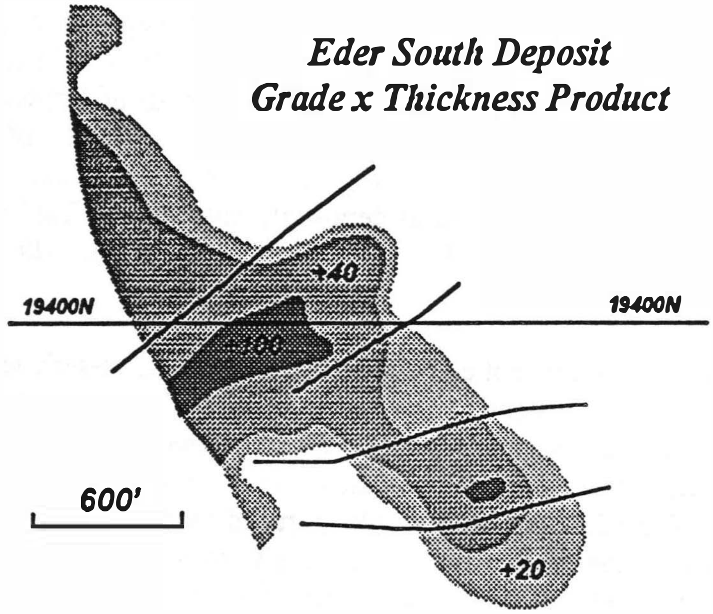


Fig 6-5


Eder South Deposit
Grade x Thickness Product
19400N
19400N
+40
+100
600'
+20

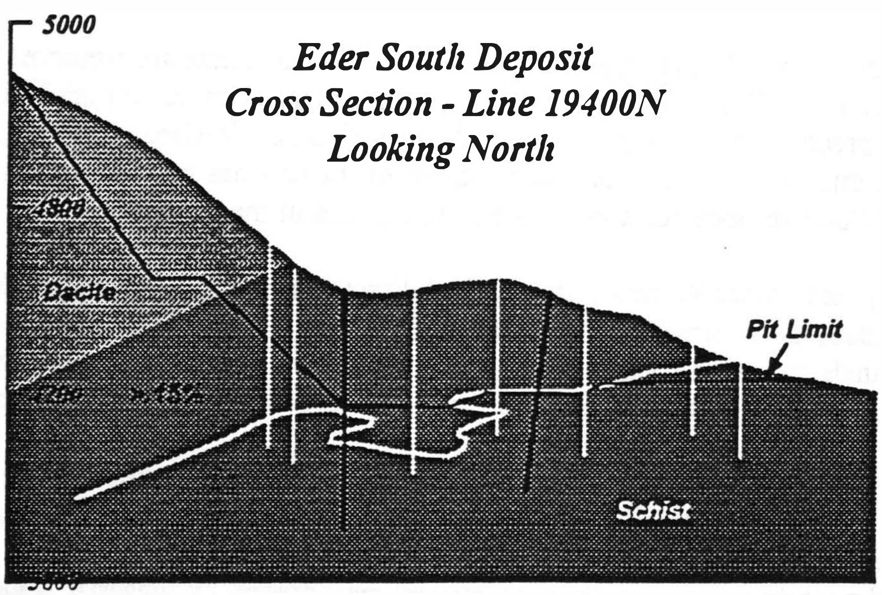

5000
Eder South Deposit
Cross Section - Line 19400N
Looking North
Dacite
Pit Limit
Schist

Fig 6-6

Project Geology and Mineralization

Description of Rock Types

Significant rock types in the area of the Carlota-Cactus-Eder deposits range from Precambrian to Recent in age and include (from oldest to youngest): Pinal Schist, Lost Gulch Quartz Monzonite, clastic rocks of the Apache Group and diabase all of Proterozoic age, Paleozoic calcareous rocks, early Tertiary or Laramide (60 Ma) Schultze Granite, Mid-Tertiary Whitetail Conglomerate (30 Ma), an informally defined unit referred to as Cactus Breccia (the primary host for mineralization at the Carlota/Cactus deposits), Apache Leap Tuff of Early Miocene age (17-20 Ma), Gila Conglomerate (3-10 Ma), and Recent unconsolidated alluvial deposits

The Pinal Schist is a variable unit but consists primarily of a quartz-sericite or quartz-muscovite schist. The amount of mafic minerals varies quite a bit, as does the texture, ranging from the predominant schist to coarsely granular gneiss. Where altered, the schist is often little affected except for a "bleached" appearance. The schist is the main host rock for mineralization at the Eder South deposit. The schist has been locally intruded by the Lost Gulch Quartz Monzonite, the primary host rock for the Pinto Valley deposit, and massive brown-to-black diabase, which appears as sill-like intrusives. Scattered exposures of Paleozoic carbonate rocks are preserved north of the Kelly Fault. Exposures of Schultze Granite in the Carlota area are generally lacking but are noted at the Pinto Valley deposit and at the south end of the Eder claims. The Schultze Granite is the "mineralizer" in the Globe-Miami District and hosts ore in many of the deposits near Miami. It does not appear to have any direct genetic significance, however, to the copper mineralization within the Carlota Project area.

Remnants of the basin and/or channel-filling Whitetail Conglomerate are preserved locally in the Carlota Project area. The Whitetail is up to several hundred or more feet thick in the area and is comprised predominantly of poorly stratified sand-to-cobble-sized diabase and limestone fragments. A thick volcanic ash unit near the top of the unit has been dated at approximately 30 Ma. The Whitetail does not appear to be mineralized in the project area.

At least locally, the Cactus Breccia was deposited directly on top of the Whitetail Conglomerate. Like the Whitetail, the informally defined Cactus Breccia was deposited in small, evolving basins or filling channels incised into older units. The unit is named after exposures of breccia at the Cactus deposit, which Peterson (1962) mistakenly mapped as brecciated Pinal Schist.

The Cactus Breccia is composed primarily of variably altered quartz-muscovite schist clasts derived from the Pinal Schist. Other clasts are thought to be derived from altered Lost Gulch Quartz Monzonite, Shultze Granite, and quartzite units of the Apache Group. The breccia is clearly of sedimentary origin and likely represents megabreccia or subaerial landslide deposits not unlike similar units in Arizona deposited during this time (20-30 Ma). Limonite coating on clasts and limonite disseminated within clay matrix impart a characteristic red color to the breccia. Clast sizes are variable and range from house-size boulders down to sand-size fragments. The breccia is typically chaotic and unsorted, with clasts generally quite angular. Based on the relative proportion of clay/sand matrix to clasts, the breccia has locally been subdivided into matrix-rich and matrix-poor varieties. Elongated clasts and vague bedding layers showing specific clast lithologies, as well as internal shearing, suggest a crude layering in the deposit dipping moderately to the northeast. Preserved thickness of the breccia exceeds 600 feet.

Depositionally overlying the Cactus Breccia is the Apache Leap Tuff. The tuff is generally dacitic in composition and brown in color, often exhibiting crude generally subhorizontal layering. The tuff is generally welded and often is relatively fresh in appearance. An approximately 10-foot-thick black vitrophyric zone is often present near the base of the tuff. A thin ash layer is also present locally near the base of the tuff. The tuff is a significant ore host in the Carlota area. The Gila Conglomerate is present in the northeastern part of the area and locally appears to be weakly mineralized. These poorly-sorted alluvial fan deposits record a period of erosion deposition and uplift predating the current period of tectonic activity.

Structure

The structure of the Carlota area is largely a record of Tertiary extensional tectonics. The north-trending Castle Dome Horst, hosting the Pinto Valley Mine, and the northwest-trending Carlota Graben are the two most significant structural features which, in concert, led to the localization of the Carlota/Cactus deposit

Uplift of the Castle Dome Horst was accommodated by at least several thousand feet of vertical movement along the boundary fault which defines the east and west limits of the Pinto Valley deposit. Uplift was most likely initiated in the mid-Tertiary, probably after deposition of the Whitetail Conglomerate, and continued intermittently through the Tertiary. Erosion and mass wasting from the uplifted block led to the deposition of the Cactus Breccia, which was deposited in local, probably subsiding, basins peripheral to the horst. Movement along the Cactus Fault, a low-angle feature which underlies the entire Cactus Breccia unit within the area of the Carlota Graben and separates it from the underlying Precambrian rocks, was initiated during and shortly after deposition of the breccia. The Cactus Fault is marked by a zone of crushed and "gougy" rock, 4- to 10-feet thick. Within the graben, the breccia appears to have been rotated moderately to the northeast. The eastern limit of the Cactus deposit is defined by the outcrop of the Cactus Fault within this graben.

Movement along the Kelly Fault zone, the south-bounding fault of the Carlota Graben, was likely initiated after the emplacement of the breccia in this area. Movement of at least several thousand feet of combined oblique slip is based largely upon the absence of both breccia and dacite to the south of the fault. There appears to be lesser movement on a parallel fault (North Fault) defining the graben to the north. Cactus Breccia and the contact with overlying dacite have been preserved in the graben, whereas these features have been largely eroded away outside the graben. The Carlota Graben is typically 1,200- to 1,500-feet wide and can be traced for over

7,500 feet along the length of the Kelly Fault. Westward tilting of some 15- to 25-degrees of the regional tectonic block west of the Carlota Dome Horst is suggested by the westward dip of the Apache Leap-Pinal Schist contact in the Eder area.

Mineralization

Based on the visual examination of surface exposures, drill core and cuttings, and associated petrographic work, copper mineralization at the Carlota-Cactus-Eder deposits is exotic in origin, supergene in nature, and broadly similar in aspect between the deposits. While chrysocolla is the dominant ore mineral in all the deposits, significant amounts of chalcocite and malachite are present at Cactus. The fracture-filling nature of the copper minerals results in excellent metallurgical characteristics.

The Cactus Breccia is the primary host rock for mineralization at the Carlota/Cactus and Eder North deposits. At Carlota, mineralization in the dacite overlying the Cactus Breccia is important, as is mineralization along approximately 3,300 feet of the Kelly Fault, which bounds the Cactus and Carlota deposits to the south. Kelly Fault mineralization is hosted in brecciated diabase (northwest segment) and Pinal Schist (southeast segment). Mineralization at the Eder South deposit is hosted within fractured and brecciated Pinal Schist.

Chrysocolla, which can vary between the more typical blue color and a black, manganiferous and iron-oxide variety, is generally present filling and lining fractures within brecciated rocks of the Kelly Fault, Pinal Schist, and Apache Leap dacite, as well as larger clasts in the Cactus Breccia. Within the Cactus Breccia, chrysocolla can also be found rimming clasts, filling vugs and open spaces, and locally replacing clay matrix. In the dacite, chrysocolla can also be found filling or lining vugs or crystal cavities and replacing altered feldspar phenocrysts. Occasionally associated with chrysocolla and generally sharing the same habits are black copper pitch and/or neotocite (Cu-, Mg-, Fe-oxide). Malachite is locally abundant in the eastern portion of the Cactus deposit and sporadically along the Kelly Fault. In the Cactus deposit, malachite appears to be related to oxidized chalcocite mineralization, is generally found as veinlets within breccia clasts along with iron oxides and pyrite, and is typically present within a local transition zone between underlying chalcocite mineralization and overlying chrysocolla mineralization. Within the Cactus Breccia, copper-bearing clays and copper-bearing iron oxides (hematite) can locally contain significant amounts of copper. The only significant copper sulfide mineral identified is chalcocite, where it is restricted to the lower parts of the Cactus deposit. The chalcocite is commonly found rimming or partially to totally actively replacing pyrite, which is often found as veinlets or individual grains within breccia clasts.

Paragentic relationships among the various copper oxide minerals have been elucidated based on petrographic examinations. At least three probably closely-spaced periods of chrysocolla deposition have been noted with and without intervening periods of authigeonic montmorillonite-type clay deposition. Where noted, malachite usually precedes chrysocolla deposition, and occasionally chrysocolla has been noted replacing earlier formed malachite. Chalcocite is generally never seen in contact with chrysocolla, whereas malachite altering from and replacing chalcocite is fairly common at the Cactus deposit.

Form of Deposits

The form or distribution of significant copper mineralization at the Carlota Project is for the most part determined by results from drilling. As such, the following discussion will rely heavily on drill-generated information which has been used to generate a number of geologic and assay sections through each of the deposits as well as other graphic products.

Carlota/Cactus Area

The Carlota and Cactus deposits will be discussed together because they are not only adjacent to each other, but share many common attributes and are intimately related. For this discussion, the Cactus deposit is defined as being east of Pinto Creek with Carlota lying to the west of Pinto Creek.

Outcropping mineralization at Carlota is restricted to local exposures along the Kelly Fault. The distribution of the more significant mineralization hosted in the lower part of the dacite and within the Cactus Breccia is known only through drilling. Mineralization at Cactus does outcrop and is predominantly hosted within the Cactus Breccia, within the Kelly Fault, and locally within the dacite. Only oxide-type mineralization is found in outcrops while the sulfide-rich mineralization at Cactus is known only from drilling.

The Kelly Fault defines the southern limit of mineralization at both the Carlota and Cactus deposits and contains exclusively oxide mineralization over widths of from 10 to 70 feet with typical grades of 0.6- to 1.0-percent copper. Mineralization at both deposits is generally floored by the low-angle Cactus Fault which separates overlying, potentially mineralized Cactus Breccia from underlying, generally barren Pinal Schist. Mineralization at both deposits appears to be strongest (>0.50 percent total copper) adjacent to or in closer proximity to the Kelly Fault with diminishing intensity farther away from the fault. However, significant mineralization may be present up to 1,000 feet or more from the fault. Proximity to the eastern, up-dip limit of the Cactus Fault also appears favorable for better grade mineralization. At the Carlota property, mineralization and the favorable breccia both thin out going to the west. Relatively lean mineralization is present (> 0.10- to 0.35-percent total copper) in a central area between the two deposits. Along the length of the two deposits, significant mineralization is noted for roughly 3,600 feet. The form of the Carlota/Cactus deposit is well illustrated in Figure 3-3, a contoured grade x thickness product map derived from drill-hole intercepts (100 feet thickness at 1 percent copper=100).

The envelope of significant mineralization at the Carlota and Cactus deposits can be up to 600-feet and 400-feet thick, respectively, near the Kelly Fault where the preserved thickness of the breccia is greatest, but generally diminishes as the breccia thins going to the north away from this fault. At Carlota, the top of the mineralized zone is generally within the lower part of the dacite, is relatively flat, and is apparently related to the present groundwater table. Mineralization is most often persistent and highest in grade along the dacite-Cactus Breccia contact. Within the breccia, higher-grade mineralization is also often noted near the Cactus Fault contact. Dacite-hosted mineralization at Cactus is relatively minor, due in part to its small areal distribution and location above the present ground water table.

Mineralization at Carlota is entirely of oxide-type, with the oxide-sulfide interface generally rising in elevation to the east on the Cactus property. Over much of the Cactus deposit, the oxide-sulfide boundary (n.s. copper %/total copper % <50%) mimics the current groundwater table and is as close as 50 feet to the surface. Sulfide mineralization (chalcocite) is generally quite uniform and consistent in tenor, often grading about 0.70-percent copper but with multipercent grades often present immediately below the oxide-sulfide boundary. Oxide mineralization at Cactus is more erratic in distribution and grade, commonly with a relatively thin mineralized zone (<100 feet) near the surface and separated by a relatively barren zone from a deeper mixed-oxide-sulfide or sulfide-mineralized zone. Surface mineralization at Cactus is generally present as chrysocolla which appears to have formed after preexisting malachite. Malachite is the most common oxide mineral from immediately below the surface to the oxide-sulfide boundary and locally below.

Eder North and South Areas

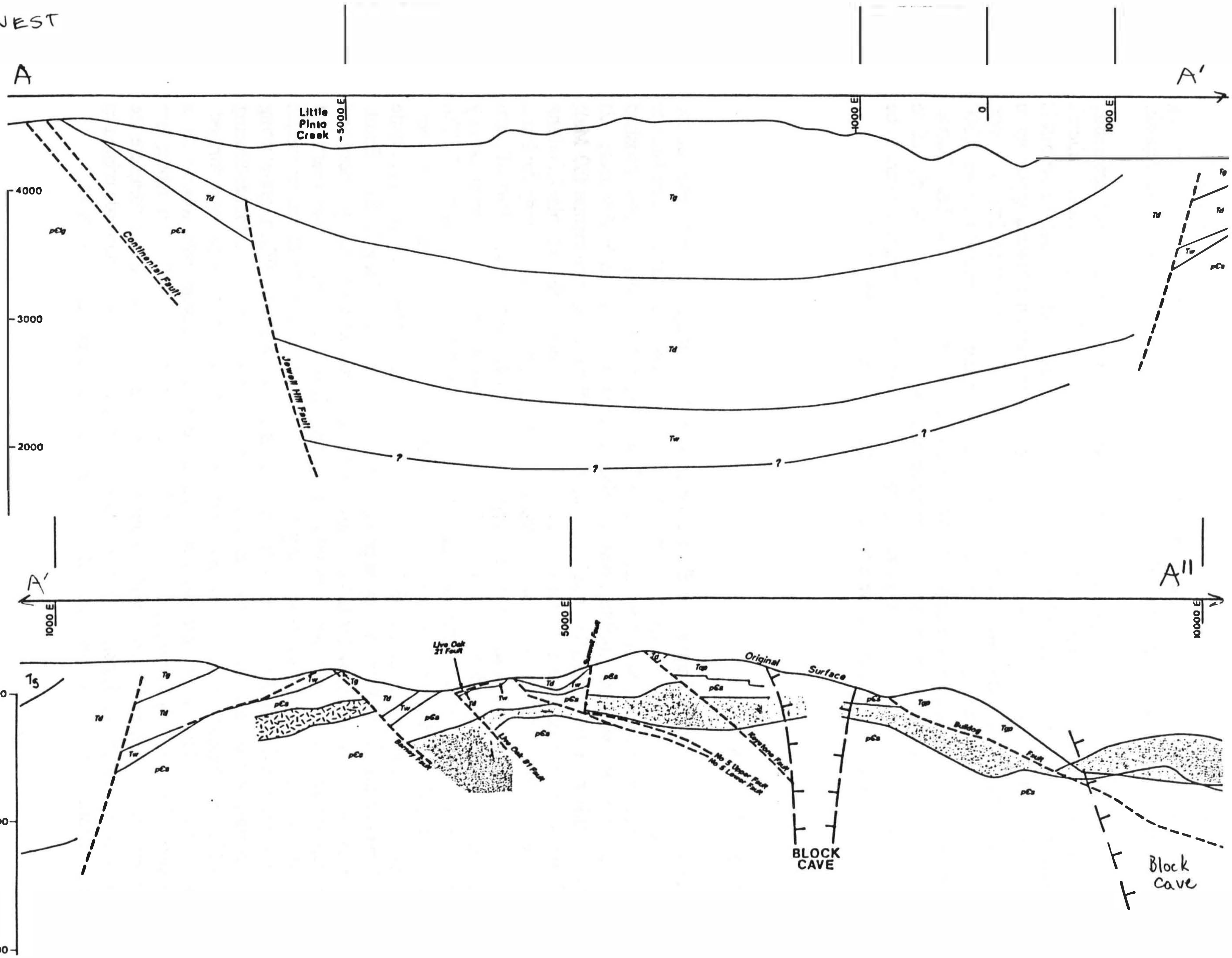
Mineralization at Eder South is present mainly as chrysocolla along fractures within the Pinal Schist. No sulfide mineralization, including pyrite, has been found at Eder South; the rocks appear to be thoroughly oxidized. Extensive faulting, generally along northeast trends, has created sufficient fracturing and brecciation in the Pinal Schist so as to localize the deposit. Significant (>.15 percent) near-surface copper mineralization at Eder South is present over an area measuring roughly 2,400 feet (north-south) by at least 1,000 feet (east-west). Mineralization often extends from the surface to depths of roughly 200 to 300 feet with the bottom of mineralization at approximately the 4,200-foot elevation. The western portion of the deposit is overlain by essentially barren Apache Leap Dacite. The eastern edge of mineralization is defined by erosion. Mineralization is known to extend at least 1,000 feet west of the outcropping zone under the dacite "cap," but an economic limit is imposed by topography rising steeply in this direction. Mineralization to the north and south appears to diminish gradually, perhaps related to a lack of faulting and ground preparation. Near the south end of the deposit, mineralization appears to increase along the east-west trending structural/intrusive boundary of

Schultze Granite and then diminishes within the granite farther to the south. Figure 3-4 is a grade x thickness map of the Eder South deposit illustrating the northeast-southwest trending control to the mineralization. Drawing 3-6 is a representative cross section through the deposit.

At the Eder North deposit, mineralization is hosted within Cactus Breccia, which apparently infills a northeast-southwest trending channel carved into underlying Pinal Schist and Whitetail Conglomerate. The north and south limits of the deposit are poorly defined, but the deposit is known to extend for roughly 1,000 feet, across the channel trend with the breccia appearing to thin, and the grade diminishing away from the axis of the channel. The eastern limit is defined by erosion, while the western limit is also poorly defined, but is known to extend for over 1,300 feet down-dip from the outcrop and under the overlying essentially barren Apache Leap Dacite. An economic limit, however, is imposed in this direction, owing to the westwardly dip (20 to 30 degrees) of the breccia into the steep dacite ridge. Significant mineralization appears to be generally in the more basal part of the breccia and can be over 200-feet thick.

Origin of the Deposits

The genesis of the Carlota/Cactus and Eder copper deposits is thought to be a result of the following significant events: 1) Local intrusions of Laramide-age (60 Ma) Schultze Granite altered and mineralized Pinal Schist and Lost Gulch Quartz Monzonite wall rocks and deposited concentric zones of hypogene sulfide mineralization at depth in the Pinto Valley area; 2) Relatively stable conditions persisted until deposition of the Whitetail Conglomerate (30 Ma); 3) Following this, significant mid-Tertiary tectonic activity with related uplift and block faulting affected the area, and a portion of the altered and weakly mineralized schist overlying the Pinto Valley deposit was shed as landslide or megabreccia deposits (Cactus Breccia) into adjacent basins; 4) Low-angle faulting (Cactus Fault) and continued graben development largely preserved the Cactus Breccia within the Carlota Graben from subsequent erosion; 5) The emplacement of the welded ash flow sheet of the Apache Leap Tuff (20 Ma) then covered most of the region from Superior to Globe; 6) Continued tectonic movement led to uplift of the Castle Dome Horst containing the Pinto Valley deposit, with related movement along the Kelly Fault. Copper was leached by surface water and groundwater from the uplifted Pinto Valley deposit and copper-rich solutions moved downgradient into the adjacent Carlota Graben; 7) Downward and lateral flow of copper-bearing solutions along the Kelly Fault and Cactus Fault was important and mineralized the Cactus Breccia and dacite as well as the Kelly Fault. Where pre-existing sulfides (pyrite) in breccia clasts were oxidized prior to the introduction of the copper-bearing solutions (Carlota deposit), only oxide-copper minerals, principally chrysocolla, were formed. Where residual sulfides were still present (Cactus deposit) chalcocite was formed as a replacement of pyrite; 8) Deposition of the Gila Conglomerate (3-10 Ma) and subsequent rejuvenation of the topography along with moderate warping and westward tilting complete the history of the Carlota area. Erosion, oxidation, and redistribution of copper minerals related to the latest tectonic movements continue, both above and below the present water table.


WEST
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pCg
Continental Fault
Jewell Hill Fault
?
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A''
1000 E
5000 E
10000 E
Ts
Live Oak
21 Fault
Live Oak 81 Fault
Barney Fault
Keystone Fault
No 5 Upper Fault
No 5 Lower Fault
Bulldog Fault
Original Surface
Tgp
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CAVE
Block
Cave

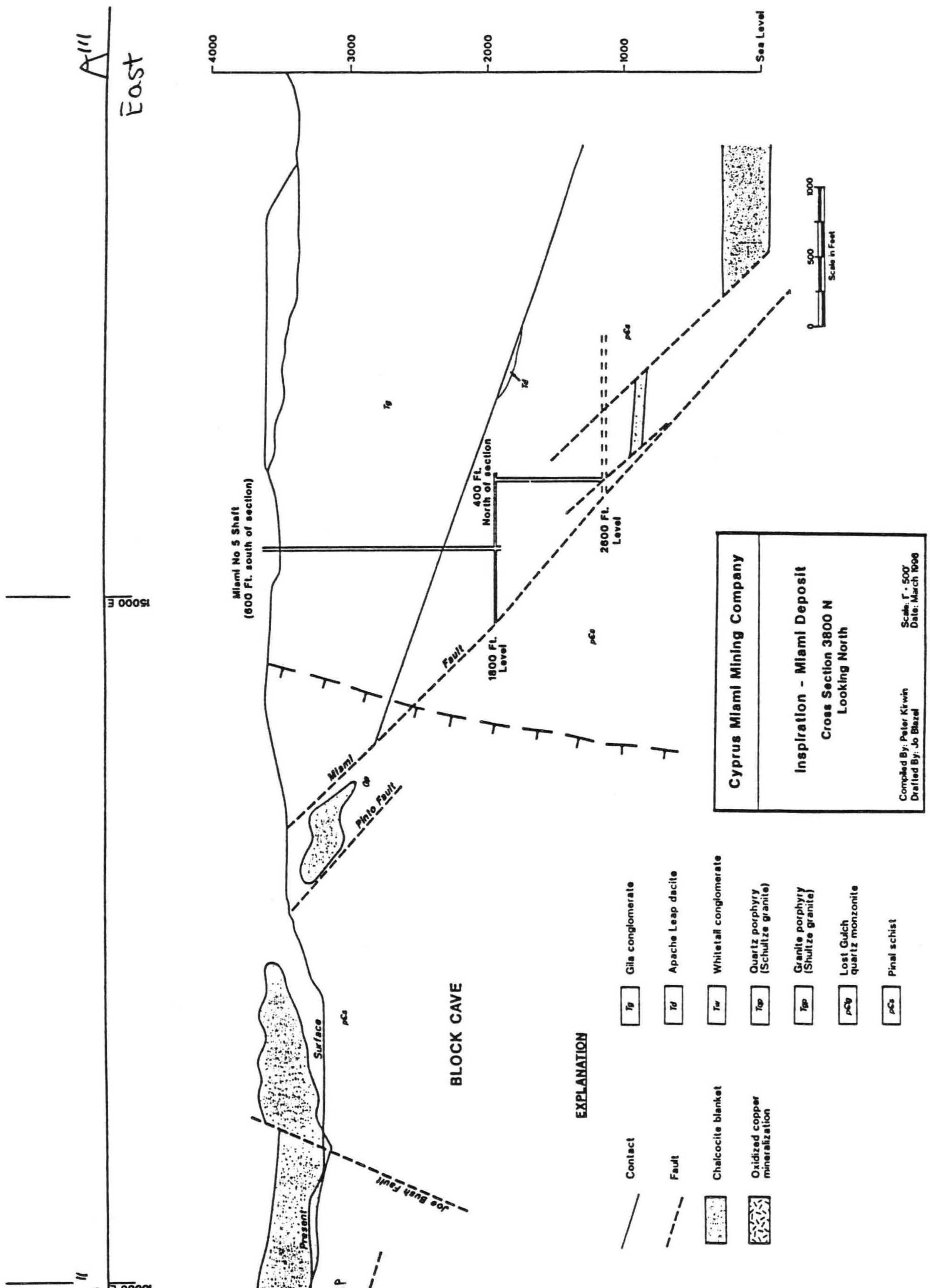

Figure 7.1. Cross section of the Inspiration Miami Deposit. Section line located on Figure 2