COMPILATION GEOLOGIC MAP OF THE RAY-SUPERIOR AREA, CENTRAL ARIZONA

by
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This report is preliminary and has not been edited or reviewed for conformity with Arizona Geological Survey standards

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INTRODUCTION

This geologic map was produced to compile and reinterpret published geologic information, and present the result of new geologic mapping in the Ray-Superior area. This data set serves as the basis for ongoing efforts to better understand the geologic history of this area, particularly with respect to the distribution and origin of mineral deposits.

MAP COMPILATION

This compilation is based on published USGS and Arizona Geological Survey geologic maps of the Picketpost Mountain [Peterson, 1966; Spencer and Richard, 1995], Superior [Peterson, 1969], Pinal Ranch [Peterson, 1963], Mineral Mountain [Theodore et al., 1978], Teapot Mountain [Creasy et al., 1983], Sonora [Cornwall et al., 1971], North Butte [Richard and Spencer, 1997], and Grayback [Cornwall and Krieger, 1975] quadrangles. More detailed mapping by Stan Keith in a strip west from the Ray Mine to the belt of Apache Group strata south of Picketpost Mountain was part of a master's thesis project that was completed as an Arizona Bureau of Geology and Mineral Technology Open-File Report [Keith, 1983]. Detailed 1:12,000-scale maps from this report have been generalized as necessary to show at a scale of 1:24,000 for this compilation. Several faults shown in the northern Dripping Spring Mountains, separating Apache Group strata and diabase (Yd), have been inferred from the distribution of units in the Apache group, based on mapping by Cornwall and Krieger [1971].

The geology around the Ray pit is based on Keith [1983], Creasy et al. [1983], Cornwall et al. [1971], and John [1994]. A particular problem in this area is the major modifications to the terrane resulting from mining operations. The location of the earth's surface in the mine pit changed significantly between the time Cornwall et al. and Creasy et al. did their mapping (1965-1970), Keith did his mapping (early 1980's), and John did his mapping (early 1990's). Because the contour lines on the base map indicate the earth's surface in the early 1960's, east of the Diabase fault, the geology shown is from Cornwall et al. [1971]. The pit limit shown on the map is from John [1994]. Geology west of the Diabase fault and within the 1994 pit limit is from John, and thus is unrelated to the topography shown on the base map. Dumps and tailings now bury large areas adjacent to the pit that were exposures of bedrock when the various maps were made. The patterned area on the base map approximates the area affected by mine operations. The map shows outcrops that are now buried but had previously been mapped within these areas.

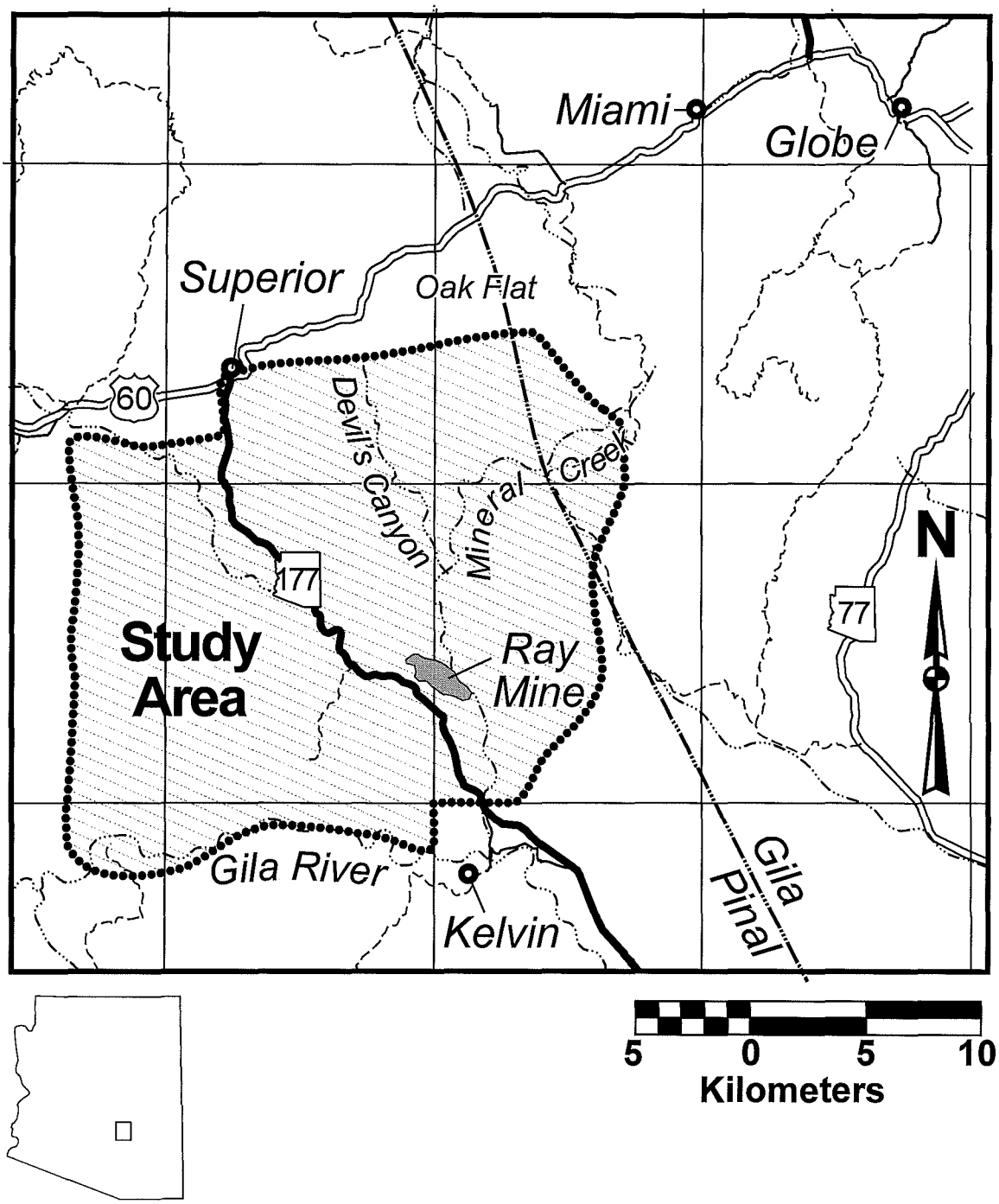


Figure 1. Map showing location of study area

Additional data included on this map includes mapping by Dickinson [1995], data from mineral exploration drilling in the north-central part of the map area [Sell, 1995], and unpublished mapping by the authors. In general, the most detailed or recent mapping has superseded older mapping. Particularly on the Teapot Mountain quadrangle, reinterpretations of the nature of faults and contacts in small areas by the authors have been applied to parts of these contacts not studied by the authors. Stratigraphic names suggested by Dickinson [1995] have been applied to nearby areas where units were originally mapped as lithologic units.

STRUCTURE

The map area records the effects of at least three major periods of faulting. Late-stage normal faulting that post-dates the Apache Leap Tuff shaped the present physiography. Low-angle normal faulting during and after deposition of the Whitetail Formation was responsible for most of the extension in the map area. Faulting that largely pre-dates intrusion of the Granite Mountain Porphyry (Tgm) superposed Pinal Schist on top of rocks as young as the Paleozoic Naco Formation along the Walnut Canyon thrust system and Emperor thrust (Section B-B', Plate 3). These structures will be discussed from youngest to oldest because understanding the older structures requires reconstruction of deformation related to younger structures. Figure 2 shows the location of faults discussed in the text.

Tertiary fault systems

Post-Apache Leap tuff

Faults that cut the Apache Leap tuff are mostly north- to northwest-trending, and bound the eastern margins of basins containing thick sections of Miocene rocks. These faults typically dip 40-60° west or southwest.

Concentrator fault

The Concentrator fault bounds the eastern side of the Superior Basin [Peterson, 1969]. The fault can be traces southward from the town of Superior. In the NW part of Sec. 14, T2S R12E (UTM 3679940N, 491470E) the Concentrator fault bifurcates, and an eastern branch parallels the main trace, located about 2 km to the east. The main trace continues southward, juxtaposing Tertiary conglomerate in the hanging wall against pre-Tertiary strata in the footwall. In the NW of Sec. 26, T2S R12E

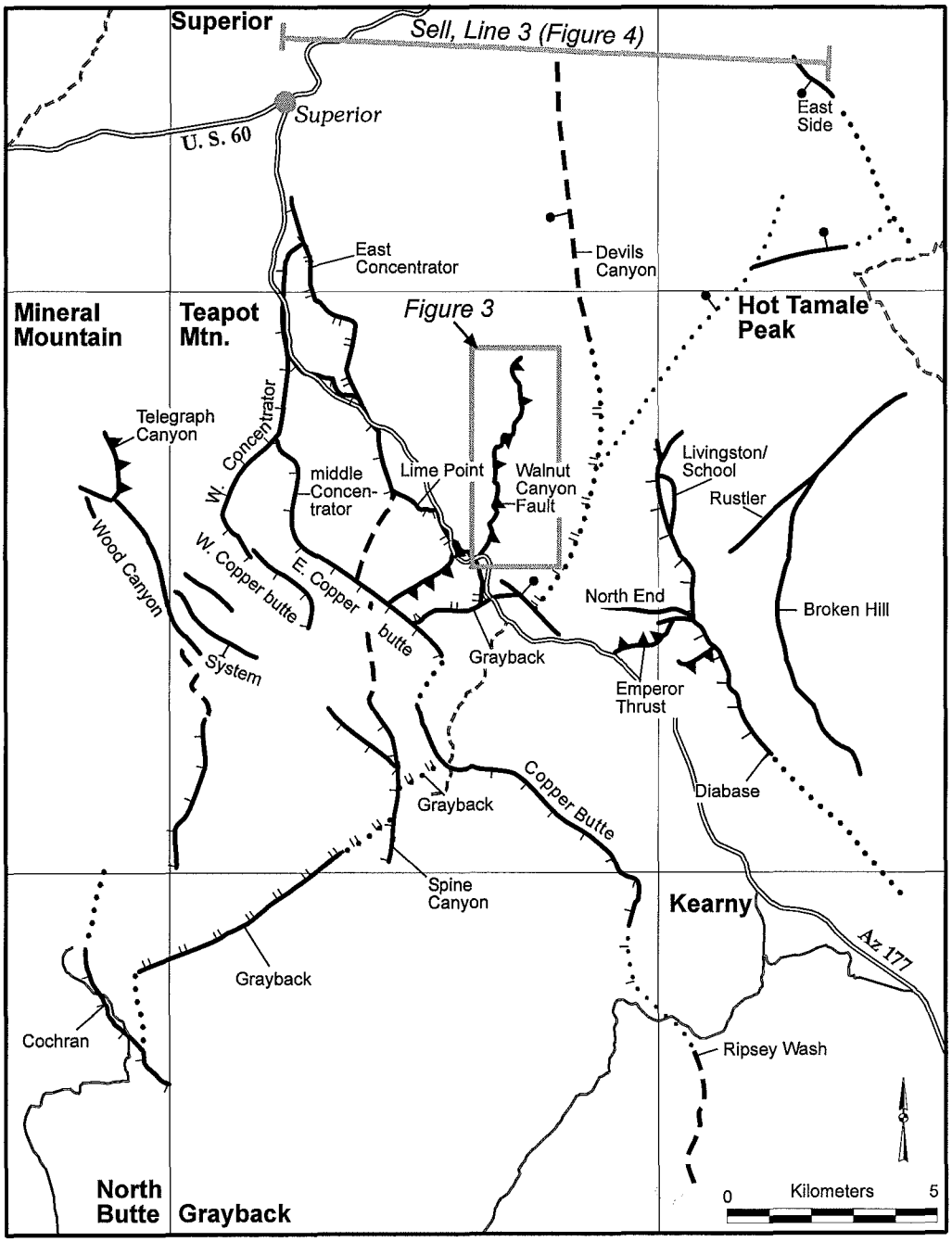


Figure 2. Map showing location of faults referred to in text. Cross section line in Figure 4 shown in gray, near top of figure. Quadrangle names shown in corners of 1:24000-scale topographic quadrangles.

(UTM 3676900N 491300E) the fault bifurcates again and loses definition as a basin-bounding fault. The continuation of this fault zone is discussed below as the Copper Butte-Concentrator transfer zone.

Copper Butte fault

The Copper Butte fault (Dry Wash fault of Schmidt [1971]) is the northward continuation of the Ripsey Wash fault system [Schmidt, 1971, Dickinson, 1995]. These two faults together define a fault system that can be traced about 15 miles (24 km) south from Copper Butte. Within the map area, the Copper Butte fault trends northwest and dips 40-60° SW. It cuts Proterozoic granite (Yg), Pinal Schist (Xp), various Laramide igneous rocks, and Whitetail conglomerate (Tw). At Copper Butte, the Copper Butte fault juxtaposes Pinal Schist on Granite Mountain porphyry (Tgm). The Copper Butte fault loses clear definition northwest of its intersection with a fault interpreted to be the Grayback normal fault (discussed below), in SW SW SW sec. 19, T3S R13E (UTM 3667670N 494790E).

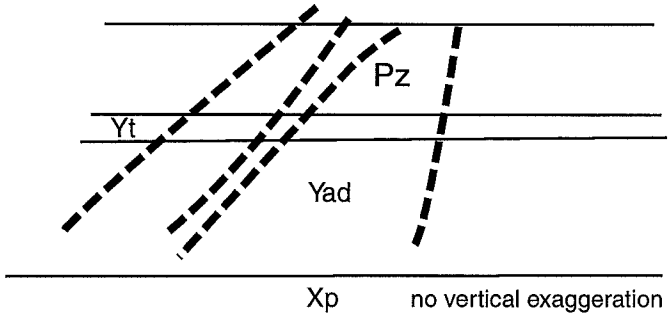
Copper Butte-Concentrator transfer zone

Between Copper Butte and the northwest corner of sec. 26, T2S R12E (UTM 3677100N 491200E), the Copper Butte fault and Concentrator faults are linked through a transfer zone of distributed faulting. Within this zone, the Copper Butte-Concentrator fault system cuts the Walnut Canyon thrust system and the Grayback normal fault. Important relationships within this zone are described here from north to south.

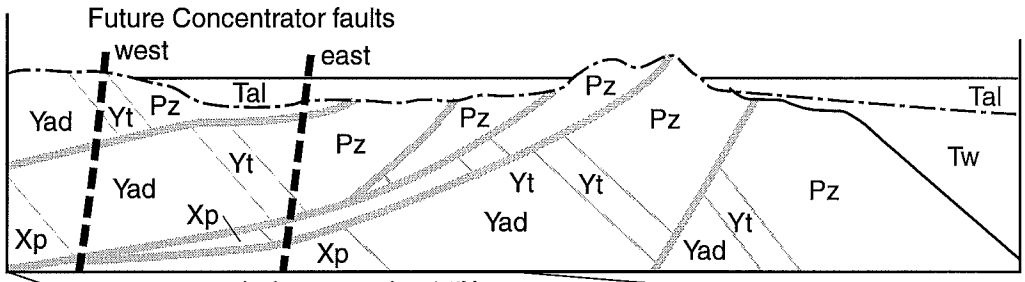
The western (main) trace of the Concentrator fault continues south of the bifurcation, and is apparently overlapped by rhyolite lava(?) (Trr of Creasey et al. [1983], Tr on this map) in NE SE sec. 27, T2S, R12E (UTM 3676300N 491100E). Some brecciation of Proterozoic diabase (Yd) near the contact suggests faulting, but basalt lava(?) (Tb) in exposures along contact is not brecciated. The dashed-line fault along this contact indicates uncertainty as to the nature of the contact. We interpret the contact to be a buttress unconformity where rhyolite lava was deposited against a fault scarp after movement had ceased on the western branch of the Concentrator fault (Figure 3). Apparently, a volcanic construction formed by the rhyolite lava effectively inverted the topography. When the basalt lava (Tb) was erupted, it ponded against an east-facing escarpment formed by the rhyolite dome approximately along the trace of the now inactive western branch of the Concentrator fault.

The eastern branch of the Concentrator cuts conglomerate (Tc) that overlies the rhyolite lava, and cuts basalt lavas correlated with the lavas that butt against the rhyolite lava along the western branch. Creasey et al. [1983] mapped a depositional contacts of basalt lava (their unit QTb, Tb on this map)

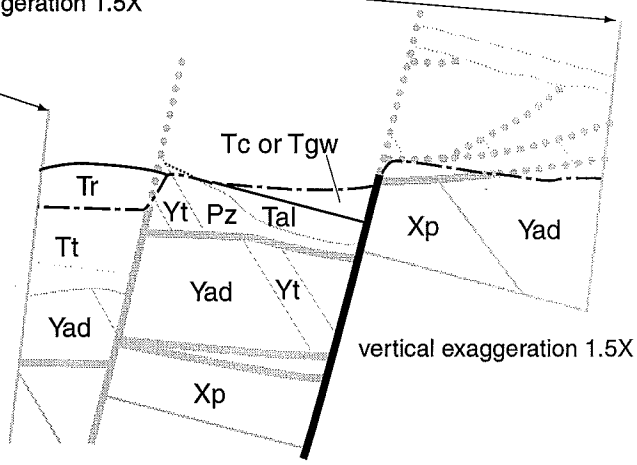
1. Before onset of normal faulting, flat-lying stratigraphic section in footwall of Walnut Canyon Thrust. Dashed lines show future traces of first generation normal faults.



2. After first generation of normal faults and eruption of Apache Leap Tuff. Paleozoic and Apache Group strata from ridges that were not buried by tuff; tuff overlaps normal faults, lies in angular unconformity on Naco Formation and Whitetail Formation. Dashed lines show future trace of Concentrator fault system faults.



3. After movement on western branch of Concentrator fault, eruption of rhyolite dome with buttress unconformity against inactive fault scarp.



4. After eruption of basalt, at end of displacement on eastern branch of Concentrator fault. Preferential erosion of shattered Apache Group and Paleozoic strata in footwall of western branch results in inverted topography. An escarpment of resistant rhyolite now marks the trace of the inactive western branch of the Concentrator fault. This escarpment, and the scarp along the eastern branch of the fault confine the basalt lava flows to the block between the branches.

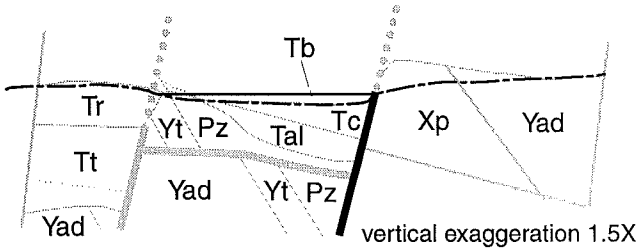


Figure 3. Schematic cross sections showing sequence of events at the southern end of the Concentrator fault.

and Apache Leap Tuff on rocks in the footwall of the east branch of the Concentrator fault indicating that the volcanic rocks overlap this fault. We found that basalt lava and associated volcanic-lithic sandstone (unit Tbs) are faulted against the pre-Tertiary rocks. Good exposures of the fault were observed in a road cut along AZ highway 177 (SE SW SW sec 25, UTM 3675710N 493095E), on the south side of Arnett Creek just south of this road cut, and in a small tributary of Arnett Creek in NE NE SE sec. 26 (UTM 3676338N 492656E). Along strike to the south slivers of various pre-Tertiary units are interleaved and brecciated along the fault zone. The contact between Apache Leap Tuff and Madera Diorite in SW SE sec. 36, T2S R12E (UTM 3674245N 493585E) is poorly exposed. Discontinuous exposures of brecciated vitrophyre overlie non-welded tuff, which in turn contains stringers of breccia composed of Apache Group and Troy Quartzite clasts. The contact between the non-welded tuff and Madera Diorite is not exposed. The contact between non-welded tuff and vitrophyre breccia dips steeply to the west. North along the contact eutaxitic foliation in the vitrophyre is irregularly rotated between breccia blocks, and the vitrophyre breccia overlies Apache Group breccia along a contact that dips 70° W. Contacts with the Madera diorite are not exposed. This contact is interpreted as a faulted unconformity along the eastern branch of the Concentrator fault.

The western branch of the Concentrator fault zone bifurcates again in NE sec. 34, T2S R12E (UTM 3675300N 490830E), one branch continuing south and the other trending more southwesterly. The western, southwest-trending branch is overlapped by the upper part of the tuff of White Canyon (Ttw_4), and probably by basalt lava (Tb) (contact shown as queried fault on map, SW NE sec. 34 T2S R12E). At this latitude (across S sec. 34 & 35, T 2S R12E, and sec. 6, T2S R13E, line from UTM 3674400N, 489600E to 3674400N, 493900E) the Concentrator fault system has a western branch (along Wood Canyon), a central branch, and an eastern branch (near Arnett Creek). About 1.5 miles (2 km) south of the bifurcation of the western and central branches, both these faults curve to a southeast trend, approximately parallel with the Copper Butte fault. The southeast-trending fault segments are considered part of the Copper Butte fault system. The center branch of the Concentrator system changes to southeasterly strike and becomes the eastern branch of the Copper Butte system. The west branch of the Concentrator fault curves to a southeast trend, and dies out in the tuffs of White Canyon and associated rhyolite dome complexes in upper White Canyon.

At the south end of the basin along upper Arnett Creek, the east branch of the Concentrator fault intersects the Lime Point fault (see Pre-Apache Leap structure, below). Some late-stage displacement on the Concentrator fault may be transferred to the Lime Point fault. The strike of the east branch of the Concentrator fault changes from north-south to SSW where it intersects the Lime Point fault. The

relatively straight trace of this SSW-trending fault indicates that it is quite steeply dipping, but the fault zone is not exposed. The east branch of the Concentrator fault is truncated where it intersects the east branch of the Copper Butte system (the southeast-trending continuation of the Concentrator central branch) in SE NW sec. 12, T3S R12E (UTM 3671920N 492730E). The east branch of the Copper Butte system curves into this intersection zone and is slightly offset (NW NW sec. 12, T3S R12E), but the SSW-trending east branch of the Concentrator system does not cut conglomerate (Tc) that overlies tuff of White Canyon (Ttw) along strike across the intersection.

The east branch of the Copper Butte system continues to the southeast toward Walnut Canyon, superposing conglomerate (Tc), then Apache Leap Tuff (Tal) and finally Whitetail Formation onto pre-Miocene rocks to the northeast. Whitetail Formation in the hanging wall strikes northerly, at a high angle to the fault strike, and the fault crosses the Whitetail-Pinal contact. Where the east branch of the Copper Butte system reaches Walnut Canyon in center section 18, T3S, R13E (UTM 3670180N 494730E), it places Pinal Schist against Pinal Schist. This contact was mapped as a thrust fault by Creasey et al. [1983]. Pinal Schist is crushed in a 10-15 meter wide zone at the fault. The fault could not be followed on the south side of Walnut Canyon. In the bottom of a small gully 50-100 m south of the main wash, the fault was located to within a 1 meter-wide covered zone separating shattered Pinal Schist from similar, folded but not shattered Pinal Schist. Pinal Schist along Walnut Canyon from Walnut Spring southwest is intensely shattered, and is interpreted to be a zone of distributed brittle deformation. Within this zone, the east branch of the Copper Butte fault system steps to the southwest by about 6000 feet (1800 m); on the map this is shown as dashed or concealed fault segments, but the details of the structure within this zone could not be resolved.

About 1000 feet (300 m) east-southeast of Copper Butte, Whitetail Formation is shown as deposited on Pinal Schist by Creasey et al. [1983] (NE SW sec. 19, T3S R19E, UTM 3668195N 494465E) but this contact is crushed over a 1 m wide zone interpreted here as a fault that dips 40° to the west. Approximately 200 m to the east Pinal Schist is shown by Creasey et al. [1983] to be thrust over Granite Mountain porphyry (Tgm). A mafic dike intrudes this contact and the Granite Mountain porphyry is not particularly fractured near the contact, suggesting that the contact was not a fault before dike intrusion. Thus, the main displacement on the Copper Butte fault (proper) may occur along a fault that continues NW along the NE side of Copper Butte, and the small body of Teapot Mountain porphyry (Ttm) previously considered to be in the hanging-wall block of the fault may actually be in the footwall block.

The Wood Canyon fault system is a zone of normal faults that are on trend with the main Copper Butte fault and have similar senses of separation (down-to-the-SW). These faults are considered part

of the Copper Butte fault system. This belt of normal faults is about 2.2 miles (3.6 km) wide, and can be traced from Copper Butte northwestward to upper Telegraph Canyon where the faults cut the Telegraph Canyon thrust (discussed below). At the southeast end of this belt (near Copper Butte), these northwest-trending faults are overlapped by or lose displacement in the tuff of White Canyon, but to the northwest they cut the tuff of White Canyon. Age constraints on the tuff of White Canyon do not determine if this is due to diachroneity in the age of the tuff or in the age of faulting. It is interesting that where Copper Butte system faults do not cut the tuff of White Canyon, the tuff is folded (see 'Contraction structures' below), but where the faults do cut the tuff, the folds die out.

Spine Canyon fault

The Spine Canyon fault [Dickinson, 1995] juxtaposes Apache Leap Tuff and gravel of Walnut Canyon (Tgw) against Whitetail Formation (Tw). The tuff of White Canyon overlaps the fault and is deposited in buttress unconformity against the fault paleoscarp. Gravel of Walnut Canyon is thick in the hanging-wall block, and thin to absent in the footwall block of this fault. The fault branches in the area north of the Copper Butte Mine into a north-trending east branch and northwest-trending west branch. The east branch is interpreted to link with faults north of Walnut Canyon that juxtapose strongly tilted and shattered Apache Leap Tuff, rock avalanche deposits derived from Apache Leap Tuff ($Tgw_{(Tal)}$), and Whitetail Formation against Whitetail Formation in the footwall. Shattered Apache Leap tuff in the footwall of this fault is interpreted to be the source of rock avalanche deposits that are present in the gravel of Walnut Canyon. The western branch of the Spine Canyon fault is exposed only at the junction of White Canyon and Walnut Canyon (SW NW sec 24, T3S R12E, UTM 3668570N 492500E), where it dips 30° SW. The youngest part of the gravel of Walnut Canyon overlaps the western branch of the Spine Canyon fault to lie in angular unconformity on Whitetail Formation and buttress unconformity against Apache Leap Tuff or sedimentary breccia derived from tuff. This relationship is clearly exposed in the cliff at the end of the ridge north of the junction of White and Walnut Canyons (SE NW NW sec. 24, T3S R12E).

Cochran Fault

The fault zone bounding the eastern margin of a Tertiary basin at the southwest edge of the map area is named the Cochran fault [Richard and Spencer, 1997]. North of the Gila River, the Cochran fault is intruded by the felsite complex of Cochran (map unit Tri). The fault is inferred to have separated Whitetail conglomerate (map unit Tw) from tuff (map unit Ttw) north of the river before intrusion of the felsite. Slip on the fault is transferred to the east within the main mass of intrusive rhyolite.

The eastern branch of the fault is inferred to lie close to the eastern margin of the intrusive rhyolite body. This fault loses displacement to the north, eventually dying out in the tuff of White Canyon and associated rhyolite domes just south of the peak labeled Sleeping Buffalo by Creasey et al. [1983]. This fault is cut by the northwest-trending normal faults of the Wood Canyon fault system.

Diabase Fault

The Diabase Fault is a major normal fault that bounds the eastern margin of the northernmost San Pedro Valley. The fault dips 55-85° W; dip apparently decreases northward into the Ray Mine area. John [1994] interprets the fault to end at the North End fault on the north side of the Ray Mine, and reports that the fault has 800 feet (240 m) of offset (separation?) at the north end of the mine, increasing to 1600 feet (480 m) at the south end. Displacement on the Diabase fault appears to increase southward to the edge of the map area, indicated by the appearance of Tertiary basin fill in the hanging wall. South of the map area, the early Miocene Cloudburst Formation dips 65° to the east at the base of the section. The Cloudburst Formation depositionally overlies granitic rocks that are continuous with those beneath the Copper Butte Fault [Schmidt, 1971; Cornwall and Krieger, 1975; Dickinson, 1991], and intrude Pinal Schist above the Diabase Fault. The tilting of the Cloudburst Formation is consistent with the 60° of eastward tilting proposed for the Ray ore deposit above the Diabase fault [John, 1994]. The reconstruction proposed here (Section B-B', Plate 3) infers on the order of 4500' of pre-Apache Leap tuff normal separation on the Diabase fault, about 900' of which were removed by post-Apache Leap tuff reverse separation. Because of its relatively steep dip, changes in the displacement on the Diabase fault do not significantly impact the horizontal extension estimate.

East-side Fault

The East-side Fault (Figure 4, Line 3 of Sell [1996]), separates Apache Leap tuff from Pinal Schist in the northeastern part of the map area. Southward along strike, Apache Leap Tuff directly overlies Pinal Schist at the eastern edge of the map area in the southwestern Pinal Mountains (SE sec 6, T2S R14E, UTM 3682100N, 504230E) [Peterson, 1963]. At the northern end of the Dripping Spring Mountains, Apache Leap tuff overlies Dripping Spring Quartzite of the Apache Group (NW SW sec. 18, T2S R14E, UTM 3679625N 503125E). About 1 mile (1.6 km) to the south, Mescal Limestone (and diabase) are overlain by thin Whitetail Formation and Apache Leap Tuff across the entire range from west to east. This onlap of tuff onto younger strata to the SSW results from some combination of burial of a northeast-facing topographic escarpment formed by Apache Group strata and a regional, gentle SSW dip of the Apache Group. Drill holes in the valley north of the Dripping Spring

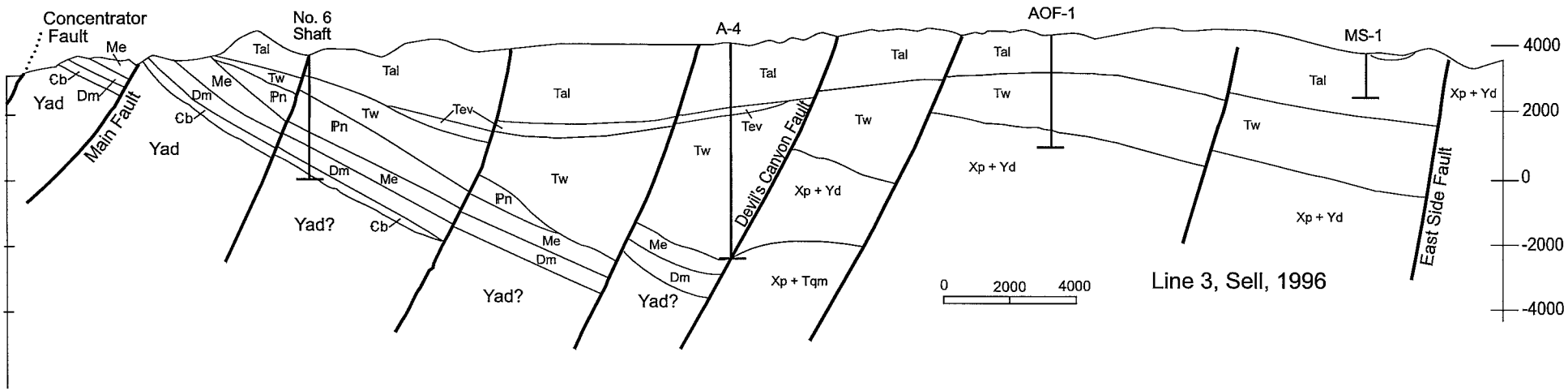


Figure 4. East-west cross section across Oak Flat at the north edge of the study area (after Sell, 1996). Location of Section line show in Figure 2.

Range (QDC-2, see geologic map) and east of the northern Dripping Spring Range (MJ-4) penetrated >700 and >2700 feet of Whitetail Formation respectively. The lack of significant Whitetail Formation beneath Apache Leap Tuff in the Dripping Spring Mountains indicates that the tuff buried the margin of a Whitetail-age basin. The base of the Apache Leap Tuff on the crest of the Dripping Spring Mountains is at an elevation of about 4200 feet, and there is no Whitetail Formation between the tuff and pre-Tertiary rocks. The base of the tuff in QDC-2 and in MJ-4 is about 2800 feet (850 m) and about 1900 feet (580 m), respectively, below the base on the crest of the Dripping Spring Mountains. These relationships suggest that a down-to-the-west fault lies between these holes and the northern Dripping Spring Mountains; this fault may have bound a Whitetail-age basin, and have continued movement after eruption of the Apache Leap tuff. This fault probably connects northward with the East-side fault, cutting across the trend of SSW-dipping Apache Group strata. The East-side fault is a composite of this older fault and a post-Apache Leap Tuff fault that is probably related to the formation of the Dripping Spring Valley.

Contractional structures

The most enigmatic structures in the map area are a set of folds and reverse faults distributed in a northeast-trending belt from The Spine to the northern end of the Dripping Spring Valley. These structures involve rocks as young as conglomerate overlying tuff of White Canyon (Tc). The best known of these is the Spine Syncline [Keith, 1983; Dickinson, 1995], an en echelon series of northwest-trending open synclines. Reverse faults north of the Ray Mine and an associated syncline in Tertiary strata constitute a second zone of contractional structure. An open syncline at the northern end of the Dripping Spring Valley is a third, apparently contractional structure.

The Spine syncline is an open, upright syncline. The southeast end of the fold is defined by the easternmost exposures of the tuff of White Canyon; no marker exist to define the fold in the Pinal Schist and Proterozoic granite (Yg) southeast of these exposures. The fold has an interlimb angle of 150° at its southeast end, and is trending southeastward towards the Copper Butte Fault as that fault swings to a more southerly trend. From the SE end of the fold to the northwest, the fold's hinge-plane trace is parallel to the Copper Butte fault, and lies about 0.4 mile (600 m) south of the fault. The syncline has an interlimb angle of 110° just north of The Spine in the area of tightest folding. The hinge-plane trace shifts 1200 feet to the southwest across the projection of the Spine Canyon fault, but this fault does not cut the tuff of White Canyon that forms the fold. The interlimb angle also increases to about 145° westward across the trace of the Spine Canyon Fault. The 50°SW dip in tuff of White

Canyon in NW SW NW sec. 30, T3S R13E (UTM 3667070N 493940E) is in tuff of White Canyon in a buttress unconformity against Apache Leap Tuff; the steep dip is at least in part related to initial dip. The tuff of White Canyon is about 125 feet thick east of the Spine Canyon fault and 350 feet thick west of the fault (thicknesses based on outcrop widths), indicating that the tuff of White Canyon buried an escarpment at the Spine Canyon fault and lapped out eastward onto what was probably an elevated footwall block when the tuff was deposited. The change in fold geometry across the Spine Canyon fault probably results from this change in thickness and from the mechanical effects of the paleofault scarp. The distribution of the tuff east of the Spine Canyon fault suggests the possibility that it is preserved in a paleovalley. If the tuff were deposited in a steep-walled valley, then at least part of the apparent tighter folding north of the Spine might be due to opposing initial dips in a paleovalley.

A second group of significant contractional structures has been mapped north of the Ray Mine. The Livingston and School faults are west-dipping thrust faults that superpose Pinal Schist on Apache Leap Tuff, and Apache Leap Tuff on tuff of White Canyon(?). In addition, the tuff of White Canyon(?) and older rocks are folded into an open, upright syncline in the footwall of these faults. Apparent stratigraphic separation on these faults is quite large, but if the Pinal Schist in the hanging wall of the School and Livingston faults is in the hanging wall of the Emperor thrust (see below), then these could be mostly normal faults, with only minor late-stage contraction. More data are necessary to resolve the kinematics of the School and Livingston faults.

An anticline-syncline pair between the northern end of the Dripping Spring Mountains and Pinal Mountains are the third contraction-type structure in the map area. The syncline is in conglomerate (Tc), tuff (Tt), and Apache Leap Tuff (Tal) at the northern end of the Dripping Spring Valley. Tuff involved in the folding had yielded an $^{40}Ar/^{39}Ar$ sanidine date of 16.91±0.05 Ma [McIntosh and Ferguson, in prep.]. The fold is upright, gentle, and plunges gently to the south-southeast. Drill hole QDC-2 penetrated 1030 feet of conglomerate before hitting Apache Leap tuff, and was spudded in conglomerate stratigraphically below the tuff unit (Tt). Only 6000 feet (1800 m) south of this hole, the tuff laps out against Apache Leap Tuff. Most of the thinning of the conglomerate occurs across an east- or ENE-trending fault at the northern end of the Dripping Spring Mountains. This fault was active during deposition of the conglomerate or at least produced the basin in which the conglomerate was deposited. Tuff (Tt) overlies Apache Leap Tuff on the east limb of the syncline 3100 feet (950 m) northeast of hole QDC-2. This is measured perpendicular to the hinge surface trace of the syncline. If the area mapped as QTs is mostly underlain by conglomerate (Tc), which seems quite likely, then the apparent thickness of the conglomerate, based on its outcrop width, does not change appreciably until reaching the eastern limb of the syncline. This implies a very rapid loss of the 1000 feet of conglom-

erate beneath the tuff in SE SW sec. 6 and SE NE sec. 7 of T2S R14E (between UTM 3682240N 504160E and 3681700N 504650E). It seems probably this thinning occurs across a north-trending fault (dotted on the map) inferred from disconnected fault segments and the outcrop distribution shown by Peterson [1963]. It is unclear whether this thinning is due to uplift and erosion of conglomerate deposited on the east side of the fault, or to non-deposition of the conglomerate on the uplifted east side of the fault. In view of the dramatic stratigraphic variations and pre-fold structure, the hinge-surface trace of the syncline in the northern Dripping Spring Valley is remarkably straight.

The distribution of Apache Leap Tuff across the northern end of the Dripping Spring Mountains defines a box-like anticline. The eastern limb involves rocks as young as the basin-fill conglomerate (Tc) with interbedded tuff (Tt); this limb is the west limb of the northern Dripping Spring Valley syncline. The western limb of the anticline is a northeast-trending monoclinal flexure defined by the base of the Apache Leap Tuff. The basal contact of the tuff dips 20-40° northwest along the steep limb of the monocline, but eutaxitic foliation in tuff exposed in Mineral Creek is very gently dipping, and the outcrop of the base of the tuff on top of Government Hill indicates a very gentle dip there as well. The tuff overlies Mescal Limestone and diabase that intrudes the Mescal, with a few thin lenses of basalt or Troy Quartzite at the unconformity. Bedding in Apache group strata underlying the tuff is broadly concordant with bedding in the basal part of the tuff. These relationships suggest that the tuff was folded with the Apache Group strata, but some of the apparent folding may be due to deposition of tuff on terrain that reflected the morphology of a pre-existing fold in the Apache Group. This flexure trends northeast, and is apparently overlapped by east-dipping conglomerate (Tc) that forms the west limb of the northern Dripping Spring Valley syncline in NE sec. 15, T2S R14E (UTM 3680200N 503700E). The anticline is thus a composite of a northeast-trending monoclinal flexure and a younger syncline.

The Apache Leap Tuff is deposited on Mescal Limestone and diabase intruding Mescal Limestone on both limbs and the hinge of the anticline. Pre-Apache Leap faults that cut the Apache Group in the northern Dripping Spring Mountains trend northeast, and the subcrop unit beneath the Apache Leap changes southward across these faults. These relationships indicate that the Apache Group was not significantly tilted to the east or west before eruption of the Apache Leap Tuff.

Pre Apache Leap Tuff

Grayback normal fault

The major normal fault in the map area, referred to here as the Grayback normal fault, is exposed along the southwestern edge of the map area. This fault was referred to as the Walnut Canyon fault by Richard and Spencer [1997]; a different name is recommended to avoid confusion with the Walnut Canyon thrust fault, a name which has precedence [Keith, 1983]. Moderately to steeply tilted Whitetail conglomerate in the hanging-wall block is superposed on Teacup granodiorite (TKtc). The fault dips gently NNW where it is exposed, and it is interpreted to turn abruptly to the south as it crosses the Gila River. Tertiary rhyolite (map unit Tri) intrudes the Grayback fault south of SE SE sec. 4, T4S R12E (UTM 3663100N 489330E). Rhyolite that intrudes the fault has yielded a $^{40}Ar/^{39}Ar$ sanidine date of 16.18 ± 0.5 Ma (Sample 1-17-96-1, Table 2). Southwest of the map area, the Grayback fault separates Proterozoic rocks that underlie the Whitetail conglomerate in its hanging-wall block from Teacup granodiorite in the footwall block. South of the Gila River, the Cochran fault cuts the rhyolite that intrudes the Grayback normal fault and is clearly younger.

Diabase dikes (Yd) that trend north and dip near 90° intrude Proterozoic granite (Yg) in the hanging wall of the Grayback fault in the North Butte Quadrangle, southwest of the map area [Richard and Spencer, 1997]. These are interpreted to have been intruded as horizontal dikes, typical of Proterozoic diabase in the region [Howard, 1991]. If this is the case, then crystalline rocks in the hanging wall of the Grayback fault in that area have tilted eastward by about 90° since Proterozoic time. The 19 Ma tuff of North Butte dip 15-20° to the east where it overlies these crystalline rocks, indicating that much of the tilting occurred before 19 Ma [Richard and Spencer, 1997].

Slip on the Grayback normal fault is not well constrained. We suggest that the belt of north-south striking diabase dikes in the Grayback quadrangle [Cornwall and Krieger, 1975] was originally part of a group of sheet intrusions contiguous with similarly oriented diabase dikes in the North Butte area [Richard and Spencer, 1997], and that the east-west striking Laramide dike swarm in the North Butte area was originally contiguous with the east-west striking dike swarm along the southern margin of this map area. The intersection of the horizon of the top of the diabase sheets and the Laramide dikes provides a piercing point to estimate fault slip. This assumes that all tilting of the diabase sheets is middle Tertiary, and resulted from slip on a now sub-horizontal Grayback normal fault. Based on these assumptions, movement on the Grayback normal fault translated rocks in its hanging wall 17 km towards 250° relative to rocks in the footwall.

Along the southwestern edge of the map area, the Grayback normal fault superposes a hanging-wall block consisting of a tilted sequence of Whitetail Formation on top of a tilted slab of crystalline rocks referred to as the Grayback block. Dip of strata in the hanging-wall block decreases to the east at higher stratigraphic levels. Both blocks presumably tilted at the same time [Howard and Foster, 1996; Richard and Spencer, 1997]. The Grayback normal fault is overlapped by the upper part of the Whitetail Formation just east of Walnut Canyon [Dickinson, 1995] (SW NE sec. 36, T3S R12E, UTM 3665450N 492430E). This relationship indicates that the Whitetail Formation in the southern part of the map area was deposited in a half graben during tilting and extension, and that movement on the Grayback normal fault ended late during the period of deposition of the Whitetail Formation.

All post-Whitetail Formation structures, including the Spine Canyon fault and the Copper Butte Fault, should cut the Grayback normal fault. Because the Grayback fault dips north, separation across the younger, west-dipping normal faults should have a left sense. A short segment of fault juxtaposing Whitetail Formation on Pinal Schist between Copper Butte and the Copper Butte fault (SW SW SW sec.19 T3S R13E, UTM 3667600N 494720E) is probably a segment of the Grayback normal fault. The northwest-dipping fault 2 miles north of Copper Butte and truncated by the east Copper Butte fault in SW sec. 7, T3N R13E (UTM 3670930N 494110E) is interpreted to be the offset continuation of the Grayback normal fault. This fault consists of a series of anastamosing shear zones that bound 10-20 cm thick lozenges of less deformed rock, and define a rough planar fabric parallel to the fault. The shear zones are 1-5 cm thick and consist of poorly indurated to non-indurated gouge. Hanging wall Pinal Schist is much more disrupted than the granodiorite (Tgm) in the footwall. Within about 1 meter beneath the fault, the granite is chloritic, but otherwise typical of the granodiorite far from the fault. The east branch of the Copper Butte fault truncates the Grayback normal fault on the west, and is characterized by a 5-10 meter wide zone of massive crushed rock. The continuation of the Grayback normal fault east of where it is covered by alluvium in NW SW SE sec. 7, T3S R13E (UTM 3671160N 494550E) can not be determined with confidence because Pinal Schist in this area is extensively shattered and lacks marker beds.

This interpretation requires that the Grayback normal fault cut the unconformity at the base of the Whitetail Formation so that both its hanging wall and footwall are Pinal Schist. The Whitetail Formation is in contact with Pinal Schist in the hanging wall of the east branch of the Copper Butte fault along Walnut Canyon. This contact is exposed in the north side of Walnut Canyon in NE NE sec. 24, T3S R12E (UTM 3669070N 493680E), where Pinal Schist-clast, monolithologic, sedimentary breccia of the Whitetail Formation (Twp) grades into shattered Pinal Schist. The Pinal Schist exposed along Walnut Canyon in this area is so shattered that it might be a series of rock avalanche deposits. The

discordance of the Whitetail-Pinal contact to bedding in the Whitetail Formation requires that this contact is a buttress unconformity or that there has been some post-depositional movement of the conglomerate relative to the shattered schist.

The easternmost fault zone associated with the Grayback normal fault crops out in E center sec. 8, T3S R13E (UTM 3671580N 496150E), where a fault zone dipping 30° to the north can be mapped because several slivers of granodiorite (Tgm) are present along the fault zone. Rock above and below the fault is crushed, and veinlets containing minor amounts of pyrite are present in the granodiorite, but predate faulting. A northwest-trending post-Whitetail fault cuts this fault zone at the southwestern boundary of the thick section of Whitetail Formation beneath Teapot Mountain.

Fault beneath Teapot Mountain

The Whitetail Formation is tilted up to 60° eastward at the base of the section beneath Teapot Mountain (NW NE sec. 8, T3S R13E, UTM 3672300N 496370E), and dip decreases progressively up section. South of Teapot Mountain (W SE & S NE sec. 9, T3S, R13E, UTM 3671140N 497760E) the contact between Whitetail Conglomerate and underlying pre-Oligocene rocks follows topographic contours, revealing its gently dipping geometry. Whitetail Formation above the contact dips moderately to steeply northeast and is discordant to the contact with the underlying bedrock in this area. (Two small outcrop areas mapped as Whitetail Conglomerate by Creasey et al. [1983] near the south edge of sec. 9 are interpreted here as Quaternary deposits derived from the Whitetail Conglomerate.) Clasts in the Whitetail conglomerates consist primarily of Proterozoic diabase (Yd), and carbonate rock and quartzite derived from the Apache Group or Paleozoic units. Local bedrock Pinal Schist and Teapot Mountain porphyry are poorly represented among conglomerate clasts in general but Pinal Schist is locally abundant near the contact with bedrock Pinal Schist, suggesting local derivation. Pinal Schist is not unusually crushed near the contact with overlying conglomerate. This gently dipping contact is interpreted as a buttress unconformity above which clasts derived from other areas were deposited over local basement with only a minor contribution of clasts from the local basement. We thus support the interpretation of Creasey and others [1983] that this is a depositional contact. Restoration of bedding to horizontal in overlying conglomerate makes the contact moderately to steeply west dipping.

We infer that a major normal fault underlies Teapot Mountain, and bounds a half graben in which the lower Whitetail Formation accumulated. Deposition and tilting of the Whitetail was synchronous with movement on this fault, but deposition of the Whitetail conglomerate continued after movement on the fault had ceased, and the upper part of the Whitetail overlapped the fault and part of the foot-

wall as exposed in the outcrops south of Teapot Mountain. This proposed history is identical to that proposed for the Grayback fault. Based on the hypothesized continuation of the Grayback fault to the edge of the Teapot Mountain Whitetail basin, this fault beneath Teapot Mountain is considered a continuation of the Grayback normal fault. Mapped faults bounding the Whitetail Formation east and northeast of Teapot Mountain may be outcrops of this fault zone. Displacement on this fault would be linked to syn-Whitetail movement on the Devil's Canyon and East Side faults (see below).

Devil's Canyon fault

Extensive drilling to explore a copper deposit buried beneath Oak Flat [Sell, 1995; Sell, 1996] indicates the existence of two major faults (Figure 4). The Devil's Canyon fault is a north-trending fault that underlies Devil's Canyon. This fault produces a minor down-to-the-west separation in Apache Leap tuff on Oak Flat, mapped by Peterson [1969] in sections 27 and 34, T1S R13E. This zone of surface faulting can be traced to the vicinity of the confluence of Devil's Canyon and Mineral Creek (Sell, personal communication, 1998). In the subsurface, the Devil's Canyon fault has much larger separation. In the hanging wall of the fault, as much as 5500 feet (1700 m) of Whitetail Formation overlie a section of Paleozoic strata through Escabrosa Limestone, which is presumably underlain by a complete Apache Group section. East of the Devil's Canyon fault on the order of 2000 feet (600 m) of Whitetail Formation are present, and are deposited directly on Pinal Schist with Proterozoic diabase intrusions (Yd). The stratigraphic separation across this fault is thus more than 6000 feet (1800 m) down-to-the-west. The dip of the fault is poorly constrained by the drilling data. Published cross sections [Sell, 1996] (Figure 4) show the fault dipping about 60° to the west, based on correlation of a fault intercepted in hole A-4 (located north of map area) with mapped surface faults cutting Apache Leap Tuff [J. D. Sell, personal communication, 1998].

Lime Point Fault

The Lime Point fault is a top-to-the-west low-angle normal fault that drops Naco Formation in its hanging wall (which forms Lime Point) against rocks as old as diabase intruding Dripping Spring Quartzite. The geometry of the Lime Point fault suggests it is largely a pre-Apache Leap structure. This fault cuts the Walnut Canyon Thrust fault, so that southeast of Walnut Spring (SW SW sec. 5, T3S R13E, UTM 3672530N 495560E) the Lime Point normal fault has Pinal Schist in its hanging wall and in its footwall. The fault cannot be followed in the netherworld of shattered Pinal Schist around Walnut Canyon, and we interpret that it merges into the Grayback normal fault in this area.

Thus, some displacement from the Grayback normal fault would be transferred to the Lime Point fault.

Laramide Structure

Thrust faults

We hypothesize that two imbricate thrust faults exist in the map area. The western, structurally higher Walnut Canyon thrust system [Keith, 1983] superposes Pinal Schist on Apache Group and Paleozoic strata as young as the Naco Formation. The Telegraph Canyon thrust and Walnut Canyon fault are dismembered segments of this fault. The name Walnut Canyon thrust system will be used to refer to the regional structure, and Walnut Canyon fault to refer to the thrust fault that superposes Pinal Schist on Naco Formation in upper Walnut Canyon. The Emperor thrust in the Ray Mine is an eastern, structurally lower fault. Each separate fault segment is described below, and then the system as a whole will be discussed.

Some rock previously mapped as Pinal Schist in the hanging wall of a thrust fault [Theodore et al., 1978; Creasy et al., 1983] is interpreted here as sedimentary breccia and rock avalanche deposits. These deposits would have been transported from the hanging wall of thrust faults described below onto their footwall during deposition of the Whitetail Formation (Oligocene(?)-early Miocene). In the area of White Water Spring (NW sec. 1, T3S., R.12E, UTM 3673250N 493100E), we interpret the thoroughly brecciated Pinal Schist as a rock avalanche deposit that was deposited on Naco Group. The contact with overlying Apache Leap tuff is marked by local thin stratified gravels derived from Pinal Schist or small clasts of Pinal Schist incorporated into basal 1-2 meters of Apache Leap tuff. Apache Leap tuff is also variably vitric at contact. North of this breccia Creasey et al. [1983] shows a thin belt of Pinal Schist on the northeast side of an alluvium filled wash (NW NE sec. 35, T2S, R12 E, UTM 3676280N, 494080E). This Pinal Schist is not shattered and appears to be bedrock. The schist exposed in the hanging wall of the thrust along Walnut Canyon in the Walnut Spring area is intensely shattered, to the point of resembling a rock avalanche deposit. Definitive distinction between crushed but in place Pinal Schist and Tertiary mass-wasting deposits is not possible in some areas.

Telegraph Canyon Thrust

The Telegraph Canyon thrust juxtaposes Pinal Schist and Apache Group strata in upper Telegraph Canyon in the eastern part of the Mineral Mountain 7.5' quadrangle (NE sec. 32, T2S R12E and N center sec. 5, T3S R12E, UTM 3673000N 489200E and 3675300N 487000E). The southern end of the

fault is poorly exposed, and the present trace of the contact between the Pinal Schist south of the fault and Apache Group to the north is a composite of faults with several orientations. Northwest-trending faults appear to cut small Tertiary rhyolite dikes (Tri) in Pinal Schist south of the fault trace. These faults are interpreted to be Miocene in age because they are broadly aligned with the Wood Canyon fault system, and have similar senses of separation. Northeast-trending segments of the Pinal Schist-Apache Group fault are very poorly exposed, but the outcrop trace suggests a SSE-dipping fault that superposes Pinal Schist on top of Apache Group strata. A small outcrop in a hill-slope wash (NW NE NE sec. 5, T3S R12E, UTM 3673850N, 4886950E) exposes tectonite derived from Pinal Schist just above the fault; quartz veins and thin pegmatite dikes in the schist are transposed to parallel a cleavage oriented 025/18W. This cleavage transects the steeply dipping laminated compositional banding in the Pinal Schist. This is the only exposure seen of fault rocks interpreted to be related to the northeast-trending fault segments. The style of these fault rocks, apparent superposition of Pinal Schist above Apache Group, and the regional distribution of Apache Group strata together support interpretation of this structure as a Laramide thrust or reverse fault.

Farther north, in the northern part of section 32, Pinal Schist is shown by Theodore and others [1978] as thrust over Apache Group rocks. This fault contact is characterized by brittle deformation with no evidence of ductile deformation, even in underlying Mescal Limestone, which is suggestive of shallow depths and low temperatures at time of juxtaposition of contrasting rock types. Pinal Schist here may be in a Tertiary slide block or a remnant of the hanging wall of the Telegraph Canyon thrust.

The Telegraph Canyon thrust cuts up section across the Apache Group with a cut-off angle of about 60°, indicating steep initial dip of the thrust or that the Apache Group strata are folded into a footwall syncline. The existence of a footwall syncline is indicated by the mapped structure in the Apache Group north of the fault trace, but the geologic relations require that the thrust cut up section to the east across the Apache Group. Reconstruction of the pre-Miocene geometry of the Telegraph Canyon thrust is poorly constrained because of uncertainty about its present geometry and uncertainty about the magnitude of Tertiary-extension-related tilting.

Walnut Canyon Fault

The Walnut Canyon fault juxtaposes Pinal Schist against Troy Quartzite, Proterozoic diabase, and Paleozoic strata as young as the Naco Formation. Intersecting Tertiary low-angle normal faults complicate this fault. The southern segment of the Walnut Canyon fault is presently exposed as a relatively planar fault oriented 058/70SE that can be traced for about 1.5 km across the NW of Sec.7 T3S, R13E (UTM 3671300N 493600E to 3672150N 494980E). In the canyon at the northeast end of this

segment of the fault, Pinal Schist is crushed over an area of several 10's of meters; this crush zone is interpreted as the intersection between the Walnut Canyon fault and the Lime Point normal fault. Slivers of diabase (Yd), Apache Group, and Troy Quartzite are present along the Walnut Canyon fault zone. The Lime Point normal fault truncates the Walnut Canyon fault, and continues eastward to Walnut Spring (SW SW sec. 5, T3S R13E, UTM 3672515N 495570E), where it is covered by late Cenozoic alluvium along Walnut Canyon.

The trace of the Walnut Canyon fault continues northward along the west side of Walnut Canyon at the base of a steep dip-slope in Naco Formation. The outcrop shown by Creasey et al. [1983] and Keith [1983] (NE SW SW sec. 5, T3S R13E, UTM 3672755N 495895E) at which Naco Formation overlies Pinal Schist in a gently southwest-dipping fault contact is here interpreted as a rotated fault in a landslide deposit. Naco Formation outcrops above this fault are in large blocks, and bedding is randomly oriented between blocks. Apparently the Naco Formation failed along bedding planes allowing a sheet of limestone to move down slope over Pinal Schist in the hanging wall of the Walnut Canyon thrust.

The trace of the Naco Formation-Pinal Schist contact along this part of Walnut Canyon is broken into north-trending and northwest-trending segments. The north-trending segments follow a consistent stratigraphic horizon in the Naco Formation. This horizon is a yellow-tan weathering, fine-grained calcareous quartz arenite; lenses of pebble to cobble conglomerate are associated with this sandstone. The conglomerate contains angular tan, gray, and white chert pebbles and cobbles to 15 cm diameter in a hematite-calcite-cemented, quartz-sandstone matrix. These rocks are exposed in float except for rare outcrops. Pinal Schist is not exposed near the fault, and no fault rock was observed that could be definitely associated with the fault. Northwest-trending fault segments transect bedding in the Naco Formation; in one outcrop (NE NE SW sec. 5, T3S R13E, UTM 3672579 496348), a southwest-dipping fault surface is exposed, with hematite-stained limestone breccia along the fault. The northwest-trending fault segments are interpreted as Tertiary faults.

The north-trending fault segments are interpreted as segments of a bedding-parallel thrust fault. When the Naco Formation and basal part of the Whitetail conglomerate are rotated back to horizontal, the segment of the Walnut Canyon thrust now southwest of AZ highway 177 (in the hanging wall of the Lime Point fault) rotates to an orientation of about 075/45SE, and the segment of the fault northeast of AZ highway177 rotates to nearly horizontal. This reconstruction indicates that the Walnut Canyon fault cut up-section to the north across units in the Apache Group and was parallel to bedding in the Naco Formation.

The hanging wall of the Walnut Canyon fault in upper Walnut Canyon contains a large, overturned fold that has been tilted to the east by about 40° in Miocene time (Figure 5). The result is a synfomal anticline (synform with the oldest rocks in the core of the fold). The hinge plane trace is in two discontinuous sections, with a separation that matches separation across a normal fault mapped in Paleozoic rocks in the footwall of the Walnut Canyon thrust (SW sec 29, T2S R13E, UTM 3675700N, 495815E). Although this relation has not been field checked, it seems that the normal fault must cut the Walnut Canyon thrust and fold as shown by the queried fault in Figure 5. Stereonet analysis of bedding measurements from Keith [1983] indicates that the present orientation of the hinge of this fold is 14°/165°. When the fold is untilted by 40° about an axis trending NNE, the reconstructed fold is an east-vergent overturned anticline with a hinge oriented 10°/345°.

Emperor Thrust

The Emperor Thrust superposes Pinal Schist on an east-tilted section of Apache Group strata in the Ray Mine. John [1994] reports that the thrust cuts and is cut by Granite Mountain Porphyry (Tgm). Regional distribution of the porphyry in the mine area indicates that most movement occurred before intrusion of the porphyry. Small apophyses of the pluton are present in both the hanging wall and footwall of the thrust in the Ray pit, but are regionally restricted to a small area in the vicinity of the mine. The thrust cuts up-section through the Apache Group with a cut-off angle of about 60°. It dips about 30°N at the north edge of the Ray Mine, about 15°E in the central part of the mine, and about 20°S beneath the south side [John, 1994], thus defining a gently east-plunging open antiform. Alteration, mineralization, and overprinting by younger faults obscure the character of the original thrust fault.

Interpretation

Our working hypothesis is that the two major thrust faults are present in the map area: the Walnut Canyon Thrust system and the structurally lower Emperor Thrust. Before Miocene extension, the Walnut Canyon thrust system trended easterly across the study area. Northward decrease in stratigraphic separation and disappearance into folded Naco Formation along Walnut Canyon suggests that the thrust has a displacement component to the north. The pre-Tertiary SSE dip (075/45SE) of the ramp segment of the fault now southwest of AZ highway 177 (in the hanging wall of the Lime Point fault) is also consistent with northward transport. The geometry of the fold above the thrust in upper Walnut Canyon suggests transport to the ENE. The simplest reconciliation of these observations is that the fault was a left-reverse fault. Correlation of the base of the Apache Group between its hanging

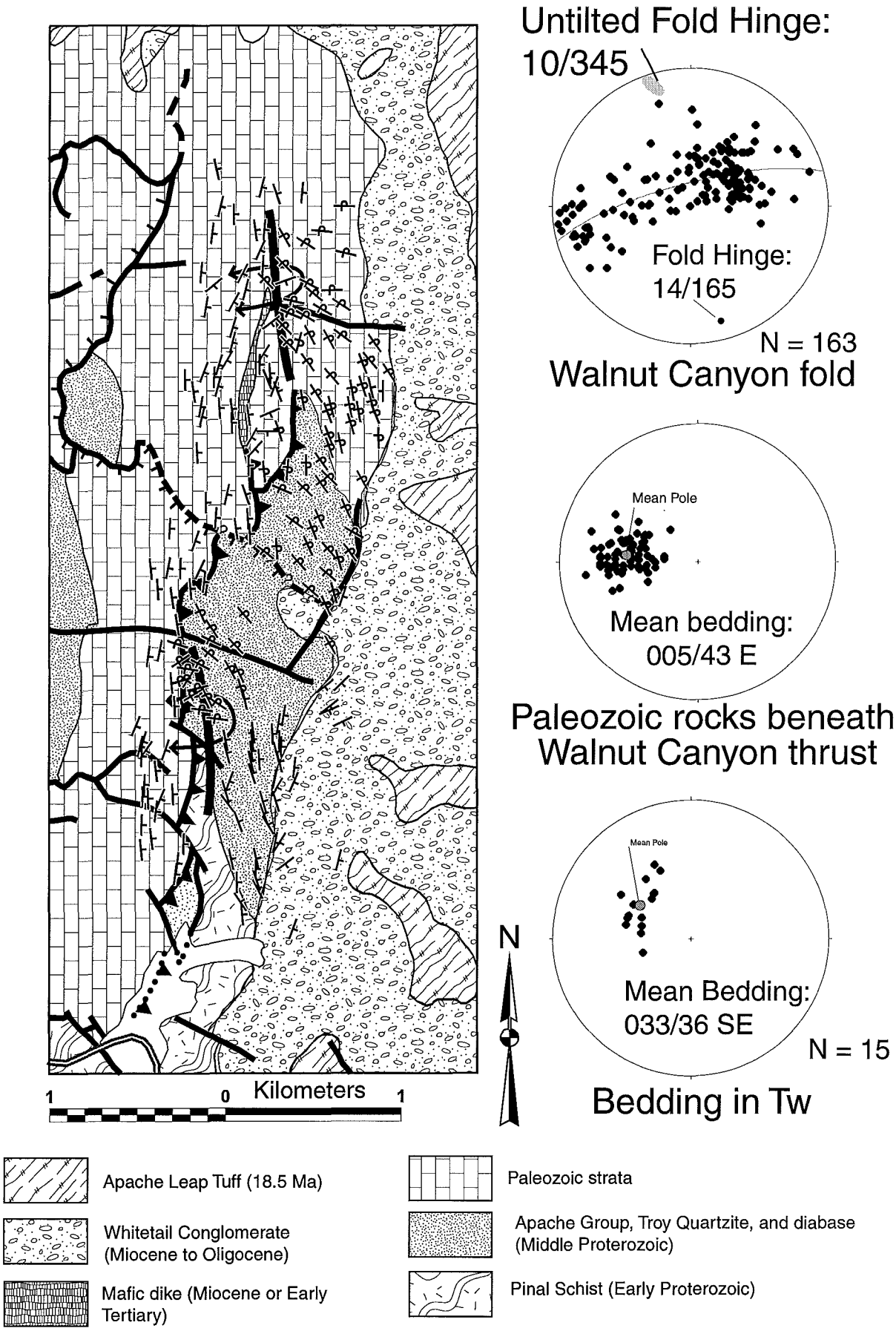


Figure 5. Detail map of Walnut Canyon fold. Location of map shown in Figure 2.

wall and footwall cut off (reconstructed section B-B', plate 3), and unfolding of the overturned fold in the hanging wall (the Walnut Canyon synformal anticline), indicates about 7.9 km ENE contraction. This hypothesis implies that Apache group strata south of Picketpost Mountain and in the Teapot Mountain quad are in the footwall of this fault, and should reconstruct to a subhorizontal layer-cake before the onset of middle Tertiary extension. Pinal Schist, Oracle Granite, and Laramide igneous rocks south of the Walnut Canyon thrust fault in the vicinity of the Gila River represent the hanging wall block, which had its cover of Paleozoic and upper Proterozoic strata stripped in early Tertiary time.

The Emperor thrust cuts up section to the east across footwall Apache Group strata in a fashion similar to the Telegraph Canyon Thrust. Some of the tilting of footwall Apache Group strata may be due to the presence of a footwall syncline. An orientation of about 160/40-60°W for the Emperor Thrust before Tertiary tilting is consistent with the reported dip of Apache Group strata in the Ray pit [John, 1994], and with the dip of Early Miocene Cloudburst Formation along strike to the south [Cornwall and Krieger, 1975a; Dickinson, 1991]. Displacement on this structure is poorly constrained. The overlap of tilted Apache Group by Pinal Schist in the Ray pit (~2400 feet, 730 m) requires a minimum horizontal contraction of between 1800 and 1200 feet (550 and 360 m) for a fault initially dipping 40° and 60°, respectively (assuming originally horizontal bedding). The orientation and geometry of the Emperor thrust is consistent with a thrust or reverse fault that was part of a north trending fault system between the Tortilla and Dripping Spring Mountains, with the west side up.

The Emperor thrust and Walnut Canyon thrust project northwards toward a reconstructed intersection near or at the northern end of the present Dripping Spring Mountains. The relationship between these structures is problematic. None of the structures in the Dripping Spring Mountains can be correlated with the Walnut Canyon or Emperor thrust faults. Our interpretation that the two faults are the same age and that the Walnut Canyon thrust is in the hanging wall block of the Emperor thrust is only one possible solution. It is geometrically simple in cross section, but does not account well for the apparent discrepancy in strike between the two thrust faults. Two other hypotheses that should be considered are:

1. The northeast-trending fault in the hanging-wall block of the Lime Point normal fault is a northeast-trending fault similar to the Rustler fault in the Dripping Spring Mountains, and cuts the Walnut Canyon fault exposed east of Highway 177. This relationship is obscured by the younger Tertiary normal faults. Such a fault might be a tear fault in an Emperor-Walnut Canyon thrust system.

2. The Walnut Canyon thrust continues to trend northeast, and is cut by or cuts the Emperor Thrust. Its northeastward continuation is underneath the northern Dripping Spring Mountains, and continues northeastward, to become the Sleeping Beauty fault in the Pinto Valley-Miami area. This fault system could form the northwestern boundary of the Pinal Mountains uplift [Richard and Spencer, 1998].

Determination of the actual relationship between these faults awaits further data.

Dripping Spring Mountains

In contrast to pre-Tertiary strata in the central and western parts of the map area, Apache Group and Paleozoic strata in the Dripping Spring Mountains mostly dip gently SSW, and are cut by numerous high-angle faults. The faults form a broadly arcuate pattern, trending northeast at the northern end of the Dripping Spring Mountains, and trends swing to NNW along the southeastern edge of the map area. Mutually crosscutting relationships between NE-trending and NNW-trending faults suggest a composite history of faulting. Some of the northeast-trending faults at the northern end of the range probably originated in Middle Proterozoic time associated with intrusion of diabase into the Apache Group [Force, 1998]. Most of the NNW-trending faults to the south cut Paleozoic strata indicating a post-Paleozoic history. Some of the faults were present in Laramide time. Dikes related to the Teapot Mountain Porphyry (Tr) intrude along and terminate at the NE-trending Rustler fault (labeled on map), and intrude across and terminate at the N-trending Broken Hill Fault. Rhyodacite dikes (Trd) cross cut and terminate at north-trending faults parallel to and east of the Ransome Fault just southeast of the map area boundary. Several northeast-trending faults with down-to-the-north separation are overlapped by Apache Leap Tuff. All of the faults are steeply dipping and northerly trending and cannot be matched kinematically or geometrically with the Walnut Canyon thrust system. Many of the NNW to N-trending faults have down-to-the-east separation, and cut Apache Leap Tuff in several places at the northern end of the Range. These faults are broadly parallel to the trend of the Dripping Spring Valley and northern end of the San Pedro Valley, and almost certainly have at least some Miocene movement history.

CROSS SECTIONS

Two cross sections were constructed perpendicular to the average strike of tilted upper Proterozoic, Paleozoic, and Tertiary strata along the section line. To the extent that this direction is a good estimate of the regional extension direction, slip vectors for Tertiary normal faults will lie entirely

within the cross section, and the sections can be reconstructed to their pre-extension geometry by realigning originally continuous features 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. The present structural relief on the pre-Apache Leap unconformity is interpreted to be mostly the result of faulting after deposition of the Apache Leap tuff. In light of the abundant evidence for pre-Apache Leap faulting, this assumption is not entirely valid, but serves as a simple, workable approximation. The fault displacement and extension that occurred after deposition of the Apache Leap tuff is relatively small (see below), except for the poorly understood fold and reverse fault system between the Dripping Spring Mountains and Teapot Mountain (section B-B'). The Dripping Spring Mountains have been untilted by about 20° to restore the projected base of the Apache Leap tuff along the western side of the range to horizontal, and to restore the Troy Quartzite on Scott Peak to a near horizontal dip. The fold and reverse fault (School Fault) have been reconstructed to produce a low-relief surface on the base of the Apache Leap tuff, and conserve the length of the nonconformity beneath the tuff in the cross section-line. The displacement inferred on the School Fault is the minimum necessary to place Pinal Schist west of the fault beneath the projected base of the Apache Group east of the fault.

The second step in the reconstruction was 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 A-A' can reasonably be assumed to have been originally contiguous. Apache Group strata in the steeply east-tilted section at the west end and near the center of cross section B-B' are interpreted to form the footwall block of the Walnut Canyon thrust. This footwall block is continuous northward with the Apache Group strata of section A-A'. The gently west-dipping strata at the east end of cross section B-B' are interpreted to form the footwall block of the Emperor Thrust, cut by the Rustler, Broken Hill, and related faults. There is a great deal of uncertainty in the reconstruction of relationships around the Diabase fault. In this reconstruction, the Emperor thrust and underlying Apache Group strata have been projected from the Ray pit into the line of cross section, and this projected base of the Apache Group has been reconstructed to align with the base of the Apache Group across the reconstructed School fault and associated fold. Slip on the Grayback fault is restored by placing the projected base of the Apache Group in the footwall block of the Walnut Canyon thrust above the structurally highest Pinal Schist in the hanging wall block of the Emperor thrust (now exposed north of the

Ray pit between Teapot Mountain and the northern Dripping Spring Mountains). These restorations have attempted to minimize the displacement on the Grayback, Diabase and Emperor faults.

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 (Ya).

In section A-A', 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 B-B' should be mentioned:

- Reverse-drag bending of fault blocks above listric normal faults has been inferred in two places. Near the western 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 west branch of the Concentrator fault. 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 faults on the north side of the Ray Mine and north of there along Mineral Creek are superimposed on an inferred pre-Apache Leap Diabase fault. The Pinal Schist in the hanging wall block of the Livingston and School faults is also in the hanging-wall block of the Emperor Thrust, which is projected above the Dripping Spring Range in our interpretation. Thus the juxtaposition of Pinal Schist on top of Tertiary strata requires a reverse separation equivalent to the stratigraphic thickness of the Tertiary units.
- 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 ob-

served in Tertiary strata south of these Naco Formation outcrops progressively closer to the east branch of the Concentrator fault system. This syncline is apparently the northern end of the Spine Syncline. The fold here is interpreted to be related to normal drag along the major 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 (Tri) in the western part of the section has not been reconstructed, but may account for ~1000' feet (300 m) of additional extension.
- Post Apache Leap normal faults in this section intersect the pre-Apache Leap faults at angles of 25 to 40°.
- The Rustler, Broken Hill, and several related faults at the eastern end of the section line have Laramide or Proterozoic (syn-diabase) displacement histories, and are overlapped by Apache Leap Tuff. On the map these faults trend northeast and project into the section line. Faults of this type have not been recognized in the Precambrian rocks north of the Ray Mine, and are not shown on the cross section west of the School/Diabase fault.
- The cross section shows about 3600' (1000 m) of normal separation on the Diabase fault, significantly greater than the 800' (240 m) estimated by John (1994). This separation is dictated by the depth of the Emperor thrust and the base of the Apache Group projected from the Ray pit to the section line, and the interpretation that the Dripping Spring Mountains are in the footwall of the Emperor thrust. The discrepancy in separation estimates indicates that the Emperor thrust and base of the Apache Group can not be projected as planar features over the ~7500 feet (2300 m) between the section line and the pit. In the absence of data to better constrain these features in the section line, the simple projection has been used. Because of the steep dip of the Diabase fault, uncertainty in the magnitude of normal separation on this fault has little impact on the total extension estimate.
- The reconstruction indicates that the mineralized rock of the Ray ore deposit was buried a minimum of 11000 feet (3300 m) at the time of mineralization. The thickness of rock removed by erosion from above the Dripping Spring Mountains during Tertiary time was probably less than this. It seems unlikely that the Emperor thrust sheet was continuous across the entire range, and the Walnut Canyon thrust probably broke the surface above the range as well. Initial erosion from this thrust front would have provided detritus now preserved in Eocene con-

glomerates along the Mogollon Rim, and subsequently have provided sediment now preserved in the thick Whitetail conglomerate section beneath Oak Flat and Teapot Mountain.

- An alternate interpretation is that Precambrian rocks north of the Ray Mine, between the Whitetail Formation and the School/Livingston fault system correlate with basement rocks beneath Apache Group of the Dripping Spring Mountains. This interpretation requires 1) that the Walnut Canyon thrust and Emperor thrust are part of a single fault system that would have had to curve from an ENE to more N-S strike between Walnut Canyon and the Ray Mine; and 2) that the hanging wall block of the Diabase fault is truncated at the North End fault, such that Precambrian rocks north of the North End fault are actually in the footwall block of the Walnut Canyon Thrust system. A reconstruction based on this interpretation results in significantly less slip on the Grayback and Diabase normal faults, and a total length change of 4.5 km along the section line. The imbricate thrust hypothesis is favored because the geometry of the Laramide structures is less astonishing, and because the 7.1 km length change estimated based on this model (Table 6) seems more consistent with extension estimated along section A-A' (which does not include the northern continuation of the Grayback and Diabase faults), and with 5-7 km extension estimated across the northern end of the Tortilla Mountains (also not including slip on the Grayback fault; S.M. Richard, unpublished data, 1997).

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 cross 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 west branch of the Concentrator fault and the Teapot Mountain tilt block; 3) the Teapot Mountain block, bounded on the east by the Grayback fault system; and 4) the Dripping Spring Mountains, east of the Grayback fault. Section A-A' crosses do-

	extension (%)					length change (km)				
domain	1	2	3	4	total	1	2	3	4	total
A-A'										
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**
B-B'										
pre Tal	58%	36%	1254%	8%	58%	1.4	1.3	3.6	0.4	6.8
present	6%	5%	1%	-5%	1%	0.2	0.3	0.0	-0.3	0.2
total					**60%**					**7.1**

Table 6. Extension summary for cross sections.

mains 1 and 2, and section B-B' crosses all 4 domains (domain numbers are labeled on the cross sections).

GEOCHRONOLOGY

Four new $^{40}Ar/^{39}Ar$ isotopic dates obtained from sanidine in tuff interbedded in Tertiary conglomerates are reported here. Complete analytical data are included in McIntosh and Ferguson [in prep.].

Sample	Unit	Location	Latitude deg.	Latitude min	Longitude deg.	Longitude min	n	K/Ca	±2s	Age (Ma)	±2s
01-17-96-01	Cochran hypabyssal felsite	North of Cochran	33	6.9922	-111	8.8263	14	80.6	17.3	16.18	0.05
02-03-97-02	Tuff near top of Whitetail conglomerate	Ray open pit	33	10.5816	-110	58.8190	25	73.8	56.3	18.72	0.11
04-08-97-01	Tuff, interbedded in conglomerate	Dripping Spring Valley	33	15.3720	-110	57.0969	14	71.5	8.2	16.91	0.05
04-11-96-02	Tuff, interbedded in conglomerate	Superior Basin	33	15.2064	-111	5.9463	16	97.7	14.0	15.92	0.04

Table 1. Summary of new isotopic ages from the Ray-Superior Area [McIntosh and Ferguson, in prep]. Dates are averages

A K-Ar biotite data of 33.2±0.6 Ma has been reported from an "air-fall tuff" within the Whitetail Conglomerate in the Ray Mine area (NE 1/4, sec. 11, T3S R13E; Banks et al. [1972], sample #B72:21; recalculated by Reynolds et al. [1986]). This area has since been buried by Ray Mine dump material, and re-sampling was not possible in 1997. About 100 m of Whitetail Conglomerate was exposed in the Ray pit in 1997, along strike and about 1 mile south of the previously sampled tuff. The conglomerate is deposited on diabase (Yd) and is overlain conformably by Apache Leap Tuff (Tal). This conglomerate section contains two thin tuff beds. The upper tuff bed, located about 60-70 m above the base of the section, was sampled and yielded a $^{40}Ar/^{39}Ar$ date of 18.7±0.1 Ma (sample 02-03-97-02 in Table 1). The sample location is shown on the map as within Apache Leap tuff (geology from Cornwall et al. [1971], but the tuff has been removed by enlargement of the Ray Pit and the sample location was in Whitetail outcrop in 1997. The large discrepancy between these dates is most likely due to detrital biotite in the sample that yielded the older date.

Age determinations reported here indicate that deposition of Whitetail conglomerate east of the Diabase fault probably continued until eruption of the Apache Leap Tuff. The age of the oldest Whitetail conglomerate is bracketed only by the youngest ages of underlying Laramide igneous rocks—about 60 Ma. Deposition of conglomerate in the Dripping Spring Valley was ongoing at about 17 Ma. Tuff near the top of the conglomerate section in the Superior Basin and rhyolite intruding the Cochran fault are both about 16 Ma, suggesting that the latest faulting and basin formation was underway at that time.

MINERALIZATION

Copper Butte Mine.

Abundant 1-5 cm clasts of black chalcocite ("copper wad" of Phillips [1976]) in Whitetail Conglomerate at west end of the Copper Butte mine area grades up section to the east into red, hematite stained conglomerate. Black clasts are in zones crudely parallel to bedding, possibly suggestive of zones where mineralizing fluids were more active in the conglomerate. Green and blue copper minerals are locally present on fracture surfaces. Distribution of copper and iron mineralization along fractures and in pore spaces indicates that mineralization is not entirely clastic (syngenetic) but was at least partly due to later mineral precipitation from underground mineralizing fluids (epigenetic). Possibly, mineralization could be largely due to movement of mineralizing fluids that originated in an area where sulfide mineral deposits were undergoing oxidation.

Phillips [1976] concluded that Copper Butte mineralization was the result of fluid migration from an area where a copper sulfide mineral deposit was undergoing oxidation in a near surface environment. The location of this sulfide deposit is not known. The Ray copper deposit is 3 to 4 miles away and is in a different drainage basin, which makes it an unlikely but not impossible source. Possibly, at the time of mineralization at Copper Butte, surface and subsurface drainage patterns were much different than now.

Mineral deposits similar to Copper Butte, located 2 miles west-southwest of Copper Butte at the Buckeye deposits within Whitetail Conglomerate, are even farther from the Ray mine deposit. Phillips (1976, p. 178-179) states that "The presence of copper oxides and carbonates west of the Buckeye mineralization could indicate proximity to a source since these minerals seemingly tend to form closer to the original sulfide mineralization than do chrysocolla or the black copper mineral(s)" at Copper Butte. Furthermore, another 2-3 miles to the west-southwest in the northeastern part of the North Butte Quadrangle, chrysocolla, malachite, and iron oxides coat fractures and form open space fillings in several different rocks types at a cluster of small mines and prospects [Richard and Spencer, 1997]. These deposits also could be related to the mineralizing fluids from which the Copper Butte and Buckeye deposits were derived (fracture filling chrysocolla occurs within the felsite complex of Cochran north of the Gila River; this could indicate that mineralization in this area is younger than and unrelated to intrusion of the felsite complex of Cochran). In conclusion, the source of copper in all of these deposits remains unknown.

Sunset Mine.

Iron and manganese oxides with sparse blue and green copper mineralization appear to be localized within crushed rocks along shear zones in psammitic facies Pinal Schist. One strongly mineralized shear zone is oriented N50°W, 50°NE.

Mine, SW sec.7 T3S R13E (UTM 3671134N 494491E)

Prospect pit and 10 m adit along fault zone (Grayback normal fault?). Shaft just to west is 80-100 feet deep, vertical, with an iron collar and screen, apparently sunk to meet the adit along the strike of the fault zone. Rock on dump is mostly sheared and brecciated Pinal Schist. Some granular galena and sphaelerite, intergrown with epidote(?) is present. Cleavage surfaces in galena are curviplanar. Trace of barite intergrown with acicular epidote present. No mineralized rock crops out. Some diabase (Yd) is present in dump, suggesting that the mineralization might be associated with slivers of Apache Group along the fault zone. Fault oriented 067/75NW.

Mine, SW NW NW sec. 33 T3S R13E (UTM 3665500N 497210E)

Glory hole about 50' deep in intrusive(?) breccia (Kd). Pyrite disseminated in epidote-actinolite skarn from blocks in breccia. Mineralization associated with fractures trending 120/90. Some disseminated pyrite in breccia matrix, but largest sulfide concentrations are associated with skarn in clasts. Drusy epidote lines open space in fractures; fractures are filled with brown calcite. See no copper or base metal minerals. In the wash east of the shaft a banded quartz vein containing disseminated pyrite about 10 cm thick cuts across the contact between the breccia and its wall rocks; the vein is oriented 110/90.

Prospect, SE NW sec.3 T4S R13E (UTM 3663760N 499065E)

Shaft about 70 feet deep along a mineralized shear/vein in Tortilla Quartz Diorite (Kt). Shear zone is oriented 087/85N. Chrysocolla, azurite, hematite present in and adjacent to vein. Diorite is sericitized within the vein and in adjacent wall rock; thin veinlets of quartz are present in vein zone. Many similar veins cut the diorite in this area, but presence of copper minerals is unusual.

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MAP UNITS

d Disturbed surficial deposits (Holocene) – Deposits of unconsolidated material resulting from human activities (e.g. mining, road construction, dam building).

Qs Surficial deposits (Quaternary) -- Undivided surficial deposits, includes non-indurated to poorly indurated sand, silt, and gravel. Generally includes alluvium in active channels, older alluvium underlying adjacent terraces, and some colluvium and talus. Unconformably overlies all older units.

Qal Active alluvium (Holocene) -- Non-indurated sand and gravel in active stream channels Nonconformably overlies all older units.

Qtc Talus and colluvium (Holocene and Pleistocene) -- Unconsolidated talus and colluvium on slopes. Consists of locally derived angular to subangular cobbles and boulders with variable amounts of sand or mud matrix. Unconformably overlies all older units.

Qoa Older surficial deposits (Pleistocene to Pliocene) -- Slightly to moderately indurated conglomerate and sandstone. Conglomerates typically are poorly sorted cobble to boulder conglomerate, massive to poorly bedded, with low-angle cross beds and channels preserved. Sandstone occurs as thin, discontinuous lenses. Deposits underlying surfaces 2-10 m above modern stream channels, well developed soil profiles on surface of deposit. Typically these are veneers on pediments cut on older basin fill deposits or bedrock. Unconformably overlies conglomerate (Tc).

QTal Apache Leap tuff-boulder deposits (Pleistocene or Pliocene) -- Non-indurated to poorly indurated deposits of cobbles to blocks of Apache Leap Tuff in a matrix of sandy clay. Clasts up to 10 m long. Generally poorly exposed, and commonly mapped as bedrock on older maps. Apparently these are largely lag deposits of tuff blocks and boulders mantling underlying rock units; in some areas includes probably landslide deposits. Unconformably overlies older units.

QTls Landslide deposits (Pleistocene or Pliocene) -- Poorly consolidated to unconsolidated, very poorly sorted mud to large boulders, characterized by a hummocky surface littered with boulders. Bedding or foliation in boulders (when present) varies greatly between outcrops. Contacts of landslide deposits range from sharp to gradational.

QTs Basin Fill (Pleistocene to Late Miocene) -- Undivided alluvium (Qal), old alluvium (Qoa), and conglomerate (Tc). Commonly overlies older, slightly tilted and more indurated conglomerate on a gradational contact or with slight angular unconformity; overlies other rocks unconformably. In Superior basin and northern Dripping Spring Valley is a thin deposit blanketing a pediment cut on Tc. The contact between QTs and Tc is poorly exposed and has not been mapped in detail.

Tc Conglomerate (Miocene) -- Massive conglomerate, ranges from pebble and cobble conglomerate to boulder conglomerate with scattered large blocks up to about 5 m in diameter. A few thin sandstone units are interbedded. Generally buff colored, poorly to moderately indurated, and nonresistant. The unit commonly forms low hills with little or no outcrop, but steep cliffs a few meters high occasionally occur in washes. In upper Arnett creek, unit contains boulder beds consisting of clasts of Apache Leap Tuff up to 1.5 m in diameter interpreted to be debris flows. Most of the unit contains clasts of a variety of rock types found in nearby bedrock exposures. Bedding is visible in sparse sandstone lenses; conglomerate is mostly massive.

Equivalent to conglomerate subunits of Big Dome Formation (Tbd) mapped by Keith [1983]. Tuff interbedded in conglomerate (Tt) in northern Dripping Spring valley yielded a date of 16.91 ± 0.05, and tuff interbedded in conglomerate in the Superior Basin yielded a date of 15.92± 0.04 (both dates are Ar/Ar single crystal sanidine analyses). Conglomerate in the northern San Pedro Valley, south of the Ray Mine, has been included the Quiburis Formation [Dickinson, 1991, 1998]. Dates reported here from tuffs interbedded in the conglomerate in the Superior Basin and northern

Dripping Spring Valley indicate that these conglomerates are older than Quiburis Formation in the San Pedro Valley, and are probably time-equivalent to the upper San Manuel Formation. Contact with QTs has not been mapped in detail, but is apparently a slight angular unconformity. Contact on tuff of White Canyon (unit Ttw) is generally concordant.

Tci Conglomerate, granite clast (Miocene) -- Conglomerate facies in which most clasts are derived from Middle Proterozoic granite (Yg) or Tortilla Quartz Diorite (Kt). Unconformably overlies granitic rocks, grades into mixed-clast conglomerate (Tc)

Tcc Conglomerate, Paleozoic carbonate clast (Miocene) -- Conglomerate facies in which most clasts are derived from Paleozoic carbonate formations of the Dripping Spring Mountains. Unconformably overlies pre-Tertiary strata of the Dripping Spring Mountains, grades into mixed clast conglomerate (Tc)

Tbs Tuff and volcanic-lithic sandstone (Miocene) -- Dark red brown, volcanic-lithic sandstone composed of basaltic cinders, some possible basaltic tuff, interbedded with and overlain by white, bedded tuff and tan, poorly indurated, volcanic-lithic sandstone. White tuff beds contains sparse 1 mm diameter feldspar and tiny biotite crystals, and abundant basaltic lithic fragments. Exposed in stream cuts along west side of Highway 177 about 5.5 km northwest of Teapot Mountain. Conformably overlies basalt lava flows (Tb).

Tb Basalt, upper unit (Late Miocene to Middle Miocene) -- Very fine-grained basalt lava flows with salt and pepper groundmass, containing about 1% crystals of black pyroxene(?) and olivine altered to iddingsite in subequal amounts. Platy weathering in many outcrops. Vague flow lamination are visible on some weathered surfaces. Weathered surfaces commonly have 'elephant hide' look. Conformably overlies Tc, unconformably overlies older units. Overlying units not exposed.

Picketpost Mountain Volcanics (Early Miocene to Middle Miocene) --

Tri Felsic intrusive rocks (Miocene to Miocene) -- Light colored felsic intrusive rocks, typically with quartz, plagioclase, K-feldspar and sparse biotite crystals in a very-fine grained to aphanitic white or light pink or gray groundmass. Ranges from massive to flow banded. Associated with felsic extrusive rocks (Tr), and distinction of intrusive and extrusive felsite can be quite difficult. Intrusions are typically more massive than extrusive rocks, but identification of intrusive rocks is generally based on observation of intrusive contacts at the margins and cross cutting relationships with other rock units. Felsic intrusive rocks included in this unit, mapped as Sleeping Buffalo Rhyolite (Tsb) and Road Runner Rhyolite (Trr) by Creasey et al. [1983] have silica contents ranging from 70.5% to 76.6%. A north-trending belt of irregular intrusions along the western margin of the map area is probably the central part of a volcanic complex from which the rhyolite lavas of Tr and abundant associated pyroclastic rocks (Ttw) were erupted. Contacts commonly have vitrophyric zones along margins.

Tr felsic volcanic rocks (Miocene) -- Felsic lava flows, with associated vitrophyre, autobreccia, and tuff. Colors vary from dark gray to black for massive vitrophyre to white, light gray, or yellow in devitrified or deuterically altered parts of flows. Flow banding, amygdules, and brecciated zones are common. Rocks typically have phenocrysts of quartz, two feldspars, and sparse biotite or hornblende; tiny magnetite crystals are a common accessory. Quartz ranges from euhedral to resorbed. Phenocrysts make up to ~40% of rock in some units. Contacts with associated hypabyssal intrusions or endogeneous dome complexes are difficult to locate. Chemical analyses in Creasey et al., 1983 indicate the lavas in the western part of the map area are rhyolite. Interbedded with associated pyroclastic

deposits of unit Ttw, and intruded by hypabyssal rhyolite of unit Tri. Overlain by conglomerate (Tc).

Tmt Pinal schist-clast tuff (Miocene) -- lithic rhyolite tuff containing abundant 1-4 cm diameter, generally angular clasts of Pinal Schist; sparse biotite crystals less than 1 mm in diameter, abundant 1-2 mm-diameter quartz, and sparse sanidine crystals commonly present. White on fresh surfaces, tan weathering. Contains 1-2 cm diameter pink pumice fragments, and clasts of aphyric felsite in variable quantities. Thick bedded to massive. Found in sections of tuffs associated with Picketpost Mountain volcanics and similar rocks in central Arizona. Lithic rhyolite tuff, exposed in Wood Canyon area of Teapot Mountain quadrangle; contains about 30% angular clasts of Pinal Schist, and 70% clasts of rhyolite (units Tr or Tri). Unit Tmt of Keith [1983]. Not differentiated from Ttw outside of Keith's [1983] map area. Conformably overlies other tuffs or rhyolite lavas. Interbedded in tuff of White Canyon (unit Ttw)

Ttw Tuff of White Canyon (Miocene) -- White to light gray very thin- to thin-bedded tuff associated with Picketpost Mountain volcanics. Little or no evidence of reworking after deposition. Sparse conglomerate horizons are present near the base. Battle Axe Butte is a volcanic center that was one source of these tuffs. This unit forms resistant mesas and ridge tops. Contains 1-2 mm crystals of quartz, feldspar, and minor biotite and magnetite in a fine-grained ash matrix. Sparse 1-3 cm lithic fragments are present. Equivalent to older tuff (Tto) of Creasy et al. [1983]. Subdivided by Keith [1983] into 4 sub-units, apparently based on topographic breaks. These are numbered with subscripts on the map but are not described separately. In the central part of the basin in the western part of the Teapot Mountain quadrangle, is interbedded with rhyolite lava, and intruded by hypabyssal rhyolite. Paraconformity on gravel of Walnut Canyon (Tgw); unconformably overlies all older units. Deposited on landscape with appreciable local relief.

Tbo Basaltic rocks (Miocene) -- Dark gray basalt, basaltic or andesite lava flows, typically vesicular, and associated with red, scoriaceous deposits. Purplish to greenish gray, aphanitic to very fine-grained amygdaloidal basalt lava flows; consists of a mat of tiny (~0.015 mm) plagioclase needles, magnetite, and alteration products comprising carbonate, epidote, chlorite, clay, and hematite. Crops out in west-central part of map area. May be equivalent to basalt upper unit (Tb). Mostly overlies gravel of Walnut Canyon (unit Tgw) conformably, but overlaps gravel of Walnut Canyon to unconformably overlie Pinal Schist at the NW tip of its exposure.

TKmd Basaltic hypabyssal intrusive rocks (Miocene or Cretaceous) -- Small irregular bodies of dark gray, fine-grained to aphanitic basalt or andesite. Small bodies intrude Naco Limestone near the southern end of the strike belt southwest of Oak Flat. North-trending, steep dikes in Middle Proterozoic granite (Yg) north of Gila River, and north-trending, west-dipping dikes in Tea Cup granodiorite in southwest corner of map area.

Tgw Gravel of Walnut Canyon (Middle Miocene) -- Poorly to moderately consolidated gray to buff conglomeratic strata, ranging from sandy conglomerate to sedimentary breccia. Bedding is poorly defined, and the conglomerate is generally massive. Lenticular(?) sedimentary breccia bodies are monolithologic, and consist of clasts of Oracle-Ruin Granite (Yg), Tea Cup Granodiorite (TKg), or Apache Leap Tuff. Outcrops of breccia derived from Apache Leap Tuff along the lower part of the canyon east of White Canyon may be proximal equivalents of breccia sheets in this conglomerate unit.

The Older Gravel unit (Tgo) of Creasey et al [1983] and conglomerate in the eastern part of the Mineral Mountain Quadrangle mapped as Tpg and Tog by Theodore et al. [1978], are correlated with the gravel of Walnut Canyon. Conglomerate in SW SE sec. 32, T2S, R12E (UTM 3674370N,

487250E) is mostly massive with some possible rock avalanche breccia, and consists almost exclusively of Pinal Schist clasts, which are typically 20-50 cm diameter and unsorted. Bedding is very crude. Along strike to north, sparse clasts of Dripping Spring Quartzite are present in the lower part of the conglomerate where it overlaps a fault contact (Telegraph Canyon thrust) between Pinal Schist and Dripping Spring Quartzite, thus revealing local derivation of clasts. Sparse clasts of Pioneer Shale are also present at base of the conglomerate unit where it overlies Pioneer Shale. These conglomerates underlie the tuff of White Canyon, and have dips that are most similar to post-Apache Leap strata. Conglomerate mapped as Tc that overlies Apache Leap Tuff along Arnett Creek in the north-central part of the Teapot Mountain quadrangle may be gravel of Walnut Canyon. Stratigraphic terminology used here is that proposed by Dickinson [1995].

Tgx(t) sedimentary breccia (Miocene) -- Outcrops of monolithologic breccia consisting of angular blocks of Apache Leap tuff (unit Tal) in a matrix of comminuted Apache Leap tuff. Ranges from matrix-rich types in which clasts have clearly rotated and moved relative to each other to matrix-poor varieties in which the clasts have not been significantly displaced relative to each other. Apparently forms lenses in gravel of Walnut Canyon. Locally overlain unconformably by tuff of White Canyon.

Tgx(g) Sedimentary breccia, granite clast (Early Miocene to Middle Miocene) -- Coarse sedimentary breccia consisting of angular to subangular clasts of coarse-grained biotite granite (Yg) and Laramide Teacup Granodiorite (TKtc). Individual bodies tend to be composed of one or the other rock type. These are probably in part debris-avalanche megabreccia [Dickinson, 1995]. Overlies Apache Leap Tuff (Tal), Overlies and interfingers with gravel of Walnut Canyon (Tgw). Overlain by tuff of White Canyon (Ttw)

Tal Apache Leap Tuff (Late Oligocene) -- In typical, well exposed sections, a basal white non-welded to partly welded tuff (0-45 m thick) grades up section with increasing welding to black vitrophyre (1.5-15 m thick). Vitrophyre is overlain by densely welded tuff; degree of welding decreases up section to poorly welded or locally non-welded at top. Tuff is crystal rich, with 35-45% phenocrysts of plagioclase (2-4 mm diameter, 24-32%), quartz (2-3 mm, 4-6%), biotite (1-3 mm, 3-5%), sanidine (2-3 mm, trace to 2%), hornblende (1mm length, 0-1%), opaque oxide (< 1 mm, trace - 2%). Accessory sphene is commonly discernible with a hand lens; zircon and apatite are also present. Plagioclase is typically subhedral, twinned and zoned, and is andesine or oligoclase. Quartz phenocrysts are rounded and deeply embayed. Biotite is euhedral to subhedral in thin books and flakes. Plagioclase decreases in abundance up section, while quartz and sanidine increase up section. Fiamme area strongly flattened, nearly invisible in the lower, strongly welded parts, and become more equant, only slightly flattened in the upper part. Fiamme are generally sparse. The lower, strongly welded parts are medium reddish brown in color, and the color lightens up section with decreasing welding. Zones of vapor-phase alteration tend to be light gray in color. Overlies all older units with slight to strong angular unconformity on a surface of moderate relief. In several areas the contact is moderately to steeply tilted along faults that were apparently active during eruption. Contacts on Whitetail conglomerate are generally concordant, and appear conformable.

..... cooling break (Early Miocene) -- Non-resistant horizon that forms a prominent ledge in outcrops of Apache Leap Tuff along the southeast side of Oak Flat. Mapped from a distance, not studied in outcrops.

vvvvv vitrophyre, Apache Leap Tuff (Early Miocene) -- Black vitrophyre observed near base of tuff

Whitetail Formation (Eocene to Early Miocene) --

Tw Undivided (Early Miocene to Eocene) -- Undivided pre-volcanic sandstone and conglomerate. Overlies a wide variety of pre-Tertiary units on a non-conformity to angular

unconformity. Most undivided Whitetail Formation is conglomeratic. Clast compositions in Whitetail Conglomerate on the north flank of Copper Butte varies from dominantly subrounded clasts of Paleozoic carbonate and quartzite to angular clasts of Pinal Schist mixed with quartz porphyry (probably Teapot Mountain porphyry of Creasey and others [1983]). Rapid variations in clast composition suggest local derivation of clasts. Steeply west-dipping conglomerate north of the Grayback normal fault in NW sec.2 and NE sec.3, T4S R12E (around UTM 3664100N, 490500E) consists entirely of Pinal Schist clasts low in the section on the west, and includes progressively more Paleozoic carbonate and granitoid clasts up section to the east. The contact between Pinal-clast and carbonate-clast conglomerate was not mapped. Most of the conglomerate is massive, some beds may be debris flows or even rock avalanche breccias. Clasts are typically 3-30 cm in diameter, but locally up to 1 m in diameter.

Twc Conglomerate, carbonate clast (Miocene to Eocene) -- Massive conglomerate in which rounded pebbles to boulders of various Paleozoic carbonate and clastic units are predominant clast types; bedding difficult to discern except in sparse sandstone lenses. Conglomerate beneath Apache Leap tuff, located at SE NW sec. 26, T2S, R12E (UTM 3676490N 491650E) is massive and bedded with clasts of Paleozoic and Apache Group carbonate and quartzite. Sub-angular to subrounded clasts are 2-20 cm, locally up to 1 m in diameter. Lack of Pinal Schist and Madera Diorite is striking and suggests that this conglomerate was deposited before normal faulting uncovered these crystalline rocks.

Conglomerate grades into other facies of the Whitetail Formation vertically and horizontally.

Twe gypsum and mudstone (Miocene to Eocene) -- Buff siltstone to mudstone with associated evaporite minerals. Outcrops of evaporite component typically highly disrupted because of mobility of anhydrite and salt, and original sedimentary structures have not been observed. Gypsiferous Whitetail mudstone is present in the map area along the Grayback normal fault in the southwest part of the map, and along the north side of Walnut Canyon about 0.8 km upstream of its confluence with White Canyon. Contacts not exposed; probably grades into other facies of Whitetail Formation.

Tws fine-grained member (Miocene to Eocene) -- Light gray to red brown laminated mudstone with interbedded, very thin beds of fine-grained sandstone. In southwestern part of map area contains lenses of pebble to cobble conglomerate; some of these contain only angular clasts of Pinal schist, others contain granite (Yg and TKtc), Pinal schist, and carbonate or quartzite clasts from the Apache Group or Paleozoic section. Pinal schist-clast conglomerate is predominant in exposures in Walnut Canyon upstream of confluence with White Canyon. Contacts are gradational into other facies of Whitetail Formation.

Twp conglomerate, Pinal schist-clast (Miocene) -- Massive, angular clast conglomerate consisting of clasts of Pinal Schist. Commonly associated with probable rock avalanche deposits; matrix is lithic sand to mudstone, apparently composed of disaggregated Pinal schist; matrix or clast supported, weakly to moderately indurated; blocks are up to about 3 m in diameter. Interpreted to include talus, coarse alluvium and debris-flow deposits. Generally, found at the base of Whitetail Formation; contact with underlying Pinal Schist gradational through shattered schist; contact commonly faulted. Upper contact gradational into other facies of Whitetail Formation. Contact on shattered Pinal Schist along Walnut Canyon 4 km southwest of Teapot Mountain is difficult to locate in detail; shattered schist grades into schist breccia, then bedded monolithologic conglomerate over about 5 m.

Tch Chaos (Miocene or Oligocene) -- Rock bodies in which superposed faulting has mixed units on a 5-50 m scale with such complexity that relationships cannot be shown on the map. Area mapped in north-trending fault zone NE NW SW sec. 25, T2S R12E consists of Apache Group, diabase, and lower Paleozoic units. Contacts with more intact rock bodies are faults.

Tx(p) Sedimentary breccia (Early Miocene to Eocene) -- Shattered Pinal Schist, lacking sedimentary structures clearly indicative of deposition by mass wasting. Zones of comminuted schist and apparent rotation of foliation in adjacent coherent blocks, and general penetrative nature of shattering is suggestive of rock avalanche deposit. Parts of this unit mapped as breccia are of indeterminate origin, and may be shattered rock overlying the Walnut Canyon thrust. These outcrops are mostly along the belt of outcrop north from White Water Spring (5 km west of Teapot Mountain). Northern parts of this outcrop belt are mapped as Pinal Schist because they are more coherent than those to the south, but may be part of a large rock avalanche. Overlain depositionally by Apache Leap Tuff; basal contact on Naco Limestone is fault or landslide surface.

Tx(a) sedimentary breccia (Late Oligocene) -- Sedimentary breccia consisting of angular pebbles to boulders of Apache group and Lower Paleozoic strata in a matrix of comminuted rock. Ranges from matrix rich types in which clasts have clearly rotated relative to each other and some mixing has occurred to matrix-poor varieties in which the clasts have not been significantly displaced relative to each other. At northern end of Dripping Spring Range, breccia mapped at base of Apache Leap Tuff consists of clasts of Apache Group and Diabase. Appears to overlie Apache Group unconformably; overlain unconformably by Apache Leap Tuff.

Laramide Igneous rocks (Eocene to Late Cretaceous) --

Tfd Felsite (Paleocene) -- Light-colored felsite dikes, plagioclase (2-5 mm diameter) is most abundant phenocryst, minor biotite phenocrysts 1-2 mm diameter, quartz phenocrysts are sparse; hornblende phenocrysts present in some dikes. Groundmass is aphanitic, to very fine-grained aplitic. Intrudes Tortilla quartz diorite (Kt) and Middle Proterozoic granite (Yg).

Ttm Teapot Mountain Porphyry (Paleocene) -- Salt and pepper gray granitic porphyry; gray groundmass with white or pink feldspar crystals. Groundmass is holocrystalline, microcrystalline, and granophyric. Phenocrysts make 60-70% of roc, and in order of abundance include plagioclase (2-5 mm), dipyramidal quartz (5-10 mm), biotite (~2 mm), potassium feldspar (10-50 mm), and opaque oxides. Large K-feldspar phenocrysts are generally sparse, locally they are spectacularly large and euhedral. The groundmass is chiefly granophyric aggregate of quartz and feldspar. Rock is characteristically altered; plagioclase to sericite, clay and carbonate, biotite to chlorite, sericite and leucoxene and K-feldspar to carbonate and clay. Crops out in small irregularly shaped intrusive masses along a NE-trending zone. Intrudes Pinal Schist and Granite Mountain porphyry, cut by rhyodacite porphyry dikes.

Trp Rhyolite (Paleocene) -- Dikes related to Teapot Mountain Porphyry are crystal rich, with 30-60% phenocrysts. In order of abundance, phenocryst minerals include plagioclase, quartz, K-feldspar, biotite, hornblende and opaque oxide minerals. Distinctive feature of dikes is presence of large K-feldspar phenocrysts, normally up to about 3 cm long. Quartz is in euhedral dipyramids, locally up to 1 cm diameter and also in rounded, resorbed crystals. Relative abundance of phenocryst types is highly variable. Intrudes Apache Group and Pinal Schist in northeast-trending belt centered on Ray Mine. In the Dripping Spring Mountains, the dikes are shown intruded along and truncated at the Rustler fault, and intruding across and truncated at the Broken Hill Fault, suggesting that these are Laramide structures.

Trd Rhyodacite (Paleocene) -- White, cream and tan felsic dikes characterized by prominent quartz phenocrysts. Phenocrysts make 10-45% of rock; plagioclase is usually the most abundant phenocryst mineral, followed by quartz; biotite is the dominant mafic phenocryst, and hornblende is commonly present. Quartz and plagioclase crystals are typically 3-5 mm in diameter. More crystal-rich dikes contain quartz phenocrysts up to 20 mm diameter in the Dripping Spring Mountains; crystal-rich dikes generally contain more hornblende than crystal poor dikes. Dikes intrude Naco Formation and all older rock units, Tortilla Quartz Diorite, and Rattler Granodiorite. Dikes cross cut and terminate at north-trending faults parallel to and east of the Ransome Fault in the Dripping Spring Mountains just southeast of the map area boundary. Relationship of dikes to Rustler fault zone is ambiguous.

Tap aplite and pegmatite (Paleocene) -- Aplite and pegmatite dikes associated with Granite Mountain Porphyry (Tgm) Intrude Middle Proterozoic granite (Yg), Granite Mountain Porphyry (Tgm), and Tortilla Quartz Diorite.

Tgm Granite Mountain Porphyry (Paleocene) -- Texturally variable equigranular granodiorite to granite porphyry. Typically, groundmass is holocrystalline, phanerocrystalline, fine-grained, and aplitic, and is sprinkled with black shiny biotite crystals to produce light salt-and pepper effect. Grain size of groundmass increases in the central part of the stock, and texture changes to seriate with medium to coarse grain size. In the Sonora Quadrangle Cornwall, Banks and Phillips (1971) report composition of 43-52% plagioclase, 22-29% quartz, 15-30% potassium feldspar, 5-10% biotite and 0.5-1% magnetite. Ranges in composition from granodiorite to quartz monzonite. Plagioclase is chiefly in tabular phenocrysts 4-12 mm long; quartz is anhedral and occurs as both phenocrysts and in the groundmass. Sparse K-feldspar phenocrysts are up to 30 mm long, and with inclusions of plagioclase, quartz, biotite and magnetite. K-feldspar is also present as small anhedral crystals associated with quartz in the aplitic groundmass.

Small outliers of this unit along Walnut canyon, north of the main body, are medium-grained (2-3 mm) equigranular biotite granodiorite composed of 50-60% plagioclase, 20-25% K-feldspar, 20% quartz and 2-4% biotite in 1-2 mm diameter columnar books. Dikes of aplitic granite are abundant along the contacts between these bodies and enclosing Pinal Schist. Shattered dike-like bodies of this rock near the fault bounding the southwestern end of the Whitetail conglomerate contain abundant pyrite altered to limonite along fractures. Includes one large stock and three smaller peripheral masses that presumably join the large stock at depth. Intrudes Pinal Schist.

TKap aplite and pegmatite (Paleocene to Late Cretaceous) -- Fine-grained aplite dikes, consisting of quartz, feldspar and sparse biotite or muscovite; minor muscovite pegmatite. Dikes in Middle Proterozoic granite (Yg) were interpreted as Precambrian by Creasey et al. [1983]. Dikes intrude Tea Cup granodiorite (TKtc) and Middle Proterozoic granite (Yg).

TKtc Tea Cup granodiorite (Paleocene) -- Equigranular, medium-grained leucocratic granodiorite. Consists of 30-40% 3-10 mm anhedral quartz, 25% pink subhedral 3-4 mm K-feldspar intergrown with 30-40% subhedral white plagioclase in 2-4 mm grains, and 2-3% 1 mm chloritized biotite. Overlain depositionally by Tc, and intruded by mafic dikes (TKmd). Intrusive contacts with Proterozoic units in southwestern part of map area are obscure because differentiation of Laramide granodiorite and mixed igneous rocks in adjacent Proterozoic granitoid complex could not be made with poor outcrop. Contact with Middle Proterozoic granite (Yg) on NE end of outcrop has not been described.

TKd Dark rhyodacite porphyry (Paleocene to Cretaceous) -- Dark-colored dikes characterized by 5-15 mm diameter plagioclase and quartz phenocrysts; hornblende (up to 5 mm long) is the dominant mafic phenocryst, with subordinate biotite (in 1-3 mm flakes). Dikes

weather to rounded boulders. Groundmass consists of very-fine grained hornblende, plagioclase, K-feldspar, and quartz. Intrude Tortilla Quartz Diorite and Rattler Granodiorite, Middle Proterozoic granite (Yg), and Paleozoic strata as young as the Escabrosa Limestone.

TKi Dacite (Paleocene to Late Cretaceous) -- Cream to medium-gray colored dikes containing 25-50% phenocrysts. Plagioclase (andesine-labradorite, 3-8 mm diameter) is the dominant phenocryst; quartz (0.5-3 mm diameter) is sparse to absent; hornblende (1-3 mm long) is the dominant mafic phenocryst; biotite is subordinate to rare. TKr and TKr1 of Cornwall et al. [1971]; gray, crystal rich Trd of Creasey et al. [1983]. Intrudes strata as young as Escabrosa Limestone, Middle Proterozoic granite (Yg), and Tortilla Quartz Diorite. Prominent swarm of these dikes southeast of the Ray Mine cuts the Broken Hill fault, and one dike terminates at the Ransome fault.

Kt Tortilla Quartz diorite (Late Cretaceous) -- Light to medium gray, fine-grained, hypidiomorphic granular quartz diorite. Average crystal size is about 0.5 mm, with sparse plagioclase crystals up to about 3 mm long. Rock consists of euhedral to subhedral labradorite (40-60%), equant, subhedral pyroxene (0-15%), hornblende (~5%) as reaction rims on pyroxene and as anhedral crystals associated with biotite, biotite (10-20%) in ragged anhedral crystals, anhedral interstitial quartz (10-15%) and K-feldspar (up to 15%). Accessory minerals include 1-2% magnetite, sparse to abundant sphene, common apatite, and sparse zircon. Weak alteration is pervasive, with plagioclase replaced by clay, sericite and epidote, and hornblende and biotite replaced by chlorite and epidote. Several separate small intrusions southeast of the Ray mine, total outcrop area is about 2.6 square km. Intrudes Madera Diorite (Xm) and coarse-grained porphyritic granite (Yg); cut by Laramide dikes.

Ktgd granodiorite phase (Late Cretaceous) -- Border(?) phase of Tortilla Quartz Diorite adjacent to Copper Butte fault north of Gila River. Rock has lighter color, and contains more quartz and biotite than the main phase. Quartz forms equant 2-3 mm grains in this unit, contrasting with interstitial quartz between plagioclase crystals in the main phase. Contacts with main phase of Tortilla Quartz Diorite are irregular, abrupt gradation over 1-3 m.

Kd diorite and diorite porphyry (Late Cretaceous) -- Several small intrusions in southeastern part of map area of texturally variable fine-grained diorite and diorite porphyry. Diorite porphyry phase has fine-grained to very fine-grained aplitic groundmass of anhedral plagioclase, quartz, K-feldspar, biotite and hornblende, with phenocrysts of plagioclase (40-50%) in crystals about 1 mm long and clusters of crystals up to about 3 mm in diameter, and aggregates of hornblende, pyroxene and sparse biotite (15-25% of rock). Aggregates are mostly hornblende with a reaction rim of biotite or pyroxene with a reaction rim of hornblende. Accessory minerals include magnetite (1-2%), common sphene and rare apatite. Small body of diorite forms core of intrusive(?) breccia (Kbx) about 1.2 km east of The Spine. This body consists of texturally variable fine-grained, equigranular diorite consisting of 2-20% mafic minerals, mostly hornblende with some biotite, in a groundmass of anhedral to subhedral plagioclase. Quartz and K-feldspar are sparse or absent. Locally grades into a dark gray, microcrystalline diorite. Intrudes Pinal Schist. Relationship to Granite Mountain Porphyry not described. Smaller body associated with breccia (Kbx) appears to form matrix of breccia and contact with breccia is gradational.

Kbx breccia (Late Cretaceous) -- Locally flow-banded breccia composed of fragments of volcanic rocks, diorite, Pinal Schist, and Middle Proterozoic coarse-grained granite in a semicircular mass about 1.2 km east of The Spine (UTM 497000E, 3665500N). Quartz and feldspar crystals in volcanic rock clasts are generally rounded (comminution?). Matrix is medium to dark gray and very fine-grained to aphanitic, with scattered 1-4 mm diameter xenocrysts(?) of quartz and feldspar. Matrix is similar to very-fine-grained phases

in diorite core (Kd) of breccia. Lenses and pods of marble present in breccia are partially or completely altered to epidote-actinolite skarn; sparse vitreous quartzite clasts are also present. The marble and quartzite association suggests derivation from Paleozoic or Apache Group units, but some of the carbonate may be secondary. Sulfide mineralization (pyrite) is associated with the skarn inclusions. Interpreted as intrusive breccia [Creasey et al., 1983] associated with diorite (Kd). Laramide dikes cut breccia. Intruded into or overlies Proterozoic coarse-grained granite (Yg), contact appears sharp. Contact with diorite (Kd) is gradational.

IPn Naco Formation (Pennsylvanian) -- Gray, blue-gray, tan and yellowish gray fine-grained limestone in 1.5-3 m-thick beds, interbedded with gray, pink and olive marl and shale. Limestone forms prominent, ledgy outcrop. Shaly units form swales between limestone ledges. . Some beds are quite fossiliferous with a variety of brachiopods, corals, and bryozoan.

Stanley B. Keith [1983] divided these rocks into upper Horquilla formation (500-1500' thick) and lower Black Prince formation (100-150' thick); these units are not shown separately on this map. The Horquilla formation consists of interbedded limestone (with some dolomite), shaly limestone and sandstone. Limestone units are richly fossiliferous, containing crinoid columnals, fusilinids, brachiopods, bryozoan and corals. Clastic units are pinkish to maroon very fine-grained sandstone and shale or marly limestone. This unit forms prominent banded outcrops. Light orange-tan sandstone associated with angular chert-pebble conglomerate crops out just below Walnut Canyon thrust in upper Walnut Canyon. Lower part is more clastic rich, consisting mostly of pinkish and reddish siltstone and shale. A quartzite or chert-pebble conglomerate is reported at the base of the Horquilla formation. The Black Prince formation includes a lower, slope-forming maroon shale or siltstone with a basal chert breccia, and an upper unit of thick-bedded white crinoidal limestone; fusilinids are absent in this unit. Chert nodules are present in carbonate units throughout the Naco Formation. Contact with Escabrosa Limestone (Me) is subtle, placed at top of prominent thick limestone beds of Escabrosa. Upper contact mostly faulted (Walnut Canyon thrust), but locally unit is depositionally overlain by sedimentary breccia (Tx(p)).

Me Escabrosa Limestone (Mississippian) -- Gray to blue-gray massive crystalline limestone in beds up to 3 m thick. Crinoid columnals abundant; corals abundant in some beds. Forms prominent, cliffy outcrops. Some parts contain abundant chert. Black chert bands prominent near base of formation. Minor interbedded silty or marly limestone. Top is variably developed karst zone with clasts of limestone in a red-brown clay matrix. Keith [1983] describes an upper unit he named the Eskiminzin formation that overlies karsted horizon at the top of the Escabrosa Limestone; this unit (0-110 feet thick) consists of pink to yellowish orange unfossiliferous fine-grained to aphanitic dolomite. Lower contact with thinner bedded, generally slope-forming Martin Formation is sharp and usually clear. Upper contact with Naco formation is subtle change to more ledgy outcrop.

Dm Martin Formation (Late Devonian) -- Brown, gray and tan dolomite and dolomitic limestone; chocolate brown sandy dolomite at the base; one or two coarse poorly-sorted sandstone beds are present; carbonate beds are laminated, massive and mottled. Gray carbonate units commonly have a petroliferous smell on fresh surfaces. Keith [1983] describes three units in the Martin Formation of the Teapot Mountains area, consistent with the measured section in Creasey et al. [1983]. The upper unit is a slope-forming thin- to medium-bedded fine-grained orange-tan silty dolomite with interbedded siltstone and shale; contains scattered hematite concretions and some corals. The middle unit consists of 30-50 feet of ledge-forming, fossiliferous, dark gray thin- to medium-bedded sandy limestone with corals, bryozoa, and abundant brachiopods and crinoid columnals. The sandy limestone overlies about 200 feet of slope-forming light gray to yellow gray thin bedded aphanitic dolomite and limestone. The lower unit consists of 20-35 feet of dark gray, medium-bedded, laminated, fetid dolomite. A basal sandstone, 0-40 feet thick, correlated with the Becker's Butte Member of the Martin Formation is locally present. This sandstone is friable, well sorted, medium- to

coarse-grained quartz arenite. Disconformably overlain by Escabrosa Limestone and disconformably overlies Abrigo Formation. Upper contact placed at base of Escabrosa limestone cliffs above upper orangish units of the Martin.

Єb Bolsa Quartzite (Middle Cambrian) -- Maroon-gray feldspathic sandstone. Grit and pebble conglomerate at the base grade up into medium- to fine-grained sandstone with siltstone partings up section. Planar tabular cross beds are common in quartzite beds in the lower part. Brick-red to light gray, fine- to medium-grained, well sorted and bedded sandstone. Abundant iron oxide gives rock red color. Commonly preserved in channels cut into underlying rock units. Lithologic distinction from Troy quartzite is cryptic; depositional contact on top of diabase is only sure way to distinguish units. Bolsa-Abrigo transition is a gradation into dark gray, maroon and gray-green sandy shale with a few thin, locally bioturbated siltstone beds. Disconformably overlies Precambrian rocks, typically on a deeply weathered zone. Unconformably on Proterozoic diabase (Ydb) or Troy Quartzite. Contact with Martin formation is abrupt transition to carbonate deposition.

Ya Apache Group, Troy Quartzite, and diabase (Middle Proterozoic) -- Undivided in structurally complex zones.

Ydb Diabase (Middle Proterozoic) -- Dark gray dikes with typical sub-ophitic, diabasic texture. 35-45% 1-3mm plagioclase lathes in black groundmass of pyroxene; accessory magnetite(?) is common. Locally crude layering is defined by variation in ratio of plagioclase to groundmass and in size of plagioclase crystals. Dark gray-green (fresh) fine- to coarse-grained diabase. Diabasic texture with lath-shaped plagioclase (labradorite) surrounded by anhedral pyroxene, hornblende, sparse olivine, and opaque oxide minerals. Weathers easily to form slopes and swales with characteristic olive-drab granular soil. Intrudes Proterozoic granitoid. Major sills intrude upper Dripping Spring quartzite, Mescal Limestone, and Troy Quartzite.

Yt Troy Quartzite (Middle Proterozoic) -- Rusty-red, pink and tan, medium- to coarse-grained and grit-sized, moderately to poorly sorted, locally massive quartzite. Beds are 0.3 to 1.5 m thick. Pebbly conglomerate lenses and beds and individual pebbles of quartz or chert are present throughout the unit. Pebble conglomerate at base contains clasts of underlying basalt (unit Yb). Does not part prominently along bedding surfaces; bedding is delineated by grain size variation in sandstone. Troughy and planar tabular crossbedding is common. Sandstone lacks prominent pinkish feldspar grains characteristic of Dripping Spring Quartzite. Intruded irregularly by diabase sills (Ydb). Disconformably overlies basalt (Yb) or Mescal Limestone. Bolsa Quartzite or Martin Formation overlie disconformably.

Apache Group (Middle Proterozoic) --

Yb basalt (Middle Proterozoic) -- Gray, black or brown basalt lava flow or flows. Basalt is massive, locally with fragmental texture. Tops of lava flows are vesicular or amygdaloidal. Some flows are porphyritic with 2-15 mm diameter plagioclase phenocrysts. Basalt groundmass is ubiquitously altered to very fine-grained chlorite, epidote, calcite, sericite and opaque oxide minerals. Difficult to distinguish from diabase where diabase intrudes basalt. Depositionally overlies Mescal Limestone. Disconformably overlain by Troy Quartzite.

Ym Mescal Limestone (Middle Proterozoic) -- Medium-bedded, tan to white dolomite or limestone, locally very cherty. Basal units of poorly sorted quartz sand in argillaceous or dolomitic matrix; sedimentary breccia deposits related to solution of evaporite minerals present in many areas. This is overlain by thin- to thick-bedded dolomite or limestone, with variable amounts of chert as bedding parallel stringers, and calcareous shale partings. Dolomite is tan, limestone light gray to white. These strata are ordinarily 150-200 feet

thick, and form most of the formation. A middle member of massive dolomite or limestone with structural features attributed to the growth of algal colonies during deposition is present in well preserved sections. An upper member of chert, feldspathic siltstone, and thin limestone is preserved in some areas. Light-gray, yellowish-gray and white medium- to coarse-grained crystalline dolomite, some limestone in upper part of section; well, bedded, with beds 0.3 to 0.6 m thick. Chert is found in lenses, irregular globs and laminations. Rock with laminated chert weathers to form ribbed outcrops. Commonly intruded by diabase sills (Ydb). Conformably overlies Dripping Spring Quartzite; conformably or disconformably overlain by basalt (Yb) or Troy Quartzite.

Yds Dripping Spring Quartzite (Middle Proterozoic) -- Feldspathic to arkosic quartzite, sandstone, minor shale; lower and uppermost parts form tan to brown cliffs. Middle part typically slope-forming. Upper part is thin-bedded arkosic quartzite, weathers light-brown to reddish green, typically fine- to very fine-grained; forms flaggy outcrops; joints often stained with hematite or goethite and show liesegang banding. Middle part is thin to very thin bedded siltstone, fine-grained sandstone and sparse shale; shale and siltstone weather to form small shingles; micaceous sheen common on bedding surfaces; light gray, dusky red, tan, locally black colors. Lower part is thin- to thick-bedded quartzite, arkose to quartz arenite; yellowish brown to white. At base is Barnes conglomerate (0-50 feet thick), a pebbly coarse-grained sandstone to cobble conglomerate. Clasts are well rounded pebbles and cobbles of gray, brown, and reddish quartzite, red jasper, and white bull quartz. Disconformably overlies Pioneer formation, conformably overlain by Mescal Limestone, intruded by diabase (Ydb)

Yp Pioneer Formation (Middle Proterozoic) -- Reddish brown to dusky purple sandstone, siltstone and minor shale; light gray to white reduction spots are characteristic. In this area, 10-20% of unit is red-brown arkosic fine-grained sandstone. Uppermost part is gray on fresh surface, brown weathering fine- to very fine-grained, almost porcelaneous sandstone. Most of formation is slope-forming. Overlain disconformably by Barnes Conglomerate of Dripping Spring Quartzite; contact is sharp. Non-conformably overlies Madera diorite or Pinal Schist.

Yg Coarse-grained, porphyritic biotite granite (Middle Proterozoic) -- Light brown to light gray porphyritic biotite granite; contains 2-8 cm diameter phenocrysts of K-feldspar in a coarse-grained groundmass of plagioclase, quartz, K-feldspar and biotite. Accessory apatite, zircon, magnetite and rare sphene are present. Weathers rapidly to grus. Thin aplite-pegmatite dikes are common. Intrudes Pinal Schist, and intruded by various Laramide plutons and dikes. Contact with Pinal Schist east of The Spine is a mixed zone with abundant screens and xenoliths of schist in granite near contact. Overlain by Apache Leap Tuff (Tal) and Whitetail conglomerate on erosional unconformity with significant relief.

XYgp Granite and schist (Middle Proterozoic and Early Proterozoic) -- Zones of biotite granite (Yg) with abundant, partially resorbed inclusions of Pinal schist. Mixed zones are common in contacts between these units. Gradational contacts into homogeneous granite (Yg).

Xm Madera Diorite (Early Proterozoic) -- Diorite, quartz diorite, granodiorite; generally massive except for foliation developed near contacts. Madera diorite intrudes Pinal Schist. In SE SE NW sec. 25, T2S, R12E (UTM 3676361N 493334E) the east-west striking thrust contact shown by Creasey et al. [1983] that places Pinal Schist over Madera diorite is clearly an intrusive where it is exposed in a stream bank.

Xm_2 Equigranular biotite granodiorite (Early Proterozoic) -- Equigranular biotite granodiorite, grain size typically 2-4 mm. Subdivision Madera Diorite made by Keith [1983]. Contains 4-6%, locally up to 20%, biotite. Some phases contain hornblende in elongate prisms.

Only locally foliated, especially near contacts with Pinal Schist. Intrudes Pinal Schist; Keith [1983] reports that this unit intrudes quartz diorite (Xm1).

Xm_1 Quartz diorite (Early Proterozoic) -- Medium-grained, medium to dark gray, biotite-hornblende quartz diorite; subdivision of Madera Diorite made by Keith [1983]. Hornblende is present throughout the unit as blocky or stubby equant crystal clusters. Intrudes Pinal Schist, depositionally overlain by Pioneer Formation. Keith [1983] reports that biotite granodiorite (Xm2) intrudes this unit.

Xp Pinal Schist (Early Proterozoic) -- Generally tan to bluish-gray fine-grained quartz-muscovite-chlorite ± biotite semi-schist to phyllite. Non-resistant to weathering, generally highly fractured, with foliation disrupted by small scale folding and faulting. Where hornfelsed adjacent to intruding Xm, Xm1 or Xm2 becomes coarser-grained (3-5 mm diameter muscovite), and massive. Hornfelsed schist adjacent to Granite Mountain Porphyry (Tgm) is very fine-grained and massive. Commonly hosts landslides. Pods and veins of white bull quartz are common. Oldest rock unit recognized in map area. Intruded by Madera diorite (Xm, Xm1, Xm2) and Granite Mountain porphyry (Tgm), depositionally overlain by Pioneer Formation and Whitetail Formation.