Geologic field guide to the Copper Butte area, eastern Pinal County, Arizona

by
William R. Dickinson
Emeritus Professor of Geology
University of Arizona

Arizona Geological Survey
Contributed Report CR-01-C

November 2001

16 pages

Arizona Geological Survey
416 W. Congress St., #100, Tucson, Arizona 85701

The Wonders of Copper Butte

Arizona Geological Society Fall Field Trip, 17 November 2001

William R. Dickinson

Department of Geosciences, University of Arizona, Tucson, Arizona 85721

Overview: Less than five miles southwest of the Ray open pit lies a geologic wonderland centered on the copper prospect at Copper Butte. Not only are the Tertiary stratigraphic and structural relationships wondrous – a microcosm of challenges faced in deciphering southern Arizona geology – but the copper deposit is wondrous in its own way, and you will have the opportunity on this trip to make up your own mind about its origin based on what you can see for yourself in the field. This excursion is a detective story and it is your job as a participant to solve the whodunit! To your own satisfaction, at least.

Databank: Areal geologic relationships around Copper Butte have been depicted at various scales by Phillips (1976), Creasey et al. (1983), Keith (1986), Dickinson (1995), and Richard and Spencer (1998). A geologic map (and legend) of the local Copper Butte area from the Dickinson (1995) report and a segment of the regional Richard and Spencer (1998) map are included in this field trip guide.

Assembly Point [Tucson contingent]: Parking lot at Oracle and Magee. Assemble at 6 AM for the drive to the first stop at 8 AM. Try to compact as much as possible into 4WD vehicles. Although high clearance is sufficient to get to the central staging point within the field trip area, 4WD is required to reach principle stops down sandy washes. For comfort and convenience, some may wish to take 2WD vehicles to the central staging point, but should ascertain at the assembly point that room is available in 4WD vehicles to continue farther (one or two miles on each of three forays from the central staging point).

Approach Route

Go north from Tucson on Hiway 77, bearing right at Oracle Junction to continue on Hiway 77 around the north end of the Santa Catalina Mountains past Oracle. From the summit divide just beyond Oracle, the skyline ahead is the Galiuro Mountains beyond the San Pedro trough, which was delineated by pre-mid-Miocene faulting, and partially filled by post-mid-Miocene Quiburis Formation [see map of Quiburis facies distributions by Dickinson (1998) and description of Quiburis depositional systems by Dickinson (2001)]. From Mammoth in the floor of the San Pedro trough, continue NNW along the San Pedro River for 20 more miles to Winkelman, where you TURN LEFT (west on Hiway 177) just beyond the bridge over the Gila River. About 12 miles beyond the turn (just past Kearny) look for bold white flatirons, across the Gila River to the left (SW), composed of debris-avalanche limestone megabreccia bodies (Krieger, 1977) intercalated within the Upper Oligocene (to lowermost Miocene?) Hackberry Wash facies of Cloudburst Formation [stratigraphic terminology after Dickinson, 1991], resting unconformably (Schmidt, 1971) on Precambrian rocks of the Ripsey Hill spur (skyline ridge) of the Tortilla Mountains, and dipping ENE (toward you). Basaltic andesite lava intercalated within the Hackberry Wash facies of the Cloudburst Formation in Jim Thomas Wash has been dated (K-Ar) as 25.4 Ma (Dickinson and Shafiqullah, 1989).

Rendezvous Point [join Phoenix contingent]: Ray Mine overlook (ON RIGHT) about 11 miles past Kearny [do NOT turn on Ray Mine Road!; turnoff to overlook is about 4.5 miles farther up the hill just beyond the *historical marker* sign].

STOP #1. Ray Mine Overlook. Sterling Cook will describe key geologic features visible within the Ray open pit, with special focus on aspects of Ray geology relevant for analysis of relations at Copper Butte. Most (though not all) geologists agree that the Copper Butte deposit, hosted within the Upper Oligocene(?) to Lower Miocene Whitetail Formation (Richard and Spencer, 1998; Whitetail Conglomerate of past usage), derived its copper from the Ray porphyry system, but there has been contentious past speculation whether the Copper Butte deposit arose from detrital transport of chunks of porphyry ore in sedimentary breccias, or was formed instead as a so-called exotic copper deposit by transport of copper in a fossil contaminant plume travelling as groundwater through sedimentary strata of the Whitetail Formation.

Before leaving the overlook, cast your eyes up to Teapot Mountain above the Ray pit on the skyline ridge west of Mineral Creek. Note the bold summit outcrops of gently dipping Apache Leap Tuff, which is Lower Miocene ignimbrite (ash-flow tuff) erupted 18.6 Ma from the Superstition Cauldron of the Superstition Mountains (McIntosh and Ferguson, 1998). Then look below at the fanning-upward easterly dips in subdued slope outcrops (tawny) of the underlying Whitetail Formation (especially clear under Teapot Mountain proper). The maximum eastward dips low in the Whitetail section along the skyline ridge are 40°-60° (Creasey et al., 1983), although the steepest visible dips are only 25°-35°. The fanning dips reflect syndepositional tilting of Whitetail bedding during faulting (down-to-the-west) along the Teapot Mountain fault (dip 50°-65° west), which trends NNE-SSW along the rubbly slope between the Ray pit and Teapot Mountain (Creasey et al., 1983; Keith, 1986; Richard and Spencer, 1998). Whitetail Formation reaches a stratigraphic thickness of ~900 m within the half-graben west of the Teapot Mountain fault (Keith, 1986). Uppermost horizons of the Whitetail Formation overstep the Teapot Mountain fault, which predated Apache Leap eruption, and a tuff interbedded within Whitetail Formation stratigraphically just below Apache Leap Tuff in the Ray pit, where Apache Leap Tuff is ~75 m thick (John, 1994), has yielded an $^{40}Ar/^{39}Ar$ age of 18.7 Ma (Richard and Spencer, 1998). No one yet knows the age of the oldest horizons of Whitetail Formation in the keel of the thick half-graben to the west where the most steeply tilted beds may also be Early Miocene in age, or might include basal horizons as old as Late Oligocene in age. In either case, an oft-cited thirty-year-old Early Oligocene K-Ar age of 33.2 Ma (date #21 of Banks et al., 1972; date #903 of Reynolds et al., 1986) for the

Whitetail Formation is apparently spurious (probably contaminated by detrital pre-Whitetail Laramide biotite), for it derives from a tuff at essentially the same horizon (±100 m) as the 18.7 Ma $^{40}Ar/^{39}Ar$ age.

To the left (south) of Teapot Mountain, the subordinate russet peak is a subsidiary tiltblock of Apache Leap Tuff dipping NE against a normal fault dipping 60° SW (downfaulted approximately 125 m from correlative outcrops on Teapot Mountain). In line with our view of the tiltblock, and of Teapot Mountain itself, beds of the Whitetail Formation dipping 15°-45° northward (Richard and Spencer, 1998) rest unconformably (Creasey et al., 1983) on Precambrian Pinal Schist and Laramide porphry exposed in the downthrown hanging wall of the Teapot Mountain fault (suggesting that the basal contact of the Whitetail Formation along the floor of the half-graben west of Mineral Creek is a buttress unconformity of complex configuration). The half-graben is terminated to the southwest by a normal fault, striking NW-SE and dipping NE at 60°-70° (Creasey at al., 1983; Richard and Spencer, 1998), with a surface trace visible just above bare patches of whitish and gray outcrop downhill from tawny and bush-covered slopes underlain by Whitetail Formation. This fault is informally termed the "turnoff fault" for discussions today (from its proximity to where we turn off the highway after leaving the overlook), but is probably the western extension of the North End fault in the Ray pit (Keith, 1986; John, 1994).

<u>Entry Route</u>

SPECIAL DRIVING INSTRUCTIONS: In leaving the Ray Mine overlook, please space the vehicles in the caravan 100 yards or so apart, and maintain that spacing going up the grade, because we turn abruptly left across a cattle guard into Battle Axe Road at the very crest of the grade, and fast traffic could spell danger (to us!) if our caravan effectively blocks the highway; when you take the turn into Battle Axe Road, try to move as crisply as possible off the highway to leave space for following vehicles to turn across the cattle guard.

Continue west on Hiway 177 from the Ray mine overlook for about 2.5 miles, then TURN LEFT across a cattle guard into Battle Axe Road (turnoff is right at the crest of the grade immediately beyond the sign warning of a 10% grade ahead). As we approach and reach the turnoff at the top of the grade, exposures of Whitetail Formation beneath the Apache Leap Tuff along the high ridge west of Mineral Creek are terminated on the south about 600 m to our right by the "turnoff" normal fault (see Stop #1). At the turnoff, we are in the footwall block of the "turnoff" fault. As we turn, we are also on the intrusive contact between Precambrian Pinal Schist (uphill to the right) and Laramide Granite Mountain Porphyry, into which we turn as we start down Battle Axe Road toward Copper Butte.

STOP #2. <u>Panoramic Overview</u>. Pull off as well as you can on the right shoulder (about three-quarters of a mile from pavement), and walk forward for a viewpoint chalk talk.

As we stand on the piedmont slope, we are within the outcrop area of Laramide Granite Mountain Porphyry (68-60 Ma), composed of porphyritic to granular biotite granodiorite and granite (note grus along road shoulders), and identified as the causative intrusion of the Ray porphyry copper system (Cornwall, 1982; John, 1994). The granitic body is tilted, top down to the northeast, with the Ray orebody structurally above the intrusion. Along tectonic strike 10-12 km SSE of the Ray pit near Riverside on the Gila River, 60° dips in the Upper Oligocene to Lower Miocene Hackberry Wash facies of Cloudburst Formation exposed along the eastern flank of the Ripsey Hill spur of the Tortilla Mountains (recall the megabreccia flatirons southwest of Kearny) provide one measure of the presumed tilt of the Granite Mountain Porphyry, and the estimated 60° tilt of the Ray orebody (John, 1994) is compatible. Basal beds of the Hackberry Wash facies rest depositionally on the tilted Sultana crustal block (named for Sultana Mine near Riverside) of Howard (1991), and the Granite Mountain Porphyry occupies a northern extension of the Sultana block. The Hackberry Wash facies attains dips as great as ~75° southward from the Gila River, and underlying strata of the Precambrian Apache Group that rest depositionally on the basement are locally subvertical in attitude. Although the implied net tilt of the Sultana crustal block by ~90° south of the Gila River seemingly declines northward to only ~60° north of the Gila River, the ground transect across Granite Mountain Porphyry exposed between Copper Butte and the Ray Mine is closer to an originally vertical profile through the intrusion than to an originally horizontal transect.

Prominent topographic features of the field trip area visible in the middle foreground include (from left or south to right or west): (a) The Spine, a dipslope ridge of Apache Leap Tuff beyond the axis of the Spine syncline; (b) Copper Butte, capped by Apache Leap Tuff; (c) Battle Axe Butte (Hells Peak of Keith, 1986), an equant plug of intrusive to domal rhyodacite (pale hues) injected into the throat of an ash cone (reddish outcrops with inclined ash-fall stratification discernible with field glasses); and (d) a dissected mesa of Apache Leap and younger tuff forming the divide between Walnut and White canyons.

Visible on the far skyline through Spine Canyon between The Spine and Copper Butte is Grayback Butte (beyond the Gila River), underlain by Laramide (69-62 Ma) Tea Cup Granodiorite forming part of a strongly tilted (vertically inclined; topping east) crustal panel (Grayback crustal block of Howard, 1991, and Howard and Foster, 1996) west of the Tortilla Mountains. The Grayback crustal block apparently exposes, across an E-W horizontal transect along the present ground surface, an originally vertical profile of ~10 km into Precambrian crust (and the Laramide intrusion) below an erosional surface at the base of the Precambrian Apache Group.

On the skyline to the right (west) of Battle Axe Butte, the bold dark outcrops are Apache Leap Tuff (forming cliffs rimming The Rincon just north of the Gila River), but the pale bluffs beyond (highest peak visible) are outcrops of a younger felsic igneous complex [Sleeping Buffalo Rhyolite of Creasey et al., 1983; Picketpost Mountain Volcanics of Richard and Spencer, 1998; Picketpost Mountain Formation of Ferguson and Trapp, 2001] comparable in age and character to the plug at Battle Axe Butte.

Four Tertiary stratigraphic units of the field trip area are separated by unconformities:

1. Whitetail Formation (see Stop #1, Ray Mine Overlook, for discussion of age): rests nonconformably on Precambrian basement (Pinal Schist north of Copper Butte; Oracle Granite south of Copper Butte); offset by pre-Apache Leap Tuff faulting; preserved thickness reaches 750 m in lower Walnut Canyon beyond Copper Butte.

2. Apache Leap Tuff (18.6 Ma): rests with angular unconformity on Whitetail Formation at Copper Butte, and in Spine Canyon to the south, but rests concordantly on Whitetail Formation in lower Walnut Canyon to the southwest of Copper Butte; overlaps eastward across a syn-Whitetail normal fault (viewed closer at Stop #4) to rest nonconformably on Precambrian Pinal Schist and Oracle Granite east of Spine Canyon; preserved thickness 125-250 m (thickening westward from Spine Canyon to Walnut Canyon).

3. Gravel of Walnut Canyon: deposited unconformably on Apache Leap Tuff (and locally on Whitetail Formation) within a downfaulted half-graben formed west of the Spine Canyon fault, but wholly absent above Apache Leap Tuff of the adjacent tiltblock to the east; intruded by the Battle Axe Butte rhyodacite plug, which has not been dated directly but comparable bodies farther north and south have yielded Early Miocene K-Ar ages of 17.5-16.3 Ma (Creasey et al., 1983) and an $^{40}Ar/^{39}Ar$ age of 16.2 Ma (Richard and Spencer, 1998) near the Early/Middle Miocene time boundary; includes ~300 m of moderately consolidated sandy conglomerate and sedimentary breccia, the latter including debris-avalanche megabreccias that were derived individually from either Precambrian Oracle Granite or Laramide Tea Cup Granodiorite (reflective of a provenance lying south of the Copper Butte area near or beyond the Gila River), as well as debris-avalanche megabreccias of Apache Leap Tuff (outcrop in White Canyon regarded erroneously during previous mapping as bedrock) shed from a paleoscarp along the Spine Canyon fault.

4. Tuff of White Canyon: forms ash cone flanking the Battle Axe Butte plug, and much more widespread dispersal facies resting paraconformably or disconformably on Gravel of Walnut Canyon, but unconformably elsewhere on older Apache Leap Tuff, Whitetail Formation, and Precambrian basement; the rugged Battle Axe Butte monolith (plugging one of the source vents for the Tuff of White Canyon) includes both intrusive and extrusive phases, with the former cutting Gravel of Walnut Canyon on the far side of the butte (and displaying vertical jointing in the interior of the butte), and the latter bulging outward with fanning joints above ash-cone strata on the near side of the butte; preserved thickness of dispersal facies is 125-250 m.

Staging Point. The large parking area beside corrals about a mile and three-quarters from pavement allows for dropoff of 2WD vehicles if necessary during the course of the day. We will make three forays from here: first straight ahead up to Copper Butte, then down left fork of road into Spine Canyon, finally right off the Copper Butte road into Walnut Canyon.

First Foray : Copper Butte

STOP #3. Copper Butte fault. About two miles from pavement; right fork of road leads to Walnut Canyon. Before continuing straight to Copper Butte, park at intersection and examine outcrop of sheared and shattered Pinal Schist, in hanging wall of Copper Butte fault, as exposed in a drainage ditch beside the road to Copper Butte just beyond the road junction (the fault contact between Granite Mountain Porphyry and Pinal Schist is located at the color change in the roadbed about 100 m back up the road toward the corrals, and at the similar color change on the low spur east of the road). Permissive piercing points provided by possibly offset bodies of Laramide Teapot Mountain Porphyry (~65 Ma) and Tortilla Quartz Diorite (75-70 Ma), actually biotite-hornblende-pyroxene granodiorite, imply S55W horizontal transport of the upper plate of the Copper Butte fault by 3-4 km (Keith, 1986). To the northwest, the Copper Butte fault passes, through a structurally complex transfer zone, into the Concentrator fault system of the Superior area (Richard and Spencer, 1998).

Southeast from Copper Butte, the Copper Butte fault, dipping 40°-50° SSW, extends across the Gila River (at the mouth of Ripsey Wash), and continues along the west side of the Tortilla Mountains as the Ripsey fault, also dipping 40°-50° WSW (Dickinson, 1996). South of the Gila River, the Ripsey Wash sequence of the San Manuel Formation occupies a compound half-graben parallel to the Ripsey fault. Early Miocene K-Ar ages (20.3-17.5 Ma) for interbedded tuffs (Dickinson and Shafiqullah, 1989) imply that the Ripsey Wash sequence includes beds both older and younger than Apache Leap Tuff, Gravel of Walnut Canyon and Tuff of White Canyon in the Copper Butte area.

STOP #4. Whitetail Formation. From the road junction near the trace of the Copper Butte fault, the road to the top of Copper Butte angles up through slopewash on Pinal Schist (cut locally by dikes of dark Precambrian diabase and pale Laramide granitic rock), with the Copper Butte fault crossing spurs below the road to the left where white outcrops of Granite Mountain Porphyry (in the footwall) are juxtaposed against gray outcrops of Pinal Schist (in the hanging wall). In due course, the road angles across a contact between Pinal Schist and Whitetail Formation; a readily accessible outcrop of the latter occurs on the point of a curve about half a mile up toward Copper Butte from the road junction (pack vehicles tightly off the road to the left at the curve so no one has to park on the steep grade). Whitetail bedding in unmineralized conglomerate exposed at the curve strikes N45W and dips 60° SW. Subrounded to subangular clasts in braided-stream deposits are dominantly Precambrian schist, quartzite, and minor diabase, with subordinate Paleozoic limestone present as well. Dips decline (to N20-25W, ~25° SW) uphill toward the base of the Apache Leap Tuff, which is marked by a prominent zone of white discoloration. In exposures of Whitetail Formation above our road on this northeast flank of Copper Butte, small local patches of blue-green oxide mineralization are similar lithologically to extensive outcrops of analogous alteration at the copper prospect on the southwest flank of Copper Butte (serving to indicate that copper mineralization extends laterally beneath the capping of Apache Leap Tuff on the crest of Copper Butte).

Approximately 75 m back down the road from the curve, rubbly Whitetail sedimentary breccia composed of angular to subangular clasts of Pinal Schist is juxtaposed against Pinal Schist along a fault contact, marked by a thin seam (<10 cm) of red gouge and interpreted as a subsidiary strand of the Copper Butte fault system (Richard and Spencer, 1998). This fault contact was mapped erroneously as depositional by Creasey et al. (1983) and Dickinson (1995). Around the north base of Copper Butte, the fault horse between the main Copper Butte fault surface and this subsidiary strand is composed of Pinal Schist extensively intruded by Laramide (~65 Ma) Teapot Mountain Porphyry (Creasey et al., 1983; Richard and Spencer, 1998), not mapped separate from Pinal Schist by Dickinson (1995). Hypabyssal Teapot Mountain Porphyry presumably represents a shallower level of the Laramide igneous system responsible also for the deeper seated Granite Mountain Porphyry exposed in the footwall of the Copper Butte fault.

Ahead along the sidehill to the southeast, Whitetail Formation is faulted against Pinal Schist along a steeply dipping normal fault that strikes at nearly right angles (NE-SW) to the Copper Butte fault, and is overlapped by Apache Leap Tuff. The fault is apparently an extension (to the northeast, beneath younger cover and across the much younger Spine Canyon fault) of the NE-SW Grayback normal fault (down to the northwest) mapped by Richard and Spencer (1998) near the Gila River. Between Walnut and Spine canyons to the southwest of Copper Butte, the Grayback fault is locally overstepped by Whitetail Formation in a stratal relationship reminiscent of the Whitetail Formation overstep of the Teapot Mountain fault west of Mineral Creek near the Ray pit. The Teapot Mountain fault is accordingly interpreted as a further continuation of the Grayback fault to the northeast (Dickinson, 1995; Richard and Spencer, 1998). The Grayback fault trending through the Copper Butte area in the hanging wall of the Copper Butte fault is stepped to the northwest across the SW-dipping Copper Butte fault, to a location in its footwall due north of Copper Butte as inferred by Richard and Spencer (1998), and then stepped back eastward across the NE-dipping "turnoff" normal fault that bounds (on the southwest near the highway) the Whitetail Formation half-graben exposed on the ridge west of Mineral Creek. Looking back at Teapot Mountain, one can envision from here how the stratal assemblage now exposed at Copper Butte was displaced by the Copper Butte fault from original continuity with the half-graben system along the ridge west of Mineral Creek, and hence was once in much closer proximity to the Ray porphyry copper system. Horizontal restoration (to N55E) of the Copper Butte area by 3.5 km across the Copper Butte fault (see above) would put Copper Butte in line with Teapot Mountain along the trend of the half-graben west of Mineral Creek, and place the Copper Butte mineralization only 3 km from the Ray orebody.

Reviewing the geometry of fault offsets from near Ray to Copper Butte: (1) step the NW-dipping Teapot Mountain fault to the NW along the NE-dipping "turnoff fault" (North End fault?) near the highway, (2) then step its offset segment, which places Pinal Schist against Pinal Schist up Walnut Canyon from Copper Butte, to the SE across the SW-dipping Copper Butte fault, and (3) one emerges with the Teapot Mountain fault equivalent to the Grayback fault of the Copper Butte area and the Gila River valley to the southwest. The offset segment of the Teapot Mountain/Grayback fault placing Pinal Schist against Pinal Schist thus occupies a horst, between the Copper Butte and "turnoff" faults, from which Whitetail Formation has been removed by erosion.

Continuing up the road, the base of Apache Leap Tuff (overlapping the Pinal/Whitetail contact at the Grayback/Teapot Mountain fault) crosses the road at the sharp curve in the saddle on the southeast spur of Copper Butte (the fault itself trends up the ravined slope from Spine Canyon toward the outcrop of Apache Leap Tuff just beyond the saddle). Rounding the curve, the deep ravine to the left is the segment of Spine Canyon we will traverse at Stop #6. Beyond Spine Canyon to the ESE, the keel of the Spine syncline is well defined by inward dips in the Tuff of White Canyon capping a nearly flat-topped mesa up a tributary drainage.

About half a mile beyond Stop #4, where a small side track descends into Spine Canyon, the keel of the Spine syncline is also visible directly ahead, again as defined by inward dips in the Tuff of White Canyon, which is draped in onlapping unconformity over a buttress of Apache Leap Tuff (darker color) in the middle ground (the buttress was a promontory on the paleofault scarp of the Spine Canyon fault flanking the far side of the buttress). To the right of the buttress, joint offset of Apache Leap Tuff and the Tuff of White Canyon by a younger fault repeats the contact between the two units on the wall of a cliff to the left of the road just before one enters the old workings atop Copper Butte.

STOP #5. Copper Butte Deposit. At the crest of Copper Butte, follow the lead vehicle past various pits and dozer cuts to a broad parking area at the southwest edge of the workings (about a mile and a half from the corrals at the staging point). This is your opportunity to examine at your leisure the mineralization in the Whitetail Formation of the Copper Butte prospect, and its local setting (note that Whitetail bedding dips northeasterly rather than southwesterly, though whether from folding or faulting is unclear, and that bluffs of Apache Leap Tuff loom above the prospect area). As a sendoff, Sterling Cook will briefly review the history of mining and exploration.

The recommended tour is to first walk north along the road in view to see pits that display oxide copper mineralization (technicolor blue-green in a near pit, then B&W black oxides in a far pit), work your way (if you like!) up the rubbly slope above the pits to the upper road cuts where the base of Apache Leap Tuff is exposed, then come back to observe Tuff of White Canyon locally faulted down against Whitetail Formation near the parking area (note small patch of copper mineralization just below the fault contact, which may pass westward into a nearly unfaulted unconformable contact within the span of the outcrop).

Uphill from the workings, the basal horizon (1-2 m) of Apache Leap Tuff is unwelded white ash-flow tuff (common at the chilled base of ignimbrite sheets), succeeded by several meters of densely welded black vitrophyric tuff passing upward into the main body of brown-weathering pink Apache Leap Tuff (all three lithologies better exposed and easier to access at Stop #6). Directly beneath Apache Leap Tuff, Whitetail Formation is monolithologic Pinal-clast (schist-clast) sedimentary breccia in rudely bedded debris-flow deposits (maximum clast size pebbles or cobbles), but no debris-avalanche megabreccia occurs in the Whitetail Formation on Copper Butte.

Low bluffs of Tuff of White Canyon near the dirt berm at the south end of the parking area expose intercalated ash-fall deposits (shower-banded airfall layers in thin beds) and meter-scale massive units of probably laharic (or else block-and-ash flow?) tuff-breccia enclosing unvesiculated blocks of rhyodacite up to a meter in diameter.

Genesis Hints. Neither Dickinson (1995), nor Phillips (1976) before him, could find any evidence for clasts of copper ore (either primary or supergene) at Copper Butte. Copper minerals occur principally as clast coatings (except where some limestone clasts have been largely replaced by oxide copper minerals), or within interstitial matrix. The occurrence of some of the copper minerals in veinlets and fracture fillings implies partial lithification of Whitetail Formation prior to mineral emplacement. Phillips described the varied oxide copper mineralization (chrysocolla, black or brown "wad", and copper-bearing jarosite-goethite) as so-called "exotic" copper produced by subsurface flowage of copper-bearing groundwater solutions. Given the inferred proximity of the Copper Butte area to the Ray porphyry system in mid-Miocene time, before tectonic transport to the southwest along the Copper Butte fault, the ultimate source of the copper was presumably the Ray sulfide orebody during Early Miocene time. Although Copper Butte and Ray lie now in different hydrological drainages, such would not have been the case before displacements along the Copper Butte fault. John (1994) inferred that the Pinal Schist clasts in debris-flow deposits just beneath Apache Leap Tuff were derived from a leach capping above the Ray orebody, and may have brought sulfides and native copper in fracture fillings to the Copper Butte area where local vertical leaching of copper may have contributed to the oxide copper mineralization in Whitetail Formation exposed down-section. Phillips (1976) concluded, however, that volumetric relations (he estimated >1,000,000 tons of copper metal at the Copper Butte prospect) require significant lateral groundwater transport of copper into Whitetail Formation from outside its basin of deposition.

<u>Second Foray:</u> Spine Canyon

From the staging point, take left fork of road down Spine Canyon for about a mile [WASH DRIVING ETIQUETTE (to keep our impact minimal): as much as possible, follow previous wheel tracks unless deep sandy ruts cannot be negotiated], past bold outcrops of Apache Leap Tuff in wash narrows (we will see much better down-canyon) into exposures of Tuff of White Canyon, and PARK FOR LUNCH STOP at axis of Spine syncline (watch for last south-dipping outcrop on left and first north-dipping outcrop on right, with reversal of dip visible in wash wall on right at lunch stop).

Spine Syncline. The Spine syncline is a notorious structure because it documents local stratal shortening during a time interval of inferred regional extension. Concordant dips of ~35° in both Apache Leap Tuff and Tuff of White Canyon in both limbs of the syncline indicate post-Early Miocene deformation. Dips in both fold limbs decrease, however, to only 5°-15° within about a kilometer along strike from the km-long segment of the fold displaying steeper dips.The structurally most compressed segment of the Spine syncline occupies a part of the hanging-wall block of the Copper Butte fault that lies directly adjacent to a prominently curved segment of the fault trace convex to the southwest. Taking a "down-plunge" view of the hanging wall shows that the convexity in the fault trace represents a protuberance in the footwall block over which the hanging wall was forced to travel. Stratal shortening in the Spine syncline of the hanging wall may thus stem from molding an otherwise planar base of the hanging-wall block around an irregularity in the footwall block as slip proceeded. Possible ramp-flat geometry (down-dip) along the Copper Butte fault may also have contributed to the Spine syncline flexure in the hanging wall.

STOP #6. <u>Spine</u> <u>Canyon</u> "<u>Hike</u>" <u>(Stroll)</u>. After lunch, we will take a half-mile walk (each way) down the sandy floor (no tough stuff) of Spine Canyon, through the north-dipping south limb of the Spine syncline to observe pyroclastic strata in the Tuff of White Canyon and the Apache Leap Tuff. If anyone does not wish to go all the way, just stall or stop anywhere along the way, as all will be coming back up. The recommended program is to persevere to the base of Apache Leap Tuff, where one can view the base of an ignimbrite sheet about as well exposed as can be found anywhere. Keys to things to watch for along the way:

1. The first stage of the walk is along strike in Tuff of White Canyon displaying two kinds of beds: (a) laterally continuous ash-fall laminae (mm to cm scale) without cross-bedding or scour features (it fell from the sky!); (b) massive and coarser m-scale beds, also mainly aggradational but locally scoured or load-casted at their bases in a manner suggestive of mudflow transport and deposition (or make your own call!).

2. Sharp left turn at the end of the long-strike reach crosses strike through finely laminated whitish tuff (and a cluster of tall cottonwoods) to the top of Apache Leap Tuff (pinkish

hue), which is massive and poorly sorted ignimbrite (welded ash-flow tuff) containing both undistorted blocky clasts of unvesiculated glassy lava and compacted (lenticular) collapsed pumice fragments (fiamme), the latter much more prominent well ahead toward the base of the single cooling unit present.

3. A walk of maybe a quarter mile long-strike through hundred-percent outcrop of the ignimbrite reaches a prominent cliff (behind a cottonwoood grove) displaying bedding-parallel jointing that may or may not separate individual flow units (careful examination of textural details is required to establish whether a single ignimbrite cooling unit was formed by a single giant ash flow, or by a series of related ash flows emplaced in rapid enough succession to cool jointly).

4. Continuing through an ess-curve of the canyon and over a megaboulder pile (best path is to the left and then under two giant boulders) reaches a second ess-curve with a low, readily traversible dry falls held up by densely welded ash-flow tuff (black vitrophyre) near the base of Apache Leap Tuff resting on Whitetail Formation (the basal 2-5 m of tuff is less densely welded because of chilling against the sedimentary substrate); fiamme are especially well displayed in brownish tuff stratigraphically above the vitrophyre in cliffs of the nearest part of the ess-curve (back up-canyon).

[SPECIAL NOTE: Down-canyon from the "vitrophyre dry falls", Spine Canyon swings briefly back up-section into Apache Leap Tuff before cutting stratigraphically back down to Whitetail Formation exposed extensively toward the Gila River in the lower reaches of Spine Canyon. Exposures down-canyon are not superior to those already taversed, and the footing is a good bit rougher below the "vitrophyre dry falls", but those with the time and vigor to go a few hundred more yards (just to say they saw the whole gorge?) can watch for an old rusty pipe on the right upon again approaching the base of Apache Leap Tuff [although the base is not as well exposed as at the "vitrophyre dry falls"].

Recovery Route. Retrace steps to vehicles (at lunch stop) and drive back to staging point.

<u>Third Foray</u>: Walnut Canyon

From staging point at corrals, drive again toward Copper Butte, but turn right into Walnut Canyon from Pinal Schist outcrop of Stop #3. About a mile from the corrals, Pinal Schist outcrops appear beside the road where it reaches Walnut Canyon. A quarter of a mile down-canyon the route passes an unexposed contact between Pinal Schist and Whitetail Formation composed of Pinal-clast sedimentary breccia. The contact is the local trace of the subsidiary strand of the Copper Butte fault observed at Stop #4. View directly ahead down-canyon of mesa-rim cliffs of Tuff of White Canyon above poorly exposed Whitetail Formation beneath vegetated slopes.

STOP #7. WHITETAIL REDBEDS. About a mile and a half from the corrals is a cutbank exposure of redbed lacustrine facies within Whitetail Formation (stratigraphic-structural relations with conglomeratic strata are unknown): finely laminated red mudrock with thin interbeds of laterally continuous, laminated to cross-laminated sandstone (some with low-amplitude hummocky cross-stratification suggestive of gentle wave action); bed of granule conglomerate with scoured base low in the exposed section implies fluvial influence, and coarse alluvial conglomerate appears again beside the wash less than half a mile down Walnut Canyon.

STOP #8. WALNUT/WHITE CONFLUENCE. About two miles from the corrals, White Canyon joins Walnut Canyon from the west, as Battle Axe Butte looms above to the SW. Park beside road just before ford, rather than along side road to artesian well (tight dead end with constrained turning space for multiple vehicles), which flows tepid water 24 hours a day, 365 days a year. Three geologic features are especially worth seeing here:

1. Some 75-100 m below the ford, Gravel of Walnut Canyon on the south (vertical cliff of gently dipping coarse fanglomerate visible down-canyon) is downfaulted locally against Whitetail Formation (largely alluvial redbeds with intercalated lenticular beds of partly pebbly sandstone and sheets of matrix-supported pebbly to cobbly debris-flow deposits).

2. On the point of the mesa between White and Walnut canyons, all three of the Miocene unconformities in the Copper Butte area are stacked up within little more than an acre of ground: Whitetail Formation (masked by slopewash) is overlain by Apache Leap Tuff (without distinct bedding) forming the bold russet base of the mesa-rim cliffs; Gravel of Walnut Canyon onlaps both Whitetail Conglomerate and Apache Leap Tuff in buttress unconformity (overlapping the contact between the two); well bedded Tuff of White Canyon forms brown-stained white cliffs overlying Apache Leap Tuff and Gravel of Walnut Canyon (with the latter pinched out eastward between Apache Leap Tuff and Tuff of White Canyon).

3. On the mesa rim east of Walnut Canyon, tall cliffs of Tuff of White Canyon display multiple scour surfaces covered progressively by festoon-like packets of beds draped successively over one another (suggesting intermittent syndepositional scour by base surges of pyroclastic flows emerging from the nearby vent filled by the Battle Axe Butte plug; whatever its origin, this style of internal bedding is not present elsewhere in the Tuff of White Canyon, and is interpreted as characteristic of a near-vent proximal facies).

References Cited

Banks, N.G., Cornwall, H.R., Silberman, M.L., and Marvin, R.F., 1972, Chronology of intrusion and ore deposits at Ray, Arizona; part I, K-Ar ages: Economic Geology, v. 67, p. 864-878.

Cornwall, H.R., 1982, Petrology and chemistry of igneous rocks, Ray porphyry copper district, Pinal County, Arizona, *in* Titley, S.R., ed., Advances in geology of the porphyry copper deposits, southwestern North America: Tucson, University of Arizona Press, p. 259-273.

Creasey, S.C., Peterson, D.W., and Gambell, N.A., 1983, Geologic map of the Teapot Mountain quadrangle, Pinal County, Arizona: U.S. Geological Survey Geologic Quadrangle Map GQ-1559, scale 1:24,000.

Dickinson, W.R., 1991, Tectonic setting of faulted Tertiary strata associated with the Catalina core complex in southern Arizona: Geological Society of America Special Paper 264, 106 p.

Dickinson, W.R., 1995, Tertiary stratigraphy and structural relationships in the Copper Butte area, Teapot Mountain quadrangle, Pinal County, Arizona: Arizona Geological Survey Contributed Report CR-95-H, 15 p. [text paragraph and additional reference inserted in 1996]

Dickinson, W.R., 1996, Geologic map of Ripsey Wash area, Pinal County, Arizona: Arizona Geological Survey Contributed Map CM-96-B, scale 1:24,000 with 7 p. text.

Dickinson, W.R., 1998, Facies map of post-mid-Miocene Quiburis Formation, San Pedro trough, Pinal, Pima, Gila, Graham, and Cochise counties, Arizona: Arizona Geological Survey Contributed Map CM-98-A, scale 1:24,000 (10 sheets) with 6 p. text.

Dickinson, W.R., 2001, Depositional facies of the Quiburis Formation, basin fill of the San Pedro trough, southeastern Arizona Basin and Range province, *in* Reynolds, R.G., and Flores, R.M., eds., Cenozoic systems of the Rocky Mountain region, USA: Denver, Rocky Mountain Section (SEPM), in press.

Dickinson, W.R., and Shafiqullah, M., 1989, K-Ar and F-T ages for syntectonic mid-Tertiary volcanosedimentary sequences associated with the Catalina core complex and San Pedro trough in southern Arizona: Isochron/West No. 52, p. 15-27.

Ferguson, C.A., and Trapp, R.A., Stratigraphic nomenclature of the Miocene Superstition volcanic field, central Arizona: Arizona Geological Survey Open-File Report 01-06, 103 p.

Howard, K.A., 1991, Intrusion of horizontal dikes: tectonic significance of Middle Proterozoic diabase sheets widespread in the upper crust of the southwestern United States: Journal of Geophysical Research, v. 96, p. 12461-12478.

Howard, K.A., and Foster, D.A., 1996, Thermal and unroofing history of a thick, tilted Basin-and-Range crustal section in the Tortilla Mountains, Arizona: Journal of Geophysical Research, v. 101, p. 511-522.

John, E., 1994, Geology of the Ray porphyry copper deposit, Pinal County, Arizona: Arizona Geological Society Spring Field Trip Guidebook, p. 15-29.

Keith, S.B., 1986, A contribution to the geology and tectonics of the Ray-Superior region, Pinal County, Arizona, *in* Beatty, B., and Wilkinson, P.A.K., eds., Frontiers in geology and ore deposits of Arizona and the Southwest: Arizona Geological Society Digest, v. 16, p. 392-407.

McIntosh, W.C., and Ferguson, C.A., 1998, Sanidine, single crystal, laser-fusion $^{40}Ar/^{39}Ar$ geochronology database for the Superstition volcanic field, central Arizona: Arizona Geological Survey Open-File Report 98-27, 74 p.

Phillips, C.H., 1976, Geology and exotic copper mineralization in the vicinity of Copper Butte, Pinal County, Arizona, *in* Woodward, L.A., and Northrup, C.A., eds., Tectonics and mineral resources of southwestern North America: New Mexico Geological Society Special Publication No. 6, p. 174-179.

Reynolds, S.J., Florence, F.P., Welty, J.W., Roddy, M.S., Currier, D.A., Anderson, A.V., and Keith, S.B., 1986, Compilation of radiometric age determinations in Arizona: Arizona Bureau of Geology and Mineral Technology, Geological Survey Branch, Bulletin 197, 184 p.

Richard, S.M., and Spencer, J.E., 1998, Compilation geologic map of the Ray-Superior area, central Arizona: Arizona Geological Survey Open-File Report 98-13, scale 1:24,000 with 47 p. text.

Schmidt, E.A., 1971, A structural investigation of the northern Tortilla Mountains [Ph.D. thesis]: Tucson, University of Arizona, 248 p.

LEGEND FOR GEOLOGIC MAP

ages revised slightly from Dickinson (1995)

[local talus deposits, sandy modern wash-floor alluvium, and slightly older Quaternary gravels of stream and pediment terraces not mapped separately]

Qls: Pleistocene (?) landslide megabreccia of Apache Leap Tuff blocks and colluvium (deeply dissected by active modern drainages)

Tsb: Lower to Middle Miocene (16-17 Ma) Sleeping Buffalo Rhyolite [Picketpost Mountain Volcanics of Richard and Spencer (1998); Picketpost Mountain Formation of Ferguson and Trapp, 2001]

Ttw: Lower Miocene (c. 17-18 Ma) Tuff of White Canyon

Tgw: Lower Miocene (18-19 Ma) Gravel of Walnut Canyon

Tal: Lower Miocene (c. 19 Ma) Apache Leap Tuff

Twc: Upper Oligocene(?) to Lower Miocene (>19 Ma) Whitetail Conglomerate (=Formation of Richard and Spencer, 1998)

Tgmp: Uppermost Cretaceous to Paleocene (60-68 Ma) Granite Mountain Porphyry (late Laramide)

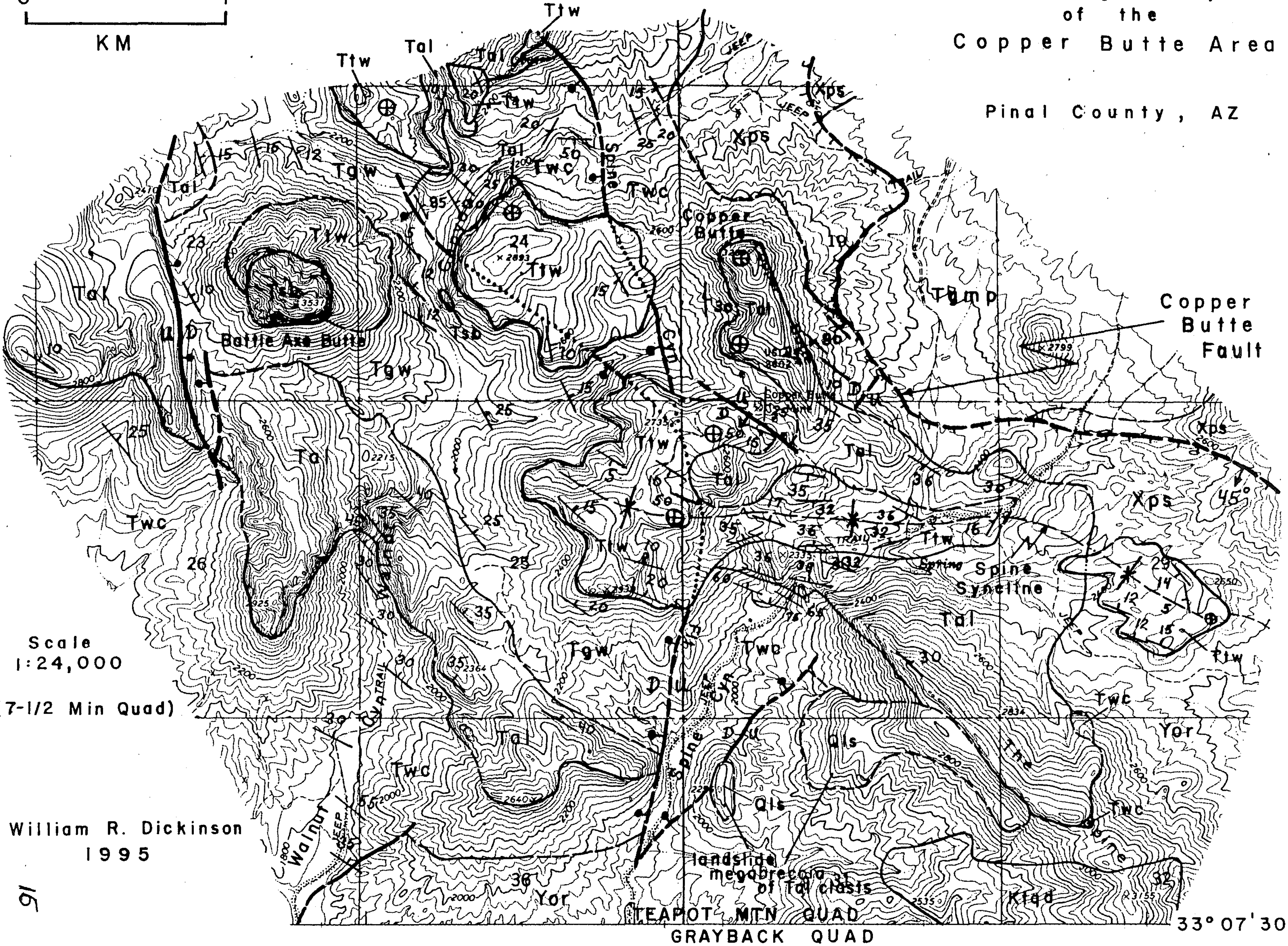
Ktqd: Upper Cretaceous (70-75 Ma) Tortilla Quartz Diorite (early Laramide)

Yor: Middle Proterozoic (1420-1450 Ma) Oracle(-Ruin) Granite

Xps: Lower Proterozoic (>1700 Ma) Pinal Schist

Geologic Map of the Copper Butte Area

Pinal County, AZ



Scale
1:24,000
(7-1/2 Min Quad)

William R. Dickinson
1995