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Geologic Map of the Chino Valley North 7½′ Quadrangle, Yavapai County, Arizona, v. 1.0

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Joseph P. Cook

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ARIZONA GEOLOGICAL SURVEY

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Yavapai County, Arizona

by

Brian F. Gootee, Charles A. Ferguson, Jon E. Spencer, and Joe P. Cook

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Introduction

The Chino Valley North 7 ½' Quadrangle covers portions of Big Chino Valley and Chino Valley and the uppermost reach of the Verde River, and includes the towns of Chino Valley and southern Paulden. These valleys are flanked by bedrock of Sullivan Buttes to the west and southwest and the westernmost portion of Black Hills to the north and northeast. The Verde River is fed by significant tributaries Big Chino Wash, Williamson Valley Wash, Chino Wash, Granite Creek and Lonesome Valley Wash (Figure 1).

Production of this new geologic map continues the Arizona Geological Survey mapping program of the Verde River valley. This mapping was done under the joint State-Federal STATEMAP program, as specified in the National Geologic Mapping Act of 1992, and was jointly funded by the Arizona Geological Survey and the U.S. Geological Survey under STATEMAP Program Contract award number 08HQAG0093. Mapping was compiled digitally using ESRI ArcGIS software. The Chino Valley North Quadrangle was mapped previously by Krieger (1965).

This mapping depicts the bedrock geology of the northwestern most part of the Black Hills and a small part of the Sullivan Buttes. Much of the mapping effort was focused on the late Cenozoic geology of the region, especially Quaternary units within and along the Chino Valley basin, with special attention to differences between the major drainage networks (Big Chino Wash, Chino Valley Wash and Granite Creek. New mapping also revealed a newly discovered Quaternary fault that flanks the western boundary of the Black Hills.

The Chino Valley North 7 ½' Quadrangle lies within the physiographic province known as the Transition Zone, which forms a belt that stretches northwest to southeast across Arizona and lies between the Colorado Plateau to the northeast and the Basin and Range Province to the south and southwest. The Transition is generally underlain by bedrock consisting largely of Proterozoic crystalline rocks that are contiguous with those beneath the Paleozoic sedimentary rocks of the Colorado Plateau, with a significant cover of upper Cenozoic volcanic rocks. These rocks are locally broken by normal faults that have produced late Cenozoic, sediment-filled basins. The map area encompasses parts of Big Chino and Little Chino valleys, which are both alluvium-filled basins produced by late Cenozoic normal faulting (Figure 2). The Quaternary landscape is represented by a unique network of significant tributaries to the Verde River in the map area which include parts of Chino Valley Wash, Lonesome Valley Wash, Williamson Wash, and Big Chino Wash.

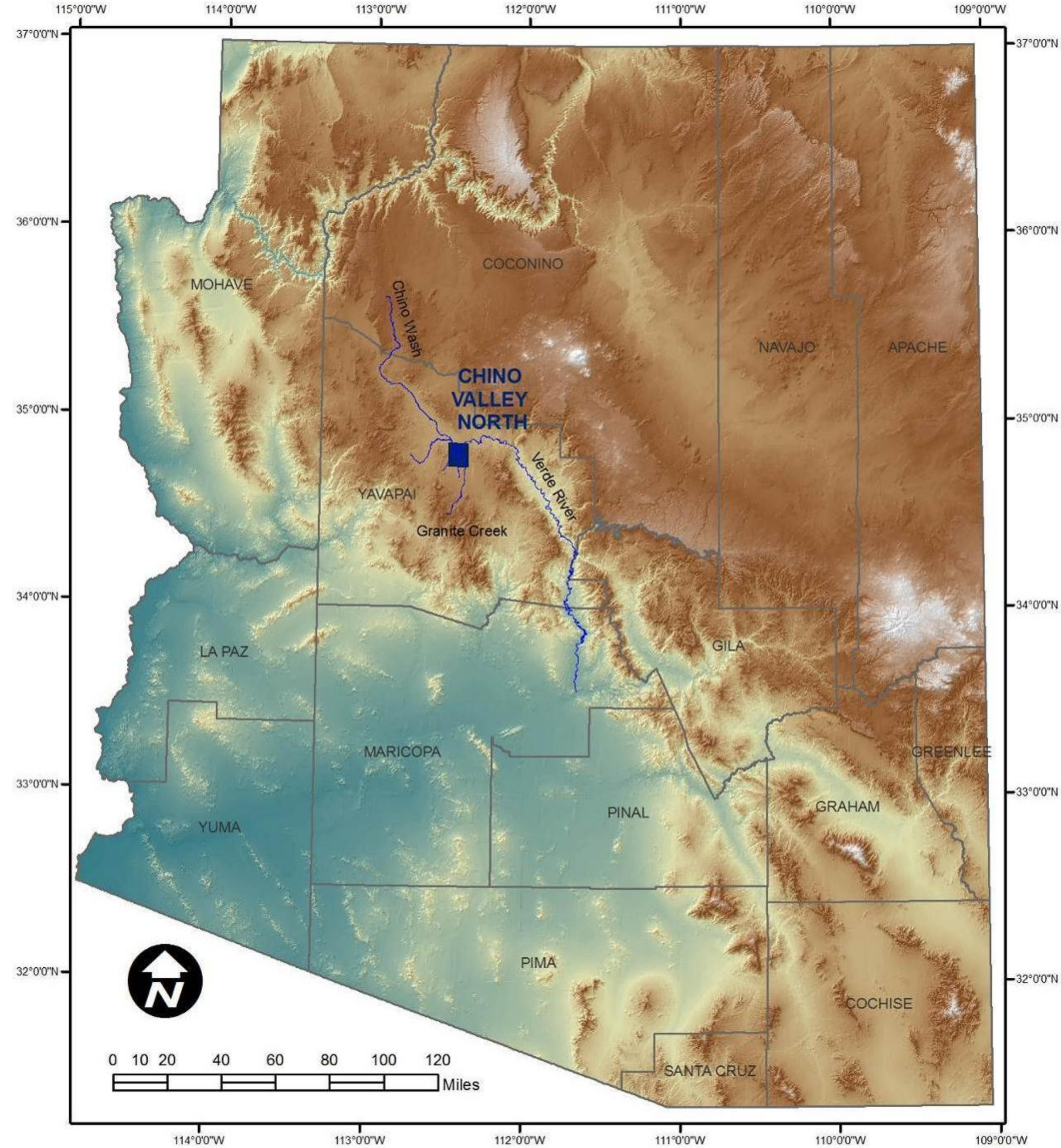

Figure 1. Location map of the Chino Valley North quadrangle and significant tributaries to the Verde River.

Geologic Discussion

Quaternary faulting

Quaternary faults are present in the vicinity of the Chino Valley area. These faults are relicts of a late Miocene to Pliocene period of active faulting and volcanism. Minor historic seismicity is inferred to reflect crustal extension southward from active faults near the edge of the Colorado Plateau in northwestern Arizona (Pearthree and Bausch, 1999). Reconnaissance investigations of the Big Chino fault zone indicate that it has had substantial activity in the middle and late Quaternary (Pearthree et al., 1983). A newly discovered Quaternary fault, herein named the Little Chino fault, borders the northeast margin of Chino Valley (Figure 2). Mapping of the two fault zones suggest Quaternary deformation is nearly continuous in Big Chino and Little Chino Valleys, and provides new insight into basin formation, faulting and drainage evolution of the Verde River and its tributaries.

The Little Chino fault is a narrow zone of predominantly normal faults that border the northeastern margin of Chino Valley. Although the Little Chino fault zone is largely concealed by Holocene colluvium and alluvium, fault exposures and geomorphic features probably related to Quaternary faulting indicate that the fault extends from the Granite Creek/Lonesome Valley confluence north to the southern edge of the Paulden 7 ½' quadrangle, approximately 11 km (7 mi) in length. Most exposed faults dip very steeply (between 79 and 90^0) to southwest. North of Del Rio Springs the trace of the Little Chino fault zone becomes less certain. Near Del Rio Springs, the Little Chino fault zone truncates a prominent northeast-striking Tertiary fault zone. The fault is part of swarm of co-planar faults that extend to the northeast into the Granite Creek – Verde River confluence area. The westernmost strand of this swarm cuts only Paleozoic or older units and is overlain by the basal Tertiary conglomerate (Tc). Along strike to the southwest, in the vicinity of Del Rio Spring, a series of west-side-down geomorphic scarps cutting Tertiary units swing to the south into parallelism with the Quaternary Chino Valley fault. The scarps suggest that the Little Chino fault zone, instead of continuing to the northwest, turns to the north and crosses the Verde River just upstream of its confluence with Granite Creek. If Quaternary faulting has occurred along this belt, it would imply that the Little Chino and Big Chino faults occupy essentially the same zone of deformation.

Minor earthquakes were recorded as recently as December 25, 2009 near a fault strand interpreted to be an extension of the Big Chino fault on the Paulden/Chino Valley North quad boundary and another on May 5, 1999 at 5 km depth near the Little Chino fault (Figure 2). To actually demonstrate that small or moderate earthquakes actually occurred on a particular fault is difficult, and requires accurate horizontal position, hypocentral depth, and an idea of fault geometry at depth. Thus it is difficult to relate the two earthquake events to faults directly; however, historical seismicity suggests that deformation in this region is ongoing.

North of Chino Valley, previous Quaternary fault mapping (Menges and Pearthree, 1983) and preliminary detailed mapping of the Paulden quadrangle (AZGS, in progress) shows the Big Chino fault zone extending from Big Chino Valley towards the Verde River in the Chino Valley North quadrangle as a diffuse zone of multiple northwest-trending low-relief fault scarps expressed as linear geomorphic features. Geomorphic indicators include linear benches, ridges and valleys. Fault zone exposures are rare and often obscured by Holocene and Pleistocene alluvium and colluvium. Tilted basin-fill units in the Paulden area suggest faults underlying Big Chino Wash are likely. The overall trend of the Big Chino fault zone coincides with northwest-trending Laramide monoclines present in Black Mesa and western Mingus Mountains. Relationships between the Big Chino fault zone and Little Chino fault are not clear and additional research would help to define the relationships between new surficial mapping of faulted areas, subsurface geology, groundwater flow paths and groundwater chemistry.

A roadcut along Road 6 North (3853712, 368910) exposes approximately an 80-meter transects across part of the Little Chino fault zone; the total zone of deformation appears to be at least 230 meters wide in this area. This roadcut also coincides with thick early Pleistocene gravels preserved on a saddle near the divide between Little Chino and Granite Creek watersheds. Early Pleistocene gravels are faulted into the subsurface. Many faults and several buried paleosols developed on younger deposits are exposed in the roadcut; they indicate that the Little Chino fault has ruptured repeatedly in the Quaternary (Figure 3). A detailed survey of this roadcut was conducted in the fall of 2009, and investigations into the age of youngest movement and the history of recurrent fault are continuing.

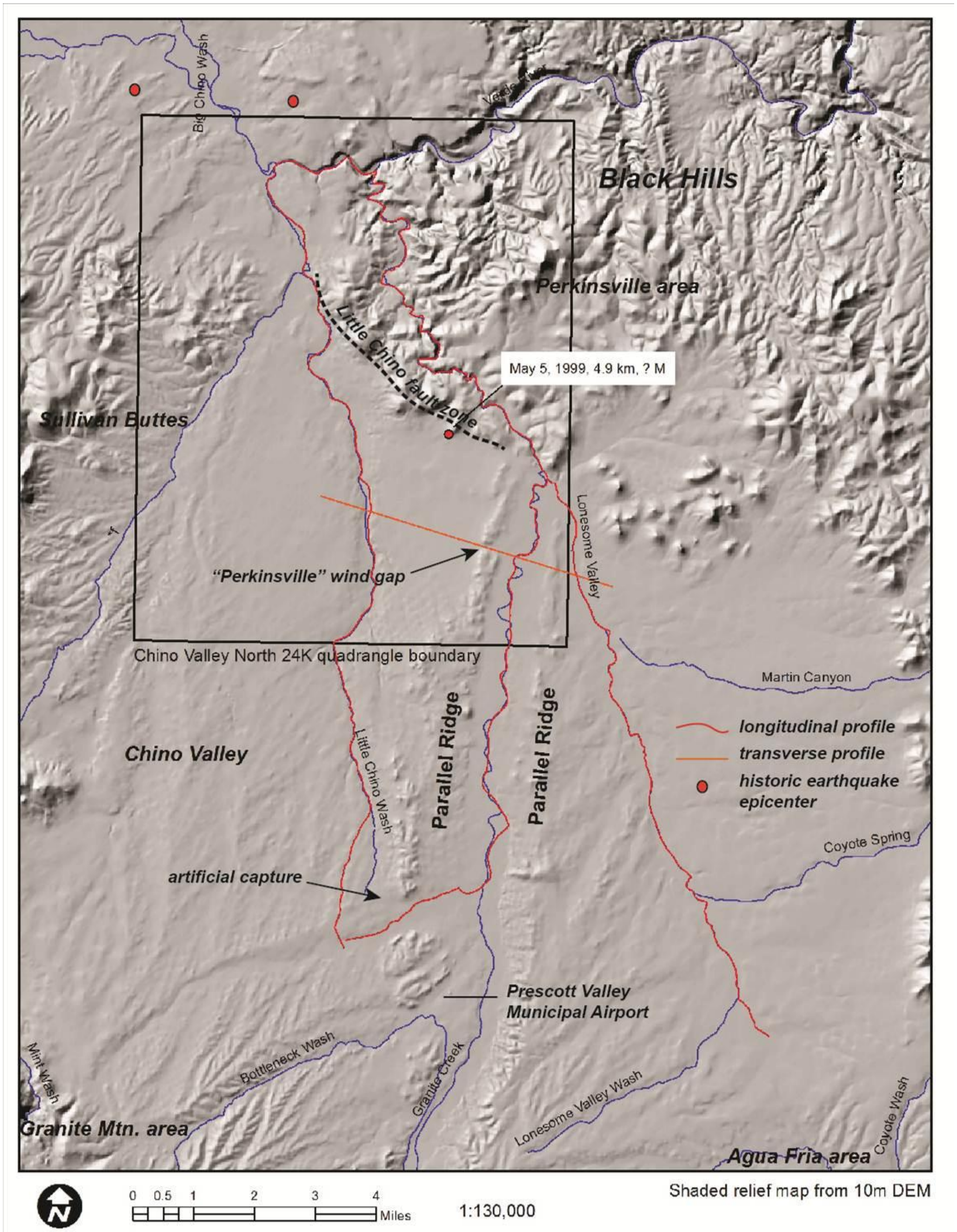

Figure 2. Regional shaded-relief map of the Chino Valley North quadrangle area showing drainage tributaries to the Verde River discussed in text.

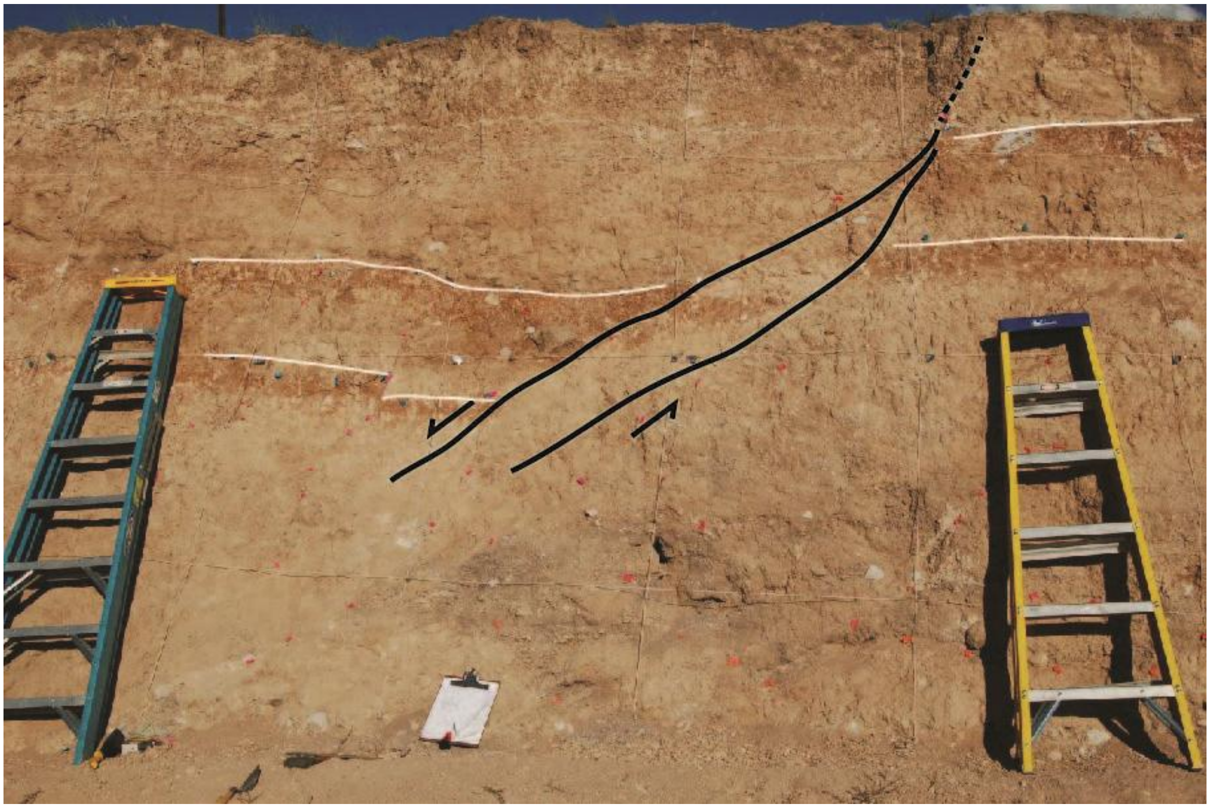

Figure 3. Photo of faulted and buried paleosols across the Little Chino fault zone along Road 6 North, view east-northeast. The two youngest pair of paleosol argillic soils are offset approximately 1.5 meters, (pair of white lines). A Holocene soil forms the uppermost layer. Note 1-meter string grid and colored nail-flagging.

The intersection of the Little Chino fault zone with two older, prominent northeast-striking fault zones may play a significant role in groundwater flow. One of these two intersections coincides with the nearby Del Rio Springs and may act as a groundwater conduit from Little Chino Valley to Del Rio Springs. Granite Creek Springs, which supply some base flow to the uppermost Verde River, are located farther northeast along the northeast-striking fault zone.

If the Little Chino fault has been active throughout the Quaternary this raises the question of what is the drainage history in the Little and Big Chino valleys with regards to active tectonicism. The Little Chino Valley and Granite Creek offer important insights into such history.

Groundwater resources

Population growth around Prescott and Chino Valley has placed increasing pressure on groundwater supplies. As a result of concerns that groundwater would be depleted, the Little Chino Valley drainage basin was made part of an Active Management Area (AMA) by the Arizona Department of Water Resources in 1980. The Prescott AMA has a statutory goal of achieving basin-wide safe-yield, balancing annual groundwater withdrawal with natural and artificial recharge, by 2025. Recharging water in one part of an AMA can offset groundwater-level declines in another portion of the AMA. In spite of AMA management, the water table, as measured in 90% of the groundwater wells in the AMA, is declining, with an average rate of decline of 2.7 feet per year. Water pumping is now estimated to be 45% greater than recharge.

A recent compilation of well-water chemistry in the Prescott – Chino Valley area outlined the areal extent of wells with elevated arsenic levels (Blasch et al., 2005). The highest levels in the area are adjacent to the southeast end of the active normal fault at the northeast margin of Big Chino Valley. High levels are also apparent in spring discharges. For example, all nine samples analyzed from Upper Verde River Springs contained 13 to 29 ppb arsenic. Elevated arsenic levels are thought to be derived from lower Paleozoic aquifer units and from fine-grained, basin-interior sediments in Big Chino Valley (Wirt, 2004a).

Base flow, which is the amount of flow in a river that results from groundwater inflow and is unrelated to prompt runoff from precipitation, increases along a several-mile stretch of the Verde River in the Chino Valley North 7.5' Quadrangle (Wirt, 2004b). Springs in the streambed, primarily near Upper Verde River springs and above the Paulden gauging station, emanate from Paleozoic sedimentary units and sustain a base flow of about 25 ft^3/s. This base flow maintains critical habitat for the threatened spikedace minnow (*Meda fulgida*). The Arizona Game and Fish Department recently acquired 796 acres along the upper Verde River in order to protect the area's native-fish abundance and diversity (Wirt, 2004b). Arizona Game and Fish's primary management objectives for this area are to monitor, manage, and maintain the extant native fish populations, which also include roundtail chub (*Gila robusta*), razorback sucker (*Xyrauchen texanus*), desert sucker (*Catostomus clarki*), Sonora sucker (*Catostomus insignis*), Longfin dace (*Agosia chrysogaster*), and speckled dace (*Rhinichthys osculus*).

Geologic mapping presented in this report serves at least two purposes in improving understanding of groundwater behavior in the upper Verde – Chino Valley – Little Chino Valley area. (1) Better mapping of the margins of the late Cenozoic basin fill will allow more accurate hydrogeologic modeling. (2) A fault zone with possible Quaternary offset that extends from near Del Rio Spring to the area of the Upper Verde River Springs, shown on the accompanying map, could be a significant conduit for groundwater movement. However, Wirt et al. (2004) determined on the basis of groundwater geochemistry that Verde River Springs water was derived dominantly from the Big Chino Valley basin-fill aquifer, with only minor contributions from the Little Chino basin-fill aquifer. The close association of Verde River Springs with the mapped northeast-striking fault zone suggests that the faults are conduits for the groundwater emanating from the springs. However, geochemistry suggests that spring water was derived from western sources (Big Chino Valley basin fill) not associated with the fault. It thus appears that groundwater flow paths are complex, possibly with groundwater flow from the Big Chino aquifer through unidentified faults or rock units toward the northeast-striking faults and then flow through the faults and fault-damage zones to Verde River Springs.

Flood hazards

Potential flood hazards exist along piedmont drainages throughout the map area. The Chino Valley area is generally dry, but the area is subject to occasional incursions of moist air from the south and, rarely, associated large floods with relatively deep, high velocity flow. In addition, lateral bank erosion and drastic changes in channel position may occur during floods. This is especially likely along banks formed in weakly cohesive Holocene terrace deposits and underlying basin fill unit exposed along tributaries in Little Chino Valley. Especially in low-relief portions of the valley, flash floods can cover broad portions of piedmonts with sheet wash. Such floods are infrequent and of short duration, but are potentially devastating to homes because of the extent of inundation and the potential for developing new channels especially in areas mapped as Qy3 and Qy2.

History of Granite Creek

Granite Creek originates in the northern Bradshaw Mountains in the Prescott area (upper Granite Creek), flows north across Chino Valley (middle Granite Creek), and through the western Black Hills where Granite Creek joins the Verde River (lower Granite Creek). The Chino Valley North quadrangle includes lower Granite Creek and a portion of middle Granite Creek (Figure 2). Lower Granite Creek cuts through a structural and topographic high (Black Hills) and as such classifies Granite Creek as a transverse drainage or drainage anomaly (Douglass et al., 2009). Remnants of the Granite Creek drainage anomaly are well represented by two conspicuous parallel ridges (Figure 2). In addition to detailed mapping of terrace deposits along middle and lower Granite Creek, the newly discovered Quaternary Little Chino fault records a history of uplift of the western Black Hills area into the north-flowing Granite Creek, a process known as antecedence. Granite Creek may be one of the best-preserved examples of antecedence in Arizona (Douglass, J., personal communication).

Middle Granite Creek

Middle Granite Creek is characterized by two conspicuous north-trending parallel ridges bordering Granite Creek. The ridges are composed of an underlying basin-fill unit (Tbf) capped by coarse-grained Quaternary alluvium interpreted to be remnant terrace or alluvial fan deposits. The basin-fill unit is nearly everywhere composed of light red-brown silt, commonly fractured and weathered; the capping alluvium is composed of clast-supported gravel, cobbles and boulders. Clast lithologies include a variety of plutonic and metamorphic rocks (meta-sedimentary and meta-igneous) derived from the headwaters of Granite Creek in the Bradshaw Mountains. The contact between alluvium and basin fill is unconformable everywhere and has very low relief.

The parallel ridges are nearly flat-topped with a less than 1^0 slope dipping towards Black Hills. The sides of the ridges slope 3^0 to 15^0, where Holocene colluvial deposits obscure most exposures on basin-fill deposits. Along the uppermost tributaries to Little Chino Wash multiple terrace horizons are clustered below the highest-capping terrace on the western parallel ridge (Figure 4). These terraces are composed of coarse lag gravel derived from the uppermost Granite Creek-sourced terrace deposits and related colluvial deposits. The lag gravel deposits are transport-limited and as such tend to armor the relatively soft underlying basin-fill unit while preserving early remnants of headward incision from Little Chino Wash tributaries. Exposures of alluvium formed by the uppermost tributaries of Little Chino wash along the parallel ridges and lower terraces are often obscured by Holocene soil, precluding confident age-determination of the gravels associated with Little Chino Wash.

Figure 4. View south along the western flank of the Granite Creek parallel ridge. Uppermost terrace to the left (Qi1) is sourced from an ancestral Granite Creek. Multiple terraces below and to the right (black arrows) are formed along the uppermost tributaries to Little Chino Wash, armored by lag gravels derived from the uppermost Granite Creek-sourced terrace.

Krieger (1965) interpreted Little Chino Wash as once occupying the southern portion of Chino Valley between the Prescott Valley Municipal Airport and Granite Dells area, now occupied by two tributaries to Granite Creek. Krieger reported that Granite Creek was in the process of capturing Chino Valley Wash; however, this is impossible since the base level for Granite Creek is significantly lower than Chino Valley wash. Instead, Little Chino Wash and its tributaries have been capturing a system of northeast-flowing ancestral tributaries to Granite Creek, and continue to do so (Figure 2). Wind gaps present today mark the location most likely for tributaries of Little Chino Valley to capture the Granite Creek tributaries through stream piracy (Douglass et al., 2009) (Figure 2). At the divide between Chino Valley and Granite Creek along Perkinsville Road a significant wind gap is present with approximately 10 to 12 feet of relief between the two divides (Figure 5). If the “Perkinsville” wind gap is overtopped or eroded by flood flows on Granite Creek, it is possible that Little Chino Valley could capture upper Granite Creek in the not-too-distant future.

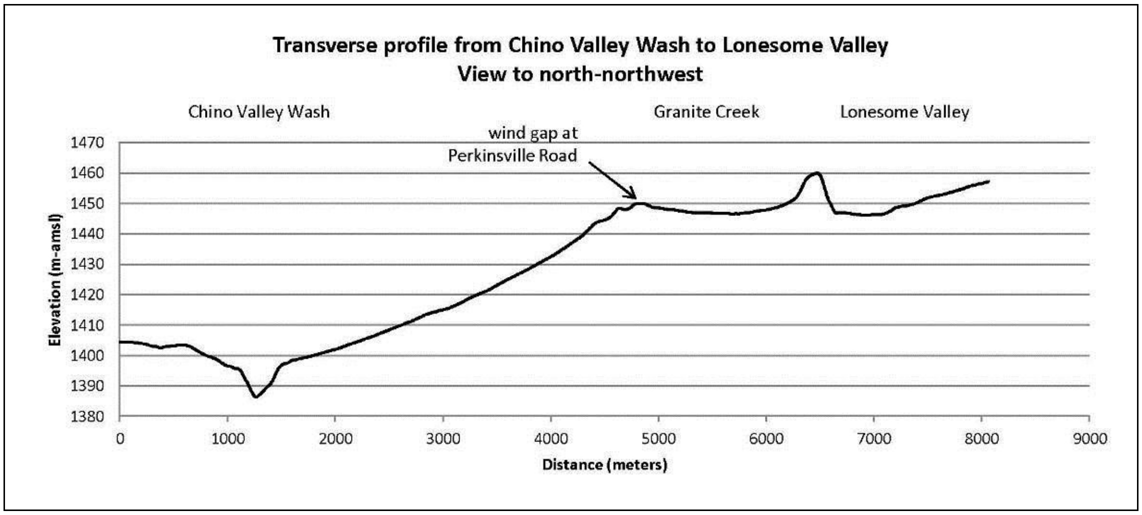

Figure 5. Transverse profile from Chino Valley Wash to Lonesome Valley across the wind gap at Perkinsville Road. Refer to Figure 2 for location of transverse profile.

Additionally, the northernmost tributary to Granite Creek south of the mapping area has artificially integrated with Chino Valley Wash with help from an irrigation canal reportedly constructed by a Mormon community in the 1930's.

Lower Granite Creek

Lower Granite Creek represents a transverse drainage across a structural and topographic high (Douglass et al., 2009). A record of strath terrace deposits are present at several horizons along middle and lower Granite Creek and record the incisional history of Granite Creek.

To demonstrate relationships of base level, stream capture and terrace deposits between Little Chino Wash, Granite Creek and Lonesome Valley (a tributary to Granite Creek), longitudinal profiles were constructed along each channel thalweg; another longitudinal profile along a tributary to Granite Creek was used to show where the irrigation canal constructed in the 1930's captured flow from a wind gap. The map location of the profiles is shown in Figure 2 and cross-sectional views shown in Figure 6.

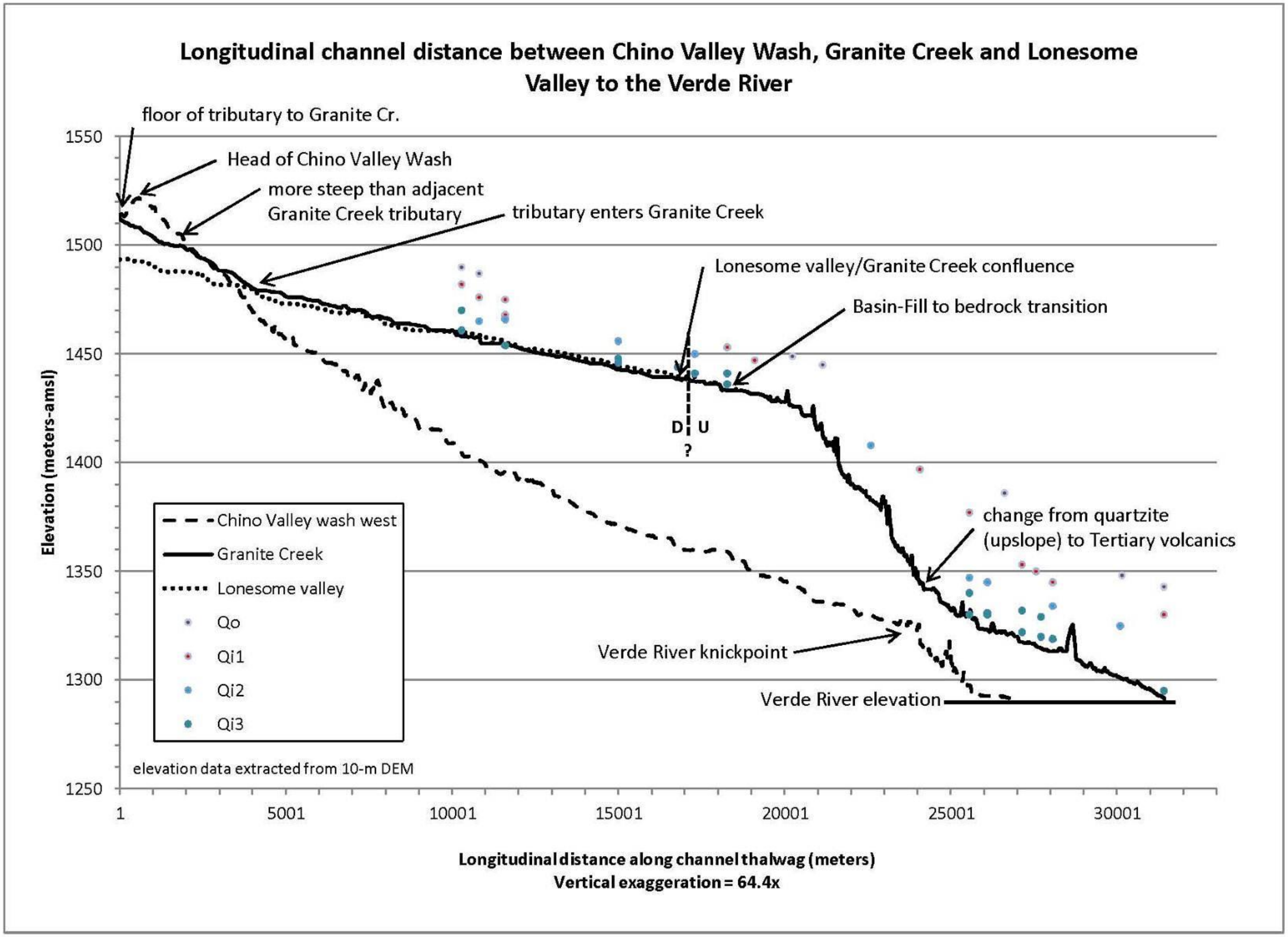

Figure 6. Longitudinal profiles along major tributaries to the Verde River. See Figure 2 for location of profiles.

From Figure 6 it is clear that because of its much steeper gradient in Little Chino Valley, Chino Wash has a lower base level capable of capturing higher base levels along Granite Creek and its tributaries. Unsurprisingly Lonesome Valley Wash and Granite Creek share similar channel gradients and elevations; Krieger (1965) correctly identified that the headwaters of the Aqua Fria watershed to the southeast are in the process of capturing the Lonesome Valley headwaters, thereby reducing the watershed capacity and stream power of Lonesome Valley and causing Lonesome Valley to aggrade and become 'stagnant'.

Alluvial terrace deposits along Granite Creek and their ages are shown in Figure 6. The uppermost mapped terrace elevations interpreted to be early Pleistocene (Qo) are at 1,490 meters elevation, approximately 30 meters above the channel floor. Near the confluence with the Verde River, the same or similar age deposits of Qo rest at 1,343 meters, approximately 50 meters above the channel. The difference in elevation of 20 meters between the strathed terrace deposits and the channel floor over a channel length of approximately 20 km is apparent in all terrace deposits of similar age (Figure 6). This splay of terraces downstream suggests that the western Black Hills are actively uplifting as Granite Creek downcuts into them. Splayed terraces are a well-known phenomenon associated with active uplift and incision in Kathmandu basin, Himalayas (Lavé and Avouac, 2000). Although a more thorough analysis of elevation data and age-determination of terrace deposits would be beneficial, these data suggest several meters or tens of meters of uplift of western Black Hills occurred during the Pleistocene.

Early Pleistocene deposits are found preserved as discontinuous exposures throughout the western Black Hills. The oldest deposits (Qi1 and Qo) cap Tertiary basalt mesas and overlie many exposures of Tertiary volcanic and conglomerate rocks. These early Pleistocene deposits are usually capping older rock units and form well rounded slopes that blend smoothly with colluvial slopes generated from nearby bedrock. In many cases flat-graded ridge-saddles of bedrock without Pleistocene alluvium are associated with nearby strath-deposits along the same horizon. Some graded saddles and benches lacking terrace deposits are also formed abruptly against knobs of resistant quartzite; the saddles are interpreted to be erosional landforms formed by streams during early Pleistocene.

In the area of Boundary Tank (eastern-central portion of the quadrangle) alluvial deposits similar to Qo-age may represent an ancestral tributary adjacent to Granite Creek. These deposits are derived from local bedrock sources and can be as much as 15 meters thick. The base of Qo in this area rests on bedrock and appears to be graded towards the west to a level above most present-day quartzite hills.

During the early Pleistocene the elevated strath-terrace remnants found in saddles, along bedrock-benches and tops of mesas, especially bordering the southwestern most Black Hills adjacent to the Little Chino fault seem to suggest that ancestral tributaries to Granite Creek once flowed northeast across the present-day Chino Valley area. Little Chino Wash has a history of capturing late Pleistocene tributaries to Granite Creek and it is conceivable that tributaries to Granite Creek once flowed through passes in the western Black Hills as far north as Del Rio Springs, likely separated by a divide between Sullivan Buttes and Black Hills.

A more thorough discussion of the evolution of Granite Creek and Little Chino Valley basin evolution will be covered in a future publication related to discussion result of the ongoing work and research of the Little Chino fault exposed in Road 6 North.

Tertiary structure

The youngest faults in the map area are Quaternary in age. A pair of pre-Paleozoic faults have been identified, and there are a series of northeast-striking faults that cut Paleozoic units but are overlain by the oldest Tertiary unit in the area, the older conglomerate (Tc), and some of these may be, at least in part much older than Tertiary. There are faults young and old striking both northwesterly and northeasterly. Intersections are rarely preserved. The basin-bounding fault zone is the principal young northwesterly striking structure. Faults of this orientation also occur farther northwest, but none of these obviously cut units younger than and including the younger basalt (Tb). A northeast-striking fault swarm near the confluence of Granite Creek and Verde River includes several strands. The swarm consists of several very steep faults that display inconsistent, usually minor, but sometime major offsets of the gently dipping units they cut. Some faults splay to the south, and others, striking northwesterly, appear to be truncated by strands of the main swarm. The eastern main strand cuts units as young as the Tertiary conglomerate (Tc), older mafic lava (Tbl), and latitic rocks south of Granite Creek. The main western strand, however, is overlain by the basal Tertiary conglomerate (Tc). Because they display inconsistent offset of units, anastomosing map patterns, and high-angles, the faults are interpreted as a strike-slip. No kinematic indicators were observed, but the map pattern is weakly suggestive of sinistral motion.

Tertiary volcanic rocks

Latitic rocks

Two latitic volcanic complexes are present in the map area. K-Ar and Ar/Ar ages, summarized in Riggs et al. (1997), on biotite, hornblende, and whole rock range from 27.4 to 21.3Ma. The eastern flank of the Sullivan Buttes complex extends into the western edge of the map area. It consists of an amalgamated series of pyroxene-biotite latite lavas that were lumped together as (Tsb), just as was done by Tyner (1984, his unit Ta). There seems little need to map individual flows in this area. The exposure is limited and access to the land is difficult. The other latite complex, named the Wells Ranch volcanic field, lying in the northeast part of the map area, is deeply incised and significantly more complex.

The Wells Ranch volcanic field lies just southeast of the confluence of the Granite Creek and Verde River (Ward, 1993; Tyner, 1984; Riggs et al., 1997). Three massifs dominate the field, each dominated by distinct unit(s). The rocks are alkalic intermediate to mafic composition flows that were differentiated in the field on the basis of their main phenocryst phase; biotite, hornblende, or pyroxene. The same minerals are also present to varying degrees as subordinate phenocrysts or in the matrix of nearly all the flows. Other minerals in the matrix that have been described are olivine, magnetite, sanidine, and sphene. Some of the flows contain abundant crustal and mantle xenoliths.

As noted by Riggs et al. (1997), the term latite for many of the Sullivan Buttes area volcanic rocks is a misnomer. Detailed studies have shown many of these rocks to be trachytic in composition. The term latite is herein used only as a field term for alkalic, intermediate to mafic lavas. All of the latites are complexly interbedded with a variety of monolithic breccias (probable autobreccia and/or block and ash-flows). Pyroclastic rocks locally include zones of heterogeneous clasts including non-volcanic ones in some areas (Riggs et al., 1997). Riggs et al. (1997) attempted to differentiate the flows from the breccia and pyroclastic units. Considering the scale and time constraints of our mapping this was not attempted during our mapping, but we were able to differentiate a few more of the flow units. Some units show sedimentologic evidence of epiclastic origin (the Tmb unit of Riggs et al., 1997), and these where mapped separately where possible (Tcy). The upward change from non-volcaniclastic to volcaniclastic in the conglomerate sequence (Tc to Tcy) may be a reflection more of availability of volcanic detritus than relative age. Some conglomerate lenses that clearly overlie volcanic flows are non-volcaniclastic, whereas some others that seem to be younger are volcaniclastic.

Riggs et al. (1997) show that a basal mafic shoshonitic lava (our Tbl) was emplaced during the waning stages of deposition of a thick, non-volcaniclastic conglomerate unit. The rocks have been regionally correlated with a widespread sequence of Paleogene, mostly Eocene (Young 2010) conglomerates that mantle the southwestern edge of the Colorado Plateau. The conglomerates are northeast-directed as are the ones associated with the late Oligocene volcanic rocks in Chino Valley. However, as the conglomerates in this area are traced to the northeast, paleocurrents swing to the east and southeast. This paleocurrent pattern, plus the close association in time with an Oligocene volcanic complex suggest that these rocks correlate with a younger regional sequence of conglomerate, the Beavertail Formation of Blakey (2010).

Riggs et al. (1997) show the shoshonite lava and cinder cone complex intruded by and overlain by a hornblende latite dome complex (Thu) that is, in turn overlain and intruded by a younger biotite latite unit (Tlbu). Just to the east of the complex, they also show an older biotite latite (Tlbm) that underlies the hornblende latite (Thu). Our mapping in the area where all three massifs come together suggests that another, even older biotite latite (Tlbl) is probably present erosionally overlain by the uppermost 20-30m of the non-volcaniclastic conglomerate (Tc). The middle biotite latite (Tlbm) is overlain by volcaniclastic conglomerate to the south, and non-volcanic conglomerate to the north. It can also be demonstrated that Tlbm is overlain by the pyroxene latite (Tpl) which forms the eastern massif, and is apparently the youngest latitic lava in the area. The pyroxene latite (Tpl), and the middle biotite latite (Tlbm) overlie an older xenolith-rich, hornblende latite (Thl) which forms the southern massif. We tentatively identify an intermediate age hornblende latite (Thm) making up some portion of the southwesterly part of the northwestern massif that shows evidence of being overlain by the younger hornblende latite (Thu) and overlying the older one (Th1). Hornblende-porphyritic latitic units in this area are sandwiched between non-volcanic conglomerate (Riggs et al., 1997), as well as being overlain by younger conglomerate (Tcy) and a younger biotite latite (Tlbu).

Scattered around the volcanic complex are outliers of various flows and plugs that are tentatively correlated with parts of the complex. Farther away, a number of eroded intrusive masses of biotite latite are simply mapped as undifferentiated biotite latite (Tlb).

Mafic lavas

Two map units composed of mafic lavas are recognized. The older is a unit at or near the base of the latitic volcanic complex mapped as older mafic lavas (Tbl) which corresponds to the shoshonite lava and cinder cone complex of Riggs et al. (1997). A younger suite of post-latitic complex, mafic lavas (Tb) of probable middle Miocene age, cap mesas throughout the area. Along Verde River, the younger mafic lavas overlies all of the latitic units, and overlies faults that cut the older Tertiary units. To the south, a series of mafic lavas cap mesas and overlie whichever latitic unit is present in that area. These are tentatively mapped as younger mafic lava (Tb), but they may instead be part of the older sequence. At least one is petrographically distinct; a thin-section (CAF-2-24087) shows a southern flow to be a two pyroxene mafic lava without olivine phenocrysts, whereas flows to the north are olivine-phyric with little or no pyroxene phenocrysts and abundant plagioclase (CAF-2-24191). We advise caution in attaching too much significance to this difference. Where the older mafic lava is overlain by the younger lava in the north, and there is independent evidence indicating a significant difference in age, there are several places where the two lavas appear to be nearly identical olivine-phyric basaltic lavas.

Paleocanyon?

In most areas along Verde River, the unconformity below the younger basaltic lava (Tb) is relatively gently dipping. In two areas along the southern wall of Verde River Canyon, there is good evidence that the unconformity is a north-dipping, steep depositional contact, possibly a paleocanyon wall. The contacts show no evidence of shearing or faulting and there is no evidence below the unconformity of any offset of older units. In both cases the basalt overlies hornblende latite. In the northeast corner of section 13, the contact dips northeasterly at least 30 degrees. In the northern part of section 18, the contact is even steeper and it truncates a flat-lying older depositional contact. Together, the pair of contacts might represent a meander bend of a paleocanyon filled with the younger mafic lava (Tb) oriented roughly east-west. The younger basalt lava in this area contains several outcrops of hornblende latite, some of which are strongly autobrecciated (lava) and/or contain abundant pyroclastic material which is not typical of intrusive bodies. The surrounded hornblende latite masses appear to be derived from flows just to the south that underlie the basaltic lava. The easternmost outcrop is probably a continuation of the larger area just to the east and therefore a part of that canyon wall, but the other outcrops are interpreted as toppled blocks caved into the canyon as it was being filled by the younger basalt. One of these, exposed along the wall of a small canyon, appears to be surrounded on all sides, and its brecciated texture is atypical of an intrusion.

Discussion

The volcanic complex near the confluence of Granite Creek and Verde River is exceptionally complex, possibly even more so than shown by Riggs et al. (1997). Flows of at least three types, biotite, pyroxene, and hornblende dominant, are interleaved throughout the sequence and interleaved with non-volcaniclastic and volcaniclastic conglomerate. The volcanic complex was emplaced into an area already receiving abundant non-volcanic sediment from the southwest, and that sediment probably overwhelmed the volcaniclastic contribution in many parts of the system. Paleocurrents change from northwesterly to easterly and southeasterly towards the northeast and suggest that the rocks were part of an Oligocene, Transition Zone, graben-filling succession, the Beavertail Conglomerate.

Paleozoic stratigraphy

Cambrian rocks are sparsely preserved below a regional sub-Devonian unconformity. Basement highs persisted into the Devonian in many areas, one of them being along the upper reaches of Granite Creek. The Cambrian Tapeats Sandstone appears suddenly just south of the confluence with Verde River, and as it thickens to the north, so does another enigmatic unit that we identify simply as undifferentiated lower Paleozoic rocks (DC). The signature lithology of these strata is a distinctive, creamy white weathering, very fine-grained dolomicrite with thin, light green shale interbeds. The thin (~20m) sequence contains no identifiable fossils, is bounded by unconformities, and represents an important stratigraphic marker that has a fairly complex history of nomenclature. The strata were described as units a and b of the Martin Formation (Krieger, 1965) with unit b corresponding to the distinctive, very fine-grained or lithographic dolomicrite. The unit was later studied in detail and described as the Upper Cambrian Chino Valley Formation (Hereford, 1975), and then reassigned to the Middle Devonian Beckers Butte Member of the Devonian Martin Formation (Hereford, 1977, see also Beus, 1989) based largely on Elston and Bressler's (1978) paleomagnetic analysis of a similar unit near Jerome. The strata near Jerome have a paleopole nearly identical to that of the Martin Formation elsewhere in Arizona, and widely dissimilar to known paleopoles for the Lower Cambrian Tapeats Sandstone. No comparison was made with possible Upper Cambrian, Ordovician or Silurian paleopoles (Elston and Bressler, 1978). Hereford (1977) states that the unit likely correlates with a blanket-like Devonian Beckers Butte Member of the Martin Formation which he shows truncating Lower Cambrian units from east to west across this part of Arizona. The sudden appearance of the unit in the northern part of the map area, along with the Cambrian Tapeats Sandstone is inconsistent with this view. The unit bears some, although not many, lithologic similarities to Middle Cambrian carbonate rocks of the Muav Limestone in the Grand Canyon area (McKee and Reesor, 1945; Middleton, 1989) but might also correlate with parts of the underlying Bright Angel Shale which intertonques with the Muav. Another possibility is that it correlates with a poorly understood, unfossiliferous, Upper Cambrian (?) dolostone that overlies the Muav in the western Grand Canyon informally known as the Grand Wash dolomite (Brathovde, 1986), undifferentiated dolomites (McKee and Reesor, 1945), undifferentiated Cambrian (Middleton, 1989), or supra-Muav (Wood, 1956). The very fine-grained, sometimes referred to as "aphanitic" but more accurately lithographic, texture of the unit's signature lithology is most similar to descriptions of these loosely defined Upper Cambrian rocks.

Proterozoic structure

There are no definitive contact relationships between the three Proterozoic rocks types in the map area; quartzite, mafic lava, and schist. The pebbly quartz sandstone unit, the Del Rio Quartzite (Xq), is the most abundant. In the core of a major anticline that bisects the middle reaches of Granite Creek, the quartzite appears to overlie a deeply weathered greenstone unit that probably correlates with a mafic lava unit (Xm) whose only other outcrop belt is a small, isolated area just to the north. At this locality, the mafic display good examples of pillow lava, pillow breccia and hyaloclastite texture. The quartzite is strongly folded, and the greenstone probably is also, but neither host penetrative tectonic fabrics. The metamorphic grade in the quartzite, based on the mineralogy of sparse argillites (Krieger, 1965), is sub-greenschist. The metavolcanics also appear to be lower greenschist or lower grade.

Throughout most of its outcrop belt, the quartzite is tightly to closely folded with relatively long, consistently oriented, north to northeast-striking axial planes. To the south, the belt is sharply deflected into a narrow, mostly very steeply-dipping, northeast-facing limb that extends all along the southwestern edge of the bedrock. Wilson (1939) suggested that this deflection might be drag folding related to a major fault buried by basin-fill just to the southwest. Krieger (1965) defers on the fault, but agrees that the deflection is probably the result of a secondary fold. This idea is supported by our observations in a small outlier of the quartzite in the northeast corner of the map area. Several beds define two divergently oriented belts that can be traced through a secondary, east-plunging synform in a pattern very similar to the eastern half of the structure at Granite Creek.

In the Granite Creek area, two major north- to northeast-striking anticlines dominate the map pattern. The western anticline is refolded on the south by a pair of open, moderately steeply, oppositely plunging synforms. The eastern anticline is not deflected. Instead, at Granite Creek, it is sharply truncated by the southeast-striking belt of quartzite. Krieger (1965) showed this juxtaposition as a fault. There is good evidence for this. The juxtaposition is exceptionally abrupt, and the fault lines up with an abrupt change in the Proterozoic basement farther to the northwest. This seems reasonable and we show the same structure.

The main phase(s) of deformation of these structures is Precambrian in age. There is no evidence of major offset or change in dip in Paleozoic rocks across any of them. The fault along Granite Creek is buried by a paleovalley of Paleozoic age. Dips in Paleozoic units in the paleovalley up to 25 degrees are probably due to differential compaction over sharp declivities in the substrate. It is possible that the declivity was created by reactivation of the structure, and this could have occurred as late as the early Paleozoic.

A third Proterozoic unit occurs along Granite Creek near the confluence with Verde River. These rocks are penetratively deformed psammitic biotite-sericite schist. These rocks are juxtaposed with the Del Rio Quartzite along a single, straight, northeast-striking contact that is either a fault or unconformity. Facing direction in the quartzite adjacent to the fault is consistent with the quartzite being younger, but the contact is not exposed. The schist displays compositional layering strongly suggestive of an interbedded argillite and sandstone protolith, possibly a turbidite succession, and hosts a pervasive syn- to post-metamorphic cleavage or schistosity that is typically strongly inclined to the compositional layering. The resultant intersection lineation is associated with an approximately coincident crenulation lineation and indicates that the main schistosity post-dates an older micaceous fabric.

The lack of any tectonic fabric in either the mafic lava (Xm) or Del Rio Quartzite (Xq) provides a strong argument (Krieger, 1965) that these rocks are significantly younger than the metasedimentary rocks (Xs). That both rock suites record two probable phases of deformation suggests that there may be some overlap of deformation.

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Geologic Map Units

Miscellaneous Units

d **Disturbed ground (upper Holocene)** – Areas substantially modified by development and other human activity. Original geologic features are obscured.

p **Plowed Areas** – Historically or actively plowed fields, irrigated pasture, and other lightly disturbed ground.

Qvc **Quaternary regolith and colluvium formed on basin-fill deposits** – in situ deposits mantling gentle to moderate slopes on fine-grained basin-fill deposits. Deposits commonly are sand, silt and clay, with minor clasts of reworked carbonate and fine gravel. Soil development is generally weak.

Qtc **Quaternary talus and colluvium** – very poorly sorted, angular, weakly bedded to massive, hillslope deposits associated with bedrock.

Qls **Landslide deposits (Quaternary)** – Coherent and semi-coherent blocks and masses in landslides along Verde River.

QTt **Early Quaternary/Late Tertiary talus deposits** – Semi-consolidated to moderately consolidated, very angular, very poorly sorted colluvium derived from local bedrock sources at the base of steep slopes along the Little Chino fault zone. Cobble- and boulder-size clasts cemented in a gray-green-brown coarse sand- and gravel-supported matrix. Massive to crude bedding is preserved. Stage IV to V calcrete is poorly preserved; however, calcite-lined fractures are common. Extensive epidote-alteration is exhibited in latite boulders. The exposure of QTt is faulted against a latite autobreccia flow, where large boulders of latite rest on steep slopes formed by QTt.

Verde River Alluvial Units

Qycr **Active river channel deposits (Holocene):** Deposits are dominantly unconsolidated, very poorly sorted sandy to cobbly beds exhibiting bar and swale microtopography but can range from fine silty beds to coarse gravelly bars in meandering reaches based on position within the channel. Clasts are typically well-rounded but may be angular to sub angular. Qycr deposits are typically unvegetated to lightly vegetated and exhibit no soil development. Qycr deposits are entrenched from 30 cm to 10 meters or more below adjacent early historical floodplain deposits depending on location, geomorphic relationship, and local channel conditions. These deposits are the first to become submerged during moderate to extreme flow events and can be subject to deep, high velocity flow and lateral bank erosion. In some areas, channel deposits are very thin to discontinuous exposing underlying bedrock. Extent of channel deposit and exposed bedrock varies and shifts with significant flooding.

Qy4r **Flood channel and low terrace deposits (Holocene):** Deposits are found adjacent to active channels that form lightly vegetated in-channel bars, small planar fluvial terraces within 30 cm of river elevation, and recent erosional meanders outside the presently active channel. Terrace deposits are inset into older river alluvium and usually narrow, rarely more than 100 meters across. Qy4r deposits are composed of poorly sorted unconsolidated sediments ranging from fine silts to gravel bars depending on location in the channel at the time of deposition. Pebbles and cobbles are well-rounded to sub-rounded. These surfaces are commonly inundated under moderate to extreme flow events and can be subject to deep, high velocity flow and lateral bank erosion. These deposits do not exhibit soil development but may exhibit light vegetation cover consisting of small trees and bushes and grasses due to their relatively frequent inundation.

Qy3r **Historical river terrace deposits (Holocene):** Terrace deposits that occupy elevations from 1 to 2 meters above Qycr or Qy4r deposits and are inset below the pre-incision historical floodplain. These surfaces are generally planar but exhibit bar and swale microtopography. Although no soil development is present, dense grasses and small mesquite trees abound. Sediments composing these deposits are poorly sorted silt, sand, pebbles and cobbles. Pebbles and cobbles are well-rounded to sub-angular. Trough cross-bedding, ripple marks, and stacked channel deposits viewable in cross-section indicate deposition in a low to moderate energy braided stream environment. These deposits are prone to flooding during extreme flow events, and undercutting and rapid erosion of Qy3r surfaces is possible during lower flow events.

Qy2r **Latest Holocene to historical river terrace deposits (Latest Holocene):** Deposits associated with the floodplain that existed prior to early historical entrenchment of the Verde River. Qy2r deposits are associated with broadly planar surfaces that locally retain the shape of historical river meanders. Qy2r surfaces are up to 7 meters above modern Qycr deposits and are the most extensive river terraces in the valley. Qy2r deposits are typically fine grained floodplain deposits with occasional pebbly to cobbly interbeds. Dense mesquite bosque and tall grass is typically present on these surfaces except where historic plowing or grazing has taken place. These surfaces appear predominantly fine grained at the surface due in part to the input of organic matter and windblown dust deposition but are composed of interfingering coarse sandy to pebbly braided channel and fine sand to silty river floodplain deposits. Where Qy2r deposits are moderately to deeply incised they not subject to inundation by river floods, but they may be flood-prone in areas with less channel incision. Qy2r deposits are subject to catastrophic bank failure due to undercutting and lateral erosion during flow events. Distal piedmont fan deposits (Qy2 and Qyaf) onlap onto Qy2r deposits although an interfingering relationship likely exits in the subsurface.

Piedmont Alluvial Units

Qyc **Active tributary channel alluvium:** Unconsolidated, very poorly sorted sandy to bouldery ephemeral piedmont-tributary channel deposits associated with larger tributary washes. In many places Qyc is present but unmappable at scale. Qyc in Little Chino Wash is approximately 0 to an estimated 2 meters thick, incised into basin-fill unit Tbf. In the Sullivan Buttes area Qyc overlies bedrock units Tb and Tsb in the shallow subsurface.

Qy4 **Latest Holocene to modern alluvium:** Unconsolidated sand and gravel deposits on low terraces adjacent to the channel along Granite Creek, active during historic times.

Qy3 **Latest Holocene alluvium**: Unconsolidated sand, silt and gravel deposits associated with active drainages. Includes sand, cobbles and boulders in channels, and more extensive sand and silt in low terrace deposits and in unincised valley axes. Fine-grained deposits generally are light brown to gray. Mapped areas lie within and in some areas may be bound the extent of the active floodplain. Vegetation generally includes mesquite, sage brush, salt brush and grasses.

Qy2 **Late Holocene alluvium:** unconsolidated sand, silt and gravel deposits with weak soil development associated with broad valley floors, low terraces and sheetflood areas. Channels in this unit are small and discontinuous and typically flank Qy3 and Qyc units. Topographic relief across Qy2 surfaces is generally very low.

Qyaf **Early to latest (?) Pleistocene rock avalanche deposit**: unconsolidated to weakly consolidated, very angular, moderately sorted, cobble-rich clastic deposit derived from local bedrock units adjacent to steep slopes along the Little Chino fault zone. Qyaf deposits exhibit weak soil development.

Qy1 **Early to late Holocene alluvium**: Unconsolidated to weakly consolidated sand, silt, clay and gravel deposits with weak to moderate soil development. Qy1 deposits are typically found along the margins of tributary valleys, on young alluvial fans, and filling faulting-related depressions along the Little Chino fault zone. Surface deposits are typically fine-grained and gray or brown; gravel deposits are uncommon and are primarily found in upper piedmont areas. Qy1 deposits along Granite Creek range from zero to six meters thick and consist of colluvium from adjacent bedrock and terrace units.

Qi3b **Latest Pleistocene alluvium**: Unconsolidated to weakly consolidated sand, gravel, cobbles and boulders forming low-lying alluvial terrace deposits. Clasts are sub-angular to rounded derived from local and exotic sources. Qi3b deposits are relieved 1 to 2m above adjacent active channels with up to 0.5 meters of relief, often associated with Qy1 and colluvium along its margins. Soil development exhibits lightly reddened soil. Clasts exhibit moderate clay coatings with nearly continuous calcium-carbonate coatings in the subsurface (stage I to early II). A light to moderate pavement is occasionally present. Vegetation consists of abundant grass, some shrubs and scattered juniper trees.

Qi3 **Late Pleistocene alluvium**: Unconsolidated to weakly consolidated sand, gravel, cobbles and boulders forming low-lying alluvial terrace deposits. Clasts are subangular to subrounded, occasionally well rounded, especially along Granite Creek derived from local and distant sources. Clasts are also poorly sorted, commonly smooth-abraded boulders up to 0.5 meter diameter. Surfaces are lightly reddened with stage I(+) to II(-) soil development. Surfaces are of low relief with smooth slopes and shallow-incised stream channels. Thickness of Qi3 deposits from zero to approximately 2m thick. Where streams are incised through Qi3 and into the underlying Tbf, gullies and arroyos with steep channel walls are cut into the underlying less resistant and slightly consolidated basin fill clay, silt and sand.

Qi2f **Middle to late Pleistocene rock-avalanche deposit**: Cobble-rich, very angular localized clasts derived from steep slopes adjacent to the Little Chino fault zone. Angular clasts consist of locally-derived units, typically Xq and Tsb. Qi2f deposits exhibit approximately stage III to IV argillic and calcic horizons, although much of the argillic horizon is eroded. Generally the fan-shaped morphology is well preserved, lacking significantly-incised gullies.

Qi2 **Middle to late Pleistocene alluvium**: unconsolidated to semi-consolidated sand, gravel, cobbles and boulders forming elevated strath terrace deposits. Clasts are poorly sorted, subangular to subrounded to rounded, derived from local and distant source areas. Some boulders measure up to1.5 meters in the long-dimension. In the area between Granite Creek ridges and Chino Valley Wash, Qi2 forms a broad flat plain. Thickness of Qi2 deposits range from 0 to 6 meters. Soil development is exhibited by weak to strong argillic and calcic horizons (stage II to III+) up to 1 meter thick. Where Qi2 deposits form broad planar surfaces of low relief on basin-fill unit Tbf, gullies and arroyos are incised up to 5 meters of relief into Tbf.

Qi1f **Early to middle (?) Pleistocene rock avalanche deposit**: Very angular, cobble-rich clasts derived from steep slopes derived from local bedrock units along the Little Chino fault zone. Clasts are angular, averaging 15 cm in the long direction, up to 30 cm. Clasts exhibit thin sub-millimeter carbonate coatings with light to moderate rock varnish development. Remnants of strong argillic and calcic horizons are present, partially eroded from gullies incised into this unit.

Qi1 **Early to middle Pleistocene alluvium**: Weakly to moderately-consolidated sand, gravel, cobble and boulder deposits forming elevated strath terraces adjacent to and overlying bedrock approximately 20 to 30 meters above the channel floor. Clasts are subangular to subrounded, poorly sorted, derived from mostly local and distant sources. Polished boulders are up to 0.7 to 1m in the long dimension. Thickness of Qi1 deposits range from zero to 9 meters and form well-rounded slopes along its margin. Soils exhibit stage III to IV development with a moderate pavement. Qi1 deposits are in general poorly exposed and less extensive than younger Qi2 deposits. In some cases only a gravel and cobble lag deposit is present. Where Granite Creek is incised into bedrock, planed surfaces on bedrock units (especially Xq) are associated with elevations consistent with nearby Qi1 deposits. These planed surfaces are interpreted to be the location of former Qi1 deposits associated with an ancestral axial-drainage of Granite Creek. The parallel ridges bordering Granite Creek east of Chino Valley are capped by Qi1 deposits which form a colluvial wedge of cobbles and boulders; which, in effect armor the underlying relatively soft basin-fill unit from extensive erosion (see section on Granite Creek ridges for further discussion).

Qof **Early Pleistocene alluvial fan deposits:** Moderately consolidated sand, gravel, cobble and boulder fanglomerate deposits. Clasts angular to subangular to subrounded, very poorly sorted, derived from local bedrock sources in the Sullivan Buttes area west and northwest of Chino Valley. Bedding poor to absent, massive and clast-supported with intercalations of sand and sandy gravel. Soil development exhibits stage III to V+ carbonate accumulation. Qof forms broad planar elevated surfaces with steep, rounded slopes approximately 20 meters above the adjacent valley floor.

Qo **Early Pleistocene alluvium**: Weakly to moderately-consolidated sand, gravel, cobble and boulder deposits forming elevated strath terraces and saddles overlying bedrock approximately 35 to 50 meters above the main channel. Thickness of Qo ranges from zero to 15 meters thick, averaging 2 to 3 meters thick where deposits are more extensive. Qo deposits are more extensively exposed as strath terraces, where fewer exposures are found associated with bedrock saddles in the mountains north of Chino Valley. Clasts exhibit heavy rinds (continuous carbonate coatings up to 3mm) with moderate to well-developed rock varnish and pavement where preserved. Soil development is exhibited by stage IV to V-, rarely VI calcic horizons. The provenance of clasts varies from location to location and crudely reflects the modern Verde River tributary system. Qo deposits found in bedrock-saddles northeast of Chino Valley are interpreted to represent former paleo-tributaries derived from southwest sources feeding into the Granite Creek system (see discussion on middle and lower Granite Creek). Qo deposits are faulted along the Little Chino fault zone, well exposed along the Little Chino Wash/Granite Creek divide on Road 6 North (see discussion on Little Chino fault zone).

Qau **Quaternary alluvium undifferentiated**: Quaternary alluvium of unknown relative or absolute age forming elevated strath terraces and saddles overlying bedrock.. Faulting and lack of adequate exposure contribute to an insufficient age determination. Qau deposits in the far southeast portion of the quadrangle along the western Granite Creek ridge are likely latest Pleistocene lag-gravel deposits derived from adjacent coarse-grained deposits capping Granite Creek ridge.

QTa **Quaternary/Tertiary alluvium**: Moderately consolidated sand, gravel and silt deposits of unknown age formed near steep hillslopes adjacent to bedrock along the Little Chino fault zone. QTa deposits are predominantly composed of silt and sand with discontinuous lenses of poor to moderately sorted gravel derived from local sources. Exposures are often obscured by colluvium and Qy1 surfaces. QTa deposits are faulted against Qo and QTt deposits which may suggest similar or younger age. Some gravel layers are tilted towards the Little Chino fault zone, up to 50 degrees. Imbrication in one gravel bed indicates a northwesterly (N70W) flow, possibly along a strike-valley associated with Little Chino Wash.

Basin Fill Unit

Tbf **Tertiary basin fill deposits**: moderate to well-consolidated fine-grained silt and clay deposits associated with closed-basin deposition. Tbf deposits exhibit a light brown to dark reddish-brown overall color. Tbf is predominantly composed of massive-bedded silt with minor amounts of clay, interpreted to represent distal fan deposits. Many exposures of silt often exhibit moldic porosity indicative of interstitial gypsum subsequently dissolved. These features suggest playa conditions. In addition traces of 90% pure clay layers indicate localized playa conditions. Traces of clam-bored muddy-limestone present in northern Chino Valley may represent pluvial or sustained playa conditions. Tributaries to Little Chino Wash commonly form steep-sided arroyos. Northwest/southeast fractures and small-scale faults (up to 0.5m offset) are exposed in some arroyos. Thickness of this unit is best represented by well logs throughout the Chino Valley area where clay, silt and sand overly bedrock units.

Bedrock Units

Tsy **Younger siliciclastic conglomerate (Tertiary)** - Semi-consolidated sand and gravel deposits derived from the Black Mesa Hills area. Southern extent of deposits likely reworked into Quaternary lag gravel deposits. Clasts are derived from local bedrock source terrains and include abundant Tertiary volcanic rocks and Paleozoic limestones. Thick accumulations of calcrete are often present in the upper few meters where exposed. Where calcrete is eroded a gravel lag is present, consisting of diagnostic red chert and limestone gravel.

Tb **Younger basaltic lava, undifferentiated (Tertiary)** – Basaltic lavas at the top of the sequence. The lavas vary in phenocryst composition from place to place. In the north, some of the lavas contain 5-7% olivine up to 2mm, 10% plagioclase up to 1mm in a plagioclase microlite-rich matrix. One of the flows in the south contains 12-15% <1mm clinopyroxene, 5-7% <1mm orthopyroxene in a plagioclase microlite-rich matrix.

Tcy **Volcaniclastic conglomerate and breccia (Tertiary)** – Conglomerate, breccia, minor sandstone, and pyroclastic rocks. Sequences of conglomerate, sandstone, and epiclastic breccia that may contain minor pyroclastic units. Clasts are typically of mixed volcanic units mixed with 0-50% pre-volcanic clasts typical of the older conglomerate (Tc).

Tpl **Pyroxene-porphyritic latite (Tertiary)** – Pyroxene-porphyritic latite lava, lava breccia, and related pyroclastic rocks. This lava is similar to the biotite latites in that it contains abundant matrix biotite, but it also contains 2-10%, 2-6mm and rarely up to 10mm equant green clinopyroxene phenocrysts, 20% 0.2-0.7mm orthopyroxene(?), and sparse 1mm plagioclase.

Tbc **Tertiary basalt, cinder deposits**: Scoriaceous texture, plagioclase phenocrysts 5 to 7%. My descriptions:

Tsb **Sullivan Buttes latitic rocks (Tertiary)** – Undifferentiated latitic lava, lava breccia and associated pyroclastic rocks in the Sullivan Buttes area (west of US highway 89). Most of these rocks are pyroxene-porphyritic with varying amounts of matrix biotite, hornblende, pyroxene, olivine, and magnetite.

Tlbu **Upper biotite latite (Tertiary)** – Biotite-porphyritic latite lava, lava breccia and related pyroclastic rocks. Biotite latite with abundant matrix biotite and 1-10% phenocrysts up to 4mm. It consist of a central plug or dome in the north and several outliers of lava and pyroclastic rocks farther south.

Tlbm **Middle biotite latite (Tertiary)** – Biotite-porphyritic latite lava, lava breccia and related pyroclastic rocks. Biotite latite with abundant matrix biotite, 5-20% biotite phenocrysts up to 4mm, and 5-20% <1.5mm clinopyroxene>orthopyroxene phenocrysts.

Tlbl **Lower biotite latite (Tertiary)** – Biotite-porphyritic latite, mostly massive and locally flow-foliated. This unit is a single exposure of biotite latite with abundant matrix biotite and several % phenocrysts up to 4mm located in the northeast corner of the map area that appears to be erosionally overlain by the upper part of the conglomerate unit Tc.

Tlb **Biotite latite (Tertiary)** – Biotite-porphyritic latite, mostly massive and locally flow-foliated. The latite contains abundant matrix biotite and plagioclase <<1mm, 5-10% biotite phenocrysts up to 2mm, up to 10% <1mm euhedral clinopyroxene, 1-3% <1mm euhedral orthopyroxene, and 1-3% <2.5mm hornblende rimmed with opaque mineral. This map unit is applied to isolated bodies of the latite that are probably eroded plugs and/or basal portions dome complexes.

Thm **Middle hornblende latite (Tertiary)** - Hornblende-porphyritic latite lava, lava breccia, and related pyroclastic rocks. The latite contains 5-15%, 1-10mm hornblende phenocrysts.

Thu **Upper hornblende latite (Tertiary)** - Hornblende-porphyritic latite lava, lava breccia, and related pyroclastic rocks. The latite contains 5-15%, 1-10mm hornblende phenocrysts.

Thl **Lower hornblende latite (Tertiary)** – Hornblende-porphyritic latite lava, lava breccia, and related pyroclastic rocks. The latite typically contains two populations of hornblende phenocrysts; 10-20% <2mm, and 1-5% 2-15mm. The latite also contains sparse hornblende gabbro xenoliths up to 30cm, minor plagioclase up to 0.5mm, and a trace of sphene.

Tbl **Lower basaltic rocks (Tertiary)** – Mafic lava and scoria. Basaltic lavas and scoria containing up to 10% total phenocrysts of olivine, pyroxene, and plagioclase. These rocks occur as a flow or series of flows and a related cinder cone(s) at the base of the Tertiary volcanic succession southeast of the confluence of Granite Creek and Verde River. The lava is virtually indistinguishable in the field from the younger basaltic lavas (Tb) and therefore can only be confidently assigned to the older unit where stratigraphic context is available. The lava has been analyzed and classified geochemically as a shoshonite (Riggs et al., 1997).

Tcy **Volcaniclastic conglomerate (Tertiary)** – Conglomerate, breccia, pebbly sandstone, sandstone, and minor pyroclastic rocks. These rocks contain abundant immature, volcaniclastic material derived from nearby latitic lavas and tuffs. These rocks are typically very poorly sorted and contain a mixture of different varieties of lava (hornblende-, biotite-, and pyroxene-porphyritic latites, and basaltic lava) along with 0-70% non-volcanic clasts similar to those in the underlying conglomerate (Tc).

Tc **Conglomerate (Tertiary)** – Conglomerate, pebbly sandstone, and sandstone. Massive, commonly poorly preserved outcrops of conglomerate, pebbly sandstone, and lesser arkosic, lithic-rich sandstone are weakly medium- to thick-bedded as defined by pebble trains and diffuse channellized conglomeratic zones within pebbly sandstone. Clasts consist of varying amounts of quartzite, quartz sandstone, limestone, schist, argillite/siltstone, mafic granitoid, and felsic granitoid. Clasts range in size from pebbles to boulders up to several meters, and in shape from rounded to angular. Most clasts are sub-rounded to sub-angular pebbles and cobbles. Schist, limestone, and argillite clasts are commonly strongly nonequant and help define well-developed imbrications. Tertiary volcanic clasts are absent and distinguish this unit from younger, typically strongly volcaniclastic conglomerate and sandstone units interbedded with the overlying Tertiary volcanics. In some areas, non-volcaniclastic conglomerate of this unit occurs above some of the basal Mid-Tertiary volcanic units (Tbl and Tlbl), and if possible, this relationship is depicted as an intraformational contact extending into the main body of the map unit.

Paleozoic Rock Units

Mr **Redwall Limestone (Mississippian)** – Limestone, and minor dolostone. Medium- to thick-bedded, in mostly tabular, amalgamated sets, carbonate of this unit is typically strongly recrystallized skeletal packstone and grainstone with abundant crinoid columnals. Chert in this unit is typically rounded, in large bread-loaf shaped masses.

Dm **Martin Limestone (Devonian)** – Dolostone, minor quartz sandstone, and minor quartzite granule-pebble, carbonate-matrix conglomerate. The unit is dominated by tabular sets of amalgamated, medium- to thick-bedded, variably thin-ribbon cherty, recrystallized, light tan to brown dolostone. These rocks are interbedded with 5-30%, conspicuous, typically ledge and/or cliff-forming, algal laminated, vuggy, thin- to medium-bedded dolostone intervals up to 5m thick. The unit is characteristically devoid of recognizable fossils. A basal interval, up to 10m thick, is commonly quartz sandy, locally with quartzite granules and pebbles. The basal unit is much thicker in some areas to the south where the unit appears to fill paleovalleys, and it is possible that some of these rocks may be older, particularly in a broad valley of Granite Creek along the eastern edge of the map area. It is possible that parts of this unit in this and other areas may correlate with poorly understood, possibly Middle or Upper Cambrian rocks mapped as undifferentiated lower Paleozoic rocks (DC) in the northern part of this map area.

Dº **Undifferentiated lower Paleozoic rocks (Devonian-Cambrian)** – Dolostone, limestone, quartzite-pebble conglomerate, and minor green shale in an unconformity bounded sequence in the northern part of the map area. The main part consists of tabular, medium-bedded, very fine-grained, creamy white micritic dolostone with thin (<5cm) light green shale interbeds. These rocks grade downwards into tan to light brown, variably quartzose dolostone, locally with quartzite pebbles. The base of the unit is a conglomeratic zone 1-8m thick, and the top is defined by a similar quartzose conglomeratic carbonate at the base of the Martin that typically overlies a reddish altered (paleosol?) zone at the top of this unit. No fossils have been recognized, and the unit's age remains unclear. The main part of the unit is recessive, forming slopes in some areas, and overhung cliffs along steep canyon walls of lower Granite Creek and the Verde River. See the text for a description of this unit's nomenclatural history. Thickness ranges from 0 to 20 meters.

ºt **Tapeats Sandstone (Cambrian)** – Medium- to coarse-grained and locally granule and pebbly quartz sandstone, typically cross-stratified in medium-bedded, tabular and wedge-shaped sets.

Proterozoic Rock Units

Xq **Del Rio Quartzite (Paleoproterozoic)** – Quartzite, pebbly quartzite, and pebble-cobble conglomerate. A heterogeneous sequence of complexly interbedded quartzite, pebbly quartzite, and pebble-cobble conglomerate. Quartzite and pebbly quartzite are invariably cross-stratified in medium- to thick-bedded trough, wedge, and tabular sets, mostly with sweeping asymptotic basal cross-strata. Ripple-laminated zones are also present but not common. Rare, thin, and poorly exposed reddish argillite units are present in some areas. Clasts consist almost exclusively of white vein quartz and red jasper or argillite.

Xqc **Del Rio Quartzite, conglomerate unit (Paleoproterozoic)** – Massive to plane-bedded to cross bedded (up to 25 cm thick sets) to channelized coarse sandstone and pebble to cobble conglomerate with clasts dominated by well rounded, 1-10 cm (locally to 25 cm), white vein quartz. Bedding is well defined by variations in grain size and by dark, magnetite(?)-rich sandstone layers. Channels are up to 40 cm deep. White clasts in matrix of reddish brown, magnetite-bearing sandstone are visually striking. Most clasts are subrounded to, less commonly, rounded or subangular. Minor clast component includes fine grained, red siltstone and fine grained sandstone, some perhaps is hornfelsed, and <1% of possible basalt or metabasalt. Three ribs of siliceous conglomerate separated by swaths of buried, less resistant sandstone in S ½ of section 24 suggests development of conglomerate depolobes downstream from channelized upper alluvial fan.

Xqb **Del Rio Quartzite, black-sand unit (Paleoproterozoic)** – Magnetite-rich quartzite, with black sands in layers 1-10 mm thick forming an amalgamated black sand unit ~10 m thick. Black sand unit is locally conglomeratic.

Xqs **Del Rio Quartzite, silty quartzite unit (Paleoproterozoic) –** Reddish (hematite-stained), silty, somewhat micaceous sandstone.

Xqu **Del Rio Quartzite, undivided unit (Paleoproterozoic)** – Quartzite, pebbly quartzite, and pebble-cobble conglomerate. A heterogeneous sequence of complexly interbedded quartzite, pebbly quartzite, and pebble-cobble conglomerate. Quartzite and pebbly quartzite are invariably cross-stratified in medium- to thick-bedded trough, wedge, and tabular sets, mostly with sweeping asymptotic basal cross-strata. Ripple-laminated zones are also present but not common. Rare, thin, and poorly exposed reddish argillite units are present in some areas. Clasts consist almost exclusively of white vein quartz and red jasper or argillite.

Xm **Mafic metavolcanic rocks (Paleoproterozoic)** – Lava, pillow lava, hyaloclastite breccia, and minor volcaniclastic rocks. Plagioclase phenocrysts are recognizable in some of these rocks, but the mafic phenocrysts are either altered or metamorphosed beyond recognition.

Xs **Metasedimentary rocks (Paleoproterozoic) –** Quartzite-biotite-sericite schist and psammitic schist. Compositional layering in these rocks is strongly reminiscent of relict bedding. The layering typically ranges between a few cm to a meter. In one area, to the northwest, the layering is very well preserved in the form of graded beds (in the form of mica-rich zones with wispy laminae suggestive of ripple-lamination at the top of thicker psammitic intervals) strongly reminiscent of turbidite Bouma (1962) ac and/or abc divisions. The schist is invariably intruded by quartz veinlets locally as much as 10% of the rock. Schistosity invariably produces a strong intersection lineation which is in some places parallel to a crenulation lineation along compositionally layered “bedding” surfaces.

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