Mapping of Holocene River Alluvium along Oak Creek, Wet Beaver Creek, West Clear Creek, Fossil Creek, and the East Verde River, Central Arizona

by

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Introduction

The purpose of these investigations is to document and map the extent of Holocene channel and floodplain alluvium associated with five large tributaries to the Verde River in central Arizona. These tributaries are Oak Creek, Wet Beaver Creek, West Clear Creek, Fossil Creek, and the East Verde River. Mapping completed in this study may be used by Arizona Department of Water Resources (ADWR) staff as part of their effort to delineate subflow zones in the Verde River Watershed. Geologic mapping is a primary function of the Arizona Geological Survey (AZGS), so in cooperation with ADWR staff we have established procedures and protocols for documenting and mapping the extent of Holocene floodplain alluvium along rivers in Arizona.

This report and associated maps complete the second part of an effort to map Holocene channel and floodplain alluvium mapping along the Verde River corridor. In the first phase of this effort, we mapped Holocene river deposits along the Verde River (Cook et al., 2010). Together, this mapping effort includes over 370 miles of new and updated surficial geologic mapping along the Verde River, Oak Creek, Wet Beaver Creek, West Clear Creek, Fossil Creek, and the East Verde River.

Surficial geologic mapping methods

The AZGS has been actively involved in mapping surficial deposits in Arizona for the past 22 years. During this time, the AZGS has produced many 1:24,000-scale 7 ½' quadrangle maps with detailed surficial geologic mapping in southern, central and western Arizona. All of these maps differentiate alluvial deposits based on relative age, and most maps separate deposits associated with larger axial drainages (rivers or washes) from local tributary deposits. AZGS geologists have mapped surficial geology along the Verde River previously (Cook et al., 2010; House and Pearthree, 1993; House, 1994; and Pearthree, 1993) and updated geologic maps for the Page Springs and Cornville 7 ½' quadrangles are near publication (House et al., in press). Portions of these maps are visible along the lower sections of mapped tributaries near their confluence with the Verde River (Figure 1). Although these mapping efforts were not directed specifically at delineating Holocene floodplain alluvium, they provide information about the distribution of deposits of various ages and from various sources and thus were helpful in delineating the extent of Holocene river deposits.

Mapping criteria. Quaternary geologists use several criteria to differentiate and map river and tributary alluvial deposits of different ages. Deposits along Oak Creek, Wet Beaver Creek, West Clear Creek, Fossil Creek, and the East Verde River (river deposits as used in this report) commonly consist of two fairly distinct phases: channel deposits dominated by sand and gravel and including boulders in narrow canyon reaches, and overbank floodplain deposits that are composed of sand, silt and clay with minor gravel. River channel deposits are distinguished from tributary channel deposits based on the presence of well-rounded pebbles and cobbles composed of diverse rock types derived from upstream areas along the river. Tributary deposits typically have less diversity of rock types, and pebbles, cobbles and boulders tend to be more angular. As one moves upstream along the tributaries mapped for this report, this distinction becomes less apparent, because tributaries cut through the same bedrock layers as the main channel and have channel deposits that have similar characteristics as the mainstem channel deposits. Overbank or floodplain deposits associated with the river typically are thicker and more laterally extensive than fine-grained tributary deposits, although floodplain deposits of large tributaries may be quite similar to river deposits. Landforms associated with deposits also provide clues to their origin. This is especially important for mapping purposes because landforms can be analyzed using topographic information and aerial photos. Slopes of landforms associated with river deposits (the river

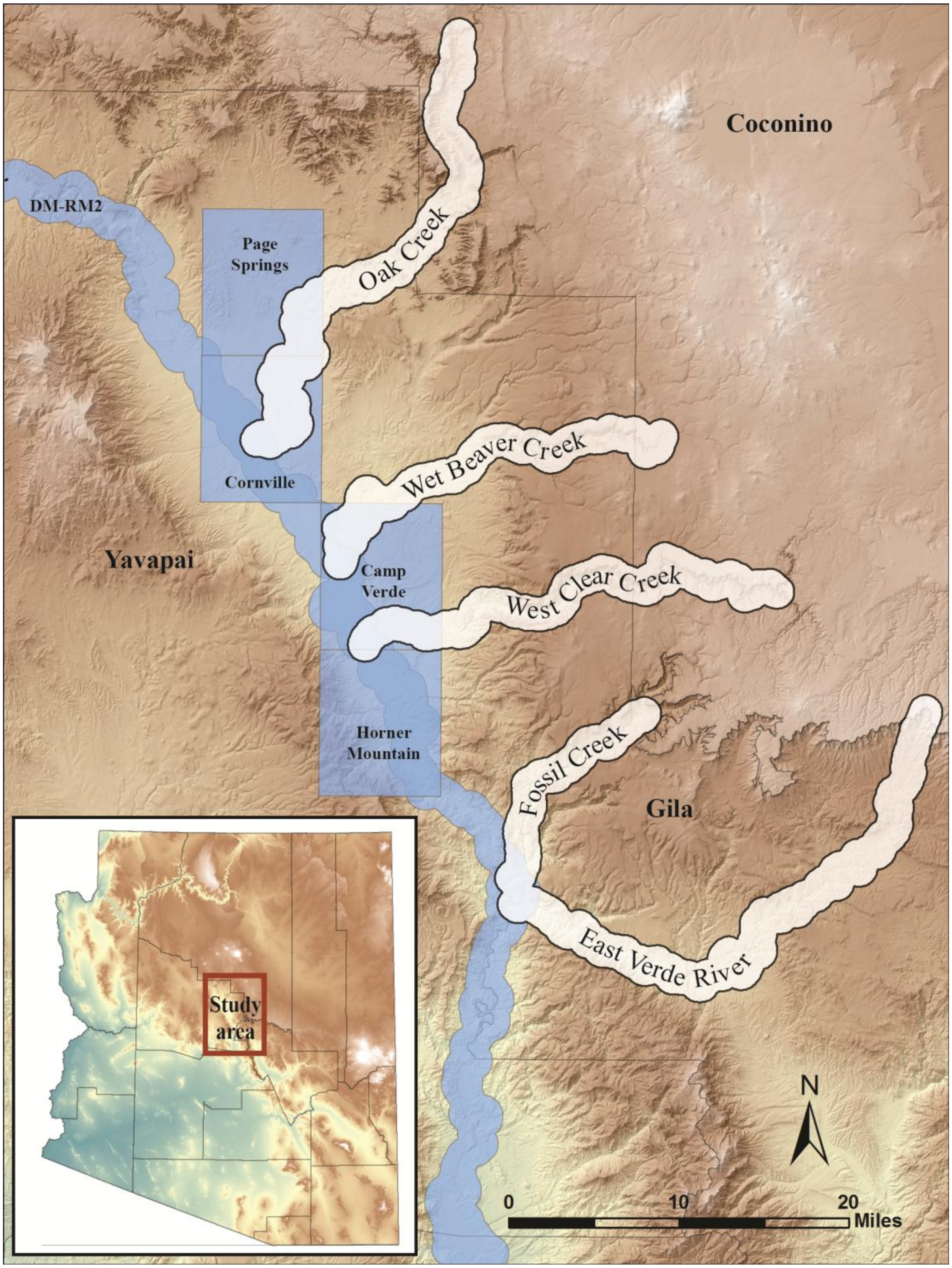


Figure 1. Location map showing the extent of mapping of Holocene floodplain alluvium discussed in this report. Mapped area is shown by white overlay. Blue strips and boxes represent areas previously or presently mapped by AZGS geologists. New surficial mapping along the full length of each tributary was completed for this report. The final strip maps include bedrock geologic mapping compiled from various pre-existing AZGS and USGS geologic maps.

channel, flood plain and terraces) are typically quite low and generally mimic the down-valley slope of the modern river, whereas the gradients of landforms associated with tributary deposits are typically are steeper and slope toward the valley axis. Along the river, slopes formed on bedrock and older basin deposits, and reworked sediment derived from them, are steeper yet and slope toward the river. Deposits and alluvial surfaces associated with them may also be differentiated by age using a variety of criteria (e.g., Gile et al, 1981; McFadden, 1981). In the semiarid southwestern U.S., surface color varies with age because of soil color, vegetation, and rock varnish.

Alluvial surfaces on piedmonts and river deposits of Holocene age typically are light gray to light brown in color (10 YR to 7.5 YR on a soil color chart), reflecting the color of the silt, sand, pebbles and cobbles that make up most of the deposits. Pleistocene surfaces typically have slightly or distinctly reddened color (7.5 YR to 2.5 YR) associated with clay accumulation and oxidation in the near-surface soil, and may be mantled by reddish- or black-coated pebbles and cobbles. Relatively young alluvial surfaces typically retain abundant evidence of the depositional processes that initially shaped them (channels, sand and gravel bars, and swales) whereas older surfaces have been smoothed by local erosion of bars and infilling of swales. Dendritic tributary (joining downstream) drainage patterns are characteristic of older surfaces that are not subject to extensive flooding, and typically older deposits are increasingly more deeply incised and eroded by tributary drainages. Because of this, very old surfaces may be substantially degraded by erosion. The net result of all of these varying surface characteristics is that surfaces of different ages have quite different aspects on the ground and on aerial photographs.

Development of the Verde River and major tributaries, and ages of river deposits. The through-flowing Verde River developed several million years ago. In Verde Valley, lacustrine and related fan deposits of the Verde Formation that pre-date the development of the river accumulated until about 2.5 Ma [million years ago] (Bressler and Butler, 1978). The very highest alluvial fan remnants preserved around the margins of Verde Valley (map units QTo and QTor) record the maximum level of sediment accumulation in Verde Valley probably date to about this time as well (House and Pearthree, 1993). When the through-flowing Verde River developed, it began to downcut through Verde Formation sediments. To meet lowering base level of the Verde River, Oak Creek, Wet Beaver Creek, West Clear Creek, Fossil Creek, and the East Verde River have also undergone downcutting. The headwaters of each of these drainages originate on the Mogollon Rim; incision has created steep-walled, narrow, bedrock lined canyons that become less confined nearer the confluence with the Verde River. Isolated high river terrace deposits found throughout Verde Valley record former river levels through the Pleistocene. The highest preserved early Pleistocene river terrace deposits along most of the Verde River and major tributaries are about 350-400 feet above the modern river channel, but are inset well below the highest remnants of the Verde Formation. The only exception to this is Table Mesa along Oak Creek southwest of Sedona (location of the Sedona airport), which is capped with coarse, rounded gravel (map unit QTor) that we interpret to have been deposited by Oak Creek when it was feeding into the highest levels of Verde Formation deposition.

The Verde River has also downcut dramatically upstream and downstream of Verde Valley during the past several million years, resulting in the development of deep bedrock canyons and deeply dissected alluvial basins. Although there are no dated deposits that bear directly on the age of initial river development in these areas, river terrace deposits along the lower Verde River that range up to about 400 feet above the modern river channel (Péwé, 1978, Menges, 1983, Pearthree, 1993; this study) likely record a generally similar downcutting history as the river terraces in Verde Valley.

Soil development provides a somewhat quantitative basis for estimating deposit and alluvial surface ages. Significant soil development begins beneath an alluvial surface after it becomes isolated from active flooding and depositional processes (Gile et al., 1981; Birkeland, 1999). Over thousands to tens of thousands of years, distinct horizons rich in reddened clay (argillic) or calcium carbonate (calcic) develop in soils. Comparison of soil horizon development in surficial deposits along the Verde River with other soil sequences in the western United States is the primary method used to estimate the ages of the different alluvial surfaces (Gile et al, 1981; McFadden, 1981; Machette, 1985; Bull, 1991). There is uncertainty in age estimates derived from soil characteristics, particularly for river deposits that date approximately to the early Holocene to latest Pleistocene (approximately 5 to 20 ka [thousands of years ago]).

Where they exist and have been investigated, archaeological sites, paleontological remains, and other dated organic material can provide direct numerical age estimates for Holocene and latest Pleistocene deposits. We reviewed the records of these investigations and visited several of the sites in the field. The implications of archaeological features and sites for the ages of young river deposits are discussed later in this report.

The AZGS currently employs a naming standard scheme for surficial geologic units utilizing a “Qy” and “Qi” designation for Holocene (young) and Pleistocene (intermediate) age deposits, respectively. Older Pleistocene deposits are labeled “Qo”, while units spanning early Quaternary to latest Tertiary time are labeled “QT”. Further temporal subdivisions are expressed using number (i.e., Qy1, Qy2). Younger units have higher numbers relative to other units within the general designation. For example, Qi3 (late Pleistocene) sediments were deposited after Qi2 and Qi1 deposits and before all Qy deposits (Table 1). Older maps geologic maps produced by the AZGS used somewhat different nomenclature for surficial deposits; this nomenclature has been replaced in the maps that accompany this report.

	Epoch	Age	AZGS unit name: river alluvium	AZGS unit name: piedmont alluvium		Relative Age
Quaternary	Holocene	present day	Qycr	Qyc		younger
			Qy4r Qy3r	Qy3	Qyaf	
		2 Ka	Qy2r	Qy2	Qys	
			Qy1r	Qy1		
		10 Ka				
	Pleistocene		Qi3r	Qi3	Qis	
		130 Ka	Qi2r	Qi2		
		760 Ka	Qi1r	Qi1		
			Qo3r Qo2r	Qo2		
			Qo1r	Qo1		
		2.6 Ma	QTa, QTo			
Tertiary	Pliocene	5.3 Ma	Tvl, Tvm, Tvv, Tvf Tsy, Tsu			
	Miocene					older

Table 1. Generalized geologic time scale displaying relative ages and naming conventions for Quaternary to late Tertiary age surficial and lithostratigraphic units. Ages of Holocene/Pleistocene, Pleistocene/Pliocene, and Pliocene/Miocene boundaries are from Walker and Geissman (2009); other age boundaries are informal. All river-deposited units receive an “r” designation while similarly-aged piedmont deposits do not. Descriptions for all map units shown on map sheets A through J are located in the last section of this report.

Mapping the extent of Holocene floodplain alluvium

Our strategy for mapping Holocene floodplain alluvium involved the following steps:

1) compilation of existing geologic mapping in an ArcGIS framework
2) re-evaluation and revision of existing mapping using aerial photos and topographic data
3) new mapping of Holocene river alluvium where no large-scale geologic mapping had been done previously
4) field-checking of the boundaries of Holocene alluvium in various geologic environments along the river, including systematic collection of GPS field points with observations and ground photos (field notes and digital photos available on accompanying CD)
5) depiction of all Holocene river alluvium units on 1:24,000-scale strip maps associated with this report

We compiled all of the existing geologic mapping conducted by the AZGS as well as relevant geologic mapping from outside sources covering the Verde River. During the past 7 months, we have checked and revised existing AZGS geologic maps that cover the five major tributaries to the Verde River and have integrated this Holocene mapping with updated geologic mapping in the Page Springs and Cornville 7 ½' quadrangles, which include the lowermost sections of Oak Creek. We revised existing geologic mapping based on aerial photo interpretation, topography from 7 ½' quadrangles, 10-meter DEM (USGS, 2008) interpretation along the river, and extensive field investigations, so they accurately portray the extent of Holocene river alluvium. We also completed new mapping along each tributary floodplain where no previous mapping existed.

Boundaries of Holocene river alluvium were verified through extensive fieldwork and map analyses. We collected GPS points, made field observations, and took ground photos at the lateral margins of Holocene river alluvium at approximately 1-mile spacing along the river. We used standard geologic nomenclature (solid, dashed and dotted lines) to depict the positional uncertainty of the lateral limits of Holocene river alluvium. From the geologic quadrangle maps, we extracted an approximately 2-mile-wide strip geologic map centered on each tributary to depict the extent of Holocene river alluvium (Figure 2). Some geologic mapping outside of the Holocene river alluvium corridor was compiled from older USGS and thesis maps where AZGS mapping does not exist. In all cases, the relationships and extent of Holocene river alluvium and bounding units throughout the mapped area were mapped and field checked as part of this project. Holocene river alluvium is depicted as active channel(s) (unit Qycr), flood channels, low terraces, and remnants of Holocene floodplains (Qy_4r – Qy_1r). Holocene river alluvium is bounded by Holocene tributary alluvial fans and channels, Pleistocene alluvial fans and river terraces, eroded basin deposits, and bedrock (Figure 3). The 2-mile-wide strip was chosen to illustrate the nature of the bounding limits of Holocene river alluvium, because the certainty of the limit of Holocene river alluvium is strongly dependent on the nature of the bounding geologic units.

Field data collection and access. We collected field data on the lateral limits of Holocene river alluvium every mile where access was permitted, and made observations at other sites as needed. Data collected include GPS waypoints, ground photos, and field notes. River access generally is good, but private property limited field data collection in a few areas. Significant portions of Wet Beaver Creek, West Clear Creek, Fossil Creek, and the East Verde River are located within designated wilderness boundaries. Access to these remote areas is extremely limited so mapping was conducted on foot over the course of numerous 2-5 day long backpacking trips. Throughout steep-walled canyon reaches such as the uppermost and middle sections of each tributary, GPS reception may be weak to nonexistent due to obstruction of satellite signal or reflected signals from canyon walls, and in the best cases positional uncertainty is relatively large. In these reaches GPS control points were recorded where signal was available as near as possible to the Holocene river alluvium boundary. Detailed notes and photos were recoded for these locations and map linework was compiled using a combination of field collected data and high resolution aerial photography (Figure 4, for example).

Geologic contacts. We use 3 different line types to delineate the margins of Holocene river alluvium depending on the clarity of the contact.

1) Solid line – The contact between Holocene alluvium and the bounding geologic unit is clear and associated with a distinct topographic feature. We find these clearly defined, accurately located contacts associated with bedrock hillslopes, fairly steep scarps or terrace risers cut into older deposits, distinct margins of small active alluvial fans or talus slopes, and boundaries of small entrenched tributary channels (Figures 4, 5, and 6). We estimate that solid line location is accurate to within 50 feet (±25 ft).
2) Dashed line – The contact between Holocene river alluvium and the bounding geologic unit is subtle or gradational and more difficult to confidently identify on the ground. These subtle contacts are commonly found at the boundaries between Holocene river alluvium and Holocene fine-grained tributary fans (Figures 6, 7 and 10). Slopes in the distal portions of these larger fans are relatively low and little different from floodplain slopes, and deposits from both sources are typically quite fine-grained. In some areas, vegetation changes at the contact between floodplain and distal fan deposits, but in other areas obvious vegetation changes do not appear to correspond with these contacts and may be reflecting other variables such as depth to water. Dashed line boundaries are also commonly located within historically plowed fields. We estimate that dashed line location is accurate to within 100 feet (±50 ft).
3) Dotted line – The contact between Holocene river alluvium and the bounding geologic unit (typically, tributary fans or slightly higher river terraces) has been thoroughly obscured by anthropogenic activity and must be inferred using other information. In these areas, we place the lateral boundary of Holocene floodplain alluvium based on topography if it has not been altered and interpretation of older aerial photos that pre-date disturbance (Army Map Service (AMS) 1953, Forest Service (FS)/United States Department of Agriculture (USDA) 1977-1979, and Soil Conservation Service/USDA 1940's era photos). There is greater uncertainty in the location of these contacts, and occupation of these sites in the field does not substantially improve positional uncertainty (figure 9). Dotted line boundary location is probably accurate to within 500 feet (±250 ft) depending on level of disturbance.

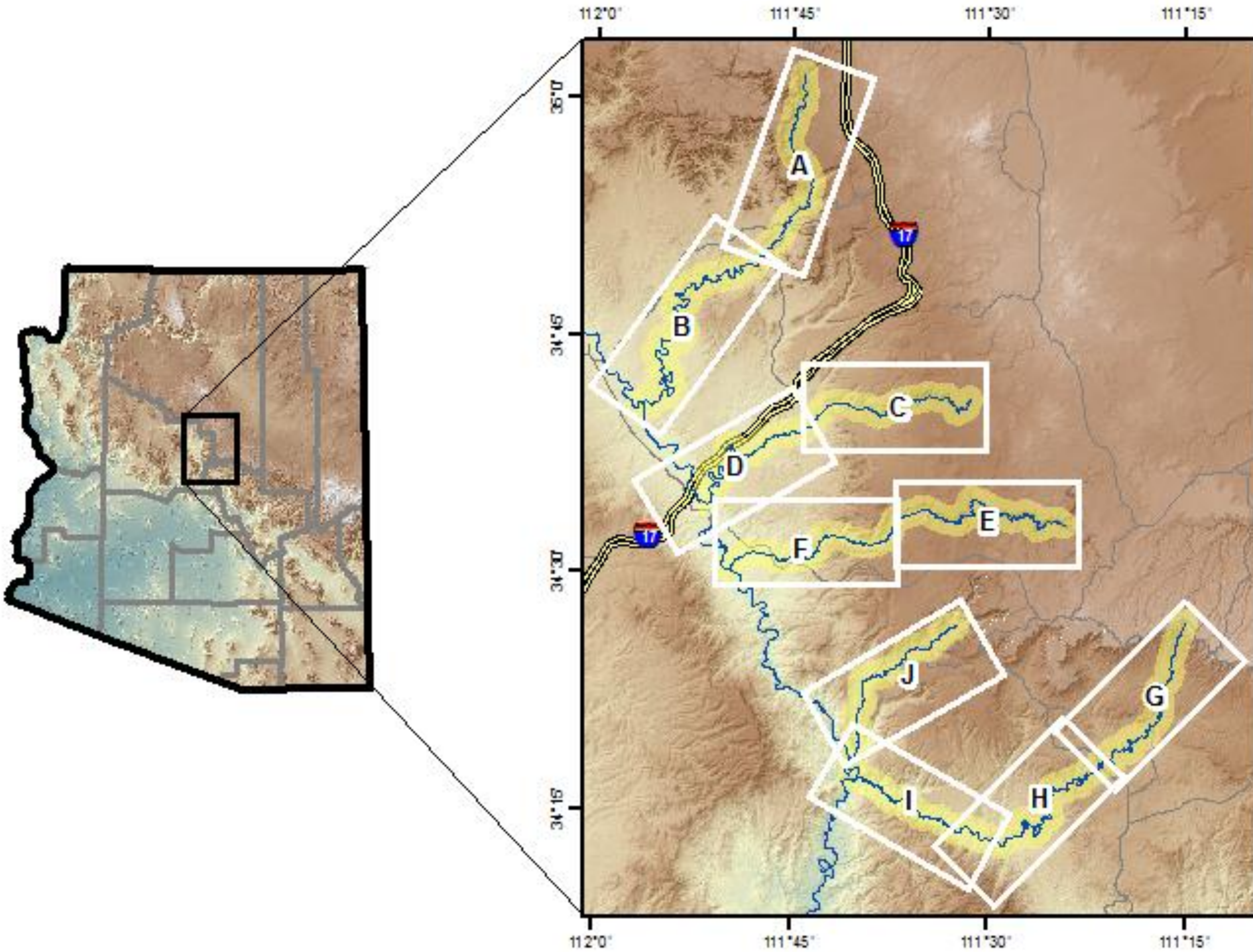
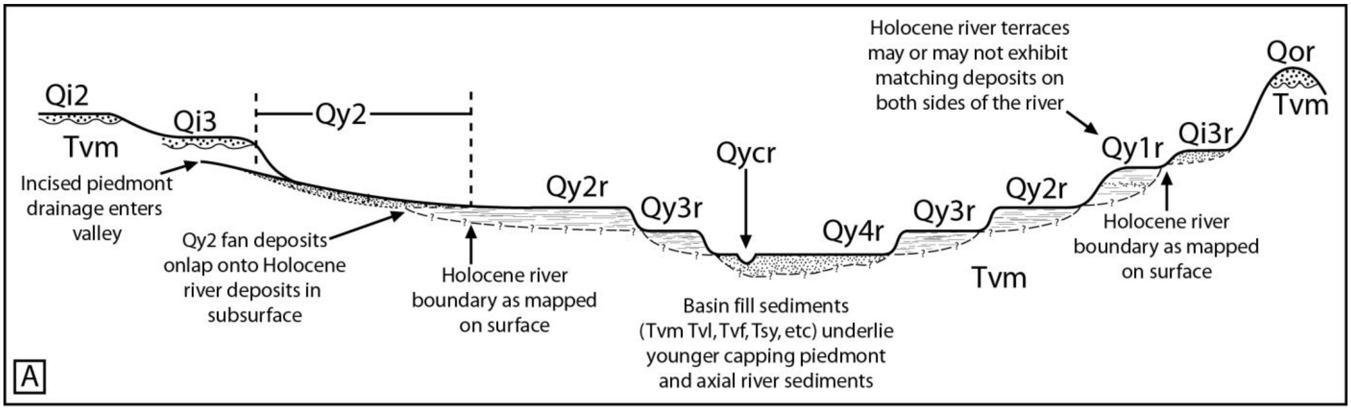


Figure 2. Schematic diagram depicting distribution of map sheets A through J (white boxes). Individual map sheets often span multiple 7 ½’ USGS quadrangle maps. Overlap of sheet figures is intentional to ensure complete coverage of mapped areas.



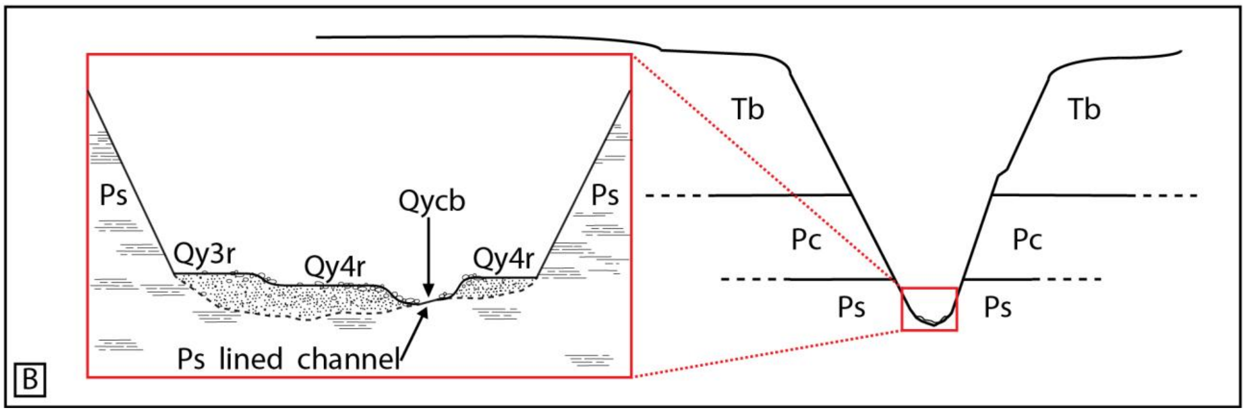


Figure 3. A) Generalized cross section of geomorphic relationships between Tertiary basin fill sediments, Pleistocene piedmont and river (Qi_n, Qi_nr, Qo_nr units), and Holocene piedmont and river (Qy_n, Qy_nr units) deposits. Boundaries between units are based on surface mapping. B) Generalized cross section of geomorphic relationships between Holocene river deposits in narrow bedrock canyon sections. Deposits are bound by steep bedrock walls, terraces are generally thin, channel sediments are coarse, and bedrock is exposed locally in the channel bottom. Subsurface relations are not well-constrained and likely vary along the river.

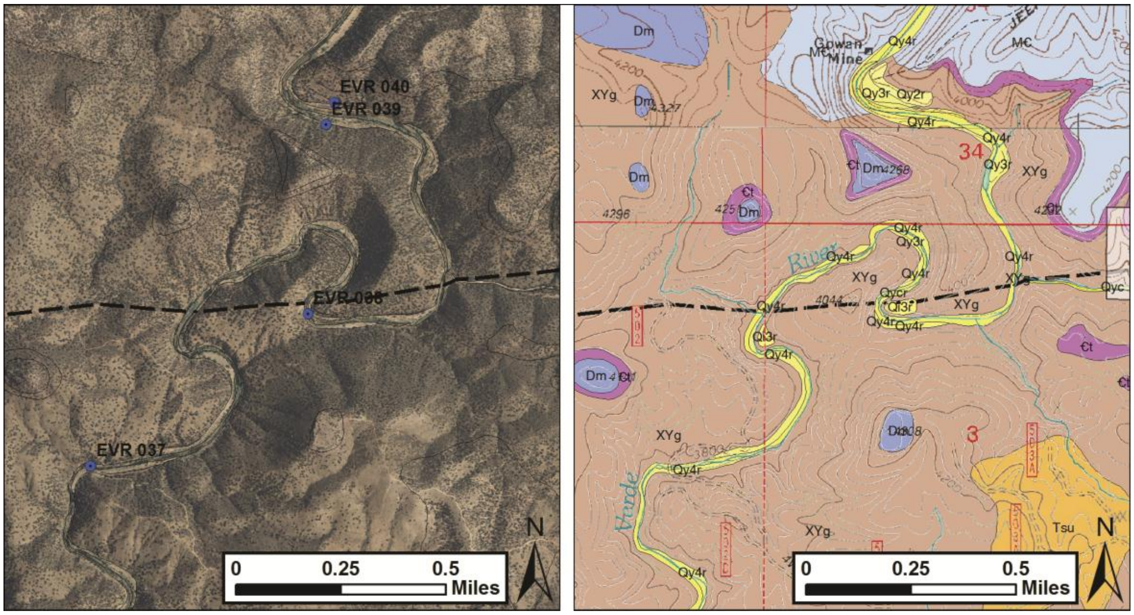


Figure 4. Map of bedrock-bound Holocene floodplain alluvium in the central portion of East Verde River. Abrupt bedrock walls mark the extent of Holocene alluvium. Elevated Qi3r terraces are Pleistocene in age and separated from the modern floodplain. Holocene terraces are better preserved on inside meander bends. Heavy dashed line is a fault mapped by Wrucke and Conway (1987).

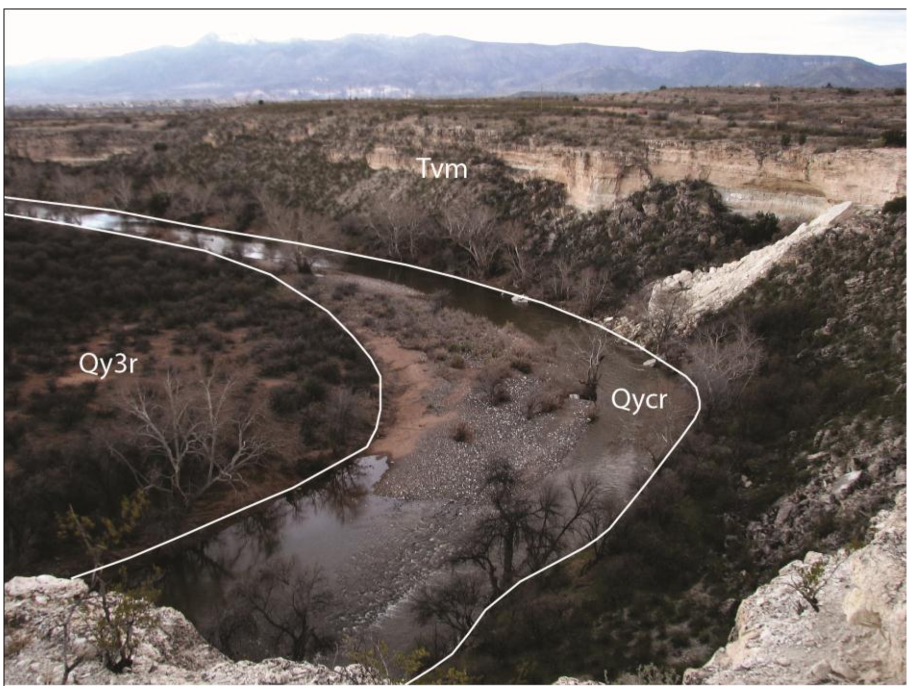


Figure 5. Ground photo of lower Wet Beaver Creek incised into late Miocene to Pliocene Verde Formation. Abrupt boundaries are mapped with solid lines. The limit of Holocene floodplain alluvium on the right is located at the base of the lacustrine beds of the Verde Formation. An abrupt change in vegetation and terrace elevation marks the boundary between active channel (Qycr) and latest Holocene (Qy3r) deposits to the left.

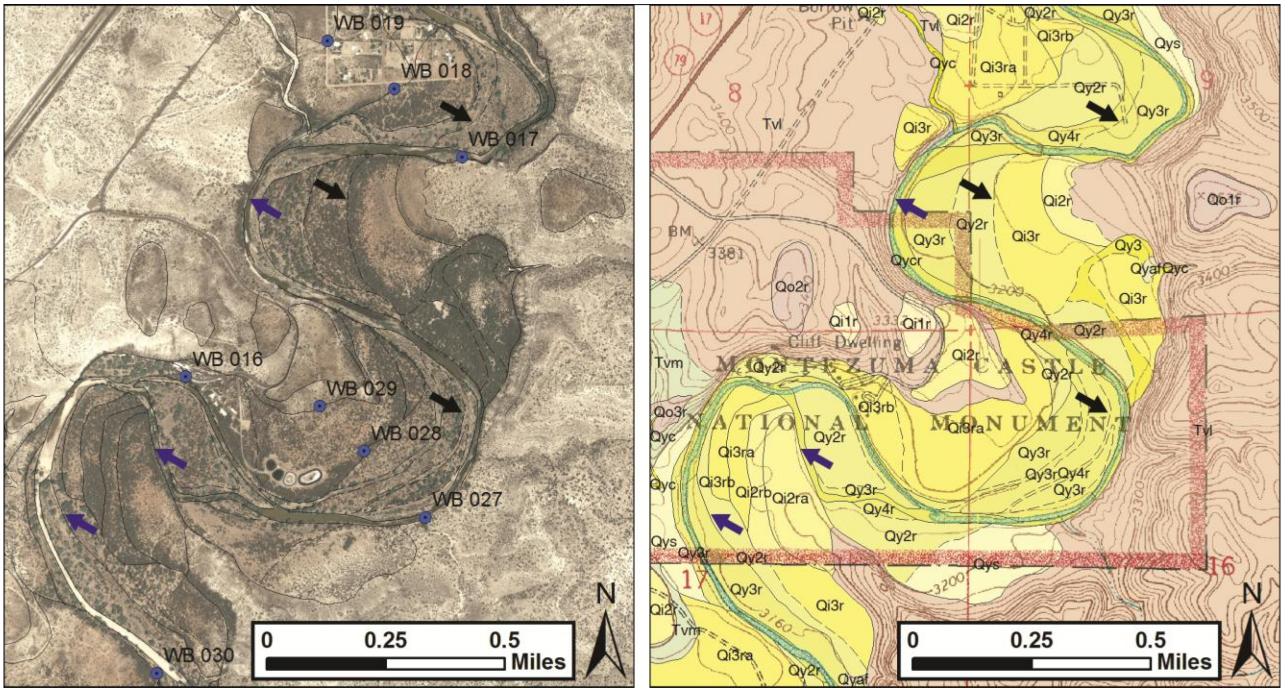


Figure 6. Blue arrows point to solid line boundaries marked by cliff faces and distinct terrace elevation changes in lower Wet Beaver Creek. These contacts are abrupt and apparent in the field and in aerial imagery. Black arrows point to dashed line boundaries marked by low relief, diffuse terrace transitions or contacts obscured by vegetation or recent flood activity. These transitions are gradual and more ambiguous in the field and in aerial imagery.

Figure 7. Ground photo of the transition between late (Qy2r) and older (Qy1r) Holocene floodplain alluvium. A subtle change in slope marks the contact. An isolated, relatively wide valley along the central East Verde River allows for greater preservation of Holocene river terraces in an otherwise narrow, bedrock-lined canyon.

Figure 8. In narrow bedrock lined canyon reaches, the channel bottom is often devoid of sand and gravel underlying bedrock is exposed. A) Central West Clear Creek, B) upper Wet Beaver Creek, C) central East Verde River, and D) upper Fossil Creek. Large cobbles to boulders resting directly on underlying bedrock are the dominant bedload in these reaches.

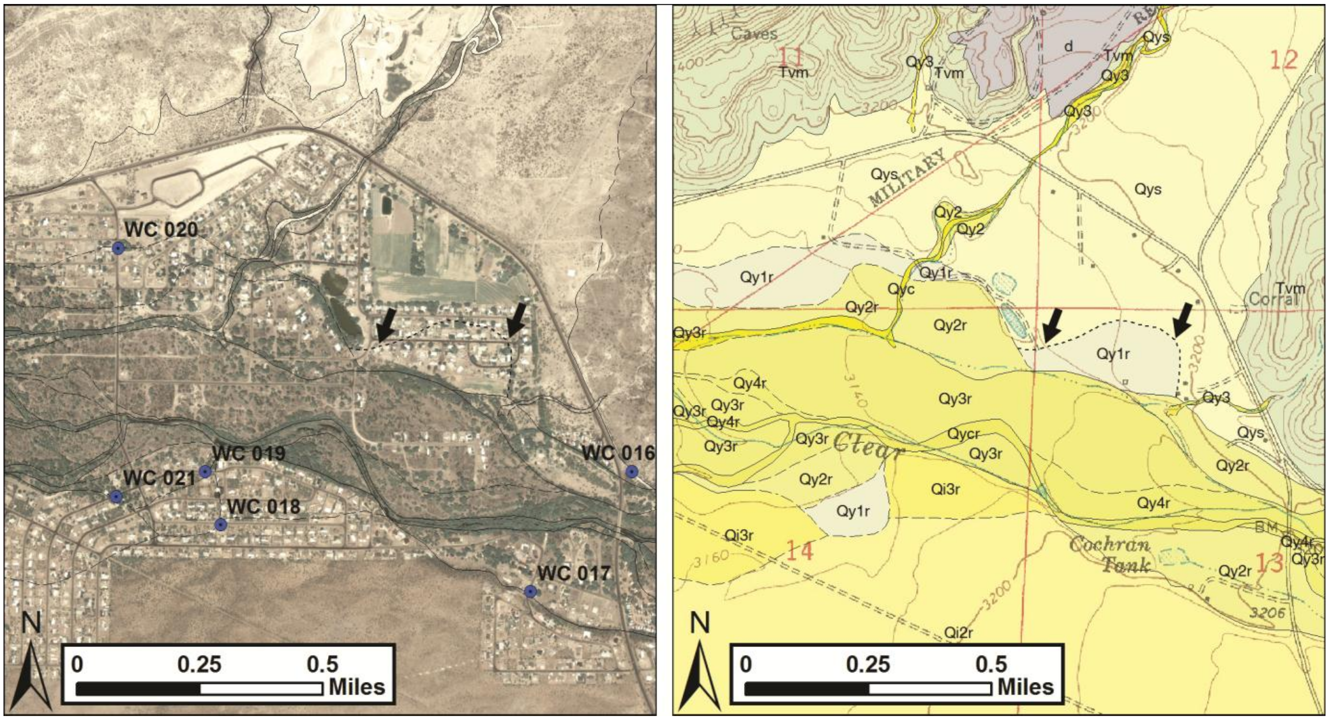


Figure 9. In populated areas such as along lower West Clear Creek, topographic relief between Holocene tributary fans and river terraces is low and often heavily disturbed or obscured by agriculture or residential development. Dotted line contacts (highlighted by arrows) are used where geomorphic contacts are obscured by anthropogenic activity.

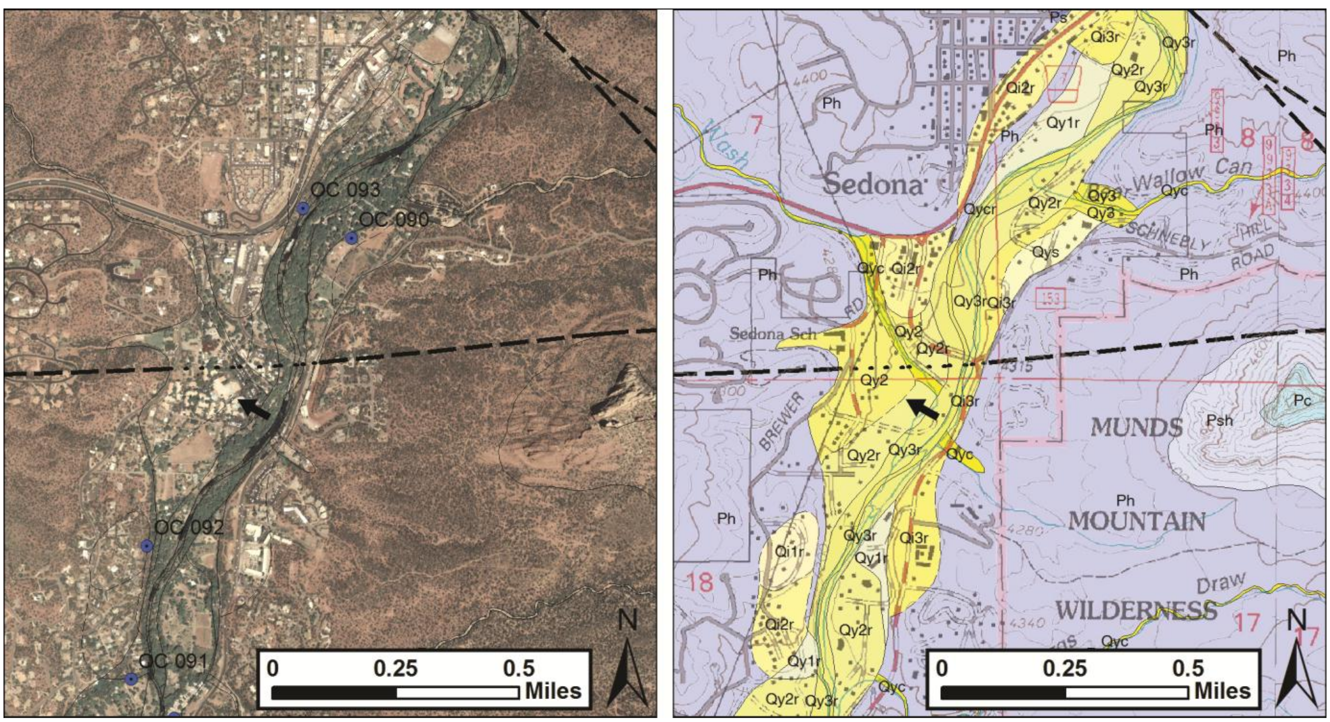


Figure 10. A combination of tributary fan onlap and residential development obscures the boundary between tributary deposits and Holocene river alluvium in upper Oak Creek in Sedona. This contact, marked by the black arrow, was mapped using a dashed line.

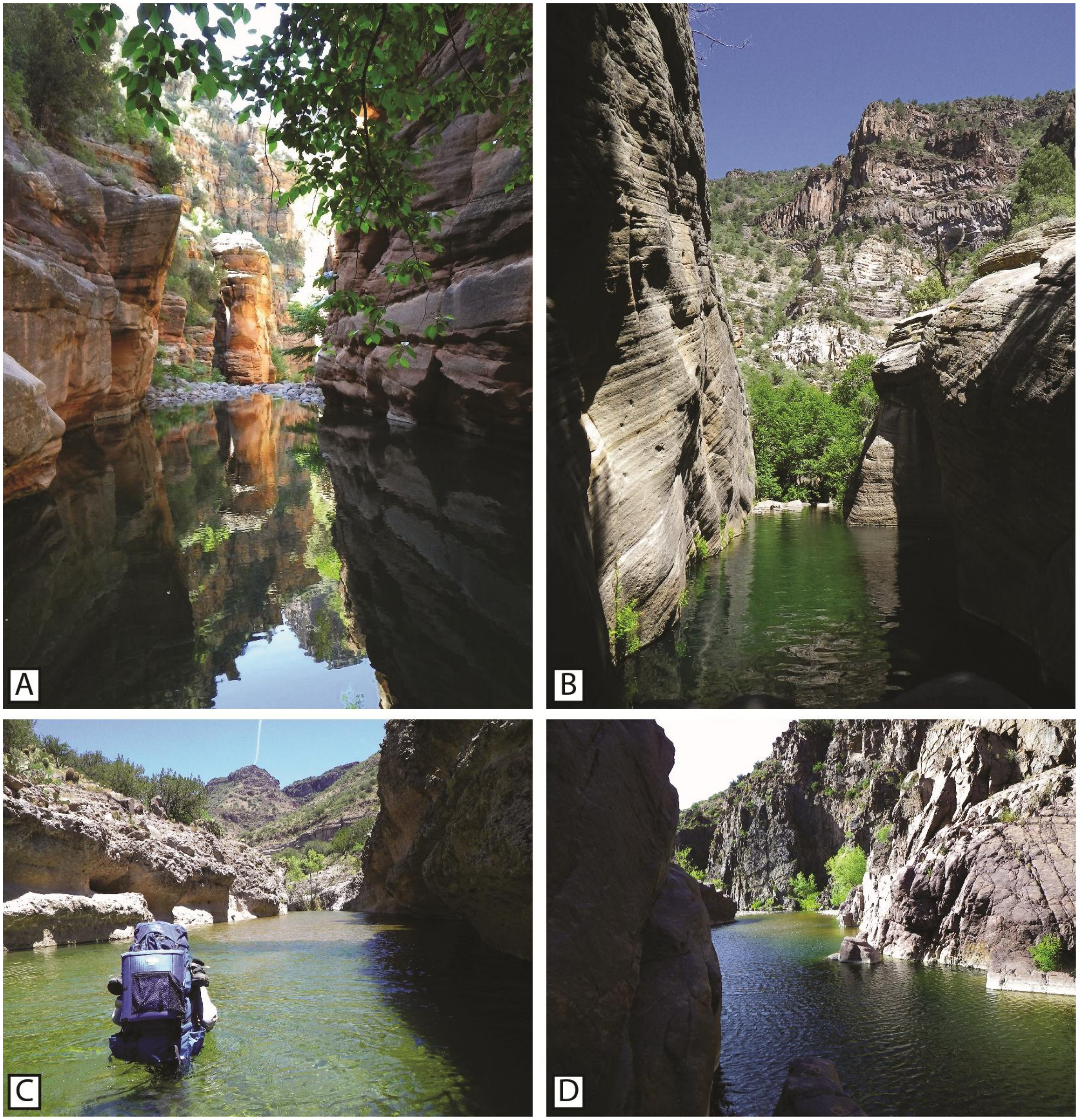


Figure 11. Deep wall to wall pools are encountered in narrow bedrock-lined canyon sections. Some pool bottoms are lined with sand and gravel while others with large boulders. Many are too deep to touch bottom and require swimming to proceed. A) Deep pool in central West Clear Creek, B) deep pool in upper Wet Beaver Creek, C) waist deep pool in lower Fossil Creek, D) deep pool in central East Verde River.

Extent of Holocene river floodplain alluvium. We depict all of the various Holocene river deposits except the active channel with the same map color (dark green) to show the extent of Holocene river alluvium on the strip maps (Map Sheets A – J). Active channels of each tributary drainage (unit Qy_cr) are delineated based on 2007 orthophotos (NAIP, 2007). Various surficial and bedrock geologic units that bound Holocene river floodplain alluvium are depicted in the strip maps.

The lateral extent of Holocene floodplain alluvium varies dramatically along each tributary mapped for this report (see Map Sheets). In reaches where the channels have cut through bedrock, such as the steep upper and middle sections of each tributary, the lateral boundaries of Holocene floodplain alluvium are sharply defined and the total width of floodplain alluvium is a few hundred feet or less. Where the channels are incised into the basin-fill deposits of the Verde Formation or other basin deposits, such as the lower reaches of Oak Creek, Wet Beaver Creek, and West Clear Creek, the width of the Holocene floodplain varies from 1,000 to over 3,000 feet (Figure 12). Although wider near their confluence with the Verde River than within the canyon lined sections upstream, the active channels in the lower reaches of Fossil Creek and the East Verde River remain lined by cohesive bedrock. The extent of preserved Holocene alluvium in these reaches is narrow relative to that found in the three northern tributaries. The width of the Holocene river floodplain typically is less where reasonably large tributaries join the main channel, as the alluvial fans deposited by tributaries restrict the lateral extent of deposition by the river. In areas where large, low-gradient tributaries join the mainstem drainages, there is substantial uncertainty in the location of the contact between Holocene river alluvium and tributary alluvium (e.g., Figure 10).

Although many deposits flanking Holocene river alluvium are also Holocene in age, only the youngest piedmont units typically convey surface flow to the river channel. Qyc deposits (modern stream channel deposits) occupy the lowest elevations within the piedmont and incised tributary canyons, receive runoff from adjacent surfaces during storms, and convey flow down gradient to the valley axis when infiltration capacity is exceeded. However, Qyc deposits are only extensive enough to depict at 1:24,000-scale along relatively large tributaries. Qy3 deposits (latest Holocene alluvium) include smaller tributary channels and slightly elevated terraces along tributary channels. These surfaces are the first to become inundated during higher flow events when channel capacity is exceeded, thereby contributing to the transport of runoff precipitation to the valley axis. Qyaf deposits (late Holocene alluvium, active fan deposits) represent the active distributary portion of late Holocene fans. These deposits are typically found where an otherwise confined Qyc or Qy3 channel becomes unconfined and surface flow spreads out, dropping transported sediment. Surface flow in piedmont channels often infiltrates into the subsurface of Qyaf deposits due to the transition to unconfined flow and the coarse, porous nature of these deposits. Older Holocene units (Qy2, Qy1, and Qy deposits for example) occupy higher positions within the landscape and do not transmit surface flow under normal conditions. Although precipitation falls throughout the entire piedmont, Qyc, Qy3, and Qyaf deposits represent the most active portion of the tributary drainage system.

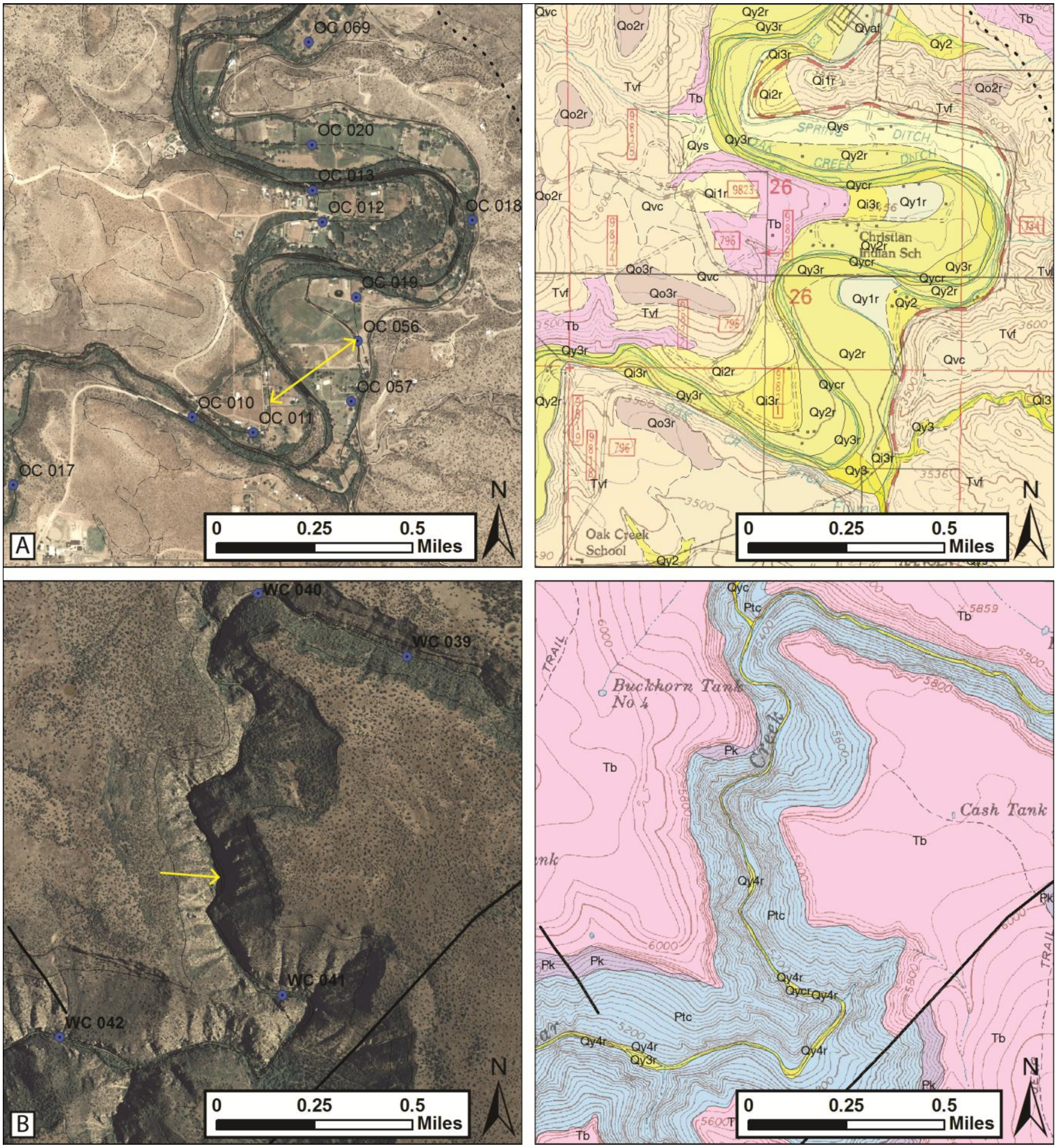


Figure 12. A) Example of less confined reach of Oak Creek. Here Oak Creek has incised through basin fill (Tvf) deposits and exhibits wide meanders, secondary channels, and widespread Holocene deposits. The width of Holocene alluvium along the yellow arrow is 1,500 ft. B) Example of narrow bedrock confined reach of central West Clear Creek. The entire narrow canyon bottom is covered by channel (Qycr and Qy4r) or young terrace (Qy3r) deposits due to flooding and channel migration. The width of Holocene alluvium near the yellow arrow is 95 ft.

Geology and geomorphology of Oak Creek, Wet Beaver Creek, West Clear Creek, Fossil Creek, and East Verde River

From north to south, Oak Creek, Wet Beaver Creek, West Clear Creek, Fossil Creek, and the East Verde River compose most of the central Verde River watershed (Figure 1). This area encompasses a region of diverse terrain in the transition between the Basin and Range and Colorado Plateau physiographic provinces in central Arizona. The uppermost parts of the tributary watersheds drain the margin of the Colorado Plateau, where shallowly-dipping Paleozoic sedimentary rocks are locally capped by late Cenozoic volcanic complexes that rise to over 12,000 ft above sea level. The margin of the Colorado Plateau is the Mogollon Rim—a NW-SE-trending escarpment whose crest ranges in altitude from 5,500 to 7,700 ft above sea level. The mountains of the Central Highlands and the Mogollon Rim pose a significant orographic barrier to moisture imported from the southwest during frontal storms, which can result in widespread and occasionally large amounts of precipitation across the region (e.g., House and Hirschboeck, 1997). The high altitude of the Colorado Plateau above the rim is conducive to the accumulation of significant snow pack during winter storms, which has contributed to runoff in many flood events on the Verde River and its larger tributaries (e.g., House et al., 1995). The deeply incised south- to southwest-draining tributaries mapped for this study efficiently concentrate and convey runoff from the plateau margin through canyons and incised valleys to the Verde River. The headwaters of each of these tributary drainages are located near the Mogollon Rim east of the Verde River.

Along the entire course of each mapped tributary to the Verde River, numerous minor drainages as well as a number of major streams feed into the main channel. In deeply incised canyon reaches, bedrock is likely fairly shallow beneath the channel and both axial channel and tributary deposits are laterally confined due to their entrenchment into adjacent bedrock or indurated basin fill deposits. In broader reaches, such as lower Oak Creek, Wet Beaver Creek, and West Clear Creek, both Holocene river and adjacent piedmont deposits are far more widespread. In general, tributaries drain relatively short and steep catchments oriented more or less perpendicular to the main valley axis. Deposits from most tributaries impinge on the Holocene river floodplain, resulting in an inward bowing of the margin of the Holocene river deposits (Figure 10). Larger tributaries contribute much greater amounts of water and sediment to the valley bottom than smaller tributaries and thus have a greater impact on Holocene boundaries.

Oak Creek. The bed elevation of Oak Creek ranges from 5,690 ft above sea level (asl) at its inception at the confluence of Sterling Canyon and Pumphouse Wash 11 miles northeast of Sedona in Coconino County, to 3,179 ft asl at the Verde River confluence in Yavapai County. The total length of the channel is just over 50 miles (Figure 1). Upper Oak Creek flows through a narrow bedrock canyon composed of basalt capped walls of Kaibab limestone, Coconino sandstone, and Permian sedimentary rocks from the Toroweap, Supai, and Schnebly Hill Formations. Initially flowing from north to south, Oak Creek bends to the southwest as it passes through Sedona and Red Rock. As Oak Creek enters the Hermit Shale and Tertiary basalt its characteristic tight entrenched meanders become apparent. Overall, the width of the canyon bottom from the headwaters in Oak Creek Canyon to Page Springs remains fairly narrow (< ~1,500 ft). Downstream of Page Springs, Oak Creek enters the Tertiary fluvial and lacustrine beds of the Verde Formation. From here to the Verde River Confluence, Oak Creek's entrenched meanders become wider, preserving more extensive (up to 2,400 ft wide) suites of Holocene river terraces on inside meander bends. Primarily downstream of Sedona, Pleistocene strath terraces composed of well rounded river cobbles sit atop eroded bedrock or Verde Formation benches from 10 to over 250 ft above the oldest preserved Holocene floodplain deposits.

Wet Beaver Creek. The bed elevation of Wet Beaver Creek ranges from 6,165 ft asl at the confluence of Jacks and Brady Canyon 8 miles southwest of Happy Jack in southern Coconino County to 3,073 ft asl at the Verde River confluence in Yavapai County. The total length of the channel is approximately 34 miles (Figure 1). The uppermost section of Wet Beaver Creek is an extremely narrow (often less than 50 feet wall to wall) canyon cut into basalt. Waterfalls, plunge pools, and extremely large in-channel boulders are common. Downstream, the canyon remains narrow and incision by the creek increases the height of the bedrock walls lining the canyon to over 900 ft. Wet Beaver Creek cuts through Kaibab limestone followed by the Toroweap Formation. The first preserved suite of Holocene to latest Pleistocene river terraces is evident in a wider section of canyon approximately 6 miles downstream from the headwaters. The canyon promptly narrows again, winding a sinuous WSW course through a deep, narrow, sandstone lined canyon. Near vertical walls are commonly less than 40 feet apart and numerous deep pools are encountered (Figure 11). The canyon bottom is alternately covered by active channel, deep pools, and cobble to boulder bars. Upon entering the Supai Formation upstream from Bell Crossing, the canyon bottom begins to gradually widen, exhibiting more extensive preserved Holocene river terraces. The Tertiary basalt caps lying atop the Supai Formation beds are more laterally removed from the canyon bottom resulting in more gradual slopes on both sides of the canyon. A mile upstream from Montezuma Castle National Monument Wet Beaver Creek enters the lacustrine facies of the Tertiary Verde Formation. Here the width of the Holocene river floodplain begins to dramatically increase, exceeding 3,000 ft across near Lake Montezuma. Near the confluence with Dry Beaver Creek, Wet Beaver Creek begins a series of many tight meanders with stairstep-like suites of Holocene to Pleistocene terraces preserved on inside meander bends. High-standing, early Pleistocene river terraces capping Verde Formation beds far removed from the modern channel course predate meander entrenchment. Near the confluence with the Verde River, the Wet Beaver Creek floodplain is wide and flat. Extensive latest to early Pleistocene river terraces north of the modern confluence mark previous paths of lower Wet Beaver Creek.

West Clear Creek. The bed elevation of West Clear Creek ranges from 6,060 ft asl at the confluence of Willow Valley and Clover Creek 11 miles northeast of Strawberry in Coconino County to 3,000 ft asl at the Verde River confluence in Yavapai County. The total length of the channel is approximately 37 miles (Figure 1). The upper section of West Clear Creek strongly resembles that of Wet Beaver Creek except no waterfalls were encountered. Canyon walls composed of Coconino sandstone rise over 700 ft above the narrow sand to pebble lined channel bottom. The width of the canyon bottom in the upper canyon reaches is commonly less than 100 ft. West Clear Creek flows predominantly from east to west through a series of tight incised meanders all within Coconino sandstone capped by Kaibab Formation beds, which are in turn capped by Tertiary basalt. After a sharp southward bend in the canyon West Clear Creek enters the Supai Formation. The canyon narrows dramatically in this section, resulting in numerous deep slot canyon pools with wall to wall water (Figure 11), smooth sculpted sandstone walls, and evidence of deep flooding. Downstream the sequence of basalt flows grows thicker and canyon walls become less vertical. The main channel remains narrow and typically consists of active channel, exposed sections of bedrock canyon bottom (Figure 8), and cobble to boulder bars. The lower third of West Clear Creek, beginning a few miles above Bull Pen Ranch, exhibits numerous late Pleistocene river terrace deposits perched on Supai benches 50 ft or more above the modern channel. Below Bull

Pen Ranch, West Clear Creek has incised into a thick sequence of Tertiary basalt. The canyon bottom widens to 500 ft in places and preserved Holocene river deposits are more laterally extensive relative to those upstream. The creek enters the Tertiary Verde Formation near the upstream end of Wingfield Mesa, located immediately south of the canyon. The more easily eroded character of the Verde Formation is evident from the dramatic expansion in lateral extent of Holocene to late Pleistocene river terraces. Here the Holocene floodplain reaches over 3,000 feet across and nearly one mile across near the Verde River confluence. Wingfield Mesa is composed of a large complex of early to middle Pleistocene alluvial fan and terrace deposits derived from West Clear Creek overlying Verde Formation; the capping deposits are dominated by basalt cobbles and boulders. These extensive terraces stretch over 4 miles along the lower reaches of West Clear Creek. Similarly aged river deposits cap Verde Formation beds near the Verde River confluence north of West Clear Creek. These similarly aged river deposits represent a paleovalley floor near the confluence that would exceed four miles across.

Fossil Creek. The bed elevation of Fossil Creek ranges from 4,600 ft asl at the confluence of Calf Pen and Sandrock Canyon four miles northwest of Strawberry in Coconino County to 2,560 ft asl at the Verde River confluence. For most of its length downstream, Fossil Creek defines the boundary between Yavapai and Gila County (Figure 1). The total length of the channel is approximately 17 miles. The headwaters of Fossil Creek are bound by Permian and Pennsylvanian sedimentary rocks. Similar to the canyons to the north, upper Fossil Creek is very narrow, yet is less dramatically incised. Bedrock walls are more gently sloping and slot canyon reaches are uncommon. The canyon bottom and associated Holocene river deposits in the upper canyon rarely exceed 350 feet across. Below Fossil Springs the amount of flow in the canyon increases dramatically, and the channel has a more sinuous pattern with perched latest Pleistocene to Holocene terraces preserved on inside channel bends emerges. On the north side of the canyon, an extensive (over 2,000 ft across) early to middle Pleistocene river terrace is preserved. This is the only such terrace in the canyon; all others are far less extensive, are located closer to modern creek elevation, and are located within canyon walls. From this point to the confluence with the Verde River downstream Fossil Creek is entirely bound by Tertiary basalts. In this stretch some travertine-coated waterfalls with deep plunge pools are encountered. Below the old Irving Powerplant site extensive Holocene to latest Pleistocene river terraces are preserved in a brief wider section of the canyon. Just downstream, Fossil Creek abruptly narrows at a southward bend on the east side of Ikes Backbone, a formidable N-S trending basalt ridge separating Fossil Creek from the Verde River. Narrow latest Pleistocene river terraces are perched on basalt benches along this stretch of Fossil Creek. The canyon bottom remains narrow and extremely large boulders choke the channel, creating numerous rapids. The canyon floor is alternately composed of scoured bedrock (Figure 8), submerged in deep pools, or covered by extensive cobble to boulder bars. Hardscrabble Creek joins Fossil Creek from the east, creating a large side canyon. At the confluence with the Verde River, numerous Pleistocene age deposits are inset into the basalt walls on the south side of the canyon.

East Verde River. The bed elevation of East Verde River ranges from 7,240 ft asl below the Mogollon Rim at the Coconino/Gila County border 15 miles northeast of Payson to 2,470 ft asl at the Verde River confluence at the Gila/Yavapai County border. The total length of the channel is approximately 54 miles. The headwaters of the East Verde River start essentially at the Mogollon Rim (Figure 1). In the uppermost reaches of the East Verde River the active channel is typically less than 10 feet across, choked with large angular to subrounded boulders, and flanked by debris flow levees. Further from the steep slopes of the Rim, the river passes through more gentle terrain and incises through Permian to

Pennsylvanian sedimentary rocks, followed by Mississippian, Devonian, and Cambrian sedimentary rocks. The active channel of the East Verde River throughout this reach is often bedrock lined, and the river is shallowly incised into the surrounding well rounded hills. Several tributary channels are similar in size to the main river channel, and Holocene terrace preservation is limited. Downstream near the confluence with Ellison Creek, the river passes through an outcrop of Proterozoic granite resulting in a series of short waterfalls and a steep, narrow bedrock-lined channel (Figure 8). Below this point, the East Verde again cuts through the same series of Cambrian to Permian sedimentary layers, leaving a few isolated Pleistocene terraces on the upper slopes of inside meander bends. The channel widens below the confluence of Webber Creek and Shoofly Canyon. Here, preserved Holocene river deposits are more extensive, filling the canyon bottom. Passing under Highway 260 north of Payson, the East Verde again enters Proterozoic granite and resumes an extremely narrow incised channel (60 – 80 ft across) with little Holocene terrace preservation outside the active channel and associated flood bank deposits. For the next 16 miles the river remains narrow and maintains a meandering course to the southwest, deeply incised into alternating exposures of fractured Proterozoic granite and Cambrian to Permian sedimentary rocks. Immediately east of the Mazatzal Wilderness boundary 9 miles west of Payson the floodplain along the East Verde widens dramatically. In this short, less confined reach the main channel has swept back and forth resulting in a series of extensive Holocene river terraces preserved on the south side of the river. The modern floodplain consists of a bifurcated main channel punctuated with islands of Qy3r and Qy4r deposits. Within the Mazatzal Wilderness the river narrows dramatically when passing through the early Proterozoic East Verde River Formation (Wrucke and Conway, 1987). For the next 11 miles the East Verde River flows west-northwest through a bedrock canyon alternately lined with Cambrian Tapeats sandstone, Tertiary basalt, the sedimentary and volcanic East Verde River Formation, and Proterozoic rhyolite, andesite, and conglomerate. This reach consists of a narrow canyon with short wider sections. Within the narrow reaches Holocene terrace preservation is minimal, and Holocene river deposits consist mainly of flood channel deposits and boulder bars. Wall to wall pools are common (Figure 11) in tight meanders and along very narrow straight sections of canyon. In the wider sections Holocene to elevated Pleistocene river terraces are inset adjacent to bedrock on both sides of the active channel. The lowermost three basalt-lined miles of the East Verde River canyon gradually widen before joining with the Verde River three miles below the Fossil Creek confluence. Here the active channel is wide, shallow, and flanked by extensive Qy4r deposits.

Fluvial geomorphology. The geomorphology of the active fluvial system for each mapped tributary to the Verde River may be divided into several components that are found to a greater or lesser degree along both alluvial and canyon reaches (Pearthree, 2008). The smallest but most persistent element is the perennial or low-flow channel. In alluvial reaches, the low-flow channel winds through the flood channel, a much larger channel shaped by flood flows. The character of the flood channel is strongly dependent on the time since the last large flood, particularly in terms of the amount of vegetation growing in the channel. Slightly higher terraces that are subject to partial or total inundation during large floods bound the flood channel in many places. These flood terraces or floodplain areas typically are moderately to densely vegetated, and vegetation in these areas is not substantially affected by the occurrence of floods except in the case of lateral bank erosion. Finally, along some river reaches there are extensive Holocene terraces that are rarely or never inundated by floods. These deposits may record periods of river aggradation earlier in the Holocene, or may have been emplaced in rare floods that were larger than any recorded historically (e.g., House et al., 2002).

Low-flow Channel. The low-flow channel conveys the perennial flow of the river, and varies in size and character based on the flow rate. Alternating pools and riffles (rapids) are ubiquitous in channels with bed load coarser than sand (Leopold et al., 1964), and this is certainly the case along each mapped tributary to the Verde River in both bedrock canyon bound and broader reaches. Pools are relatively wide and deep, and low-flow velocities are quite low. Riffles are narrower, shallower, and steeper, and flow velocities are much higher. Bed material in pools may include some cobbles and boulders left by floods, but typically it consists of silt, sand and fine gravel. Riffles form in areas of gravel bar deposition during larger flow events (Knighton, 1998), so gravel is always an important component of the bed material in riffles. Particle size in riffles typically ranges from pebbles to cobbles and in some cases small boulders. Gravel bar deposition along a river commonly alternates from side to side, so riffles also alternate from one side of the flood channel (or floodplain) to another (Figures 5, 12). In bedrock canyons, steeper channel reaches are commonly floored by bedrock and may consist of waterfalls. Changes in water-surface slope associated with riffles (or waterfalls) and pools result in a stepped water-surface profile, with flatter, less steep pool reaches and steeper riffle reaches. With increasing flow rates, the water-surface profile becomes smoother and pools and riffles become less apparent (Leopold et al., 1964).

Flood plain / Flood Channel. The flood channel is the most dynamic element of each creek or river's geomorphic system. The flood channel consists of lightly vegetated areas adjacent to and slightly higher than the low-flow channel that are bounded by more densely vegetated and somewhat higher flood plain or flood terrace areas. Sediment in flood channels is dominantly sand, but also includes pebbles and cobbles in gravel bars, and silt and clay in swales and small channels. In narrow canyon reaches, flood channel deposits may be composed of large cobbles to boulders. Local topography typically is undulating, with gravel bars several feet higher than adjacent dry channels. Vegetation size and density varies with the time since the most recent flood, as vegetation typically is removed or substantially reduced in large floods and recovers between floods. The flood channel of the river is subject to substantial changes in size, position and vegetation cover during floods, especially along alluvial reaches. In most of the canyon reaches of each river, the flood channel occupies almost the entire canyon bottom, with small and laterally discontinuous flood terraces perched above it (Figures 5, 12).

Flood plain / Young Terraces. Low terraces flank the flood channel along most of the basin reaches of the river and are also found in canyon reaches. These landforms are considered part of the active fluvial system (the flood plain) if they are subject to inundation in floods – areas that are lower or closer to the flood channel are inundated more frequently. Most low terraces are densely vegetated with trees and shrubs; areas that are more open commonly are covered by grass or shrubs. Young terraces are small and discontinuous in the upper canyon reaches of each mapped tributary. Along the lower reaches of Oak Creek, Wet Beaver Creek, and West Clear Creek, floodplain terraces commonly are wide and extend continuously along the flood channel for long distances. Because Fossil Creek remains tightly confined by bedrock for almost its entire course, preserved floodplain terraces are more isolated. In the East Verde River, floodplain terraces of limited extent lie along the lowermost reaches and within occasional breaks in an otherwise narrow bedrock lined canyon. Low flood terraces and floodplain areas are inundated fairly frequently, whereas higher flood terraces and marginal floodplain areas may only be inundated in the largest floods or may not be subject to inundation in the modern stream regime. Sand and silt deposited by floods cover most low terrace /floodplain surfaces, although gravel deposits are found locally. Cuts into these landforms commonly reveal evidence of multiple stacked flood deposits (e.g., House et al., 2002). Soils typically are dark brown and relatively rich in organic material. Many of the low terraces in the Verde Valley along Oak Creek, Wet Beaver Creek, and West Clear Creek are cultivated.

Modern channel conditions. Along the lower reaches of each mapped tributary outside narrow canyon walls, the modern floodplain is composed of an incised channel with numerous secondary flood channels and interspersed gravelly bars and low terraces, and typically is hundreds of feet wide (Figure 12). Dense stands of riparian vegetation mark other areas along the river and secondary flood channels where surface or near-surface flow is found consistently. Sections of the river with shallow bedrock often exhibit greater surface flow relative to sandy channel sections due to the less permeable nature of bedrock.

Along the upper and middle sections of each tributary, Ponderosa Pine, Douglas Fir, Blue Spruce, Engelmann Spruce, Holly Oak, Gambel Oak, and Juniper can be found on the hills and slopes adjacent to the channel in higher elevation canyons. Cottonwood, Alder, Coyote Willow, Sycamore, Locust, and Poison Ivy line active and flood channels while vegetation on fine grained Holocene terraces is commonly medium to large Juniper, Mesquite, Desert Broom, and Tamarisk. Along the lowermost reaches of each channel, Mesquite, Catclaw Acacia, and Tamarisk dominate most Holocene age terraces although stands of Cottonwood, Coyote Willow, and Sycamore thrive on active channel banks. Older, higher standing Pleistocene age river deposits as well as similarly aged piedmont deposits tend to exhibit greater populations of Juniper, Creosote, Catclaw Acacia, Prickly Pear, Barrel Cactus, Agave, and Cholla.

Sediments within the active channel are generally coarser than Holocene terrace deposits exposed in channel walls. This phenomenon is particularly evident just downstream from steep tributary drainages and confined canyon reaches. Many of these tributaries are dry, sandy to bouldery washes, although a number of major tributaries exhibit frequent flow over at least part of their reaches. Flood flows in these drainages result in the introduction of large pulses of coarse gravelly sediment into the main channel following precipitation events. In narrow canyon reaches sediment introduced in this manner is efficiently transported downstream because of the confined, high-energy flow. Large, very coarse rubble from debris flows or rockfall may persist in or near the active channel for some time. Sediment delivered in unconfined, lower energy reaches may onlap onto Holocene floodplain terraces or temporarily divert channel flow around the terminus of the deposit.

Because Oak Creek, Wet Beaver Creek, West Clear Creek, Fossil Creek, and the East Verde River are incised into bedrock or basin deposits for their entire lengths, the overall width of the Holocene floodplain is relatively stable. With shifts in channel position during large flood events, however, river or tributary deposits can become inundated and subsequently buried, undercut and eroded away, or reshaped through partial erosion. In bedrock lined reaches the floodplain may be confined to 60 – 400 ft across whereas in less confined reaches the Holocene floodplain may be 1,000 to 3,000 ft wide. Piedmont tributary deposition can overlap and mask the original extent of Holocene river deposits. Unconfined flow at the mouths of tributary washes or the toes of piedmont fan networks can prograde onto (and likely interfinger with in the subsurface) and obscure the outermost reaches of river terraces. Each modern channel is largely confined within well-defined channel banks in most places, although some reaches are certainly less incised than others. For this reason the overall width of Holocene floodplain is much more extensive than the modern floodplain except where confined by bedrock or indurated basin fill deposits.

Geoarchaeological Evaluation of Verde River Tributaries

Methods. Archaeological data were used to evaluate and refine the age ranges assigned to terrace surfaces along the major tributaries of the Verde River on the basis of soil development, geomorphic relationships, and historical records. Dated archaeological material buried in terrace fills can provide a maximum age for the overlying deposits and geomorphic surface, whereas dated archaeological material on a terrace tread surface can provide a minimum age for the underlying deposits. Archaeological site locations and descriptive summaries were obtained primarily from records, notes, maps, and reports archived at the Arizona State Museum (ASM), as well as from the museum's AZSITE relational database search engine accessible through the internet. Site locations were acquired as a GIS layer from the ASM, although some site locations were corrected using the original museum site records. Additional site information not available from ASM was obtained from unpublished contract archaeology reports.

A GIS map layer with polygons depicting the horizontal extent of all archaeological sites falling within the 2-mile-wide mapping project corridor was overlain on the draft geologic map. Relevant site attributes were then tabulated. These attributes included associated terrace surface(s), whether the site was deeply or buried or exposed on the modern ground surface, whether or not artifacts appeared to be reworked by erosion into secondary contexts, USGS quadrangle name, radiocarbon dates, and a brief, general description of the archaeological materials and features found at the site, including temporally sensitive artifact types. Sites plotted on multiple surfaces were eliminated from this analysis unless it could be determined from the site description which surface was associated with which archaeological age indicators. Suspect or ambiguous site data were field checked or discarded.

Age ranges for temporally significant site attributes were extracted from the archaeological literature. These temporally sensitive archaeological traits are summarized in Table 2. Some archaeological variables are associated with fairly broad temporal parameters, whereas others are quite narrow. For example, Wingfield Plain Ware pottery dates from AD 300-1300 (Wood 1987), whereas Medicine Black-on-red pottery dates from AD 1000-1115 (Deaver 1997).

Dated archaeological material buried in terrace fills can provide a maximum age for the overlying deposits and surface, as well as a minimum age for the underlying fill. The Paleoindian Clovis Culture, dated between 11,500 and 10,900 BP (Waters and Stafford 2007), represents the oldest uncontested human occupation of the New World. Clovis artifacts found on terrace treads would suggest a Pleistocene age for the underlying fill. In contrast, post-Clovis archaeological material found in buried contexts presumably would date to the Holocene and indicate a Holocene age for the overlying sediment and geomorphic surface, as well as for any inset (i.e., younger) terrace surfaces.

Buried archaeological material and associated radiocarbon dates with more precise chronometric bounds can be used to further constrain the age of the overlying terrace surface if this material does not appear to have been reworked. For example, if charcoal radiocarbon dated to 1500-2000 BP is associated with an archaeological hearth feature buried within a terrace fill, the earlier end of the associated range (i.e., 2000 BP) provides a maximum age for the overlying terrace surface. In this example, the terrace surface is inferred to be younger than 2000 BP, and any terraces inset into this terrace are inferred to post-date 2000 BP. Similarly, the later end of the associated range (1500 BP) provides a minimum age for the terrace fill deposits underlying the archaeological material, as well as any older deposits or surfaces. However, although archaeological material eroded from its original context and deposited in a secondary context also provides a maximum age for overlying deposits, it does not provide a minimum age for the underlying deposits because these deposits could be either younger or older than the reworked artifact.

Archaeological surface sites, on the other hand, constrain the minimum age of the terrace surface on which they lie because the surface must exist before archaeological material can accumulate on top of it. The more recent limit of the age range associated with the oldest age indicator found on a surface site generally provides the best minimum age estimate. For example, a type of Hohokam pottery known as Sacaton Red-on-buff was made from AD 950–1150 (Oppelt 2007). The presence of a sherd of this pottery type on a geomorphic surface indicates that the surface must be older than AD 1150. It also provides a minimum age for the underlying terrace fill and for any older surfaces and deposits. If surface artifacts are reworked from archaeological deposits originating on topographically higher geomorphic surface, the artifacts merely constitute one type of clast comprising the deposits capping a younger terrace. Although the older bound of the age range associated with such artifacts provides a maximum age for the reworked sediment, it does not provide any useful age constraints for the underlying terrace, which could be either older or younger than the artifact.

Like most dating methods, the use of archaeological material for constraining geomorphic surface ages, requires certain assumptions. One must assume that the age ranges associated with the various archaeological phenomena are accurate. Also, one must presume that the archaeologist recording the site accurately identified these phenomena and accurately recorded the site location. Further, it must be assumed that artifacts were not “curated”, meaning that their prehistoric owners didn’t salvage them from old archaeological sites or, alternatively, reuse or keep or keep an artifact as an heirloom for so long a time that the context that the artifact was finally abandoned in does not temporally reflect the period in which that style was made (Thomas 1979:459). In addition, it is assumed that the geomorphic surface associated with the archaeological material are correctly mapped and that Holocene terraces are cut and fill features and not significantly time-transgressive . And finally, when age constraints are derived from archaeological radiocarbon dates, it is assumed that the date reflects the age of the stratigraphic context in which it was found. Charcoal eroded from older deposits and prehistoric burning of “old wood” for fuel (Schiffer 1986) can violate this assumption.

Results.

Qycr and Qy4r. AZSITE maps implied that three prehistoric sites along Oak Creek (NA19858; O:1:32 [ASM]; O:1:13 [ASM]) and two along East Verde River (NA6354; NA6355) are recorded on Qy4r surfaces. In addition, one prehistoric site (O:1:17 [ASM]) is recorded on a Qycr surface along Oak Creek. Review of the associated site records, however, indicated that these sites were incorrectly plotted and do not coincide with these surfaces. This is not surprising given that most of these sites were recorded before GPS technology was routinely used by archaeologists and many of the sites were originally plotted on old 15-minute USGS quadrangle maps.

Prehistoric site O:5:87 (ASM) coincides with the mapped boundary between Qycr and Qy4r along Wet Beaver Creek. However, this surface site consists of two large boulders with bedrock mortars that were probably created when the boulders were associated with an older surface that was subsequently eroded during the creation of younger terraces.

The effective absence of prehistoric archaeological sites on Qy4r and Qycr is not surprising given the active nature of these surfaces, with Qycr constituting active channel deposits and Qy4r undergoing inundation during moderate to extreme stream-flow events.

Qy3r. Initial examination of ASM records suggested that three prehistoric surface sites were recorded on Qy3r terraces along both Oak Creek and East Verde River. The Oak Creek sites include a petroglyph on a small basalt boulder (O:1:16[ASM]), a rectangular rock outline interpreted to represent the remains of a field house (O:1:17[ASM]), and a linear rock alignment near a cluster of cobbles interpreted to represent a field house wall and an associated roasting pit (O:1:18[ASM]). The associated site records noted no other evidence of prehistoric activity, such as pottery sherds, ground stone, flaked stone, or charcoal. We attempted to field-check all three of these Oak Creek sites because their prehistoric antiquity contradicted the historical period age assigned to the Qy3r fill based on geologic and soil criteria, but we could not find any prehistoric archaeological material either at or within a 100 m radius surrounding the mapped site locations. These sites were all recorded in 1981, and it is possible that flooding that dispersed the boulders subsequently destroyed the sites. Furthermore, amateur archaeologists associated with a local archaeological society recorded the sites. It is possible that the rock alignments they observed were not prehistoric features, but instead represent either fortuitous natural arrangements of floodplain cobbles or features constructed during historic or modern times. Because the questionable validity of these sites, they were not used to make inferences about the age of Qy3r deposits. The East Verde River sites include a petroglyph (O:11:3 [ASM]) and two rockshelters (O:11:2 [ASM] and NA6340). The plotted locations of these sites on Qy3r surfaces appear erroneous, as their descriptions indicate that they are associated with exposed bedrock. Therefore, none of the available archaeological data provided direct constraints on the age of the Qy3r fill and surface.

Qy2r. In total, eight prehistoric sites and three historic period sites are situated on Qy2r terraces along the Verde tributaries.

Oak Creek. One historical period and one prehistoric archaeological site along Oak Creek are associated with Qy2r. The historical period site consists of the Crescent Moon Ranch stead (NA19824), which dates to the 1800s. This site provides little chronometric information regarding the age of Qy2r, but its age is consistent with a latest Holocene age for the Qy2r fill and suggests that the Qy2r terrace was formed by channel entrenchment that pre-dates AD 1900.

The prehistoric site (O:1:88 [ASM]) was excavated and found to contain evidence of several occupations, including both surface and buried components (Shepard et al. 1998). The site matrix consists of a one-meter-thick layer of sandy, weakly soil altered Qy2r alluvium underlain by a petrocalcic soil horizon formed in coarse, rounded Pleistocene gravels. Shepard et al. (1998) recovered the base of a Clovis projectile point immediately above the unconformable contact between the petrocalcic horizon and the overlying veneer of Qy2r alluvium. Clovis points date between 11,300-10,700 BC (Waters and Stafford 2007). This is consistent with the Pleistocene age inferred for the underlying cemented gravels and suggests that the overlying Qy2r alluvium dates to the Holocene. Shepard et al. (1998) argued that post-Clovis people found and brought the Clovis point to the site. We believe, however, that the point more likely represents brief, Clovis period use of the site because the point's fragmented condition makes it an unlikely prehistoric curio.

Artifacts found buried in the Qy2r alluvium include several San Pedro projectile points (1500 BC-AD 300) and Basketmaker corner-notched and side-notched points (AD 300-800). A few San Pedro and Basketmaker points were also found on the surface. A radiocarbon date of 2700$\pm$40 BP (2 sigma calibrated range of 910-800 BC; Beta-111966) on detrital charcoal recovered at the base of the Qy2r fill is consistent with the presence of these point types and suggests that deposition was underway by 2700 BP. The San Pedro and Basketmaker points recovered throughout the alluvium suggest Qy2r deposition ended sometime after AD 300.

A varied prehistoric ceramic assemblage was documented at site O:1:88(ASM), with almost all of the sherds found on the surface of the Qy2r alluvium. Shepard et al. (1998) thought that field leveling and plowing resulted in substantial disturbance of Qy2r deposits prior to archaeological excavation of the site. While some disturbance is plausible, the paucity of subsurface pottery and the site location at the downslope edge of the terrace suggest that this disturbance has been relatively minimal. Pottery types identified and their associated age ranges include Black Mesa Black-on-white (AD 1000-1150), Deadman's Black-on-red (AD 900-1100), Medicine Black-on-red (AD 1000-1115), Tusayan Black-on-red (AD 1045-1240), Tusayan Corrugated (AD 1020-1210), Verde Brown (AD 1100-1300), Tuzigoot Plain (AD 1100-1400), Wingfield Plain (AD 300-1300), Lino Gray (AD 500-950), and Alameda Brown (AD 700-1400). The two oldest pottery types (Lino Gray and Deadman's Black-on-red) suggest that Qy2r deposition ended before AD 950.

Wet Beaver Creek. A Camp Verde phase surface artifact scatter (site NA 21059) is recorded on a Qy2r terrace tread along Wet Beaver Creek, suggesting that Qy2r deposition ended prior to AD 1150. In addition, segments of a historic period canal (NA 25344) cross Qy2r, Qy3r, and Qy4r surfaces along Wet Beaver Creek. The associated site record suggests that this canal was built in AD 1876, but it likely that flooding has periodically destroyed portions of the canal on the Qy3r and Qy4r terraces have been periodically destroyed by flooding, necessitating repair or reconstruction.

Fossil Creek. Three prehistoric sites and one historic site are recorded on Qy2r surfaces along Fossil Creek. The age of one of the prehistoric sites (NA19214) is ambiguous, but the age ranges associated with Camp Verde phase (AD 900-1150) ceramic types at the other two sites (NA19215 and NA19216) imply that Qy2r deposition ended before AD 1150. A historic road with an associated rock alignment (site NA19219) dates between AD 1880 and 1920, consistent with entrenchment of the Qy2r floodplain either during or before this period.

East Verde River. Three prehistoric sites described as surface artifact scatters (NA9736, O:11:28 [ASM] and O:11:14 [ASM]) have been recorded along the East Verde River on Qy2r surfaces. Ceramics from these sites suggest that Qyr2r deposition ended sometime prior to AD 1400.

In summary, archaeological material associated with Qy2r surfaces and deposits along the Verde tributaries suggests that deposition of Qy2r fill began by roughly 2700 years ago and effectively ended between approximately 1700 and 1050 years ago. Entrenchment of the Qy2r surface appears to predate AD 1900.

Qy1r. One historical period site was recorded on a Qy1r surface along the main trunk of Oak Creek, and one prehistoric site was recorded on this surface along the East Verde River. The historical period site (O:2:6 [ASM]) consists of a log cabin built in the 1870s or 1880s. This site contributes little to our understanding of the age of Qy1r deposits because it was already known that Qy1r fill has a prehistoric age. The prehistoric site (O:2:23 [ASM]) contained a possible one-room stone masonry structure and an artifact scatter that included Little Colorado White Ware (AD 1050-1375) and Tonto Plain Ware (AD 700-1400) ceramics. Age ranges associated with these archaeological traits indicate that the Qy1r surface predates AD 1400. Archaeological dating of the Qy2r surface, however, suggests that Qy1r fill was deposited more than 2700 years ago.

Discussion. In sum, archaeological dating of sites recorded along the major Verde River tributaries suggests:

- Qy1r deposition predates 2700 BP
- Qy2r deposition began prior to 2700 BP and largely ended between 1700 and 1050 years ago
- Qy3r deposition began after 1050 BP

Although relatively few archaeological sites have been recorded on Holocene terrace surfaces along the Verde River tributaries, chronometric data from these sites are consistent with archaeological dating of Holocene terraces along the main trunk of the Verde River. Extensive archaeological surface site data and very limited subsurface data from Verde River terraces suggested that Qy2r fill deposition began sometime prior to ca. AD 500-600 and was insubstantial after ca. AD 900-1150 (Cook et al. 2009). Subsequent Qy3r fill deposition there began by ca. AD 1150 and continued until historical arroyo cutting at the end of the 19th century.

Qy2r and Qy3r terrace formation along both the main trunk of the Verde River and its major tributaries appears to be roughly synchronous with the formation of T-2 (also known as the Lehi terrace) and T-1, respectively, along the middle Gila River and the lower Salt River (Onken et al. 2004; Waters and Ravesloot 2000), perhaps corroborating the archaeological dating along the Verde and its tributaries. T-2 fill deposition along the middle Gila and the lower Salt Rivers ended sometime between AD 1000 and 1150 with channel downcutting and widening taking place sometime during this 150-year period. Subsequent T-1 fill deposition was underway by AD 1150 and continued until the onset of historical arroyo cutting in the late 1800s.

Table 2. Temporally Sensitive Archaeological Artifacts and Site Characteristics

Description	Years AD/BC	Reference
PREHISTORIC ARCHITECTURAL FEATURES		
Surface rooms/ field houses	AD 900-1400	Fuller et al. 1976; Van West et al. 2005
PREHISTORIC ARTIFACTS		
Alameda Brown Ware	AD 700-1400	Oppelt 2007
Black Mesa Black-on-white	AD 1000-1150	Mills and Herr 1999
Deadman's Black-on-red	AD 900-1100	Hegmon et al. 1997
Lino Gray Ware	AD 500-950	Oppelt 2007
Medicine Black-on-red	AD 1000-1115	Deaver 1997
Little Colorado White Ware	AD 1050-1375	Oppelt 2007
Tonto Plain Ware	AD 700-1400	Wood 1987
Tusayan Black-on-red	AD 1045-1240	Christensen 1994
Tusayan Corrugated	AD 1020-1210	Christensen 1994
Tuzigoot Plain Ware	AD 1100-1400	Colton 1958; Oppelt 2007; Wood 1987
Verde Brown Ware	AD 1100-1300	Colton 1958
Wingfield Plain Ware	AD 300-1300	Wood 1987
Clovis projectile points	11,300-10,700 BC	Waters and Stafford 2007
San Pedro projectile points	1500 BC-AD 300	Huckell 1984
Basketmaker projectile points	AD 300-800	Shepard et al.1998

Map units

The following is a comprehensive list of geologic units shown on the map sheets. Because the strip maps include approximately a mile of surrounding geology on both sides of the river, many piedmont, basin fill, and bedrock unit descriptions are presented here. In some cases numerous subdivisions exist for a particular unit resulting in several separate but similar units and associated descriptions. An effort has been made to standardize unit terminology across quadrangle boundaries. However, in situations where non-AZGS maps were incorporated, unit names and descriptions were not changed, thus some redundant naming exists.

Surficial deposits

Other units

d - Disturbed ground - Heavily disturbed ground due to agriculture, extensive excavation, mining activity, or construction of earth dams.

/ / - Plowed areas – Historically or actively plowed fields, irrigated pastures, and other lightly disturbed ground are depicted with a hachured overlay.

df – Debris flow chutes - Slope failure and debris flow scars on steep canyon slopes and along drainages. Debris flow initiation points are often located at the base of near vertical bedrock cliffs. Where debris flows reach the canyon bottom, debris flow snouts and associated sediments are deposited and mixed with well rounded river sediments. Debris flow scoured channels are often eroded down to underlying bedrock and expose adjacent moderately consolidated hillslope mantling sediments.

Qls – Landslide deposits – Unsorted sediment resulting from mass down-slope movement (Wrucke and Conway, 1987). The age of these deposits is uncertain, but they are almost certainly Quaternary in age.

Qtc - Quaternary hillslope talus and colluvium - Unconsolidated to weakly consolidated, very poorly sorted angular rock debris deposited at the base of bedrock slopes.

Qvc - Regolith and colluvium formed on deposits of the Verde Formation – Generally fine-grained, in situ deposits mantling gentle slopes on the Verde Formation.

Oak Creek, Wet Beaver Creek, West Clear Creek, Fossil Creek, and East Verde River alluvium

Holocene river deposits

Qycr - Active river channel deposits - 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 1 to 30 ft or more below adjacent early historical floodplain deposits depending on location, geomorphic relationship, and local channel conditions. Some of these deposits are submerged by the low-flow river channel, and remaining areas are submerged during moderate to extreme flow events. These areas are subject to deep, high velocity flow and lateral bank erosion. In some areas, channel deposits are very thin to discontinuous exposing underlying bedrock, with the extent of channel deposits and exposed bedrock varying with significant flooding.

Qycb - Bedrock lined river channel - Portions of the active channel where flow passes directly over exposed bedrock. A discontinuous layer of pebbles to boulders may be present but smooth, polished bedrock lines the channel bottom. Qycb reaches are most often encountered within or just downstream from tightly-confined, bedrock-lined canyons. Due to the more confined nature of these sections of channel, consistently higher energy concentrated streamflow transports finer sediment downstream. Exposed bedrock in the channel bottom is generally fluted and sculpted from long term scouring of passing water and bedload.

Qy4r - Flood channel and low terrace deposits - Deposits are found adjacent to active channels that form lightly vegetated in-channel bars, small planar fluvial terraces within 2 feet of river elevation, and recent erosional meanders outside the presently active channel. Terrace deposits are inset into older river alluvium and usually narrow. Qy4r deposits are composed of poorly sorted unconsolidated sediments ranging from fine silts to cobble 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 - Terrace deposits that occupy elevations from 5 to 10 feet above Qycr or Qy4r deposits and are inset below the pre-incision historical floodplain. These surfaces are generally planar but locally exhibit bar and swale microtopography. Although minimal or no soil development is present, dense grasses, shrubs, cottonwood, sycamore, and in lower elevations, small mesquite trees abound. These deposits consist of poorly sorted silt, sand, pebbles and cobbles, but most commonly the deposits are capped with fine sand and silt. Exposures reveal trough crossbedding, ripple marks, and stacked gravel deposits. Pebbles and cobbles are well-rounded to sub-angular. These deposits are prone to inundation during large floods, and undercutting and rapid erosion of Qy3r surfaces is possible during lower flow events.

Qy2r - Late Holocene to historical river terrace deposits - Qy2r deposits are associated with broadly planar surfaces that locally retain the shape of past river meanders. Qy2r surfaces are up to 20 ft above modern Qycr deposits and are often the most extensive river terraces in the Verde 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 historical 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 are 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 ,Qyaf, and Qys) onlap onto Qy2r deposits although an interfingering relationship likely exits in the subsurface.

Qy1r – Late to early Holocene river terrace deposits - Deposits associated with slightly higher terraces that represent higher elements of older Holocene aggradation periods. These terraces appear predominantly fine-grained on the surface but often exhibit coarse gravelly to cobbly beds in the subsurface. Surface features have often been disturbed by cattle grazing. When undisturbed, Qy1r deposits are densely vegetated by mature mesquite trees and tall grasses. Soil development is moderate and surface color ranges from 10 to 7.5 YR 4/4 although some terraces appear more reddish due to local source lithologies. Due to the dense vegetation input of organic matter at the surface, a thin (< 10 cm) organic soil horizon may be present. A light dusting (incipient stage I) of calcium carbonate accumulation is evident on the undersides of some buried clasts. Qy1r surfaces stand up to 35 ft above the active channel in highly incised locales and typically are 10 ft higher than adjacent Qy2r surfaces.

Pleistocene river deposits

Qi3r - Late Pleistocene river terrace deposits, undivided - River terrace deposits standing up to 65 ft higher than the active channel. These terraces can be located up to 0.25 miles outside the margins of the modern channel but are usually located along incised portions of the river valley. These deposits consist of well rounded to subangular pebbles to cobbles exhibiting stage I+ calcium carbonate accumulation with cross-bedded coarse sandy interbeds. Qi3r soils are moderately developed with orange to reddish brown (7.5YR) sandy loam to clay loam argillic horizons and stage II calcium carbonate accumulation. Qi3r terrace surfaces are planar, often surrounded by distal piedmont alluvium, and are lightly vegetated by small shrubs, cactus, and grasses. Commonly, Qi3r deposits are inset into adjacent piedmont alluvial deposits but can also be inset into older river gravel terraces. Locally, late Pleistocene river terraces are subdivided into 2 members that have similar physical characteristics.

Qi3rb - Late Pleistocene river terrace deposits, younger member.

Qi3ra - Late Pleistocene river terrace deposits, older member.

Qi2r - Middle to late Pleistocene river terrace deposits, undivided - Terrace deposits are similar to Qi3r deposits but occupy higher positions in the landscape. Terrace surfaces are slightly to moderately rounded. Clast composition is diverse. Well-rounded pebbles to cobbles with stage I-II calcium carbonate accumulation armor Qi2r surfaces. Vegetation includes small juniper, shrubs (creosote and acacia), cactus (prickly pear, cholla, and barrel) and desert grasses depending on elevation. Qi2r soils are moderately well developed, reddened (5yr), clay argillic horizons, with obvious clay skins and subangular to angular blocky structure. Underlying soil carbonate development is typically stage II to III, with abundant carbonate through at least 1 m of the soil profile. Soil development is more evident in finer grained sections. Qi2r surfaces are typically found as high-standing isolated mounds surrounded by distal fan alluvium or as elongate terraces inset into older river, fan, or basin fill alluvium. Locally, middle to late Pleistocene river terraces are subdivided into 2 members that have similar physical characteristics.

Qi2rb – Middle to late Pleistocene river terrace deposits, younger member.

Qi2ra – Middle to late Pleistocene river terrace deposits, older member.

Qi1r - Middle Pleistocene river terrace deposits, undivided - Deposits are associated with high-standing, well-rounded river gravel terraces. Where Qi1r deposits are extensive, remnant planar caps are preserved near the center of the surface. Qi1r deposits are composed of very well rounded to well rounded pebbles and cobbles from diverse lithologies. Cross-bedded sands with pebbly stringers are interbedded throughout. Near-surface cobbly beds exhibit stage II+ calcium carbonate accumulation. Moderately to strongly calcium carbonate coated clasts or cemented aggregates of clasts mantle the flanks of Qi1r deposits, but clay accumulation is variable, probably due to poor surface preservation. Where surfaces are well-preserved, Qi1r soils are reddened (5-2.5YR), clay argillic horizons, with obvious clay skins and subangular to angular blocky structure. Underlying soil carbonate development is typically stage III-IV, with abundant carbonate through at least 1 m of the soil profile. Sparse small shrubs, weeds, and cacti are present on these surfaces. Qi1r terraces typically are at least 100 ft above the modern river. Locally, middle Pleistocene river terraces are subdivided into 2 members that have similar physical characteristics.

Qor - Early Pleistocene river terrace deposits, undivided - Well rounded to subangular moderately consolidated pebble to cobble river gravels and fine-grained river deposits. Locally, planar terrace surfaces are preserved, but more commonly terrace deposits are highly eroded, sloping remnants. Deposits are thin and poorly sorted, clay to gravel. Soil development is strong where surfaces are well preserved, with substantial clay and calcium carbonate accumulation. More commonly, however, terrace deposits are substantially eroded and soil development is weak to moderate. Qor terrace deposits are typically at least 150 ft above the modern channel. These deposits are thought to be correlative to those in the Verde Valley, which have been subdivided into 3 members based on their height above the river (House and Pearthree, 1993; House, 1994).

Qo3r - Early Pleistocene river terrace deposits, younger - Terraces range from 160-180 ft above the modern river channel.

Qo2r - Early Pleistocene river terrace deposits, middle - Terraces range from 180-220 ft above the modern river channel.

Qo1r - Early Pleistocene river terrace deposits, older - Terraces range from 280-360 ft above the modern river channel.

QTor – Late Pliocene to early Pleistocene river terrace deposits - Moderately consolidated, coarse river terrace or alluvial fan deposits capping Table Mesa southwest of Sedona. Deposits are very poorly sorted, rounded cobbles, boulders and pebbles, with some sand, silt and clay. The QTor surface is about 700 ft above the modern Oak Creek channel. Surface color is reddish brown. Soils have very clay-rich argillic soil horizons and stage III-V calcic horizons. QTor deposits rest on top of Paleozoic bedrock and may be up to 30 m thick.

Piedmont alluvium and surficial deposits

Holocene deposits

Qyc - Modern stream channel deposits - Active channel deposits composed of very poorly-sorted sand, pebbles, and cobbles with some boulders to moderately-sorted sand and pebbles. Channels are generally incised 3 to 7 ft below adjacent Holocene terraces and alluvial fans, but may be incised 30 ft or more below adjacent Pleistocene deposits. Channel morphologies generally consist of a single thread high flow channel or multi-threaded low flow channels with gravel bars. Channels are extremely flood prone and are subject to deep, high velocity in moderate to large flow events, and severe lateral bank erosion.

Qy3 - Latest Holocene alluvium - Recently active piedmont alluvium located primarily along active drainages including floodplain, low-lying terraces, and tributary channels. Qy3 deposits are composed of unconsolidated to very weakly consolidated sandy to pebbly deposits and exhibit greater vegetation than Qyc deposits. These deposits generally exhibit bar and swale microtopography and are susceptible to inundation during moderate to extreme flow conditions when channel flow exceeds capacity. Soil development is generally absent or incipient on Qy3 deposits, which exhibit pale buff to light brown (10 YR) surface coloration.

Qyaf - Late Holocene alluvium, active fan deposits - Qyaf deposits consist of active alluvial fan deposits with distributary drainage patterns and are extremely prone to flooding and channel migration. Sediments are unconsolidated and consist of very poorly sorted sand to cobbles. Vegetation includes small juniper, mesquite trees, shrubby acacia, prickly pear, and medium creosote.

Qy2 - Late Holocene alluvium - Qy2 deposits consist of piedmont terrace and minor channel deposits located primarily along the flanks of incised drainages, broad low-relief distal fan deposits onlapping onto Holocene river alluvium, and infrequently active tributary drainage deposits. These deposits consist of predominantly fine grained unconsolidated to weakly consolidated sediments although isolated sub-rounded to sub-angular cobbles and boulders may be present at the surface in small quantities. Where inset into older alluvium, Qy2 deposits are planar with remnant bar and swale microtopography. Distal fan Qy2 deposits are broad and sandy with numerous small braided channel systems. Rarely active Qy2 tributary drainages are generally of limited extent, relatively steep, and more densely vegetated than Qy3 tributary drainages. Soil development on Qy2 deposits is minor, characterized by incipient stage I calcium carbonate accumulation in the form of small filaments and medium brown (10 YR) surface coloration. Vegetation on Qy2 surfaces ranges from numerous small mesquite trees and grasses in distal fan environments to medium creosote, acacia, and cholla in tributaries and inset terraces. These surfaces are subject to inundation during moderate to extreme flow conditions when channel flow exceeds capacity or due to channel migration on low-relief portions of broad distal fan deposits. Planar Qy2 terraces are typically elevated from 30 cm to 1.5 m above active channels.

Qy1 – Older Holocene alluvium - Qy1 deposits consist of terraces along tributary drainages and broad, low-relief, undulating fan deposits that exhibit shallow widespread braided drainage patterns and sit higher in the landscape than younger Holocene alluvium. Portions of these deposits are mantled by coarse to very coarse angular sands to gravels and exhibit diverse vegetation patterns dominated by juniper and mesquite at higher elevations and cholla, prickly pear, small (4-5 ft tall) mesquite, and numerous small shrubs and grasses at lower elevations. Overall relief between broad fan crests and incised drainages on gently rolling Qy1 deposits typically does not exceed 5 feet. Numerous shallow braided channels drain widespread portions of Qy1 surfaces. Qy1 deposits exhibit incipient calcium carbonate accumulation (stage I) and soil development characterized by medium brown (10-7.5 YR) coloration where unincised.

Qys – Holocene fine grained deposits - Unconsolidated, very fine to fine grained alluvium located in close proximity to basin fill deposits. These sediments are lighter in color and finer than alluvium derived from further upfan. In general, Qys deposits are composed of fine sands to gravels and may contain significant amounts of carbonate fragments derived from basin fill deposits. Vegetation on Qys deposits consists of small shrubs, grasses, creosote, and acacia. Qys deposits are generally derived from erosion of fine-grained basin-fill deposits.

Qy – Holocene alluvium - Holocene alluvium, undivided.

Pleistocene deposits

Qis – Fine grained Pleistocene deposits - Older fine-grained deposits derived primarily from the Verde Formation. Soil development is moderate, commonly with some reddening and stage II to III calcic horizon development.

Qi3 - Late Pleistocene alluvial fan and terrace deposits - Unit Qi3 is composed of slightly dissected terraces and alluvial fans. Active channels are incised up to about 10 feet below Qi3 surfaces. Qi3 fans and terraces are slightly lower to much lower in elevation than adjacent older surfaces. Qi3 deposits consist of pebbles, cobbles, and finer-grained sediment. Qi3 surfaces commonly are fairly smooth with local bar and swale topography and loose to pebble and cobble lags. Surface clasts typically exhibit weak rock varnish. Qi3 soils are moderately developed, with brown to reddish brown loamy (7.5 to 5 YR) near-surface horizons and stage I to II calcium carbonate accumulation.

Qi2 - Middle to late Pleistocene alluvial fan and terrace deposits, undivided - Unit Qi2 is composed of moderately dissected relict alluvial fans and terraces with moderate to strong soil development found throughout the map area. Qi2 surfaces are drained by moderately incised tributary channel networks; channels are typically 3-7 feet below adjacent Qi2 surfaces. Well-preserved, planar Qi2 surfaces are smooth with pebble and cobble lags; surface color is reddish brown; surface clasts are moderately varnished. More eroded Qi2 surfaces are characterized by scattered cobble and pebble lags and broad ridge-like topography. Soils associated with planar surface remnants typically contain reddened (5 to 2.5 YR), clay loam argillic horizons, with clay skins and subangular blocky structure. Underlying soil carbonate development is typically stage II with areas to stage III. Locally, middle to late Pleistocene fan and terrace deposits are subdivided into 2 members that have similar physical characteristics.

Qi2b - Middle to late Pleistocene alluvial fan and terrace deposits, younger member.

Qi2a - Middle to late Pleistocene alluvial fan and terrace deposits, older member.

Qi1 - Middle Pleistocene alluvial fan and terrace deposits - Unit Qi1 is composed of moderately to deeply dissected relict alluvial fans with strong soil development. Qi1 surfaces are drained by broad swales and well developed, moderately to deeply incised tributary channel networks. Well preserved, relatively planar Qi2 surfaces are smooth with pebble and cobble lags; surface color is reddish brown, and surface clasts are moderately to strongly varnished. More eroded Qi1 surfaces are characterized by strongly varnished cobble to cobble and pebble lags with broad ridge-like topography. Soils associated with well-preserved Qi1 surfaces are reddish brown to red and very clay-rich with strong subangular to angular blocky structure. Calcic horizon development is quite variable, but ranges from stage II to stage IV.

Qo – Early Pleistocene alluvial fan deposits, undivided - Very high, moderately consolidated gravelly deposits with strong soil development. High, thin, early Pleistocene alluvial fan remnants deposited on erosional surfaces cut on the gravel and lacustrine members of the Verde Formation. Qo surfaces typically are inset 20 to 50 ft below adjacent surfaces. Where Qo surfaces are well preserved, soil development is strong with very clay-rich argillic horizons and stage IV calcic horizons.

Qo1 – Early Pleistocene alluvium, older member.

Cenozoic basin deposits

Tvl – Late Miocene to Pliocene Verde Formation, lacustrine facies - Laminated lacustrine facies includes interbedded mudstone, limestone, gypsum, and diatomite beds of varying thickness, with sparse and thin intercalations of laminated lacustrine sandstone. Diatomite beds range from 20 cm to 1 m thick. Where diatomite beds interbedded with siltstone dominate this facies exhibits a characteristic white outcrop color, although silt and mud commonly coat outcrop surfaces. Diatomite beds are resistant to weathering and commonly form cliff-slope-cliff topography. Relatively softer beds are composed of a mix of mudstone, siltstone, and limestone. Rare beds of soft, unconsolidated volcanic ash are preserved best underlying resistant beds of gypsiferous siltstone and diatomite. Insects commonly burrow in the volcanic ash layers (House and Pearthree, 1993).

Tvm - Late Miocene to Pliocene Verde Formation, lacustrine marl facies – olive green marl locally containing gypsum and minor halite (van de Poll and Nations, 1996).

Tvv - Interbedded gravel, lacustrine and volcanic facies. This designation is used in areas where volcanic rocks (lava flows and volcaniclastic rocks) are clearly interbedded with fluvial and lacustrine facies of the Verde Formation (House, 1994).

Tvf - Late Miocene to Pliocene Verde Formation, fluvial clastic facies - Fine to medium grained, carbonate-cemented, reddish arenite interbedded with marls and white to buff massive limestones.

Tsy – Late Miocene to Pliocene deposits - Weakly to strongly consolidated conglomerate and sandstone deposited in basins during and after late Cenozoic faulting. Includes lesser amounts of mudstone, siltstone, limestone, and gypsum. These deposits are generally light gray or tan. They commonly form high rounded hills and ridges in modern basins, and locally form prominent bluffs. Deposits of this unit are exposed widely in the dissected basins of southeastern and central Arizona.

Tsu – Tertiary deposits, undivided - Moderately to strongly consolidated conglomerate, undivided.

Bedrock units

Tb – Tertiary basalt – Miocene, Pliocene, and possibly Oligocene basalt flows, associated cinder cones and pyroclastic rocks, intrusive basalts, and mafic rocks.

Tt – Tertiary tuff - Felsic ash flow tuff, pumice, and siliceous flows.

Ts – Tertiary Sandstone, undivided - Sandstone, volcanic sandstone, nonwelded tuff beds, and interbedded mudstone to cobble conglomerate.

Pk – Kaibab Formation - lower Permian silty to sandy dolomite, dolomitic and cherty limestone, and lenses of fine grained sandstone (Weir et al., 1989).

Ptc - Toroweap Formation and Coconino Sandstone, undivided - Very fine to fine grained quartzose sandstone in medium to large scale crossbeds and rare horizontal beds.

Psh – Permian Schnebly Hill Formation - Tan to light-gray, eolian, crossbedded sandstone and minor mudstone, limestone, and evaporitic beds. Regionally, correlates with upper part of Supai Group. Thickness near Sycamore Canyon about 640 feet. Thickness at Sedona about 740 feet. Thickness at West Clear Creek about 900 feet. Thins to the west (from DeWitt et al., 2008).

Ph – Permian Hermit Shale - Reddish-brown sandstone, mudstone, and pebble conglomerate. Thickness in Sedona area and near Sycamore Canyon about 300 ft. Thins to the northwest. Typically forms relatively gentle slopes (from DeWitt et al., 2008).

Ps – Permian and Pennsylvanian Supai Formation - Mudstone, siltstone, sandstone, limestone and dolomite, commonly calcitic or dolomitic, mostly laminated and thin-bedded. Forms moderate to steep slopes (from DeWitt et al., 2008).

Pc – Coconino Sandstone - Light gray to tan, fine-grained eolian, cross-bedded sandstone. Thickness as much as 780 ft near Sedona. Thins to the west. Thickness north of Clarkdale about 525 - 690 ft (from Dewitt et al., 2008).

Ptcs - Toroweap Formation, Coconino Sandstone, and upper Supai Formation, undivided (Weir et al., 1989).

P - Permian sedimentary rocks, undivided - Gray to tan, cherty limestone of the Kaibab and Toroweap Formations, and underlying white to tan, fine-grained Coconino Sandstone (Richard et al., 2000).

PIP - Permian to Pennsylvanian Sedimentary rocks, undivided - Interbedded sandstone, shale, and limestone usually characterized by ledgy outcrops. Orange to reddish sandstone forms cliffs near Sedona. This unit includes Supai Group and Hermit Shale in northern Arizona and Naco Group in southern Arizona. It was deposited in coastal-plain to shallow-marine settings during time of variable and changing sea level. Rocks of this map unit in southern Arizona may be in part equivalent to Permian rocks of map unit P in central and northern Arizona (Richard et al., 2000).

Mr – Mississippian Redwall Limestone - Gray limestone and minor chert, typically quite resistant to erosion and thus forms steep slopes and cliffs. Thickness is about 250-300 ft (from DeWitt et al., 2008).

Dm – Devonian Martin Formation - Dark-gray dolomite, minor limestone, and sandy siltstone. Thickness about 300-450 ft (from DeWitt et al., 2008).

Ꞓt – Cambrian Tapeats Sandstone - Reddish-brown sandstone and conglomerate. Thickness about 50-200 ft, and it thickens to the west.

MꞒ- Mississippian, Devonian, and Cambrian Sedimentary rocks, undivided - Brown to dark gray sandstone grades upward into green and gray shale, overlain by light to medium gray or tan limestone and dolostone. This unit includes the Tapeats Sandstone, Bright Angel Shale, Muav Limestone, Temple Butte Formation and Redwall Limestone in northern Arizona, and the Bolsa Quartzite, Abrigo Formation, Martin Formation, and Escabrosa Limestone in southern Arizona. These rocks record intermittent sea-level rise and inundation in early Paleozoic time.

XYg – Proterozoic granite, undivided - Fine to coarse grained granitoids, quartz monzonite, porphry, rhyolite ash flows, mylonite, and granophyre.

Xevr – East Verde River Formation - interbedded siltstone, graywacke, shale, conglomerate, mafic volcanics, felsic flows and tuff (Wrucke and Conway, 1987).

Xdg - Early Proterozoic diorite and gabbro.

Xr – Proterozoic rhyolite, basalt, andesite, conglomerate, and ash flow tuffs, undivided – Wrucke and Conway, 1987.

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