Mapping of Holocene River Alluvium along the 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 the Verde River in central Arizona. 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.

Surficial geologic mapping methods

The AZGS has been actively involved in mapping surficial deposits in Arizona for the past 20 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 portions of the Verde River previously (Pearthree, 1993; House and Pearthree, 1993; House, 1994; Skotnicki, 1995; Skotnicki, 1996a; Skotnicki, 1996b; Skotnicki and Leighty, 1998; and Ferguson et al., 1999), and preliminary geologic mapping has been completed for the Chino Valley North 7 ½' quadrangle during the past year (Figure 1). Although most of 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 can be 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 the Verde River commonly consist of two fairly distinct phases: channel deposits dominated by sand and gravel, 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. Along the Verde River, however, several relatively large perennial tributaries 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 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; Pearthree and Calvo, 1987). In the semiarid southwestern U.S., surface color varies with age because of soil color, vegetation, and rock varnish.

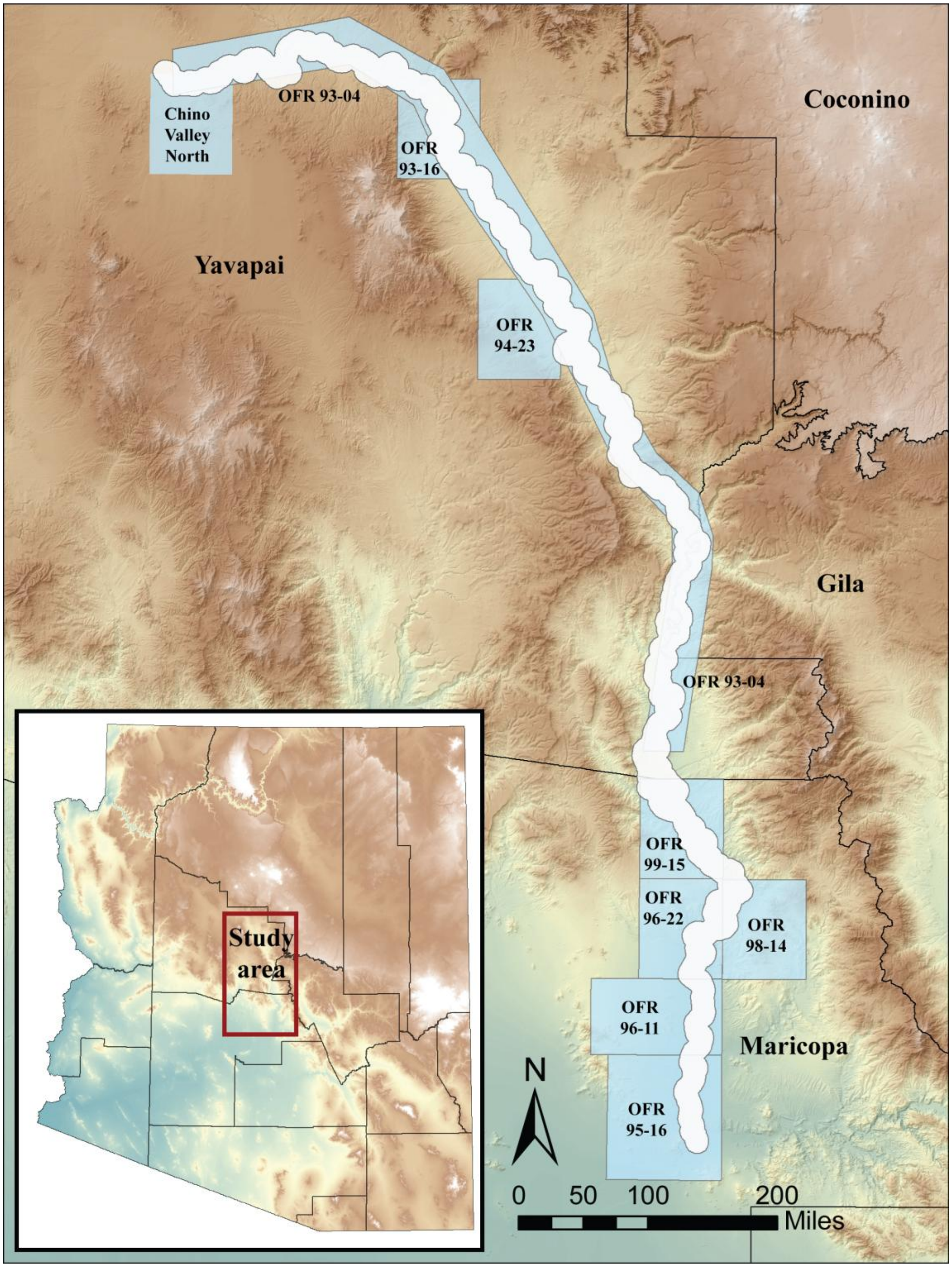

Figure 1. Location map showing the extent of mapping of Holocene floodplain alluvium discussed in this report. Mapped area is shown by white overlay. Blue strips and boxes represent areas previously or presently mapped by AZGS geologists. New and updated surficial mapping along the full length of the Verde River was completed for this report. Where available, existing non-Holocene river alluvium geologic mapping (i.e. prior AZGS and USGS bedrock mapping) will be included in the final strip maps.

Surfaces on piedmont 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 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 that 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. Isolated high river terrace deposits found throughout Verde Valley record former river levels through the Pleistocene. The highest preserved early Pleistocene river terrace deposits are about 350-400 feet above the modern river channel, but are inset well below the highest remnants of the Verde Formation. 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 are not aware of any paleontological remains in Verde River terrace deposits. Numerous archaeological investigations have been conducted at various sites along the Verde River, however (e.g., Whittlesey et al, 1997). We reviewed the records of these investigations and visited several of the sites in the field. In addition, field investigations of river deposits emplaced by historical and prehistoric floods were investigated at several locations along the river (paleoflood studies; House et al, 1995; House et al, 2002). Multiple radiocarbon dates were obtained from each of these locations. The implications of archaeological features and sites and paleoflood 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.

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

Table 1. Simplified 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 14 months, we have checked and revised existing AZGS geologic maps that cover the Verde River and have integrated this Holocene mapping with new geologic mapping in the Chino Valley North 7 ½' quadrangle, which includes the uppermost section of the Verde River. We revised existing geologic maps 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 the Verde River 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 the Verde River 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) and 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.

The Verde River is impounded by Horseshoe and Bartlett Dams northeast of Phoenix. Consequently, extensive areas (up to 2,722 and 2,815 acres respectively) upstream of each dam are seasonally inundated by standing water. The seasonal rise and fall of reservoir levels has altered natural tributary drainage patterns entering the former river bottom. Extensive lake sediment masks both the appearance and morphology of preexisting surficial piedmont and river deposits. Because the modern setting along the Verde River in these locales is standing water at times, control points were collected around the high water line on both reservoirs. Where possible when reservoir levels were low, limited surficial mapping was conducted below the high water line where landform shape was discernable. Further interpretation was made possible through the use of high resolution aerial imagery taken at relatively low reservoir levels. The level of mapping detail presented below high water lines for each reservoir is significantly less than mapping outside reservoir boundaries as field and photo interpretations were less reliable due to overlying water and sediment.

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. Throughout steep-walled canyon reaches such as near the headwaters or along much of the Wild and Scenic reach between Beasley Flat and Sheep Bridge, 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, boundaries of small entrenched tributary channels, and well marked high water lines around reservoirs (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 7 and 8). 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, 10, and 11). Dotted line boundary location is probably accurate to within 500 feet (±250 ft) depending on level of disturbance.

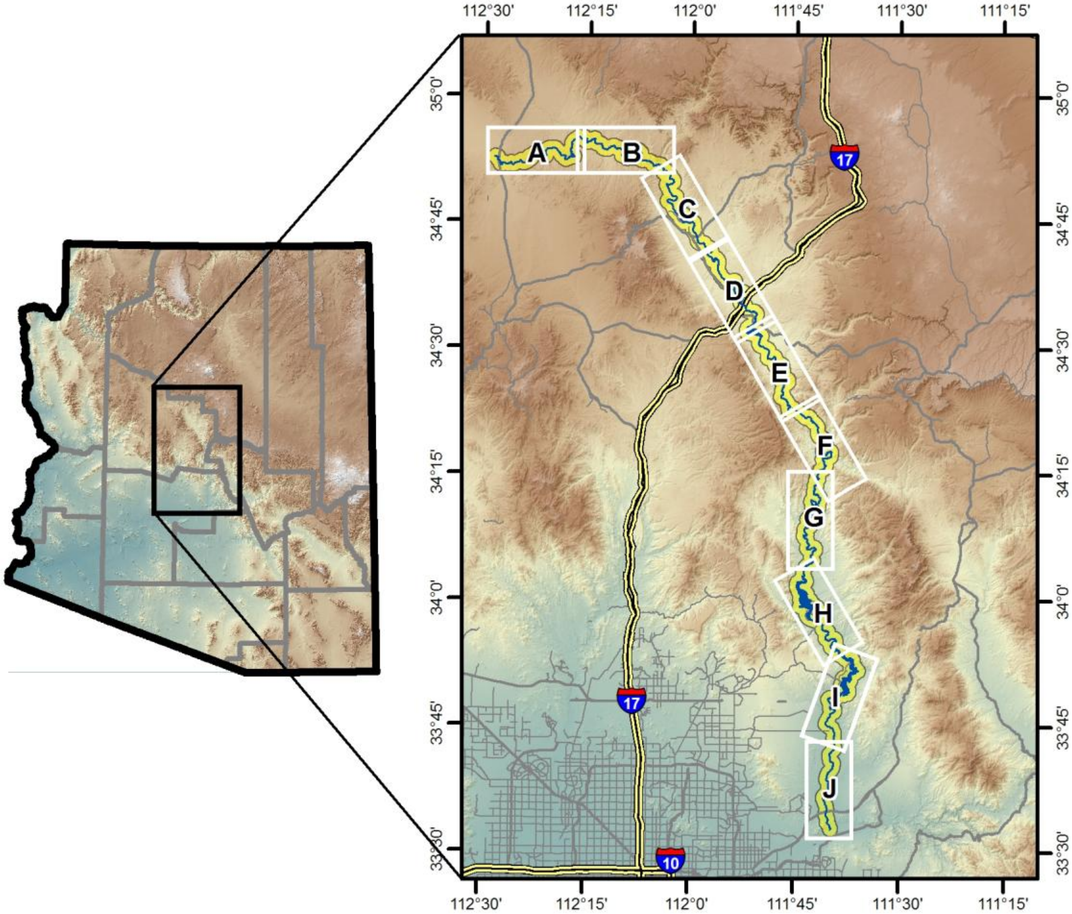

Figure 2. Schematic diagram depicting distribution of map sheets A through J (white boxes). Individual map sheets often span multiple 7 ½' USGS quadrangle maps. Overlap of sheet figures is intentional to ensure complete coverage of mapped areas.

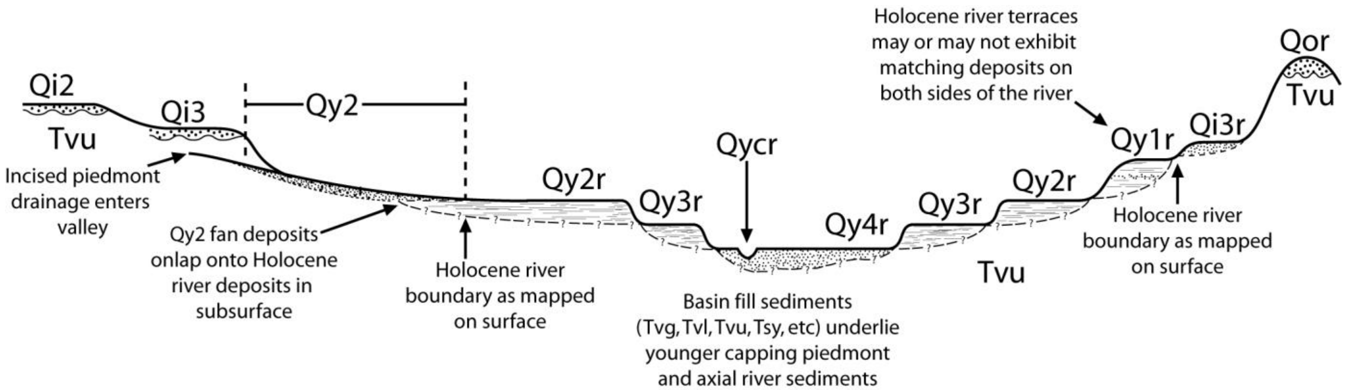

Figure 3. Generalized cross section of geomorphic relationships between Tertiary basin fill (Tsy, Tvu, Tvl), Pleistocene piedmont and river (Qi_n, Qi_nr, and older Qo_nr units), and Holocene piedmont and river (Qy_n and Qy_nr units) deposits. Boundaries between units are based on surface mapping. Subsurface relations are not well-known and likely vary along the river.

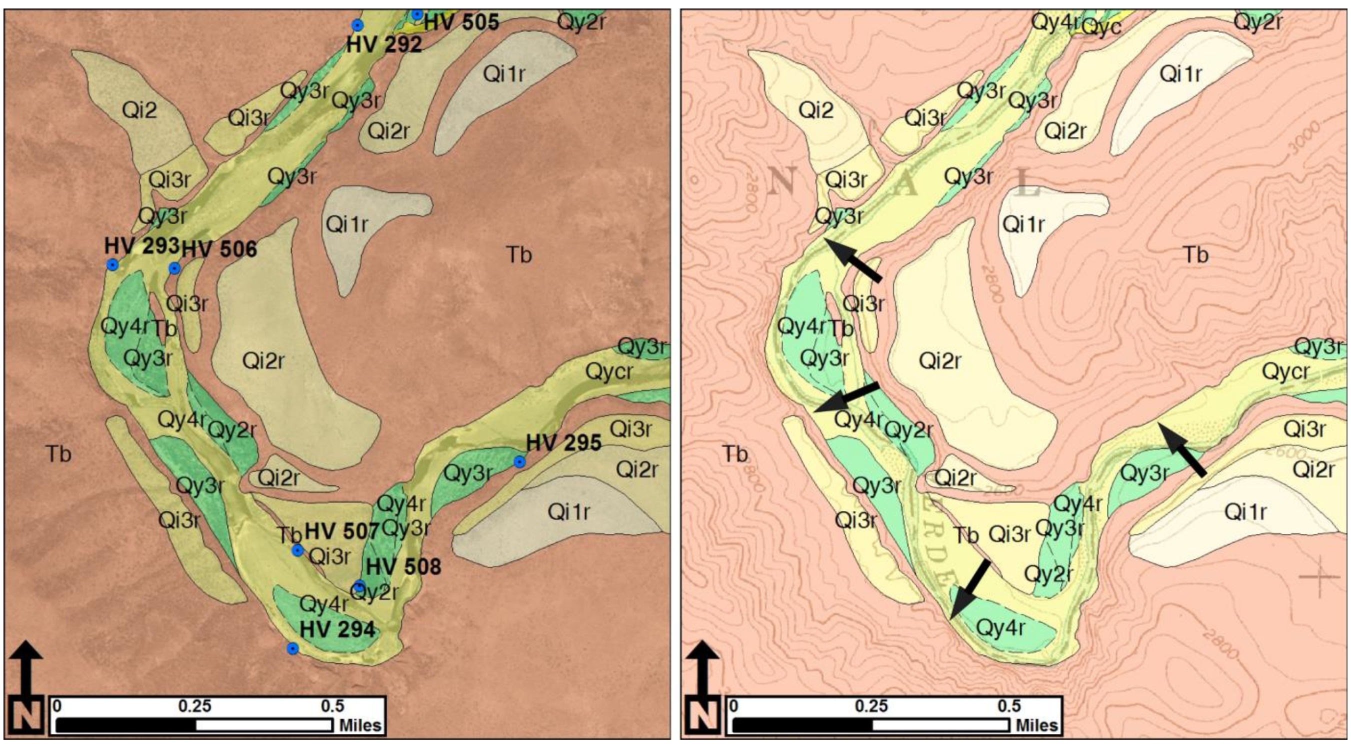

Figure 4. Map of bedrock-bound Holocene floodplain alluvium below Childs. Abrupt bedrock cliffs mark the extent of Holocene alluvium. Elevated Qi3r, Qi2r, and Qi1r terraces are Pleistocene in age.

Figure 5. Ground photo of incised portion of upper Verde River. Abrupt boundaries are mapped with solid lines. The limit of Holocene floodplain alluvium is at the base of basalt walls on both sides of the channel.

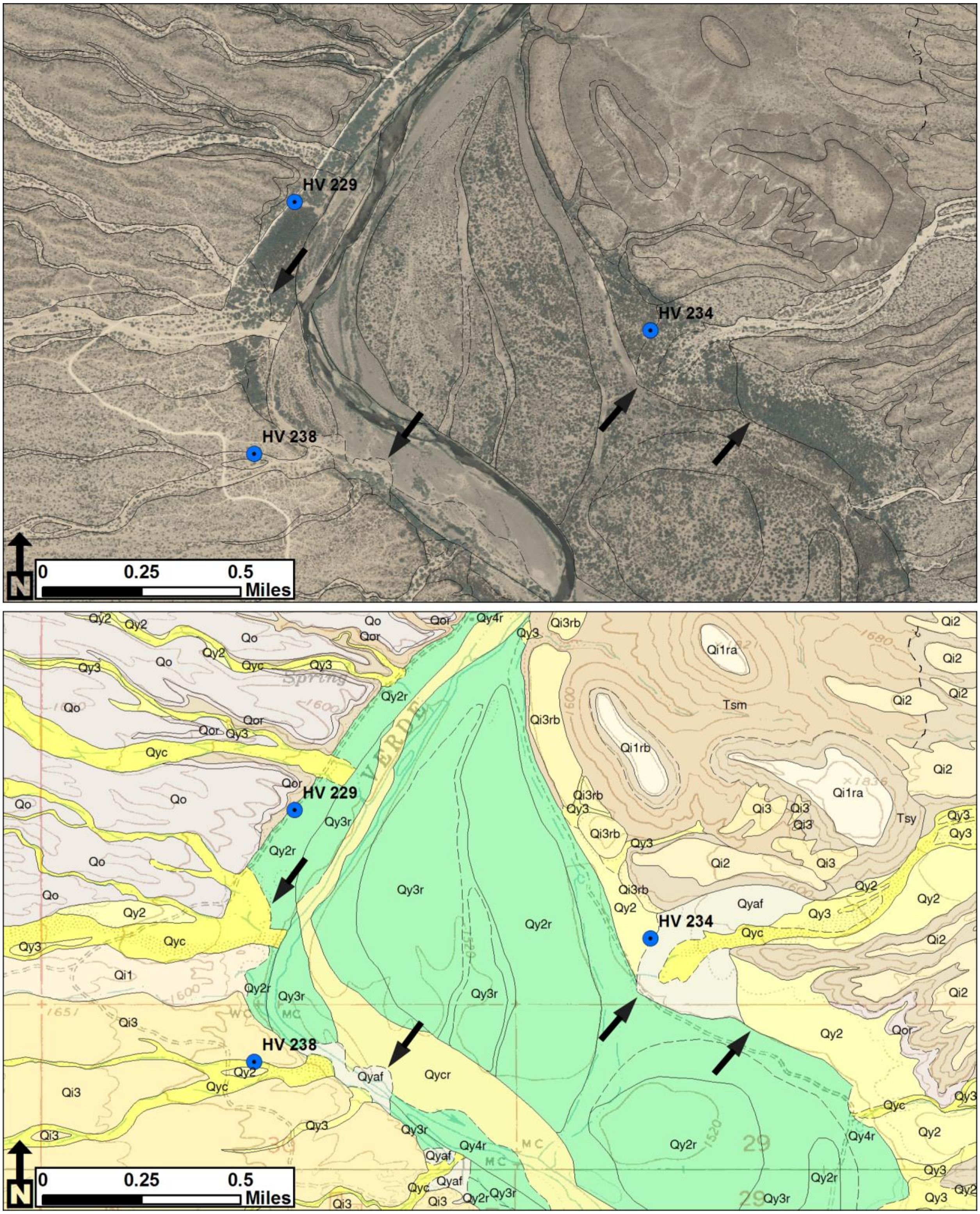

Figure 6. Arrows point to short, steep fans located at the base of Cenozoic basin fill bluffs. Portions of the fan toe end abruptly and can be accurately pinpointed in the field and on aerial photos. These boundaries are mapped with a solid line. The extent of nearby fans is lower relief and subtle. These portions are mapped with a dashed line.

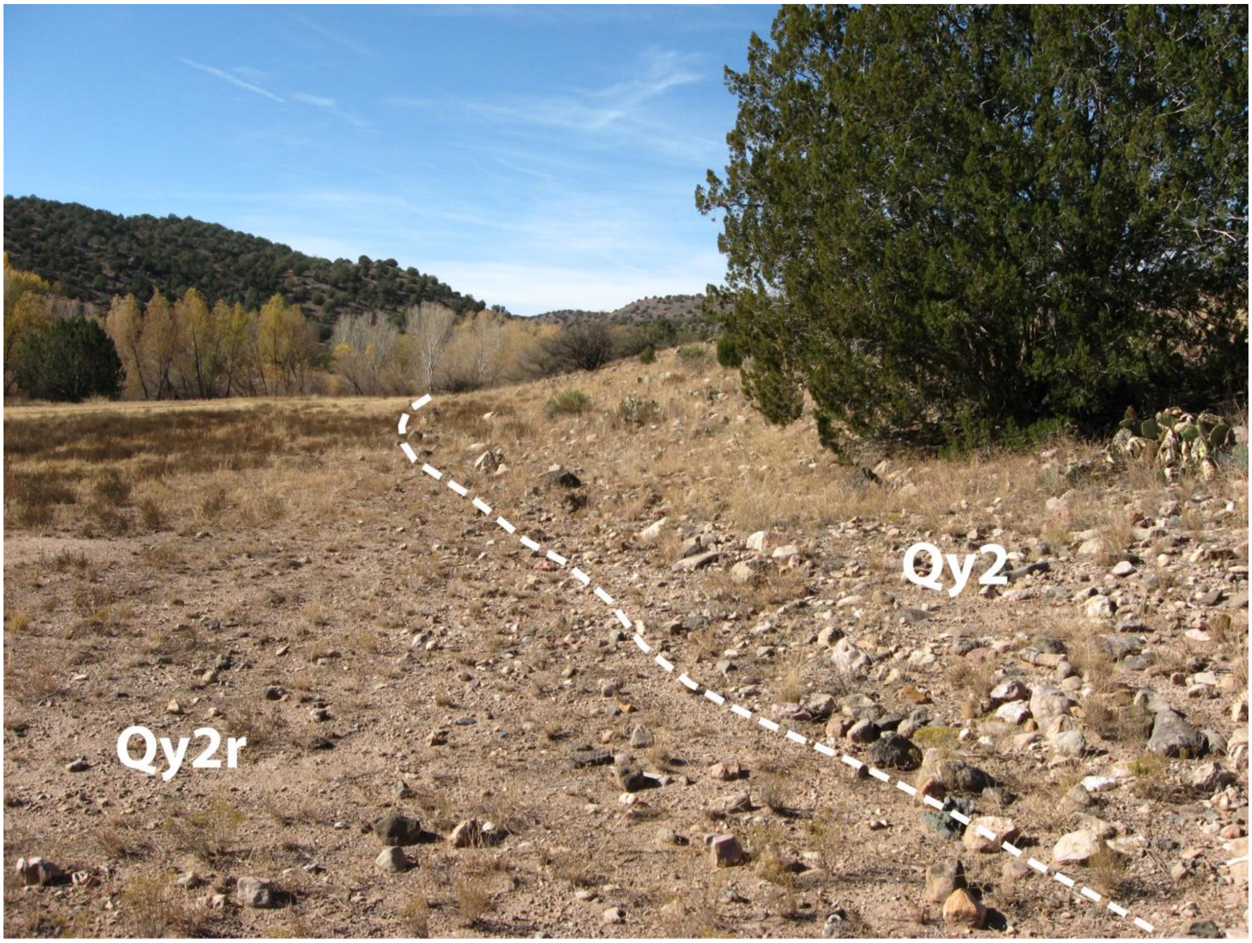

Figure 7. Ground photo of the slope break between Holocene floodplain alluvium (Qy2r) and tributary fan alluvium (Qy2) derived from canyon walls and steep, piedmont drainages.

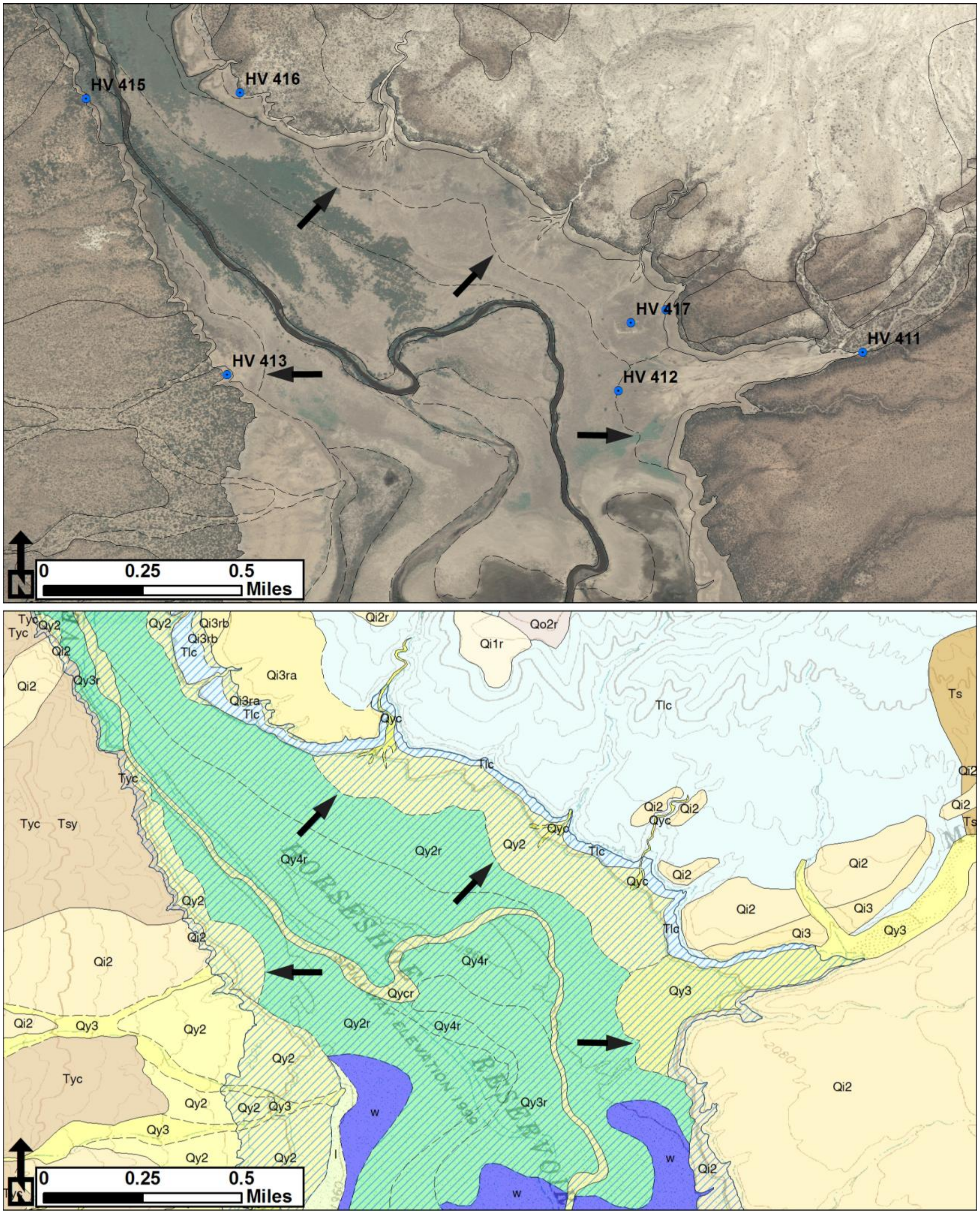

Figure 8. Holocene tributary fan deposits (Qy2) derived from several sizable tributary fans form a continuous apron of variable width along the margin of Holocene river floodplain alluvium in the upper part of Horseshoe Reservoir. Dashed lines are used to represent boundaries between Qy2, Qy3, and Qy2r deposits because the field relationships are subtle and obscured by lake sediments.

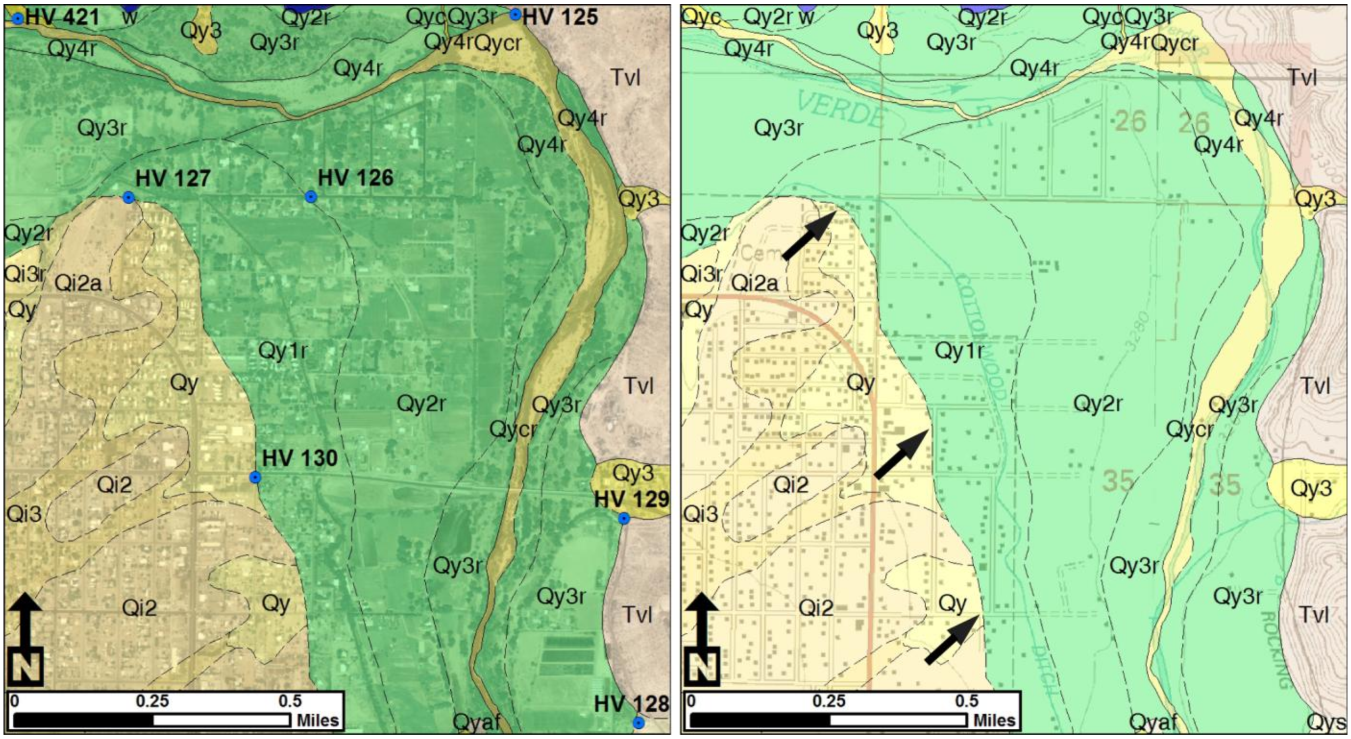

Figure 9. In populated areas such as Cottonwood, topographic relief between Holocene tributary fans and river terraces is very low and heavily disturbed. Dotted line contacts (highlighted by arrows) are used where geomorphic contacts are obscured by anthropogenic activity.

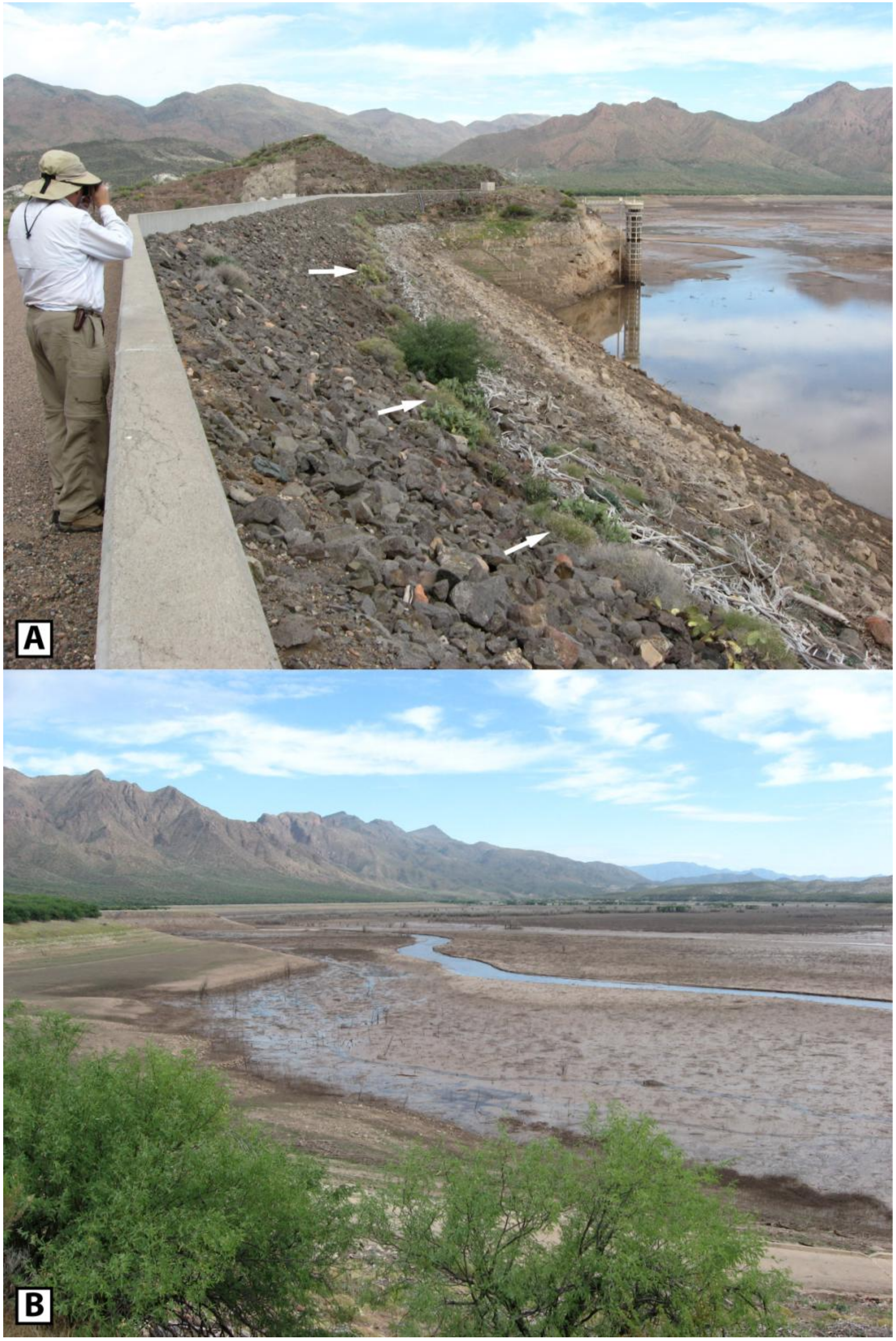

Figure 10. A) View to the west toward Horseshoe Dam. High water line above recently drained reservoir marked by white arrows and piled sticks. B) View to the northeast from above Horseshoe Reservoir. Piedmont fans near the left side of the photo exhibit numerous water lines. Verde River (Qycr) in center of photo. Photos taken 6/09/09, Horseshoe Reservoir 0% full (http://www.srpwater.com/dwr/report.asp?dt=06/09/2009).

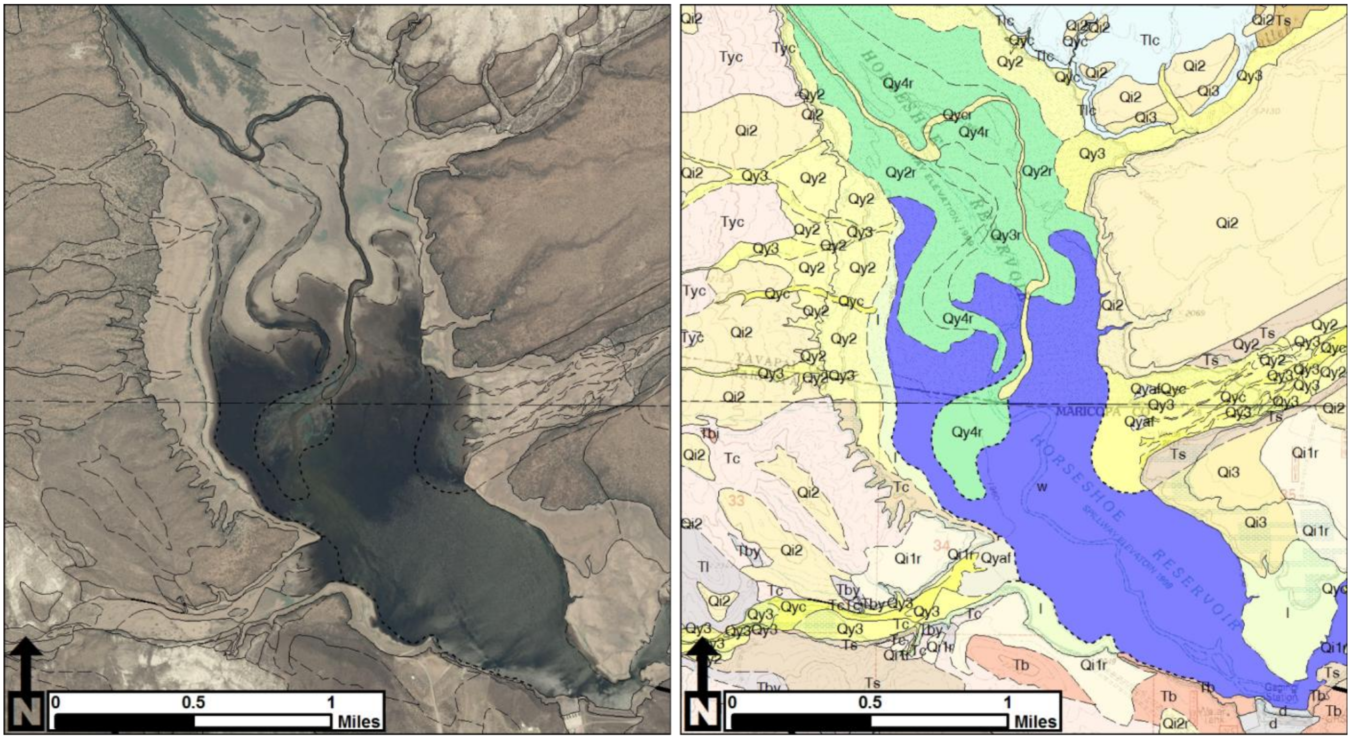

Figure 11. Deposits submerged when reservoir levels are high were mapped through a combination of field checking (if possible) and aerial photo interpretation. As shown in Figure 10, even low water levels do not clearly expose underlying deposits.

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 the Verde and major tributaries (unit Qy$_{c}$r) 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 the Verde River (see Map Sheets). In reaches where the streams have cut through bedrock, such as downstream from the headwaters of the Verde River; from just below Perkinsville to below Sycamore Canyon; and much of the Wild and Scenic reach of the Verde River (Figure 12), the lateral boundaries of Holocene floodplain alluvium are sharply defined and the total width of floodplain alluvium is a few hundred feet or less. More commonly, where the river is incised into the basin-fill deposits of the Verde Formation or other basin deposits, the width of the Holocene floodplain varies from 1,000 to 3,000 feet. The width of the Holocene river floodplain is less where reasonably large tributaries join the Verde River, 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 11). Deposits of 5 of the largest Verde River tributaries (Oak Creek, Beaver Creek, West Clear Creek, Fossil Creek, and East Verde River) are depicted as river alluvium.

Although many deposits flanking Holocene river alluvium are also Holocene in age, only several piedmont units typically convey surface flow to the river channel. Qyc deposits (modern stream channel

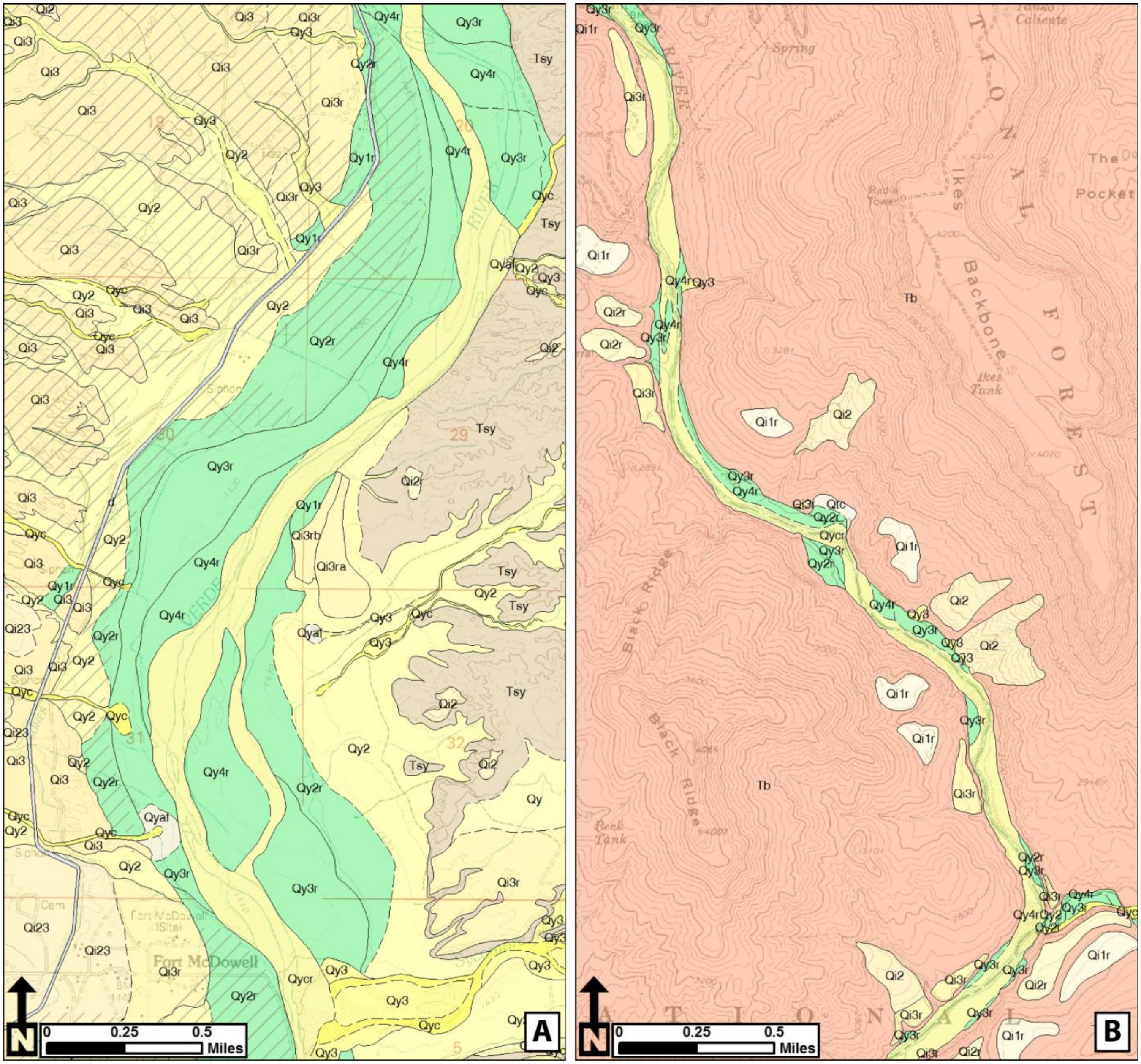

Figure 12. A) Example of less confined reach of Verde River. Below Bartlett Reservoir the Verde River has incised through basin fill (Tsy) deposits and exhibits wide meanders, secondary channels, and widespread Holocene deposits. B) Example of bedrock confined reach of Verde River below Childs. Almost the entire valley bottom is covered by channel (Qycr and Qy4r) or young terrace (Qy3r) deposits due to flooding and channel migration.

deposits) occupy the lowest elevation within the piedmont, 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 typically 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.

Geologic map versions. The geologic interpretations depicted in the maps that accompany this report are based on a combination of pre-existing mapping and new mapping. Thus, this mapping supersedes previous mapping in regards to the extent of Holocene Verde River deposits. The AZGS will eventually release new versions of some of the previously released geologic quadrangle maps from Verde Valley that are consistent with the delineation of Holocene alluvium depicted in this report. These maps were previously released as Open-File Reports (OFRs), but we plan to release the new versions as Digital Geologic Maps (DGMs). The previous reconnaissance strip geologic map along the Verde River above Horseshoe Reservoir (Pearthree, 1993) is completely superseded by our new river maps. We have made some fairly substantial modifications to the existing geologic maps along the Verde River from Verde Valley to below Sheep Bridge, and additional detail was added to existing maps below Bartlett Reservoir to the Verde's confluence with the Salt River. We do not plan to release new versions of the quadrangle maps at this time.

Verde River geology and geomorphology

The Verde River is a relatively large and dynamic fluvial system that drains much of central and northern Arizona from its inception point located approximately 22 miles north of downtown Prescott at Sullivan Lake. The upper Verde River flows east through deeply entrenched meanders approximately 30 miles (smoothing out tight meanders) to its confluence with Sycamore Creek. From here, the Verde changes course and flows over 45 miles to the south-south east through Cottonwood and the Verde Valley before swinging southward for another 50 miles until its confluence with the Salt River east of the Phoenix metropolitan area (Figure 1). All estimates flow direction distances are as the crow flies. Due to its meandering course, the cumulative length of the Verde River is approximately 178 miles (Byrkit, 1978).

The Verde River watershed 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 watershed are on 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. Most of the watershed is in the rugged Arizona Central Highlands, which consist of large dissected mountain blocks underlain by Precambrian granitic rocks and Tertiary volcanic rocks and variably dissected late Cenozoic sedimentary basins (Richard et al., 2000). 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 (e.g., House et al., 1995). Numerous deeply incised south-draining tributaries efficiently concentrate and convey runoff from the plateau margin through steep canyons to the Verde River.

River bed altitude ranges from 4,366 ft above sea level (asl) at its inception below Sullivan Lake to 1,320 ft asl at the Salt River confluence. The location of Sullivan Dam approximately coincides with the location where axial valley drainage becomes incised and is named the Verde River on USGS topographic maps. The Verde watershed is approximately 6,646 mi^2, including parts of Coconino, Yavapai, Gila, and Maricopa Counties. Historically the Verde River has been divided into upper (above Sycamore Canyon, at the northwest edge of Verde Valley), middle (below Sycamore Canyon but above Fossil Creek), and lower (below the Fossil Creek confluence) reaches (Byrkit, 1978). The upper Verde River is confined for much of its course to a relatively narrow canyon of entrenched meanders through basalt flows, Paleozoic limestones, and basin filling sediments. These deposits are flanked by Big Black Mesa to the northwest and the Black Hills to the southeast. The middle Verde River traverses a much broader valley than that of its headwaters, cutting through more Paleozoic limestone as well as extensive late Miocene to Pliocene Verde Formation sediments consisting of lacustrine and playa deposits, silt and clay rich deposits, and freshwater limestone. Mountains flanking the Verde Valley consist of the Black Hills to the southwest and Mogollon Rim country to the northeast. Below the Verde's confluence with West Clear Creek south of Camp Verde, the river once again becomes confined to canyon reaches, this time for over 50 miles. This stretch of the Verde River flows through an extremely rugged and dissected canyon landscape whose walls consist of middle to late Cenozoic basin deposits, thick sequences of basalt flows, and Precambrian granites. The river is flanked by the southernmost Black Hills, Pine Mountains, and Bloody Basin on the west and Hardscrabble Mesa and the Mazatzal Mountains and Wilderness area on the east. Below this canyon reach, the Verde River valley alternates between fairly broad sedimentary basins and separated by an incised bedrock canyon reach. The river is impounded by Horseshoe and Bartlett Dams, so much of the river valley is inundated depending on reservoir levels. The valley floor as well as a significant portion of the lower piedmont is often submerged at Horseshoe Reservoir while the entire valley bottom and a portion of the surrounding bedrock is commonly under water at Bartlett. Below Bartlett Reservoir to its confluence with the Salt River, the Verde River flows through a fairly broad valley that is flanked by the McDowell Mountains to the west and Granite Mountains to the east.

Along its entire course, the Verde River is fed by numerous minor drainages as well as a number of major tributary streams. In deeply incised canyon reaches, bedrock is likely fairly shallow beneath the channel and both Verde and tributary deposits are laterally confined due to their entrenchment into adjacent bedrock or indurated basin fill deposits. In broader reaches, such as the Verde Valley and below Bartlett Reservoir, both Verde River Holocene 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 (see Figure 8). 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. Deposits associated with 6 large tributaries (Sycamore Creek [northern], Oak Creek, Beaver Creek, Clear Creek, Fossil Creek, and East Verde River) are mapped as “river” deposits, and thus are not shown separately on the map accompanying this report.

Fluvial geomorphology. The geomorphology of the active Verde River fluvial system 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. This low-flow channel winds through the flood channel, a much larger channel that is 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 the Verde River in both canyon and bedrock reaches. Pools are relatively wide and deep, and 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 (Figure 5, 12). Changes in water-surface slope associated with riffles 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 the Verde River 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. 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 the river, the flood channel occupies almost the entire canyon bottom, with small and laterally discontinuous flood terraces perched above it (Figure 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 grass- or shrub-covered. Flood terraces are small and discontinuous in the upper canyon reach. In Verde Valley, floodplain terraces commonly are wide and extend continuously along the flood channel for long distances. 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 are cultivated.

Modern channel conditions. 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. In these areas it may be possible to observe dry surface conditions during the day and wetter conditions overnight due to the phreatophytic nature of the local vegetation. 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 the Verde River, cottonwood, willow, and sycamore line active and flood channels while vegetation on fine grained Holocene terraces is medium to large mesquite, desert broom, and tamarisk. Throughout much of the lower Verde, mesquite, acacia, and tamarisk dominate most Holocene age terraces although thin strands of cottonwood, 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 creosote, catclaw acacia, brittlebush, ocotillo, prickly pear, barrel, cholla, and saguaro.

Sediments within the active Verde 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. Most of these tributaries are dry, sandy 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 Verde channel following precipitation events (Figure 14).

Because the Verde River is incised into bedrock or basin deposits, the overall width of the modern and historical Verde floodplain has been 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 Verde floodplain may be confined to 100 – 400 ft across whereas in less confined reaches the Holocene floodplain typically is 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. The modern Verde 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.

An excellent and large-scale example of an abandoned meander forming an oxbow is Peck's Lake near Tuzigoot National Monument upstream from Cottonwood. Here the Verde used to flow in tight meanders doubling back to the north before swinging back south along the cliffs formed by the Verde Formation (Figure 13). Erosion of the outside walls of the upstream and downstream channel south of Tuzigoot NM breached the divide formed in Verde Formation deposit and caused the meander to be abandoned, probably about 2.6 ka (Davis and Turner, 1986). The entrance to the abandoned meander is now filled by mine tailings; an artificial lake (Peck's Lake) is supplied by water piped from the Verde River,; a more extensive marshy area (Tavasci Marsh) downstream is probably more representative of prehistoric conditions (Davis and Turner, 1986, p. 184). At the downstream end of the abandoned meander, the former valley floor now stands several meters higher than the modern active channel.

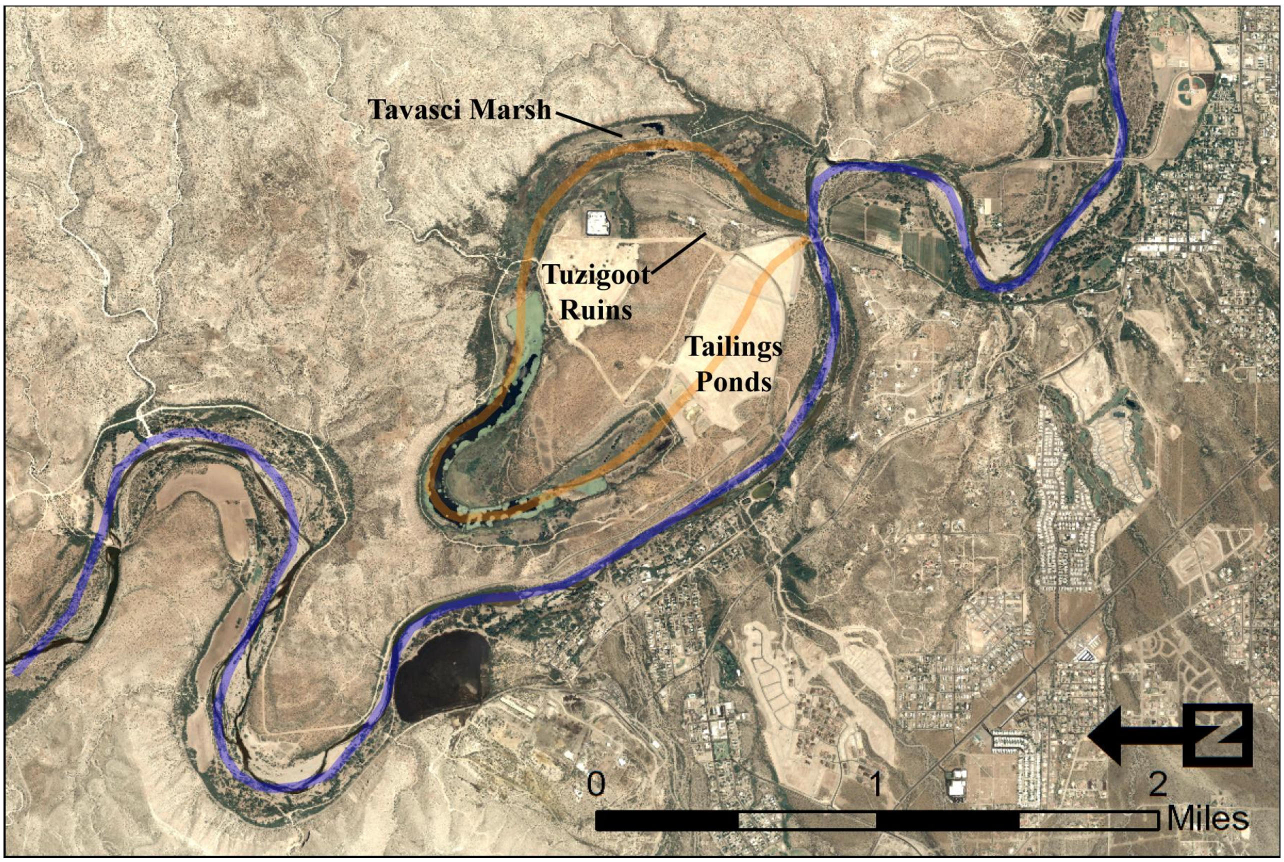

Figure 13. Verde River at Tuzigoot upstream from Cottonwood. River flow direction is from north to south (left to right). Blue path marks the current channel location of the Verde River. Red path (now disturbed by mill tailings) marks former channel location, now an abandoned meander.

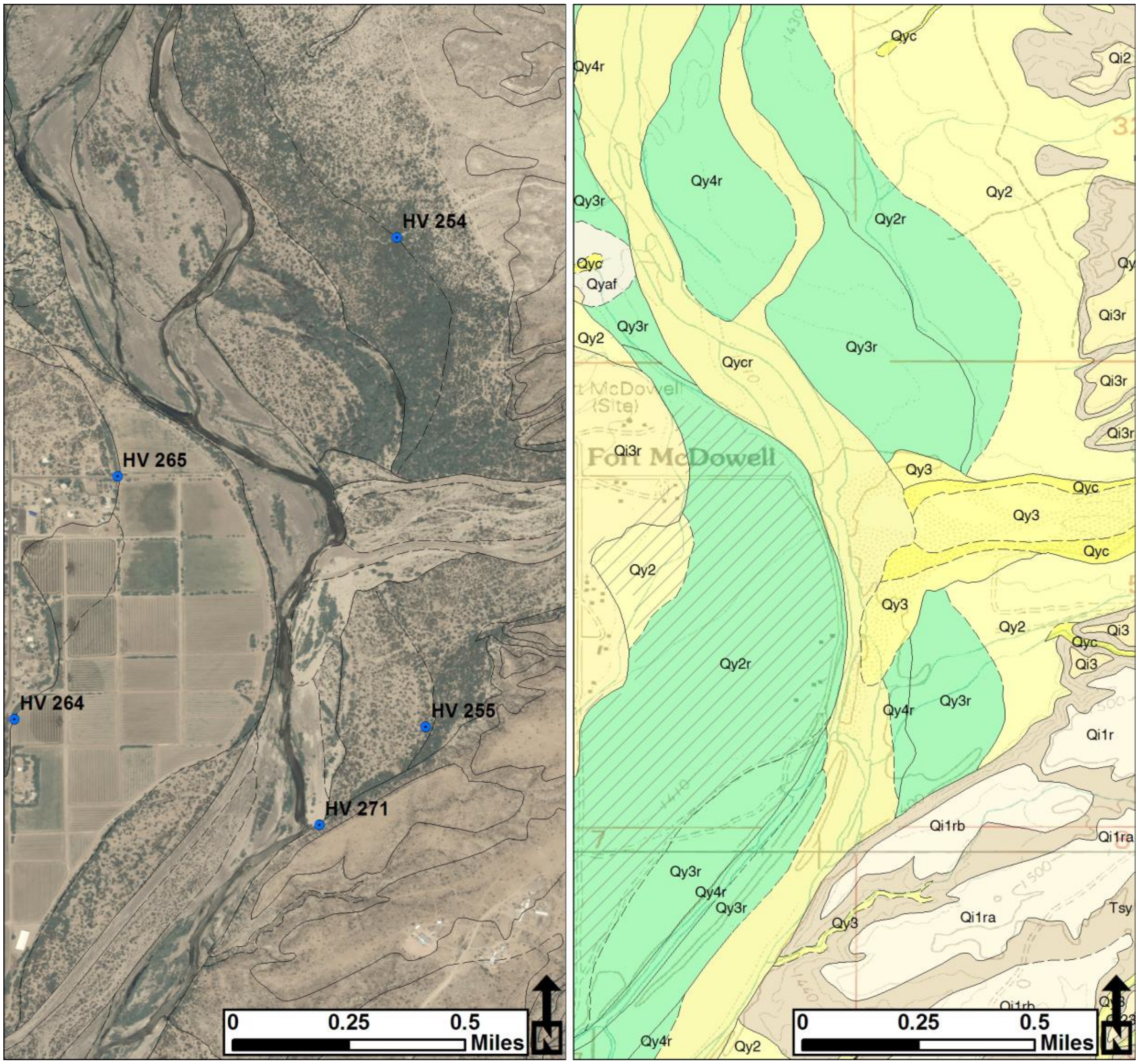

Figure 14. Significant sediment influx from Sycamore Creek (near the Fort McDowell Indian Reservation) joins and covers Verde River deposits near Fort McDowell. Although deposits from large tributary channels may be rounded to well rounded, lithology often differs and is less diverse.

Age constraints on Verde River Holocene deposits

Archaeological data and radiometric dates from paleoflood investigations were used to evaluate and refine the age ranges assigned to river terrace deposits and surfaces. Datable organic material or artifacts buried in terrace deposits can provide a *maximum* age for the overlying deposits and geomorphic surface, whereas datable material on a terrace tread surface can provide a *minimum* age for the underlying deposits.

Archaeology. 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. Most site locations were acquired as a GIS layer from the ASM, although locations of more recently recorded sites were copied manually from museum paper records. Some site locations were corrected using the original museum site records. Additional site information not available from ASM was obtained from unpublished theses and 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 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 was either 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, Tonto Plain Ware pottery dates from AD 700-1400 (Wood, 1987), whereas Gila polychrome pottery dates from AD 1350-1400 (Oppelt, 2007).

Buried archaeological material and associated radiocarbon dates with relatively 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 associated with an archaeological hearth feature buried within a terrace fill is radiocarbon dated to 1500-2000 yrs BP, the earlier end of the associated range (i.e., 2000 yrs BP) provides a maximum age for the overlying deposits and the terrace surface. In this example, the terrace surface must be younger than 2000 yr BP, and any terraces inset into this terrace must also post-date 2000 yr BP. Similarly, the later end of the associated range (1500 yr BP) provides a minimum age for the terrace fill deposits underlying the archaeological material. Archaeological material eroded from its original context and deposited in a secondary context also provides a maximum age for overlying deposits, but 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 terrace surface indicates that the surface and underlying deposits must be older than AD 1150.

If surface artifacts are reworked from archaeological deposits originating on a topographically higher adjacent 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). In addition, the alluvial deposits and surface associated with the archaeological material must be correctly mapped, as must be the location of the archaeological site. 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.

Table 2. Temporally Sensitive Archaeological Artifacts and Site Characteristics

Description	**Years A.D.**	**Reference**
CULTURAL PERIODS		
Historical	1600-1950	Van West et al. 2005
Classic Period (Hohokam)	1100-1450	Whittlesey et al. 1997
Sinagua Culture	500-1425	Fuller et al. 1976
Honanki Phase (Sinagua)	1100-1300	Fuller et al. 1976
PREHISTORIC ARCHITECTURAL FEATURES		
Pit house villages	1-1150	Heckman et al. 2000; Fish and Fish 1977
Ball courts	700-1150	Van West et al. 2005
Surface rooms/ field houses	900-1400	Fuller et al. 1976; Van West et al. 2005
Walled compounds	1100-1450	Fuller et al. 1976 Whittlesey et al. 1997
Small pueblos	1100-1400	Fuller et al. 1976; Van West et al. 2005
Large pueblos	1300-1425	Van West et al. 2005
PREHISTORIC CERAMICS		
Black Mesa Black-on-white	1000-1150	Mills and Herr 1999
Black-on-white (Indeterminate)	550-1330	Mills and Herr 1999
Deadman's Black-on-gray	900-1100	Deaver 1997; Goetze and Mills 1993; Oppelt 2007
Dogoshzi Black-on-white	1060-1320	Mills and Herr 1999

Description	Years A.D.	Reference
Floyd Black-on-gray	700-1200	Hays-Gilpin 2001
Gila Plain Ware	300-1300	Breternitz 1966; Colton and Hargrave 1937 in Fuller et al. 1976
Gila Polychrome	1350-1400	Oppelt 2007
Hohokam Buff Ware	300-1400	Oppelt 2007
Holbrook Black-on-white	1050-1150	Deaver 1997; Hays-Gilpin and van Hartesveldt 1998; Oppelt 2007
Indeterminate prehistoric ceramics	200-1450	Van West et al. 2005
Jeddito Black-on-yellow	1275-1450	Deaver 1997; Oppelt 2007
Kana'a Black-on-white	825-1000	Deaver 1997; Mills and Herr 1999; Oppelt 2007
Little Colorado White Ware	1050-1375	Oppelt 2007
Medicine Black-on-red	1000-1115	Deaver 1997
Pinedale Polychrome	1290-1330	Mills and Herr 1999
Prescott Gray Ware	800-1400	Beck and Christensen 2005
Red-on-buff (Indeterminate)	500-1250	Heckman et al. 2000
Sacaton Red-on-Buff	950-1150	Oppelt 2007
San Franscisco Mountain Gray Ware	900-1100	Oppelt 2007
Santa Cruz Red-on-buff	850-950	Heckman et al. 2000; Oppelt 2007
Shato Black-on-White	1080-1130	Oppelt 2007
Tanque Verde Red-on-brown	1150-1300	Heckman et al. 2000
Tizon Brown Ware	700-1890	Dobyns and Euler 1958; Oppelt 2007
Tonto Plain Ware	700-1400	Wood 1987
Tonto Polychrome	1350-1400	Oppelt 2007
Tusayan Black-on-red	1045-1240	Christensen 1994
Tusayan Black-on-white	1200-1320	Mills and Herr 1999
Tusayan Corrugated	1020-1210	Christensen 1994
Tusayan Gray Ware	600-1300	Oppelt 2007
Tusayan White Ware	600-1330	Mills and Herr 1999
Tuzigoot Plain Ware	1100-1400	Colton 1958; Oppelt 2007; Wood 1987
Tuzigoot Red Ware	1150-1400	Oppelt 2007; Wood 1987
Verde Black-on-gray	1050-1300	Deaver 1997
Verde Brown Ware	1100-1300	Colton 1958 in Fuller et al 1976
Verde Gray	1100-1300	Oppelt 2007
Verde Red	1150-1400	Wood 1987
Wingfield Plain Ware	300-1300	Wood 1987
MISCELLANEOUS		
Sun-colored amethyst (SCA) glass	1870s-1917	Firebaugh 1983

Results

***Qycr and Qy4r*.** Although AZSITE maps implied that 15 sites were recorded on the Qycr and/or Qy4r surfaces, subsequent review of the associated site records and field-checking indicated that these sites were misplotted and did not coincide with these surfaces. 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. The absence of archaeological sites on Qy4r and Qycr surfaces is not surprising given the active nature of these surfaces, with Qycr constituting active channel deposits and Qy4r undergoing inundation during moderate to high stream-flow events.

***Qy3r*.** Arizona State Museum records initially suggested that nine prehistoric and four historical period surface sites were recorded on the Qy3r terrace (Table 3). The prehistoric sites were field-checked because the age of these sites would not be consistent with the historical age assigned to the Qy3r fill. Five of the prehistoric sites were accessible. We found no archaeological material on the Qy3r portions of these five sites, and we conclude that the site locations were inaccurately plotted on ASM records. These prehistoric sites were recorded in the 1950s, 1970s or early 1990s, all prior to the wide availability of inexpensive and accurate GPS receivers.

The oldest (U:6:183 [ASM]) of the four historical period sites on Qy3r contains a ditch constructed between 1890 and 1900 (Figure 15 and Table 3). Two radiocarbon dates on wood charcoal from hearths buried approximately 2.5 and 3 m below the Qy3r surface at the Black Canyon locality several miles south of Bridgeport date to AD 1300-1430 and AD 1330-1610, respectively (Figure 16 and Table 4) (Kornmeyer, 2002). These hearths are presumably contained in Qy3r fill deposits, and when considered in conjunction with the surface sites suggest that the Qy3r terrace fill deposition began sometime prior to AD 1300. Investigations of flood deposits associated with Qy3r terraces revealed that they are locally capped by historical flood deposits, including deposits from the floods of January and February of 1993 (House et al, 2002). Radiocarbon dates from subsurface contexts below the Qy3r terrace tread, including six dates on detrital charcoal, two bulk sediment dates, and two dates on lenses of charcoal or uncharred flotsam, are also summarized on Figure 16 and Table 4. The bulk sediment dates and the deeper of the detrital charcoal dates from Riverfront Park overlap with dates from the Qy2r terrace deposits discussed below.

***Qy2r*.** One buried archaeological site and 39 surface sites containing chronometric information are associated with Qy2r (Tables 3 and 4; Figures 16 and 17). The buried site consists of an archaeological hearth buried 1.6 m below the Qy2r tread at the Dead Horse Cliffs locality near Cottonwood, and a radiocarbon date on charcoal from this hearth has a two sigma calibrated range of AD 430-720 (House et al., 2002; Huckleberry and Pearthree, 2005). Six of the surface sites contain only historic components, but the others all have prehistoric components post-dating AD 1. The presence of Santa Cruz Red-on-buff (AD 850-950 BP) (Heckman et al., 2000; Oppelt, 2007) or Kana'a Black-on-white (AD 825-1000) (Deaver, 1997; Mills and Herr, 1999; Oppelt, 2007) pottery at four surface sites on the Qy2r tread imply that there has been no significant deposition of Qy2r fill since AD 900-1000 at those sites (see Figure 17). Archaeological temporal indicators at nine other Qy2r prehistoric surface sites suggest that Qy2r fill deposition ended by AD 1150, while temporal indicators at the remaining 20 prehistoric surface sites on Qy2r imply that deposition ended sometime before ca. AD 1400 (see Figure 17). Archaeological age constraints support a late Holocene age for the Qy2r fill, but post-AD 1400 deposition has been negligible at all of the sites.

The temporal framework implied by the archaeological dating suggests that some of the non-archaeological dates summarized on Table 4 and Figure 16 may be problematic. Johnson et al.'s (1997) two bulk sediment dates (AD 1410-1640 and AD 1300-1450) from 1-1.5 m below the Qy2r tread at the H-1 and H-5 localities near Horseshoe Reservoir are suspect because they postdate the majority of the archaeological sites documented on the Qy2r tread. Similarly, three dates from deposits underlying the Qy3r tread are suspect, including the two bulk sediment dates from Johnson et al.'s (1997) H-2 locality near Horseshoe Reservoir, as well as the deeper detrital charcoal sample from Huckleberry and Pearthree's (2005) Riverfront Park locality near Cottonwood. These dates are problematic because they apparently pre-date the deposition of Qy3r fill. These anomalously old dates may actually be from Qy2r deposits underlying a locally thin layer of Qy3r fill inset into Qy2r fill at these two localities. Alternatively, the dated material could be reworked from older deposits. Holocene river terraces are mapped primarily based on their surface character and geomorphic position relative to the modern river channel, and the stratigraphic details of the deposits associated with the terraces are likely quite complex in three dimensions. Thus, it is possible that deposits associated with Qy3r and Qy2r terraces overlap in age depending on the details of any particular location.

In sum, extensive archaeological surface site data and very limited subsurface data suggest that Qy2r fill deposition began prior to ca. AD 500-600 and was insubstantial after ca. AD 900-1150. Subsequent Qy3r fill deposition began by ca. AD 1300 and continued until historical arroyo cutting at the end of the 19^{th} century. When the problematic, non-archaeological dates discussed above are excluded, the other dates suggest that Qy3r deposition began by AD 1150.

Qy2r and Qy3r terrace formation along the main trunk of the Verde River 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 River. T-2 fill deposition 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 channel incision in the late 1800s.

<u>Qy1r</u>. Only one site (AZ U:6:102[ASM]) has been recorded on a Qy1r surface along the main trunk of the Verde River. This site, which extends onto adjacent Qy2r and bedrock surfaces, is a Hohokam surface site dating to the Colonial and Sedentary periods (AD 750-1150). Unfortunately, this site contributes nothing to our understanding of the age of Qy1r deposits because it was already known from geomorphic relationships that Qy1r fill is older than the AD 500-600 maximum age inferred for Qy2r.

Table 3. Characteristics of archaeological surface sites used to constrain terrace age estimates.

Site	USGS 7.5’ Quadrangle	Archaeological Temporal Indicators
Qy3r		
N:8:21 (ASM)	Cottonwood	House post-dating AD 1920
U:2:142 (ASM)	Bartlett Dam	Historical period campsite associated with Bartlett Dam construction from AD 1935-1940
U:6:182 (ASM)	Fort McDowell	Historical period trash scatter dating from AD 1903-1939
U:6:183 (ASM)	Fort McDowell	Historical period trash scatter and ditch (Jones Ditch, constructed AD 1890s)
Qy2r (Upper Verde)		
N:3:44 (ASM)	Chino Valley North	Prescott Gray Ware; Tizon Brown Ware
N:3:48 (ASM)	Chino Valley North	Prescott Gray Ware; Tizon Brown Ware; Tusayan Corrugated
N:4:17 (ASU)	Perkinsville	Black Mesa Black-on-white; Deadman’s Black-on-gray; Holbrook Black-on-white; Kana’a Black-on-white; Medicine Black-on-red; Tusayan Black-on-red; Verde Black-on-gray; Verde Gray
NA 14520	King Canyon	Prehistoric ceramics; surface rooms
NA 14703	Hell Point	Prehistoric ceramics; surface rooms
Qy2r (Middle Verde)		
N:4:32 (ASM)	Clarkdale	Kana’a Black-on-white; Tusayan Black-on-red; Tusayan White Ware; Tusayan Black-on-white; Verde Brown Ware; Historical period component; SCA glass
N:4:33 (ASM)	Clarkdale	Pithouse village; Floyd Black-on-gray; Prescott Gray Ware; Verde Brown Ware; Wingfield Plain Ware; San Francisco Mountain Gray Ware
O:5:188 (ASM)	Camp Verde	Verde Brown Ware; Verde Red; Tuzigoot Red Ware; Tusayan or Dogoshzi Black-on-white; Tusayan Corrugated; Tusayan White Ware; Tusayan Gray Ware
O:9:3 (ASM)	Horner Mountain	Verde Brown Ware
NA 3502	Clarkdale	Pithouse village
NA 5226	Clarkdale	Pithouse village; early Pueblo II (AD 900-1000) per site record

Site	USGS 7.5' Quadrangle	Archaeological Temporal Indicators
NA 5228	Clarkdale	Pithouse village; Pueblo II (AD 900-1150) per site record
NA 12515	Camp Verde	Historical period, Camp Verde Swetnam Party site (AD 1865) per site record; Honanki Phase
NA 15557	Camp Verde	Historical period, Fort Verde site dating AD 1871-1891 per site record
<u>Qy2r (Lower Verde)</u>		
O:14:8 (ASM)	Chalk Mountain	Wingfield Plain Ware; Verde Brown Ware; Tonto Plain Ware
O:14:9 (ASM)	Chalk Mountain	Tonto Plain Ware; late ceramic (i.e., AD 1300-1500 per site record)
O:14:14 (ASM)	Chalk Mountain	Little Colorado White Ware; Gila Plain Ware; Verde Brown or Gray Ware; Surface rooms
O:14:15 (ASM)	Chalk Mountain	Surface room; Prehistoric ceramics
O:14:16 (ASM)	Chalk Mountain	Pit house; Hohokam Buff Ware; Tonto Plain Ware; Verde Brown Ware; Tuzigoot Plain Ware
O:14:44 (ASU)	Chalk Mountain	Surface rooms; Prehistoric ceramics
O:14:81 (ASU)	Chalk Mountain	Little Colorado White Ware
O:14:89 (ASM)	Chalk Mountain	Walled compound; Little Colorado White Ware; Shato Black-on-white
O:14:95 (ASM)	Chalk Mountain	Late ceramic (i.e., AD 1300-1500 per site record)
O:14:96 (ASM)	Chalk Mountain	Late ceramic (i.e., AD 1300-1500) and Classic Period per site record)
O:14:129 (ASU)	Chalk Mountain	Surface rooms
U:2:19 (ASU)	Horseshoe Dam	Gila Plain Ware; Sacaton Red-on-buff; Hohokam Buff Ware
U:2:84 (ASM)	Horseshoe Dam	Small pueblo; Verde Brown Ware; Verde Red; Wingfield Plain Ware; Classic period per site record
U:2:120 (ASM)	Horseshoe Dam	Sinagua, per site record; prehistoric ceramics
U:2:146 (ASU)	Horseshoe Dam	Surface room; prehistoric ceramics
U:2:297 (ASU)	Horseshoe Dam	Surface room; prehistoric ceramics
U:6:10 (ASM)	Fort McDowell	Large pueblo; Gila Polychrome; Tonto Polychrome; Tanque Verde Red-on-brown; Jeddito Black-on-yellow; Pinedale Polychrome; Hohokam Buff Ware
U:6:79 (ASM)	Fort McDowell	Historical period
U:6:102 (ASM)	Fort McDowell	Ball court; Santa Cruz Red-on-buff; Hohokam Buff Ware; Sacaton Red-on-buff; Black Mesa Black-on-

Site	USGS 7.5' Quadrangle	Archaeological Temporal Indicators
		white; Black-on-white (indeterminate)
U:6:180 (ASM)	Fort McDowell	Historical period wood frame house built between AD 1900 and 1910 per site record
U:6:182 (ASM)	Fort McDowell	Historical trash scatter dating between 1903 and 1930 per site record
U:6:184/185 (ASM)	Fort McDowell	Historical trash scatter dating between 1890 and 1920 per site record
U:6:248 (ASM)	Fort McDowell	Hohokam Red-on-buff; Santa Cruz Red-on-buff; Sacaton Red-on-buff
U:6:251 (ASM)	Fort McDowell	Historical trash scatter dating between 1880 and 1930 per site record; SCA glass
U:6:334 (ASM)	Fort McDowell	Tonto Polychrome; Gila Polychrome; Black-on-white (indeterminate)

Table 4. Radiocarbon Dates from Qy2r and Qy3r Alluvium

Locality	**Surface**	**USGS Quadrangle**	**Material Dated**	**Depth Below Surface (m)**	**Radiocarbon Date (with 2 sigma calibrated range*)**	**Reference**
Dead Horse Cliffs	Qy2r	Cottonwood	Charcoal from archaeological hearth feature	1.6	1430 ± 80 BP/ A.D. 430-720 (A-10062)	House et al. 2002; Huckleberry and Pearthree 2005
Riverfront Park	Qy3r	Cottonwood	Alluvial detrital charcoal	1.4	620 ± 40 BP/ A.D. 1290-1410 (Beta-133670)	Huckleberry and Pearthree 2005
			Alluvial detrital charcoal	2.4	1450 ± 50 BP/ A.D. 440-670 **	Huckleberry and Pearthree 2005
Del Rio	Qy3r	Cornville	Alluvial detrital charcoal	1.02	480 ± 40 BP/ A.D. 1330-1480 **	Kornmeyer 2002
			Alluvial detrital charcoal	2.8	1040 ± 40 BP/ A.D. 890-1150 **	Kornmeyer 2002
Black Canyon	Qy3r	Cornville	Charcoal lens	0.55	330 ± 40 BP/ A.D. 1470-1650 **	Kornmeyer 2002
			Charcoal from archaeological hearth feature	2.55	570 ± 40 BP/ A.D. 1300-1430 **	Kornmeyer 2002
			Charcoal from archaeological hearth feature	3.05	470 ± 40 BP/ A.D. 1330-1610 **	Kornmeyer 2002
Yavapai-Apache	Qy3r	Cornville	Uncharred flotsam lens	2.1	Modern **	Kornmeyer 2002
River Caves	Qy3r	Camp Verde	Charcoal lens (*Juglans major*)	1.7	390 ± 40 BP/ A.D. 1440-1630 **	Kornmeyer 2002
			Alluvial detrital charcoal (wood gall)	2.4	1010 ± 50 BP/ A.D. 900-1160 **	Kornmeyer 2002
			Alluvial detrital charcoal (*Juniperus osteosperma*)	4.2-4.5	1030 ± 40 BP/ A.D. 900-1150 **	Kornmeyer 2002
H-1	Qy2r	Horseshoe	Bulk sediment	1.05-	420 ± 60 BP/	Johnson et al. 1997

Locality	Surface	USGS Quadrangle	Material Dated	Depth Below Surface (m)	Radiocarbon Date (with 2 sigma calibrated range*)	Reference
		Dam		1.15	A.D. 1410-1640 (Tx-8096)	
			Bulk sediment	2.57-2.67	1280 + 50 BP/ A.D. 660-870 (Tx-8097)	Johnson et al. 1997
H-2	Qy3r	Horseshoe Dam	Bulk sediment	1.14-1.24	1550 + 60 BP/ A.D. 400-630 (Tx-8098)	Johnson et al. 1997
			Bulk sediment	2.3-2.4	1780 + 60 BP/ A.D. 90-400 (Tx-8099)	Johnson et al. 1997
H-3	Qy2r	Horseshoe Dam	Bulk sediment	1.7-1.8	1120 + 60 BP/ A.D. 780-1020 (Tx-8100)	Johnson et al. 1997
H-5	Qy2r	Horseshoe Dam	Bulk sediment	1.25-1.35	530 + 50 BP/ A.D. 1300-1450 (Tx-8101)	Johnson et al. 1997
			Bulk sediment	2.16-2.21	1220 + 50 BP/ A.D. 670-940 (Tx-8102)	Johnson et al. 1997
B-1	Qy2r	Bartlett Dam	Bulk sediment	0.56-0.66	940 + 50 BP/ A.D. 1020-1210 (Tx-8103)	Johnson et al. 1997

* All dates calibrated with INTCAL 04

** Lab number not provided

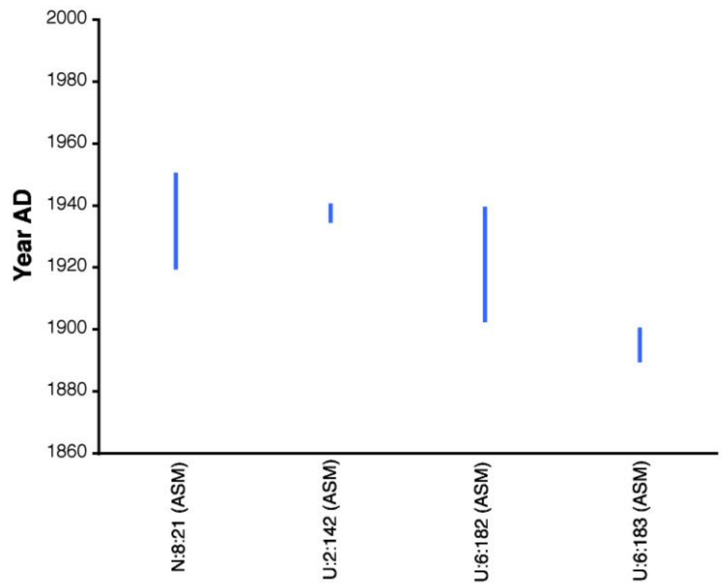

Figure 15. Age ranges of Historical Period archaeological surface sites situated on Qy3r terraces.

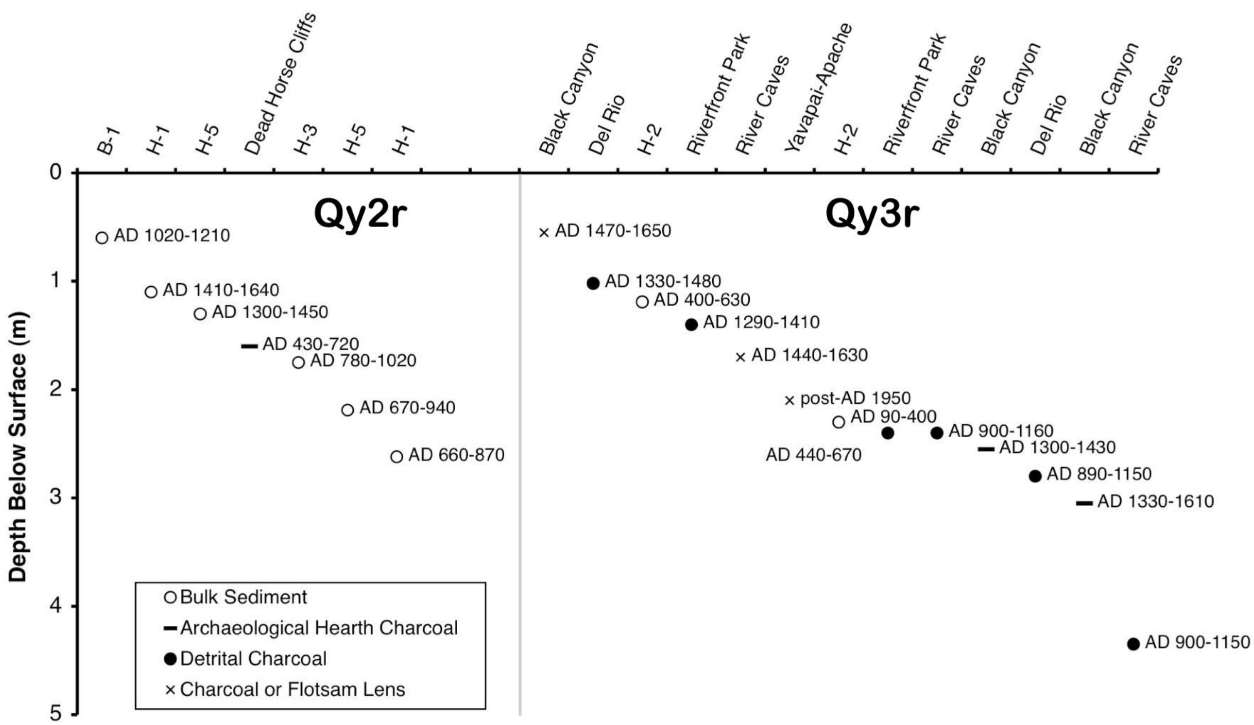

Figure 16. Radiocarbon dates (calibrated 2-sigma ranges) associated with alluvium underlying Qy2r and Qy3r terrace surfaces. Apparently there is substantial overlap in the ages of deposits associated with Qy2r and Qy3r terraces.

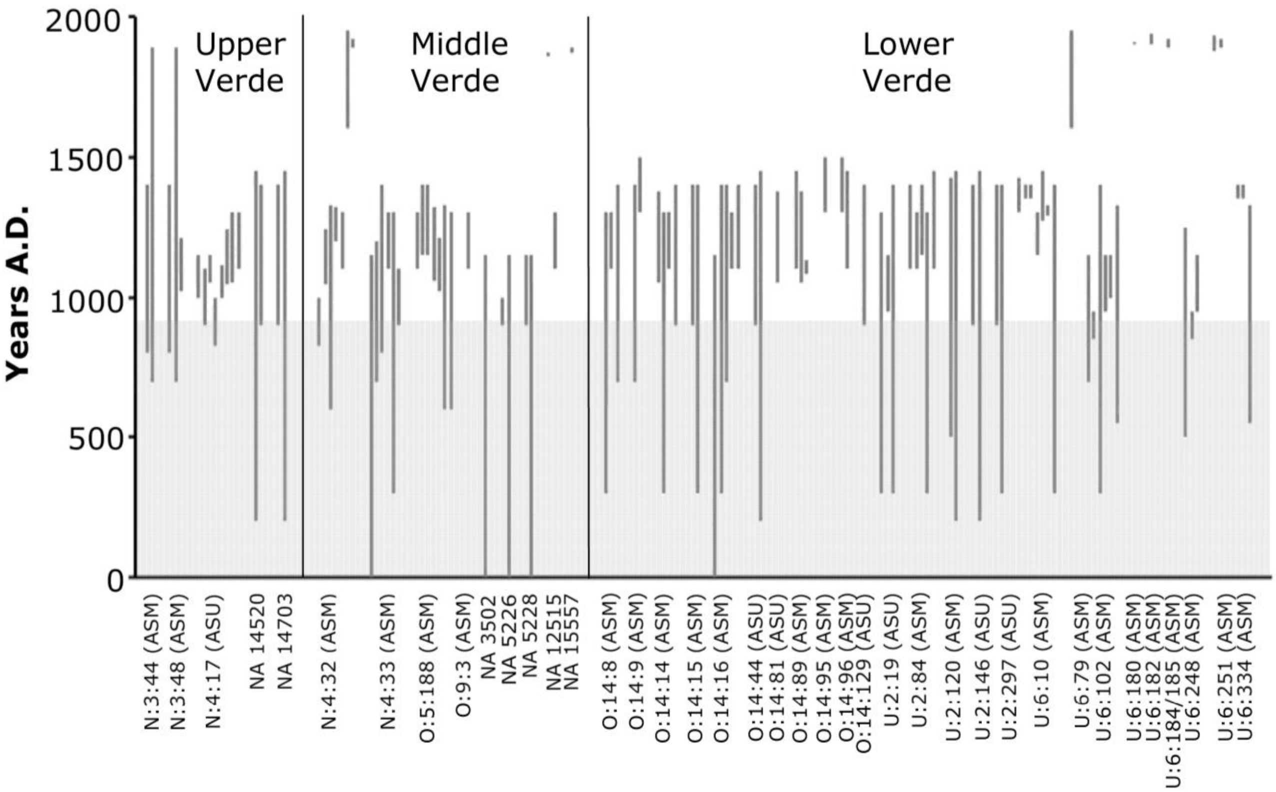

Figure 17. Age ranges associated with temporally diagnostic traits and artifacts at sites located on Qy2r treads. The shaded portion of the graph illustrates the inferred period of Qy2r deposition, which appears to have ended at most sites by ca. AD 1400.

Paleoflood studies. Detailed paleoflood investigations have been conducted at 4 sites along the Verde River near USGS stream gages (House et al., 2002; House et al., in prep.). The most upstream site is located between the USGS gage near Paulden and Perkinsville. The second site is near the USGS gage at Clarkdale. The third site is at the USGS gage near Camp Verde, at the mouth of Chasm Creek. The most downstream site is at Sheep Bridge, just upstream from the USGS gage near Tangle Creek. The primary purpose of these investigations was to develop a longer-term context for the large floods that have occurred on the Verde River in the past 120 years. At each of these sites, numerous radiocarbon dates that were obtained from organic material in Verde River slackwater deposits (fine-grained alluvium deposited in areas of reduced flow velocity during floods). These dates help constrain age estimates for Holocene river terrace deposits.

At each of the paleoflood sites, multiple flood deposits underlie late Holocene river terrace deposits. Radiocarbon dates from late Holocene deposits that are fairly high above the modern river channel (unit Qy2r) range from early historical or very young prehistoric to a few thousand years. Younger inset terraces (unit Qy3r) locally contain historical artifacts (House et al, 2002), but are also underlain by deposits that are equivalent in age to Qy2r deposits. At the Horse Creek paleoflood site just above the

Tangle Creek stream gage, the highest Qy2r terrace is capped with about 1 m of late Holocene deposits that are less than 1 ka. Several late Pleistocene dates were obtained from deposits beneath the late Holocene deposits, however. An adjacent, slightly lower Qy2r terrace is underlain by several meters of late Holocene deposits, with no evidence of late Pleistocene deposits.

Table 5. Radiocarbon dates from Verde River slackwater deposits. Data extracted from House et al (2002; in prep.). Dates are in approximate stratigraphic order for each site, with the lowest, generally oldest dates at the bottom and the highest, generally youngest dates at the top. *Qi3r deposits at the Horse Creek site are exposed in a steep bank and are not depicted on the river map.

Site	**mapped surface unit**	**material dated**	**^{14}C yrs before 1950**	**Calendar yrs before present (2-sigma)**
Bear Siding	Qy2r	unknown	740 ± 50	760-630, 600-560
		unknown	1120 ± 50	1170-930
		palo verde	1150 ± 40	1180-960
		juniper	1440 ± 50	1420-1260
		unknown	1780 ± 80	1880-1520
		ash	1750 ± 40	1820-1540
		willow	1760 ± 40	1820-1560
		oak	1970 ± 50	2060-1810
		willow	2480 ± 50	2740-2360
		willow	2970 ± 50	3330-2960
Duff Canyon	Qy2r	unknown	370 ± 50	510-310
		unknown	550 ± 60	660-500
		mesquite	1480 ± 40	1520-1290
		palo verde	2240 ± 50	2350-2120
		unknown	1760 ± 40	1820-1560
		mesquite	2250 ± 50	2350-2140
		palo verde	3020 ± 50	3360-3060
		unknown	2970 ± 50	3330-2960
		mesquite	1960 ± 50	2050-1730
Chasm Creek	Qy3r	pine	160 ± 40	290-0
		conifer	170 ± 40	300-60,40-0
	Qy2r	juniper	220 ± 50	430-360,330-240,230-60
		unknown	470 ± 40	620-610,560-460
		juniper	270 ± 40	470-270,180-140,20-0
		mix	1250 ± 50	1290-1060
		unknown	700 ± 40	710-550
		conifer	1290 ± 50	1300-1070
		seed	820 ± 50	910-860,830-660
		pine	590 ± 40	660-530
		oak	430 ± 40	530-440,350-330
		ash	570 ± 50	650-510

Site	mapped surface unit	material dated	^{14}C yrs before 1950	Calendar yrs before present (2-sigma)
Horse Creek	Qy3r	unknown	280 ± 60	500-270,220-140,20-0
		juniper	360 ± 50	510-310
		unknown	100 ± 50	280-170,150-0
		acacia?	320 ± 50	500-290
	Qy2r	unknown	340 ± 50	500-300
		unknown	130 ± 40	280-170,160-0
		ash	290 ± 50	480-270,180-150
		acacia?	380 ± 50	520-310
		acacia?	710 ± 50	730-620,610-550
		ash	840 ± 40	910-860,830-670
		mix	1430 ± 40	1410-1280
		snails	1560 ± 50	1550-1330
		unknown	1280 ± 40	1290-1080
	Qi3r*	mix	12,320±160	11,900-13,493
		unknown	13,600±70	13,890-14,890
		snails	13,990±50	14,3670-15,320
		mix	7000±40	5750-5985
		mix	14,490±50	14,930-15,915

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

w - Water - Underlying geology obscured by standing water (Pecks Lake, Horseshoe and Bartlett Reservoirs), no geologic unit information available

s – submerged - Unit submerged due to seasonal inundation in Bartlett and Horseshoe Reservoirs, identity discernable with low reservoir levels and aerial photo interpretation

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

d - Plowed areas – Historically or actively plowed fields, irrigated pastures, and other lightly disturbed ground

Qyl - Modern lake and marsh sediments - Underlying geology buried by lake or marsh sediments (Pecks Lake, Horseshoe and Bartlett Reservoirs)

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

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 or basin deposits, with the extent of channel deposits and exposed bedrock varying with significant flooding.

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 6 ft of the low-flow river channel, and recent erosional meanders outside the presently active channel. Qy4r deposits are composed of poorly sorted unconsolidated sediments ranging from fine silt to cobbles and boulders depending on location in the channel at the time of deposition. Pebbles and cobbles typically are well-rounded to sub-rounded, but may be subangular to angular. These surfaces are commonly inundated under moderate to extreme flow events and are subject to occasional deep, high velocity flow and lateral bank erosion. These deposits do not exhibit soil development but may exhibit light to moderate vegetation cover consisting of trees, bushes and grasses.

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 floods, and undercutting and rapid erosion of Qy3r surfaces is possible during lower flow events.

Qy2r - Late Holocene to historical river terrace deposits - Late Holocene floodplain and overbank deposits of the Verde River. 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 - River terrace deposits standing up to 80 ft higher than the active channel. Along the Verde River these terraces can be located up to 0.5 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 - 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 - 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.

Qi1rb - Middle Pleistocene river terrace deposits, younger member.

Qi1ra - Middle Pleistocene river terrace deposits, older member.

Qor - Early Pleistocene river terrace deposits - Well rounded to subangular indurated 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 river. In the Verde Valley, early Pleistocene river terraces 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.

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 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 cholla, prickly pear, small (4-5 ft tall) mesquite, and numerous small shrubs and grasses. 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. Deposition of Qy1 sediments in a braided channel aggrading alluvial fan environment has, in places, resulted in shallow burial of adjacent piedmont deposits. This relationship is visible along incised channels where thin Qy1 deposits overly redder, clay-rich Qi2 or Qi3 deposits.

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.

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.

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.

Qi23 - Middle and late Pleistocene alluvium - Middle to Late Pleistocene alluvium, undivided.

Qi2 - Middle to late Pleistocene alluvial fan and terrace deposits - 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, Qi2 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.

Qi – Middle to late Pleistocene deposits, undivided.

Qo – Early Pleistocene alluvial fan deposits - 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 QTo surfaces. Where Qo surfaces are well preserved, soil development is strong with very clay-rich argillic horizons and stage IV calcic horizons.

Qo2 – Early Pleistocene alluvium, younger member.

Qo1 – Early Pleistocene alluvium, older member.

QTo – Latest Pliocene to early Pleistocene alluvial fan deposits - The highest level of alluvial fan remnants in the Verde Valley, which are as much as 300 ft above modern drainages near the mountain front. This unit is found on top of the gravel facies of the Verde Formation (Tvg) very near the Black Hills in the northern Verde Valley, and has been interpreted as possibly representing the highest level of the Verde Formation based on apparent stratigraphic relationships in that area (House and Pearthree, 1993). Only small, isolated remnants of QTo exist in the map area. Possible erosional remnants of this unit are not readily distinguishable from Qo deposits. Where QTo surfaces are well preserved, soil development is strong with very clay-rich argillic horizons and stage IV calcic horizons.

QTa - Late Pliocene to early Pleistocene fan gravel - Coarse gravelly deposits that erosionally overlie basin-fill sediments and bedrock units and form the upper parts of high, very rounded ridges. QTa deposits are composed of very poorly sorted angular to sub angular sand, pebbles, cobbles, and boulders arranged in alternating fine to coarse beds common in alluvial fan deposits. High standing rounded ridges are composed of carbonate-cemented fanglomerate cap which armors the underlying, less indurated basin-fill sediment. The flanks of QTa ridges are also armored against erosion due to the mantle of coarse clast cover derived from weathered sections of the cap. Exposures of QTa deposits are generally poor, but they may locally be at least 100 ft thick and are commonly the highest standing deposits in the proximal piedmont. Locally these deposits are capped by very old, very high relict Qo alluvial fan deposits, but are generally not capped and are deeply eroded.

Cenozoic basin deposits

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.

Tvg - Late Miocene to Pliocene Verde Formation, conglomeratic facies - Sandy conglomerate, conglomeratic sandstone, some sandstone, rare mudrock formed as alluvial fans and braidplain deposits. Generally very light gray and moderately to strongly indurated. Outcrops of Tvg weather moderately to well rounded. Sand is poorly sorted, angular, medium grained to granule sand, with abundant disaggregated granite particles of quartz or feldspar. Bedding generally massive yet distinguishable by grain size variations, locally by parting between beds (House and Pearthree, 1993).

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).

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).

Tvu - Late Miocene to Pliocene Verde Formation - Intermixed fine-grained beds and sandstone and conglomerate beds (House and Pearthree, 1993).

Tlc - Limestone of Chalk Mountain - White to light-gray, finely laminated, porous limestone and minor medium-gray to light-brown, thin-bedded chert. The limestone locally contains laminated stromatolite-like mounds a few centimeters across. Limestone beds locally are broken into small, overlapping slabs or brecciated into angular, centimeter size fragments separated by voids partly lined with secondary calcite. Contains sparse, silt-size quartz grains. The finely laminated limestone beds accumulated as micritic limey mudstone, possibly as algal mats. The stromatolite-like mounds consist of bladed calcite deposited as coatings on mud lumps or pieces of fragmented limestone. Probably accumulated in shallow lake or playa subjected to frequent wave action and periods of desiccation. Forms prominent cliffs and steep slopes. May be roughly correlative with part of the Pliocene and Miocene Verde Formation of the Verde Valley (Wrucke and Conway, 1987, Nations and others, 1981).

Tsm – Oligo-Miocene deposits - Moderately to strongly consolidated conglomerate and sandstone deposited in basins during and after late Tertiary faulting.

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

Toc – Older Conglomerate - Weakly consolidated conglomerate and sandstone that crops out high above the Verde River. The clasts are principally of granophyre and aplite but locally include small amounts of Proterozoic quartzite and rhyolite. Interlayered fine to coarse grained, thin to medium bedded sandstone containing lenses and beds of arkosic grit and fine pebbles forms as much as three-fourths of the unit. The unit locally contains abundant basalt flows and was deposited on irregular surface carved in Paleozoic and Proterozoic rocks (Wrucke and Conway, 1987).

Tcu - Conglomerate, breccia, and sandstone undivided (middle Tertiary) - Interbedded red-colored, matrix-supported breccia, and clast-supported conglomerate, sandstone, and minor siltstone and limestone. Breccia layers are matrix-supported, very-poorly sorted, weakly to non-bedded, and contain outsized clasts up to 30 ft across, and probably represent debris flows. Conglomerates and sandstones are locally normally graded. Locally interbedded with and intruded by mafic volcanic rocks (Skotnicki, 1995).

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.

Tla – Tertiary intermediate volcanic rocks - Hornblende and biotite latites, rhyodacite, dacite, andesite, and associated volcanic and sedimentary rocks.

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).

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).

MDrm – Redwall Limestone and Martin Formation, undivided.

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

DꞒ – Undifferentiated lower Paleozoic rocks - Dolostone, limestone, quartzite-pebble conglomerate, and minor green shale in an unconformity bounded sequence along the uppermost Verde River (Gootee et al., 2009).

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

Xms - Proterozoic sedimentary, metasedimentary, and metavolcanic rocks, undivided. Includes quartzite, sandstone, and metavolcanic rocks.

Xdg - Early Proterozoic diorite and gabbro.

Xb – Early Proterozoic basaltic flows - Fine- to medium-grained metamorphosed tholeiite, basalt, and minor ultramafic rocks (from DeWitt et al., 2008).

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