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Geologic and Geomorphic Setting of the Verde River from Sullivan Lake to Horseshoe Reservoir

by

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Arizona Geological Survey

Open-File Report 93-4

March 1993

Arizona Geological Survey
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Funded by the
U.S. Environmental Protection Agency
and the Arizona Geological Survey

Summary

The central Verde River is one of the primary perennial, free-flowing streams in Arizona. Portions of the river have been significantly impacted by human activities, and its future flow may be threatened by groundwater depletion. The Arizona Geological Survey received a grant from the U.S. Environmental Protection Agency to evaluate and map the geologic units along the Verde River between Sullivan Lake in Big Chino Valley and Horseshoe Reservoir as part of an Advanced Identification (ADID) project to identify sites that may be suitable or are generally unsuitable for disposal of dredged or fill material. Variations in the physical characteristics of geologic units found along the Verde River have important implications for assessment of the riparian environment because they are the substrate for riparian biotic communities and they are the primary aquifers for riparian vegetation along the river. This report summarizes the geologic and geomorphic setting of riparian areas along the central Verde River.

Geologic units along the Verde River were mapped through interpretation of aerial photographs, field checking and description of units, analyses of topographic maps, and compilation of mapping by previous workers. Mapping focused on alluvial deposits associated with the Verde River and its tributaries because these deposits had not been mapped previously in any detail. Alluvial deposits were differentiated into five age categories ranging from modern to more than 1 million years old; deposits of the Verde River and its perennial tributaries were discriminated from deposits of smaller, ephemeral tributaries. Basin-fill sediments and bedrock were divided into 5 general categories based on their age and physical properties.

Riparian environments along the central Verde River exist almost entirely on young alluvial deposits or at the interfaces between young deposits and various older units. Young alluvial deposits are thin, but they are very permeable, they have good water-holding capacity, and substantial water is available to saturate them because they are just beneath or adjacent to the river. Vegetation in active channel areas is periodically damaged or removed by floods. Vegetation density and size typically is greatest on low terraces immediately adjacent to active channels, because the water supply is ample and they are not subject to frequent flooding. In areas along the Verde River where young terraces have been cultivated and the native vegetation removed, it is not clear what the previous extent of riparian vegetation might have been.

The potential for erosion during floods along the Verde River depends on the proximity of an area to active channels and the character of the substrate. Erosion typically is greatest on the outside banks of meander bends, and major shifts in channel positions may occur in areas where there is little topographic confinement of the present

channel. Channels and young terraces are most susceptible to erosion because they are near (or in) active channels and they have little cohesion and no cementation. Within areas of young deposits, areas that are relatively low and close to active channels are the most vulnerable to erosion. Older alluvial deposits found along the Verde River are not completely indurated and thus may be subject to bank erosion. Older deposits are more resistant to erosion, however, because they typically are fairly coarse and soil development provides some cohesion. The resistance of basin-fill deposits to stream erosion is quite variable. Limestone beds typically are more resistant to erosion than are the alluvial units. Silt- and clay-rich beds are quite easily eroded, however. Gravelly beds in basin-fill units are fairly resistant to erosion. The bedrock units exposed along the Verde River are all quite resistant to bank erosion, so erosion is effectively limited by the bedrock valley sides.

The distribution of pre-Quaternary bedrock and basin-fill units effectively controls the extent and character of Quaternary alluvial deposits and the maximum potential extent of riparian environments along the Verde River. In areas where the Verde River flows through resistant bedrock, the river valley is steep and fairly narrow and alluvial deposits and riparian areas are limited in extent. Where lithologies are less resistant to erosion, such as the Verde Valley, the river valley is relatively broad, alluvial deposits of different ages are extensive, and the potential extent of riparian areas is greater.

The geomorphology of the study area also records the evolution of the Verde River. The river developed something like its modern form around 2.5 million years ago. Prior to that time, sediment was accumulating in playas or shallow lakes in the Verde Valley. Dramatic downcutting of the river began in this area after 2.5 million years ago. Long-term downcutting has continued through the Quaternary, leaving behind terrace deposits that mark former positions of the bed of the Verde River. Young alluvial deposits along the Verde River are quite thin, and the Verde Formation is exposed at a number of localities in the bed of the river, implying that the long-term of trend stream downcutting has continued to the present. Long-term downcutting has dominated the reaches of the Verde River upstream and downstream from the Verde Valley as well. The rugged terrain along most of the central Verde River is a product of the dramatic downcutting of the Verde River that has occurred in the past few million years.

Introduction

The Verde River is one of the primary perennial streams in Arizona. The free-flowing reach of the river, which extends from the eastern end of Big Chino Valley to Horseshoe Reservoir, supports diverse riparian environments and provides habitats for fish and wildlife. The relatively lush riparian areas along the Verde River afford opportunities for recreation that are uncommon in Arizona. Portions of the river have been significantly impacted by human activities, including diversion of water for agricultural purposes and extraction of aggregate for use in construction in central and northern Arizona. In addition to these competing uses for the Verde River, its future flow may be threatened by groundwater depletion. In recognition of threats to the riparian ecosystems along the Verde River, the U.S. Environmental Protection Agency (EPA) has proposed to implement an Advanced Identification (ADID) project to identify sites that may be suitable or are generally unsuitable for disposal of dredged or fill material.

The Arizona Geological Survey (AZGS) received a grant from the EPA to evaluate and map the geologic units along the Verde River between Sullivan Lake in Big Chino Valley and Horseshoe Reservoir (see figure 1). The purpose of this mapping effort was to define the physical framework in which the riparian environments along the river exist. Variations in the physical characteristics of geologic units found along the Verde River have important implications for assessment of the riparian environment. Alluvial deposits of Quaternary age (less than 2 million years old) form the channel bed and banks of most of the central Verde River. Alluvial deposits thus are the substrate for riparian biotic communities, and they are important aquifers for riparian communities along the river. Factors such as particle-size distributions (percentages of clay, silt, sand, pebbles, cobbles, and boulders in deposits), induration or cementation, and soil development vary between different alluvial deposits. Differences in the character of alluvial deposits strongly influence the susceptibility of channel banks to lateral erosion, potential water-holding capacity and ground-water recharge, and biotic assemblages. Alluvial deposits of the Verde River also record its evolution over the past few million years. Older, pre-Quaternary geologic units significantly affect the riparian environment along the Verde River, because they contain regional aquifers and they define the local and regional physiographic framework in which the younger alluvial units were deposited.

This report summarizes the geologic and geomorphic setting of the central Verde River. Surficial alluvial deposits of the Verde River and its tributary drainages, basin-fill deposits, and generalized bedrock units are differentiated on the basis of physical characteristics and age. These units are mapped in a strip that encompasses at least one mile (1.6 km) on either side of the Verde River at a scale of 1:24,000 (Plates 1a - 1e).

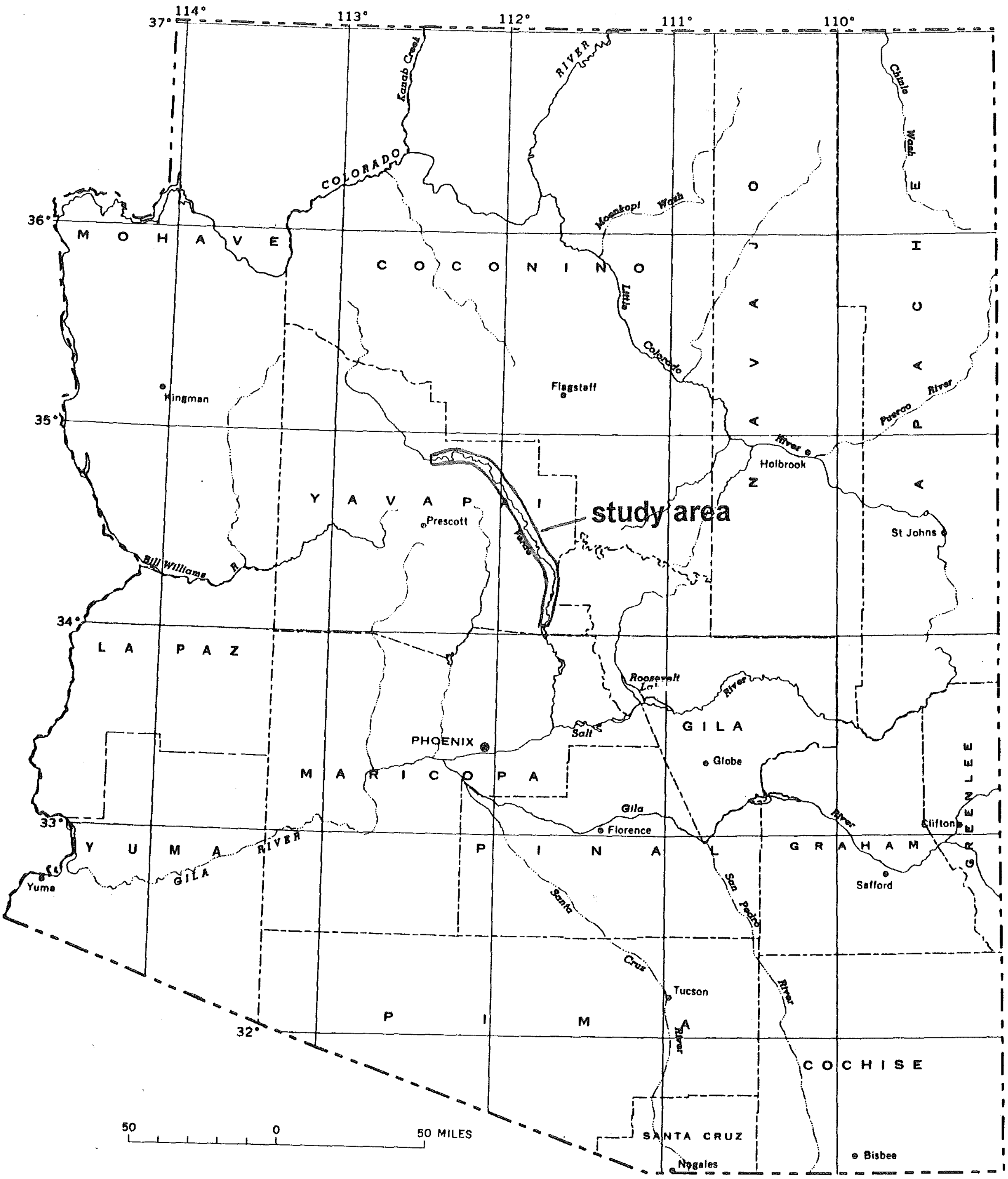


Figure 1. Approximate limits of the area along the Verde River mapped in this study.

The physical characteristics of the geologic units, including their induration/cohesion, hydrogeologic properties, sedimentology, and soil development, are characterized in order to evaluate their ability to resist stream erosion and their potential to sustain riparian vegetation. The final section of this report outlines the development and evolution of the Verde River during the past few million years as recorded by the geologic units along the river.

Methods

Geologic units along the Verde River were mapped through a combination of (1) interpretation of aerial photographs; (2) field checking and description of units; (3) analyses of topographic maps; and (4) compilation of mapping by previous workers. The distribution of different general types of bedrock and basin-fill deposits along the Verde River was compiled primarily from previous work. In a few localities, bedrock or basin-fill unit contacts were modified from previous mapping based on interpretation of aerial photographs. Surficial alluvial units along the central Verde River, which include channel and terrace deposits of the Verde River and its perennial tributaries, and channel, alluvial-fan, and terrace deposits of ephemeral tributaries, had not been mapped in any detail previously. Therefore, this study focused primarily on defining surficial alluvial units with different physical properties and ages and mapping the extent of these units along the river.

Many physical characteristics of alluvial deposits that obviously have important implications for their ability to sustain riparian environments correlate well with the age of the deposits. Characteristics such as the potential for deposits to hold water, the likelihood that they actually will hold significant water, the amount of clay and calcium carbonate in soils, and resistance to stream erosion correlate to greater or lesser degrees with the age of the deposits. These same characteristics may also vary depending on whether the deposits were emplaced by a large perennial stream, such as the Verde River or one of its major tributaries, or a smaller tributary stream. Therefore, differentiating and mapping alluvial deposits based on their age and their sources provides important information about the physical setting of riparian environments.

Physical characteristics of alluvial surfaces (surfaces on top of alluvial deposits) can be used to differentiate surficial alluvial deposits by age. Initial surface forms are shaped by depositional processes. Thus active depositional surfaces associated with sizable streams or washes typically are composed of relatively coarse-grained, high-standing bars and finer-grained swales. When alluvial surfaces are isolated from further deposition or reworking by large streams, they are gradually modified over thousands of years by processes that operate very slowly, on a smaller scale. Modifying processes include (1) small-scale erosion and deposition that smooths original surface topography; (2) bioturbation that obliterates depositional structures; (3) development of soils, primarily through accumulation of silt, clay, and calcium carbonate; (4) development of tributary dendritic (tree-like) stream networks on surfaces; and (5) entrenchment of these dendritic stream networks below original depositional surfaces and dissection of these surfaces. The Verde River has been downcutting throughout the Quaternary. As a result of this downcutting, the height of a terrace or alluvial fan above the active channel is a good indicator of the age of the deposit (see figure 2 for examples).

Alluvial surfaces of similar age have a characteristic physical appearance because they have undergone similar post-depositional modification, and they have distinctly different characteristics from both younger and older surfaces. For example, young terraces or alluvial fan surfaces (less than about 10,000 years old) still retain clear evidence of original depositional topography and have minimal soil development. Young surfaces are not very far above active channels and are basically undissected. Very old alluvial surfaces, which have not been subject to large-scale flooding for hundreds of thousands of years, typically have strong soil development in the form of clay- and calcium carbonate-rich horizons, and well-developed dendritic stream networks that are entrenched several meters or more below the fan surface. Along the Verde River, very old terraces are 30 meters (100 ft) or more above the active channel. Numerical ages of alluvial surfaces in Arizona can be roughly estimated based on these surface characteristics, especially soil development (Gile and others, 1981; Bull, 1991).

Interpretation of aerial photographs, substantial field-checking, and analyses of topographic maps were used interactively to define and map alluvial deposits along the central Verde River. The first phase of the mapping process involved interpretation of aerial photographs. Stereoscopic examination of aerial photographs reveals relative topographic relationships between alluvial surfaces in an area. In addition, variations in surface color, surface topography, drainage-network development, and vegetation that reflect surface age usually are quite evident on aerial photographs. Preliminary maps of alluvial surfaces along the Verde River were completed utilizing 1:58,000-scale false color infrared aerial photographs, which were taken in 1980 as part of the National High Altitude Photography Program. These photographs have the advantages of (1) providing uniform coverage of the whole area; (2) being high-quality photographs that remain sharp at 2- and 4-power magnification; (3) showing vegetation and variations in vegetation quite well. The disadvantages of these photographs are that they do not show true surface colors that can be observed in the field and their scale is significantly smaller than the final maps.

The second phase of the mapping involved field examination of alluvial deposits in critical areas. Field studies were conducted to verify or correct the aerial photointerpretation and to accumulate observations with which to characterize the physical properties of the various alluvial units. Extensive field-checking was done in the Verde Valley, were vehicular access is relatively good. Along more remote reaches of the Verde River, surficial alluvial units were examined in the field at locations where it was feasible.

The third phase of the mapping process involved transfer of mapping from aerial photographs to 1:24,000-scale topographic base maps. Preliminary mapping was finalized by examining topographic relationships revealed on the base maps. In particular, terraces of the Verde River and its major tributaries were grouped into age categories based on their altitude above the active channel.

Physical Characteristics of Geologic Units Along the Verde River

The physical characteristics of the geologic units defined in this study are summarized in table 1. As was discussed above, surficial alluvial units along the central Verde River were defined and mapped in this study. Previous geologic studies conducted near the Verde River had focused on bedrock units or basin-fill deposits. Therefore, the distribution and character of these older geologic units was primarily compiled from descriptions and maps of previous workers. The following sections consider the age and distribution of the various geologic units found along the Verde River and the properties of these units that affect the extent and character of riparian areas along the river.

Bedrock Units. Bedrock along the Verde River was grouped into three categories based on the character and the age of the rocks. Each of the bedrock units described is quite resistant to erosion and forms steep slopes or cliffs above the Verde River. Therefore, wherever the Verde River flows through areas dominated by bedrock, the extent of alluvial deposits is quite limited.

The oldest rocks along the river are reddish-colored Precambrian granite (map unit pCg, table 1, plate 1). Granite is exposed extensively on the west side of the Verde River from just south of the confluence of the East Verde River southward to the Sheep Bridge area (Wrucke and Conway, 1987; see plate 1e, this report). These intrusive igneous rocks, composed primarily of visible feldspar and quartz crystals, were emplaced about 1.7

Table 1. Geologic units along the Verde River from Sullivan Lake to Horseshoe Reservoir.

Unit	Description
Qc	Deposits of active channels of the Verde River and major tributaries; poorly sorted, relatively coarse deposits of sand, pebbles, cobbles, and boulders are highly permeable and have excellent water-holding capacity; quite thin, probably less than a few meters thick in all areas; highly subject to erosion and deposition during floods; riparian vegetation in channel areas adversely effected by large floods, but recovers during intervals between floods; the area of active channels changes frequently, increasing during large floods and decreasing during periods between large floods; active channel areas shown on these maps was determined using aerial photos that were taken in 1980 and 1981, following several large floods that occurred in 1978 and 1980.
Qty	Low terraces of the Verde River and major tributaries; coarse gravel facies composed of abandoned channels and bars, fine facies composed of sand deposited in low velocity, slack-water areas during large floods; minimal soil development; deposits usually less than 5 meters thick; both coarse and fine facies are highly permeable and have very good water-holding capacity; however, permeability also facilates rapid draining of the portion of these deposits that is above the low-flow level of adjacent streams; proximity to perennial streams makes these deposits primary aquifer for riparian vegetation; vegetation ranges from dense to moderate, and from small bushes to large trees; these areas also commonly utilized for agriculture, especially in the Verde Valley; susceptible to erosion, although riparian vegetation tends to stabilize these deposits; additionally, many of these low terraces are inundated during large floods; estimated age less than 10,000 years old (Holocene) in all cases, typically tens of years to a few thousand years old.
Qfy	Channels and low terraces of tributary streams; typically poorly sorted, mix of silt, sand, and gravel; particle-size depends on source rocks; minimal soil development; relatively thin; permeable with good water-holding capacity, but less so than Qty; water in these deposits varies depending on proximity to water sources; they support some riparian vegetation; moderate to no sediment cohesion, no cementation, susceptible to erosion; estimated age less than 10,000 years (Holocene).

Qtm Mid-level terraces of the Verde River and major tributaries; terrace surfaces typically are 5 to 30 meters (15 to 100 ft) above the active channel of the Verde River; typically, deposits are coarse gravel facies of relict channels and bars; moderate soil development with some clay accumulation; deposits less than 5 meters thick, commonly much less thick; deposits quite permeable, although soil clay retards infiltration from the surface, and have good water-holding capacity; these deposits typically are spatially separate (above) perennial streams and stream channels, and therefore water drains out of them quite readily; they typically support upland desert vegetation including shrubs, cactus, and small trees, but they typically do not support riparian vegetation; fairly resistant to stream erosion; not inundated during large floods; estimated age range 10,000 to 500,000 years old (late to middle Pleistocene).

Qfm Mid-level terraces and alluvial fans associated with tributaries of the Verde River; typically, deposits are poorly sorted silt to gravel; moderate soil development with some clay accumulation; deposits quite thin; fairly permeable, although clay accumulation probably retards infiltration from the surface, and good water-holding capacity; these deposits typically are spatially separate from water sources, and therefore typically do not hold much water nor support riparian vegetation; fairly resistant to erosion; estimated age range 10,000 to 500,000 years old (late to middle Pleistocene).

Qtmo Older mid-level terraces of the Verde River and major tributaries; terrace surfaces typically are 30 to 60 meters (100 to 200 ft) above the active channel of the Verde River; typically, deposits are coarse gravel facies of relict channels and bars; strong soil development with substantial clay and calcium carbonate (caliche) accumulation; locally, soil horizons cemented with calcium carbonate; deposits usually less than 5 meters thick; deposits quite permeable, but soil clay and carbonate accumlations retard infiltration from the surface; reasonable water-holding capacity; these deposits typically are high above stream channels, and therefore do not hold much water nor support riparian vegetation; resistant to erosion; estimated age range 500,000 to 1 million years old (middle to early Pleistocene).

Qfmo — Older mid-level terraces and alluvial fans associated with tributaries of the Verde River; typically, deposits are poorly sorted silt to gravel; strong soil development with substantial clay and calcium carbonate (caliche) accumulation; locally, soil horizons cemented with calcium carbonate; deposits fairly thin; deposits fairly permeable, but clay and carbonate accumulation retard infiltration from the surface, and reasonable water-holding capacity; these deposits typically are high above stream channels, and therefore do not hold much water nor support riparian vegetation; resistant to erosion; estimated age range 500,000 to 1 million years old (middle to early Pleistocene).

Qto — Very high terraces of the Verde River and major tributaries; terrace surfaces are more than 60 meters (200 ft) above the active channel of the Verde River; typically, deposits are very coarse, well-rounded cobbles and boulders; strong soil development with substantial clay and (or) calcium carbonate (caliche) accumulation; soil horizons completely cemented with calcium carbonate are typical; deposits less than 10 meters thick; deposits quite permeable, but clay and carbonate accumulation minimize infiltration from the surface; reasonable water-holding capacity; water drains quickly from these deposits because they are far above stream channels, and therefore do not hold much water nor support riparian vegetation; highly resistant to erosion; estimated age range 1 to 2.5 million years old (early Pleistocene to latest Pliocene).

Qfo — Very high alluvial fans of tributaries to the Verde River; typically, deposits are coarse, with sand, pebbles,cobbles, and boulders; strong soil development with abundant clay and (or) calcium carbonate (caliche) accumulation; soil horizons completely cemented with calcium carbonate are common; deposits quite permeable, but clay and carbonate accumulation minimize infiltration from the surface; reasonable water-holding capacity; water drains quickly from these deposits because they are high above stream channels, and therefore do not hold much water nor support riparian vegetation; deposits typically rest on surfaces eroded into older rock units, but locally grade gradually downward into coarse fan facies of the Verde formation and other basin-fill units (see below); highly resistant to erosion; estimated age range 1 to 2.5 million years old (early Pleistocene to latest Pliocene).

Tv — Verde Formation; sediments deposited in the Verde basin before the Verde River existed; typically limestone and fine-grained, silt and clay rich deposits; limestone beds are permeable and hold substantial ground water and are quite resistant to erosion; commonly form low cliffs along Verde River; gravelly fan facies of Verde Formation derived from Black Hills seen locally on southeast side of Verde River; 2.5 to 8 million years old (Pliocene to late Miocene).

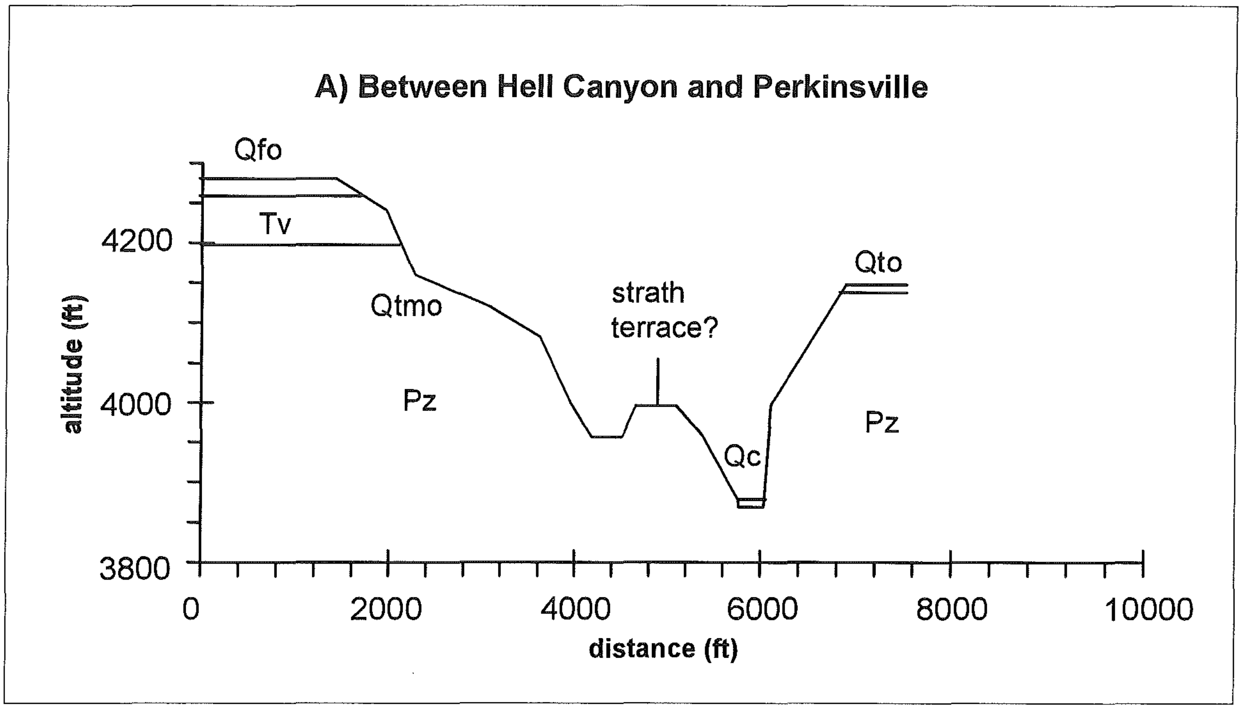
Tg	Basin-fill sediments in Perkinsville area and north of Horseshoe Reservoir; deposited in structural basins prior to the existence of the through-going Verde River; generally correlative in time with the Verde Formation, or slightly older; deposits range from siltstone and limestone to coarse fan gravels; typically coarser than Verde Formation; good permeability and water-holding capacity; fairly resistant to erosion (Pliocene to Miocene).
Tb	Basalt flows and intercalated sediments; joints, fractures, and sediments potentially hold substantial ground water, but typically flows and sediments are far above rivers and washes and water readily drains out of them; coarse, thin talus slopes may hold water derived from river; flows are highly resistant to erosion, form cliffs along river and cap high mesas; 4 million to 15 million (early Pliocene to Miocene).
Pz	Ancient sedimentary rocks; predominantly limestone, with siltstone, and sandstone; limestone may hold significant groundwater if fractured, sandstone is good aquifer, but not common along Verde River; limestone is very resistant to erosion, forms cliffs along Verde River upstream of confluence with Sycamore Creek; thin, coarse talus slopes adjacent to river may hold some water to support riparian vegetation; about 250 to 400 million years old (Paleozoic).
pCg	Granitic rocks; crystalline igneous rocks, generally not very permeable or porous,so water-holding capacity is limited; some groundwater stored in fractures, and in areas where the original crystalline fabric of the granite has been altered by weathering; quite resistant to erosion unless weathered; about 1.5 billion years old (Precambrian).

Table 1. Geologic units along the Verde River from Sullivan Lake to Horseshoe Reservoir.

billion years ago (Anderson, 1989). Granitic rocks are generally not very porous or permeable, but hold some groundwater in fractures and in portions of the granite that have been extensively altered by weathering. The granite adjacent to the Verde River is fairly resistant to erosion, and forms steep slopes above the river.

The next oldest map unit is composed of Paleozoic sedimentary rocks (map unit Pz). This unit is predominantly limestone along the Verde River, but it also includes siltstone and sandstone. Paleozoic strata are the predominant rock type along the Verde River upstream of the confluence with Sycamore Creek. Rocks that compose this unit were deposited primarily in shallow marine environments between about 400 and 240 million years ago. The limestone and sandstone beds form relatively good aquifers, especially if extensively fractured (Twenter and Metzger, 1963; Owen-Joyce and Bell, 1983). Limestone units are very resistant to erosion, and form cliffs and steep talus slopes along the river. Downcutting of the Verde River into these resistant rock units has resulted in the formation of canyons and steep valleys in much of the area upstream of Sycamore Creek (see figure 2A).

The final bedrock map unit consists primarily of Tertiary basalt and other fine-grained volcanic rocks (map unit Tb). This unit also includes thin sedimentary units deposited between basalt flows. Extensive basalt flows were erupted in central Arizona beginning about 15 million years ago and continuing until about 10 million years ago (McKee and Anderson, 1972). Basalt flows of this age cap the Black Hills on the southwestern margin of the Verde Valley; they also comprise the southeastern margin of the Verde Valley (Wolfe, 1983) and are found along or near the Verde River southward to Horseshoe Reservoir (Wrucke and Conway, 1987). Younger basalt flows, ranging in age from about 8 million to about 4 million years old, were erupted extensively from the Tapco area westward to Sullivan Lake (McKee and Anderson, 1972). Basalt flows are very resistant to erosion, and typically form cliffs and steep, coarse talus slopes above the Verde River. Bedrock canyons or steep-sided valleys with limited alluvial deposits are typical of areas where the Verde River has downcut into basalt. Examples of this situation are the reaches between Beasley Flat and Sheep Bridge (see figures 2G and 2H), and the reach between Tapco and the Sycamore Creek confluence. Basaltic rocks can potentially hold extensive groundwater in voids and fractures and in the intercalated sedimentary units (Twenter and Metzger, 1963). In many situations along the Verde River, however, these rocks occupy topographically high positions in the landscape, so the potential for them to hold significant groundwater is limited.



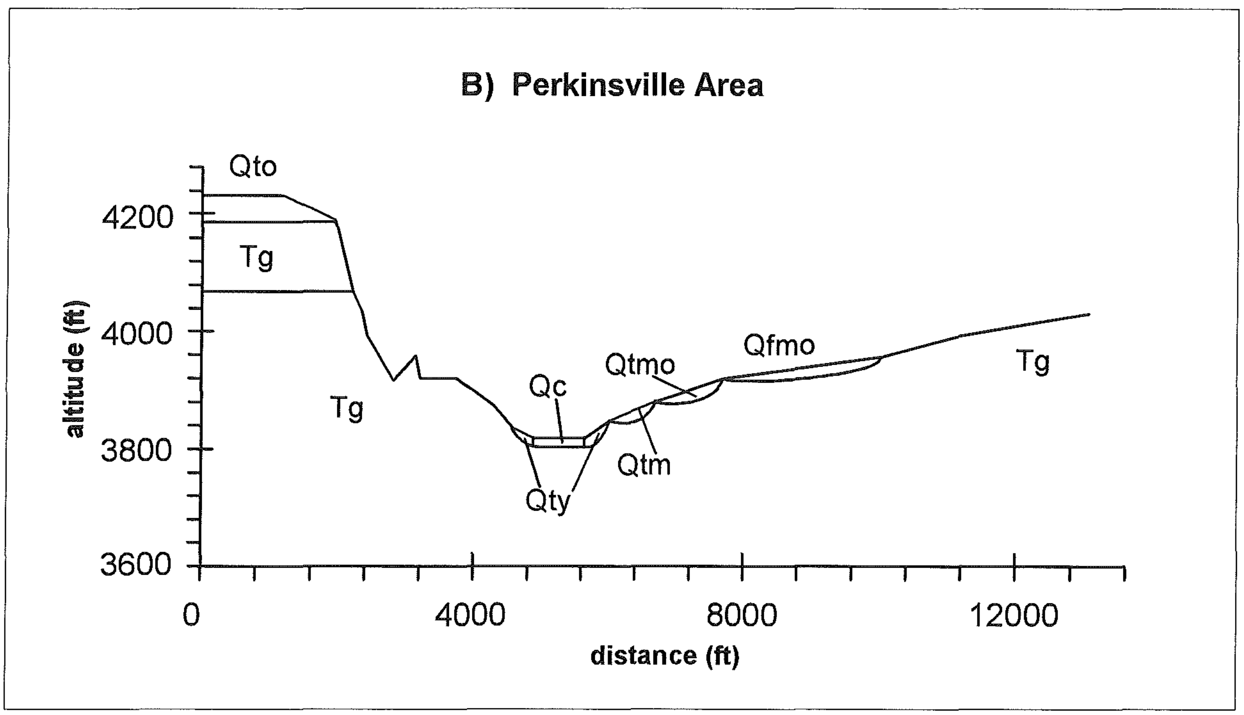
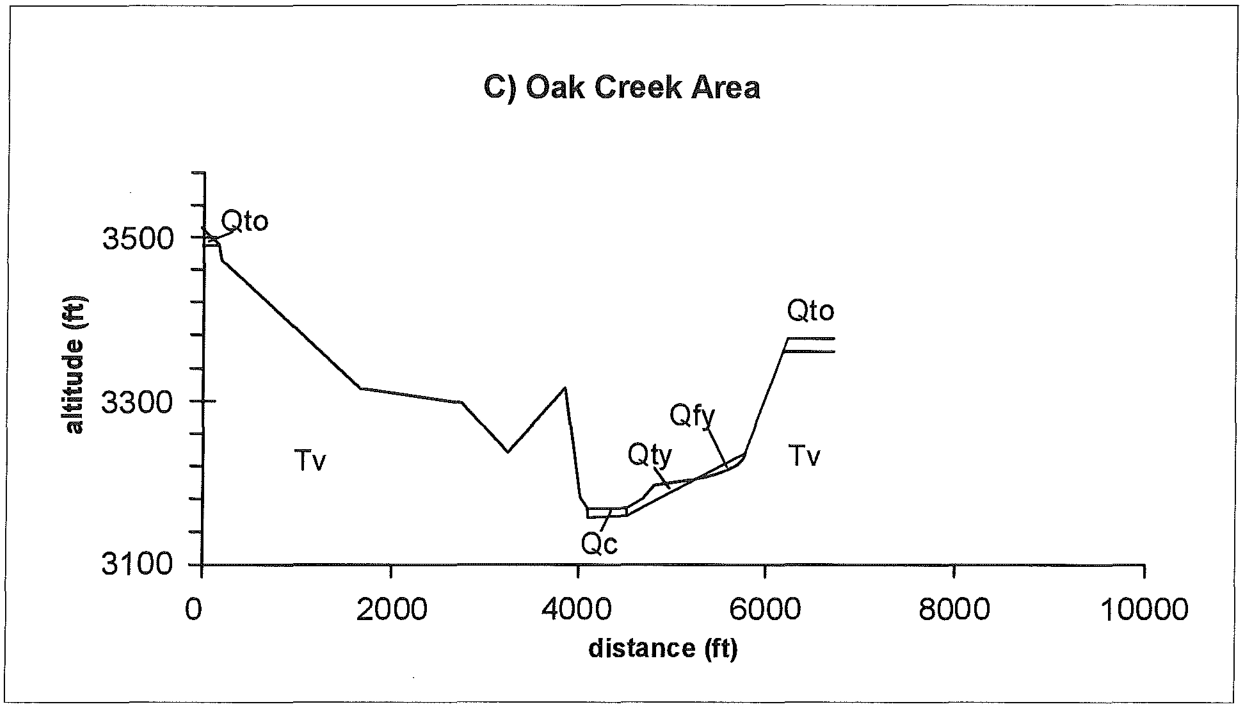
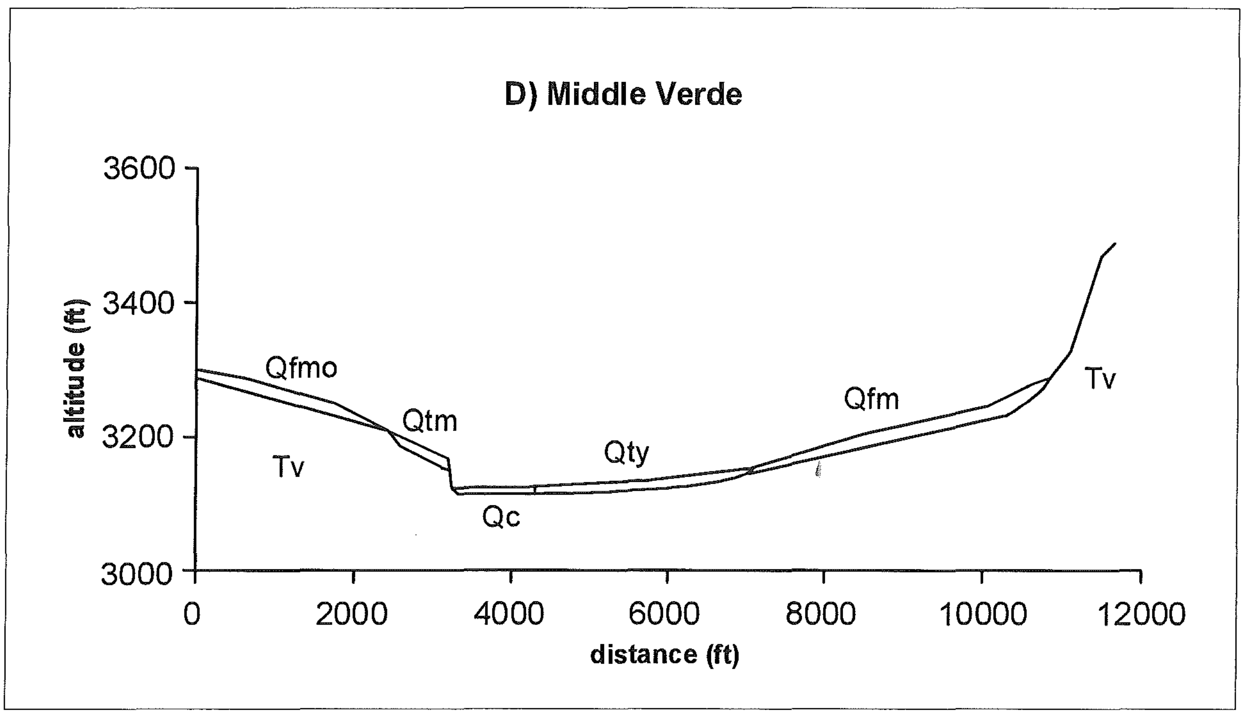


Figure 2. Topographic cross-sections and schematic depictions of alluvial units.





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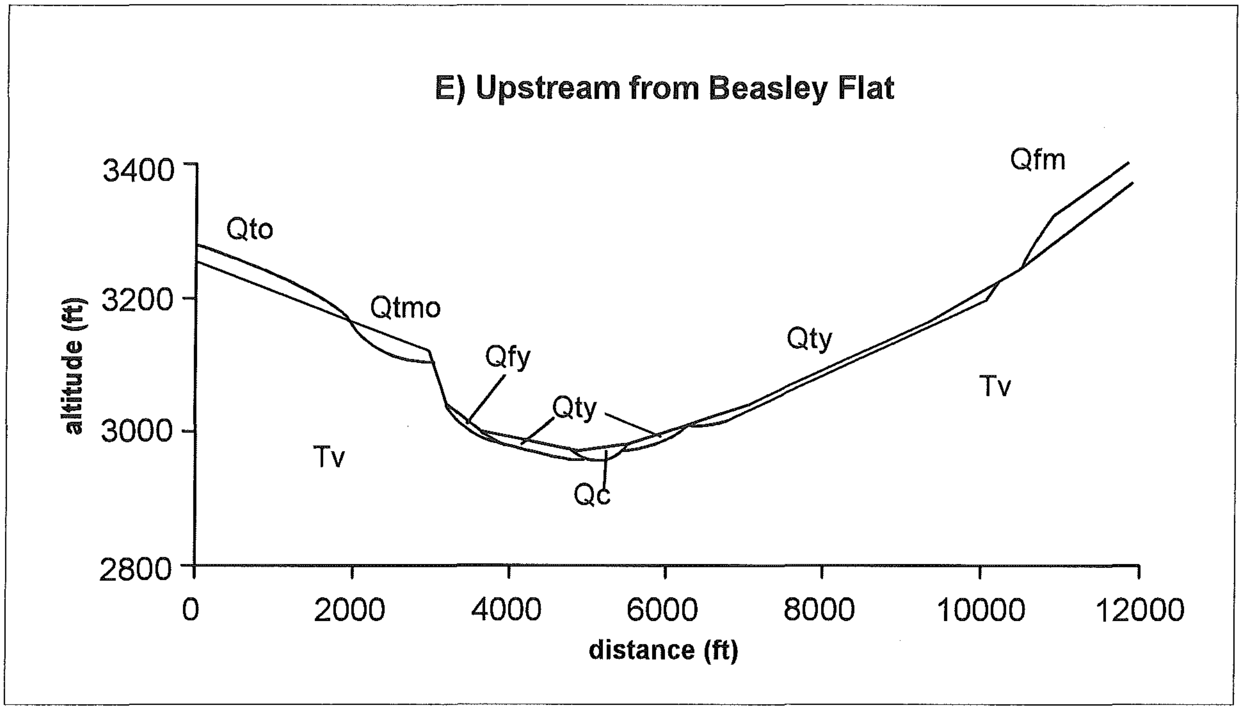

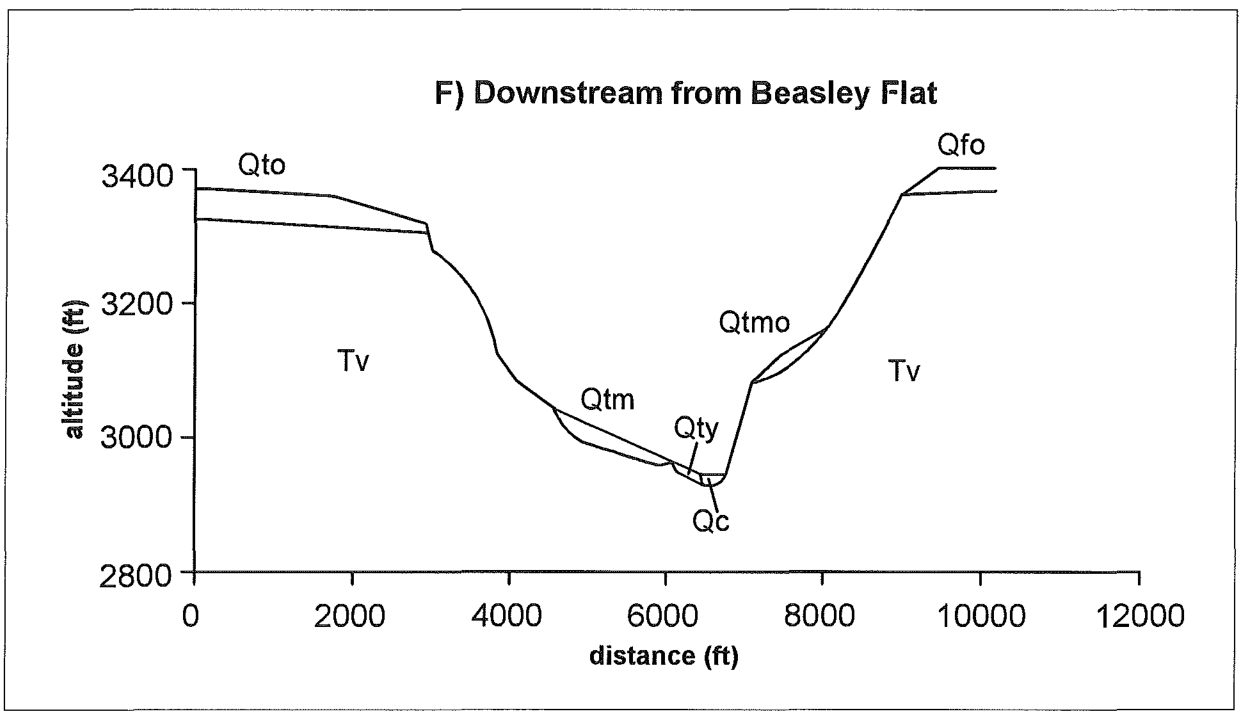

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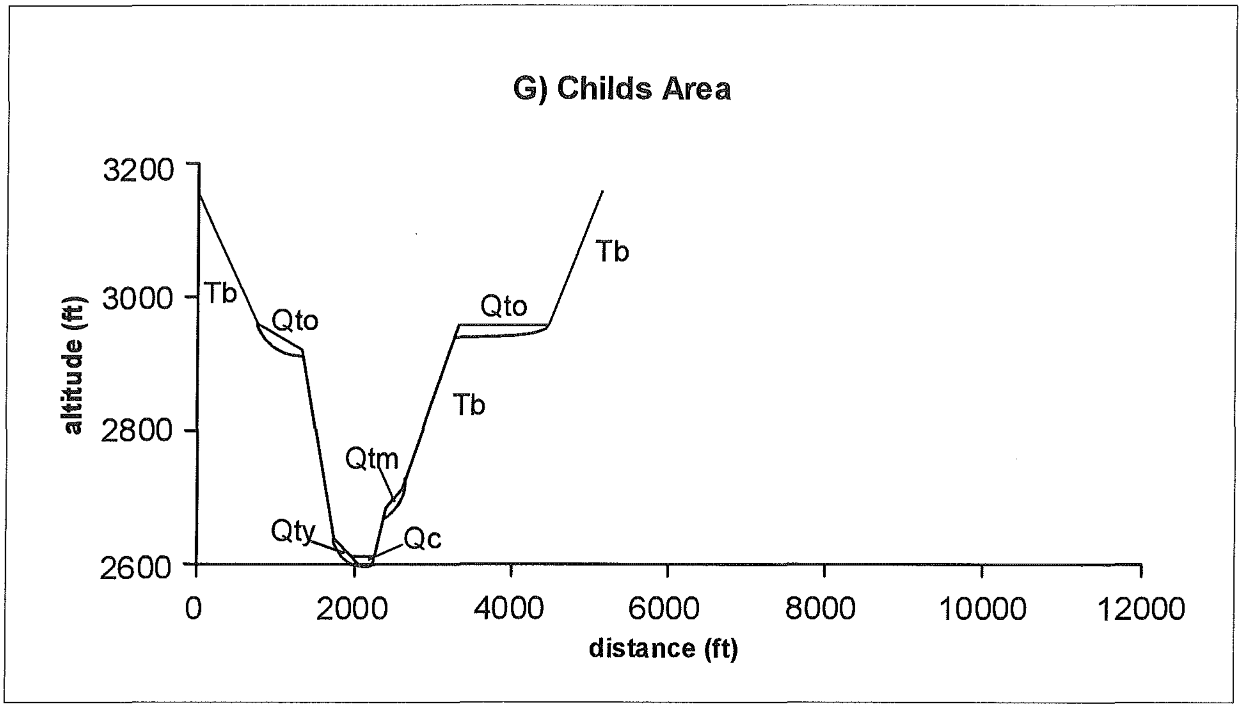

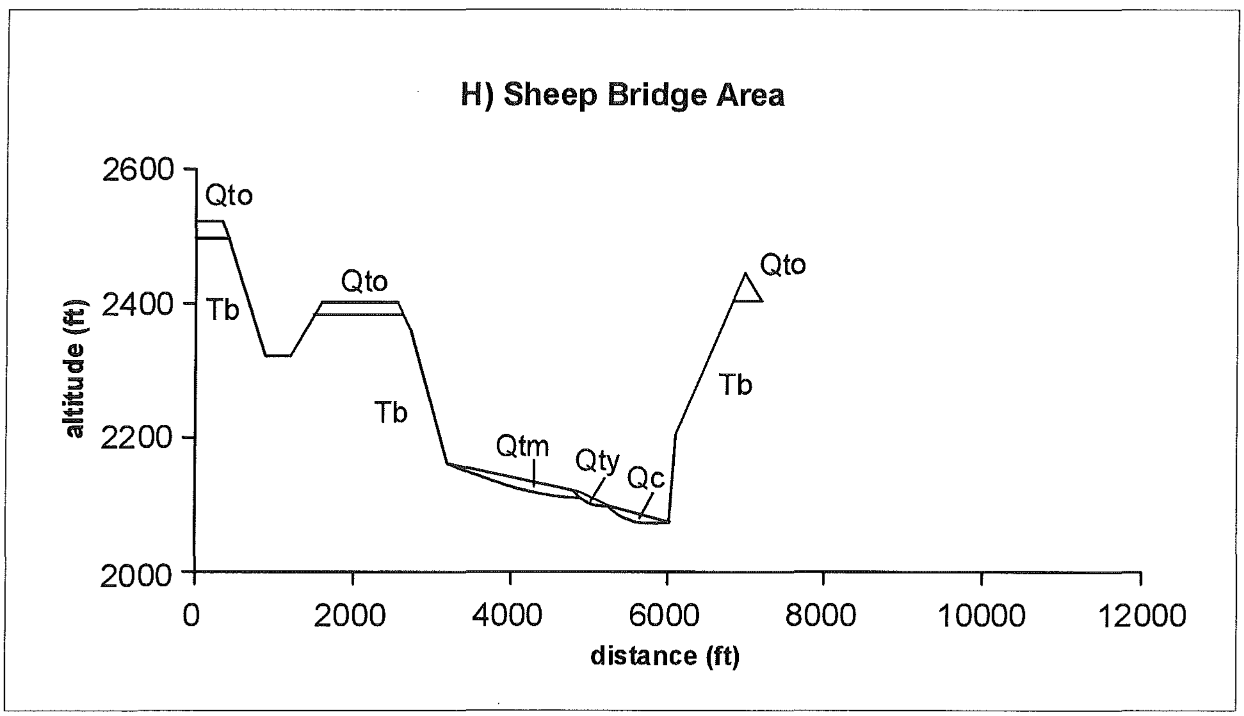

Figure 2. Topographic cross-sections and schematic depictions of alluvial units.

Basin-fill Deposits. Basin-fill sediments are the dominant rocks along the Verde River in the Verde Valley and in the Perkinsville area. These sediments were deposited in closed structural basins prior to the development of the through-flowing modern Verde River system. The Verde Formation (map unit Tv) was deposited in the structural basin that is now the Verde Valley between about 8 million and 2.5 million years years ago (Bressler and Butler, 1978; Nations and others, 1981; Nations and others, 1982). The Verde Valley was displaced downward, and the Black Hills moved up, across the Verde fault zone at the base of the Black Hills. This resulted in formation of a closed (internally drained) basin. A change in the character of the units within the Verde Formation that occurred in the late Miocene - early Pliocene (about 5 million years ago) suggests that the Verde Valley may have become partially integrated with downstream areas at that time (Nations and others, 1981). The total thickness of the Verde Formation is several thousand feet. The highest altitude of Verde Formation beds is about 5000 feet above sea level (Ranney, 1989).

The portions of the Verde Formation exposed along the Verde River are composed primarily of limestone, with lesser amounts of sandstone and fine-grained, silt- and clay-rich beds. The limestone and sandstone beds are quite permeable and hold substantial ground water (Twenter and Metzger, 1963; Owen-Joyce and Bell, 1983). They typically are quite resistant to erosion; commonly forming low cliffs along Verde River. Silt- and clay-rich beds generally are not very resistant to erosion and are not good aquifers. The gravelly alluvial-fan facies of Verde Formation derived from Black Hills is exposed locally on southeast side of Verde River.

Other sequences of basin-fill sediments that are found in the Perkinsville area and in the area upstream from Horseshoe Reservoir are mapped as a separate unit (Tg). Basin-fill sediments in the Perkinsville area are probably of similar age as the Verde Formation (McKee and Anderson, 1972). The age of Tg sediments found along the Verde River upstream of Horseshoe Reservoir is not well-constrained, although they are probably of late Miocene age (Wrucke and Conway, 1987). The basin-fill deposits mapped as unit Tg are composed mainly of sand and gravel, although limestone and siltstone predominate in some areas. Therefore, this unit is generally quite permeable and moderately resistant to erosion.

Surficial Deposits. Surficial alluvial deposits along the central Verde River are composed of deposits associated with the Verde River and its major tributaries (channel deposits and terrace deposits) and deposits derived from smaller ephemeral tributary streams (channel deposits, terrace deposits, and alluvial-fan deposits). Each of these two general categories was subdivided based on the estimated age of the deposit. Age groupings are modern (recently active channels; map unit Qc), Holocene (less than 10,000 years old; map units Qty and Qfy), late to middle Pleistocene (10,000 to 500,000 years old; map units Qtm and Qfm), middle to early Pleistocene (500,000 to 1 million years old; map units Qtmo and Qfmo), and early Pleistocene (1 to 2 million years old; map units Qto and Qfo). This level of detail in the separation of map units was chosen because it can be applied throughout the map area. Each map unit may be composed of deposits of substantially different ages, within the rather broad age categories.

The youngest (Holocene) alluvial deposits along the Verde River consist of active channels (unit Qc) and relatively low terraces (unit Qty). Differentiating low terraces and active channels is not always straightforward, and the extent of channels and low terraces along the Verde River is constantly changing. Active channel areas were defined primarily by the the fresh appearance of the deposits and the absence of large vegetation. Young terraces are slightly higher topographically and have a wide variety of vegetation types and sizes, including in many cases large trees. The area of active channels increases dramatically during large floods and decreases gradually during periods between large floods. The active channel areas shown on Plate 1 are relatively large, because mapping was done using aerial photos that were taken shortly after three large floods that occurred in 1978 and 1980. Field investigations in conducted in 1992 indicate that some areas that were active channels in 1980 now appear to be low terraces.

Channels and low terraces are both composed of recent deposits of the Verde River and its major tributaries, so they share many characteristics. Channel deposits are poorly sorted and relatively coarse, consisting of sand, pebbles, cobbles, and boulders. They are highly permeable and have excellent water-holding capacity, but they are quite thin. They are highly subject to erosion and deposition during floods. Terraces are composed of two distinct kinds of deposits: channel deposits as described above and much finer, sandy and silty sediments deposited in low velocity, overbank or slack-water areas during large floods. Channel deposits have no soil development. Young terraces have weak soil-horizon development with minimal increases in clay and calcium; near surface horizons (A horizons) may have significant organic material, however. Channel and terrace deposits are quite thin, probably less than about 10 m (30 ft) thick in all cases. They are highly permeable and have very good water-holding capacity; however, permeability also facilates rapid draining of the portions of these deposits that are above the low-flow level of adjacent streams. Young deposits are susceptible to erosion because they have no cementation and little cohesion, although riparian vegetation tends to stabilize these deposits. Additionally, some low terraces are inundated during large floods. The estimated age of young terraces (unit Qty) is less than 10,000 years old (Holocene) in all cases, they are probably less than a few thousand years old in most areas.

Channels, low terraces, and active alluvial fans of smaller tributary streams (unit Qfy) equivalent in age to active channels and low terraces of the Verde River typically are more poorly sorted mixtures of silt, sand, and gravel. Particle-size of these deposits depends on strongly on source rocks. For example, tributary streams that drain the Verde Formation tend to produce relatively fine-grained deposits; streams that drain bedrock units deposit much coarser sediment. Soil development in these deposits is similar to young Verde River terraces, but soils may be quite calcareous if the sediments are derived from limestone sources. Young tributary deposits are relatively thin, but typically are permeable with good water-holding capacity. The amount of water in these deposits varies depending on proximity to water sources. They support some riparian vegetation, especially near major streams. There is little sediment cohesion and no cementation, so these deposits are susceptible to erosion.

Older deposits of the Verde River and its tributary drainages generally are spatially separated from riparian areas, and thus have minimal direct impact on the extent and character of riparian areas (see figure 2 for examples). The physical characteristics of these units are summarized in Table 1. Soil development (clay and calcium carbonate content) generally increases with the age of the deposit, resulting in decreasing permeability and increasing resistance to erosion. However, these older units typically are fairly coarse-grained. Thus these deposits remain fairly permeable and have the potential to hold significant groundwater, but their relatively high positions in the landscape do not permit them to retain much water. Vegetation on these older deposits typically is upland desert or grassland. Riparian vegetation commonly exists at the interface between older deposits (especially mid-level stream terraces) and active channels.

Hydrogeology of Riparian Areas

Young alluvial deposits are the primary aquifer for riparian areas along most of the central Verde River and its perennial tributaries. Water in alluvial deposits along the Verde River is part of the regional aquifer, at least between Sullivan Lake and Fossil Creek (Owen-Joyce and Bell, 1983). Along this portion of the river, the water table is at or near the ground surface (Levings and Mann, 1980), and thus intersects the young alluvium along the river. Young alluvial deposits along the Verde River are permeable but quite thin. This may in fact be an advantageous situation for riparian vegetation. If the permeable alluvial deposits are underlain by less permeable rocks (and they probably are in almost all cases), then water derived from the Verde River and water flowing into the river from surrounding areas may be effectively perched at shallow levels and available to riparian plants. Young terrace deposits that are above the base flow of the perennial streams may hold water during and shortly after large flow events, or during relatively wet portions of the year. Due to their permeability, water likely drains relatively rapidly from these deposits during intervals of low flow. However, portions of units Qc and Qty that are below the level of base flow are probably saturated year-round.

Riparian environments along the Verde River are restricted to areas of young deposits or the interfaces between young deposits and older alluvial, basin-fill, and bedrock units in almost all cases. Vegetation in active channel areas is periodically damaged or removed by floods. Vegetation density and size typically is greatest on low terraces immediately adjacent to active channels. Water supply in these areas is ample, and they are not subject to frequent flooding. In areas along the Verde River where young terraces are extensive (i.e., much of the Verde Valley), they have been irrigated and cultivated and the original vegetation has been removed. It is not clear whether all young terraces in the Verde Valley formerly supported or could potentially support riparian vegetation..

Potential for Lateral Stream Erosion and Shifts in Channel Position

Some areas along the Verde River are likely to be subject to significant bank erosion during floods. Bank erosion typically is greatest on the outsides of meander bends. Major shifts in channel positions (avulsions) may occur in areas where there is little topographic confinement of the present channel. The potential for lateral bank erosion during floods depends on the proximity of an area to active channels and the character of the substrate. Areas mapped as Qc and Qty are most susceptible to erosion, because they are relatively near (or in) active channels and these young sediments have little cohesion and no cementation. Sand-sized sediment in particular may be vulnerable to erosion, while coarser deposits are more resistant to erosion during floods. Furthermore, the very existence of these young deposits demonstrates that the Verde River or its tributaries have deposited material there in the past few thousand years. In many situations, young terraces occupy positions where active channels existed in the recent past. Within areas of young deposits, and particularly where young terraces are quite broad, areas that are relatively low and close to active channels are the most vulnerable to erosion (see figure 3 for example).

Older alluvial deposits found along the Verde River are not completely indurated and thus may be subject to bank erosion. Older alluvial deposits (units Qtm, Qfm, Qtmo, Qfmo, Qto, and Qfo) usually resist erosion much more effectively than young deposits,

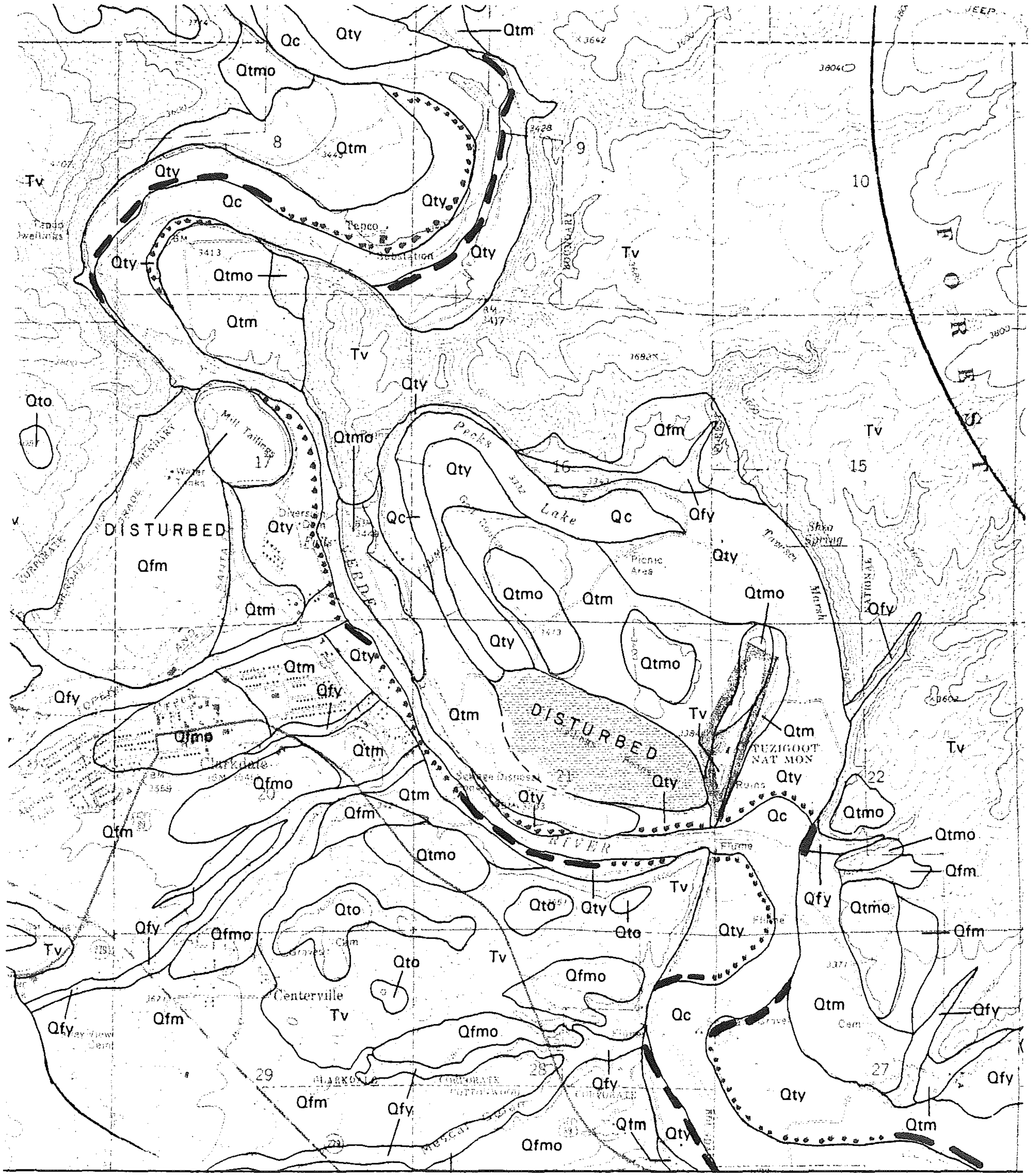

Figure 3. Vulnerability of areas along the Verde River near Clarkdale to bank erosion. All areas that are mapped as channel deposits (Qc) are likely to be subject to significant erosion during floods. Areas adjacent to active channels that are composed of young, unconsolidated sediments (Qty, Qfy) may be subject to bank erosion or shifts in channel positions (dotted lines). The potential for erosion is greatest on the outside banks of meander bends where the banks are composed of young deposits (bold dashed lines). Banks that are composed of older alluvial deposits (Qtm, Qtmo) or the Verde Formation (Tv) are much less vulnerable to erosion.

however, because (1) they typically are fairly coarse; (2) they are usually farther away from or high above the active channel; and (3) soil development provides some cohesion. Erosion of older alluvial deposits is likely to be focused on the outside portions of meander bends.

The resistance of basin-fill deposits to stream erosion is quite variable. Limestone beds typically are quite resistant, and these beds form cliffs along much of the Verde River in Verde Valley. Silt- and clay-rich beds are quite easily eroded, however. In areas where these sediments predominate, such as the area south of Camp Verde, the valley eroded by the Verde River is quite broad (see Plate 1C; figure 2D, 2E). In areas where fine-grained units are interbedded with limestone, cliffs formed by resistant limestone units may be eroded by undercutting as underlying fine-grained beds are removed by stream erosion. Gravelly beds in basin-fill units are fairly resistant to erosion.

The bedrock units exposed along the Verde River are all quite resistant to bank erosion. Where the river flows through bedrock units, the valley is typically narrow and steep. Stream erosion is effectively limited by the bedrock valley sides.

Physiography, Geomorphology and the Extent of Riparian Areas

The distribution and character of pre-Quaternary bedrock and basin-fill units effectively control variations in the physiography of the central Verde River. Variations in physiography in turn control the extent and character of Quaternary alluvial deposits. The extent of young alluvial deposits is an important factor controlling the extent of riparian environments along the Verde River. Thus there are strong connections between geology and geomorphology and riparian environments of the Verde River.

The relative resistance of bedrock and basin-fill units to erosion governs the overall shape of the valley of the central Verde River. In areas where the Verde River flows through resistant lithologies, the valley is steep and fairly narrow and alluvial deposits are meager. This description characterizes most of the Verde River between Beasley Flat and Horseshoe Reservoir, upstream from Sycamore Creek, and upstream from Perkinsville. Where lithologies are less resistant to erosion, such as much of the Verde Valley, the Perkinsville area, and the Horseshoe Reservoir area, the river valley is relatively broad and alluvial deposits are extensive. Fairly broad terrace deposits of several different ages are typical in these areas, and deposits derived from tributary drainages are widespread. The extent of active channels and young terraces, and the potential extent of riparian areas, is greatest in the Verde Valley.

The History of the Verde River

The through-flowing Verde River has developed relatively recently in geologic time. Excellent constraints on the age of the Verde Formation cited above indicate that the Verde River did not exist in the Verde Valley in anything like its current form prior to about 2.5 million years ago. From about 8 to 2.5 million years ago, sediment was accumulating in playas or shallow lakes in the Verde Valley. It is possible that the lake system of the Verde Valley spilled over into the area below Beasley Flat after about 5 million years ago, but lacustrine sediment continued to accumulate in the Verde Valley until about 2.5 million years ago (Nations and others, 1981).

Dramatic downcutting that began after 2.5 million years ago most likely signals the development of a through-going Verde River. Erosion related to this downcutting has resulted in the removal of much of the Verde Formation. Long-term downcutting has continued to the present, leaving behind terrace deposits that mark former positions of the bed of the Verde River. Tributary drainages have deposited alluvial fans and terraces at levels that were graded to former, higher positions of the Verde River. Young alluvial deposits in the Verde Valley are quite thin, and the Verde Formation is exposed at a number of localities in the bed of the river, implying that the long-term of trend stream downcutting has continued through the Holocene.

The timing of initiation of the Verde River drainage upstream from the Verde Valley evidently is generally similar to the story outlined above. The Perkinsville Formation accumulated in a basin that predates the Verde River. The paucity of fine-grained, quiet-water deposits in the Perkinsville area implies that drainage may have been integrated somehow with the Verde Valley as sediment accumulated. Sometime after 4 million years ago, dramatic downcutting began in the Perkinsville area, leaving remnants of ancient alluvial fans far above the modern river.

The age of the Verde River is probably somewhat older downstream from the Verde Valley. The highest Verde River terraces in the Horseshoe Reservoir area are probably of Pliocene age (~2 to 3.5 million years old; Piety and Anderson, 1990). This is a reasonable age estimate for the highest terrace and fan remnants mapped upstream from Horseshoe Reservoir as well. The rugged terrain between Horseshoe Reservoir and Beasley Flat is due in part to the resistant nature of the bedrock lithologies, but it also testifies to the dramatic downcutting of the Verde River that has occurred in the past few million years.

Conclusions

Geomorphic analyses and mapping of geologic units define the basic framework of the riparian environments along the Verde River between Sullivan Lake and Horseshoe Reservoir. The central Verde River has been downcutting through a variety of different rock units during at least the past 2 million years. The relative resistance to erosion of the rock units along various portions of the Verde River has controlled the general shape of the river valley. In areas where the rocks are quite resistant, the river valley is steep and alluvial deposits and riparian areas are restricted in extent. In areas where the rocks are less resistant, the river valley is relatively broad, alluvial deposits are extensive, and potential riparian areas are relative extensive as well. However, because of the long-term downcutting, all of the alluvial deposits observed along the Verde River are quite thin, and the areal extent of young deposits that are the best candidates for supporting riparian vegetation is limited along most of the central Verde River.

Terrace deposits record former positions of the Verde River as it has continued to downcut. Very old terraces of the Verde River, which were deposited more than 1 million years ago, are at least 200 feet above the modern channel. These terraces have very strong soil development indicative of their antiquity. Progressively younger terraces are found closer to the altitude of the modern channel. Terrace deposits of the major streams and alluvial fans and terraces of smaller tributaries are permeable and excellent potential hosts for groundwater. However, only Holocene terraces (less than 10,000 years old) and active channel areas are in close enough proximity to perennial water to support substantial riparian vegetation. These young deposits also are most subject to stream erosion because they have the least cohesion and they are relatively close to active channels.

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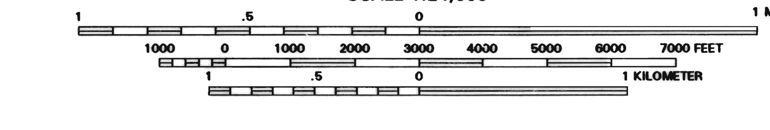

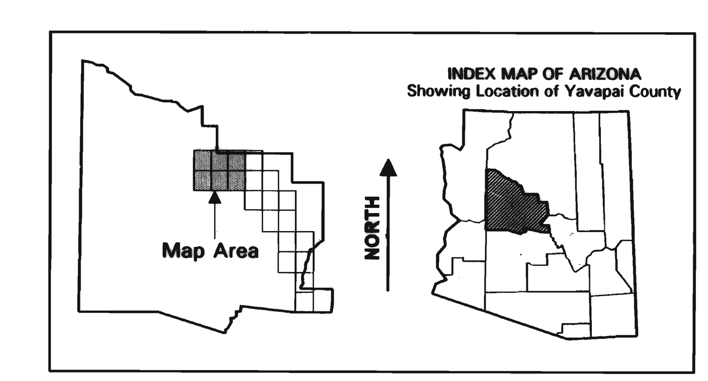

Plate 1a. Surficial Geology and Generalized Bedrock Geology along the Verde River from Sullivan Lake to Horseshoe Reservoir.

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Plate 1b. Surficial Geology and Generalized Bedrock Geology along the Verde River from Sullivan Lake to Horseshoe Reservoir.

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Plate 1c. Surficial Geology and Generalized Bedrock Geology along the Verde River from Sullivan Lake to Horseshoe Reservoir.

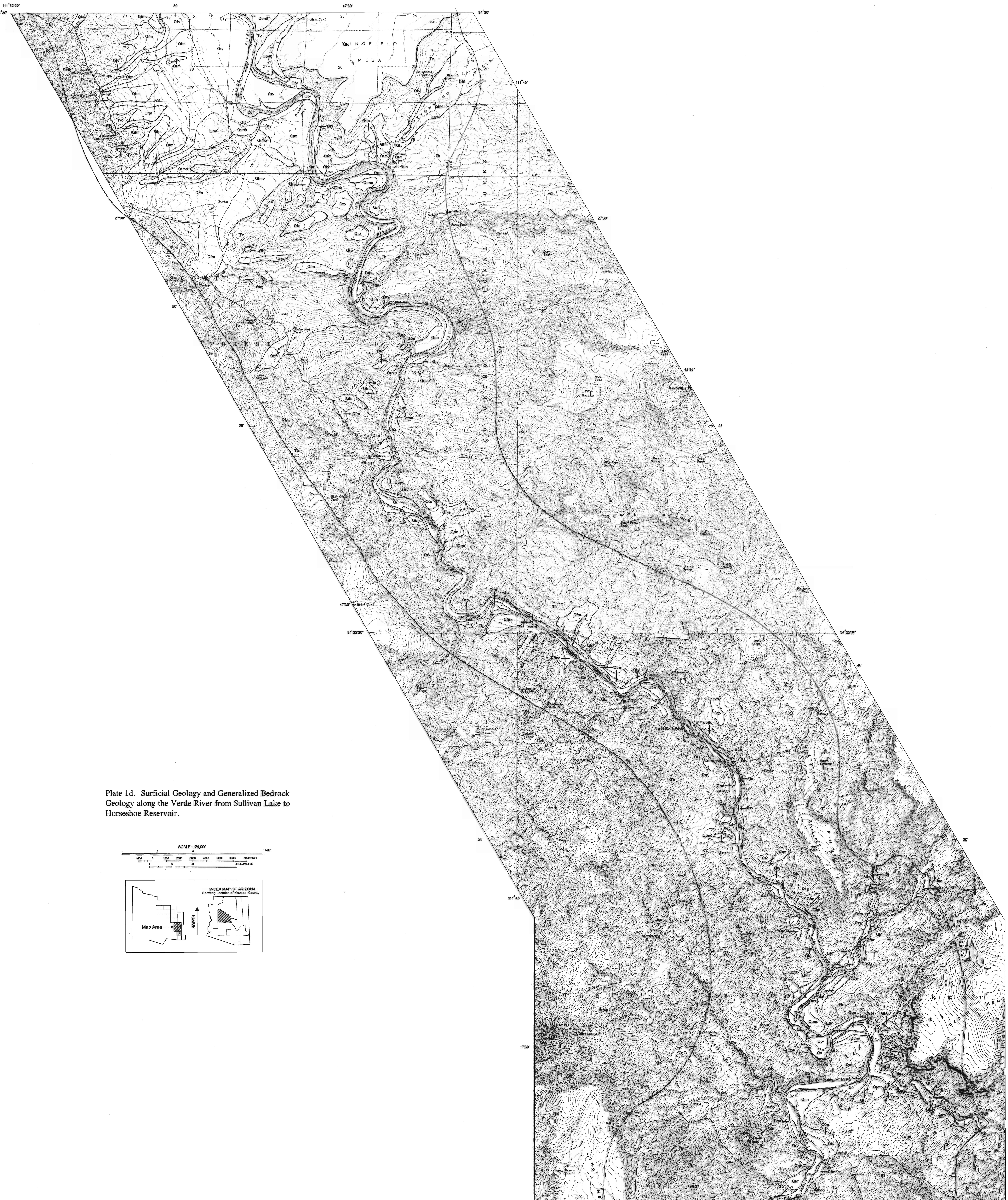
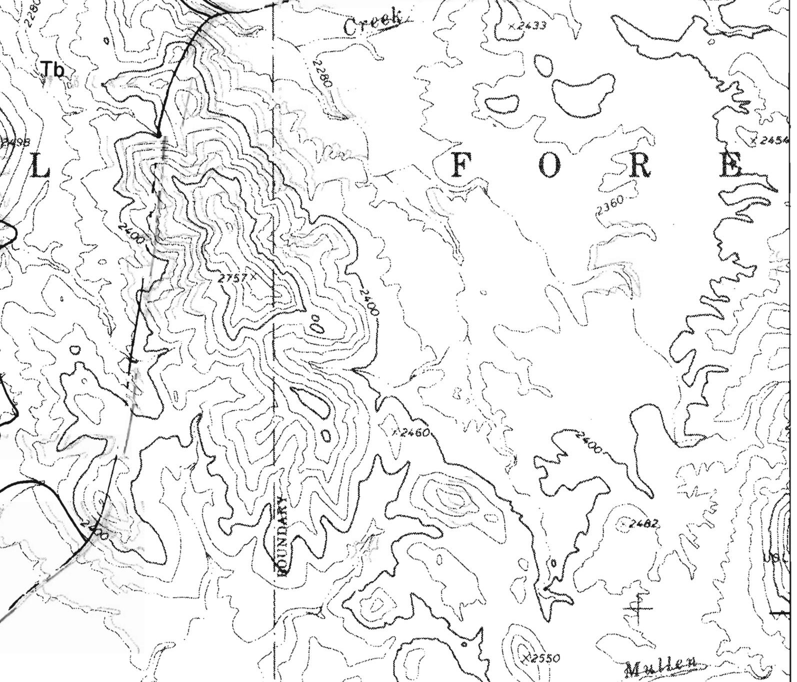


Plate 1d. Surficial Geology and Generalized Bedrock Geology along the Verde River from Sullivan Lake to Horseshoe Reservoir.

Plate 1e. Surficial Geology and Generalized Bedrock Geology along the Verde River from Sullivan Lake to Horseshoe Reservoir.



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