SURFICIAL GEOLOGY OF THE SOUTHERN VERDE VALLEY, YAVAPAI COUNTY, ARIZONA MIDDLE VERDE, CAMP VERDE, AND HORNER MOUNTAIN QUADRANGLES

by

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Introduction

This report contains three detailed maps depicting the distribution of Quaternary alluvial deposits and their associated geomorphic surfaces in the southern portion of the Verde Valley. Preliminary age estimations based on relative age criteria and soil development characteristics are assigned to each unit. Each map also depicts the distribution of generalized bedrock types in the area. The principal traces of the Verde Fault and other, subsidiary faults that may cut Quaternary surfaces are depicted in these maps, but other geologic structures are not.

This series of maps is a continuation of previously completed surficial geologic mapping of the northern Verde Valley (House and Pearthree, 1993). The surficial units are essentially the same, however, some new subdivisions of principal units have been introduced and some different generalized bedrock types are present.

Each map in this report contains abundant geological information related to the effects of Quaternary climatic fluctuations on the evolution of the Verde River, its major tributaries, and adjacent piedmont areas. The influence of drainage basin and substrate lithology on the evolution of the regional landscape and the persistence of fluvial landforms is clearly evident in these maps. In addition, the maps contain information relevant to the distribution and character of flood hazards, vegetation assemblages, potential soil problems, and the distribution of gravel deposits that may be of economic value.

Methods and Materials Used in Mapping

The mapping presented herein is based primarily on detailed examination and interpretation of aerial photographs and supplementary field reconnaissance. A large variety of aerial photo types were used in the compilation of these maps, including: 1:24,000 scale black and white photos taken in 1977 and 1984; 1:24,000 scale color photos taken in 1984; 1:14,000 scale color aerial photos taken in 1990; 1:20,000 scale black and white photos taken in 1954; 1:48,000 scale black and white photos taken in 1950; 1:58,000 scale color-infrared photos taken in 1980; and 1:129,000 scale black and white photos taken in 1972. Stereoscopic analysis of these different photo sets helped to accurately delineate the Quaternary deposits and the bedrock units. Mapping was compiled on 1:24,000 scale orthophoto maps and then transferred to 1:24,000-scale topographic maps (USGS 7 1/2' quadrangles).

Aerial photos used in the mapping were provided by the Coconino National Forest (Supervisors Office, Flagstaff, AZ) and the Soil Conservation Service (Flagstaff Field Office). Mapping of Quaternary alluvium along the Verde River supplemented previously completed mapping by Pearthree (1993). Most of the generalized bedrock mapping was taken from

previously published maps (Twenter and Metzger, 1963; Wolfe and others, 1983; Weir and others, 1989; and Carr, 1986).

Map Unit Descriptions

The surficial deposits of the southern Verde Valley were divided into 22 different units based on their inferred ages and source areas. This represents an addition of 3 units to the classification system established by House and Pearthree (1993) for the northern Verde Valley. The 22 map units are associated with 5 major groups. These surficial deposits range in age from early Pleistocene-latest Pliocene (~2 Ma) to modern. Twelve of these units were deposited by piedmont streams, and nine different ages of major river deposits (river channels and terraces) were recognized. In addition to the surficial deposits, our maps depict the distribution of three facies of basin-fill deposits (the Verde Formation) and several generalized bedrock units.

Surficial geologic units are arranged in a hierarchy based on approximate age (inferred from relative topographic relationships and degree of soil development) and the lithologic characteristics of the source areas of the deposits. This hierarchy gives the flexibility to differentiate units fairly precisely where feasible, but also permits the grouping of units or the use of a less precise age designation for a unit where necessary. The five major groups of piedmont alluvial-fan and terrace deposits are: (1) the early Pleistocene-latest Pliocene *Oxbow group*, (2) the middle Pleistocene *Montezuma complex*, (3) the middle Pleistocene to early Holocene *Chuckwalla group*, (4) the late Pleistocene to Holocene *Sheepshead group*, and (5) late Holocene stream deposits. Most of these major groups have one or more levels of subgroups that are mapped separately in some areas and grouped in others. Terrace deposits of the major rivers are differentiated on the bases of physical characteristics (soil development) and height above the river. The river terraces are tentatively correlated with the major piedmont alluvial units based on their relative topographic relationships near the rivers. Generalized bedrock map units were developed using published geologic mapping covering this area combined with aerial photograph interpretation.

Piedmont Alluvial Units

Oxbow Group: early Pleistocene to latest Pliocene
Map units O, O1, O2, O2a, O2b

The Oxbow group includes three levels of thin alluvial fans representing the oldest surficial alluvium preserved in the Verde Valley. These fan remnants range from about 80 to 150 m above modern drainages and were likely deposited during the early Pleistocene to latest Pliocene (0.8 to 2.5 Ma). There is as much as 60 m of relief between older (O1) and younger (O2a and O2b)

surfaces, implying that these units were deposited over a substantial interval. Soils developed on these units have well-developed calcic horizons (typically stage III to V; after Machette, 1985) and are extremely clay-rich where well preserved. The Oxbow alluvium is present as a relatively thin veneer that caps planar erosion surfaces cut on the Verde Formation. Deposit thickness typically is several meters and probably does not exceed 10 meters. Deposits are very poorly sorted coarse gravels. Particle sizes range from silt and sand to boulders, and clasts are typically subangular.

O1: latest Pliocene (~2 to 2.5 Ma)

The highest level of alluvial fan remnants in the Verde Valley, which are as much as 100 m above modern drainages near the mountain front, are mapped as Unit O1. 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). However, this stratigraphic relationship is not evident in the southern portion of the Verde Valley where O1 surface remnants are found below the top of the Verde Gravel facies, suggesting that there may be subsidiary O1 units in this portion of the Verde Valley that were not recognized in the northern portion of the Verde Valley, or that local tectonic activity in parts of the southern portion of the valley has complicated the relationship.

Only small, isolated remnants of O1 exist in the map area. Possible erosional remnants of this unit are not readily distinguishable from younger members of the Oxbow Group or erosional remnants of the gravel facies of the Verde Formation and are therefore designated "O".

O1 surfaces are planar where preserved. They support a low to moderate density acacia thorn scrub community; assorted grasses and prickly pear cactus are abundant. Surface materials consist of pebbles, cobbles, and boulders of metavolcanic rock and basalt in a clayey matrix. Surface color is dull reddish brown (5 YR 4/4). The soil is very clay-rich (heavy clay texture) and has angular blocky to weak prismatic structure. The very strong soil development and the extremely high topographic position of O1 units in the Verde Valley implies substantial antiquity. Menges and McFadden (1981) argued that similar alluvial fan remnants in southeastern Arizona date to the earliest Pleistocene or latest Pliocene. The highest levels of the fine-grained basin facies of the Verde Formation date to about 2 to 2.5 Ma (Bressler and Butler, 1978; Nations et al, 1981). If O1 deposits represent the highest level of the marginal gravel facies of the Verde Formation, they probably date to 2 to 2.5 Ma as well.

O2: early Pleistocene (0.8 to 2 Ma)

O2 units are high, thin, early Pleistocene alluvial fan remnants deposited on erosional surfaces cut on the Verde Formation (primarily the fine-grained, predominantly lacustrine facies). Scattered O2 surface remnants are fairly widespread on the Black Hills piedmont. South-southwest of Camp Verde O2 surfaces persist as relatively long, thin remnants separated by deep, narrow canyons carved in the underlying Verde Formation (e.g. portions of Copper, Allen, Ryal, and Lucky canyons). O2 surfaces associated with these drainages have a more northeastward orientation than the modern drainage courses. The most extensive well-preserved remnants are found below basins formed in bedrock types that are most resistant to erosion. (metavolcanic and volcanic rocks).

In some areas there are two distinct levels of O2 surfaces (O2a and O2b). Physical characteristics of these surfaces are very similar, so they can only be easily distinguished by relative elevation in areas where they are adjacent to each other. Elevation differences range from about 8 m near the mountain front to about 16 m nearer to the center of the valley. The O2 designation is used in areas where it is not possible to distinguish the two discrete surface levels. The O designation is reserved for erosional remnants with no preserved surface.

O2 deposits are composed of sediment ranging from silt to boulders. Most of the clasts are metavolcanics and basalt. Surface color is dull reddish brown (5YR 4/4-5/4). The soil on well-preserved O2 surfaces is extremely strongly developed. Argillic horizons have heavy clay textures and are dark reddish brown (2.5 YR 3/3). A stage III to IV calcic horizon exists at approximately 80 cm. Soil structure is angular blocky to prismatic. On degraded surface remnants, the argillic horizon has been partially or completely stripped and the calcic horizon is encountered at or near the surface. Well-preserved O2 surfaces support grasses, small acacias, prickly pear cactus, and scattered junipers. In the areas where the surface has been eroded and the calcic horizon is either shallow or at the surface, the density of juniper is higher and crucifixion thorn is abundant. The extremely strong soil development associated with O2 surfaces and the high topographic positions they occupy indicate that they are very old; however, the fact that O2 surfaces were deposited at levels that are much lower than adjacent O1 surfaces implies that they are significantly younger than unit O1.

Montezuma alluvial fan complex: middle Pleistocene (~500 ka)

Map unit M

Extensive middle Pleistocene Montezuma alluvial fans comprise the thickest Quaternary deposits observed in the map area. This group has been designated as a "complex" because it may include several different levels that differ only slightly in elevation. M fan remnants are inset well

below adjacent Oxbow surfaces but are 25 to 30 m (80-100 ft) above modern drainages. In the vicinity of Black Canyon in the northern Verde Valley, the alluvium is locally at least 25 m (80 ft) thick. Roadcuts along state highway 79 in the Middle Verde Quadrangle reveal sections greater than 16 m (50 ft) thick. Considerable variations in thickness of this unit are also apparent in these roadcuts suggesting that the Montezuma alluvium filled irregular paleotopography carved into the Verde Formation after abandonment of the O2b surface. The best examples extensive M surfaces are along the northern side of Cherry Creek (Middle Verde quad.), west of Camp Verde (Middle Verde quad.), and the fan above Beasely Flat (Horner Mountain quad).

Montezuma surfaces are dominated by angular clasts (gravel and cobbles) of metavolcanic, volcanic, or granitic rocks. In some places a weak desert pavement is developed on the surface. In general, the M fans below basins with volcanic or metavolcanic rocks have the most well-preserved surfaces. The M surface color is typically dull yellowish brown to brown. It hosts a low to moderate density community of prickly pear, mesquite and assorted desert grasses. Closer to the mountains and at higher altitudes the plant community is composed of moderate to high density stands of acacia, mesquite, holly, and some juniper. Soils associated with M surfaces are strongly developed with clay textures and moderately developed calcic horizons (stage II to III) at an approximate depth of 90 cm. Soft carbonate concretions are present below about 40 cm.

Chuckwalla Group: middle Pleistocene to early Holocene
Map units C, C1, C1a, C1b, and C2

The Chuckwalla group consists of relatively thin alluvial fans and narrow stream terraces. Surfaces of the Chuckwalla group are much closer to the altitude of modern drainages than adjacent M and O surfaces. There typically is not substantial relief between the three units in the Chuckwalla group (C1a, C1b, and C2). The degree of soil development differs substantially between the three units, however, indicating that this group may span much of the late Quaternary (~250 to 10 ka).

C1: middle to late Pleistocene (50 to 250 ka)

The older deposits of the Chuckwalla group consist of small, scattered remnants usually interspersed among younger members of the Chuckwalla group. The two subunits (C1a and C1b) differ primarily in degree of soil development and surface color. In areas where they are indistinguishable or intricately interspersed, they are grouped together in unit C1. C1 deposits cover much of the Black Hills' piedmont between the area across from the mouth of West

Clear Creek and Beasley Flat. Some well-preserved remnants also exist between Cherry Creek and I-17 in the Middle Verde quadrangle. Unit C1a also occurs locally as a terrace surface cut below surfaces of the Montezuma alluvial fan complex.

C1a and C1b are both composed primarily of coarse sediments ranging from sand to large cobbles and small boulders. The C1a surface color ranges from dull reddish brown to bright brown (5 YR 5/4 - 7.5 YR 5/6). There is considerable variation in surface color, however, that is a reflection of the source-area lithology (granitic vs. mafic volcanic). Soils typically have strong argillic horizons with light clay textures and moderately developed calcic horizons (stage II to III). In general, C1a is characterized by a relatively sparse shrub community and fairly good grass cover, but this varies considerably with local conditions (i.e. elevation and aspect) and source area lithology. Predominant plants include prickly pear cactus, catclaw, assorted grasses. Based on the relatively strong soil development associated with C1a surfaces, we estimate their age to be ~125 to 250 ka. C1b surface color typically is slightly less red than C1a; soils are characterized by moderately developed argillic horizons (clay loam textures) and relatively weak calcic horizons (stage I to II). C1b surfaces are dominated by a relatively high-density thorn scrub assemblage including acacia, mesquite, and holly. Based on differences in soil development, we estimate that C1b surfaces are significantly younger than C1a (~50 to 125 ka).

C2: latest Pleistocene to early Holocene (5 to 20 ka)

The youngest member of the Chuckwalla group (C2) includes relatively young, thin alluvial fans adjacent to or slightly inset into older C1 alluvium. C2 also includes low terraces adjacent to stream channels confined by higher, older alluvium or bedrock. Areas where C2 surfaces are tightly interspersed with young piedmont stream sediments (Yp) are labeled as C2/Yp.

Unit C2 is composed primarily of coarse sediments ranging from sand to large cobbles and small boulders. Nearer the Verde River, the composition of the C2 alluvial fans is finer-grained and dominated by sand, pebbles, and lesser silt. In the middle and upper piedmont areas, the C2 surface is often characterized by a dense thornscrub thicket including catclaw, mesquite, and holly. Near the river, the density of vegetation is lower.

Sheepshead Group: late Pleistocene to Holocene
Map units S, So, S1, and S2

The Sheepshead group consists of relatively fine-grained late Quaternary alluvium eroded from the Verde Formation. Unit S deposits consist of alluvial fan remnants, some piedmont stream deposits, and, in places, interspersed colluvium derived from cliffs of the Verde Formation.

In many areas, unit S can be subdivided on the basis of soil development and relative topographic position (units So, S1 and S2). In areas where such distinction is not possible, the alluvium is labeled S. Sheepshead alluvium is most extensive in central portions of the northern Verde Valley. However, it is found in the southern Verde Valley along the flanks of the White Hills, and in piedmont areas where relatively large outcrops of the Verde Formation have been exposed through erosion.

So: middle Pleistocene (~500 ka)

The oldest unit in the Sheepshead group is probably correlative with the Montezuma fan complex. Where So remnants are near the Verde River, they are at roughly the same relative elevation as remnants of the "M" complex. It is composed of a poorly sorted mixture of alluvium ranging from fine silt to small boulders. The alluvium is derived entirely from the Verde Formation and the soil is very calcareous.

This particular unit is limited in its distribution and spatial extent and is found emanating from canyons in the White Hills in a few places north of Camp Verde. Isolated remnants of this unit were also mapped in an erosional embayment in the White Hills in the vicinity of Wikieup Creek, north of West Clear Creek. In the northern Verde Valley the few remnants of this unit were mapped as "M" (House and Pearthree, 1993).

S1: late Pleistocene (10 to 125 ka)

The middle unit of the Sheepshead group is separated from the younger unit on the basis of relative elevation. In general, the two units are mapped separately only in areas where they are both present and can be easily differentiated. The unit consists of relatively fine-grained sediments (clay, silt and sand) with lesser amounts of gravel. Because these sediments are derived from the Verde Formation, the soil is very calcareous. Vegetation is dominated by relatively dense stands of creosote bushes and assorted grasses.

S2: Holocene (0 to 10 ka)

The younger unit of the Sheepshead Group includes small alluvial fans, discontinuous stream deposits and low stream terraces adjacent to modern piedmont drainages. S2 alluvium is typically fine-grained and consists primarily of clay, silt, sand, and minor gravel. The soil is moderately calcareous. Deeply incised, narrow arroyos are common in areas of S2 alluvium. Creosote bush and assorted grasses are common plants; vegetation density is variable.

Verde Mix: Indeterminate age
Map unit Vx

Unit designation Vx is used in areas where weathered Verde Formation, Sheepshead alluvium, and eolian deposits are essentially indistinguishable. Typically, this unit consists of a very thin mantle of unconsolidated deposits of uncertain origin over Verde Formation. Unit Vx is exclusively related to the Verde Formation; it is most extensive in the central portion of the Northern Verde Valley. Most contacts between Vx and Sheepshead alluvium are gradational. In general the Vx designation was reserved for rounded interfluve areas relatively high above modern washes.

Young Piedmont Alluvium: late Holocene (< 5 ka)
Map units Yp1 and Yp2

These two units comprise the youngest piedmont alluvium in the map area and are associated with currently active fluvial processes. They have been differentiated on the basis of their depositional environment and, to a certain extent, the frequency of associated deposition.

Unit Yp2 consists of modern piedmont stream channel deposits along active piedmont drainage courses. It also includes portions of small alluvial fans that are actively prograding onto terraces of the Verde River and West Clear and Beaver creeks. Composition ranges from extremely coarse very near source areas in the Black Hills and White Hills (sand, gravel, cobbles, and boulders) to more fine-grained (silt, sand, gravel) elsewhere. This designation has also been applied to continuous deposits of modern stream channels draining the White Hills or other areas underlain predominantly by rocks of the Verde Formation. This unit is frequently subject to deposition/fluvial activity.

Unit Yp1 consists of young, relatively broad alluvial fans associated with modern drainages throughout the map area. It is mapped separately to indicate the extent of young alluvium that is probably not subject to very frequent inundation. It also depicts areas that are subject to sheetflow rather than concentrated streamflow. The unit is composed of a wide range of clasts sizes, but is finer-grained overall than Yp2 deposits.

<u>Major Stream Deposits</u>

Oxbow Terraces: early Pleistocene (0.8 to 2 Ma)
Map units OT1, OT2, OT3

Three very high and old terrace remnants are found along West Clear Creek, Beaver Creek, and the Verde River. The O terraces were grouped together because of their topographic isolation

above other terraces. The oldest terraces (OT1) are about 85 to 100 m (280-350 ft) above the modern river channels; OT2 terraces range from about 55 to 70 m (180-220 ft) above the river; OT3 terraces range from about 50 to 55 m (160-180 ft) above the river. They all likely date to the early Pleistocene, and thus were deposited during the same general interval as the Oxbow piedmont alluvial units. The most extensive continuous exposures of these units in the entire Verde Valley are found on Wingfield Mesa in the Camp Verde and Horner Mountain quadrangles. Less extensive exposures are present near the airport at Camp Verde. Otherwise, the distribution of O terraces is scattered.

The oldest river terraces (OT1) are about 200 m (700 ft) below the highest levels of the fine-grained facies of the Verde Formation. Thus, OT1 is almost certainly much younger than the O1 piedmont surfaces, which probably represent the highest levels of the Verde Formation. O2a alluvial-fan remnants are at about the same altitude as OT2 near the Verde River, so they are of similar age. O2b can not be directly correlated with OT3, but O2b is well above the level of the next younger river terrace (MT), suggesting that it generally correlates with OT3. Terraces in the O group are found much farther from the present courses of the Verde River and Beaver and West Clear creeks than any of the younger terraces. Deposits are typically fairly thin, consisting of fairly well sorted silt, sand, gravel, and cobbles. Soil development is strong, with substantial clay and calcium carbonate accumulation; locally, soil horizons are cemented with calcium carbonate.

Montezuma Terraces: middle Pleistocene (~500ka)
Map unit MT

Montezuma terraces (MT) are also high above the modern stream courses but are usually found in locations nearer to the channels than are the older terrace units. MT terraces are not, however, restricted to the interiors of relatively narrow canyon reaches and are often located on bedrock shelves lining the periphery of such reaches. They are typically 25 to 30 m (80-100 ft) above the modern river channels. In places, the Montezuma alluvial fan complex is graded to MT terraces near the major streams, so they must be of equivalent age (middle Pleistocene). Soil development is fairly strong, and deposits are typically coarse gravel facies.

Chuckwalla Terraces: middle Pleistocene to early Holocene (5 to 250 ka)
Map units CT1 and CT2

Chuckwalla terraces are found in very close proximity to the present positions of the Verde River and Oak Creek. They are of limited areal extent and are typically found close to the present stream courses (e.g. the interior portions of narrow canyon reaches). The older terrace (CT1)

ranges from about 12 to 18 m (40-60 ft) above modern river channels; C1 piedmont deposits are graded to terrace CT1. CT1 thus dates to the middle to late Pleistocene. The younger terrace (CT2) is about 6 to 12 m (20-40 ft) above modern river channels; C2 piedmont deposits are graded to CT2 terraces, implying that CT2 terraces are of latest Pleistocene to early Holocene age. Typically, deposits are coarse gravel facies of relict channels and bars and are less than 5 m thick. Soil development is moderate, with some clay accumulation. CT terraces are fairly resistant to stream erosion and are not inundated during large floods.

Young Terraces: late Holocene (<5 ka)
Map units YT1 and YT2

These units comprises the youngest, relatively thin, low terrace deposits along the Verde River and Beaver and West Clear creeks. YT2 terraces are less than about 3 m (10 ft) above the lowest portions of river channels and are found directly adjacent to the active channel bed. YT1 terraces range from 10-20 feet above the modern channels and are often found at greater distances from them than are YT2 deposits; however, some YT1 deposits are small, streamlined islands surrounded by YT2 and Yr deposits. Yp channels and fans are graded to YT terraces in some places. Both YT1 and YT2 terrace deposits are composed of two distinct facies, a coarse channel and bar facies composed of pebbles, cobbles and boulders, and an overbank facies composed of sand and silt deposited in low velocity, slack-water areas during large floods. YT deposits are weakly consolidated and are susceptible to bank erosion, although they may be stabilized by riparian vegetation. YT terraces have minimal soil development. We estimate that they are less than 5 ka in all cases, and are typically tens of years to a few thousand years old. All of the YT2 terraces are probably subject to inundation during large floods, but all YT1 terraces are not necessarily subject to inundation except possibly during the largest flood events, or as a consequence of major shifts in channel position.

Active Channels of Major Streams: Modern
Map unit Yr

Active channel and flood channel deposits of the Verde River, West Clear Creek, and Beaver Creek. This unit consists of silt, sand, pebbles, and cobbles in the active channel areas of both major drainages in this portion of the Verde Valley. Most of this unit is the active bed of each stream, it also includes areas that convey floodwaters frequently enough to limit the development of mature riparian plant communities (i.e. no dense stands, or large trees).

Generalized Bedrock Units:

Verde Formation: late Miocene to Pliocene

Tvl: lacustrine facies: composed of freshwater limestone, sandstone, siltstone and marl This unit is exposed throughout the map area particularly in the White Hills and along the Verde River south of the Oak Creek Confluence. In most areas, the Verde Formation is a cliff-forming unit, but in areas where clay rich layers are exposed it is characterized by soft-looking slopes and occasional badlands-type topography.

Tvg: gravel facies. alluvial fan deposits composed of primarily gravel and cobbles. Diverse lithologies. This unit is concentrated along the eastern flank of the Black Hills and occurs as rounded, high-standing hillocks that are conspicuously gray-colored.

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.

Tvu: undifferentiated Verde Formation. This designation is used in areas where the lacustrine and gravel facies are interbedded or indistinguishable.

Tertiary Sediments: Miocene

Ts: Deposits of unconsolidated or poorly consolidated sediments (sand, gravel, cobbles) that pre-date the Verde Formation.

Basalt: Miocene and Pliocene

Tb: Late Cenozoic basalt flows. This bedrock type is found scattered through the map area. It caps mesas throughout the Black Hills. Some basalt also occurs within the Verde Formation; it is mapped separately as Tb in places where it is relatively extensive, otherwise it is grouped in unit Tvv.

Sedimentary Rocks: Paleozoic

Pzs: Sedimentary rocks ranging from limestone and dolomite to sandstone. These rocks are found in the Black Hills west of the Verde Fault and in some limited locations in the foothills.

Metavolcanic Rocks: Precambrian

Xmv: Metavolcanic rocks ranging from basalt to rhyolite. These rocks are found scattered throughout the Black Hills.

Intrusive Igneous Rocks: Precambrian

Xg: Granitic rocks in portions of the Black Hills.

Geologic Structures:

The only geologic structures depicted in these maps are the principal traces of the Verde Fault, related, subsidiary faults, and a fault on the east side of the valley in Cottonwood basin (Horner Mountain quadrangle.). On the maps, a solid line indicates the easily discernible trace of a fault (in photos and/or field) and a dashed line indicates the approximate, or inferred, trace of a fault.

A splay of the Verde Fault clearly displaces Quaternary alluvium in the vicinity of Allen and Ryal Canyons. The fault is evident as an 8 m scarp in O2 alluvium. Correction for the effect of fan slope and for backward rotation of the scarp zone results in an estimated displacement of as much as 6 m (Pearthree and Scarborough, 1984). Examination of the scarp morphology indicates that it probably records multiple ruptures. We have tentatively traced this fault to the intrabasin fault mapped by Carr (1986) which is probably a branch of the main Verde Fault that offsets units within the Verde Formation.

A previously unmapped fault was identified in the Horner Mountain quadrangle. It strikes to the northwest through a portion of Cottonwood Basin on the east side of the southern Verde Valley. There is some evidence to suggest that this fault cuts Quaternary alluvium on Wingfield Mesa (OT1).

General Geologic Setting of the Verde Valley

The Verde Valley is one of several roughly northwest-southeast trending basins in the Transition Zone geological province of Arizona. Structurally, it is a half-graben bounded on its southwest margin by the Verde Fault, a high angle normal fault along which the Black Hills have been uplifted. The Valley is bounded on the north and east by the Mogollon Rim, a prominent escarpment marking the southern edge of the Colorado Plateau.

In the late Miocene the ancestral drainage from the Verde Valley was blocked, probably by a combination of structural subsidence and volcanic activity at the southern margin of the valley (Bressler and Butler, 1978; McKee and Elston, 1980). The absence of consistent external drainage resulted in the deposition of the Verde Formation, an extensive and varied sedimentary unit composed primarily of lacustrine, fluvial, and volcaniclastic sediments and interbedded lava

flows. Concurrent with the accumulation of sediments in the middle of the basin, thick deposits of gravel were laid down as alluvial fans by streams entering the basin from the surrounding highlands. Deposition of the rocks in the Verde Formation lasted from approximately 8.5 to 2.5 Ma (Bressler and Butler, 1978; Nations et al., 1981, McKee and Elston, 1980). Interbedded basalt flows in the Verde Formation have yielded dates of 4.5 Ma, 5.5 Ma, (McKee and Anderson, 1971) and 8.3 Ma (McKee and Elston, 1980).

The geomorphic evolution of the Verde Valley changed dramatically in the latest Pliocene. Major stream downcutting and basin dissection was initiated when the through-going Verde River drainage began to breach the natural volcanic/structural dam at the southeastern end of the Verde Valley. This transformation occurred sometime in the latest Pliocene (Bressler and Butler, 1978; Nations et al., 1981). Subsequently, the geomorphology of the valley has been shaped primarily by the long-term downcutting of the Verde River and large-scale climatic variations during the Quaternary period, minor tectonic activity in the southern portion of the valley occurred in the early Pleistocene, but it played a less significant role than did climatic variation.

Quaternary Geology and Geomorphology of the Southern Verde Valley

Quaternary deposits and associated landforms mapped in this study record the recent geologic evolution of the southern Verde Valley. Quaternary deposits consist of extensive, usually thin, alluvial fans and eroded alluvial fan remnants along the flanks of the surrounding highlands and sediments deposited by the Verde River and its principal tributaries. Each Quaternary deposit has an associated geomorphic surface existing in some degree of preservation ranging from pristine to degraded.

A fluvial geomorphic surface is a distinct landform resulting from the attainment and subsequent abandonment of an equilibrium level of aggradation or degradation. The term equilibrium refers to the condition in which a balance exists between the rate of delivery of sediment to a stream system and the rate of removal of sediment from the system (Bull, 1991). A disruption in the balance may lead to either aggradation or degradation by the affected stream. The attainment of equilibrium results in the formation of a relatively uniform, planar surface (alluvial fan, pediment, or stream terrace) composed of, or capped by, alluvium. Abandonment of a fluvial geomorphic surface is usually associated with incision by streams in response to changes in the sediment and/or water discharge characteristics of their tributary drainage basins; however, abandonment may simply occur in response to major lateral changes in stream channel positions. The first mechanism involves a departure from equilibrium conditions and can have the most lasting effect on the landscape through isolation of surfaces from major episodes of erosion for thousands to hundreds of thousands of years. The stimulus for this type of change can come from

climatic change, tectonic processes, or some combination of the two. In the Verde Valley, climatic change and the long-term tendency for stream downcutting have dominated the area's geomorphic evolution over the past 2 million years.

Once a surface is abandoned, it is subject to erosion only from hillslope processes, small, superposed drainage networks, and lateral erosion by major streams and tributaries. The long-term preservation of a fluvial geomorphic surface depends on the resistance of its constituent alluvial materials to erosion, the original extent of the surface, its position relative to major streams, and, to some degree, chance. Over time, a stable surface undergoes weathering and soil formation. These processes continue indefinitely unless the surface is obliterated by erosion or buried by renewed aggradation from major streams. Under ideal conditions of surface preservation, the degree of soil development reflects the time that has elapsed since the surface was isolated from major fluvial activity. Specific soil characteristics, such as maximum clay and calcium carbonate contents, change progressively with time. These characteristics can be evaluated and related to dated soils formed under generally similar climatic conditions to estimate the surface age (Gile et al., 1981; Bull, 1991).

The Verde River and its principal tributaries, Beaver Creek and West Clear Creek, are the fundamental controls on the development of fluvial landforms in the Verde Valley because all the piedmont tributaries are graded to them. The long-term tendency of these major streams has been to downcut, possibly because of regional uplift of the Transition Zone during the Pliocene and Quaternary (Péwé, 1978; Menges and Pearthree, 1989). The pattern of geomorphic change along these major streams must be reflected in the assemblage of landforms in the piedmont areas. Eight distinct levels of major river terraces were identified in this mapping project. These terraces and terrace remnants range in age from recent (the modern channel and floodplain) to early Pleistocene. Seven roughly correlative levels of piedmont alluvial surfaces were also identified, but correlation between terrace remnants and piedmont alluvial surfaces is uncertain in most cases. Only in a few instances do fans clearly grade into terraces. It is likely that geomorphic processes in major streams and tributary piedmont drainage systems operate on different time scales, and thus their response times are different.

During the Quaternary the Verde River and its major tributaries have downcut at least 300 m (1000 ft) into the basin fill deposits (Verde Formation) of the Verde Valley. Downcutting apparently has been episodic, however, with river terraces representing intervals of stability or minor aggradation. At the present time, the major streams appear to be in a downcutting phase because of the presence of bedrock at or very near their beds in many reaches. Piedmont landforms indicate that the period of net downcutting has included at least one period of major aggradation during the middle Pleistocene and several periods of base-level stability.

Latest Pliocene-Early Pleistocene. The latest Pliocene-early Pleistocene evolution of the Verde Valley is represented by fans and terraces of the Oxbow group. This group comprises three distinct alluvial fan surface remnants and three distinct stream terrace remnants. These units have been grouped together primarily because they are found at considerably higher levels than any of the younger surfaces and their soil development is very strong.

The O1 unit represents the highest and oldest alluvial fan surface remnants in the Verde Valley. Because of its antiquity, it has been obliterated by erosion throughout the valley except in a few isolated locations. The O1 alluvium rests atop the coarse gravel facies of the Verde Formation (Tvg); however, the nature of the stratigraphic relationship between these two units is unclear. Either the O1 surface represents the depositional surface of the Verde Formation fan facies as has been proposed by House and Pearthree (1993), or it is a veneer of alluvium deposited on an erosion surface carved on the uppermost levels of the Verde formation. In the southern Verde Valley, the altitude of O1 surface remnants is about 3800 ft above mean sea level (MSL). The highest remnants of the fine-grained facies of the Verde Formation (Tvl) in the mapped area are about 3600 ft above MSL. The highest preserved river terrace remnants (OT1) are about 3500 ft above MSL. These relationships imply that the O1 surface is older than the highest preserved river terrace remnants. They also imply that major amounts of downcutting occurred during the latest Pliocene to early Pleistocene.

O2 encompasses two alluvial units that are at least 60 m (200 feet) lower than O1 in the upper piedmont near the Black Hills. The O2 piedmont units are both thin and cap an erosion surface carved in the Verde Formation. Field observations and aerial photo interpretation indicate that this unit varies in thickness from approximately 15 m (50 ft) to less than 3 m (10 ft). The O2 fans represent periods of equilibrium during a period of fairly dramatic downcutting.

The distribution of O terraces along the Verde River, Beaver Creek, and, in particular, West Clear Creek, , reveal periods of widespread lateral planation of the Verde Formation that are generally correlative to the stable intervals represented by the O2 fan remnants. In places, OT remnants are found more than 1.4 km (1 mile) from present channel positions along the major streams. In the White Hills between West Clear and Beaver Creeks, there are some enigmatic remnants of O gravel deposits that suggest major changes in drainage patterns following the early to middle Pleistocene along Beaver and/or Wikieup creeks.

Early to Middle Pleistocene. The middle Pleistocene Montezuma alluvium comprises numerous, extensive alluvial fans that are the thickest Quaternary alluvial deposits in the Verde Valley. Deposition of the Montezuma alluvium represents a major period of backfilling following an episode of relatively deep erosion into the Verde Formation. At sites where Oxbow surfaces and Montezuma surfaces are adjacent to each other, the Montezuma surface is approximately 45 to 60 m (150-200 ft) below the contact between O2 alluvium and the Verde Formation. In the

Black Canyon area the Montezuma alluvium is as much as 25 m (80 ft) thick. Thus, piedmont drainages eroded valleys as deep as 80 m after deposition of O2 alluvium ceased and prior to deposition of Montezuma alluvium. This implies that the Montezuma alluvium was deposited long after the O2 surfaces were abandoned. Deposition of the Montezuma alluvium probably represents an interval during the middle Pleistocene when climatic changes drastically increased the sediment supply to piedmont drainages, resulting in a pulse of deposition that temporarily reversed the long-term tendency for downcutting.

At some sites along the Verde River M fans are graded to MT terrace remnants. Some MT surfaces along the west side of the river have morphological characteristics typical of terraces (and are mapped as such) but are capped by thin fan deposits. In these areas, terrace and fan deposits are interfingered.

The general positions of the Verde River, Beaver Creek, and West Clear Creek were probably established in the erosional interval separating the abandonment of the Oxbow surfaces and the deposition of the Montezuma alluvium. The distribution of O terraces clearly indicates that the channels had considerable lateral mobility at times in the early Pleistocene; however, the distribution of M terraces primarily is limited to bedrock shelves lining the periphery of incised reaches of both streams; however, the lateral mobility of the Verde River has been greater in the southern part of the valley than in the northern part throughout its Quaternary history, particularly in the vicinity of Camp Verde. The relative proximity of MT deposits to the major rivers may indicate that backfilling along the streams was limited to incised reaches formed following the abandonment of O2 surfaces, and the terrace remnants represent the highest level of backfilling reached by each stream. Attainment of this level was probably accompanied by some lateral planation of the Verde Formation. Subsequent incision along Oak Creek and the Verde River was largely restricted to the alluvium filling the canyons and has re-exposed and deepened the canyons formed in the early to middle Pleistocene.

Middle Pleistocene to Holocene. The alluvium in the Chuckwalla group represents a prolonged period of relative base level stability along the major trunk streams. The group includes three different alluvial units that are topographically much lower than adjacent Montezuma surfaces. Soil development in the three members of the Chuckwalla group indicate that there is a substantial range in their ages, yet the three surfaces are separated only by minimal amounts of relief. The lack of relief between Chuckwalla surfaces suggests that the middle to late Pleistocene was an extended period of relative base-level stability which evidently followed a period of fairly dramatic downcutting and valley formation that followed deposition of the Montezuma alluvial fans. During the Chuckwalla phase piedmont streams eroded laterally and distributed relatively thin deposits over broad portions of the piedmont.

The oldest member of the Chuckwalla group (C1a) is an erosional surface cut on Montezuma alluvium in some places. In some locations bedrock can be seen protruding through the C1a alluvium. The youngest member of the Chuckwalla Group (C2) is inset slightly into the C1 units and is at a similar elevation as are the youngest deposits of alluvium. The relative topographic difference between C1 and C2 becomes more pronounced near the principal streams. In some areas, C2 fans taper to low terraces adjacent to drainages incised into older fan remnants. Elsewhere, C2 fans become widespread near the river and appear to merge with CT1 surfaces.

In portions of the Verde Valley where small streams head in areas underlain entirely by the Verde Formation, and the nature and preservation of Quaternary alluvial deposits (the Sheepshead group) is considerably different from areas where streams head in areas with more diverse and resistant lithology. The probable reasons for the major differences in the nature of the Sheepshead deposits and the other deposits in the valley include the high erodibility of the fine-grained facies of the Verde Formation and the distance of the source basins from the trunk streams. Many of the small streams heading in the White Hills have relatively rugged basins, but they are very small and quite far removed from the influence of changes along the Verde River and Oak Creek. Also, the high erodibility of portions of the Verde Formation results in heavy sediment loads which may lead to lesser amounts of downcutting in the upper portions of the streams. Additionally, the fine-grained nature of the Sheepshead alluvium is not conducive to the long-term preservation of alluvial surfaces.

Holocene: The geomorphic evolution of the Verde Valley following the deposition of Chuckwalla alluvium has been dominated by downcutting by the major streams and their tributaries. The only young units that are widespread in the area are stream deposits and relatively low-lying floodplain terrace deposits associated with the modern drainage net and the major through-going rivers. Along some reaches of West Clear Creek and the Verde River, the young terrace deposits are quite extensive in wide reaches of each stream. Some young, small alluvial fans are found in areas where small piedmont streams debouch onto stream terraces of the Verde River and Oak Creek. Because the Verde Formation is exposed in the beds of many piedmont streams and is exposed along reaches of the Verde River and Oak Creek, the late Holocene represents the deepest level of incision reached in the valley during the Quaternary.

Summary

The northern Verde Valley is characterized by a diversity of geomorphic surfaces that document approximately 2.5 million years of fluvial system response to net downcutting along the Verde River and major changes in climate. Geomorphic surfaces along the eastern flank of the Black Hills and along the Verde River and Oak Creek range in age from latest Pliocene to recent.

In this report, the Quaternary has been divided into four major phases of fluvial activity. (Oxbow: early Pleistocene, Montezuma: middle Pleistocene, Chuckwalla: late-middle Pleistocene through middle Holocene, and Post-Chuckwalla: middle Holocene to recent).

Lithologic diversity in the surrounding highlands and interior portions of the Verde Valley has resulted in an interesting and varied landscape. Surfaces emanating from basins underlain by volcanic and metavolcanic rocks in the Black Hills have persisted in pristine condition since at least the early Pleistocene; in contrast, no surfaces associated with drainages underlain by the highly erodible Verde Formation are older than about late to middle Pleistocene.

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