Geomorphology and Surficial Geology of Garden Canyon, Huachuca Mountains, Arizona

by

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Arizona Geological Survey
Open-File Report 96-5

February, 1996

Arizona Geological Survey
416 W. Congress, Suite #100, Tucson, Arizona 85701

Research funded by the Department of Defense Legacy Grant Program

This report is preliminary and has not been edited
or reviewed for conformity with Arizona Geological Survey standards

Introduction

Increasing destruction of natural habitat in the United States due to growing population has resulted in a series of laws, policies, and guidelines designed to protect and better manage natural resources. Garden Canyon, located in the pine and oak-covered Huachuca Mountains in the southern part of the Fort Huachuca Military Reservation (Figure 1), contains many plant and animal species that are federally listed or are candidates for listing as threatened or endangered. In an effort to develop a comprehensive watershed management plan for Garden Canyon that is designed to protect and maintain biodiversity, an interdisciplinary study has been funded by the Department of Defense Legacy Fund that focuses on the spatial and temporal distribution of ecological resources in Garden Canyon. This report presents the results of surficial geologic mapping of Garden Canyon and adjacent piedmont area. The surficial geology not only affects hydrology but also the distribution of soils and plant communities (Pendall, 1994). Hence this report and accompanying map serve to define the age and distribution of surficial geologic deposits and compliment other geological, hydrological, and biological studies of Garden Canyon. Together, these studies provide a foundation for developing an ecosystem management plan.

Methods

The geomorphology and surficial geology of Garden Canyon were assessed through interpretation of aerial photographs and soil maps and extensive fieldwork. Color aerial photography (1:23,000 scale) and Soil Conservation Service soil maps were used to distinguish geologic surfaces. Geomorphic surfaces of different ages and landform type were distinguished and mapped using criteria such as topographic position, degree of stream dissection, degree of surface clast weathering, and soil development (see Bull, 1991). Map unit boundaries and surface correlations were then field checked. Age estimates for the different surfaces are based on correlations to surfaces with similar weathering and soil characteristics that have radiometric age control and are located in the lower Colorado River Valley (Bull, 1991) and middle Rio Grande Valley (Gile et al., 1983).

A vector-based GIS system known as GSMAP (Selnor and Taylor, 1992) was used to map the surficial deposits. Map unit boundaries were digitized at 1:12,000 scale on a photo-enlarged mosaic of the Fort Huachuca, Huachuca Peak, and Miller Peak 7.5-minute quadrangles. The author would like to thank Sheridan Stone, Wildlife Biologist, Fort Huachuca, and Chris Cochrane, Soil Conservation Service, Tucson, for providing aerial photographs, soil maps, and other supporting materials.

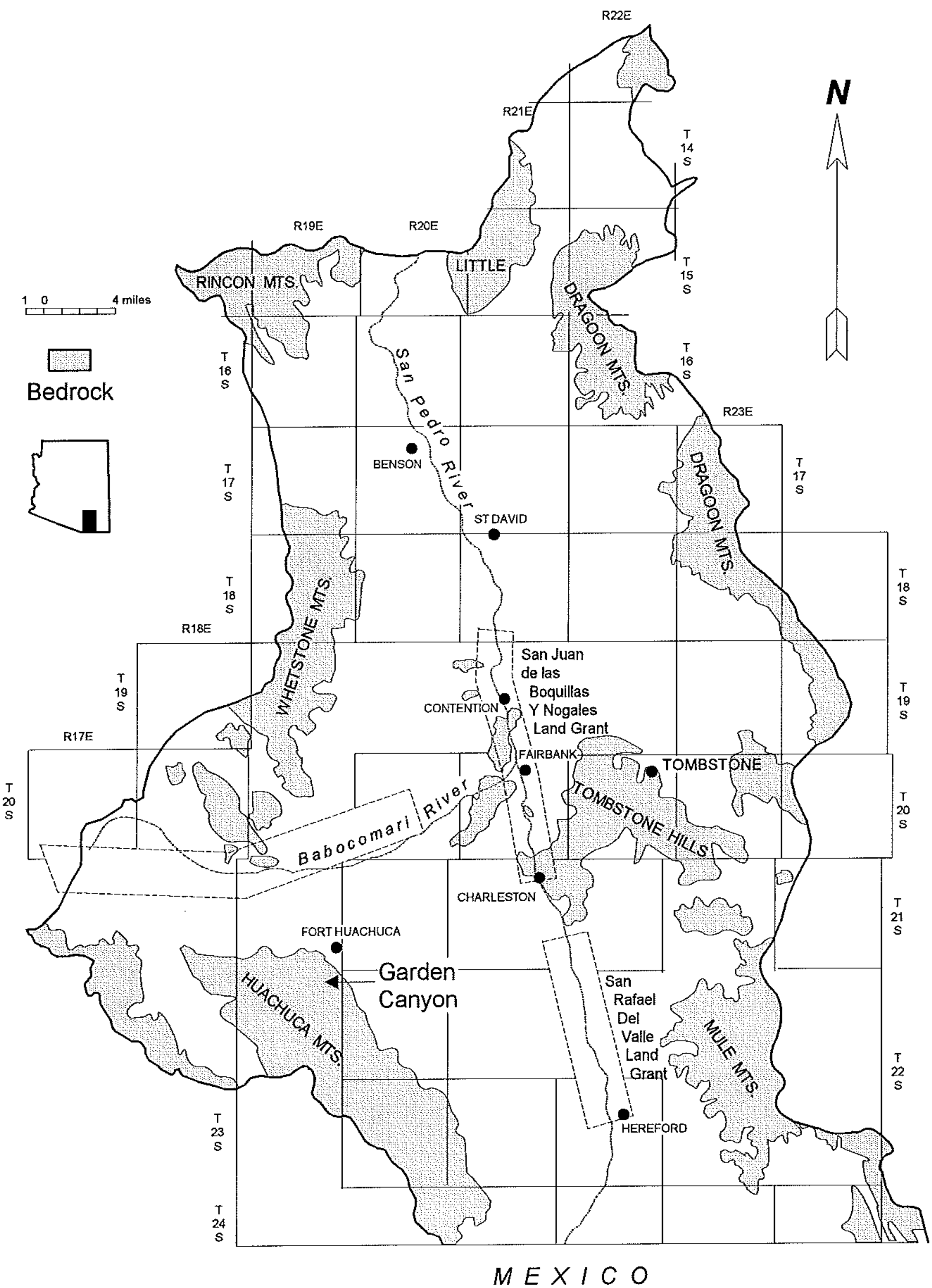

Figure 1. Location of Garden Canyon in the Upper San Pedro River Valley, Arizona

Landscape History

The primary structure of the Huachuca Mountains was produced by regional compression during the Laramide Orogeny 80 Ma[1]. This period of northeast-southwest compression lasted approximately 30 My and resulted in a series of northwest-trending reverse and thrust faults in southeastern Arizona (Keith and Wilt, 1978). One of these transects Garden Canyon and separates Precambrian granite from Phanerozoic sedimentary deposits (Hayes and Raup, 1968). The bedrock structure produced by this compression influences not only the angle and orientation of hillslopes but also stream gradients and drainage patterns (see below). The ancestral Huachuca Mountains produced during the Laramide Orogeny were subsequently reduced to an area of low relief 50-30 Ma but were later uplifted during the Basin and Range tectonic disturbance 15-8 Ma. In contrast to the Laramide Orogeny, this was a period of crustal extension resulting in steeply dipping, normal faults and associated horsts and grabens (Shafiqullah et al., 1980; Nations and Stump, 1981). During this period, the Huachuca Mountains were uplifted relative to the downdropped San Pedro. Most of these faults follow the same northwest fabric produced during the Laramide Orogeny resulting in the series of largely northwest-trending mountains and basins that characterize the landscape today. Most basin and range faulting ended approximately 5 Ma in southeastern Arizona (Menges and Pearthree, 1989). However, evidence of continued, sporadic faulting in the area includes fault scarps that cut middle Pleistocene alluvium on the eastern piedmont of the Huachuca Mountains (Demsey and Pearthree, 1994) and the 1887 Sonoran earthquake that was felt through much of northern Sonora and southern Arizona (Smith and Dubois, 1980).

Following the main phase of basin and range faulting, the predominant geological process in the region was basin filling. Approximately 5 to 1 Ma, the upper San Pedro River Valley and other basins in east-central Arizona contained lakes or playas and streams that were the loci of lacustrine and alluvial sedimentation. Some of the most studied and best dated sediments from this period are in the upper San Pedro River Valley where sedimentologic, pedologic, faunal, and paleomagnetic data shed light on the timing of climate change and basin filling (Johnson et al., 1975, Morrison, 1985; Lindsey et al., 1990; Smith et al,. 1993). Along the axis of the basin, lacustral deposits dominated 5-3 Ma but were replaced by channels and flood plains about 3-1 Ma. The upper San Pedro River Valley began to downcut dramatically approximately 0.6 Ma. Downcutting of the San Pedro lowered base level for the valley and caused dissection of basin fill deposits. At least three major erosional surfaces or pediments formed in the upper San Pedro River Valley during this period of downcutting (Bryan, 1926).

Although pervasive, not all geological processes operating here during the last 1 My were erosional. Streams continued to debouch from canyons of adjacent mountains

[1] 1 ky = 1,000 years; 1 ka = 1 ky ago; 1 My = 1,000,000 years, 1 Ma = 1 My ago (North American Commission on Stratigraphic Nomenclature, 1983).

and drop their sediment forming alluvial fans. Within these fans are erosional unconformities and soils indicating episodic deposition. Because the region has been relatively tectonically stable during the last 2 My, aggradation is believed to be driven by climate change (Melton, 1965; Morrison, 1985), but the exact relationships between glacial-interglacial climate cycles, sediment production, and alluviation are still debated. On the Huachuca Mountain piedmont, most of the alluvium is Pleistocene in age (Demsey and Pearthree, 1994), and alluviation during the present interglacial period of the last 11 ky generally has been restricted to valleys incised in older deposits and a few alluvial fans near the mountain front.

Geomorphology of Garden Canyon

Drainage basins are the fundamental unit in geomorphology, and in discussing the geomorphology of Garden Canyon, it is useful to consider the entire watershed. The drainage basin for Garden Canyon is herein defined as the area located above the confluence of Garden Canyon Creek and an unnamed tributary from Tinker and Brown canyons. This covers an area of 13.5 mi^2 (35.0 km^2) and includes McClure, Sawmill, and Scheelite canyons. Based on physiography and geology, the basin can be divided into three parts: upper canyon, lower canyon, and piedmont. The upper canyon, located above the middle picnic ground, is an area of maximum relief where unconsolidated deposits tend to be thin and discontinuous. The lower canyon extends from the meandering bedrock constriction located 0.6 km upstream from the lower picnic ground to a wider bedrock constriction located 2.2 km downstream from the lower picnic ground. This is a more open area with more extensive and thicker unconsolidated basin deposits derived from quartzitic and granitic hillslopes. The piedmont area mapped during this project extends from the lower canyon to the military reservation boundary which is contiguous with the area mapped by Demsey and Pearthree (1994).

Morphometric parameters of the Garden Canyon drainage basin are presented in Table 1. Elevations range from 8410 ft (2565 m) at Huachuca Peak to 4775 ft (1456 m) at the mouth of the basin yielding a relief of 3635 ft (1109 m). Based on contours on the Fort Huachuca, Huachuca Peak, and Miller Peak 7.5-minute quadrangles, the measured drainage density is 1.1. This is a relativley low value and indicates that much of the precipitation intercepted on the slopes flows as overland flow a substantial distance before concentrating into channels. Furthermore, some of this overland flow occurs on well-jointed limestone where it rapidly is captured and converted to subterranean flow.

As previously mentioned, the strike and dip of the bedrock produced during the Laramide Orogeny imparts a distinct fabric to the watershed influencing local hydrology. For example, drainage patterns in the upper canyon are rectangular because many of the streams flow along strike valleys. Also, stream gradients are also affected by the relative orientation of stream channel and bedrock; gradients are maximum where they cut across the strike of resistant sedimentary rocks, especially limestone,

Table 1. Morphometric Parameters for Garden Canyon

Drainage Basin Area **A**	13.5 mi^2
Drainage Basin Area **A**	35.0 km^2
Relief **R**	3635 feet
Relief **R**	1109 m
Basin Length **BL**	6.3 mi
Basin Length **BL**	10.1 km
Relief Ratio $\mathbf{R*BL^{-1}}$	0.1
Stream Order 1	61
Stream Order 2	11
Stream Order 3	3
Stream Order 4	1
Basin Order[a]	4
Total Stream Length **ΣL**	34.8 mi
Total Stream Length **ΣL**	56.0 km
Drainage Density $\mathbf{\Sigma L*A^{-1}}$	1.6 km/km^2
Ruggedness Number $\mathbf{\Sigma L*R*A^{-1}}$	1.8

[a] Stream ordering based on Strahler's (1958) system.

and minimum where they flow approximately parallel to bedrock strike (e.g., Sawmill Canyon). The longitudinal profile of Garden Canyon Creek (Figure 2) contains three parts. The uppermost reach flows parallel to the strike of the bedrock and has an average gradient of 0.044. The gradient increases to 0.078 as the stream turns northeastward and flows across the bedding of resistant sedimentary strata. Stream gradient decreases to 0.026 in the lower canyon and piedmont.

If surficial deposits in Garden Canyon are classified by the mechanisms of their deposition, then all of the deposits can be classified as either colluvium or alluvium. **Colluvium** is found on hillslopes and is transported primarily by gravity and surface runoff (Figure 3). Colluvial deposits tend to be lenticular in shape with coarse, poorly bedded, and poorly sorted stratigraphy. One type of colluvium is talus, an accumulation of coarse rock supporting little vegetation found on steep slopes. **Alluvium** is sediment deposited primarily by running water. Alluvium typically is better bedded and sorted than colluvium, and the geometry of alluvial deposits ranges from tabular to lenticular. However, zones of alluvium and colluvium overlap on slopes, and where stratigraphic exposures are absent, the delineation between colluvium and alluvium is often arbitrary.

Hillslope or colluvial processes prevail in the upper and lower parts of Garden Canyon where relief is greatest. Here slopes commonly exceed 45° (100 %), and vertical cliff faces are not uncommon. In describing colluvial processes, it is important to define hillslope components. A variety of terms are used by geomorphologists, but this report follows Ruhe's (1975) terminology (Figure 3). The hilltop (or **summit**) lies above the convex segment or **shoulder**. Below the shoulder is the **backslope** that contains the point of inflection. The lower slopes include the concave segment or **footslope** and the bottom segment or **toeslope**. Because colluvial deposits in Garden Canyon are discontinuous, lack morphological properties indicative of age, and on many slopes grade imperceptibly to bedrock, it is not possible to subdivide the colluvium to the degree of resolution possible for alluvial deposits.

Alluvial deposits are commonly found in two geomorphic contexts in this region: stream terraces and alluvial fans. Stream terraces are tabular landforms that follow continuously or discontinuously along streams. The terrace may represent the former flood plain of a stream that has incised deep enough such that floods no longer inundate the terrace tread, or the stream may only be incised slightly below the terrace such that the terrace is still part of the flood plain but is only inundated during infrequent flood events. Because channel entrenchment tends to be episodic, more than one terrace may be preserved along a stream. Stream terrace deposits consist of sediment deposited by both the main channel and by overbank flow on the terrace tread. Channel deposits represent a higher energy regime and thus contain coarser sediment than overbank deposits (Brakenridge, 1988). In mountainous terrain of southern Arizona, channel deposits contain boulders, cobbles, gravels, and sand,

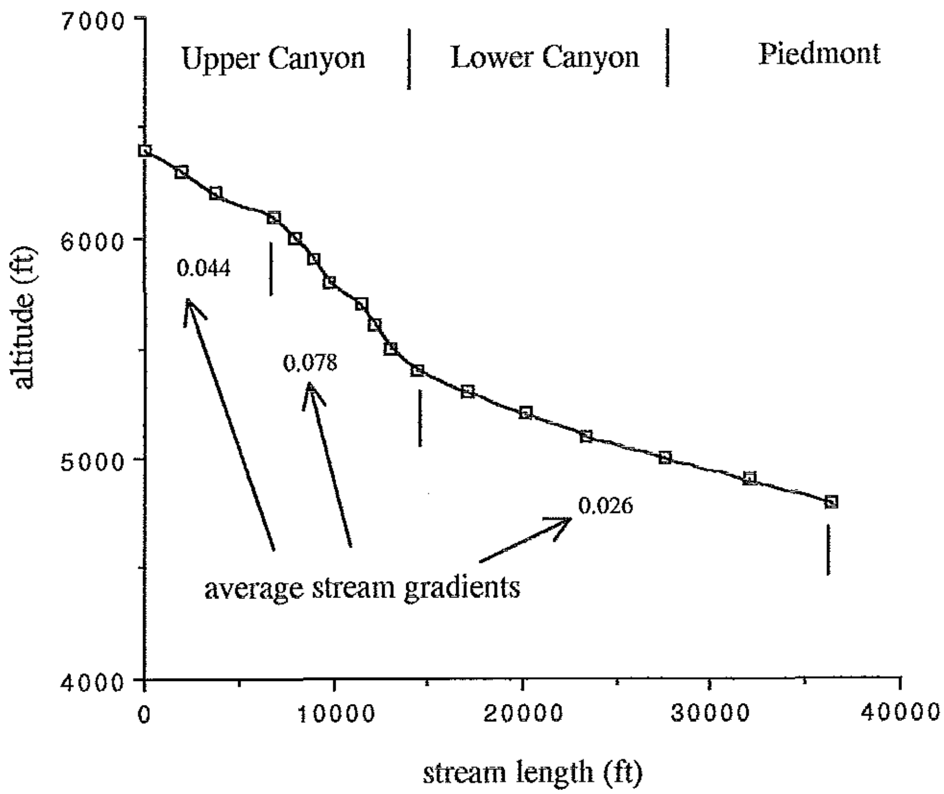

Figure 2. Longitudinal profile of Garden Canyon Creek.

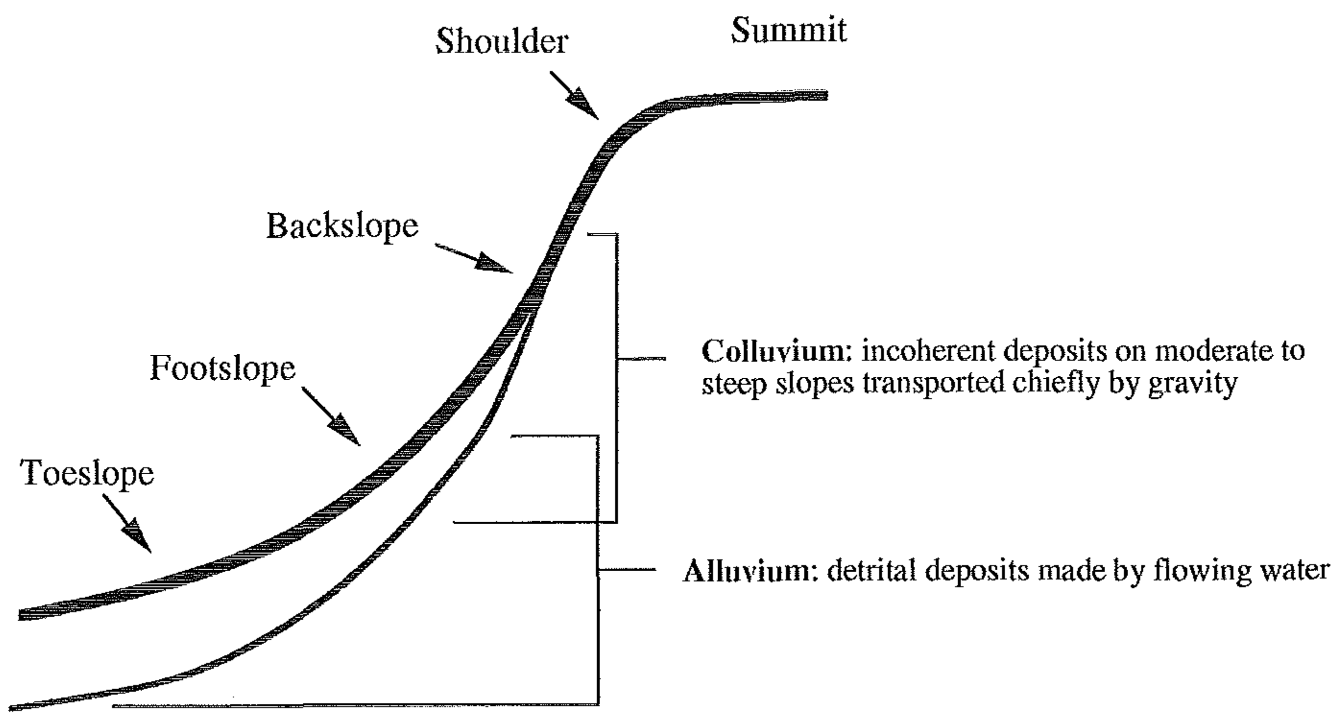

Figure 3. Hillslope components and associated deposits (adapted from Ruhe, 1975).

whereas overbank deposits are sand- and silt-dominant some gravel. Stream terraces along Garden Canyon are generally restricted to the lower canyon and piedmont areas.

By far, alluvial fans are the predominant landform in that they cover a much greater area in the lower valley and piedmont areas of Garden Canyon. An alluvial fan is a conical deposit that extends from the base of mountains into valleys (Bull, 1977). In planview, these conical deposits are fan-shaped, unless they are confined by adjacent alluvial fans in which case they form a broad alluvial apron or bajada. They are most wide-spread in arid regions but are also found in temperate and tropical environments. Unlike stream terraces which form by an overall through-flowing hydrologic system, alluvial fans are produced by stream channels that typically diminish downstream on the fan. As a stream exits a mountainous source area, it may lose its competence to transport sediment due to reduced discharge (due to infiltration losses) or due to a change in the channel hydraulics, particular a change from confined to unconfined channel boundaries (Ritter, 1986). Such hydrological changes favor the deposition of sediment and formation of an alluvial fan. Loci of deposition will shift both laterally as the surface is elevated by sedimentation, and up and down the alluvial slope. Overall, alluvial grain sizes decrease from the apex downslope to the distal ends of the fan. Grain sizes tend to range from boulders to sand, silt, and clay, but this, like stream terrace lithology, will be affected by the dominant lithology of the watershed; catchment areas containing fine-textured geologic materials will not produce bouldery fan deposits. Furthermore, the downslope decrease in particle size can be modified by channel entrenchment which can extend the confined reach of the channel and thus deposit coarser material towards the distal ends of the fan.

Debris flows are a special type of high energy alluvial deposit that exists in the Huachuca Mountains. Debris flows are viscous masses of material that flow down hillslopes and drainages and can carry large boulders in a matrix of mud (Costa, 1984). Under saturated conditions, hillslope materials may fail and flow rapidly downslope. If the hillslope deposit contains sufficient fine-grained material (sand and finer), it may become viscous and take on properties intermediate between landsliding and waterflooding. Large debris flows can capture large boulders and travel several kilometers. Debris flows have a characteristic morphology and stratigraphy. They tend to have boulder-topped levees along their margins that are lobate at the debris flow terminus, and the sediments are always poorly sorted, often with individual clasts completely surrounded in a muddy matrix. In older debris flows, however, the fines may have eroded leaving behind only boulders in contact with each other. Debris flow deposits in Garden Canyon are restricted to the upper canyon including McClure and Sawmill canyons. Most contain soils with thick mollic epipedons and cambic horizons and are probably late Holocene in age, i.e., 1-4 ka. Modern and prehistoric debris flows have been identified elsewhere in the Huachuca Mountains and have been related to a combination of woodland fires and high intensity rains (Wohl and Pearthree, 1991).

Sediments accumulate gradually on hillslopes through a combination of mechanical and chemical weathering of bedrock and influxes of eolian dust (Bull, 1991). Climates that favor sediment production vary with lithology, but relatively moist conditions such as during glacial periods are probably overall better suited for soil formation and sediment production (Melton, 1965). Hillslope movement is initiated when shear stress exceeds the shear strength of the unconsolidated material (Ritter, 1986). This may be accomplished by either increasing shear stress or by decreasing shear strength. Shear stress can be increased by saturation which increases the mass of the material, and by human modifications to slope. Shear strength can be reduced by saturation which can reduce cohesion of the material, by weathering which weakens rock material, and by removal of vegetation which plays an important role in binding unconsolidated deposits on slopes. Earthquakes also play a role primarily by decreasing the shear strength of materials through shaking. Hillslope movement may be rapid occuring at timescales of seconds, e.g., rock falls and debris flows, or slow occurring at time scales of tens to hundreds of years, e.g., soil creep.

Gravity is the predominant driving force in sediment transport on hillslopes, and earth movement in this context is referred to as mass wasting. On gentler slopes, fluvial processes are requisite for sediment transport. Like sediment production, sediment transport by both mass wasting and fluvial processes may be favored by unique climatic conditions (Bull, 1991). Thermal expansion and contraction which plays an important role in mass wasting is favored by increased diurnal temperature ranges such as occur with shifts to more arid, continental climates. In contrast, subsurface and overland flow -- important in hillslope failure and sediment transport -- is favored by relatively wet climates. Overall, climates that favor sediment fluxes in a given drainage basin will depend on lithology, morphometry, and vegetation. Because Holocene deposits are restricted in area within the Garden Canyon area, the relatively warm and dry conditions of the last 11 ky appear not to have been particularly favorable for sediment transport and deposition. This may suggest that interglacial climates favor surface stability and soil formation whereas glacial climates that are colder and ostensibly wetter favor erosion in the upper watershed and deposition in the upper piedmont. However, the present climate characterized by intense summer thunderstorms coupled with woodland habitat prone to periodic burning appears to be somewhat favorable for hillslope denudation, at least in other canyons within the Huachuca Mountains (Wohl and Pearthree, 1991). Why there is restricted Holocene sedimentation in Garden Canyon is uncertain, although a possibility is that the rock types may be insensitive to Holocene climatic conditions.

Map Units

Surficial geologic materials are subdivided into three primary categories based on estimated age, **Y** (young), **M** (middle or intermediate), and **O** (old), following the format of previous mapping in the region (e.g., Demsey and Pearthree, 1994). These are subdivided into stream terrace (**t**), alluvial fan (**a**), and colluvial (**c**) deposits. Ma deposits are further subdivided into **Ma1**, **Ma2**, and **Ma3** in order of decreasing relative age. Where two units occur together but cannot be separated, a combined map unit (e.g., Yal/Mal) is used. Steep slopes are mapped as **bc** indicating undifferentiated bedrock and colluvium. Surficial geologic units are presented in Table 2 and described in detail below.

Yt

Holocene stream deposits are mapped as Yt (Table 2). In the upper canyon these deposits are generally thin (< 3 m) and confined to narrow ribbons along the modern channels. Here the alluvium is comprised predominantly of poorly sorted boulders, cobbles, gravels, and sand. In a few areas, predominantly near confluence of Sawmill and Garden Canyon, alluvium is finer textured and dark with organic matter. Such sediments are often referred to as "cienega" deposits reflecting an origin characterized by shallow water tables and tall grass meadows (Hendrickson and Minckley, 1984). Much of the cienega at the mouth of Sawmill Canyon appears to have been enhanced by at least two check dams across Garden Canyon Creek, and thus these deposits are at least in part anthropogenic in orgin. In the lower canyon and piedmont, Yt deposits form a wider belt along Garden Canyon Creek and along some of the larger tributary drainages incised into alluvial. Here alluvial grain sizes are generally smaller than those in the upper canyon and are composed predominantly of poorly sorted cobbles, gravels, and sand. Channels developed into older alluvial fans in the upper piedmont have a limited stream competence and contain mostly gravels and sand. Recent gullies 1-2 m deep have formed in some of the tributaries in lower Garden Canyon and along the main drainage in Sawmill Canyon. Some of the gullies cut through roads built by the Army and thus have apparently formed within the last 50 yr.

Yt soils have A, Bw, and C horizons, and classify as Haplustolls and Fluvaquents (Soil Survey Staff, 1994). Some of the Yt deposits along Garden Canyon Creek are cemented by lime, but the lime has precipitated from calcium- and bicarbonate-rich waters derived from limestone higher in the watershed; it is not the product of soil formation nor a reflection of antiquity. Yt deposits are younger than 11 ka.

Mt

Late Pleistocene stream deposits along main valley streams are mapped Mt (Table 2). These deposits form terraces along lower Garden Canyon Creek and along drainages emanating from Tinker and Brown canyons in the upper piedmont. Mt deposits are composed of moderately to poorly sorted cobbles, gravels, and sand. At depth are rounded clasts of quartzite, limestone and volcanics, but the surface contains few clasts of limestone. This reflects a process of prolonged weathering on a stable surface whereby more soluble rocks like limestone are removed from the alluvial assemblage (Birkeland, 1984). Mt soils contain 5YR argillic horizons and classify as Haplustalfs (Soil Survey Staff, 1994). Because limestones are most soluble under cool,

Table 2. Physical Characteristics and Age of Surficial Deposits in Garden Canyon.

Surface	Description	Soil Series and Associations	Soil Classification	Age	Correlation
Yt	Holocene Stream Terrace	Haplustolls-Fluvaquents	Haplustolls-Fluvaquents	< 11 ka	Y, Y1, Y2 (Demsey and Pearthree, 1994)
Ya	Holocene Alluvial Fan	Haplustolls	Haplustolls	< 11 ka	Y, Y1, Y2 (Demsey and Pearthree, 1994)
Mt	Late-Pleistocene Stream Terrace	Gardencan-Lanque	Aridic Haplustalfs; Pachic Haplustolls	20-125 ka	M2 (Demsey and Pearthree, 1994)
Ma3	Late-Pleistocene Alluvial Fan	Gardencan-Lanque	"	11-40 ka	M2 (Demsey and Pearthree, 1994)
Ma2	Late-Pleistocene Alluvial Fan	Gardencan-Lanque	Aridic Haplustalfs; Pachic Haplustolls	40-125 ka	M2 (Demsey and Pearthree, 1994)
Ma1	Middle to Late-Pleistocene Alluvial Fan	Gardencan-Lanque	Aridic Haplustalfs; Aridic Paleustalfs Pachic Haplustolls	125-700 ka	M1 (Demsey and Pearthree, 1994)
MYc	Late-Pleistocene Colluvial Sheet	Gardencan-Lanque	"	0-125 ka	-
Oa	Late-Tertiary to Early Pleistocene Alluvial Fan	Terrarosa Blakeney	Aridic Paleustalfs Petrocalcic Paleustolls	0.7-2.0 Ma	Martinez Surface (Menges and McFadden, 1981) O (Demsey and Pearthree, 1994)
ct	talus	-	-	< 125 ka	
bc	Bedrock and Colluvium Undifferentiated	Budlamp-Woodcutter; Far-Hogris; Far-Huachuca-Hogris	Lithic Haplustolls; Lithic Argiustolls; Typic Ustorthents	< 125 ka	

moist conditions, a minimum age for this surface is probably the last full glacial period approximately 20 ka. Hence, the Mt surface is age estimated at 20-125 ky old.

Ya

Holocene fan deposits associated with tributaries of Garden Canyon Creek are mapped as Ya (Table 2). These fans are in the lower canyon north of the creek; they emanate from granitic hillslopes. In places, Ya deposits bury ceramic archaeological sites that date approximately 1 ka. (John Murray, Ft. Huachuca archaeologist, oral communication, 1995). Nonentrenched, Holocene alluvial fans are commonly associated with prehistoric agricultural systems in southern Arizona (Bryan, 1925; Waters and Field, 1986) and those in the lower canyon were likely utilized for flood farming. Ya soils have 10YR colors, lack a distinct argillic horizon, and classify as Haplustolls and Ustifluvents (Soil Survey Staff, 1994). These deposits are less than 11 ka.

Ma3

Latest Pleistocene fan alluvium is mapped as Ma3 (Table 2). These deposits occur in lower Garden Canyon below higher, older alluvial fan surfaces. Where partly derived from Bolsa Quartzite, clasts within the fan matrix grade downslope from boulders to sand. Where derived solely from granite, the alluvium is finer textured consisting mostly of fine gravels and sand. Soils contain moderately developed argillic horizons and classify as Haplustalfs. These deposits are probably 11-40 ky old.

Ma2

Late Pleistocene fan alluvium is mapped as Ma2 (Table 2). These deposits are common on footslopes and toeslopes of lower Garden Canyon. Some of these deposits have typical conical alluvial fan shapes, especially where derived from hillslopes containing Bolsa Quartzite. Like Ma3 deposits, grain sizes grade downslope from boulders to gravels in a sandy matrix but lack abundant large clasts where derived from granitic slopes. Ma2 surfaces are variably incised with maximum channel entrenchment occurring in the proximal portions of the fans. Soils are moderately developed with 7.5YR argillic horizons and classify as Haplustalfs. These deposits are probably 40-125 ky old.

Ma1

Middle to late Pleistocene fan alluvium occurs in the lower canyon and upper piedmont (Table 2). In the lower canyon, Ma1 deposits are derived from Bolsa Quartzite and have an armor of resistant cobbles. Ma1 soils are pedogenically mature with 5YR colors and well developed argillic horizons over 1 m thick. In places, the peds within the argillic horizon contain black coatings of manganese. These soils classify as Haplustalfs and Paleustalfs (Soil Survey Staff, 1994) and are approximately 125-700 ky old.

MYc

Steeply sloping (> 20 %) colluvium located on the backslopes and footslopes of Garden Canyon are mapped as MYc (Table 2). These deposits are distinguished from undifferented bc materials by lower slopes and absence of bedrock at the surface. Many of the MYc surfaces have been relatively stable during the Holocene. Soils are weakly to moderately developed with argillic horizon development on the more stable slopes. Soils classify as Haplustalfs and Haplustolls. These surfaces are approximately 0-125 ky old.

Oa

The oldest alluvial deposits in the Huachuca Mountains are located on the piedmont and are mapped Oa. These deposits make up very old landforms and represent the highest level of filling in the San Pedro Basin. They appear to have been dissected and abandoned as relict geomorphic surfaces well before the San Pedro River became integrated with the Gila River system (Lindsay et al., 1990). In the San Rafael Valley, such deposits comprise the Martinez Surface (Menges and McFadden, 1981), a surface that has been identified in many places in southeastern Arizona (Morrison, 1985). In the project area, the Oa surface is highly degraded; except for the very apex of the fan, constructional surfaces have been eroded, leaving only ridges and swales or a ballena topography. Not surprisingly, Oa soils are highly developed with thick (> 2 m) 2.5-5YR, clay-rich Bt horizons. Like Ma1 soils, the Bt horizons in Oa deposits also contain black manganese coatings. These soils classify as Paleustalfs within the project area, but downslope where the leaching potential is reduced and the soils contain a petrocalcic horizon, the soils classify as a Paleustoll (Soil Survey Staff, 1994). Oa surfaces are approximately 0.7-2.0 My old.

bc

Most of the project area is comprised of discontinuous mantles of colluvium on steeply sloping bedrock. Here it is not possible to separate the colluvial veneer from bedrock, and thus the area is mapped as bc undifferentiated (Table 2). Thickness of the colluvium varies from < 1 m to > 10 m. There are few landslide scars, and mass wasting processes appear to be presently subdued or dominated by nonrapid movement such as soil creep. Soils are weakly to moderately developed depending on slope stability with argillic soils developed on the more stable surfaces. Some of the soils developed in colluvium derived from limestone are cemented with calcium carbonate with Stage III-IV morphology. However, like some of the Yt deposits, these carbonates are groundwater related and do not reflect prolonged pedogenesis. Soils classify as Haplustols, Argiustolls, and Ustorthents (Soil Survey Staff, 1994). These colluvial deposits are probably younger than 125 ka.

ct

Talus deposits are mapped as ct (Table 2). These cobble and boulder fields occur on steep slopes formed on or below exposures of Bolsa Quartzite in the lower part of the canyon. The age of these deposits is uncertain but are probably no older than latest Pleistocene in age, i.e., < 125 ky old.

Summary

Five alluvial fan and two stream terrace surfaces have been identified in the Garden Canyon area. Most of these surfaces occur in the lower canyon and upper piedmont and are topographically distinct and easy to separate based on elevation and degree of stream dissection. However, the lower canyon contains a broad area of Holocene alluvial fans (Ya) that grade into stream terraces along Garden Canyon Creek. Without soil exposures, the boundaries of the Ya deposits can only be approximately located. Elsewhere, mature soils with red, clay-rich horizons indicate that most of the surfical deposits in the Garden Canyon area are Pleistocene in age. This suggests that the present interglacial climate of the last 11 ky has not been conducive for sediment transport and deposition. Overall, the Holocene has been a period of landscape stability in Garden Canyon. There are a few debris flow deposits in the upper canyon, but these appear to be at least 1 ky old. This does not rule out the possibility of future fire-induced slope instability and subsequent debris flow generation such has been documented in other Huachuca Mountain canyons (Wohl and Pearthree, 1991).

Some of the geologic surfaces correspond with individual vegetation communities. For example, riparian deciduous woodland corresponds well with Yt deposits, and open grassland is limited to Oa surfaces. The relationship between riparian deciduous woodland and Yt deposits is clear given that these are areas of perennial to ephemeral streamflow and shallow water tables, but the open grassland-Oa relationship is less certain. This latter association maybe related to the high clay content of Oa soils which somehow limit invasion by woody species. The other late Pleistocene surfaces (e.g., Mt, Ma1, Ma3) in the lower canyon and upper piedmont are largely mesquite-grass savannah, although mesquite may have colonized these surfaces during the historic period (Bahr, 1991). The rest of the Garden Canyon area contains a mosaic of plant communities including oak-grass savannah, oak woodland, mahogany woodland, mixed woodland, pinyon-juniper woodland, and pine woodland, with no apparent spatial correlation with mapped surficial deposits.

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