Detailed Surficial Geologic Map of the Southern Piedmont of the Tortolita Mountains, Pima County, Southern Arizona

by

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Introduction

This map depicts the distribution of geomorphic surfaces and associated alluvium of the southern and southwestern piedmont of the Tortolita Mountains in Pima County, northwest of Tucson, Arizona. The Tortolita piedmont is located on the northwestern fringe of the Tucson metropolitan area. Much of the eastern portion of the piedmont already has some development, and the rest of the piedmont likely will be developed in the next few decades. Delineating surficial alluvial deposits by age and physical characteristics provides a basis for assessing the character and distribution of potential geologic hazards and evaluating the Quaternary geologic history of the area.

Definition and Mapping of Alluvial Units

The geomorphology of piedmont alluvial surfaces provides clues about how much time has passed since they were deposited. Alluvial surfaces that have been deposited recently still bear the strong imprint of primary depositional processes. The suite of geomorphic characteristics that is indicative of recent deposition includes distributary drainage patterns, minimal incision of channels, obvious primary depositional topography like channel bars and swales, and minimal or no soil development beneath the surfaces. Piedmont areas that have been isolated from substantial deposition for thousands of years are dominated by erosional processes. Geomorphic characteristics associated with relict alluvial fan areas include tributary drainage patterns, relatively deep entrenchment of drainages into surfaces, erosion and rounding of surfaces adjacent to drainages, and moderate to strong soil development where surfaces are well-preserved. The longer a surface has been inactive, the more profound the impact of erosional and pedogenic (soil-forming) processes on its morphology.

The geomorphic characteristics that are associated with surfaces of similar age combine to give those surfaces a distinctive appearance on aerial photographs and on the ground. Away from active channels, young surfaces are quite smooth and channels typically are only slightly incised into them; they commonly appear dark on aerial photographs because of relatively dense vegetation. Very old surfaces characteristically are fairly bright as well, reflecting the relative paucity of vegetation on them and local exposure of calcium carbonate eroded from soil horizons. Channel networks are typically deeply incised into these surfaces, and areas between channels have been rounded by erosion related to downcutting of the channels.

Alluvial surfaces of five different ages were recognized and mapped on the Tortolita piedmont through interpretation of large-scale aerial photographs of the area, extensive field investigations, and analyses of many soil profiles. Primary surface mapping was done on mylar overlays of black-and-white, 1:12,000-scale aerial photographs; these photos were supplemented with 1:24,000-scale color photographs and 1:2,400-scale blueline copies of rectified aerial photographs with 2-ft topographic contours superimposed on them. We spent approximately 75 person-days in the field investigating surface characteristics and geomorphic relationships between surfaces. After preliminary mapping was completed, we characterized soil development associated with the mapped alluvial surfaces in 45 backhoe pits scattered across the piedmont. Primary mapping was transferred to 1:24,000-scale topographic base maps after final field-checking.

Surface-Age Estimates

We estimated the ages of alluvial surfaces and the deposits associated with them using several lines of evidence, including the geomorphic character of the surface, the degree of soil development, topographic position, and independent constraints provided by vegetation or archeology. Depositional topography and distributary drainage patterns dominate the morphologies of the relatively young Y2 and Yc surfaces; all older surfaces (Y1, M2, and M1) are dominated by erosional topography. Further, these older surfaces typically are drained by tributary stream systems that originate on the piedmont and have developed for the most part after the surfaces were isolated from deposition. These tributary drainages have downcut into and eroded the adjacent older alluvial surfaces; the depth of this downcutting correlates well with increasing surface age.

Soil development provides a more quantitative method for estimating the time since alluvial surfaces have been subject to major flooding. In desert regions, clay and calcium carbonate progressively accumulate in soils with time through the input of material from atmospheric sources (dust and rainwater) and weathering and movement of mineral constituents within the soil. Original depositional structure can be observed in sediments that have been deposited quite recently. However, animal and plant activity and accumulations of clay and calcium carbonate gradually impart distinctive properties to soils that are readily recognizable in the field. If an alluvial surface has been stable for thousands of years or more, soil fabric obscures the original sedimentary fabric. Rates of soil formation in desert regions are extremely slow relative to rates of erosion and deposition associated with active channels. Significant soil development requires that a surface be quite stable and not subject to frequent flooding.

Soil ages are estimated by analyzing soil properties and comparing them with the properties of soils in similar environments whose ages are known. Soil development has been tied to numerical ages at several localities in the Southwest; the chronosequence developed in southern New Mexico (Gile and others, 1981) is particularly relevant to this study because the climate is similar to southern Arizona. Correlation of properties of the soils of the Tortolita piedmont with the dated soils of southern New Mexico permits general estimates of surface ages on the Tortolita piedmont. Unit Y2 has only modest soil development, but the fine details of sedimentary structure have already been obscured. Soil age estimates derived from correlations of soil properties indicate that Y2 surfaces are less than a few thousand years old. The soils associated with Y1 surfaces are more strongly developed, suggesting that they are significantly older than Y2 surfaces; they probably date to the early Holocene or latest Pleistocene (5 to 20 ka). The M2 surfaces probably represent late Pleistocene deposition (20 to 125 ka), although some M2 soils are not very distinctive from Y1 soils. Unit M1 probably encompasses surfaces of several different ages. The strong soil development associated with Unit 1 surfaces indicates that they are all more than 100 ka; some M1 surfaces may well be 500 ka or older.

Archeological remains associated with some of the alluvial surfaces on the Tortolita piedmont provide another means for estimating their ages. Artifacts ranging in age from several thousand years to less than one hundred years old have been found in this area (Katzer and Schuster, 1984; John Madsen, Arizona State Museum, unpublished data; this study). Most of the artifacts are associated with the Hohokam culture of southern and central Arizona, which dates from about 1650 to 650 years before the present (Greenleaf, 1975). Hohokam artifacts on the Tortolita piedmont are found as isolated items, in clusters, or associated with dwelling places (sites). Isolated artifacts are small and some may have been transported by flood waters; they are found on piedmont surfaces of all different ages. Local clusters of artifacts were probably emplaced by the Hohokam where they are found today. Thus, clusters imply that surfaces beneath them have not been subject to significant erosion or deposition for at least 650 years. Archeological sites (dwellings or other major occupations) provide the most information regarding surface age because they were certainly emplaced by the Hohokam; they are concentrated in the lowermost portions of the piedmont.

Hohokam sites and clusters are found <u>on</u> all surfaces except Yc, and locally they are found <u>within</u> deposits associated with surface Y2. This implies that some Y2 surfaces are at least 650 years old (artifacts on the surface) and some Y2 surfaces are less than about 650 years old (artifacts in deposits beneath the surface). The sites where artifacts are buried beneath Y2 surfaces are in the lowermost portions of the piedmont, adjacent to the Santa Cruz River. Artifacts are distributed more or less equally on Y2 and older surfaces farther up the piedmont. This suggests that most of the Y2 surfaces in the middle piedmont areas are older than 650 years.

Vegetation also offers some constraints on the ages of the youngest alluvial surfaces of the Tortolita piedmont. Mature trees associated with the youngest surfaces (Yc) typically show evidence of burial or erosion; they probably flourish because of the relative abundance of water, but clearly must survive occasional floods. Smaller vegetation is found locally, depending on the recency of flooding and location of vegetation relative to channels; typically, substantial Yc areas are unvegetated sand. The lushest and most diverse vegetation, ranging from low bushes to mature trees and cacti, is found on Y2 surfaces . The larger vegetation shows little or no evidence of flood activity (scarring, burial), and xerophytic plants that require less moisture, such as cacti, are much more common than on Yc surfaces. This indicates that major, destructive flooding does not occurred frequently on Y2 surfaces. Xerophytic plants are dominant on older surfaces. Mature trees are still common on many Y1 and M2 surfaces, but the relatively dry interfluves are dominated by bursage and cacti. The oldest surfaces (unit M1) are dominated by cacti and low shrubs; the most impressive stands of saguaro cactus on the piedmont are found on these surfaces. The dominance of xerophytic vegetation in the interfluve areas of units Y1, M2, and M1 indicates that these areas are not subject to flooding in the present setting.

Quaternary Geology and Geomorphology

The Tortolita piedmont can be subdivided into three sections based on variations in the character of its Quaternary geology and geomorphogy: (1) The western section of the Tortolita piedmont, including Derrio, Cottonwood, and Cochie West drainages, is characterized by relatively broad expanses of Pleistocene alluvial-fan remnants and large channels that are downcut well below these surfaces. The large drainages terminate in small fans that onlap onto Holocene Santa Cruz River terrace deposits. (2) The middle section of the piedmont, which includes Cochie East, Wild Burro, Ruelas, and Prospect drainages, is also characterized by extensive Pleistocene alluvial fans in the upper piedmont; larger drainages are entrenched well below the Pleistocene fan surfaces. The middle and lower piedmont areas, however, have distributary drainage networks and extensive late Holocene deposits. (3) The upper portion of the eastern section of the piedmont is characterized by an extensive bedrock pediment with a thin mantle of middle Pleistocene alluvium. Alluvial deposits farther down the piedmont are an intricate mixture of Pleistocene to early Holocene alluvium; late Holocene deposits are very restricted in extent.

Variations in piedmont geomorphology may result from a combination of drainage basin size and proximity to the local base level, the Santa Cruz River. Cottonwood and Derrio washes have larger drainage basins than any of the washes to the east. The most important aspect of the large drainage basins is the stream flow in Cottonwood and Derrio washes is probably more frequent and larger. This results in more available stream power and the capacity to respond more rapidly to changes in base level. The middle Pleistocene alluvial fan complex in this section was graded to an ancestral level of the Santa Cruz River that was higher and/or farther southwest than its present position. Alluvial-fan deposition may have forced the Santa Cruz to migrate to the southwest. After sediment supplied to the fans diminished, the Santa Cruz River cut down and laterally into the toe of the fan complex. Cottonwood and Derrio washes responded to this base-level fall by entrenching into the fan complex. This scenario may have been repeated several times during the Pleistocene. However, during the latest Pleistocene and Holocene these washes have remained entrenched into the older Pleistocene fan sediments.

The central portion of the piedmont, drained by Cochie East, Wild Burro, Ruelas, and Prospect washes, has extensive latest Pleistocene and Holocene deposits. These young deposits, although quite thin, mantle most of the middle and lower piedmont. These washes have an abundant supply of sediment and a limited capacity to transport the sediment. Interactions between local base level (the Santa Cruz River again) and these washes apparently have been less dramatic, so major entrenchment across the piedmont has not occurred. Rather, these drainages have predominantly eroded laterally and deposited thin sheets of alluvium across the piedmont.

The eastern portion of the piedmont is characterized by washes with relatively small mountain drainage basins and a relatively stable location of the Santa Cruz River. We attribute the paucity of young deposits in this portion of the piedmont to the meager drainage basin areas and relatively infrequent flows of the washes. Much of the sediment that enters these washes from the mountains appears to be stored in a few wide channel reaches cut into the bedrock pediment near the mountain front.

The geomorphology of the Tortolita piedmont reveals variations in stream behavior that may be tied to drainage basin size, base-level changes, and climate changes. Clearly, drainage basin area is a critical factor in determining how rapidly and in what manner stream systems evolve in response to changes in both external and internal variables.

Geologic Hazards

A variety of potential geologic hazards may be encountered on the Tortolita piedmont. The primary geologic hazards that may affect this area are flooding and soil problems; debris flows and rockfalls present localized hazards. The general character of these hazards and the areas that may be affected by them and considered below.

Flooding. The major objective of the detailed mapping conducted on the Tortolita piedmont was to delineate areas that are prone to flooding. Of particular concern on piedmonts is the potential for alluvial-fan flooding, where flood waters derived from mountain drainage basins may spread widely across portions of the piedmont and positions of channels may change drastically during floods. The extent of alluvial-fan flooding on the Tortolita piedmont has been vigorously disputed by local floodplain-management agencies and the Federal Emergency Management Agency (FEMA), which administers the National Flood Insurance Program.

Surficial geologic mapping provides important information about the extent of flood-prone areas on this and other piedmonts. Floods leave behind physical evidence of their occurrence in the form of deposits. Therefore, the extent of young deposits on piedmonts is a good indicator of areas that have been flooded in the past few thousand years. These are the areas that are most likely to experience flooding in the future. Following this logic, the extent of potentially flood-prone areas on the piedmont varies with the extent of young deposits (units Yc and Y2). Drainages in the central portion of the piedmont (Wild Burro, Ruelas, the east branch of Cochie, and Prospect washes) have extensive young deposits (and thus active alluvial fan areas) associated with them. Channels and young deposits are inset into older deposits near the mountain front, but spread widely farther downstream. An extreme alluvial-fan flood that occurred in 1988 on Wild Burro Wash spread widely across the middle and lower piedmont, inundating much of the area associated with that drainage that is covered with late Holocene deposits (House and others, 1991; Vincent and others, in prep.). Young deposits associated with the western and eastern drainages (Cottonwood, Canada Agua, and North Ranch/Hardy washes) are quite limited in extent, implying that floods are generally confined to channels and limited overbank areas. The extent of potential alluvial-fan flooding determined by this analysis is significantly less that the area included within the 100-year floodplain in the most recent Flood Insurance Rate Maps released by FEMA (1989) (see Baker and others, 1990, and Pearthree and others, 1992, for further discussion of this issue).

Soil problems. Several types of soil/substrate problems may be encountered on the Tortolita piedmont. Soil collapse or compaction upon wetting or loading (hydrocompaction) may be an important geologic hazard in a substantial portion of the mapped area. Soil compaction has caused extensive damage to buildings in the Tucson area (Lacy, 1963; Murphy, 1975), and hydrocompaction has been reported in the Marana area (Slaff, 1986). Hydrocompaction is a reduction in soil volume that occurs when susceptible deposits are wetted for the first time after burial. Deposits that are susceptible to hydrocompaction are typically relatively fine-grained, young sediments that are deposited in a moisture-deficient environment. Deposits on the Tortolita piedmont that are candidates for hydrocompaction are the fine-grained alluvial fans of units Yc and Y2 on the middle and lower piedmont. Silty sands of the late Holocene Santa Cruz River terrace at the lower limit of the mapped area may also have the potential to compact upon loading.

Clay-rich soils associated with the middle Pleistocene M1 unit may have some potential for shrinking and swelling during dry and wet periods, respectively. In addition, M1 units commonly have well-developed accumulations of calcium carbonate (caliche) that may impact excavation potential and near-surface infiltration capacity.

Debris flows and rockfalls. Debris flows and rockfalls are potential hazards in and immediately adjacent to the Tortolita Mountains. A few fresh debris-flow or rockfall scars exist on steep slopes of the Tortolita Mountains. Possible debris-flow deposits have been observed at the junctions some steep tributary drainages with the larger drainages that form the major canyons. These debris flows may have been triggered by landslides on very steep mountain hillsides and continued downslope following stream channels until they encountered the shallower gradient of the larger trunk stream. There is no sedimentologic evidence of debris-flow activity in the young deposits investigated on the piedmont. Rockfalls are a potential hazard below bedrock cliffs and where bedrock outcrops exist at or near the top of steep mountain hillslopes. In these situations, large rocks that are loosened by weathering may cascade violently downhill. The existence of large boulders near the base of a steep slope should be considered evidence of potential rockfall hazard in most cases.

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