Geologic Mapping of Flood Hazards in Arizona: An Example From the White Tank Mountains Area, Maricopa County

by

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Introduction

Assessment of the character of flood hazards and the extent of flood-prone areas on the piedmonts of Arizona is an increasingly important concern to floodplain managers as urban areas continue to expand. Piedmonts are the low-relief, gently sloping plains between mountain ranges and the streams or playas that occupy the lowest portions of the valleys. Proper management of flood hazards on piedmonts is important because much of southern, central, and western Arizona is composed of piedmonts; they comprise most of the developable land around Phoenix and other rapidly expanding population centers of the State.

Management of flood hazards in Arizona and elsewhere in the western United States is complicated because portions of many piedmonts are composed of active alluvial fans. During floods, these fans are subject to widespread inundation and local high-velocity flow, and substantial changes in channel patterns may occur. Development that proceeds on piedmonts without regard to the locations of active alluvial fans is likely to place people and property at risk during large floods.

Geomorphic analyses and geologic mapping of piedmonts provide the best data for determining if active alluvial fans exist on a given piedmont and which portions of that piedmont may be subject to alluvial-fan flooding. Active alluvial fans have distinctive physical characteristics, including distributary drainage networks and laterally extensive, geologically young alluvial surfaces (Pearthree, 1989; Pearthree and Pearthree, 1989). Typically, large portions of piedmonts in Arizona have not been subject to flooding for many thousands of years and thus are not active alluvial fans. These areas can be distinguished from active alluvial fans by examining differences in drainage patterns, topographic relief, soil development, and surface characteristics (Christenson and others, 1978; Pearthree, 1991; Pearthree and others, in prep).

The principal objective of this study was to use geomorphic analyses and geologic mapping to delineate different flood-hazard zones on the piedmonts around the White Tank Mountains. Flood hazard designations on piedmonts obtained through geomorphic analyses and mapping are more reliable than those generated by hydrologic and hydraulic models currently available. These models, by necessity, make assumptions about rainfall intensity and duration, runoff characteristics, and flow behavior during floods. The validity of flood-hazard assessments derived through hydrologic modeling thus depends on the validity of the underlying assumptions and input parameters (Baker and others, 1990). In contrast, geologic mapping of flood hazards is based on analysis of surface characteristics and drainage patterns that actually exist on piedmonts. Geomorphic studies typically cannot resolve the details of individual floods, but they document which areas have actually been subject to significant flooding over thousands of years. Detailed geologic maps derived from these studies thus provide a long-term perspective on the distribution of flood-prone areas.

This report outlines the methods used to map and characterize flood hazard zones on the piedmonts around the White Tank Mountains. Studies of this kind could be used to delineate flood hazards on any undeveloped or sparsely developed piedmont in Arizona. Because of their wide applicability, the procedures used to map alluvial surfaces of different ages and to develop flood-hazard maps are described in some detail. The distribution of flood-prone areas around the White Tank Mountains is representative of many piedmonts in Maricopa County and elsewhere in Arizona. The report, therefore, also describes typical differences in the character and distribution of flood hazards in the upper, middle, and lower piedmont areas.

Methods Used to Map Alluvial Surfaces of Different Ages

The distribution of alluvial surfaces of different ages was the fundamental data set used to develop flood-hazard maps for this study. Interpretation of aerial photographs and field surveys provide much of the data used in our analyses, because surface characteristics evident on photographs and on the ground are related to the age of the surface. (See Table 1 for sources of data.) Aerial photographs depict surface color, dissection, vegetation density, and drainage patterns over large areas, some of which are inaccessible to motor vehicles. Subsequent ground surveys more thoroughly define the surface characteristics identified on aerial photographs and supply additional information on desert pavement, rock varnish, soil development, depositional topography, and vegetation.

Interpretation of Aerial Photographs

For this study, we interpreted 1:24,000-scale stereo-paired color aerial photographs provided by the U.S. Bureau of Land Management. Many surface characteristics are also evident on high-quality black-and-white photographs. Widely available, 1:24,000-scale, black-and-white orthophotoquads offer less resolution of surface characteristics, but they serve as an excellent base map for transferring information to 7.5' USGS topographic maps. Three characteristics that are visible on aerial photographs reflect surface age: surface color, drainage patterns, and depth of dissection and surface relief.

Surface Color. The color of alluvial surfaces depicted on aerial photographs is primarily controlled by soil color, and to a lesser extent, rock varnish. Significant soil development begins on an alluvial surface after it becomes isolated from active flooding and depositional processes (Gile and others, 1981, Birkeland, 1984; Birkeland and others, 1991). Over thousands of years, distinct soil horizons develop. Two typical soil horizons in old (> 10,000 years) alluvial sediments of Arizona are reddish brown argillic horizons and white calcic horizons. (See further description of soil formation below.) As a result, on color aerial photographs older alluvial surfaces characteristically appear redder or whiter (on more eroded surfaces) than younger surfaces.

Older surfaces have a dark brown color where darkly varnished desert pavements are well preserved. This colors is present in only small areas on the White Tank Mountain

Topographic Maps	Aerial Photographs
Drainage patterns	Surface Color
Drainage spacing	Drainage patterns
Depth of dissection	Drainage spacing
Relief between surfaces	Depth of dissection
	Relief between surfaces

Ground Survey	SCS Soil Maps
Surface color	Soil development
Drainage spacing	
Depth of dissection	
Relief between surfaces	**Vegetation Maps**
Desert pavement	Vegetation distributions
Rock varnish	
Soil development	
Depositional topography	
Vegetation types and distributions	

Table 1. Data sources for geomorphic analyses and mapping of alluvial surfaces on piedmonts of Arizona. Note that there are sometimes multiple sources of information for a single characteristic (i.e. depth of dissection).

piedmonts, probably because desert pavements have been disturbed by animal burrowing and uprooting of large vegetation. These activities expose the underlying white and red soils.

Drainage Patterns. Differences in the drainage patterns between surfaces provide clues to surface age and potential flood hazards. Young alluvial surfaces that are subject to flooding commonly display a distributary (branching downstream) or braided channel pattern; young surfaces may have very little developed drainage if unconfined shallow flooding predominates. Dendritic tributary (branching upstream) drainage patterns are characteristic of older surfaces that are not subject to extensive flooding. (See Plates 1a through 1d for examples of drainage patterns on young and old alluvial surfaces.) Tributary drainage networks typically extend headward with time, and the spacing between drainages tends to decrease with time as the drainage network becomes better developed.

Depth of Dissection and Surface Relief. Relief between adjacent alluvial surfaces and the depth of entrenchment of channels can be determined using stereo-paired aerial photographs and topographic maps. Young flood-prone surfaces appear nearly flat on aerial photographs and are less than 1 m (3 ft) above channel bottoms. On these young surfaces, channel infilling or bank erosion might redirect floodwaters anywhere on the surface. Active channels are typically entrenched 1 to 10 m (3 to 30 ft) below older surfaces. In these areas, floodwaters are conveyed in the entrenched channels and have not affected the adjacent old surfaces for 10,000 years or more.

Younger surfaces are commonly inset into and topographically lower than older surfaces in upper piedmont areas (Figure 1a). Long-term climatic, tectonic, and base-level changes have resulted in lower surface gradients on younger surfaces, so the depth of dissection on older surfaces generally decreases away from the mountain front. In some middle and lower piedmont areas, relief between surfaces of different ages is minimal (figure 1c), so other surface characteristics are needed to estimate surface ages.

Field Investigations

Field investigations provide additional information on surface characteristics and topographic relationships between surfaces of different ages. Characteristics that are best observed on the ground are used to refine map units and to further describe surfaces already identified through interpretation of aerial photographs. These characteristics include development of desert pavements, rock varnish, and soils; preservation of small-scale depositional topography; and vegetation types.

Desert Pavement. Desert pavement is a concentration of pebbles and cobbles at the surface, which forms as windblown silt and clay accumulates between pebbles and cobbles. Repeated wetting of the surface by rain causes the silt and clay to swell, thereby lifting and pushing more cobbles and pebbles towards the surface. Repeated drying of the surface causes the formation of cracks in which more silt and clay can accumulate. Over thousands of years a surface mantling of closely packed pebbles and cobbles develops over

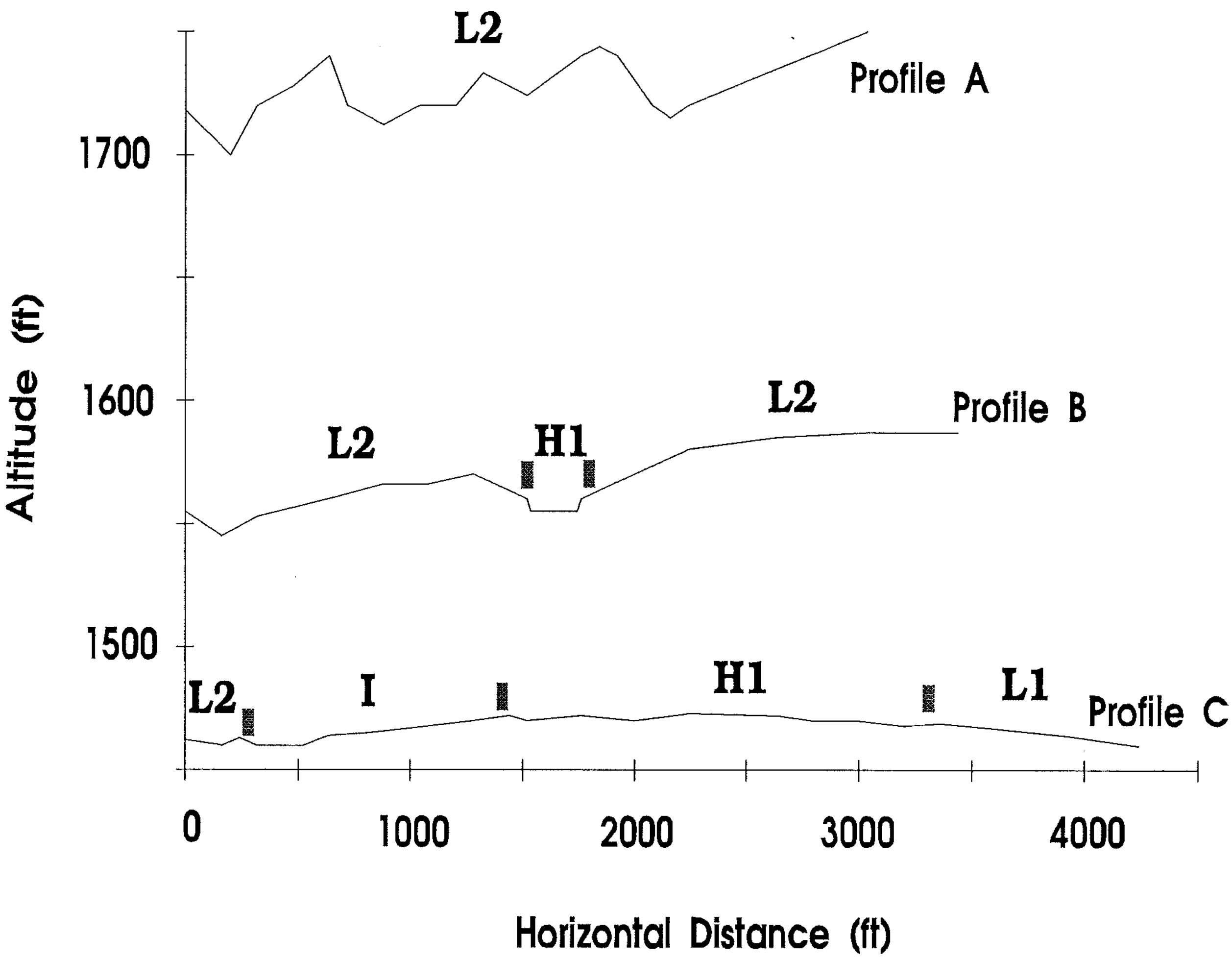


Figure 1. Topographic profiles showing changes in the extent of flood-prone areas downstream and away from the mountains. Profiles were constructed perpendicular to a large stream draining the western side of the White Tank Mountains. Flood-hazard zones are discussed in the text.

a) Upper piedmont area, where channels are deeply entrenched and flood-prone areas are very limited.

b) Transition to the middle piedmont, where flood-prone areas are still of limited extent but topographic confinement of channels is much less.

c) Middle piedmont area, where flood-prone areas are extensive, there is minimal topography on active alluvial fans, and there is little relief between areas that have been flooded recently and those that have not been flooded for 10,000+ years.

a silt- and clay-rich soil layer (Dohrenwend, 1987; Vanden Dolder, 1992). Desert pavements are generally most closely packed on relatively old alluvial surfaces; they are more open and poorly developed on intermediate aged surfaces. Young alluvial surfaces that have been flooded within the past few thousand years do not have desert pavements because surface sediments have been recently reworked by floodwaters. As noted above, desert pavements can be disrupted by animal activity or vegetation. The best developed desert pavements in Arizona are in relatively arid areas, where little vegetation grows on the alluvial surfaces.

Rock Varnish. Rock varnish forms on pebbles and cobbles at the land surface; these pebbles and cobbles are often incorporated into a desert pavement. Rock varnish that forms on rock surfaces exposed to the atmosphere is a brown to black patina composed of manganese oxides and clay minerals precipitated on the rock surface by microbial organisms (Dorn and Oberlander, 1982; Vanden Dolder, 1992). As the surface exposed to the atmosphere darkens, the undersides of the pebbles and cobbles are simultaneously reddened by the accumulation of iron oxides and clay minerals. The varnishing process is very slow in arid regions and only occurs on gravel that is continuously exposed at the surface and has not been moved for thousands of years. Rocks with weakly developed varnish indicate that a surface has not been subject to significant flooding for thousands of years; rocks with well-developed varnish have not been disturbed by flooding for tens to hundreds of thousands of years. Young surfaces that have been flooded in the past few thousand years are unvarnished because the rocks have not been in place long enough to develop varnish.

Soil Development. Soil development generally increases with the age of an alluvial surface. When the accumulation of stream deposits on a land surface ceases, the sediment beneath the surface begins to be altered into distinct horizons by soil-forming processes. The most important process that leads to the development of soils on the piedmonts of Arizona is the accumulation of material from the atmosphere (windblown dust and calcium carbonate dissolved in rainwater) in the first 1 to 2 m (3 to 6 ft) below the land surface. The ages of these soils can be roughly estimated from the amount of silt, clay, and calcium carbonate that has accumulated in them (Table 2).

Because of accumulation of windblown dust, the first 1 to 10 cm (1 to 4 in.) of sediment beneath alluvial surfaces is typically silt-rich even if the parent material (the original stream deposit) is sand and gravel. Beneath this surface horizon, rainwater percolates into the sediment and alters the parent material, producing a weak fabric in the soil (soil structure) or slight soil reddening or both; this horizon is called a cambic horizon. Suspended clay is also carried from the surface and concentrated in this portion of the soil. As the amount of clay increases with time, the cambic horizon develops into an orange to reddish brown, clay-rich argillic horizon. The strength of cambic or argillic horizon development depends on the age of the surface and climate. Cambic horizons probably form in a few thousand years to 10,000 years in Arizona. Weak argillic horizons probably forme in 10,000 years or more in most areas, and strongly developed argillic horizons have developed over hundreds of thousands of years (Gile and others, 1981; Pearthree and

Estimated Age	Soil Development			Drainage Patterns	Surface Dissection	Surface Topography	Rock Varnish
	Color	Texture	Calcic Horizon				
Late Holocene (< 3 ka)	brown	sand	thin, discontinuous rock coatings	distributary	< 1 m	bars and swales channels	none
Mid- to early Holocene (3-10 ka)	brown to orange	sand to sandy loam	discontinuous to continuous rock coatings	distributary or tributary	< 1 m	bars and swales obvious	minimal brown/ orange
Late Pleistocene (10-150 ka)	brown to orange	loamy sand sandy loam	continuous coatings whitened matrix	tributary	< 3 m	bars and swales well preserved	moderate dark brown/ orange
Late to Middle Pleistocene (150-300 ka)	orange to reddish brown	sandy loam loam	continuous coatings whitened matrix	tributary	< 6 m	bars and swales moderately to poorly preserved	moderate black/ reddish brown
Middle Pleistocene (300-800 ka)	reddish brown	clay	thick coatings locally cemented matrix	tributary	< 6 m	smooth, bars and swales poorly preserved	strong black/ reddish brown
Early Pleistocene (> 800 ka)	orange to white	loam	cemented very thick coatings	tributary	10 to 15 m	erosionally rounded ridges	variable poorly preserved

Table 2. Selected surface properties that change with increasing alluvial surface age around the White Tank Mountains. Estimated ages are in thousands of years old (ka); soil colors and soil textures reported are from the zone of silt and clay accumulation; rock varnish colors are from exposed surfaces/undersides of cobbles.

Calvo, 1987; Bull, 1991). The presence of reddened, clay-rich argillic horizons thus indicate that surfaces have not been subject to significant flooding for at least 10,000 years, and commonly much longer than that.

Comparisons of calcic horizon development on the White Tank Mountains piedmont with other soil sequences in the western United States provide one of the few methods of estimating the ages of the different alluvial surfaces. Calcium carbonate from dust and rainwater gradually precipitates in soils, forming a whitish calcic horizon. Geomorphologists and soil scientists recognize six morphologic stages of calcic-horizon development and have linked these states to soil ages in several areas in the southwestern United States (Machette, 1985; Birkeland and others, 1991). Calcic horizon development varies from fine white filaments of calcium carbonate in young soils to soil horizons completely plugged with calcium carbonate (caliche) in very old soils.

Soil horizons lie beneath the surface and thus must be examined in natural stream cuts, hand-dug soil pits, or backhoe trenches. Although soil development is a very useful characteristic in producing a geologic flood-hazard map, care must be exercised when interpreting soil- and surface-age relationships. A soil exposed beneath a surface may be a buried soil and unrelated to the surface that it is presently beneath. Young deposits on the lower piedmont are commonly only a thin veneer (<30 cm, or 1 ft) over much older soils. As a result, the presence of a well developed calcic horizon on the lower piedmont does not necessarily indicate that the overlying surface has not been flooded for a long time, unless other surface characteristics confirm that the surface is old.

Depositional Topography. The degree of preservation of original depositional surface features is another key to determining the age of an alluvial surface. One such feature, bar-and-swale topography, is common on alluvial surfaces of Arizona. Gravel bars deposited during large floods are separated by intervening sand-filled channel swales or troughs. After a surface is isolated from major flood events,it is gradually smoothed as bars are eroded and swales are filled in by windblown dust and sediment derived from adjacent bars. Bar-and-swale topography is readily apparent on alluvial surfaces that have been deposited within the past 10,000 years, but is more subdued on increasingly older alluvial surfaces; very old surfaces typically are quite smooth. It is important to note, however, that development of bar-and-swale topography also depends on the size of bedload particles conveyed by a stream. Streams that convey coarse bedloads (cobbles and boulders) typically have obvious, well-developed bars and swales. This topography is not evident on young, flood-prone surfaces on the lower piedmont because very little coarse-grained bedload is present far from the mountains.

Vegetation. The distribution of plant types is commonly associated with the age of alluvial surfaces. Vegetation is also controlled by elevation and rock type, however, so vegetation patterns are not as clear an indicator of surface ages as are some of the aforementioned characteristics. On the White Tank Mountains piedmonts, creosote and brittle bush are pervasive on all surfaces; thus their distributions cannot be used as an indicator of surface age. Saguaro, palo verde, ironwood, cane cholla, and barrel cactus are not as pervasive, but do not correlate definitively with alluvial surfaces of different ages. Jumping cholla, however, is abundant only on old flood-free surfaces; its distribution probably correlates with clay-rich soils.

Alluvial-Surface Characteristics -- Indicators of Recency of Flooding

The surficial characteristics discussed above impart a distinctive appearance to alluvial surfaces of a given age. In general, alluvial surfaces that have been flooded within the past 10,000 years are dominated by characteristics related to primary depositional processes. These characteristics include (1) distributary drainage patterns, (2) minimal entrenchment of stream channels below the surface, (3) brown surface colors, (4) little or no soil development, (5) obvious bar and swale topography; and (6) no desert pavement or rock varnish; . Old alluvial surfaces that have not been subject to substantial flooding for hundreds of thousands of years are typically characterized by (1) well-developed, moderately to deeply entrenched, dendritic tributary drainages, (2) reddish, whitish, or dark brown surface colors, (3) strongly developed soil profiles, (4) subdued, smoothed bar-and-swale topography, and (5) dark-brown to black varnish on exposed rock surfaces and orange to red varnish on the undersides of rocks. If local conditions are conducive, old alluvial surfaces may also have well-developed desert pavements. Characteristics of surfaces of intermediate age, which have not been flooded for tens of thousands of years, fall within the two extremes.

We estimated the ages of alluvial surfaces around the White Tank Mountains by comparing their characteristics, especially soil development (Table 2), with those of dated surfaces in similar climatic regions. Other means of directly dating surfaces include radiocarbon dating when carbon fragments are found and archaeological remains when present.

A single surface characteristic is insufficient to conclusively estimate surface age, because some of the characteristics mentioned above as distinctive of young surfaces may be attributes of old surfaces and vice versa. Not all the characteristics distinctive of surfaces of a certain age need be present to assign a surface that age designation, however. For example, deep dissection of a surface clearly indicates that it is not flood prone, but the absence of dissection does not necessarily mean the surface is young and flood prone. Large areas on the lower and middle piedmonts of the White Tank Mountains have not been disturbed by flooding for more than 10,000 years, even though the surfaces are less than 1 meter (3 ft) above the channel bottoms. In these areas, well-developed pavement, varnish, and soils are better indicators of surface age. In general, certain characteristics are only present on a surface of a given age, and are reliable indicators of the time since a surface was last flooded. Other characteristics are not always present or are attributes of surfaces of different ages (Table 3). A final surface-age designation is based on all of the surface characteristics outlined above.

Alluvial surfaces on the piedmonts of the White Tank Mountains range in age from

Flood Hazard	Surface Age	Characteristic Category*	Surface Characteristic
Low	10,000+	1	Mod. to well developed pavement Mod. to well developed varnish Mod. to strong soil development
		2	Deep dissection (>4 ft.)
		3	Abundant jumping cholla Reddish or whitish surface Mod. to closely spaced drainage Dendritic tributary drainage Absent or subtle bar and swale
Intermediate	1,000-10,000	1	Weak to mod. soil development Weakly developed pavement
		2	Incipient desert varnish Obvious bar and swale
		3	Dendritic tributary drainage Shallow dissection (<3 ft.) Mod. to widely spaced drainage
High	0-3,000	1	Incipient soil development No desert pavement
		2	Distributary drainage Fresh bar and swale
		3	Shallow dissection (<3 ft.) No desert varnish

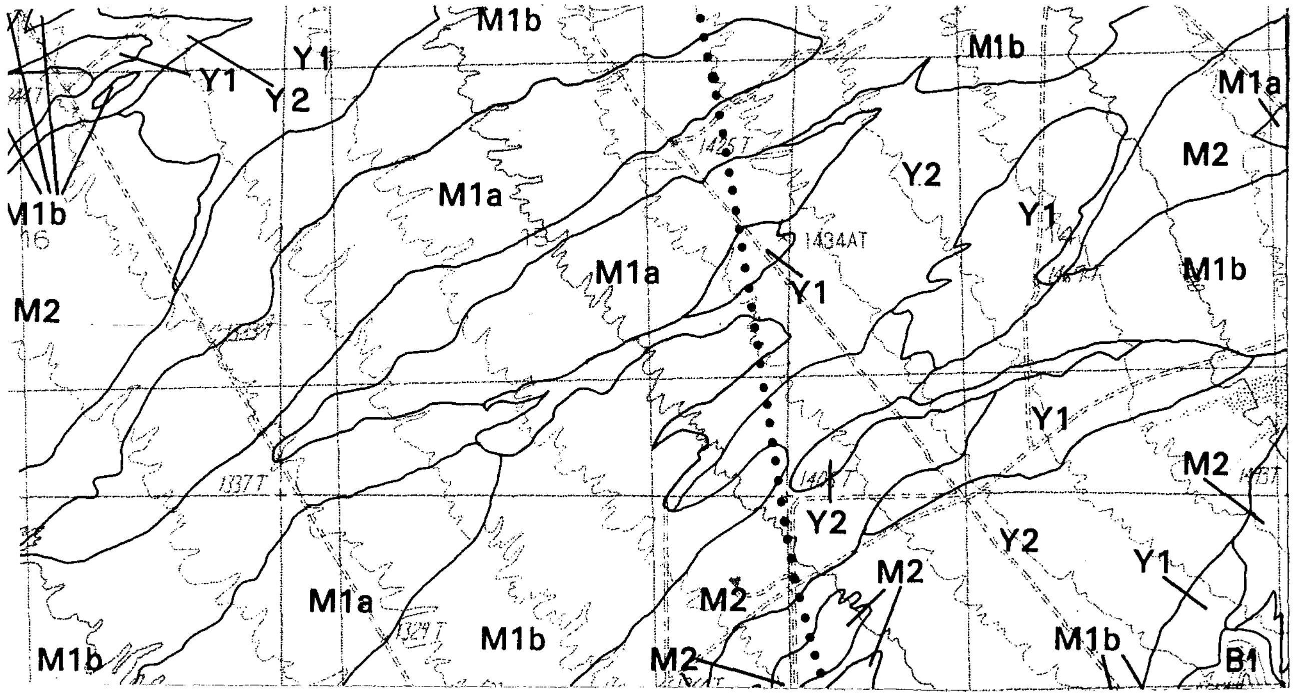
* Characteristic Category 1 - These characteristics are indicative of surface age and are almost always present on the surfaces of given age. If the characteristic is absent, the surface is most likely of a different age.

Characteristic Category 2 - These characteristics are indicative of surface age but are not always present. Absence of these characteristics from the surface does not imply the surface is of another age (as in Category 1).

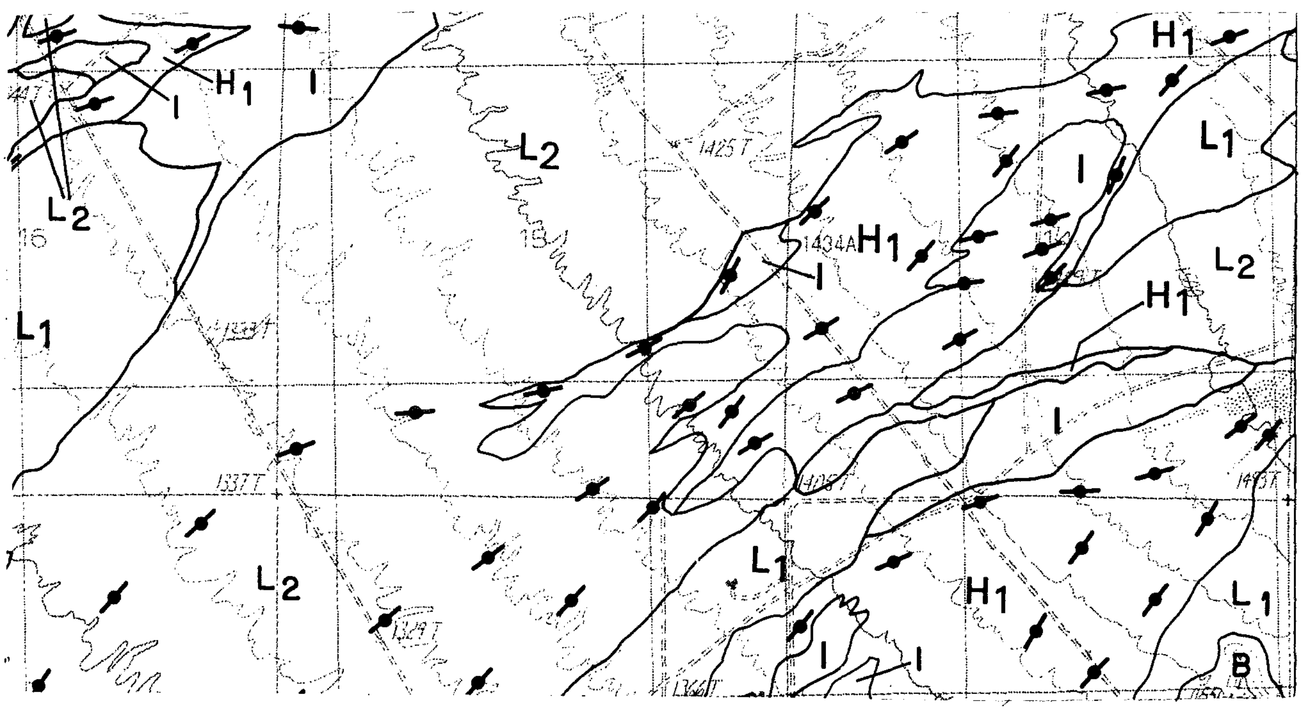
Characteristic Category 3 - These characteristics are almost always present on the surface but are not indicative of surface age, because they are found on other surfaces as well. However, if the characteristic is absent the surface is most likely of another age.

Table 3. Characteristics used to delineate three flood hazard zones on alluvial piedmonts around the White Tank Mountains. Note that the opposite of a characteristic does not necessarily imply the opposite flood hazard (i.e. shallow dissection does not always imply the surface is flood prone).

Figure 2. Development of a flood-hazard map using geologic and geomorphic data.



a) Map of alluvial surfaces covering part of the western piedmont of the White Tank Mountains. Surfaces ages (in years) are as follows: Y2, <3,000; Y1, 1,000 to 10,000; M2, 10,000 to 150,000; M1b, 150,000 to 300,000; M1a, 300,000 to 800,000.



b) Geologic flood-hazard map of the same area. Heavy dots with lines show approximate locations of channels of major drainages that head in adjacent mountains. Surface age, proximity to major drainages, local topographic relief, and evidence of channelized flow were used to delineate flood-hazard zones. See text for description of flood-hazard categories.

modern to 1,000,000 years old or more (Table 2; see Field and Pearthree, 1991, for a more complete discussion of surface characteristics and surface-age estimates). We differentiated and mapped the following alluvial surfaces: late Holocene, < 3,000 years old; late to early Holocene, 1,000 to 10,000 years old; late Pleistocene, 10,000 to 150,000 years old; late middle Pleistocene, 150,000 to 300,000 years old; early middle Pleistocene, 300,000 to 800,000 years old, and early Pleistocene, > 800,000 years old.

Development of Flood-Hazard Zones

We integrated maps of alluvial surfaces of different ages (Field and Pearthree, 1991) with other geomorphic information to delineate flood-hazard zones around the White Tank Mountains (Figure 2; Plate 1). Assessments of flood hazards were based on (1) the age of the alluvial surface; (2) local topographic relief between the surface and active channels; (3) proximity to active channels, especially channels of major distributary flow systems; and (4) the size, number, and character of active channels in the area.

The most important data we used to develop the flood hazard maps was the distribution of surfaces of different ages. The critical assumption of our analysis is that areas that have been subject to flooding over the past few thousand years are the areas that are likely to be flood prone. The potential for flooding in areas that have not been flooded for at least 10,000 years is considered to be very low, unless local circumstances suggest flow patterns have changed very recently. Areas composed of surfaces of 1,000 to 10,000 years old are considered to have intermediate or high flood potential, depending on their proximity to active channels or active alluvial fans.

Our delineation of flood-hazard zones was also based on drainage patterns, local topography, and the character of active channels. We considered areas that are within or near distributary drainage networks of the larger washes to be relatively more flood prone than areas that are spatially separated from these networks. We also incorporated local topographic relief between active channels and adjacent alluvial surfaces into our assessments. The flood potential on old surfaces that are several meters or more (5 to 10+ ft) higher than adjacent active channels is considered to be very low. In contrast, if little relief separates old surfaces and active channels, the flood potential on the old surfaces is considered to be higher because of the possibility that flooding patterns might change and affect the old surface. We subdivided flood potential in areas of extensive young alluvial surfaces based on the size and abundance of channels. Large or abundant channels indicate that relatively deep, high velocity flows are an important element of flooding. Furthermore, the positions of these channels may shift occasionally during large floods (CH2MHill, 1991), subjecting the areas covered by young deposits between the existing channels to sheet flooding or channelized flooding. Areas of extensive young deposits where channels are not evident are subject primarily to shallow sheetflooding. These areas are clearly flood prone, but the character of the flooding is far less threatening.

The characteristics of the five flood-hazard zones are summarized below.

H1 - Very high flood potential. Extensive young deposits; distributary channel system very evident. Potential for localized, high-velocity, relatively deep, channelized flows and sheetflooding; some potential for drastic shifts in channel positions.

H2 - High flood potential. Extensive young deposits, but channels are small or nonexistent. Predominantly shallow sheetflooding; channelized flow very limited in extent; broad areas probably inundated in large floods.

I - Intermediate flood potential. Areas have not been flooded recently. Near or within distributary drainage systems, and little topographic relief separates these areas from active alluvial fans or channels. Could become flood prone with relatively modest changes in channel configurations.

L1 - Relatively low flood potential. Areas have not been flooded for at least 10,000 years. Flooding has been confined to channels and immediately adjacent terraces for that long. However, these areas are near or within distributary drainage networks, and typically little topographic relief separates L1, I, H2, and H1 areas. L1 areas should be carefully evaluated to determine if potential for shifts in channel configurations or depositional patterns could result in these areas becoming flood prone.

L2 - Very low flood potential. Areas have not been flooded for at least 10,000 years, and typically for much longer. Drained by tributary streams that head on the piedmont. Streams entrenched 1 to 10 m (3 to 30 ft) below inactive alluvial surfaces; spatially separate from or topographically isolated from distributary drainage networks. Flood-prone areas limited to channels and adjacent low terraces.

Distribution of Flood Hazards on the Piedmonts of the White Tank Mountains

The distribution of flood hazards varies widely across the piedmonts of the White Tank Mountains. On upper piedmonts, flood-prone surfaces are restricted to channel bottoms and low terraces set well below older flood free surfaces (Figure 1a, 1b; Plate 1). Only the largest channel bottoms are mappable at this scale (1:24,000), but smaller, unmapped channel bottoms are also subject to high-velocity channelized flow (H1 flood hazard).

The largest areas with the highest flood potential (H1) are associated with active alluvial fans on the middle piedmont west and south of the White Tank Mountains (Figure 1c; Plate 1). These are areas where entrenched large drainages become unconfined downstream, distributing floodwaters into several smaller channels and sheetfloods. Extensive very young deposits (<3,000 years old) and distributary channel networks indicate that these areas are active alluvial fans. Some areas within the distributary-flow networks have not been subject to significant flooding for at least 1,000 years and are somewhat isolated from the distributary channels; the potential for flooding in these areas is less (intermediate flood potential; category I). Downstream from the active alluvial fans, distributary channels typically become reconfined into fairly narrow passages between older surfaces that have not been flooded significantly for at least 10,000 years. We have assigned a low flood hazard potential (L1) to areas where the relief between the reconfined channels and adjacent old alluvial surfaces is less than one meter (3 ft); we assigned the lowest flood potential (L2) to areas where the relief is more than one meter (3 ft). Widespread zones of fairly high flood hazards (H2) are present on the middle piedmont north of the White Tank Mountains (Plate 1a and 1b). In this area several large drainages become unconfined and floodwaters spread out into low-velocity sheetfloods.

On the lower piedmont, many of the major drainages again become unconfined and floodwaters spread out into sheetflows (Plate 1). High-velocity, channelized flood hazards (H1) are restricted to very small portions of the lower piedmont, but areas prone to shallow flooding (H2) are ubiquitous. A single large flood probably will not inundate the entire lower piedmont, but the absence of substantial relief across the lower piedmont makes it difficult to predict where the next sheetflow will occur.

Conclusions

The White Tank Mountains flood hazard map demonstrates the value of using geomorphic analyses and mapping to delineate flood potential on desert piedmonts. A single geomorphic characteristic, by itself, cannot conclusively establish the age of a piedmont surface. Suites of characteristics identifiable on aerial photographs and in the field, however, are diagnostic of surface age. Alluvial surfaces of different ages on desert piedmonts can be readily mapped using these diagnostic suites of characteristics. By integrating surface age information with topographic data and the character of drainage networks, geologists can reliably delineate flood potential zones across the entire piedmont. Similar detail and reliability is not possible with current numerical hydraulic models. Geologic and geomorphic studies, therefore, should be an integral part of any flood hazard management project on desert piedmonts.

References

Baker, V.R., Demsey, K.A., Ely, L.L, Fuller, J.E., House, P.K., O'Connor, J.E., Onken, J.A., Pearthree, P.A., and Vincent, K.R., 1990, Application of geological information to Arizona flood hazard assessment, *in* French, R.H., ed., Hydrology and hydraulics of arid regions: American Society of Civil Engineers, p. 621-626.

Birkeland, P.W., 1984, Soils and geomorphology: New York, Oxford University Press, 372 p.

Birkeland, P.W., Machette, M.N., and Haller, K.M., 1991, Soils as a tool for applied Quaternary geology: Utah Geological and Mineral Survey Miscellaneous Publication 91-3, 63 p.

Bull, W.B., 1991, Geomorphic responses to climatic change: New York, Oxford University Press, 326 p.

CH2MHill, 1991, Alluvial fan data collection and monitoring study, preliminary report: Flood Control District of Maricopa County [Arizona], 70 p..

Christenson, G.E., Welsch, D.G., and Pewe, T.L., 1978, Environmental Geology of the McDowell Mountains Area, Maricopa County, Arizona: Arizona Geological Survey Geologic Investigations Folio GI-1, 10 sheets, scale 1:24,000.

Dohrenwend, J.C., 1987, Basin and Range, *in* Graf, W.L., ed., Geomorphic systems of North America: Geological Society of America, Centennial Special Volume 2, p. 303-342.

Dorn, R.I., and Oberlander, T.M., 1982, Rock varnish: Progress in Physical Geography, v. 6, p. 317-367.

Field, J.J., and Pearthree, P.A., 1991, Surficial geology around the White Tank Mountains, central Arizona: Arizona Geological Survey Open-File Report 91-8, 9 p., scale 1:24,000, 9 sheets.

Gile, L.H., Hawley, J.W., and Grossman, R.B., 1981, Soils and geomorphology of the Basin and Range area of southern New Mexico -- Guidebook to the Desert Project: New Mexico Bureau of Mines and Mineral Resources Memoir 39, 222 p.

Machette, M.N., 1985, Calcic soils of the southwestern United States: *in* Weide, D.L., ed., Soils and Quaternary geology of the southwestern United States: Geological Society of America Special Paper 203, p. 1-21.

Pearthree, P.A., 1989, A geomorphic perspective on management of flood hazards on desert piedmonts of the southwestern United States, *in* Partnerships: Effective Flood Hazard Management: Association of State Floodplain Managers, Annual Conference, 13th, Scottsdale, Arizona, p. 105-111.

Pearthree, P.A., 1991, Geologic insights into flood hazards in piedmont areas of Arizona: Arizona Geology, v. 21, no. 4, p. 1-5.

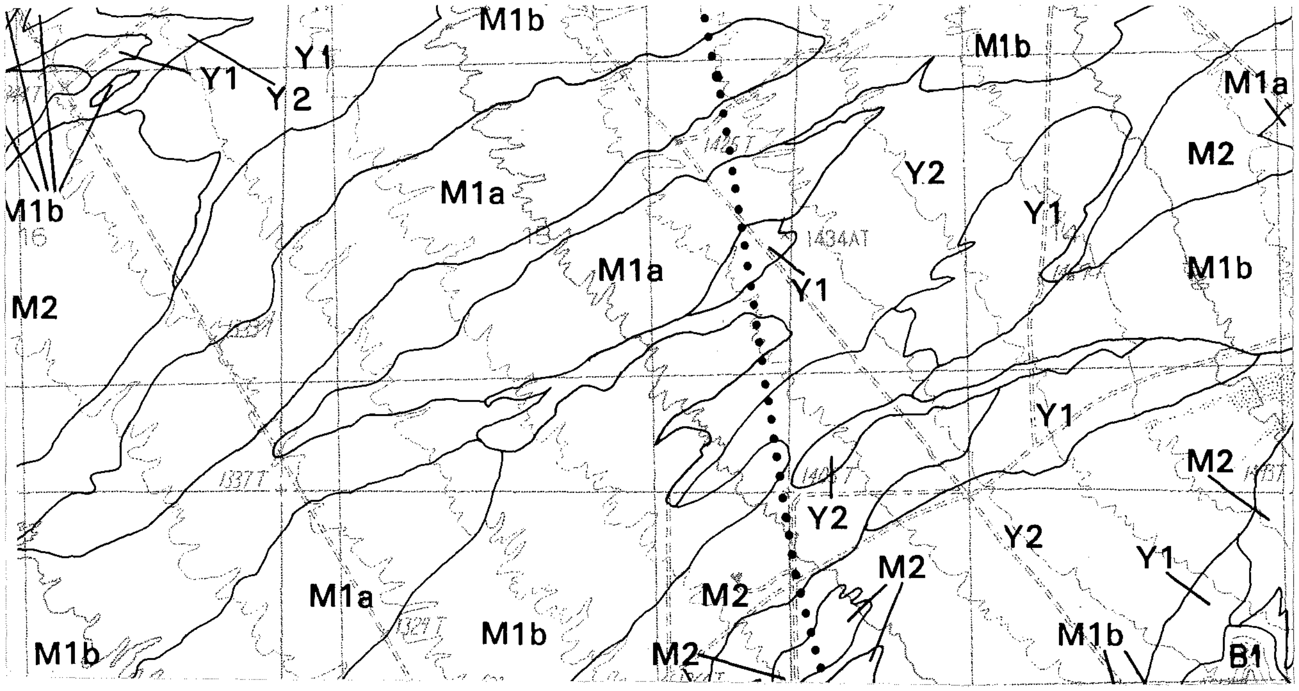
Pearthree, P.A., and Calvo, S.S., 1987, The Santa Rita fault zone: Evidence for large magnitude earthquakes with very long recurrence intervals in the Basin and Range province of southeastern Arizona: Bulletin of the Seismological Society of America, v. 77, p. 97-116.

Pearthree, P.A., Demsey, K.A., Onken, Jill, and Vincent, K.R., in prep., Geomorphic assessment of fluvial behavior and flood-prone areas on the Tortolita piedmont, Pima County, Arizona: Arizona Geological Survey Open-File Report.

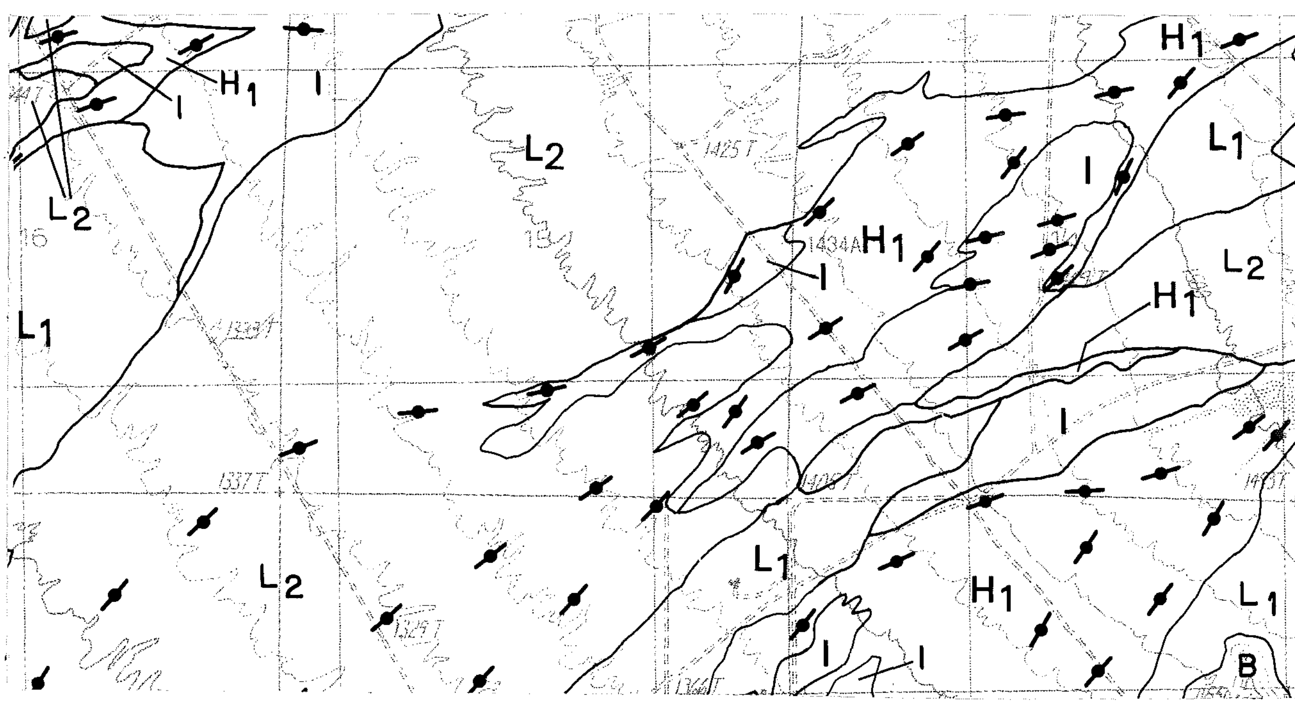
Pearthree, P.A., and Pearthree, M.S., 1989, Geomorphology and flood hazard assessment in piedmont areas of Arizona, *in* Conference on Arid West Floodplain Management Issues, Association of State Floodplain Managers, Las Vegas, 1988, p. 81-94.

Vanden Dolder, E.M. 1992, Rock Varnish and desert pavement provide geological and archaeological records: Arizona Geology, v. 22, no. 1, p. 1, 4-7.

Figure 2. Development of a flood-hazard map using geologic and geomorphic data.



a) Map of alluvial surfaces covering part of the western piedmont of the White Tank Mountains. Surfaces ages (in years) are as follows: Y2, <3,000; Y1, 1,000 to 10,000; M2, 10,000 to 150,000; M1b, 150,000 to 300,000; M1a, 300,000 to 800,000.



b) Geologic flood-hazard map of the same area. Heavy dots with lines show approximate locations of channels of major drainages that head in adjacent mountains. Surface age, proximity to major drainages, local topographic relief, and evidence of channelized flow were used to delineate flood-hazard zones. See text for description of flood-hazard categories.