GEOMORPHIC ASSESSMENT OF FLOOD-PRONE AREAS ON THE SOUTHERN PIEDMONT OF THE TORTOLITA MOUNTAINS, PIMA COUNTY, ARIZONA

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Prepared with the support and cooperation of the Pima County Flood Control District

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SUMMARY

The character of flooding and the extent of flood-prone areas on the southern piedmont of the Tortolita Mountains have been disputed by local and federal floodplain-management officials since at least 1987. Flood insurance rate maps (FIRMs) promulgated by the Federal Emergency Management Agency (FEMA) depict much of the Tortolita piedmont as being subject to alluvial-fan flooding. Officials of the Pima County Flood Control District have argued that 100-year floodplains delineated on these FIRMs include extensive areas that are not flood prone, and that the alluvial-fan methodology used to develop these maps is not appropriate for the Tortolita piedmont.

We conducted a geomorphic analysis of the southern piedmont of the Tortolita Mountains in northern Pima County to critically evaluate the floodplain designations derived using the FEMA alluvial-fan methodology (AFM) (Dawdy, 1979; FEMA, 1985; 1989). The geomorphic character of a piedmont provides a long record of flooding events that is independent of specific hydrologic models because it reflects the cumulative effects of thousands of years of flooding. Drainage patterns, surface topography, soil development, vegetation, and stratigraphic studies were used to assess the character of flooding and the extent of flood-prone areas on the piedmont. We differentiated and mapped alluvial surfaces of the following ages: <100 years; < 5,000 years; 5,000 to 20,000 years; 20,000 to 100,000 years; and >100,000 years.

Our analysis indicates that the areas that have been flooded during the past 5,000 years are substantially more restricted than the areas depicted as being within the 100-year floodplain by the published FIRMs (FEMA, 1989). Discrepancies between the geomorphic data and the FIRMs are greatest for the southeastern portion of the Tortolita piedmont, where surfaces between distributary channels typically are tens to hundreds of thousands of years old. Positions of these distributary channels must have remained quite stable for a very long time. The central and northwestern drainages (Prospect, Ruelas, and Wild Burro) have much more extensive young deposits, indicating that broader areas of the piedmont have been flooded in the past few thousand years. Sedimentologic evidence of abandoned channels found in soil pits excavated in these areas indicates that channel locations have shifted over the past several thousand years. However, relatively minor channel change occurred during a recent extreme flood on Wild Burro Wash.

Several factors contribute to the discrepancy between the extent of potential alluvial fan flooding defined by geomorphic analysis and the AFM:

(1) Distributary channel networks are not synonymous with active alluvial fans in southern Arizona. Based on the extent of 100-year floodplains shown on the FIRMs of the Tortolita piedmont (FEMA, 1989), it is evident that the assumption was made that distributary channel networks indicate the presence of active alluvial fans. However, some of the distributary channel networks on the Tortolita piedmont have been relatively stable for tens of thousands of years. These systems violate the fundamental assumption of the AFM that channels have an equal probability of following any path downslope within the

boundaries of an alluvial fan. Because channel patterns are stable, areas between channels are far less flood prone than areas in or adjacent to channels. Even on active alluvial fans, where there are extensive young surfaces between distributary channels (Wild Burro Wash, for example), drastic shifts in channel positions probably occur less frequently than implied by the AFM (Pearthree, 1991).

(2) Flood flow is not completely contained in channels of uniform or predictable geometry from fan apex to fan toe. The AFM assumes that all flood flow is contained in one or more channels of specified geometry, and peak discharge is not attenuated downfan. Flood flows in the distributary systems of the Tortolita piedmont are complexly partitioned between many channels and sheet flooding. Analysis of a recent extreme flood that affected Wild Burro alluvial fan (House and others, 1991; Pearthree, 1991) indicates that channels do not contain all flood waters and shallow sheet flow is an important component of large floods on alluvial fans in this region. This diversion of some flood water into lower velocity sheet flow results in attenuation of the peak discharge downfan.

(3) Discharges used to develop 100-year floodplain maps for the Tortolita piedmont are unrealistically large. The floodplain boundaries shown on the FIRMs are derived using 100-year discharge estimates, the assumptions of the AFM, and topography. Using unrealistically large discharge estimates in the AFM (House, 1991) results in the location of FEMA alluvial fan apices upslope of areas where there is physical evidence of young alluvial fan activity. This problem may also contribute to the excessive lateral extent of alluvial-fan areas shown on the FIRMs for this area.

Assessment of potential flooding on alluvial fans of the Tortolita piedmont and other areas in Arizona could be improved by (1) using geomorphic analysis to define the extent of active alluvial fans and other flood-prone areas; (2) making the AFM more realistic by more accurately assessing the potential for shifts in channel locations and incorporating sheet flooding into the flow model; and (3) iterating between the model results and geomorphic information on the piedmont to determine appropriate discharges for extreme flow events in this area.

GLOSSARY

active alluvial fan - Active alluvial fans are actively aggrading landforms that are subject to alluvial-fan flooding in the present fluvial environment. Active alluvial fans are recognized by laterally extensive, fairly continuous young alluvial surfaces and distributary channel networks.

alluvial fan - A depositional landform composed of alluvial sediments that is fan-shaped in two dimensions and cone-shaped in three dimensions. Alluvial fans are formed in areas of flow expansion where stream channel confinement decreases. Channel networks and loci of deposition shift around on aggrading alluvial fans over periods of thousands of years, distributing sediments across the surface of the fan. Depending on the characteristics of particular piedmonts, alluvial fans may be found immediately adjacent to mountain ranges or at any location downslope. Fans may be actively aggrading (active fans) or relict features that were deposited hundreds of thousands of years ago.

alluvial surface - Surface exposed to the atmosphere on top of alluvial (stream) deposits. Alluvial surfaces have distinctive characteristics that depend on the nature of the stream that deposited them, the size and sorting of the alluvial deposits, local climate, and the time that has elapsed since they were deposited.

distributary channel network - Channel network that branches downstream, distributing water between several channels. Channels may branch and rejoin downstream in very complicated patterns. Distributary channel networks associated with active alluvial fans in Arizona may be prone to drastic shifts in configuration, but other distributary channel networks are entrenched into old, inactive alluvial surfaces and have been stable for tens of thousands of years.

distributary flow system - Fluvial systems that distribute water downslope, in contrast to tributary systems. Water is distributed through complex distributary channel networks and shallow overbank and sheet flooding.

Holocene - The most recent geologic epoch, it comprises about the past 10,000 years.

inactive alluvial fan - Inactive alluvial fans are areas that experienced alluvial fan aggradation in the past but which are not now subject to alluvial-fan processes. They are recognized by moderate to strong soil development, entrenched tributary channel networks, and erosional modification of the original depositional surface of the fan.

interfluves - Areas between channels. May be composed of young or old alluvial surfaces.

pediment - Gently sloping, low relief bedrock erosion surfaces that extend valleyward from the base of mountain ranges; typically mantled by thin sheets of alluvial sediments.

piedmont - Piedmonts are the gently sloping areas between axial drainages or playas and mountain ranges. Desert piedmonts typically are covered with alluvial deposits and have modest topographic relief relative to adjacent mountain ranges. Piedmonts in Arizona are composed of alluvial surfaces of different ages, with young surfaces reflecting the extent of recent flooding.

Pleistocene - The geologic epoch that proceeded the Holocene, approximately the period between 10,000 and 2,000,000 years ago.

soil development - Distinct soil horizons develop with time through the input of material from the atmosphere and the weathering and translocation of material within the soil. Material is moved within the soil as water percolates downward during wetting events. In desert regions, accumulation of silt and clay and precipitation of calcium carbonate typically dominate visible soil development.

tributary drainage network - Drainage networks that collect water and concentrate it in progressively larger channels downstream. Plan-view geometry of systems typically is dendritic (tree-like).

INTRODUCTION

Proper evaluation of potential flood hazards in piedmont areas of the United States is a formidable challenge for floodplain managers and flood insurance administrators. During the past several decades, urban areas in the western United States have expanded greatly, encroaching onto the gently sloping piedmont areas between axial drainages and mountain ranges. These desert piedmonts typically are covered with alluvial (stream) deposits and have modest topographic relief relative to adjacent mountain ranges. Portions of piedmonts may be composed of active alluvial fans associated with drainages that head in adjacent mountains. Flood hazards associated with active alluvial fans are especially difficult to assess because local topography provides little confinement for stream flow, much of the flood flow is conveyed as unconfined sheet flooding, and drastic changes in channel geometries are possible during floods.

The Federal Emergency Management Agency (FEMA) has adopted a simple model of fluvial behavior to define flood-hazard zones in areas considered to be active alluvial fans. Fundamental elements of the model are: (1) an estimate of the 100-year discharge at the fan apex; (2) the assumption that the hydraulic geometry of channels on fans during floods is predictable and a function only of discharge; (3) the assumption that floodwaters may take any path down the fan during a flood, implying that drastic shifts in channel patterns are common during floods; and (4) a probabilistic assessment of the likelihood of downfan areas being affected by any given flood. The FEMA alluvial fan methodology (AFM) is used to develop maps depicting 100-year flood flow depths and velocities on alluvial fans (Dawdy, 1979; FEMA, 1985). Serious questions have been raised regarding the validity of fundamental model assumptions about fluvial behavior on fans (French, 1987; Pima County Flood Control District (PCFCD), 1988; Baker and others, 1990; Fuller, 1990; O'Brien?, 1991, Pearthree, 1991), where the FEMA methodology should appropriately be applied (PCFCD, 1987; Pearthree and Wellendorf, in prep.), and the criteria used to define the extent of areas subject to alluvial fan flooding (Pearthree and Pearthree, 1989; Pearthree, 1989).

The character of flooding and the extent of flood-prone areas on the southern piedmont of the Tortolita Mountains in Pima County (figure 1) have been vigorously disputed by local and federal floodplain-management officials since at least 1987. Flood insurance rate maps (FIRMs) published for the Tortolita piedmont were developed using the AFM (FEMA, 1989). Officials of the Pima County Flood Control District have argued that 100-year floodplains depicted on these FIRMs misrepresent flood hazards on much of the Tortolita piedmont. FEMA responded to these concerns by modifying the preliminary FIRMs, but maintained that application of the AFM was appropriate for this area.

Geomorphic and geologic analyses are particularly effective in defining areas of potential alluvial-fan flooding on piedmonts because they provide a long record of fluvial activity and they are independent of hydraulic and hydrologic models. Geomorphic characteristics and soil development reflect the ages of surfaces on piedmonts, and thus

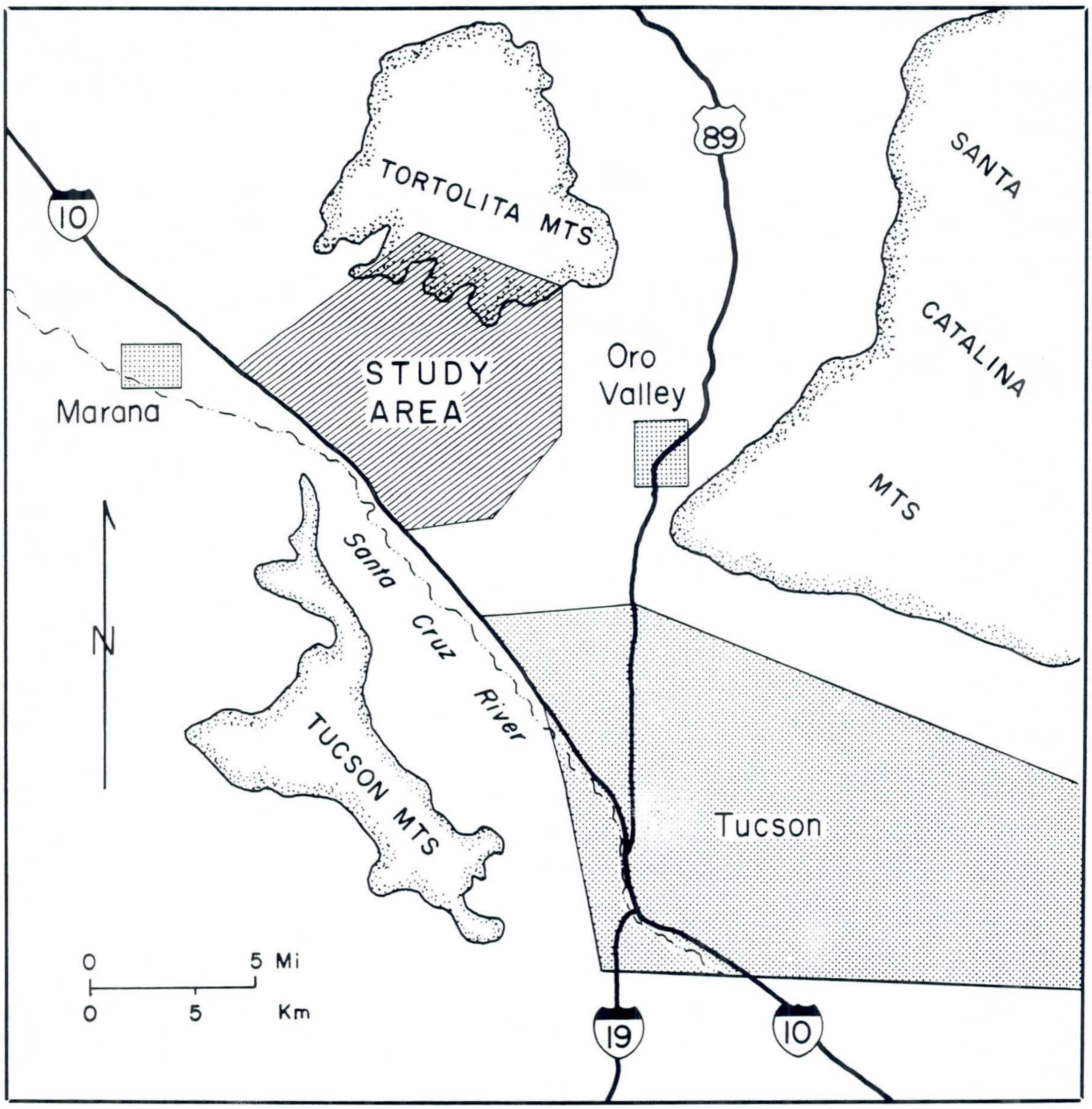

Figure 1. Location of the southern Tortolita piedmont in northern Pima County, Arizona.

can be used to delineate areas that have been subject to flooding over the past few thousand years. It typically is not possible to detail the effects of any large floods unless they have occurred very recently. However, the geomorphic character of a piedmont represents the cumulative effects of many floods. If flooding has affected portions of a piedmont in the past few thousand years, these areas are covered with young deposits. Conversely, if areas of a piedmont do not have extensive young deposits, then they have not been subject to significant flooding in a time frame that is relevant for most floodplain management concerns.

We conducted geomorphic analyses of the Tortolita piedmont in order to critically evaluate the reasonableness of the published FIRMs. Long-term patterns of flooding on the piedmont were documented through analyses of drainage patterns, surface topography, soil development, vegetation, and stratigraphic relationships. Our analyses indicate major discrepancies between areas depicted as being subject to alluvial-fan flooding on the published FIRMs and the areas that have actually been flooded in the past 5,000 years. These results cast serious doubts on the validity of using the AFM to assess flood risks on the Tortolita piedmont.

DEFINITION AND MAPPING OF ALLUVIAL SURFACES OF DIFFERENT AGES

Piedmont areas that have been flooded recently have a distinctive suite of geomorphic characteristics that differentiate them from piedmont areas that have not been subject to flooding for thousands of years. The geomorphic character of alluvial surfaces reflects the relative dominance of primary depositional processes or secondary processes that modify surfaces after they have been deposited. Active alluvial fans are predominantly depositional landforms; thus their overall physical character is dominated by depositional processes. The suite of geomorphic characteristics that is indicative of recent deposition includes distributary drainage patterns, minimal topographic relief, 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 related to major drainages for thousands of years (i.e., inactive alluvial fan areas) are dominated by erosional processes. Geomorphic characteristics that are associated with inactive alluvial fan areas include tributary drainage patterns, 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 (see table 1). For example, active, unvegetated channels appear very bright on the photographs. Young surfaces away from the channels are quite smooth because they are

Surface Characteristics

Unit	Drainage Patterns	Microtopography	Depth of dissection	Soil Development	Vegetation
2c	distributary	depositional; active channels, gravel bars, and sheetflow areas	< 1 m	no soil development; dull orange to brown	ironwood, palo verde mesquite, bushes
2b	distributary	depositional; low terraces and young fans; planar surfaces	0.5 - 1 m	slight visible carbonate; weak soil structure; dull orange to dull brown	palo verde, ironwood cholla, bushes
2a/ 1b	tributary	erosional; edges of interfluves rounded near dissecting gullies	$\leq$ 2 m	obvious visible carbonate; some clay increase; dull orange to reddish brown	bursage, palo verde ironwood, cholla
1	tributary	erosional; surfaces rounded and pervasively dissected by gullies	$\leq$ 5m	strong carbonate accumulation, typically cemented; clayey; reddish brown	saguaro cholla palo verde bursage

Table 1. Physical characteristics of geomorphic surfaces of different ages on the Tortolita piedmont. The reddest colors observed in typical soil profiles are given.

depositional surfaces and channels typically are only slightly incised into them; they commonly are dark 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. Channels 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 reconnaissance studies, and analyses of many soil profiles. Primary surface mapping was done on mylar overlays of black-and-white, 1:12,000-scale aerial photographs taken in 1979; these photos were supplemented with 1:24,000-scale color photographs taken in 1983 and 1:2,400-scale blueline copies of rectified aerial photographs with 2-ft topographic contours superimposed on them. We spent approximately 50 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 1:12,000-scale orthophoto base maps after final field-checking (Plate 1).

SURFACE-AGE ESTIMATES

The length of time since various portions of the Tortolita piedmont have been subject to flooding can be assessed by estimating the ages of the alluvial deposits and associated alluvial surfaces. We estimated the ages of these surfaces using several lines of evidence, including the geomorphic character of the surface, the degree of soil development, and independent constraints provided by vegetation or archeology. Surface age estimates are sufficiently precise to assess the recency of major flooding in general terms, thereby providing evidence to assess patterns of flooding on the piedmont.

Surface Geomorphology

The geomorphic character of surfaces of different ages reflects the relative dominance of deposition or erosion, and thus the length of time since the last major episode of alluvial fan deposition. Because active alluvial fans are primarily depositional landforms, they are evidenced by the dominant imprint of depositional processes on the surface (table 1). Depositional topography and distributary drainage patterns dominate the morphologies of the relatively young 2b and 2c surfaces; all older surfaces (2a, 1b, and 1) 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 (plate 2). These tributary drainages have downcut into and eroded the adjacent older alluvial surfaces; the depth of this downcutting correlates well with increasing surface age (figure 2).

Soil Development

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 (see figure 3a, for example). 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 tens of thousands of years or more, soil fabric obscures the original sedimentary fabric (see figure 3b, for example). 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 isolated from flooding. Estimating the time required to form a particular soil, therefore, is essentially equivalent to estimating the time since the alluvial surface it is associated with was isolated from major 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. General increases in clay, redness, and calcium carbonate content with increasing soil age in the Southwest are evident in table 2.

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 (see table 2). Unit 2b 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 2b surfaces are less than a few thousand years old. The soils associated with 2a surfaces are more strongly developed, suggesting that they are significantly older than 2b surfaces; they probably date to the early Holocene or latest Pleistocene (5,000 to 20,000 years old). The 1b surfaces apparently are somewhat older than 2a surfaces (perhaps 20,000 to 50,000 years old), although their soils are not very distinctive from 2a soils. Unit 1 probably encompasses surfaces of several different ages. The strong soil development associated with Unit 1 surfaces indicates that they are all more than 100,000 years old.

Archeology

Archeological remains associated with some of the alluvial surfaces on the Tortolita piedmont provide another means for estimating their ages. Comprehensive archeological surveys have been conducted on the Tortolita piedmont (Katzer and Schuster, 1984; John Madsen, Arizona State Museum, unpublished data), and other

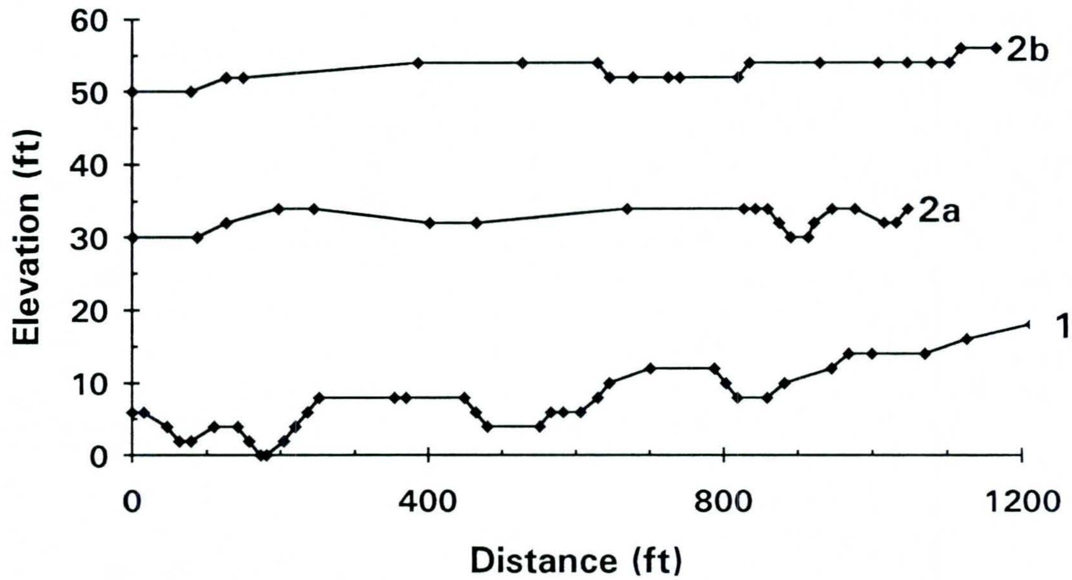

Figure 2. Cross-fan topography showing differences between active and inactive alluvial fan areas. The active fan surface (2b), which is less than 5,000 years old, is planar and is less than about 1 m (3 ft) above active channels. The older 2a surface, which has not been subject to major flooding for at least 5,000 years, is still fairly planar. However, channels are entrenched up to 1.5 m (5 ft) and 2a surfaces have been rounded by erosion adjacent to channels. Topography of the very old surface 1, which has not been subject to flooding for at least 100,000 years, is strongly erosional. Channels are entrenched up to 3 m (10 ft) and most of the surface has been rounded by erosion; few planar remnants of the original depositional surface are preserved.

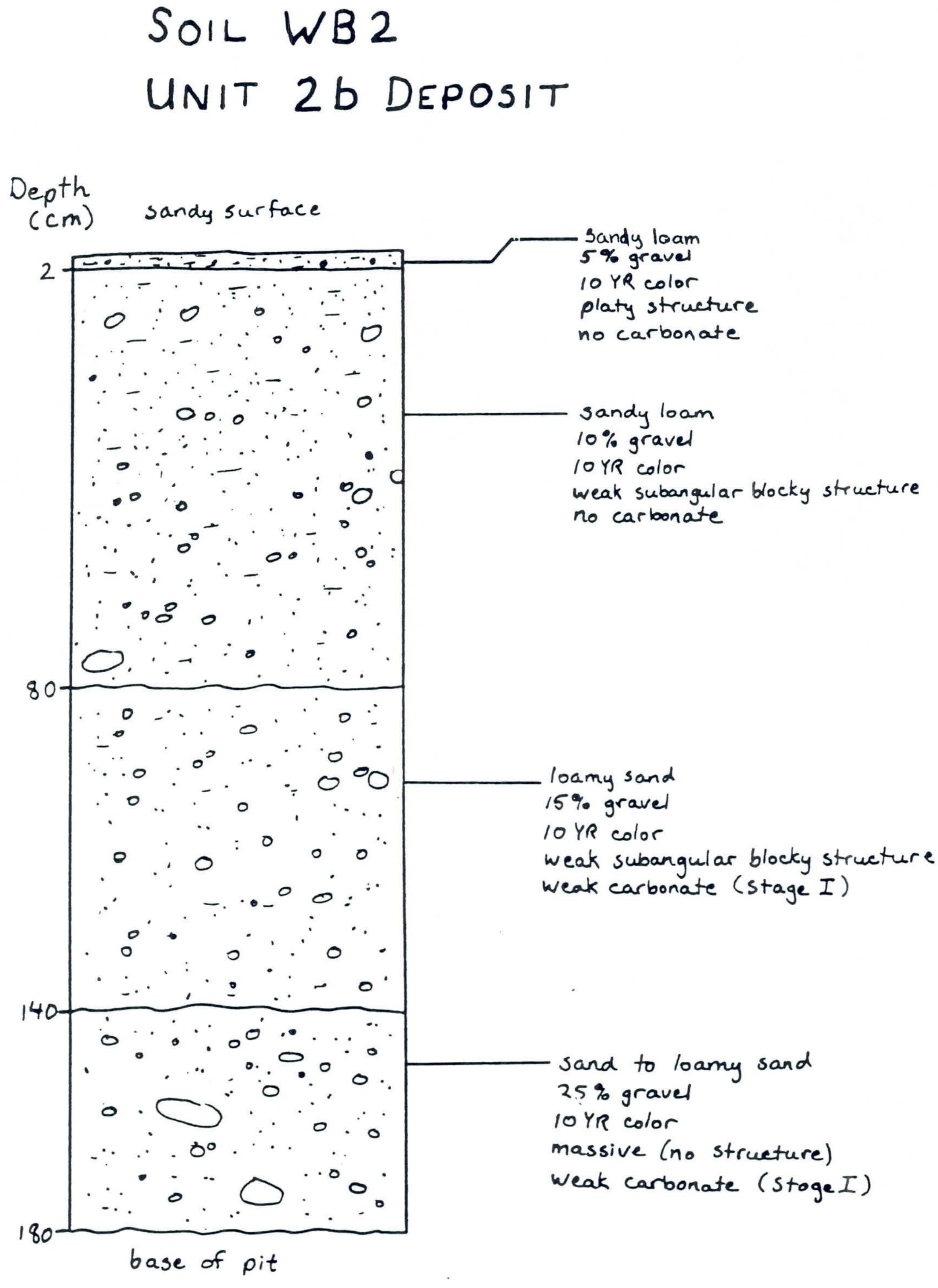

Figure 3. Schematic representations and descriptions of young and old soil profiles.

A) Weakly developed soil associated with surface 2b, less than 5,000 years old.

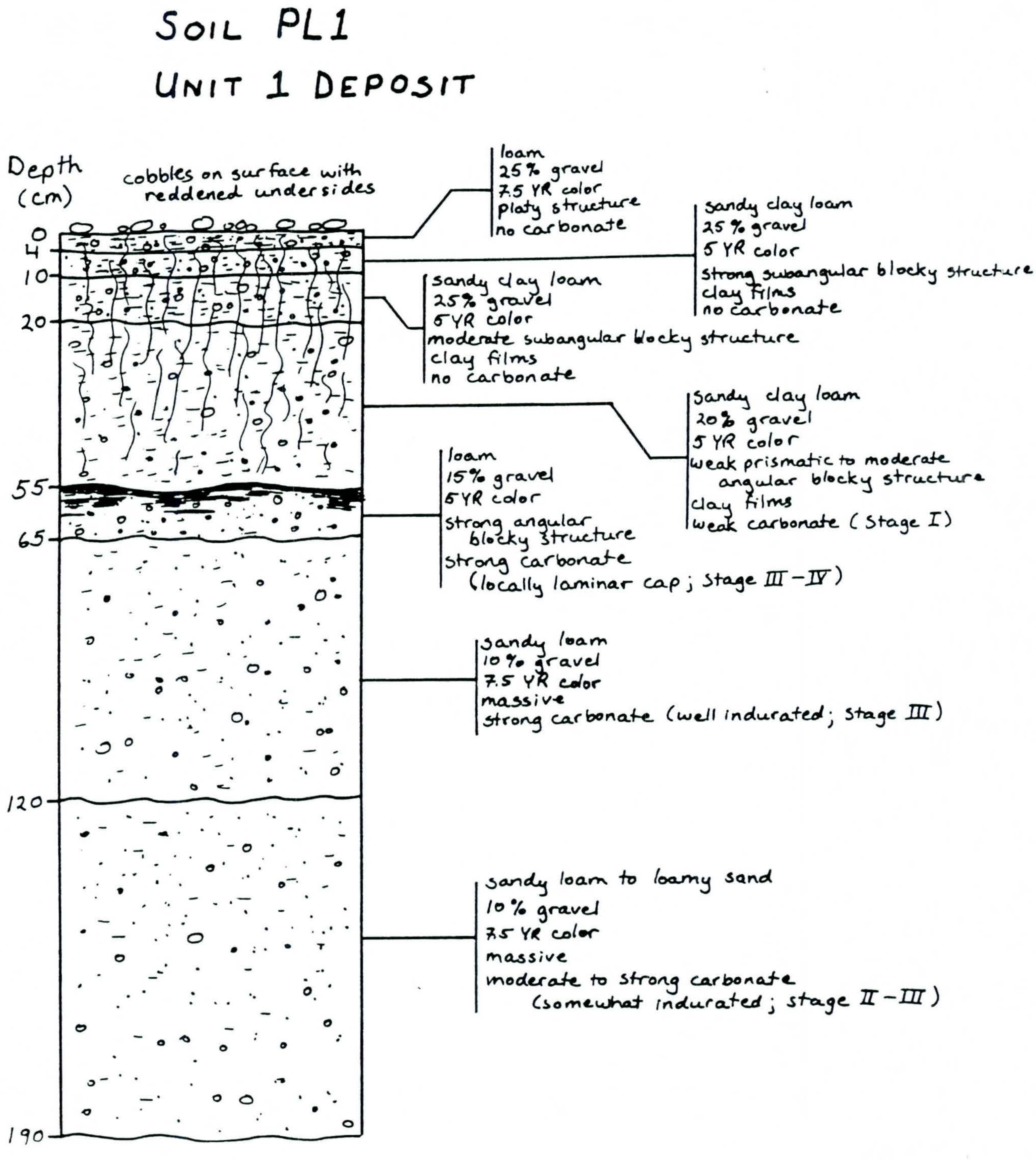

Figure 3. Schematic representations and descriptions of young and old soil profiles.

B) Strongly developed soil associated with surface 1, more than 100,000 years old.

Geomorphic Surface		Maximum Texture	Maximum Redness	Maximum Carbonate Stage	Estimated Age (x 1,000 yrs)
Southern New Mexico	**Tortolita Piedmont**				
Organ		sandy loam	5YR-10YR	I - II	< 5
	2b	**sandy loam**	**7.5 - 10YR**	**I**	**< 5**
Isaac's Ranch		loam	5YR	I - III	8 - 15
	2a	**loam**	**5 - 10YR**	**I - III**	**5 - 20**
	1b	**sandy clay loam**	**5 - 7.5YR**	**I - IV**	**20 - 125**
Jornada II		clay loam	2.5YR - 5YR	III - IV	75 - 125
	1	**clay loam**	**5 - 7.5YR**	**III - V**	**> 125**
Jornada I		clay	2.5YR - 5YR	III - V	250 - 400
Dona Ana		clay	5 YR	IV - V	> 400

Table 2. Correlation of soils and surface age estimates for the Tortolita piedmont **(bold type)** and the Desert Project on southern New Mexico (normal type) (Gile and others, 1981). Clay content in soils increases from sandy loam to loam to clay loam to clay. Soil redness increases from 10 YR to 2.5 YR. Soil carbonate stage increases from I to V. Carbonate is barely visible in weak stage I; stages IV and V are cemented "caliche".

artifacts were discovered during the course of our field studies. Artifacts ranging in age from several thousand years to less than one hundred years old have been found in this area. 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). These Hohokam artifacts provide a timeline with which to evaluate the stability of alluvial surfaces and the ages of deposits associated with them.

Hohokam artifacts on the Tortolita piedmont are found as isolated items, in clusters, or associated with dwelling places (sites). Isolated artifacts provide the least information regarding surface age. Many of these objects are small and some may have been transported by flood waters, although potsherd edges become characteristically rounded in the process. Further, these artifacts are 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 recency of flooding because they were certainly emplaced by the Hohokam; unfortunately they are concentrated only in the lowermost portions of the piedmont.

Hohokam sites and clusters are found on all surfaces except 2c, and locally they are found within deposits associated with surface 2b. This implies that some 2b surfaces are at least 650 years old (artifacts on the surface) and some 2b surfaces are less than about 650 years old (artifacts in deposits beneath the surface). In general, the sites where artifacts are buried beneath 2b surfaces are in the distal portions of the piedmont, adjacent to the Santa Cruz River,. Artifacts are distributed more or less equally on 2b and older surfaces farther up the piedmont. This suggests that most of the 2b surfaces in the middle piedmont areas are older than 650 years.

Three historical dump sites found on 2b surfaces on the lower piedmont have not been buried or seriously affected by fluvial activity since their emplacement. Refuse in these dumps dates to the early 20th century.

Vegetation

Vegetation also offers some constraints on the ages of the youngest alluvial surfaces of the Tortolita piedmont. Mature trees associated with the youngest surfaces (2c) 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 2c areas are unvegetated sand. The lushest and most diverse vegetation, ranging from low bushes to mature trees and cacti, is found on 2b 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 2c surfaces. This indicates that major, destructive flooding does not occurred frequently on 2b surfaces. Xerophytic plants become increasingly important on progressively older surfaces. Mature trees are still common on many 2a and 1b surfaces, but the relatively dry interfluves are dominated by bursage and cacti. The oldest surfaces (unit 1) 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 2a, 1b, and 1 indicates that these areas are not subject to flooding in the present setting.

Datable Organic Material

Dark organic material, probably charcoal, was recovered from four of the soil pits excavated in this study. One of the samples was extracted from unit 2b, two were extracted from unit 2a, and one was extracted from unit 1b. All of these samples are small and would require accelator mass spectrometer analysis (~ $500/sample). These samples have not been submitted for radiocarbon dating because funding is not available. Dates for the two samples extracted from 2a deposits would be most useful for several reasons: (1) the age of 2a deposits can only be generally estimated from soil development at present; (2) 2a surfaces are the youngest areas on the piedmont that we believe are not subject to flooding in the present regime; (3) constraining the age of 2a deposits would provide evidence for how long it has been since these areas have been subject to alluvial fan activity.

Summary Age Estimates and Recency of Flooding

Geomorphic characteristics, soil development, archeological remains, and vegetation assemblages provide the means to estimate the ages of alluvial surfaces of the Tortolita piedmont. The criteria used to define unit 2c, absence of vegetation and freshness of deposits, indicate that these surfaces must be very young, probably less than 100 years old in all cases. Unit 2c is clearly subject to flooding fairly often. Unit 2b probably ranges in age from several hundred years to several thousand years old. It is likely that some 2b surfaces are subject to shallow flooding in large floods, making estimation of their ages problematical. Unit 2a is distinctly older than unit 2b, based on greater soil development and the dominance of erosional topography. The soil development associated with units 2a and 1b does not imply great antiquity for the surfaces, but they probably were deposited at least 5,000 years ago, and they could be tens of thousands of years old. The erosional topography and tributary drainage networks of these surfaces suggest that they were deposited by fluvial systems that had different geometries than the systems that are currently active. Therefore, 2a and 1b surfaces are not subject to flooding in the present regime. Unit 1 has not been affected by large-scale flooding for at least 100,000 years. During this time, substantial on-fan drainage nets incised into Unit 1 and strong soil profiles developed.

SPATIAL PATTERNS OF FLUVIAL BEHAVIOR AND THE EXTENT OF ACTIVE ALLUVIAL FANS

The general patterns of fluvial activity and the extent of active alluvial fan areas across the Tortolita piedmont may be outlined using drainage patterns and the distribution of surfaces of different ages. This analysis is founded on the argument that current flood hazards on piedmonts can best be assessed using thousands of years of fluvial behavior. Alluvial-fan flooding associated with the major drainages is likely to occur only in those areas where there is physical evidence of young alluvial fan activity (areas that are covered with young alluvium and have distributary drainage patterns). Areas on the Tortolita piedmont determined to be susceptible to alluvial-fan flooding based on our geomorphic analyses can then be compared with the 100-year floodplains delineated using the AFM.

The extent of young alluvial fan activity, documented by the distribution of young deposits (units 2b and 2c), varies dramatically from drainage to drainage across the Tortolita piedmont (see plate 1). Every major drainage that heads in the Tortolita Mountains and crosses the study area is entrenched into very old alluvial fan deposits (unit 1) near the mountain front. Deposits of intermediate (1b and 2a) and young (2b and 2c) age become more extensive downslope along all of the drainages. There is, however, a trend toward increasingly more extensive young deposits from southeast to northwest across the area studied, indicating that the extent of potential alluvial fan flooding also increases along this trend. Specific characteristics of individual drainages are discussed below.

Canada Agua East and Canada Agua West

Discrepancies between the 100-year floodplains shown on the published FIRMs (FEMA, 1989) and the physical evidence of recent flooding on the piedmont are greatest for Canada Agua East and West drainages. Both of these drainages have several-kilometer-long entrenched reaches in the upper piedmont where flow is confined to a narrow path cut into old alluvial deposits (unit 1, primarily). In the middle piedmont area downslope from these simple entrenched reaches, drainage patterns become distributary. Even in these reaches, however, areas of young deposition (units 2b and 2c) are very restricted, indicating that alluvial fan flooding has not occurred there during at least the past 5,000 years. Local topographic relief in the lower portion of the piedmont is considerable (figure 4A), and the ridges in this area are composed of very old deposits (unit 1); younger deposits (2a, 2b, and 2c) are confined to the valleys. The FIRMs imply extensive alluvial-fan flooding in these lower piedmont reaches, where the physical evidence indicates that flow has been confined to valleys for tens of thousands of years.

Prospect Wash

Prospect Wash has a several-kilometer-long entrenched reach in the upper piedmont, where a narrow band of 2b and 2c surfaces occurs within an extensive area of very old (unit 1) surfaces. The middle piedmont is characterized by a distributary channel

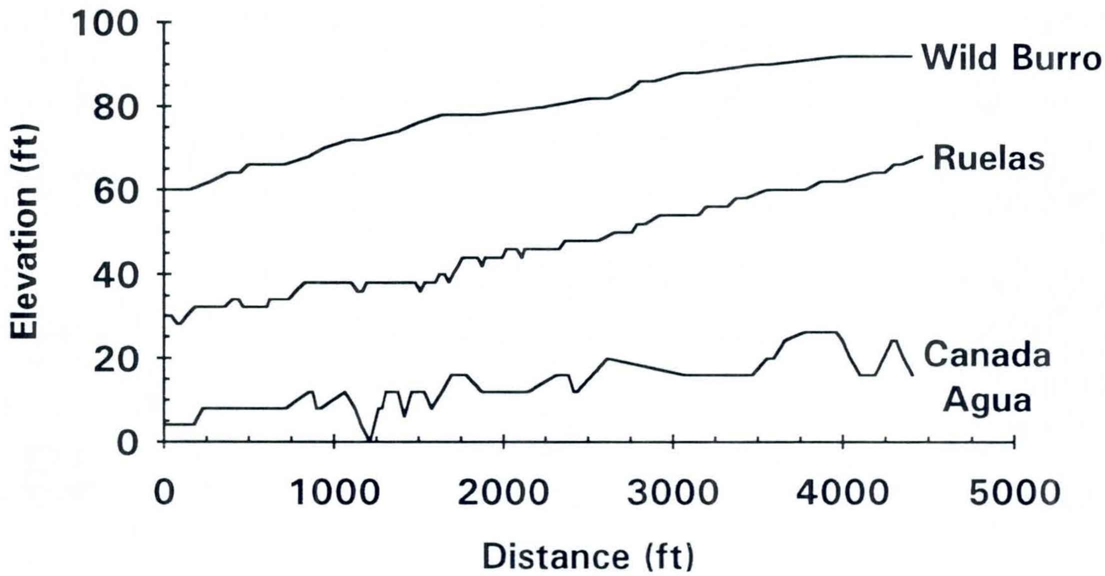

Figure 4. Topography perpendicular to channel systems in the distal portions of the Tortolita piedmont illustrating differences between active alluvial fan areas and inactive fan areas. The distributary channels of Canada Agua West are deeply entrenched into very old alluvial surfaces (unit 1); young deposits are confined to valleys and interfluve areas have not been subject to alluvial-fan flooding for tens to hundreds of thousands of years. The distal piedmont associated with Ruelas Wash contains young and old deposits. Topographic relief is much less, but interfluve areas typically are composed of unit 2a (5,000 to 20,000 years old), implying that the distributary channel network in this area is fairly stable. The distal piedmont of Wild Burro Wash is an active fan. There is very little topographic relief and the area is completely covered with units 2b and 2c (less than 5,000 years old). All of these areas are included in the 100-year floodplains shown on the FIRMs (FEMA, 1989) for the Tortolita piedmont.

pattern and extensive young (2b) surfaces, suggesting that relatively unconfined flow occurs in this area; large islands of intermediate (2a) surfaces imply that flow has been confined between these older surfaces for at least 5,000 years, however. The lowermost portion of the piedmont is completely composed of young deposits and channels are small, indicating that unconfined flow has dominated the recent history of this area. The point of widening of the alluvial fan shown on the FIRMs nearly coincides with the area of extensive young deposits and distributary drainage; it is only about 0.5 km (1600 ft) upslope from the fan apex defined from the geomorphology of the area. The main discrepancy between the physical evidence and the FIRMs is that surfaces more than 5,000 years old are common within the boundaries of the 100-year floodplain.

Ruelas Wash

Flow patterns along Ruelas Wash are the most complicated observed in the study area. The entrenched upper piedmont portion of Ruelas Wash is less that 1 km (0.5 mi.) long; below this point, extensive young deposits and distributary channels imply recent alluvial fan activity. However, farther downslope intermediate (2a and 1b) and old (1) surfaces become common again, indicating that flow is conveyed through the downslope area in valleys cut into intermediate and old deposits (see figure 4B for the topography in this area). The lowermost portion of the piedmont is again almost entirely composed of young deposits. It appears that flow changes from strongly confined in the uppermost piedmont to unconfined in the adjacent upper piedmont, then to partially confined in the middle piedmont, and finally to unconfined in the lower piedmont. The point of widening of the alluvial fan defined by FEMA coincides with the area of extensive young deposits in the upper piedmont; there is no discrepancy with the geomorphic evidence at that location. As with Prospect Wash, however, there are extensive surfaces more than 5,000 years old downslope from this area, so application of the AFM to all of the area between the fan apex and the lower piedmont is not justified.

Wild Burro Wash

The Wild Burro Wash area contains the most unambiguous evidence of extensive alluvial fan activity. Wild Burro Wash is entrenched into very old fan deposits in the upper several kilometers of the piedmont. Below this reach, intermediate and young deposits predominate all the way down the piedmont. A broad, continuous area of young deposits and a coextensive distributary channel pattern provide strong geomorphic evidence of an active alluvial fan (see plate 2; figure 4C). In the case of Wild Burro Wash, there is no suggestion that flow becomes reconfined downslope.

The primary discrepancy between the FIRMs and the physical evidence in this portion of the piedmont is that the point of widening of the alluvial fan defined by FEMA is approximately 1 km (0.6 miles) upslope of the place where young deposits (2b and 2c) become laterally extensive. This results in the inclusion of the extensive area composed primarily of intermediate (2a) surfaces located between Wild Burro and Ruelas washes within the 100-year floodplain. The area in question is bounded on northeast side by a small distributary drainage that diverges from Wild Burro Wash and joins channels associated with Ruelas Wash. However, this area is characterized by substantial soil-profile development on interfluves and tributary drainage patterns, and there is topographic confinement of the main flow of Wild Burro Wash downslope from the point where the small distributary channel exits. These features indicate the this area is not subject to alluvial fan processes at the present time.

Unnamed Wash West of Wild Burro

Our geomorphic mapping includes an area associated with a small canyon west of Wild Burro Wash that is depicted as an alluvial fan on the FIRMs (FEMA, 1989). This "Unnamed" wash is actually several washes that join together in the upper piedmont and drain into Cochie Wash, the next major wash to the west. The area included within the 100-year floodplain is a complex mosaic of young (units 2b and 2c), intermediate (units 2a and 1b), and old (unit 1) alluvial surfaces. Young alluvial surfaces are fairly extensive adjacent to the mountain front; within 1 km (0.6 mi.) farther down the piedmont old surfaces predominate and young surfaces are much more restricted in extent. The channel systems of several small drainages merge together in a complicated distributary pattern in the upper piedmont area, where young surfaces are laterally extensive (see plate 2). There may be potential for shifts in channel positions and sheet flooding in this area. The extensive old surfaces farther down the piedmont, however, indicate that the lower portion of the distributary channel network is stable and should not be considered an active alluvial fan.

North Ranch Drainage

Although the North Ranch drainage in the easternmost portion of the study area is not depicted as an alluvial fan in published FIRMs (FEMA, 1989), it was mapped and analyzed in order to compare it to the drainages to the northwest that were considered to have active alluvial fans. The configuration of the 100-year floodplain for this drainage is very similar to the drainages to the northwest, with a relatively restricted floodplain in the upper piedmont that widens into a fan-shaped entity in the middle and lower piedmont. All that distinguishes the floodplain map of North Ranch drainage from those discussed previously is the absence of specific 100-year flood depths and velocities determined through application of the AFM. North Ranch drainage was in fact treated as an alluvial fan in preliminary analysis, and was determined not to be an alluvial fan during the appeal process.

North Ranch drainage is very similar to Canada Agua East and Canada Agua West. It has a several-km-long entrenched reach in the upper piedmont, where young deposits are of limited extent and areas on either side of the wash are composed of very old (unit 1) fan deposits. The North Ranch drainage system becomes distributary in the middle piedmont, but young deposits (less than 5,000 years old) are restricted to areas adjacent to channels. The extent of young deposits and the overall character of the North Ranch drainage system, which has been determined not to be an active alluvial fan, is very similar to the Canada Agua drainages. The only obvious difference is that nearly all of the North Ranch drainage basin is on the piedmont; only the uppermost headwaters of the basin drain the Tortolita Mountains.

SEDIMENTOLOGIC EVIDENCE OF DOMINANT FLOOD PROCESSES

In the initial published formulation of the AFM, the presence of debris flows was considered to be an element of active alluvial fans that contributed to drastic shifts in channel positions (Dawdy, 1979). Debris flows are slurry flows of very poorly sorted rock and soil debris mixed with water. They have much higher strength, density, and viscosity than water floods, they are highly charged with sediment, and they can move large clasts (boulders) and trees if they are available for transport. Debris flows typically leave distinct evidence of their occurrence, including coarse boulder levees along their lateral margins and coarse boulder concentrations near their downslope termini (Costa, 1984). Debris-flow deposits are distinctly different from sediments deposited by water floods. Debris flow-deposits are very poorly sorted, with particles ranging in size from clay and silt up to boulders. They have little clast imbrication or other internal fabric, and large clasts commonly are suspended in a sand and finer matrix (matrix-supported deposits) (Bull, 1972). Debris flows have been reported in a wide range of environments, including southern Arizona. In southern Arizona, recent debris flows have been triggered on very steep mountain hillsides and have affected steep mountain canyons or uppermost piedmont areas only (Pearthree, personal observations, 1984-1991; Wohl and Pearthree, 1991).

We evaluated the relative importance of debris flows on the Tortolita piedmont through observations of sediments exposed in backhoe pits and natural exposures. The sediments associated with units 2c, 2b, 2a, and 1b that were observed on the piedmont were all deposited by water floods. These deposits are relatively well-sorted, with few large clasts. Pebbles and cobbles typically are concentrated in lenses, which are probably former channel bottoms or gravel bars. Finer sediments with little or no gravel are very common in the backhoe pits; they probably represent sheet-flood or overbank deposits. The depositional environment of unit 1 is less clear because strong soil development masks the original sedimentary structure, and not much attention was paid to stratigraphic exposures of unit 1. Sediments of unit 1 are coarser and more poorly sorted than any of the younger deposits, however, so it is possible that debris flows had a significant impact on piedmont prior to 100,000 years ago. We conclude that debris flows do not contribute to shifts in distributary channel positions in the current fluvial environment on the Tortolita piedmont.

CHANGES IN CHANNEL POSITIONS WITH TIME

Another objective of these studies was to attempt to evaluate the frequency of major shifts in channel positions (avulsions) in active alluvial fan areas. Analyses of alluvial fan deposits indicate that channel positions do shift across fans with time (Bull, 1977; Waters and Field, 1986). Several factors facilitate shifts in channel positions. Active alluvial fans are aggrading landforms. Therefore, topographic relief on active alluvial fans is very modest, and channels are not deeply entrenched. Further, the deposits of active fans are young and typically are not well-indurated, and so are fairly susceptible to lateral erosion. Finally, streams associated with active fans must carry a substantial sediment load over the long term in order to sustain fan deposition.

The AFM makes the assumption that there is an equal probability that channels will occupy any position within the limits of the fan during flow events (FEMA, 1985). This assumption implies that changes in channel positions on fans are fairly common. Shifts in channel positions on alluvial fans over time most certainly occur, but very little information exists with which to evaluate specific relationships between extreme flow events and frequency of avulsions. We are not aware of any situation where the frequency of channel shifts on an alluvial fan has been rigorously documented. Further, there could be variations in the frequency of avulsions between fans because of variations in factors such as sediment size, soil characteristics, density and type of vegetation, and the relative importance of debris flows on fans. A cursory study of numerous large flow events on alluvial fans in the western United States indicated that substantial changes in channel positions occurred during some of these events, and not in others (DMA Associates, 1985).

We found only limited information with which to assess the frequency of changes in channel positions on active alluvial fans of the Tortolita piedmont. It was not feasible to excavate a major trench that might have revealed the former positions of channels across any of the fans during the time that was available for this study. However, coarse gravel beds that are either channel or proximal fan deposits were found in many of the 45 soil pits excavated on the Tortolita piedmont. Only one of the soil pits was excavated in an active channel, so the buried gravel beds indicate that channels formerly existed in areas where they do not now exist. Units 2b and 2c are active channel, fan, or overbank areas, so only evidence from these deposits is relevant to assessment of channel change in the active fan systems. Of the 19 soil pits excavated in 2b deposits away from modern channels, 9 had probable channel deposits in them, 4 had possible channel deposits, and 6 did not have obvious channel deposits. The presence of channel deposits in at least 50% of the pits excavated in 2b surfaces indicates a substantial amount of change in channel positions over the past 5,000 years.

The frequency of channel change is also being investigated through detailed mapping and analysis of flow that occurred during an extreme flood on Wild Burro Wash in 1988 (Baker and others, 1990; House and others, 1991; Pearthree, 1991). Although the recurrence interval of this flood is not certain, it is the largest for which there is geomorphic evidence preserved in Wild Burro Canyon (House, 1991). This flood inundated much of the active alluvial fan associated with Wild Burro Wash (2c and 2b surfaces within the distributary channel system). We mapped flow depths on rectified photomaps with 2-foot contour lines that were constructed prior to the flood. Some local changes in current channel geometry relative to the pre-1988 orthophotos have been noted. In general, however, flow was controlled by topography that existed prior to the flood. No drastic changes in the positions of major channels occurred. The implication of this ongoing analysis is that major avulsions do not occur very frequently even on active alluvial fans on the Tortolita piedmont.

DISCUSSION - ACTUAL FLOOD-PRONE AREAS AND THE FEMA ALLUVIAL FAN METHODOLOGY

Geomorphic analyses and detailed geologic mapping of the Tortolita piedmont reveal major inconsistencies between alluvial fan areas determined using the AFM and alluvial fan areas indicated by drainage patterns and the distribution of young deposits (figure 5). Three general types of discrepancies were encountered: (1) prediction of laterally extensive alluvial-fan flooding where essentially no geomorphic evidence exists for recent alluvial fan flooding - illustrated by Canada Agua East and Canada Agua West; (2) prediction of alluvial fan flooding from the uppermost point where flow becomes unconfined by topography all the way to the lowermost portion of the piedmont, where geomorphic evidence indicates that flow becomes reconfined downslope from areas of unconfined flow - illustrated by Ruelas and Prospect washes, and the unnamed wash west of Wild Burro Wash; and (3) placement of alluvial fan apices substantially upslope from locations where there is geomorphic evidence of alluvial fan flooding - illustrated by Wild Burro Wash and to a lesser degree by Prospect Wash.

Most of these discrepancies result from the mistaken assumption that distributary channel networks are necessarily active alluvial fans. Examination of distributary channel networks on the Tortolita piedmont and 100-year floodplain boundaries shown on the published FIRMs reveals that in most cases the outer boundaries of the floodplains coincide with the outermost distributary channels associated with a given drainage (plate 2). Evidence presented above demonstrates that extensive areas within most of the distributary channel networks of the Tortolita piedmont have not been flooded for at least 5,000 years, and some of these areas have not been flooded for more than 100,000 years. Channel positions within these distributary systems clearly are very stable, and thus they do not satisfy the fundamental assumption of the AFM that there is an equal probability that flow will follow any path downslope within the alluvial-fan boundaries.

Because geomorphic analyses indicate that portions of almost all of the distributary systems of the Tortolita piedmont have been stable for thousands of years (Wild Burro Wash is the exception), application of the AFM in this area results in serious misrepresentation of potential flood hazards. The published FIRMs overstate the extent of

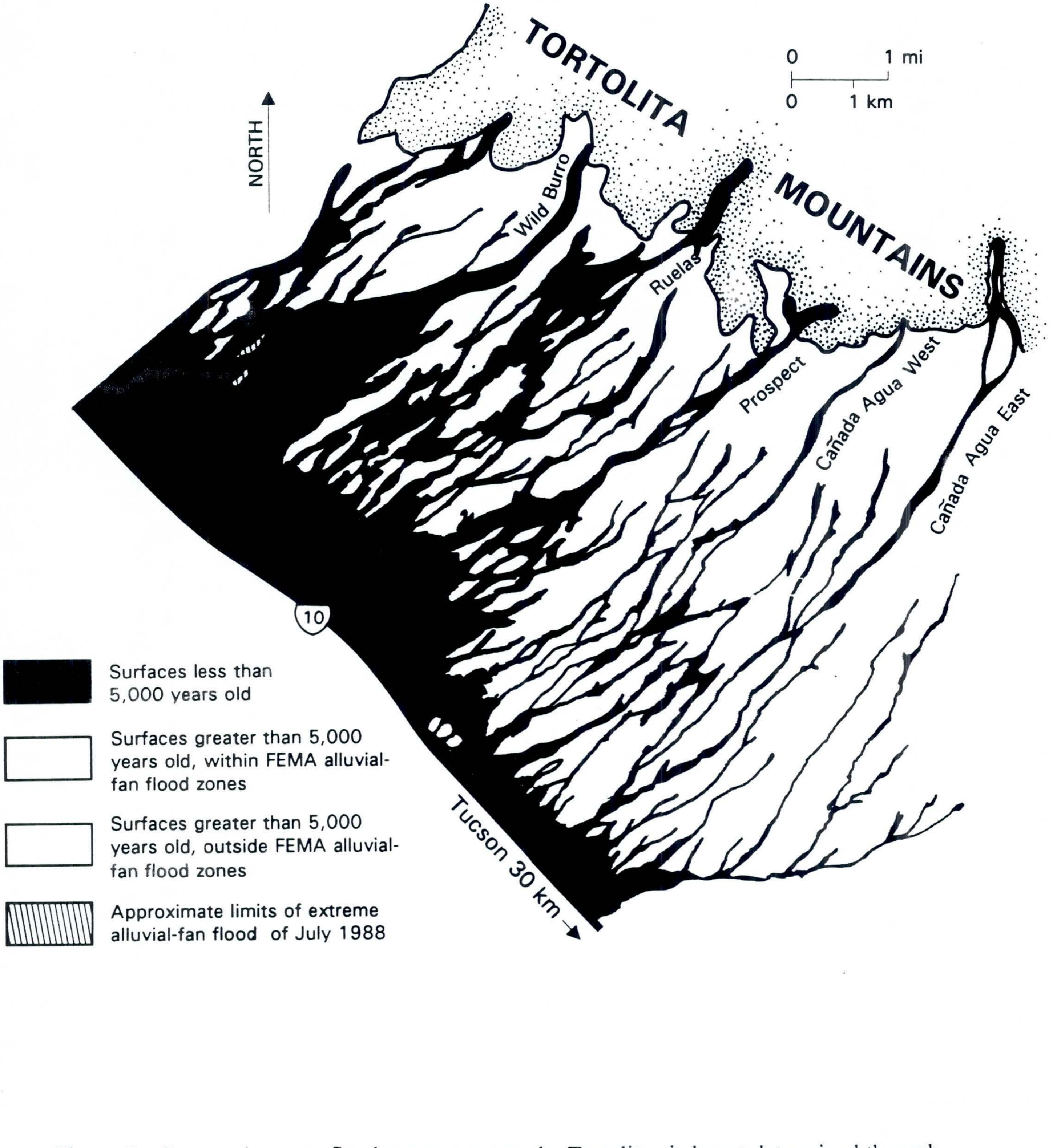

Figure 5. Contrast between flood-prone areas on the Tortolita piedmont determined through geomorphic analyses and the 100-year floodplains shown on published FIRMs (FEMA, 1989). Lightest shaded areas are included within 100-year floodplains but have not been flooded for at least 5,000 years.

flood-prone areas on the Tortolita piedmont. Broad areas included in the 100-year floodplain have not been flooded for thousands of years and should not be considered flood prone. In contrast to the fundamental assumption of the AFM, flood waters in distributary flow systems on the Tortolita piedmont are very likely to be concentrated in existing channels; areas between channels are subject to either no flooding or shallow sheet flooding. The result of using the AFM to define flood hazards for these stable distributary systems is to overestimate flood hazards in areas away from channels and to seriously underestimate flood hazards in and adjacent to existing channels.

Some of the discrepancy documented between the physical situation on the Tortolita piedmont and the alluvial-fan areas shown on the FIRMs (FEMA, 1989) may be accounted for if the 100-year discharges used to produce the maps are too large. Several factors could contribute to excessive discharges both at fan apices and in downfan areas. Clearly, an important factor is the 100-year discharges that were used in the AFM. The 100-year discharges that were developed using the Pima County Rainfall-Runoff Method (Zeller, 1979) are larger than the largest floods determined from geomorphic studies in the canyons of the major drainages that flow across the Tortolita piedmont (House, 1991). Overestimation of the sizes of 100-year floods is partly responsible for location of points of widening in the FIRMs upslope from areas where there is geomorphic evidence of alluvial fan activity (for example, Prospect Wash).

Attenuation or infiltration of flow in the confined upper piedmont reaches and in the distributary channel networks may also contribute to overestimating discharges at fan apices. All of the major drainages have substantial piedmont reaches where flow is confined by older alluvial deposits. The greatest discrepancies between the FIRMs and geomorphic evidence are found along those drainages that have the longest entrenched piedmont reaches (Canada Agua East and West). Infiltration and attenuation of peak discharges in distributary channel systems contribute to overestimation of peak discharges in areas downslope from fan apices as well. The AFM assumes that all flow is conveyed in a single channel or multiple channels from fan apex to fan toe. The geologic literature is replete with references to the increasing importance of sheet flooding (unchannelized flow) downfan (see Bull, 1977, for example), and our analysis of the 1988 flood on Wild Burro alluvial fan indicates that shallow unconfined flooding was an important component of flow. Roughness increases related to the shallow flow depths and the presence of abundant vegetation away from channels most certainly result in decreases in the velocity of any flow that is diverted into unchannelized areas. Increases in the area covered by flow and decreases in flow velocity also increase the potential for infiltration during the flood.

Behavior of the 1988 flood on Wild Burro alluvial fan indicates that 100-year flow depths and velocities shown on FIRMs for the Tortolita piedmont underestimate flow depths and velocities in existing channels and overestimate flood hazards away from channels even on active alluvial fans. Our analysis of the 1988 flood (Baker and others, 1990; House and others, 1991; Pearthree, 1991) indicates that channel geometries on the Wild Burro alluvial fan were relatively stable during this extreme flow event. Broad areas of the fan away from existing channels were inundated with flood waters less than 30 cm (1 ft) deep, but areas with relatively high depths and velocities associated with channelized flow were very restricted. All deep, high-velocity flow occurred in channels that existed prior to the flood. The assumptions about hydraulic geometry used in the AFM result in the underestimation of flood hazards in existing channels. Flow depths and velocities in relatively large channels during the 1988 flood were significantly greater than the 100-year flood values shown on the FIRMs. Thus both the likelihood of being subject to significant flooding and the actual magnitude of the flooding in existing channels are underestimated on the FIRMs.

CONCLUSIONS

Geomorphic analyses provide a long record of flooding that effectively delineates flood-prone areas on the southern piedmont of the Tortolita Mountains. We mapped alluvial surfaces of different ages based on their surface characteristics, soil development, and drainage patterns. Soil development, archeology, and surface geomorphology were used to estimate the ages of these surfaces. Areas of extensive, geologically young deposits <u>and</u> distributary drainage patterns are physical evidence of recent alluvial fan activity. These analyses indicate that there are broad areas characterized by alluvial fan behavior along several of the major drainages crossing the study area, but there is little or no evidence of alluvial fan activity along other drainages.

The extent of active alluvial fans determined from geomorphic analyses is substantially less than the alluvial fan areas delineated using the AFM. Three general types of inconsistencies between the physical evidence on the piedmont and predictions of the AFM were encountered: (1) prediction of alluvial-fan activity by the FIRMs where there is no compelling evidence of such activity in the past 5,000 years; (2) assumption of alluvial fan activity from the fan apex all the way downslope to the floodplain of the Santa Cruz River, when much of the downslope area is composed of surfaces that are more than 5,000 years old; and (3) location of fan apices upslope of areas where there is physical evidence of alluvial fan activity. Most of the discrepancy between the floodplain maps produced using the AFM and the actual extent of flood-prone areas results from the mistaken assumption that distributary channel networks are necessarily active alluvial fans. All of the distributary channel networks of the Tortolita piedmont are more stable than assumed by the AFM. Therefore, the FIRMs for the Tortolita piedmont underestimate flood hazards in and adjacent to existing channels and overestimate flood hazards away from existing channels. Excessively large discharges used in the AFM probably also contribute to unrealistic nature of the published FIRMs.

The following sequence of action is recommended to minimize discrepancies between model-based predictions and the physical evidence of alluvial fan flooding on piedmonts: (1) If alluvial fan flooding is suspected in piedmont area, a geomorphic analysis should be conducted to delineate the extent of young deposits and to define drainage patterns. (2) Methodologies that model alluvial fan behavior for flood-risk assessment or floodplain-management purposes should be applied only if physical evidence of alluvial fan activity is found in step (1). (3) When the methodologies are applied, their results should be iterated against the physical evidence to minimize differences between model predictions of alluvial fan areas and the extent of young deposits; this iteration will certainly involve varying input discharges, but might also involve varying the proportion of channelized vs. sheet flow on the fan.

Further research may provide firm evidence with which to assess the frequency of drastic changes in channel geometries during large flow events on active alluvial fans. With this evidence, it would be possible to make more realistic assessments of potential flood risk near present channels and away from present channels on active alluvial fans.

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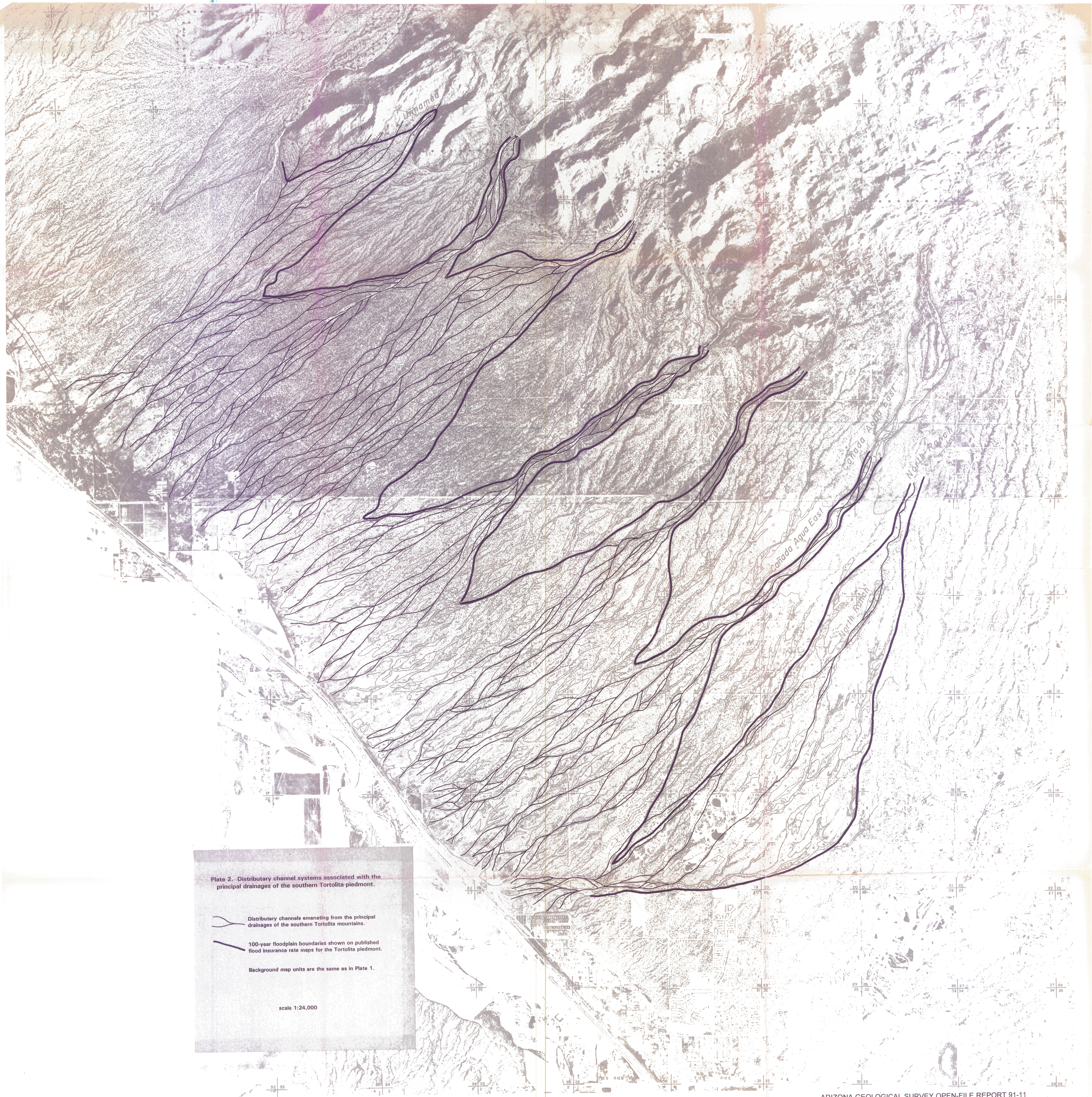
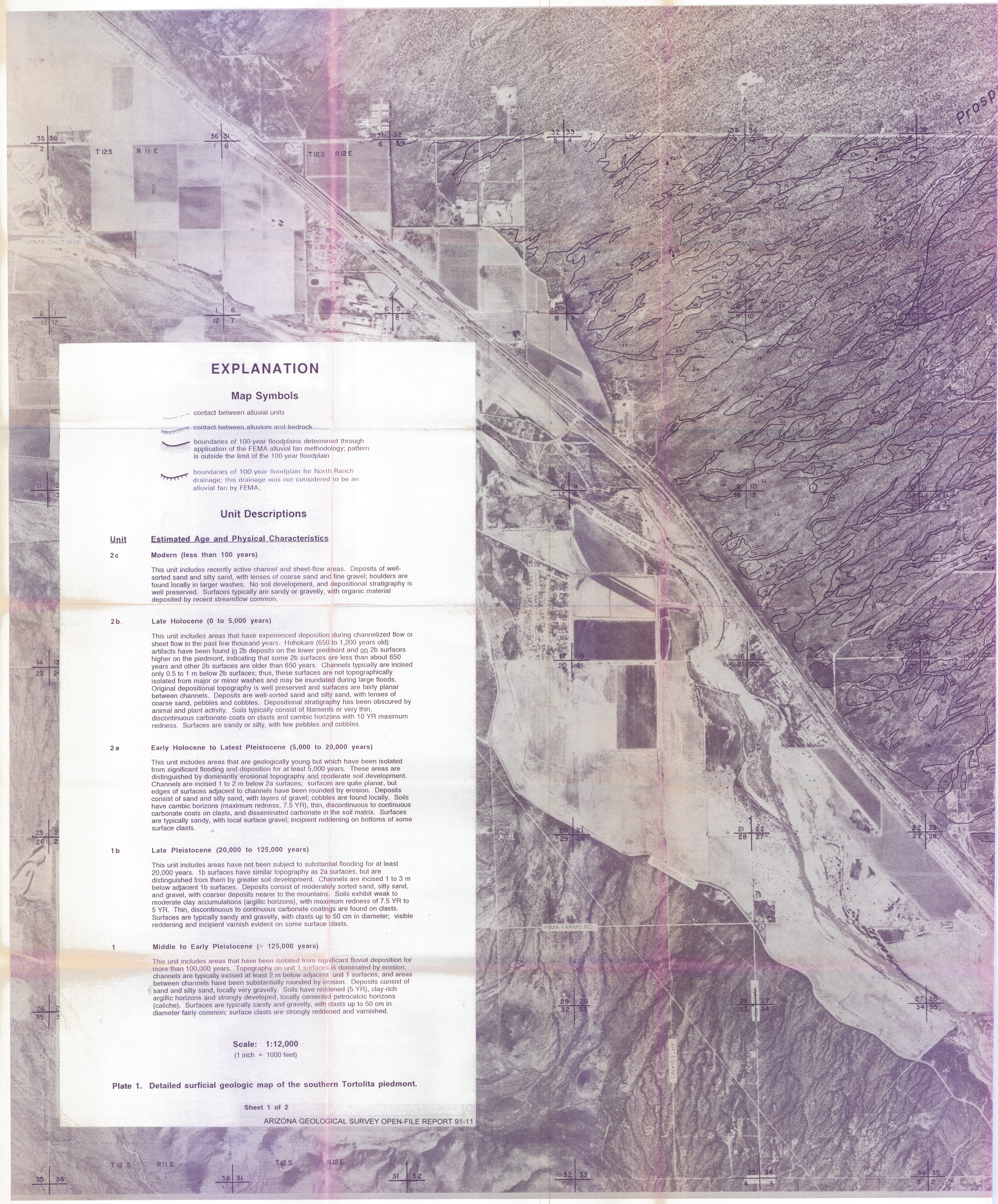


Plate 2. Distributary channel systems associated with the principal drainages of the southern Tortolita piedmont.



EXPLANATION

Map Symbols

contact between alluvial units

contact between alluvium and bedrock

boundaries of 100-year floodplains determined through application of the FEMA alluvial fan methodology; pattern is outside the limit of the 100-year floodplain

boundaries of 100-year floodplain for North Ranch drainage; this drainage was not considered to be an alluvial fan by FEMA.

Unit Descriptions

Unit	Estimated Age and Physical Characteristics
2c	**Modern (less than 100 years)** This unit includes recently active channel and sheet-flow areas. Deposits of well-sorted sand and silty sand, with lenses of coarse sand and fine gravel; boulders are found locally in larger washes. No soil development, and depositional stratigraphy is well preserved. Surfaces typically are sandy or gravelly, with organic material deposited by recent streamflow common.
2b	**Late Holocene (0 to 5,000 years)** This unit includes areas that have experienced deposition during channelized flow or sheet flow in the past few thousand years. Hohokam (650 to 1,200 years old) artifacts have been found in 2b deposits on the lower piedmont and on 2b surfaces higher on the piedmont, indicating that some 2b surfaces are less than about 650 years and other 2b surfaces are older than 650 years. Channels typically are incised only 0.5 to 1 m below 2b surfaces; thus, these surfaces are not topographically isolated from major or minor washes and may be inundated during large floods. Original depositional topography is well preserved and surfaces are fairly planar between channels. Deposits are well-sorted sand and silty sand, with lenses of coarse sand, pebbles and cobbles. Depositional stratigraphy has been obscured by animal and plant activity. Soils typically consist of filaments or very thin, discontinuous carbonate coats on clasts and cambic horizons with 10 YR maximum redness. Surfaces are sandy or silty, with few pebbles and cobbles.
2a	**Early Holocene to Latest Pleistocene (5,000 to 20,000 years)** This unit includes areas that are geologically young but which have been isolated from significant flooding and deposition for at least 5,000 years. These areas are distinguished by dominantly erosional topography and moderate soil development. Channels are incised 1 to 2 m below 2a surfaces; surfaces are quite planar, but edges of surfaces adjacent to channels have been rounded by erosion. Deposits consist of sand and silty sand, with layers of gravel; cobbles are found locally. Soils have cambic borizons (maximum redness, 7.5 YR), thin, discontinuous to continuous carbonate coats on clasts, and disseminated carbonate in the soil matrix. Surfaces are typically sandy, with local surface gravel; incipient reddening on bottoms of some surface clasts.
1b	**Late Pleistocene (20,000 to 125,000 years)** This unit includes areas have not been subject to substantial flooding for at least 20,000 years. 1b surfaces have similar topography as 2a surfaces, but are distinguished from them by greater soil development. Channels are incised 1 to 3 m below adjacent 1b surfaces. Deposits consist of moderately sorted sand, silty sand, and gravel, with coarser deposits nearer to the mountains. Soils exhibit weak to moderate clay accumulations (argillic horizons), with maximum redness of 7.5 YR to 5 YR. Thin, discontinuous to continuous carbonate coatings are found on clasts. Surfaces are typically sandy and gravelly, with clasts up to 50 cm in diameter; visible reddening and incipient varnish evident on some surface clasts.
1	**Middle to Early Pleistocene (> 125,000 years)** This unit includes areas that have been isolated from significant fluvial deposition for more than 100,000 years. Topography on unit 1 surfaces is dominated by erosion; channels are typically incised at least 2 m below adjacent unit 1 surfaces, and areas between channels have been substantially rounded by erosion. Deposits consist of sand and silty sand, locally very gravelly. Soils have reddened (5 YR), clay-rich argillic horizons and strongly developed, locally cemented petrocalcic horizons (caliche). Surfaces are typically sandy and gravelly, with clasts up to 50 cm in diameter fairly common; surface clasts are strongly reddened and varnished.

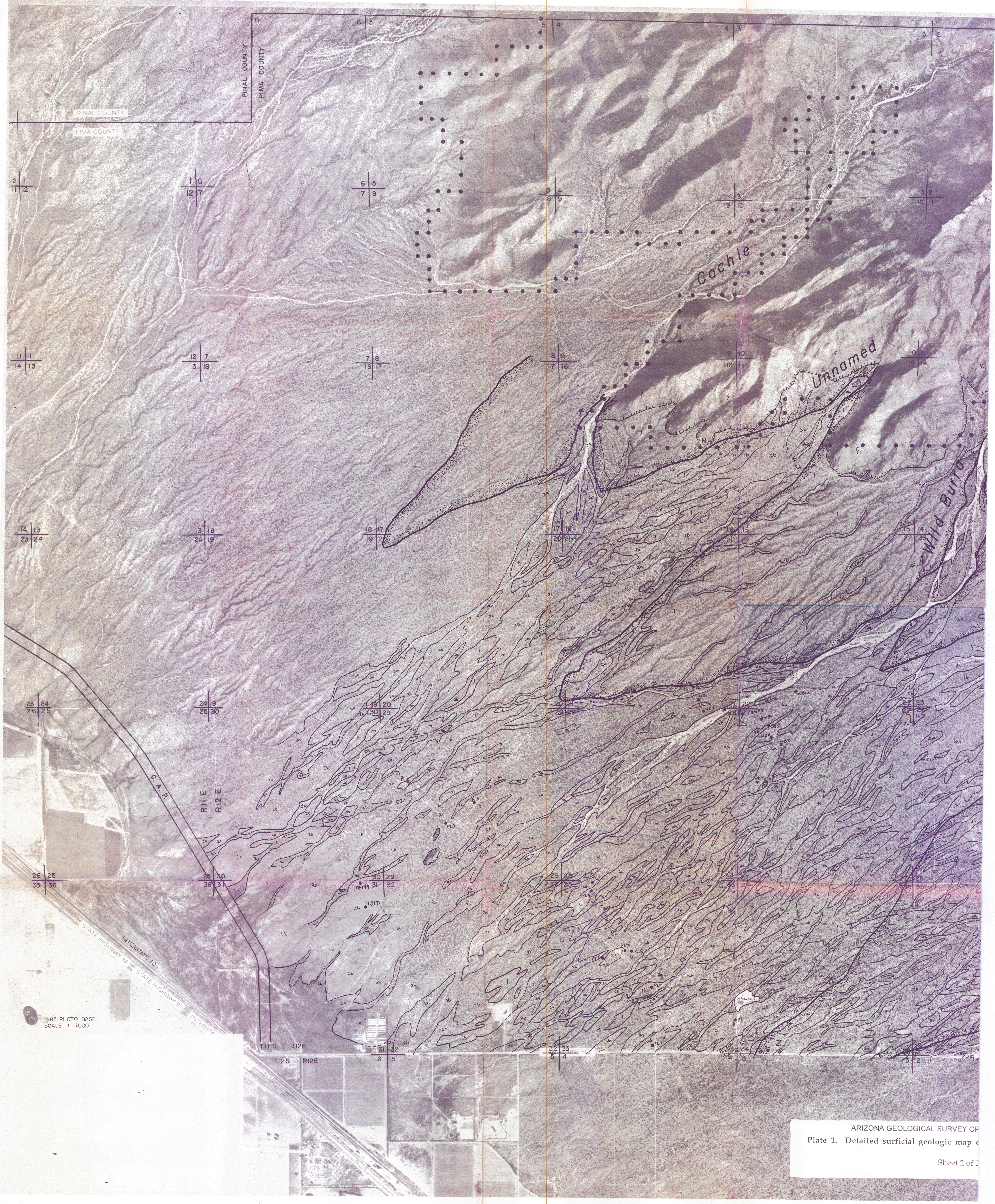
Scale: 1:12,000
(1 inch = 1000 feet)

Plate 1. Detailed surficial geologic map of the southern Tortolita piedmont.

Sheet 1 of 2

ARIZONA GEOLOGICAL SURVEY OPEN-FILE REPORT 91-11

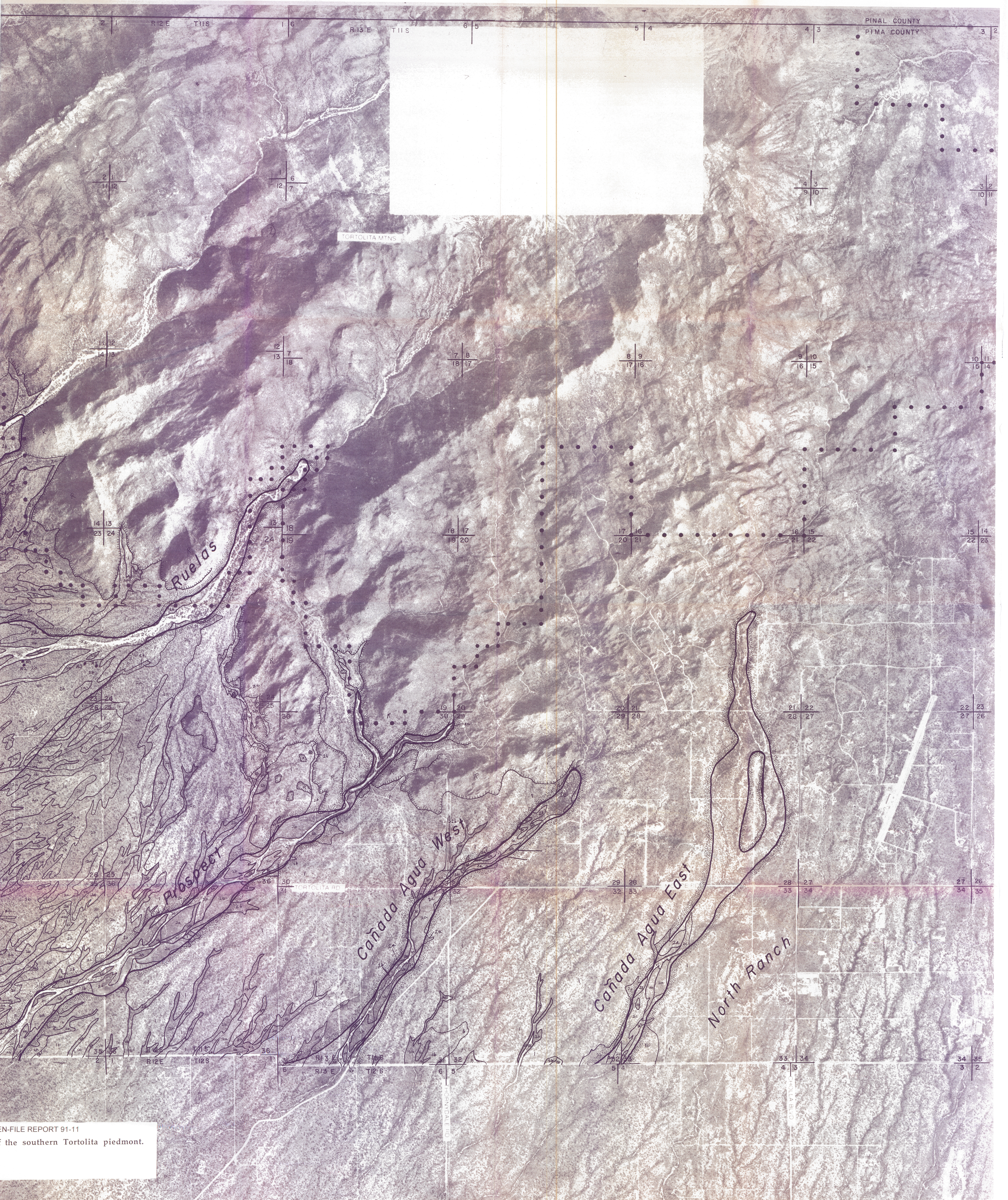

Cañada Agua West
Cañada Agua East
North Ranch
NARANJA DR.
LAMBERT LANE
OVERTON
CORTARO FARMS RD
MAGEE RD
T12S R12E
T12S R13E



ARIZONA GEOLOGICAL SURVEY OF

Plate 1. Detailed surficial geologic map o

Sheet 2 of 2



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f the southern Tortolita piedmont.