Surficial Geology of the Santan Mountains Piedmont Area, Northern Pinal and Eastern Maricopa County Area, Arizona.

by

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Arizona Geological Survey
Open-File Report 94-7

May, 1994

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

INTRODUCTION

The National Geologic Mapping Act of 1992 was established in response to the recent decline in geologic mapping activities. Approximately 75% of the United States remains unmapped or is mapped only at small scales with limited detail (Molnia, 1992). This new mapping initiative seeks to reinvigorate the investigation of bedrock and initiate a systematic investigation of unconsolidated surficial materials. Mapping of unconsolidated surficial materials has often been neglected in the past despite the fact that many areas -- including most of southern Arizona -- are dominated by unconsolidated materials at the surface. Because Arizona is one of the fastest growing states in the nation, and most of the recent urban development is on unconsolidated deposits, there is a need for detailed information on the region's surficial geology.

With recent developments in relative and numerical age-dating of soils and surficial deposits (Bull, 1991), it is now possible to distinguish several different types of surficial deposits based on age and origin. Such information has both basic and applied scientific value. An improved understanding of landform age has direct relevance to assessing surface stability, e.g., Pleistocene surfaces are not naturally prone to flooding hazards (Pearthree, 1991). Also, geomorphic chronologies provide a temporal framework for determining the context of and potential for buried cultural resources (Davidson, 1985). In addition to landform age, surficial geologic mapping describes the character of surficial deposits (e.g., grain size and soil development) that can be used to analyze soil engineering properties and to help determine potential sites for industrial mineral extraction and groundwater recharge. In sum, surficial geologic maps provide baseline data for making resource management and land-use decisions (see Fleisher, 1984) as well as provide earth scientists insight into late-Cenozoic landscape evolution.

This report presents the results of surficial geologic mapping of the Chandler Heights and Sacaton NE, 7.5-minute quadrangles located in the Santan Mountain piedmont area (herein referred to as Santan Piedmont) southeast of the Phoenix metropolitan area (Figure 1). Adjacent 7.5-minute quadrangles located to the east (Magma), south (Blackwater and Sacaton), and west (Gila Butte) have been previously mapped (Huckleberry 1993b, 1992). Most of the southern part of the Chandler Heights and Sacaton NE quadrangles is undeveloped and under the jurisdiction of the Gila River Indian Community and Bureau of Land Management; smaller areas are under private ownership and consist of low density housing. Most of the northern part of the Chandler Heights and Sacaton NE quadrangles is agriculturally developed and privately owned and includes the communities of Chandler Heights and Queen Creek. Most of the geologic materials within the project area are composed of deposits derived from the Santan Mountains except in the extreme northern and eastern portions where sediments are derived from the Superstition Mountains area (see Huckleberry, 1993b).

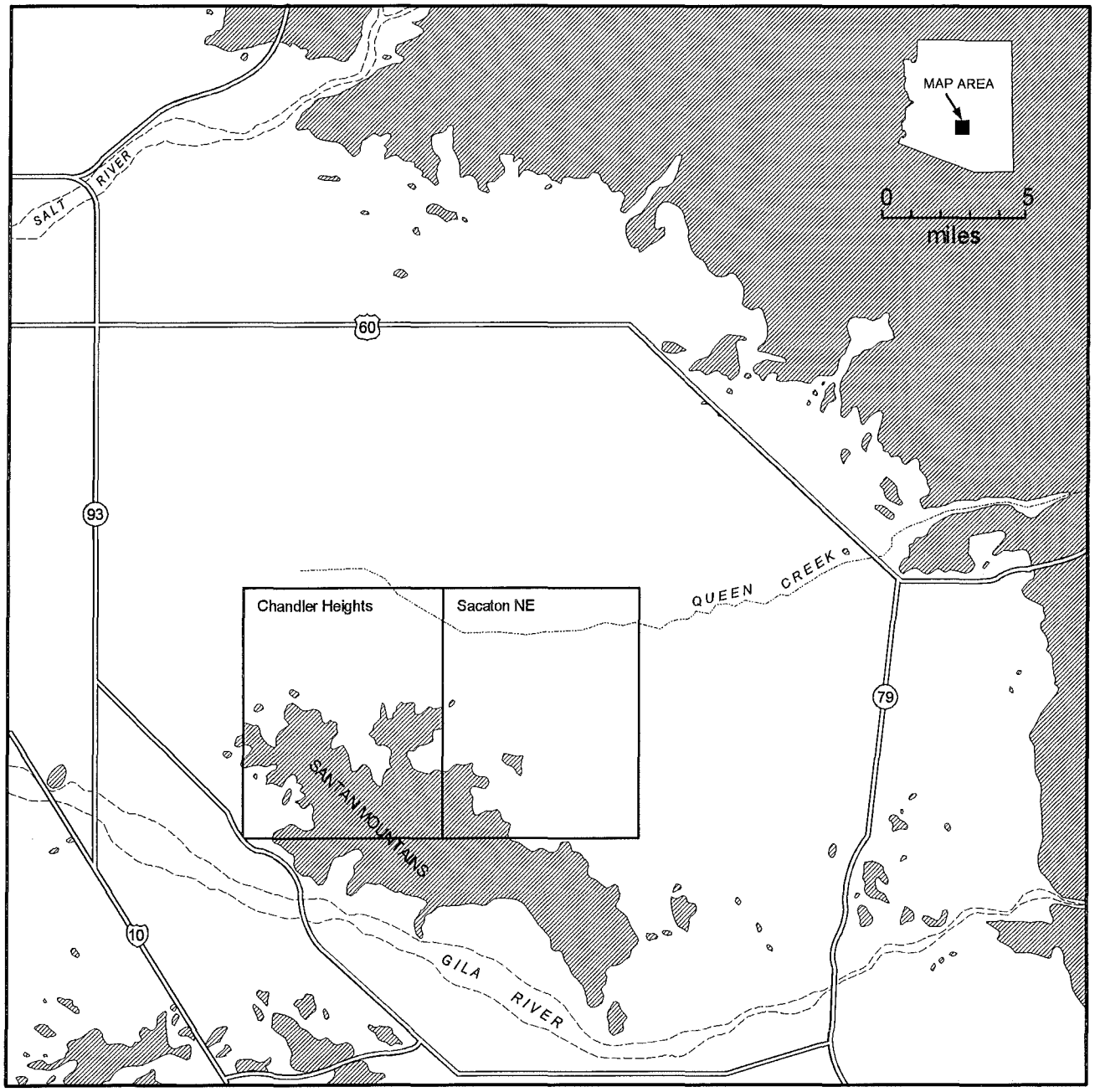

Figure 1. Eastern Phoenix Basin area and Chandler Heights and Sacaton NE quadrangle locations.

METHODS

The guiding principle behind surficial geologic mapping is that that different landforms and associated unconsolidated deposits can be distinguished and mapped based on age and genesis. In this region surficial deposits comprise landforms such as alluvial fans, pediments, and stream terraces. Most of these surfaces are Quaternary in age and have been previously lumped into one category "Qal" in earlier geologic maps. However, most of these deposits can be subdivided based on age. Criteria for relative dating geologic surfaces include:

- **topographic position** (higher surfaces are generally older)
- **degree of dissection** (older surfaces tend to be more incised by streams)
- **bar and swale topography** (younger surfaces have better preserved gravel bars and adjacent swales)
- **pavement and varnish development** (moderately old surfaces tend to have well-developed varnished pavements)
- **soil development** (older soils generally have better developed morphologic features)

These criteria provide a reliable framework for distinguishing different aged surfaces, but there can be problems if too much emphasis is placed on any one criterion. For example, soil development may not increase uniformily through time; very old soils may be degraded resulting in less-developed profiles than younger soils (Huckleberry, 1993a; Johnson et al., 1990). Moreover, soil morphology can vary substantially on isochronous surfaces due to subtle microenvironmental differences (Harrison et al., 1994), and thus one soil profile might not be representative of a given surface. Also, desert pavement and rock varnish development can be affected by processes other than time, and the oldest surfaces usually do not have the best developed pavements (see below). Consequently, relative age-estimates are most reliable when based on multiple lines of supporting evidence.

Surficial deposits in the Santan Piedmont were distinguished and mapped in four phases. The first phase involved analysis of aerial photographs and geologic maps. Black and white stereopairs at 1:20,000 and 1:60,000 scales were used to distinguish different surfaces based on surface texture, albedo, and topography. Bedrock maps of the area (Balla, 1972; Wilson and Moore, 1959) were analyzed to help delineate bedrock outcrops. Zones of ground fissures produced from groundwater withdrawal and hydrocompaction were traced from maps on file at the Arizona Geological Survey and superposed onto the surficial geologic units. The second phase involved ground reconnaissance and close inspection of surface characterstics. Phase three involved the

excavation of soil pits into selected surfaces on state land. Previous soil maps (Adams, 1974; Camp, 1986) were consulted for areas that were not accessable for excavation or ground reconnaissance. The fourth phase involved the assignment of map units based on correlation to previously defined surfaces in adjacent mapped areas (Huckleberry, 1993b, 1992).

GEOMORPHIC SETTING

The Santan Mountains are a small mountain range located within the southeastern part of the Phoenix Basin (Péwé, 1978; Figure 1). The Santan Mountains *sensu stricto* consist of a group of relatively higher peaks located in the Chandler Heights quadrangle. Some of the other bedrock masses are also specifically named, e.g., the Malpais Hills (Figure 2). Most of the bedrock exposed in the project area are granite and schist. Rhyolitic volcanics are also exposed in the northern end of the Malpais Hills and in localized areas of thin dikes. The landscape is typical central Arizona basin and range country characterized by eroded mountains rising less than 1,000 m above surrounding alluvial basins. The Sacaton Mountains are bounded by the Higley Basin on the north and the Picacho Basin on the south, two deep structural basins containing thick late-Cenozoic terrestrial sediments (Scarborough and Pierce, 1978). The Gila River flows along the southern margin of the Santan Mountains outside the project area, and a series of ephemeral streams drain the northern slopes of the Santan Piedmont.

Much of the modern regional topography originated with the Basin and Range disturbance, a period of regional extension between 8 and 15 Ma[1] that resulted in a series of normal fault-block mountains and basins (Damon et al., 1984; Shafiqullah et al., 1980). This period of tectonic activity ceased approximately 5 Ma and was followed by a period of tectonic quiescence during which a series of alluvial fans and pediments formed along the margins of the ranges. Both alluvial fan and pediment formation is linked to alternating periods of weathering and erosion during the climatic oscillations of the last 2 My (Bull, 1991; Melton, 1965). Although it is generally agreed that fluctuating Quaternary climate is primarily responsible for the series of different-aged geologic surfaces, the exact relationship between climate and denudation is still debated. Most of the Pleistocene fan deposits occur at the surface near the base of the mountain front, whereas Holocene deposits dominate the middle piedmont and basin floor along Queen Creek and Sonoqui Wash (Figure 3).

The Santan Mountains are deeply embayed with pediments that are best formed in granite but also occur in schist. Pediment size, as defined by the distance between the range-bounding fault and mountain front varies across the piedmont and is usually difficult to define because the range-bounding fault is buried by alluvium. However, earth fissures have developed within the Santan Piedmont in the Chandler Heights area due to groundwater withdrawal and hydrocompaction (Péwé and others, 1987; Raymond and others, 1978). In places, the water table has dropped 90-150 m (300-500 feet)

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

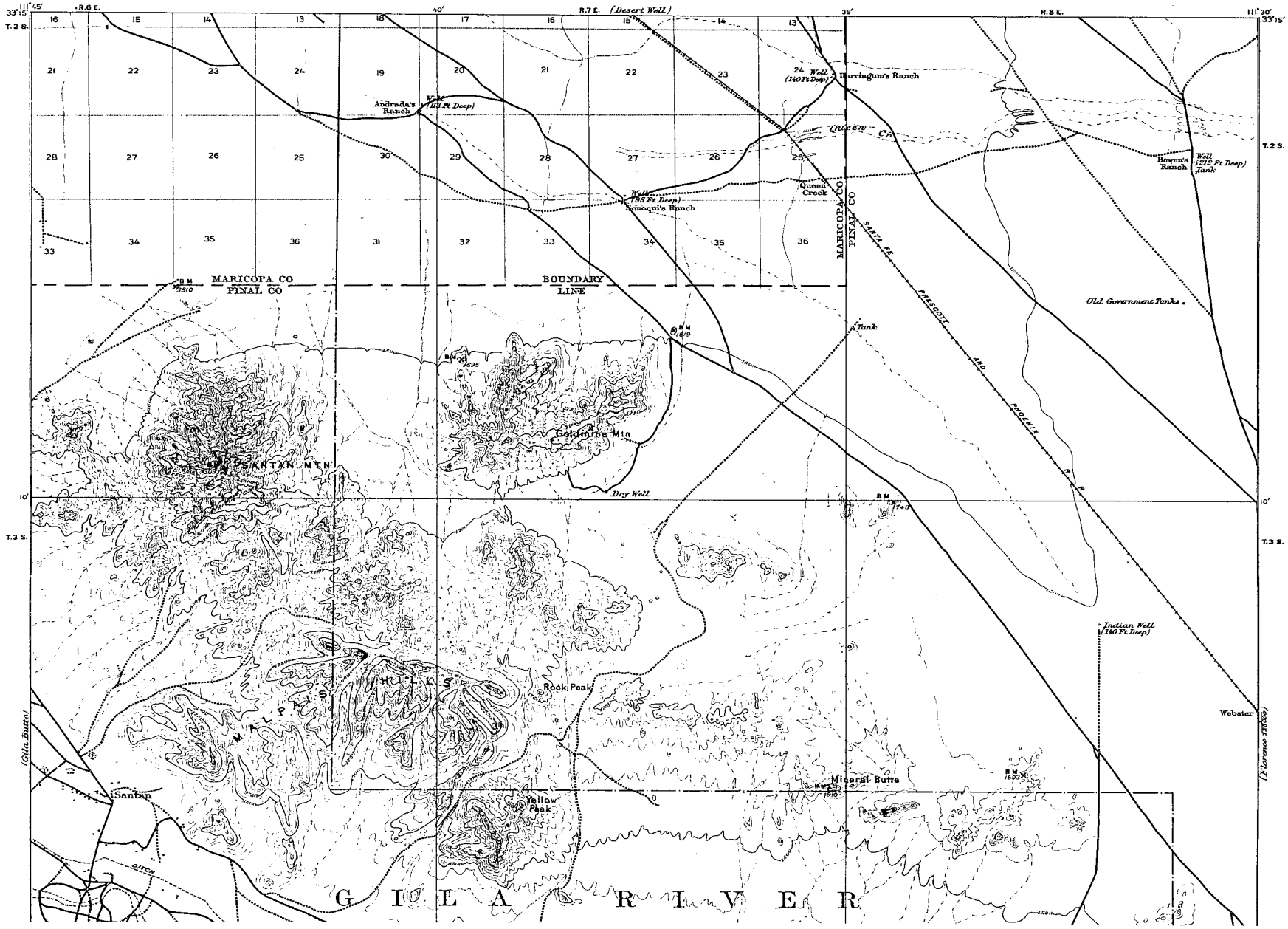

Figure 2. Northern portion of the 1907 Sacaton 15' quadrangle.

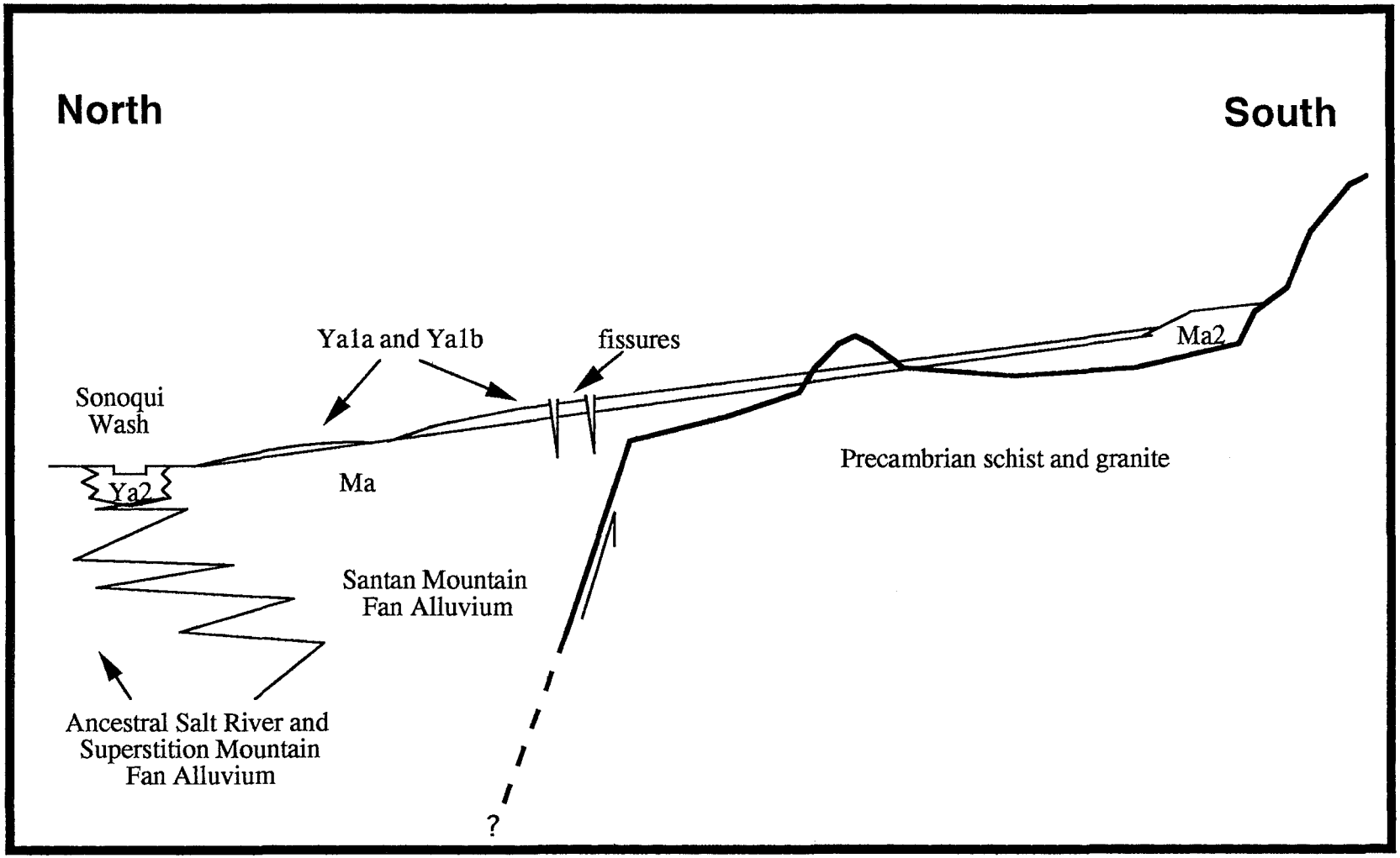

Figure 3. Schematic cross-section of northern Santan Piedmont.

(Schumann and Genualdi, 1986). The resulting fissures are probably clustered above or near the range-bounding fault as differential compaction above steeply sloping bedrock results in horizontal and vertical strain within the basin fill (Holzer and Pampeyan, 1981). If the earth fissures mark the location of the range-bounding fault, then the mountain scarp has retreated up to 8 km upslope from Chandler Heights. Assuming a pedimentation rate of 1 km/ 1 My (Damon et al., 1984), this suggests that the Santan Mountains have been tectonically stable for approximately 8 My.

SOILS TERMINOLOGY

Soils are becoming increasingly useful tools for distinguishing temporally discrete geologic surfaces (Birkeland et al., 1990; Huckleberry, 1993a). Certain standard terminology is used to describe soil morphology and horizonation. Select Santan Piedmont soils were described in the field following the guidelines of the U.S. Department of Agriculture (Guthrie and Witty, 1981; U.S. Soil Survey Staff, 1951) and are presented in Appendix A. These soils were classified at the Great Group level of the 7th Approximation soil taxonomic system (Soil Survey Staff, 1975). Calcium carbonate development is described using the morphological system of Machette (1985).

MAP UNITS

A tripartite system adopted in previous Arizona surficial geologic maps is used for the Santan Piedmont area. Surfaces are distinguished into three primary temporal groups: **Y** (young), **M** (middle or intermediate), and **O** (old). A lower case "**a**" following these primary symbols denotes alluvial fan surfaces, whereas a lower case "**p**" denotes a pediment. Bedrock outcrops are denoted by "**b**". In most undisturbed areas, surfaces are subdivided (e.g., Ma1 and Ma2) based on differences in topography and weathering. Tertiary subdivisions (e.g., Ya1a and Ya1b) are used where similar surfaces are distinguishable by relative height or stream dissection. In disturbed areas or areas lacking diagnostic surface characteristics, it may only be possible to distinguish geologic surfaces at the primary level (e.g., Ya), or they may be grouped into associations (e.g., Ma2/Ya). Distinct boundaries between different surfaces are marked by a solid line, whereas gradual boundaries are marked by a dashed line. A dotted line demarcates agricultural field boundaries or other disturbed areas.

Ya2

Modern stream channels and associated alluvium are mapped as Ya2 (Table 1). These channels only convey streamflow during or immediately following heavy rains. In the upper piedmont, the channels are well defined with steep banks, but in the lower piedmont, the channels are less incised and often interconnect forming distributary drainage patterns. Desert plants such as ironwood (*Olneya*) and

Table 1. Physical characteristics and age estimates of Santan Piedmont geological surfaces.

Surface	Stream Dissection	Soil Horizons	Maximum Carbonate Stage	Pavement and Varnish Development	Surface Age	Correlative Surface (Bull, 1991)	Representative Description
Ya2	-	C	0	none	modern	Q4b	-
Ya2'	-	C	0	none	historic to modern	Q4b	-
Ya1	> 1m	Bw, Bk, CBk, C	I	none	< 10 ka	Q4a	DW9a[1]
Ya1a	< 1m	Bw, Bk, CBk, C	I	none	< 1 ka	Q4a	-
Ya1b	> 1m	Bw, Bk, CBk, C	I	none	1-10 ka	Q3b, Q3c	SNE1, SNE2, SNE3
Ya	-	Bw, Bk, CBk, C	I	none	< 10 ka	-	-
Ma2	1-4 m	Av, Bk, Bt	III	weak-moderate	10-100 ka	Q2c, Q2b	SNE5
Ma2/Ya	-	Av, Bw, Bk, Bt, CBk, C	III	disturbed	< 100 ka	-	-
Ma1	> 2m	Av, Bt, Bk, Bkm, Bkqm	IV	poor-strong	100-500 ka	Q2a	SP-11[1]
Op	> 1m	Bt, Bk, Bkm, Bkqm	IV+	none	> 1 Ma	-	-

[1] Soil profile located outside project area.

palo verde (*Cercidium*) are common along the drainages in the upper piedmont. Alluvium within these channels ranges in thickness from less than 10 cm to over 2 m and is highly permeable. In the upper piedmont, alluvial grain sizes are predominantly cobbles, pebbles, gravels, and coarse sands; in the lower piedmont, alluvial grain sizes tend to be granules and fine sand. Ya2 sediments are modern in age and lack soil formation. Ya2 surfaces correlate to Bull's (1991) Q4b surface.

Ya2'

Ephemeral stream channels on the lower piedmont that have been obscured by agriculture are mapped as Ya2'. These former channels are identified by broad swales and sandy Torrifluvent soils (Adams, 1974; Table 2), and their boundaries are estimated by dashed lines. Ya2' surfaces are seldom inundated today due to flood control features but are nonetheless still prone to flooding under conditions of rare, high intesity or prolonged rainfall. The two largest Ya2' channels are Queen Creek and Sonoqui Wash (see below). Ya2' sediments are historic to modern in age (Table 1).

Ya1

Holocene alluvial fan surfaces are mapped as Ya1. These surfaces are mapped only in the northeastern corner of the Sacaton NE quadrangle where they are continuous with fan surfaces on the Superstition Mountain Piedmont (Huckleberry, 1993a). In the Santan Piedmont, Ya1 surfaces are subdivided into Ya1a and Ya1b based on stream dissection (see below). Ya1 surfaces are dissected > 1 m by streams including Queen Creek (Table 1). Alluvial grain sizes range from cobbles to fine sand. Ya1 surfaces contain relatively immature soils with weakly developed B horizons that are slightly oxidized, slightly enriched in silts and clays near the surface, and slightly calcified with a maximum Stage I+ carbonate morphology. Ya1 soils generally classify as Torrifluvents and Camborthids (Soil Survey Staff, 1975; Table 2). Some Ya1 soils classify as Haplargids, but this occurs only where Holocene alluvium overlies an older Pleistocene soil within 50 cm of the surface. Ya1 soils tend to be highly permeable except where they overlie older argillic horizons. Ya1 surfaces are Holocene in age and correlate to Q4a and Q3 surfaces along the lower Colorado River Valley (Bull, 1991).

Ya1a

Ya1a surfaces are younger Ya1 surfaces that are common on the lower Santan Piedmont in active fan areas. These surfaces are adjacent to shallow, distributary drainages and are prone to periodic sheetflow and overbank flow. Ya1a deposits consist of relatively poorly sorted gravels and sands, and bar and swale topography is well preserved. Ya1a soils classify as Torrifluvents (Soil Survey Staff, 1975; Table 2) and are highly permeable. Ya1a surfaces correlate to Bull's (1991) Q4a surface, and is age estimated at < 1 ka (Table 1).

Ya1b

Ya1b surfaces are the older Ya1 surfaces that are common on the middle parts of the piedmont. Channels tend to be more incised and form dendritic drainage patterns (Table 1). Ya1b surfaces are still subject to periodic overbank flow during large,

Table 2. Common geologic surface and soil associations in the Santan Piedmont area.

GEOLOGIC SURFACE	SOIL SERIES (ADAMS, 1974; CAMP, 1986)	SOIL CLASSIFICATION
Ya2	Alluvial land & gravelly alluvial land	-
Ya2'	Agualt fine sandy loam and loam	Typic Torrifluvent
	Carrizo fine sandy loam and gravelly loamy sand	Typic Torriorthent
	Gilman fine sandy loam	Typic Torrifluvent
	Vint loamy fine sand	Typic Torrifluvent
Ya1 (Ya1a, Ya1b)	Antho sandy loam and gravelly sandy loam	Typic Torrifluvent
	Carrizo very gravelly coarse sand	Typic Torriorthent
	Denure gravelly coarse sandy loam	Typic Camborthid
	Estrella loam	Typic Torrifluvent
	Gilman loam and fine sandy loam	Typic Torrifluvent
	Mohall sandy loam	Typic Haplargid
	Momoli cobbly sandy loam	Typic Camborthid
	Pahaka loam	Typic Camborthid
Ma2	Cristobal very gravelly loam	Typic Haplargid
	Gunsight very gravelly loam	Typic Calciorthid
	Laveen loam and clay loam	Typic Calciorthid
	Mohall sandy loam	Typic Haplargid
	Pinamt very gravelly loam	Typic Haplargid
	Rillito gravelly loam	Typic Calciorthid
	Tremant gravelly loam	Typic Haplargid
Ma2/Ya	Redun fine sandy loam	Natric Camborthid
	Shontik fine sandy loam	Natric Camborthid
Ma1	Cavelt gravelly loam	Typic Paleorthid
Op	Cavelt gravelly loam	Typic Paleorthid
	Pinamt very gravelly loam	Typic Haplargid

relatively rare rainfall events. Ya1b deposits are stratified and poorly sorted with grain sizes ranging from cobbles to fine sand. Bar and swale topography is well preserved on the upper piedmont. Soils mostly classify as Torrifluvents except where Ya1b alluvium overlies shallow Pleistocene soils whre they classify as Haplargids (Soil Survey Staff, 1975; Table 2). Ya1b surfaces correlate to Bull's (1991) Q3c and Q3b surfaces and are age estimated at 1-10 ka.

Ya

Ya surfaces (undivided Ya1 and Ya2; see Table 1) occur in agriculturally disturbed areas on the active portions of alluvial fans where plowing has obscured the boundaries between Ya1 and Ya2 surfaces.

Ma2

Ma2 surfaces are older fan surfaces located in the upper piedmont area. These surfaces are dissected 1-4 m, and the interfluves commonly contain varnished desert pavements (Table 1). The pavements consist mostly of quartz and schist clasts, and are best preserved on western piedmont slopes in the Gila River Indian Community. Bar and swale topography is present but subdued on Ma2 surfaces. Alluvial grain sizes range from boulders near the mountain front to sands and gravels farther downslope. Soils are strongly developed with argillic horizons with sandy clay textures commonly overlying calcic horizons. These deposits tend not to be very permeable due to the strongly developed argillic and calcic soils. In places, the argillic horizon has been eroded leaving the calcic horizon near the surface. Elsewhere, Ma2 soils overlie older petrocalcic at depths ranging 2 to 5+ m as exposed in stream cuts near the mountain front. Overall, Ma2 soils contain the most variable soil morphology of all of the geologic surfaces (Huckleberry, 1993b) and include seven different soil series (Table 2). Ma2 surfaces correlate to Bulls' (1991) Q3a or Q2c surfaces and are age estimated at 10-100 ka. This age estimate is greater than previously proposed for Ma2 surfaces in a previous study of the southern Santan Piedmont (Huckleberry, 1992). The revision is based on the recognition of greater soil variability on Ma2 surfaces, including morphological properties indicative of greater antiquity (Huckleberry, 1993b).

Ma2/Ya

Ma2/Ya surfaces (Table 1) occur in agriculturally disturbed areas where plowing has obscured surface characteristics and topographic relationships. In the Gila River Indian Community, many of these soils classify as Natric Camborthids (Camp, 1986; Table 2) indicating previous shallow water tables and subsequent high sodium content.

Ma1

Ma1 surfaces are the oldest fan surfaces within the project area. These fans are generally located in the upper piedmont and are greatly dissected (Table 1) into a series of rounded ridges yielding a ballena topography (Christensen and Purcell, 1985). Little if any bar and swale topography remains on the surface. Desert pavements vary from strongly developed to absent due to surface erosion. Most of the clasts at the surface consist of fine-grained volcanics and quartz; granite boulders tend to be planated and

concordant with the surface. Petrocalcic fragments are common at the surface. Mal deposits are poorly sorted with grain sizes ranging from boulders to sand, and tend to have low permeability due to plugged soil horizons. Mal soils are characterized by near surface or buried petrocalcic horizons (Stage IV+) with differentially preserved argillic horizons; these soils are relatively impervious.. Although Mal soils in the Superstition Mountain Piedmont classify as Haplargids (Huckleberry, 1993), Mal soils in the Santan Piedmont tend to classify as Paleorthids (Table 2) indicating that the argillic horizon has been eroded. Mal surfaces correlate to Bull's (1991) Q2a surface and is age estimated at 100-500 ka.

Op

Pediment surfaces are mapped as Op. Unlike the other geologic surfaces that are depositional landforms, pediments are erosional surfaces, and it is common for soils to be poorly preserved or absent. Where poorly preserved, Op soils often consist only of truncated petrocalcic horizonsand classify as Paleorthids (Table 1). Where the pediment contains a continuous veneer of alluvium and soils are relatively well preserved, soils classify as Haplargids (Table 2). Because these surfaces tend to be formed in granite, surface clasts tend to consist of fine gravel and granule size materials. These surfaces tend not to develop bar and swale topography or varnished pavements. Op surfaces correlate to Oap surfaces mapped in the southern piedmont (Huckleberry, 1992) are probably greater than 1 My old.

QUEEN CREEK AND SONOQUI WASH

The two largest drainages transecting the Chandler Heights and Sacaton NE quadrangles are Queen Creek and Sonoqui Wash. These two streams were noticeable features of the landscape before being channelized, diverted, or leveled for agriculture. Queen Creek is the larger ephemeral stream originating in the mountains to the east with a catchment area of 497 km^2 (191 mi^2) (Figure 1). Sonoqui Wash drains a smaller area on the northern and eastern slopes of the Santan Piedmont but is also supplied by runoff from the lower Superstition Mountain Piedmont. Both streams represent complex ephemeral fluvial systems prone to spatial shifts in channel location. Although Queen Creek and Sonoqui Wash have been drastically transformed by agriculture and flood mitigation projects, both streams are still a source of potential agricultural and urban flooding.

Before agricultural development, much of the eastern Phoenix Basin consisted of a broad desert floor transected by a series of interconnecting desert washes (Davis, 1897). Most of this predevelopment landscape is recorded in historical survey notes and plats and early irrigation maps[2]. Queen Creek consisted of channelized and alluvial fan reaches that were well known for periodic flooding (Graf, 1988). The channelized reach extended from the Superstition Mountains to a point somewhere within the Chandler Heights quadrangle. Lee (1905) noted that the Queen Creek channel was traceable to

[2]Historical General Land Office survey notes and plats are on file at the Bureau of Land Management, Phoenix. Early irrigation maps are on file at the Bureau of Reclamation, Phoenix.

"Andrade's" Well, which on the 1907 15' U.S. Geological Survey Sacaton quadrangle is located at "Andrada's" Ranch in the southwest corner of Sec. 20, T. 2 S., R. 7 E. (Figure 2). However the same map shows the Queen Creek channel ending in the center of Sec. 27 approximately 4 km east of the ranch. The channelized reach of Queen Creek seasonally supported streamflow that usually disappeared into the subsurface before reaching the alluvial fan portion of the system. Prehistorically, seasonal flow was reliable and large enough on Queen Creek for the Hohokam to construct irrigation canals (Crown, 1984; Dart, 1989). Several large prehistoric canals diverge from Queen Creek upstream from the project area but extend into the northeastern part of the Sacaton NE quadrangle.

The alluvial fan reach of Queen Creek consisted of a series of branching shallow channels (Graf, 1988; Turney, 1929:55). Periodic floods reached this area and became unconfined and spread laterally over large areas. This unconfined flow would eventually concentrate into downslope swales and channels and become confined again. During rare periods of large discharge, water would reach all the way to the Gila River downstream from Sacaton (Davis, 1897). This sequence of alternating channel and fan reaches is characteristic of discontinuous ephemeral streams (Huckleberry, 1993b; Packard, 1974). Discontinuous ephemeral streams are unstable fluvial systems characterized by spatially shifting flow transitions (e.g., channelized to unconfined flow). Channel avulsions are common either through upslope stream capture or aggradation-forced channel abandonment. Thus, although the apex of the Queen Creek fan was historically located near Andrade's Well, prehistorically it shifted up and downstream from that point.

Although most of the Queen Creek fan channels have long since been effaced by agriculture and are not easily recognizeable on aerial photography, many can be distinguished on historical and modern soil maps (e.g., Harper et al., 1926; Adams, 1974). These channels are delineated by ribbons of sandy soils (Figure 4) and are the basis for mapping the Ya2' surfaces. One particularly distinct ribbon of sandy soil extends along the northern edge of the Chandler Heights and Gila Butte quadrangles and is interpreted as a Queen Creek paleochannel (Huckleberry, 1992). Most of the Queen Creek fan system and associated channels are Holocene in age as suggested by immature Torrifluvent soils. There are, however, older Pleistocene soils with argillic horizons on the Queen Creek fan, and Pleistocene fauna have been found in some of the Queen Creek deposits near the surface (Péwé et al., 1986). It appears that the Holocene sediments form a thin and discontinuous veneer over older Pleistocene deposits resulting in complex, interfingering areas of Pleistocene and Holocene soils. Turney (1929:57) believed that much of the sandy (Holocene) alluvium at the surface in this area had been eroded since the end of Hohokam time (A.D. 1450) based on frequent exposures of argillic horizons at the surface and a paucity of Hohokam artifacts.

Sonoqui Wash is a smaller fluvial system that today is hardly noticeable at the surface. In fact, the only remnant of this ephemeral stream at the surface today is a short entrenched reach located between the communities of Chandler Heights and Queen Creek. Sonoqui Wash contains a smaller catchment area than Queen Creek and thus

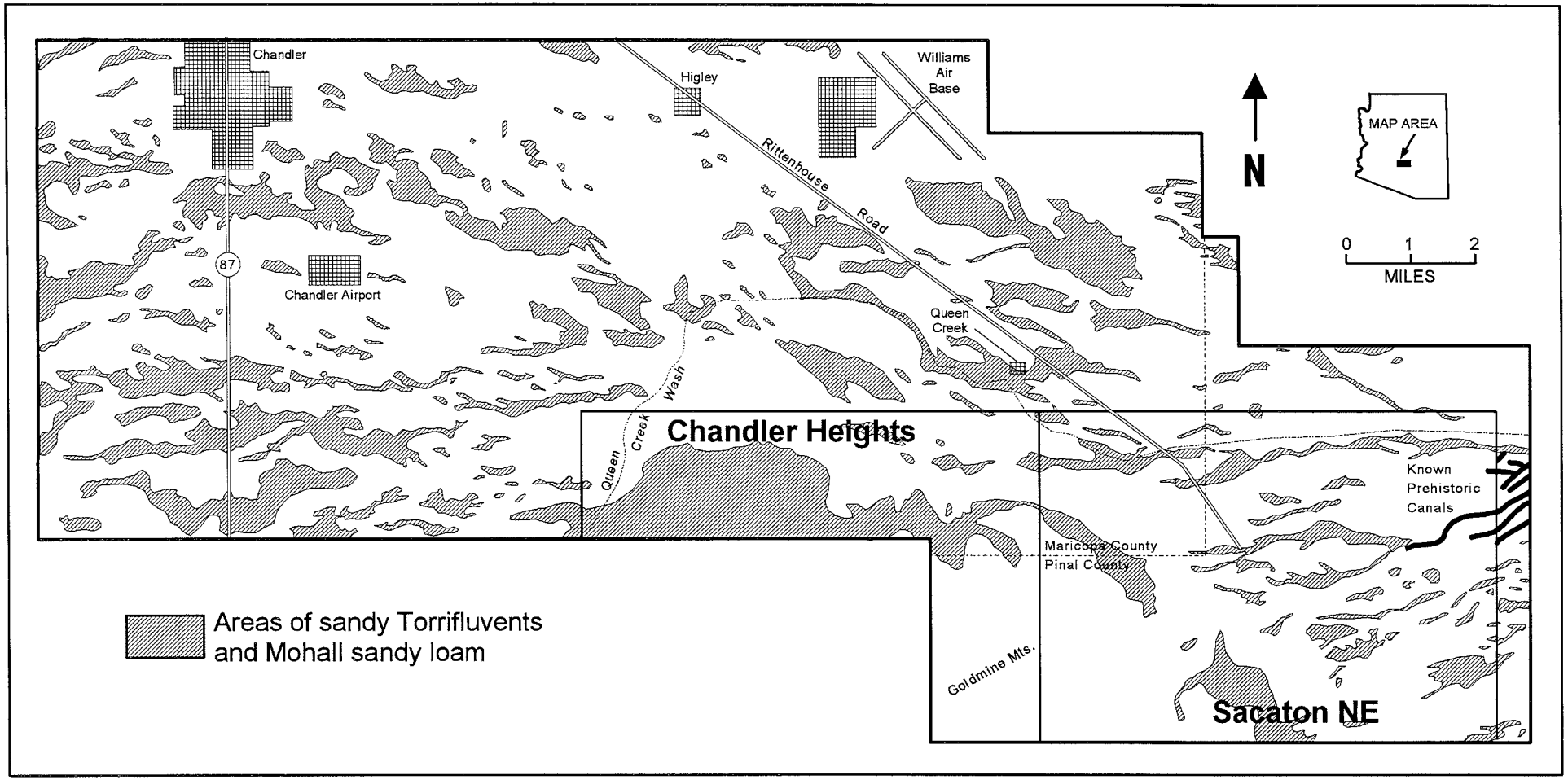

Figure 4. Distribution of sandy soils representing Holocene alluvial deposits associated with the Queen Creek and Sonoqui Wash fan systems (adapted from Dart, 1989: Figure 8).

supports smaller and less frequent streamflow. Despite the smaller size of this system, the channel is still prone to instability as evidenced by the incised relict segment that has experienced considerable bank cutting during the last 50 years.

Both Queen Creek and Sonoqui Wash contain a modern hydraulic geometry that is drastically different from their natural state. Several shallow, interconnecting channels have been replaced by a single artificial channel that containing several sharp bends. Because arid-region streams develop a natural geometry adjusted to discharge, sediment load, and flood history, deviations from the natural hydraulic geometry usually result in channel instability as the stream tries to regain its natural form (Rhoads, 1991; Schumm, 1984). This is commonly accomplished through erosion of the confining structures built for flood protection. Consequently, a potential for flood damage exists through bank cutting and inundation as was demonstrated by the floods of 1978, 1980, and 1983 (Graf, 1988). Moreover, the potential for increased future flooding may be favored by recent climatic trends characterized by increased incursions of subtropical moisture (Webb and Betancourt, 1992).

DESERT PAVEMENTS

As previously mentioned, one of the criteria used in distinguishing different aged geologic surfaces is the degree of desert pavement development (Bull, 1991; Christensen and Purcell, 1985). The degree of desert pavements is usually defined by two characteristics: the percentage of surface covered by an interlocking armor of clasts, and the darkness of varnish on the clasts. The mechanisms that produce the interlocking armor are still debated amongst earth scientists (e.g., Denny, 1965; McFadden et al., 1989; Wells et al., 1994), and it may be that processes of desert pavement genesis vary between different environments (Bull, 1991). The mechanisms of desert varnish development are also unclear although it does appear to be a biophysical accretionary process with a product that increases in thickness with time (Dorn, 1991). In the Phoenix Basin older geologic surfaces tend to have better developed desert pavements with darker varnish, but the oldest surfaces seldom contain well preserved desert pavements. Moreover, desert pavement formation can vary considerably amongst penecontemporaneous surfaces suggesting that nontemporal processes affect desert pavement formation and have to be considered in surficial geologic mapping.

Three major age groups of alluvial fans are recgonized in the eastern Phoenix Basin: Ya (Holocene), Ma (late Pleistocene), and Oa (early-middle Pleistocene). Overall, desert pavements are not common on Ya surfaces but can be well preserved on Ma surfaces, and they are generally not well preserved on Oa surfaces (Figure 5). This nonlinear relationship between desert pavement formation and time reflects intrinsic processes of geologic surface formation, stability, and eventual destruction. Although older Ya1 surfaces may contain weakly varnished pavements, Ya surfaces generally have not been stable for a sufficient length of time for the original bar and swale topography to be smoothed and the surface armor to concentrate. In contrast, Ma surfaces contain constructional surfaces that have been stable for over at least 10 ky, and these surfaces

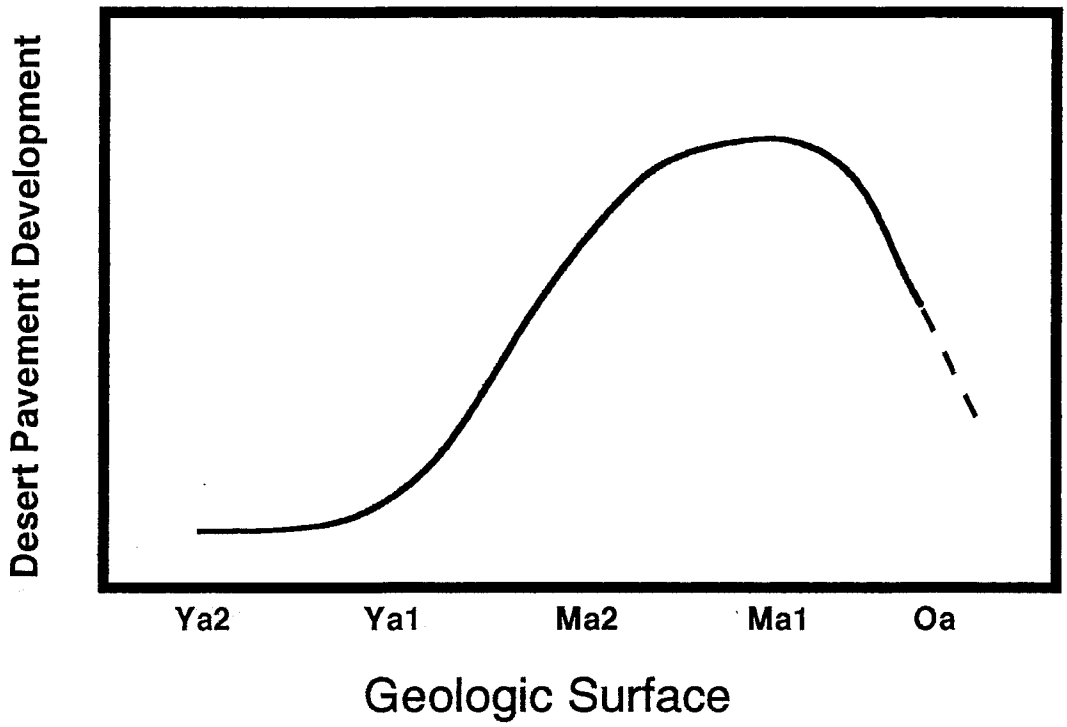

Figure 5. Trends in desert pavement formation on different geologic surfaces.

tend to be relatively smooth with clasts containing dark black varnish. These surfaces are self-enhancing in that once smoothed, subsequent eolian and fluvial processes help to maintain surface form (Bull, 1991). Eventually, however, these surfaces are attacked by fluvial processes that incise into the constructional surface and destroy pavement form. As a result, Oa surfaces seldom contain well preserved pavements. Thus desert pavements fail to achieve long-term equilibrium due to intrinsic degradational processes.

In addition to time, lithology and climate affect desert pavement formation (Bull, 1991). Alluvial fans derived from granitic source areas seldom contain well developed pavements due to the erodible nature of the lithology. Granitic clasts tend to break down rapidly into granule-sized grus preventing the formation of a varnished armor. Lithologies that are more likely to be stable in desert pavements include most volcanic rocks (e.g., basalt, andesite, and rhyolite), siliceous rocks (chert and quartzite), and foliated rocks (schist and gneiss). In the Santan Mountains, schist tends to spall along foliation planes and produce platy fragments conducive to producing good pavements.

In the eastern Phoenix Basin, desert pavements are noticeably absent on higher elevation surfaces located to the east in the Superstition Mountain Piedmont (Huckleberry, 1993b). Desert pavement formation also tends to be spatially variable in the Santan Mountains: given comparable lithologies, desert pavements are best preserved on the western side of the range in the Gila River Indian Community. The reason for this discrepancy is not clear, but vegetation may be a factor. The eastern margin of the Phoenix Basin contains a vegetation complex referred to as the Upper Sonoran Desert biome (Brown, 1982). The central and western parts of the Phoenix Basin is dominated by the Lower Sonoran Desert biome. One important difference between these two vegetation communities is the greater biomass and predominance of large tree and cactus species such as palo verde (*Cercidium*), ironwood (*Olneya*), and saguaro (*Cereus*) in the Upper Sonoran Desert biome. In the Lower Sonoran Desert biome, these species occur in lesser abundance and tend to be concentrated along drainages. The greater number of larger woody species results in greater root disturbances to the surface through normal root growth and tree throw. Lower elevation desertscrub areas are less impacted by bioturbational processes that disrupt clast armors. During the full glacials of the Pleistocene, pinon pine (*Pinus*) and juniper (*Juniperus*) woodlands extended downslope to the margins of the Phoenix Basin at elevations above 550 m (Van Devender and Spaulding, 1979), and this may partially explain the dearth of pavements in the Superstition Mountain Piedmont. Although it is unlikely that pinon and juniper ever reached the piedmonts of the Santan Mountains, the eastern slopes lacking strongly developed desert pavements may have experienced more Upper Sonoran Desert tree assemblages and associated bioturbation.

Interestingly, some of the desert pavements on Ma2 surfaces in the Santan Piedmont have been disrupted by less natural processes. Common to the proximal portions of Ma2 alluvial fans are rock piles, rows, and rectilinear forms. Locally, these features have disturbed the desert pavement. These are agricultural features constructed by the Hohokam 0.5-1.5 ky ago (Masse, 1991). Although the Hohokam are best known

for their irrigation canals, they also practiced dry farming of desert cultivars on the Santan Piedmont.

CONCLUSION

A variety of alluvial fan surfaces extend from the Santan Mountains to the eastern Phoenix Basin. Many of these surfaces interfinger with the Queen Creek alluvial fan complex derived from the Superstition Mountains. These different fan surfaces are the product of climatic oscillations during the Quaternary. The most active geologic surfaces are the Holocene Ya surfaces; these are prone to periodic flooding and spatial shifts in channel positions and are most likely to contain buried, cultural resources. Some of the Ya surfaces in the Santan Piedmont are also prone to earth fissures in areas of heavy groundwater withdrawal, although such surface ruptures may occur in older deposits as well. The older Pleistocene Ma surfaces are relatively stable and are only slowly succumbing to stream dissection and intrinsic surface degradation. Much of the lower piedmont has been agriculturally developed, but historically this was an area of periodic channelized and sheet flooding. Despite considerable effort in flood protection, the artificially channelized reaches of Queen Creek and Sonoqui Wash are sites of probable future bank erosion.

Although the relative chronology of geologic surfaces in the eastern Phoenix Basin is well defined, future research should concentrate on deriving numerical age estimates for geologic surfaces. Numerical age estimates of the Y, M, and O surfaces presented here and in other surficial geologic maps in Arizona are based largely on long distance correlations to soil chronofunctions (e.g., Bull, 1991). These correlations are somewhat tenuous due to spatial variability in soil formation rates. Surface dating techniques involving the accumulation of cosmogenic isotopes in rock minerals may soon be an ideal method for dating late Pleistocene desert pavements, although at present the methodology is still in its developmental stage. Another promising technique for dating latest-Pleistocene and Holocene surfaces is radiocarbon dating pedogenic carbonates rinds. Although ^{14}C dates from pedogenic carbonate have in the past been of dubious reliability due to suspected contamination by dead carbon (Taylor, 1987), recent diffusion modeling of soil carbon (Cerling and Quade, 1992) suggests that pedogenic $CaCO_3$ precipitates in equilibrium with atmospheric carbon content with little contamination from limestone or older calcite. Radiocarbon dating of $CaCO_3$ and other more conventional organic materials are needed to better define the ages of Ya1 surfaces and associated soils and to help distinguish younger and older Ma2 surfaces.

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APPENDIX A: SOIL PROFILE DESCRIPTIONS

Geologic Surface: Ya1b
Soil Profile: SNE1
Classification: Camborthid
Location: Pinal County, Arizona; SW 1/4, SW 1/4, Sec. 17, T. 3 S., R. 8 E.
Physiographic Position: Alluvial fan; elevation 464 m.
Topography: Gentle 1% slope
Vegetation: Creosote (*Larrea*), previously plowed or bladed in the 1950's.
Described by: Gary Huckleberry, April 25, 1994.
Remarks: Soil profile located approximately 80 m north of Bella Vista Rd., and 40 m west of canal. Soil colors are for dry conditions.

A 0-8 cm. Light yellowish brown (10YR 6/4) gravelly loamy sand; moderate, fine to medium, subangular blocky structure; soft (dry), not sticky and not plastic (wet); noneffervescent; clear smooth boundary.

Bk 8-26 cm. Light yellowish brown (10YR 6/4) gravelly loamy sand; moderate, fine to medium, subangular blocky structure; loose (dry), not sticky and not plastic (wet); noneffervescent; clear smooth boundary.

BCk 26-145+ cm. Light yellowish brown (10YR 6/4) gravelly loamy sand; single grain; loose (dry), not sticky and not plastic (wet); strongly effervescent; carbonates are disseminated and occur as discontinuous rinds on bottom of clasts (Stage I).

Geologic Surface: Ya1b
Soil Profile: SNE2
Classification: Haplargid
Location: Pinal County, Arizona; SW 1/4, SW 1/4, Sec. 17, T. 3 S., R. 8 E.
Physiographic Position: Alluvial fan; elevation 476 m.
Topography: Gentle 1% slope
Vegetation: Creosote (*Larrea*), previously plowed or bladed in the 1950's.
Described by: Gary Huckleberry, April 25, 1994.
Remarks: Soil profile located approximately 200 m east of the end of Judd Rd. Soil colors are for dry conditions.

A 0-4 cm. Light yellowish brown (10YR 6/4) gravelly sandy loam; moderate, fine, subangular blocky structure; soft (dry), slightly sticky and slightly plastic (wet); noneffervescent; clear smooth boundary.

Bw 4-12 cm. Light yellowish brown (10YR 6/4) gravelly sandy loam; weak, coarse, subangular blocky structure; soft (dry), slightly sticky and slightly plastic (wet); noneffervescent; clear smooth boundary.

Bk 12-40 cm. Very pale brown (10YR 7/4) gravelly sandy loam; massive; soft (dry), slightly sticky and slightly plastic (wet); strongly effervescent; carbonates are disseminated; clear smooth boundary.

Btk 40-58 cm. Reddish yellow (7.5YR 6/6) gravelly sandy clay loam to loam; moderate, medium, angular blocky structure; slightly hard (dry), slightly sticky and slightly plastic (wet); strongly effervescent; carbonates are disseminated and occur as few, fine, filaments (Stage I); very few, distinct clay skins forming colloidal stains on clasts; abrupt wavy boundary.

2Btkb1 58-90 cm. Strong brown (7.5YR 5/6) very gravelly sandy clay loam; single grain; slightly hard (dry), slightly sticky and plastic (wet); strongly effervescent; carbonates occur as common, fine, filaments (Stage I); many, prominent, clay skins lining interstitial pores; clear wavy boundary.

2Btkb2 90-108 cm. Strong brown (7.5YR 5/6) gravelly sandy clay loam; single grain; slightly hard (dry), slightly sticky and plastic (wet); slightly effervescent; carbonates occur as common, fine, filaments (Stage I); common, faint, clay skins lining interstitial pores; abrupt wavy boundary.

3Btkb1 108-126 cm. Brown to dark brown (7.5YR 4/4) sandy clay with pinkish white (7.5YR 8/2) mottles; moderate, fine to medium, angular blocky structure; extremely hard (dry), sticky and plastic (wet); strongly effervescent; carbonates occur as common, medium, filaments (Stage I+); many, prominent, clay skins on ped faces; clear smooth boundary.

3Btkb2 126-150+ cm. Brown (7.5YR 5/4) clay with pinkish white (7.5YR 8/2) mottles; moderate, fine to medium, angular blocky structure; extremely hard (dry), sticky and plastic (wet); violently effervescent; carbonates occur as many, medium, seams and masses (Stage II); many, prominent, clay skins on ped faces.

Geologic Surface: Ya1b
Soil Profile: SNE3
Classification: Camborthid
Location: Pinal County, Arizona; NW 1/4, SE 1/4, SE 1/4, Sec. 15, T. 3 S., R. 7 E.
Physiographic Position: Alluvial fan; elevation 500 m.
Topography: Gentle 1-2% slope
Vegetation: Creosote (*Larrea*), bursage (*Franseria*), and palo verde (*Cercidium*).
Described by: Gary Huckleberry and Elise Pendall, May 6, 1994.
Remarks: Soil profile located approximately 100 m west of Thompson Road. Soil colors are for dry conditions.

A 0-5 cm. Yellowish Brown (10YR 5/4) gravelly sandy loam; weak, coarse, platy structure; soft (dry), not sticky and not plastic (wet); noneffervescent; clear smooth boundary.

Bk 5-30 cm. Light yellowish brown (10YR 6/4) very gravelly sandy loam; weak, coarse, angular blocky structure; soft (dry), not sticky and not plastic (wet); strongly effervescent; carbonates are disseminated; gradual smooth boundary.

CBk 30-110+ cm. Light yellowish brown (10YR 6/4) very gravelly loamy sand; single grain; loose (dry), not sticky and not plastic (wet); strongly effervescent; carbonates are disseminated and occur as very fine, common filaments and discontinuous rinds on clasts (Stage I).

Geologic Surface: Ya1b
Soil Profile: SNE4
Classification: Camborthid
Location: Pinal County, Arizona; NE 1/4, NE 1/4, NE 1/4, Sec. 15, T. 3 S., R. 7 E.
Physiographic Position: Alluvial fan; elevation 488 m.
Topography: Gentle 1% slope
Vegetation: Creosote (*Larrea*), bursage (*Franseria*), and palo verde (*Cercidium*).
Described by: Gary Huckleberry and Elise Pendall, May 6, 1994.
Remarks: Soil profile located approximately 150 m east of intersection of Thompson and Roberts roads. CBk contains gravel lenses with greater than 50% gravel content. Soil colors are for dry conditions.

A 0-5 cm. Yellowish brown (10YR 5/4) gravelly sandy loam; weak, medium, subangular blocky to platy structure; soft (dry), not sticky and not plastic (wet); noneffervescent; clear smooth boundary.

Bw 5-27 cm. Yellowish brown (10YR 5/4) gravelly sandy loam; weak, coarse, subangular blocky structure; soft (dry), not sticky and slightly plastic (wet); noneffervescent; clear smooth boundary.

CBk 27-120+ cm. Light yellowish brown (10YR 5/4) gravelly sandy loam; single grain; loose (dry), not sticky and slightly plastic (wet); strongly effervescent; carbonates are disseminated and occur as discontinous rinds on clasts (Stage I).

Geologic Surface: Ya1
Soil Profile: DW9a
Classification:Camborthid
Location: Pinal County, Arizona; NE 1/4, NE1/4, NW 1/4, Sec. 33, T. 1 S., R. 8 E.
Physiographic Position: Alluvial fan; elevation 468 m.
Topography: Gentle 1% slope
Vegetation: Creosote (*Larrea*).
Described by: Gary Huckleberry, April 26, 1994.
Remarks: Soil profile located approximately 150 m east of cattle tank and 100 m south of barbed wire fence. Lens of mottled soil and charcoal occurs at 35-45 cm depth; charcoal sampled for 14C analysis. A single large cobble (18cm x 7cm x 6cm) occurs at base of Bk2. Soil colors are for dry conditions.

Bw1 0-20 cm. Light yellowish brown (10YR 6/4) sandy loam; weak, very coarse, angular blocky structure; very hard (dry), slightly sticky and slightly plastic (wet); noneffervescent; clear smooth boundary.

Bw2 20-72 cm. Brown to strong brown (7.5YR 5/5) gravelly sandy loam; massive; loose (dry), slightly sticky and slightly plastic (wet); noneffervescent; abrupt smooth boundary.

Bk 72-95 cm. Brown to strong brown (7.5YR 5/5) gravelly sandy loam; massive; slightly hard (dry), slightly sticky and slightly plastic (wet); strongly effervescent; carbonates are disseminated; abrupt wavy boundary.

2Btkb1 95-112 cm. Strong brown (7.5YR 4/6) very gravelly sandy clay loam; single grain; loose (dry), sightly sticky and plastic (wet); strongly effervescent; carbonates are disseminated and occur as common, fine filaments and continuous rinds on clasts (Stage II); common, fine, distinct, clay skins form bridges between sand grains; clear smooth boundary.

2Btkb2 112-130+ cm. Strong brown (7.5YR 4/6) gravelly sandy clay loam; massive; hard (dry), sightly sticky and plastic (wet); strongly effervescent; carbonates are disseminated and occur as common, fine filaments and few, medium, irregular, soft masses (Stage I).

Geologic Surface: Ma2
Soil Profile: SNE5
Classification: Calciorthid
Location: Pinal County, Arizona; SE 1/4, SE 1/4, SW 1/4, Sec. 30, T. 3 S., R. 8 E.
Physiographic Position: Alluvial fan; elevation 476 m.
Topography: Gentle 1% slope
Vegetation: Creosote (*Larrea*), previously plowed or bladed in the 1950's.
Described by: Gary Huckleberry, March 31, 1994.
Remarks: Soil profile located approximately 500 m east of two-track road (an extension of Gary Rd.) in a pre-existing pit. Soil colors are for dry conditions.

Ak 0-5 cm. Light brown (7.5YR 6/4) sandy loam; massive; soft (dry); slightly sticky and slightly plastic (wet); violently effervescent; carbonates are disseminated; clear smooth boundary.

Bk1 5-36 cm. Light brown (7.5YR 6/4) sandy loam; massive; soft (dry); slightly sticky and slightly plastic (wet); carbonates are disseminated and occur as few, very fine filaments (Stage I); clear smooth boundary.

Bk2 36-54 cm. Pink (7.5YR 7/4) sandy clay loam with pinkish white (7.5YR 8/2) mottles; weak, medium to coarse, subangular blocky structure; soft (dry), sticky and plastic (wet); violently effervescent; carbonates are disseminated and occur as many, medium nodules and soft masses (Stage II+); clear smooth boundary.

Bk3 54-90 cm. Pink (7.5YR 7/4) gravelly sandy clay loam with pinkish white (7.5YR 8/2) mottles; weak, medium to coarse, angular blocky structure; very hard (dry), sticky and plastic (wet); violently effervescent; carbonates are disseminated and occur as many, medium nodules and soft masses (Stage III); gradual smooth boundary.

Btk 90-110+ cm. Light brown (7.5YR 6/4) gravelly sandy clay loam with pinkish white (7.5YR 8/2) mottles; weak, fine to medium, angular blocky structure; soft (dry), very sticky and plastic (wet); violently effervescent; carbonates are disseminated and occur as common, fine nodules (Stage II); common, faint, clay skins occurring as colloidal stains on clasts.

Geologic Surface: Mal
Soil Profile: SP-11
Classification: Paleargid
Location: Pinal County, Arizona; NE1/4, SE1/4, NW1/4, Sec. 34, T. 2 S., R. 10 E.
Physiographic Position: Alluvial fan surface; elevation 586 m.
Topography: Gentle, 1 % slope.
Vegetation: Creosote (*Larrea*), bursage (*Franseria*), cholla (*Opuntia*), palo verde (*Cercidium*).
Described by: Gary Huckleberry, September 14, 1993.
Remarks: Quartz and schist gravels form discontinuous lag at surface.

Bw 0-16 cm. Strong brown (7.5YR 5/6) gravelly sandy loam; weak, coarse, angular blocky structure; soft (dry), sticky and plastic (wet), noneffervescent; abrupt smooth boundary.

Bt 16-35 cm. Yellowish red (5YR 4/6) gravelly sandy clay; strong, coarse, angular blocky and prismatic structure; hard (dry), sticky and very plastic (wet); noneffervescent; many, thick, clay skins on ped faces; gradual smooth boundary.

Btk 35-65 cm. Yellowish red (5YR 4/6) gravelly sandy clay with common, fine, prominent, white (5YR 8/1) mottles; strong, coarse, angular blocky and prismatic structure; very hard (dry), sticky and very plastic (wet); strongly effervescent; carbonates occur as filaments (Stage I); many, thick, clay skins on ped faces; abrupt smooth boundary.

Bkm 65-80+ cm. Pinkish white (5YR 8/2) petrocalcic horizon; massive; extemely hard; violently effervescent; carbonates indurate horizon and have a laminar cap (Stage IV+).