Surficial Geology of the Superstition Mountain Piedmont Area, Northern Pinal and Eastern Maricopa Counties, Arizona.

by

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Introduction

One of the fastest growing areas of Arizona is the eastern part of the Phoenix Basin near the communities of Chandler, Gilbert, Mesa, and Apache Junction. Much of this development has occurred on the piedmont near the base of the mountains where little of the surficial geology has ever been mapped. Because this area of the Phoenix Basin will continue to grow in the future, there is a need to understand the nature and distribution of surficial deposits. Surficial geologic mapping provides a spatial data base for assessing potential geologic hazards (Pearthree, 1991), for defining important groundwater recharge zones, and for analyzing the physical characteristics of surface deposits for excavation purposes. Such mapping is also valuable to earth scientists who are interested in defining the links between landscape evolution and climate change (Bull, 1991).

This report presents the results of surficial geologic mapping in the eastern margins of the Phoenix Basin including the Superstition Mountain piedmont and Queen Creek alluvial fan (Figure 1). The region mapped is contained within the Florence Junction, Florence NE, Goldfield, Magma, and Superstition Mountains SW quadrangles (1:24,000), and part of the Weavers Needle quadrangle (1:24,000). This area contains a variety of landscape elements including steep mountain slopes, pediments, and alluvial fans. Included within this report is a discussion of the origins of pediments and an analysis of streamflow processes on the Queen Creek fan.

Primary funding for the surficial geologic mapping has been provided by the COGEOMAP project, a joint geologic mapping effort by the Arizona Geological Survey and the U.S. Geological Survey. Aerial photography of the area was graciously provided by the Soil Conservation Service offices in Chandler and Casa Grande and the Tonto National Forest, Mesa Ranger Station. Tim Vidra helped in drafting the maps.

Methods

Surficial geologic mapping is based on the premise that alluvial surfaces of different ages can be distinguished based on time-dependent physical characteristics. These physical characteristics include topographic position, degree of stream dissection, desert pavement development, and soil formation (Bull, 1991; Christensen and Purcell, 1985). Some areas are easier to map than other areas. In the Phoenix Basin, areas lacking relief, desert pavement, and soil exposures, or areas that have been cultivated or urbanized, are the most difficult to map. The upper part of the Superstition piedmont area contains considerable topographic variability and is an area where it is easier to apply concepts of morphostratigraphy (see Gile and others, 1981:24) in relative age dating surfaces. In contrast, the lower piedmont in the western and southwestern part of the project area is relatively flat and undissected and hence more challenging to map. Surficial geologic map units in the lower piedmont and basin floor tend to be larger and more generic, i.e., less specific in age.

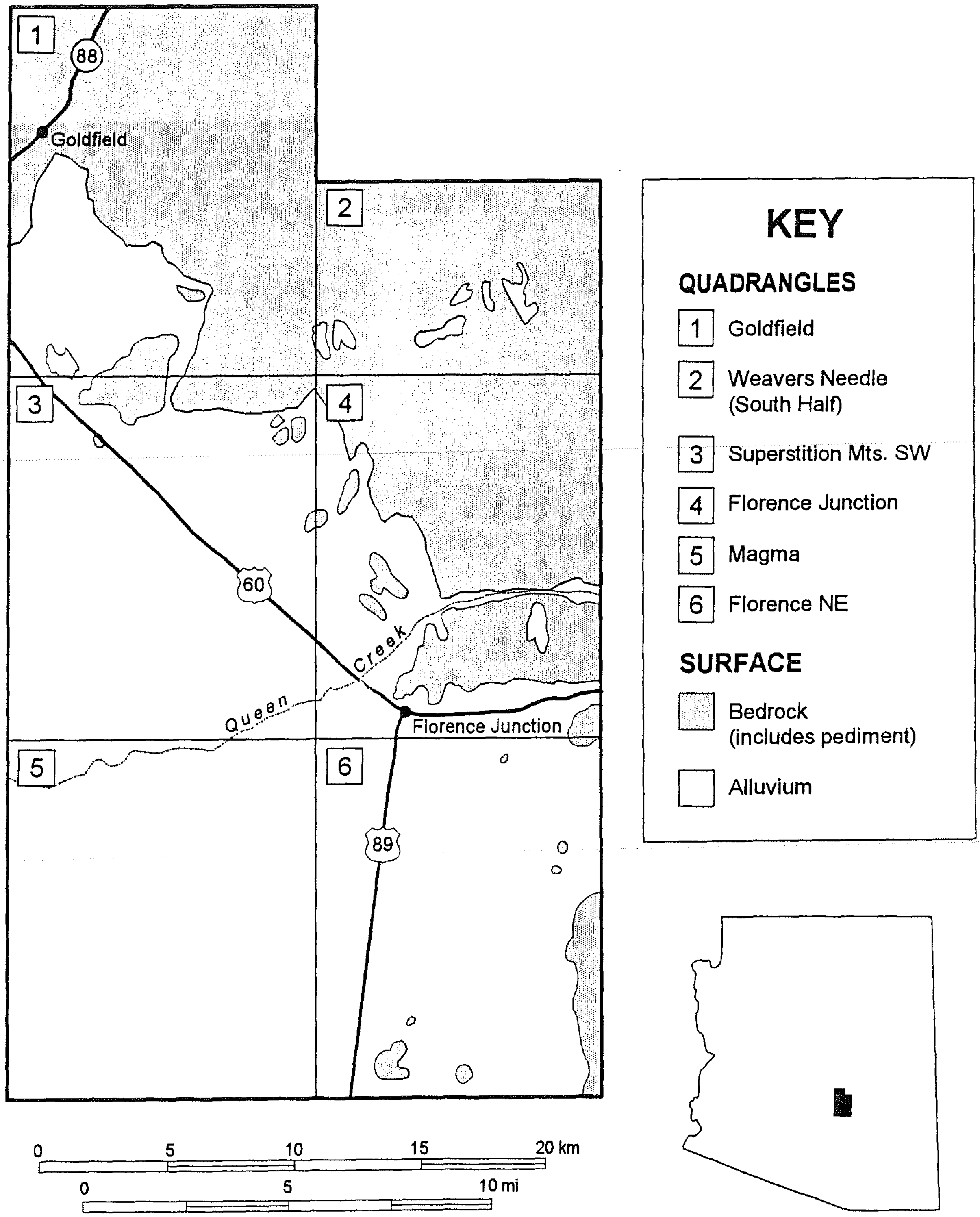

Figure 1. General distribution of bedrock and alluvial surfaces within the project area.

Surficial geologic mapping of the Superstition Piedmont involved four stages. The first stage was the use of aerial photography to distinguish geological surfaces. Color infrared photography (1:58,000 scale) was utilized for the entire project area and supplemented with color (1:24,000) and black and white (1:8,000) photography of selected areas. Based on the photography, map unit boundaries were traced onto 1:24,000-scale orthophotos.

The second stage involved field reconnaissance and checking map unit boundaries determined from aerial photography. Fieldwork was performed January through May and August through September, 1993. Soils were analyzed for age estimation and correlation of surfaces (Birkeland, 1984; Bull, 1991). Because much of the piedmont is not dissected and lacks natural soil exposures, a backhoe was used to excavate a series of soil pits. Soils were described according to guidelines established by the Soil Survey Manual (Guthrie and Witty, 1981; Soil Survey Staff, 1951). Calcium carbonate development was characterized by the morphogenetic system of Gile and others (1966) and Machette (1985).

The third stage was to check map-unit boundaries with soil surveys. To the knowledge of the author, soils have been mapped in detail in only a very small portion of the project area (Adams, 1974). This area is located in the western and southwestern margins of the Magma quadrangle and mostly in agricultural fields. The soil survey was used to estimate the boundaries of former channels now obscured by agricultural fields.

The fourth and most difficult stage of this surficial geologic mapping involved the correlation and age-estimation of surfaces. Correlating surficial deposits that vary in lithology, grain-size, and elevation can be problematic, because landforms with unique climatic/tectonic histories may have similar surficial properties. Likewise, surfaces that share a similar environmental history may appear different. In lieu of chronological control, topographic position and weathering characteristics were used to assign relative ages and correlate surfaces within the project area and to areas previously mapped to the south along the Gila River (Huckleberry, 1992, 1993). Approximate ages were assigned to surfaces based primarily on comparison of soil development to areas where soils are radiometrically dated (Bull 1991; Gile and others, 1981).

Geomorphic Context

The project area is located at the transition between the Mexican Highlands and Sonoran Desert sections of the Basin and Range physiographic subprovince (Fenneman, 1931), or alternatively, the transition between the Basin and Range and Transition zones of Arizona (Chronic, 1983). The northern and eastern parts of the project area are dominated by mountains with the Superstition Mountains forming the most prominent range. The Superstition Mountains record a period approximately 20-30 Ma[1] when the region experienced explosive volcanism resulting in the accumulation of over 1,000 m of rhyolitic flows, tuffs, and volcaniclastic rocks (Chronic, 1983; Stuckless and Sheridan, 1971; Sheridan, 1978). Most of the other mountains and hills in the eastern part of the project area are also composed of mid-Tertiary volcanics except for occasional hills of Precambrian schist and granite (Peterson and Jinks, 1983; Reynolds, 1988). Most of the surficial deposits within the mountainous zone are thin and discontinuous and include Holocene alluvium along stream channels and colluvial wedges and talus cones along steep mountain slopes.

The southern and western parts of the project area lie within the eastern margin of the Phoenix Basin, a large lowland composed of topographic and structural basins extending from the western boundary of the Mexican Highlands section to the Sierra Estrella and Whitetank Mountains to the west (Péwé, 1978). The basin began to form 8-15 Ma as the previous period of explosive Tertiary volcanism waned (Shafiquallah and others, 1980). As the Phoenix Basin dropped, it simultaneously filled with alluvial debris shed from adjacent mountains. South of U.S. Highway 60 near Dromedary Peak (Florence Junction and Florence NE quadrangles) are exposures of steeply dipping fan deposits that date to this early period of faulting and basin filling. Tectonism waned after 5 Ma, and drainage gradually became integrated between basins. During this period of relative tectonic stability, both alluvial fans and pediments developed along mountain fronts. Most of the Superstition piedmont area is composed of coalesced alluvial fans sloping west-southwest from the mountains to the east. These fan surfaces formed during the Quaternary as periods of erosion and deposition were caused by fluctuating climate. There are also three areas of pediments developed within the Superstition piedmont that are testaments not only to fluctuating Quaternary climate but also to regional tectonic stability (see **Lithologic Controls on Pediments**).

Most of the streams on the Superstition piedmont flow into the Phoenix Basin where they lose definition and eventually become obscured by agriculture and urbanization. Exceptions are drainages in the southern part of the Florence Northeast and Magma quadrangles that drain into the Gila River and drainages in the northern part of the Goldfield quadrangle that flow into the Salt River. The largest piedmont stream is Queen Creek (Figure 1). Historically, Queen Creek would flood and inundate large portions of the eastern valley (Davis, 1897; Lee, 1905). Today, Queen Creek is dammed before it reaches the Phoenix Basin and channelized into a series of drainage canals downstream from the project area (see **Queen Creek Fan**).

Map Units

Following a system established by earlier surficial geologic mapping projects located along the Gila River (Huckleberry, 1992, 1993), three primary symbols are used to distinguish geomorphic surfaces in the Superstition Mountain piedmont area based on

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

relative age: Y (young), M (middle or intermediate), and O (old). A lower case "a" following one of these primary symbols denotes alluvial fan surfaces and channels. Pediments are denoted with the symbol "Op". One Gila River terrace exposed near the southern boundary of the project area is denoted as "O". Primary symbols may be subdivided (e.g., Ma1 and Ma2) where there are distinct differences in topographic position and weathering. Tertiary subdivisions (e.g., Ma2a and Ma2b) are used where surfaces are topographically distinct (e.g., Ma2a is higher than Ma2b) but share similar weathering characteristics. If a landform has characteristics transitional between two map units, then both are presented and separated by a slash (e.g., Ma2/Ya1). Other symbols include "b" for steeply sloping bedrock surfaces and 'Tsm" for middle Tertiary basin deposits that have steeply dipping beds.

Where boundaries between temporally discrete surfaces are distinct, the boundary is marked by a solid line. Where surface characteristics change gradually, a dashed line is used to mark the approximate location of the boundary. Where a surface cannot be traced with certainty due to agricultural fields, a dotted line is used to demarcate agricultural field boundaries.

Ya2 (< 0.5 ka)

Modern ephemeral streams draining the piedmont areas are labeled Ya2. Some of the larger drainages originate in the mountains east of the project area and support streamflow in the upper piedmont area during the winter and spring. Other Ya2 channels are developed into fan surfaces, have relatively small catchment areas, and only flow during or immediately after rainfall events. Relatively small Ya2 channels are lined with palo verde (*Cercidium*), mesquite (*Prosopsis*), and ironwood (*Olneya*) whereas larger channels also contain desert willow (*Chilopsis*) and tamarisk (*Tamarix*). Relatively unoxidized, interbedded sands, gravels, and cobbles comprise Ya2 alluvium.

Drainage patterns for Ya2 channels are generally dendritic (Table 1), however within the larger Ya2 channels and on the lower piedmont where streamflow is less contained, distributary and anastomosing channel patterns are common. In the Magma and eastern part of the Florence Northeast quadrangles, some of the Ya2 channels have rectilinear drainage patterns. These generally form alongside cultural features such as railroad tracks and diversion dams. Some of the rectilinear channels, however, have developed out of two-track roads and cattle trails. Many of the Ya2 channels on the lower piedmont have discontinuous entrenched and nonentrenched reaches (see **Discontinuous Ephemeral Streams** below).

Ya2 channels contain a mixture of modern and historic sediments. Ya2 alluvium is stratified and lacks any appreciable soil formation. Most of the channel surfaces are modern in age, but there are also vegetated bars that may be serveral hundred years old. A reasonable age estimate for Ya2 surfaces is < 500 years.

Table 1. Physical Characteristics and Age Estimates of Geologic Surfaces.

Mountain Upland/Upper Piedmont

Surface	Dissection	Drainage	Soil Horizons	CO3 Stage	Soil Profile	Age Estimate	Correlated Surface (Bull, 1991)	Correlated Surface (Gile and others, 1981)
Ya2	-	distributary	C	-	-	< 0.5 ka	-	-
Ya1	> 1 m	distrib.-dend.	Bw, Bk, Cox	I	SP-7,8,13	< 10 ka	Q4a, Q3a	Fillmore
Ma2	< 2 m	dendritic	Bk, Bt, Cox	I-III	SP-5,6,9	10-100 ka	Q3a, Q2c	Isaac's Ranch
Ma2/Ya1	< 1 m	dendritic	C, Bw, Bk, Bt	I-III	SP-12	< 100 ka	-	-
Ma2/Ya	< 1 m	disturbed	C, Bw, Bt, Bk	0-III	-	< 100 ka	-	-
Ma1	> 2 m	dendritic	Bt, Bk, Bkm	III-IV	SP-1,4,11	100-500 ka	Q2a	Jornada I
Oa	> 6 m	dendritic	Bkm	III - IV+	MGR-18	0.5-2.0 Ma	Q1	Dona Ana
Op	> 3 m	dendritic	Bt, Bk, Bkm	-	-	> 1 Ma	-	-

River Valley

Surface	Dissection	Drainage	Soil Horizons	CO3 Stage	Soil Profile	Age Estimate	Correlated Surface (Bull, 1991)	Correlated Surface (Gile and others, 1981)
O	> 8 m	dendritic	Bkm, Bkqm	III - IV+	MGR-11	1-2 Ma	Q1	La Mesa

Ya1 (< 10 ka)

Holocene alluvial surfaces that have incipient soil development are labeled Ya1 (Table 1). Ya1 surfaces cover relatively broad areas at the distal ends of alluvial fans but are more restricted in area along washes in the upper piedmont. In the upper piedmont alluvial grain sizes range from coarse sand to boulders but decrease in size downstream. Ya1 soils are weakly developed and often contain primary fluvial bedforms. Pedogenesis is generally limited to surface enrichment of silt from eolian sources, slight oxidation, and weak calcification. These soils contain cambic, calcic (Stage I or less), and Cox horizons (Birkeland, 1984; Soil Survey Staff, 1975:45; Appendix A: Soil Profiles SP-7, 8, and 13). and classify as Torrifluvents, Camborthids, and Calciorthids (Soil Survey Staff, 1975:168, 170, 189). Although Ya1 soils are relatively immature, they commonly overlie older, well developed, Pleistocene soils (e.g., Appendix A: Soil Profile SP-13).

Based primarily on soil development, Ya1 surfaces are age-estimated to be younger than 10 ka. They correlate in age with Bull's (1991) Q4a and Q3c surfaces in the lower Colorado River Valley. The alluvium underlying the Ya1 surface correlates in age with the Fillmore alluvium along the middle Rio Grande River near Las Cruces (Gile and others, 1981).

Ma2 (10-100 ka)

Late Pleistocene alluvial fan surfaces labeled Ma2 are common in both the proximal and distal portions of alluvial fans where stream dissection is < 3 m (Table 1). Alluvial sediment sizes range from sand to cobbles, but surface soils are rich in pedogenic clay. Ma2 soils display considerable morphological variability but all tend to contain argillic (Soil Survey Staff, 1975:26) and calcic horizons with Stage I-II development (Appendix A: Soil Profiles SP-5, 6, and 9). These soils classify as Camborthids, Calciorthids, and Haplargids (Soil Survey Staff, 1975:159).

Ma2 surfaces correlate in age with Bull's (1991) Q3a (8-12 ka) and some of the younger Q2c surfaces (12-70 ka). Ma2 surfaces also correlate in age with Gile and others' (1981) Isaac's Ranch surface that they age-estimate at 8-15 ka. A reasonable age estimate for Ma2 surfaces is 10-100 ka (Table 1). This is a considerable wider and older age range than previously presented for Ma2 surfaces along the Gila River (Huckleberry, 1993). This revised age estimate reflects observations of older soils on Ma2 surfaces in the Superstition piedmont. This greater time span helps to explain the considerable morphological variability displayed by Ma2 soils. Although relatively mature, these soils have not yet reached a pedogenic plateau where subsequent soil formation is impeded by plugged and indurated horizons (see Johnson and others, 1990). Thus soils aged 10-100 ka will contain greater morphological variability compared to older soils with petrocalcic horizons.

Ma2/Ya1 (< 100 ka)

There is little relief in the western and southwestern parts of the project area, thus topographic position cannot be used to distinguish surfaces. These areas are flat, contain mostly fine gravel and finer sediments, and contain a variety of young and old soils. The symbol Ma2/Ya1 is used to mark these surfaces with nondescript surface morphometry that contain both argillic and younger alluvial soils. Ma2/Ya1 soils classify as Camborthids, Calciorthids, and Haplargids (Appendix A: Soil Profile SP-12). Ma2/Ya1 surfaces are only marginal areas of groundwater recharge due to the fine-textured nature of the soils. Several Ma2/Ya1 surfaces located on the upslope side of the Magma Diversion Dams are now prone to flooding.

Ma2/Ya (< 100 ka)

Surfaces that have been agriculturally developed in the western margins of the project area are labeled Ma2/Ya because it is generally not possible to distinguish Ma2, Ya1, and Ya2 surfaces. Only in a few places is it possible to estimate the boundaries of former Ya2 channels based on soils maps (Adams, 1974). Because this is an area of sheetflooding, many of the surfaces in this area are late Holocene in age. However, soil maps (Adams, 1974) indicate that most soils within the cultivated fields are Haplargids which are Pleistocene in age. Some of this discrepancy may be due to the fact that soils are still mapped as Haplargids where they are buried by less than 50 cm of alluvium. However, Haplargid soils also occur at the surface in places. Ma2/Ya surfaces are continuous with agricultural surfaces to the south mapped as M by Huckleberry (1993).

Ma1 (100-500 ka)

Geomorphic surfaces developed on middle to late Pleistocene alluvial fan sediments are labeled Ma1 (Table 1). These surfaces are most common in the proximal portion of alluvial fans in the eastern part of the project area. Alluvial grain sizes range from sand to boulders, although the surfaces are enriched in pedogenic clay. Ma1 surfaces are heavily dissected and contain mature soils with argillic, calcic, and petrocalcic (Stage II-III+) horizons (Appendix A: Soil Profiles SP-1, 4, and 11). These soils classify as Calciorthids, Paleorthids, Haplargids, and Paleargids (Soil Survey Staff, 1975:165, 176). Because of their relatively impermeable argillic and petrocalcic horizons, Ma2 surfaces are not areas of significant infiltration and groundwater recharge.

Ma1 surfaces correlate to Bull's (1991) Q2a surface (400-730 ka) and Gile and others' (1981) Jornada I surface (250-400 ka). The Ma1 surface is age-estimated at 100-500 ka (Table 1).

Oa (0.5-2.0 Ma)

The oldest alluvial fan surfaces in the Superstition piedmont area are found in the eastern part of the Florence NE quadrangle and in isolated locations south of the Superstition Mountains. One area of Oa deposits located northeast of Florence Junction (Sec. 2, T. 2 S., R. 10 E.) indicates a previous southerly drainage from the Superstition Mountains where modern drainage is predominantly to the west. Oa surfaces are deeply dissected into a series of accordant ridges that mark the highest stand of basin deposits along the upper piedmont. Alluvial grain sizes range from sand to boulders. Oa soils contain argillic and calcic horizons with the latter containing Stage III-IV+ carbonate morphologies (Appendix A: Soil Profile MGR-18); these soils classify as Paleargids. The presence of petrocalcic fragments at the surface indicates erosion of the original surface. Petrocalcic horizons limit the amount of groundwater recharge on Oa surfaces.

Oa surfaces correlate in age to the Q1 surface in the lower Colorado River Valley (Bull, 1991) and the Dona Ana surface of the middle Rio Grande Valley (Gile and others, 1981). Both of these surfaces have open-ended age estimates (> 1.2 Ma for Q1 and > 400 ka for Dona Ana). Oa surfaces also correlate to the Martinez surface (Menges and McFadden, 1981; Morrison, 1985), a high geomorphic surface common to the upper basins of southeastern Arizona. Menges and McFadden (1981) age estimate the Martinez Surface as 1-3 Ma based on soil formation and magnetostratigraphy of underlying sediments. A reasonable age estimate for the Oa surface is 0.5-2.0 Ma (Table 1).

O (1.0-2.0 Ma)

The O surface is the only surface within the project area produced directly by the Gila River. Huckleberry (1993) refers to this surface as the Target Terrace after the Arizona National Guard's Target Range located north of Florence. Within the present project area, the O surface is defined by a small area of Gila River gravels near the southern boundary of the Florence NE quadrangle. This surface grades imperceptibly into Ma2 fan deposits to the west; to the east O deposits have been eroded away. Although not observed within the project area, Target Terrace soils have thick duric and petrocalcic horizons with Stage IV+ morphology.and classify as Durorthids (Hall, 1991; Soil Survey Staff, 1975:174).

The Target Terrace correlates in age with the Salt River's Sawik Terrace (Péwé, 1978), Bull's (1991) Q1 surface, and Gile and others' (1981) La Mesa surface. The Target Terrace is estimated to be 1.0-2.0 My old (Table 1).

Queen Creek Fan

As previously mentioned, most of the streams draining the Superstition piedmont do not reach the Salt or Gila Rivers. Infrequent streamflow in Superstition piedmont channels spreads out into the lowlands of the eastern Phoenix Basin and is lost to evaporation and infiltration (Babcock and Cushing, 1952; Lee, 1905:103). Most of these streams originate on the piedmont, but there are several with larger catchment areas that originate in the mountains to the east. The largest of these streams is Queen Creek (Figure 1) with a drainage basin area of 497 km^2 (191 mi^2) (Turner and Halpenny, 1952). Queen Creek streamflow has probably always been seasonal on the piedmont during the Holocene, but although seasonal, the discharge was sufficient and reliable enough for the Hohokam to excavate several irrigation canals off of the channel (Crown, 1984). The U.S. Geological Survey periodically operated a stream gage on Queen Creek near the present Whitlow Ranch Dam (Florence Junction quadrangle) between 1897 and 1959; discharge measurements stopped after construction of the dam.

Queen Creek contains two major (Ma1 and Ma2a) and one minor (Ma2b) terraces. Péwé (1978) named the two major terraces the Radio Ridge Terrace (Ma1) and the Bridge Terrace (Ma2a). The Ma2b terrace is a small, intermediate surface located upstream from Highway 60. Péwé (1978) plotted the longitudinal profiles of the Radio Ridge and Bridge terraces and noted that they converge downstream like other stream terraces along the margins of the Phoenix Basin (Morrison, 1985). Along the Gila River near Florence there are three major and two minor terraces that converge downstream (Huckleberry, 1993; Péwé, 1978), and along the Salt River, there are four major terraces that converge downstream (Péwé, 1978). Terrace convergence along the eastern margin of the Phoenix Basin implies a gradual, regional, westward tilting (Huckleberry, 1993, Péwé, 1978). This is interpreted as the product of isostatic rebound produced by denudational unloading of the Mexican Highlands Province (Menges and Pearthree, 1989; Shafiqullah and others, 1980).

In contrast to Gila River terraces, the Queen Creek terraces have been mapped in this report as alluvial fan surfaces. Although Queen Creek is a well defined stream in the upper piedmont, and the planar surfaces along its channel can be defined as stream terraces, at a larger scale Queen Creek is a broad alluvial fan with a single entrenched channel in the upper piedmont. Before human channelization, this fan channel graded downstream into a series of distributary channels creating a broad zone of both channelized flow and sheetflow. Davis (1897) noted that in the late 1800's the largest Queen Creek floods resulted in broad areas of sheetwash covering modern day urban areas of Higley, Gilbert, and Chandler, and that this water would eventually reach the Gila River several km downstream from Sacaton. Linear deposits of sand and gravels in the Chandler area (Hoyos-Patino, 1985; Huckleberry, 1992) indicate that during the Pleistocene, Queen Creek was probably a single channel that connected all the way to the Gila River, but since the beginning of the Holocene, Queen Creek has been an alluvial fan system.

Historically, the Queen Creek channel was traceable as far as Andrade's Well (Lee, 1905:105) located in the southwest corner of Sec. 20, T. 2 S., R. 7 E. (Sacaton NE, 7.5' quadrangle). On the 1907 Sacaton 15' quadrangle, the channel is mapped as terminating farther upstream in Sec. 27, T. 2 S., R. 7 E. Today the natural channel can be traced approximately to the Southern Pacific Railroad in Section 25, T. 2 S., R. 7 E., and is confined between agricultural fields another 6 km upstream. Downstream from the railroad, Queen Creek has been converted into a series of rectilinear drainage canals emptying into the Gila River on the east side of Gila Butte near Interstate 10. The last large Queen Creek flood was August 19, 1954 where a peak discharge of 1,254 cubic meters per second (43,900 cubic feet per second) was measured at the Whitlow Ranch Dam site (U.S. Geological Survey, 1959:416). Since construction of Whitlow Ranch Dam, there has been considerable development within the Queen Creek flood plain. The most striking example is the community of Queen Valley which is partly located in the Ya2 channel of Queen Creek immediately below the dam.

Discontinuous Ephemeral Streams

In the southwestern part of the project area (Magma quadrangle) Ya2 channels have been disrupted by large diversion dams constructed in the 1960's and the Central Arizona Project canal constructed in the 1980's. Soil Conservation Service aerial photography flown in February, 1954 and enlarged to 1:8,000 scale reveal Ya2 channel patterns before dam construction. The photographs reveal several channels with alternating entrenched and non-entrenched reaches (e.g., photograph DHR-8N-80; on file at SCS office in Chandler). This pattern is typical of a dynamic type of alluvial stream channel known as the discontinuous ephemeral stream (Packard, 1974).

Discontinuous ephemeral streams are common to basins in southern Arizona that have low slopes and fine-textured alluvium. Like braided and meandering streams, discontinuous ephemeral streams have a distinct plan form but with the following components:

headcut --->
single trunk channel --->
braided tributary channel --->
sheet flow area --->
dendritic erosion swale.

The entrenched reach begins with a headcut and is followed by a single trunk channel. Where deeply entrenched, these channels are commonly referred to as "arroyos" (Cooke and Reeves, 1976). The gradient of the stream channel in the incised reach is less than that of the valley slope such that eventually the channel bottom intersects with the valley floor. Here channelized flow branches into several tributary channels and eventually a zone of sheet flow. Because flow depths decrease and the hydraulic roughness increases, sediment is deposited in these areas of sheetflow forming broad channel fans. As sediment accumulates on the channel fans, the gradient immediately upslope decreases whereas the gradient immediately downslope increases. This often results in the initation of a new headcut immediately downstream as a critical slope is attained (Schumm and Hadley, 1957). These components of discontinuous ephemeral streams are not static; both headcuts and channel fans migrate upslope, and the distance between entrenched and unentrenched reaches can vary substantially (e.g., 20 m to 5 km).

Given the dynamic nature of discontinuous ephemeral streams, they can be considered to be unstable fluvial systems. The channel has the capacity to change its hydraulic geometry in an attempt to transport its sediment load in a system of infrequent streamflow. Given their geomorphic instability, discontinuous ephemeral streams are more sensitive to climatic and human perturbations (Bull, 1991). As previously mentioned, many of the ephemeral streams in the eastern part of the Magma and western part of the Florence NE quadrangles are incised and rectilinear and were probably former roads or cattle trails. Sheetflow collects in these features and evolves into rills and gullies. Eventually, headcuts develop and migrate upstream. Discontinuous ephemeral streams are also sensitive to vegetation changes. Vegetation helps to stabilize these channels by reducing surface runoff. When the vegetations is removed, the soils are more susceptible to rill and gully formation. The project area has been grazed for over 100 years, and it is possible that many of the incised Ya2 channels in the project area developed historically like many of the arroyos in southern Arizona (Bahr, 1991).

Lithological Controls on Pediments

The Superstition Mountains rise over 900 m above the desert plain with a series of bold, steep, volcanic cliff-faces. At first glance, the entire piedmont surrounding the range appears to be composed of coalescing alluvial fans. However, on the northwest and south sides of the massif, bedrock is exposed in the piedmont with a thin and discontinuous alluvial cover. Turner and Halpenny (1952:Figure 3) mapped part of the piedmont surrounding the the Superstition Mountains as pediment, and Babcock and Cushing (1952) note that a "partly-buried pediment" extends 3-5 km (2-3 mi) west of where Queen Creek exits the mountains. Empirically, the distinction between an alluvial fan and a pediment is based on arbitrary alluvial thickness or geometry (Bull, 1984). In this study, generally level surfaces containing common exposures of bedrock are defined as pediments. Given this criterion, three pediments are mapped:

Whitlow Ranch Pediment. Located southeast of Whitlow Ranch Dam in the Florence Junction quadrangle, this pediment is developed mostly in Precambrian Pinal Schist (Wilson and Moore, 1959). It forms an embayment between Comet Peak to the north, Dromedary Peak to the south, and hills to the east near Gonzales Pass on Highway U.S. 60. The pediment area is less than 11 km^2 (4 mi^2).

Peralta Pediment. This pediment is located south of the Superstition Mountains near the Peralta Trailhead (Weavers Needle and Goldfield quadrangles). It is developed into Precambrian granite of the Ruin-Oracle suite (Peterson and Jinks, 1983) and covers an area of approximately 16 km^2 (6 mi^2).

Goldfield Pediment. This pediment occurrs near the town of Goldfield (Goldfield quadrangle). It is developed mostly on the Ruin-Oracle granite (Sheridan, 1978) and forms an embayment between the Superstition and Goldfield mountains. In places, a higher level of the pediment is preserved under Ma1 alluvium. The Goldfield Pediment covers an area of approximately 8 km^2 (3 mi^2).

As previously mentioned, pediments are common landforms in Arizona (Bull, 1984; Menges and McFadden, 1981; Morrison, 1985). Cooke (1970) estimates that approximately 30 percent of western Arizona is composed of pediments. More locally, several pediments have been identified and described in south-central Arizona (Table 2). Although common landscape features and favorite topics of study for geomorphologists, they are more easily described than explained. Early hypotheses of pediment formation favored sheetflow processes in beveling irregular bedrock surfaces (McGee, 1897; Davis, 1938), however this explanation is by itself unsatisfactory since sheetflow does not occur unless a prior planar surface exists. Others emphasized shifting channelized flow and lateral planation (Gilbert, 1877; Rahn, 1967), but this also does not explain certain pediment features such as abrupt piedmont-mountain angles along interfluvial divides (see Ritter, 1986:286-294).

Although streamflow is an important part of pediment formation, it is only part of the process. A necessary ingredient in the formation of pediments not recognized by early researchers is chemical weathering (Mabbut, 1966; Moss, 1977). In the Superstition piedmont area, pediments tend to form on coarse-crystalline rocks, especially granite (Table 2). Granite differs from other local fine-textured rocks in that it is more susceptible to chemical weathering processes like hydrolysis and oxidation (Birkeland, 1984). Moss (1977) observed that granitic pediments located approximately 13 km (8 mi) west of the project area in the Usery and Goldfied Mountains are weathered as deep as 20 m (65 ft). Similar deep weathering is evident on the Goldfield Pediment where granite beneath the $Ma1_p$ surface is loose and oxidized, and other surfaces are mantled in grus. Thus these pediments form by a combination of deep subsurface weathering and subsequent surficial stripping by running water.

The tremendous depth of weathering on these pediments implies great surface antiquity and previous moister climates. In general, pediments require over 1 My to form (Bull, 1984), and a reasonable estimate of a regional pedimentation rate is 1 km of mountain retreat per 1 My (Damon and others, 1984). Given this rate, the Goldfield and Peralta pediments, which are both approximately 2.0 km wide, are approximately 2 My in age (Table 2). The largest pediment in the Phoenix Basin is the Spook Pediment; it is at least 8 km wide (see Péwé, 1978: Figure 10), and may be a relict of the mid-Tertiary landscape (Moss, 1977).

Table 2. Physical characteristics and age estimates of selected pediments in south-central Arizona.

Pediment	Location	Altitude	Lithology	No. of Surfaces	Estimated Age	Reference
Goldfield	Superstition Mountains (northwest side)	610-760 m (2,000-2,500 ft)	Ruin Granite (Peterson and Jinks, 1983)	2	2.0 Ma	Huckleberry (this report)
Papago	Papago Buttes in Tempe	350-400 m (1,150-1,300 ft)	Tovrea Granite; Camelback Granite (Péwé and others, 1986)	1	>5 Ma	Péwé and others, 1986
Peralta	Superstition Mountains (south side)	640-790 m (2,100-2,600 ft)	Ruin Granite (Peterson and Jinks, 1983)	1	2.0 Ma	Huckleberry (this report)
Pirate	Santa Catalina Mountains (Pusch Ridge, north side)	790-1.040 m (2,600-3,400 ft)	Wilderness Suite (Catalina Gneiss) (Dickinson, 1987)	3	2-5 Ma 100 ka - 1 Ma < 100 ka	Woodward (1990) Menges and McFadden (1981)
Sacaton	Sacaton Mountains	370-520 m (1,200-1,700 ft)	Precambrian Granite (Balla, 1972)	1	3-6 Ma	Damon and others (1984); Huckleberry (1992)
San Tan	San Tan Mountain area (north of Blackwater)	410-500 m (1,350-1,650 ft)	Precambrian Granite (Balla, 1972)	1	> 4 Ma	Huckleberry (1992)
Spook	Usery Mountains	430-610 m (1,400-2,000 ft)	Precambrian Granite (Reynolds, 1988).	1	Tertiary (5-15? Ma)	Moss, 1977 Pewe, 1978
Table Top	Table Top Mountains	450-820 m (1,500-2,700 ft)	Precambrian Granite (Wilson and Moore, 1959)	5	Tertiary (5-15? Ma)	Bull, 1984

Given that these landforms are at least 1 Ma in age, they have been witness to several glacial-interglacial climate changes (Bradley, 1985), and indeed, climate change may be crucial to their formation. Glacial periods during the Pleistocene were conducive for the formation of soils and residuum on bedrock surfaces in the Southwest (Bull, 1991). A residual cover is considered essential in maintaining the subsurface moisture requisite for chemical weathering, but it may also play an important role in preserving older pediment surfaces. Remnants of Ma1 alluvium derived from the Superstition Mountains that overlie the Goldfield Pediment (mapped as $Ma1_p$) have preserved higher valley surfaces. Alluvial covers and weathered surfaces are probably removed during drier interglacial climates (Bull, 1991). Consequently, oscillating glacial-interglacial climate results in weakening of rock material and subsequent erosion, the two essential ingredients in pediment formation.

Summary

The Superstition piedmont area is composed of mountains, pediments, and alluvial fans that formed during a late Cenozoic environment of dissipating tectonism and fluctuating climate. Six major, temporally discrete, piedmont surfaces are recognized. Five of these are alluvial fan surfaces that range in age from 2 Ma to present. The other surface is a pediment over 1 My old.

The alluvial fan surfaces are moderately dissected in the upper piedmont and morphologically distinct. In contrast, alluvial fan surfaces blend imperceptibly together in the lower piedmont and are minimally dissected. Flooding has traditionally been a problem on the lower piedmont, especially within the Queen Creek drainage system. In areas of discontinuous ephemeral streams, flood hazards are relatively high since channelized reaches of streams are often replaced by broad zones of sheetwash that cover a larger area. Although in many areas, flood hazards have been mitigated directly (e.g., dams) and indirectly (CAP canal) within the last 30 years, several Ya2 and Ya1 surfaces are still prone to flooding.

Ironically, flood control structures have been both beneficial and deleterious to downstream farmers. Whereas dams and drainage canals protect farmers from floods, these structures have also contributed to regionally lowered water tables. Prior to the dams and drainage canals, as much as 50% of the streamflow would infiltrate into the subsurface (primarily on Ya2 and Ya1 surfaces) and help to replenish the aquifer (Babcock and Cushing, 1952). However, both retention and diversion dams retain water on relatively impermeable surfaces (e.g., Ma1 and Ma2) where much of the water is lost to evaporation. Also, drainage canals concentrate the flow and conduct it rapidly to the west thus inhibiting infiltration. Consequently, the phenomenon of lowered water tables driven primarily by groundwater pumping for agriculture has been exacerbated by flood control protection.

Three areas of pediments occur in the Superstition piedmont area. The pediments are formed on coarse-grained rocks that are prone to deep chemical weathering (e.g., Precambrian Oracle-Ruin granite). The distribution of pediments on the Superstition piedmont is relevant to groundwater studies in the region since pediments are areas of low groundwater potential (Bull, 1984). It is important to note these three pediment areas were identified and defined by surface exposures of bedrock. Many other areas in the upper Superstition Mountain piedmont probably contain pediment surfaces at depth and are also areas of limited groundwater storage.

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Appendix A: Soil Descriptions

Geologic Surface: Ya1
Soil Profile: SP-8
Classification: Camborthid
Location: Pinal County, Arizona; NE1/4, NE1/4, SW 1/4, Sec. 9, T. 3 S., R. 10 E.
Physiographic Position: alluvial fan; elevation 561 m.
Topography: Gentle, < 1 % slope.
Vegetation: Creosote (*Larrea*), mesquite (*Prosopsis*), and ironwood (*Olneya*).
Described by: Gary Huckleberry, September 14, 1993.
Remarks: Bw1 contains wavy laminae (< 5 mm thick) of clay. The laminae contain clay skins. Bw2, Bw3, and Bk horizons contain few pebbles throughout matrix.

Bw1 0-9 cm. Light yellowish brown (10YR 6/4) fine sandy loam with dark brown (7.5YR 3/4) clay loam laminae; weak, medium to coarse, platy to angular blocky structure; friable (moist), slightly sticky and slightly plastic (wet); noneffervescent; clear smooth boundary.

Bw2 9-40 cm. Reddish yellow (7.5YR 6/6) fine sandy loam; massive; very friable (moist), slightly sticky and slightly plastic (wet); noneffervescent; gradual smooth boundary.

Bw3 40-75 cm. Strong brown (7.5YR 5/6; moist) fine sandy loam; massive; very friable (moist), slightly sticky and slightly plastic (wet); noneffervescent; gradual smooth boundary.

Bk 75-140+ cm. Brown to strong brown (7.5YR 5/5) fine sandy loam; massive, very friable (moist), slightly sticky and slightly plastic (wet); slightly effervescent.

Geologic Surface: Ya1
Soil Profile: SP-7
Classification: Camborthid
Location: Pinal County, Arizona; SW1/4, SE1/4, NW 1/4, Sec. 19, T. 2 S., R. 9 E.
Physiographic Position: Queen Creek alluvial fan; elevation 496 m.
Topography: Gentle, < 1 % slope.
Vegetation: Creosote (*Larrea*).
Described by: Gary Huckleberry, September 14, 1993.
Remarks: Bw horizon is developed into a recent flood deposit from Queen Creek. There are no primary bedforms preserved, and the deposit predates a nearby Hohokam canal (circa. A.D. 900-1400) still visible at the surface. Underlying horizons are noticeably more oxidized.

Bw 0-35 cm. Pale brown (10YR 6/3) loam; weak, very coarse, angular blocky structure; soft (dry), sticky and very plastic (wet); strongly effervescent; abrupt smooth boundary.

2Bwb 35-55 cm. Light yellowish brown to yellowish brown (10YR 5.5/4) sandy loam; massive; slightly hard (dry), slightly sticky and plastic (wet); noneffervescent; gradual smooth boundary.

2Bkb 55-130 cm. Strong brown (7.5YR 5/6) sandy clay loam; massive; hard to very hard (dry), sticky and plastic (wet); strongly effervescent; abrupt smooth boundary.

3Bkb 130-145+ cm. Strong brown (7.5YR 5/6) gravelly sandy clay loam; massive; very hard (dry), sticky and plastic (wet); strongly effervescent.

Geologic Surface: Ya1
Soil Profile: SP-13
Classification: Camborthid
Location: Pinal County, Arizona; SW1/4, NE1/4, NW 1/4, Sec. 12, T. 1 S., R. 8 E.
Physiographic Position: Alluvial fan; elevation 522 m.
Topography: Gentle, < 1 % slope.
Vegetation: Creosote (*Larrea*), bursage (*Franseria*), ironwood (*Olneya*).
Described by: Gary Huckleberry, September 13, 1993.
Remarks: Alluvial unconformity with Holocene alluvium overlying Pleistocene soil. Surface gravels (A and Bw horizons) have been enriched in eolian silts.

A — 0-2 cm. Light yellowish brown (10YR 6/4) sandy loam; weak, fine to medium, platy structure; loose (dry), slightly sticky and slightly plastic (wet); noneffervescent; clear smooth boundary.

Bw — 2-18 cm. Yellowish brown (10YR 5/4) very gravelly sandy loam; single grain; loose (dry), not sticky and not plastic (wet); noneffervescent; clear smooth boundary.

Bk — 18-90 cm. Yellowish brown (10YR 5/4) very gravelly, coarse sand; single grain; loose (dry), not sticky and not plastic (wet); noneffervescent matrix but strongly effervescent on rinds of clasts (Stage II carbonates); abrupt smooth boundary.

2Coxb — 90-150 cm. Reddish brown (5YR 5/4) very gravelly coarse sand; single grain; loose (dry), not sticky and not plastic (wet); slightly effervescent; abrupt smooth boundary.

3Bkb — 150-180+ cm. Reddish yellow (7.5YR 6/6) sandy loam with many, medium, promiment, pink (7.5YR 8/2) mottles; massive; soft and very hard (dry), not sticky and slightly plastic (wet); violently effervescent (Stage IV carbonates).

Geologic Surface: Ma2
Soil Profile: SP-5
Classification: Haplargid
Location: Pinal County, Arizona; SE1/4, SW1/4, NE 1/4, Sec. 12, T. 2 S., R. 9 E.
Physiographic Position: Lower Queen Creek alluvial fan surface; elevation 560 m.
Topography: Gentle, 1 % slope.
Vegetation: Creosote (*Larrea*), bursage (*Franseria*), ironwood (*Olneya*), saguarro (*Cereus*), and palo verde (*Cercidium*).
Described by: Gary Huckleberry, September 14, 1993.
Remarks: Soil pit is approximately 60 m north of terrace scarp. Btk horizons are developed into channel deposits; other horizons are developed into overbank alluvium.

A/Bw 0-10 cm. Brown (7.5YR 5/4) sandy clay loam; moderate, very coarse, platy and angular blocky structure; slightly hard (dry), slightly sticky and slightly plastic (wet); noneffervescent; abrupt smooth boundary.

Bt1 10-35 cm. Strong brown (7.5YR 5/6) sandy clay loam; weak, coarse, angular blocky structure; hard (dry), slightly sticky and slightly plastic (wet); noneffervescent; gradual smooth boundary.

Bt2 35-55 cm. Strong brown (7.5YR 4/6) sandy clay loam; weak, coarse, angular blocky structure; hard (dry), sticky and plastic (wet); noneffervescent; many, moderately thick, clay skins on ped faces; abrupt smooth boundary.

Btk 55-130+ cm. Strong brown (7.5YR 4/6) very cobbly sandy clay with common, very fine, prominent, white (7.5YR N/8) mottles; single grain; hard (dry), slightly sticky and slightly plastic (wet); strongly effervescent on carbonate mottles (Stage I); many, moderately thick, clay skins forming skeletal bridges.

Geologic Surface: Ma2
Soil Profile: SP-6
Classification: Haplargid
Location: Pinal County, Arizona; NE1/4, SW1/4, NW 1/4, Sec. 19, T. 2 S., R. 8 E.
Physiographic Position: Queen Creek alluvial fan surface; elevation 494 m.
Topography: Gentle, < 1 % slope.
Vegetation: Creosote (*Larrea*), bursage (*Franseria*), ironwood (*Olneya*), and palo verde (*Cercidium*).
Described by: Gary Huckleberry, September 14, 1993.
Remarks: Very similar to soil SP-5 with Queen Creek overbank and channel deposits.

A/Bw 0-12 cm. Light yellowish brown (10YR 6/4) sandy loam; weak, very coarse, angular blocky structure; slightly hard (dry), sticky and plastic (wet); noneffervescent; gradual smooth boundary.

Bw 12-40 cm. Strong brown (7.5YR 5/6) sandy clay loam; weak, very coarse, subangular blocky structure; slightly hard to hard (dry), sticky and plastic (wet); noneffervescent; abrupt smooth boundary.

2Btkb 40-125+ cm. Yellowish red (5YR 5/6) very cobbly sandy clay loam; single grain; slightly hard (dry), slightly sticky and slightly plastic (wet); effervescent; carbonates occur as discontinuous rinds on cobbles (Stage I); few, moderatley thick clay skins forming skeletal bridges and colloidal stains.

Geologic Surface: Ma2
Soil Profile: SP-9
Classification: Haplargid
Location: Pinal County, Arizona; NE1/4, SE1/4, SE 1/4, Sec. 9, T. 3 S., R. 10 E.
Physiographic Position: Alluvial fan surface; elevation 564 m.
Topography: Gentle, 1 % slope.
Vegetation: Creosote (*Larrea*), bursage (*Franseria*), cholla (*Opuntia*), and palo verde (*Cercidium*).
Described by: Gary Huckleberry, September 14, 1993.
Remarks: Bw1 contains wavy laminae (< 5 mm thick) of clay (as in soil profile SP-8). The laminae contain clay skins. There is a surface lag of quartz and schist on the interfluves.

Bw1 0-12 cm. Reddish yellow (7.5YR 6/6) very gravelly loam with strong brown (7.5YR 4/6) clay loam laminae; weak, medium, angular blocky structure; very friable (moist), slightly sticky and slightly plastic (wet); noneffervescent; gradual smooth boundary.

Bw2 12-56 cm. Strong brown (7.5YR 5/6) very gravelly sandy clay loam; massive; very friable (moist), sticky and plastic (wet); noneffervescent; gradual smooth boundary.

Bt 56-70 cm. Strong brown (7.5YR 5/6) very gravelly sandy clay loam; massive; firm (moist), sticky and plastic (wet); noneffervescent; few, moderately thick clay skins forming skeletal bridges; abrupt smooth boundary.

Btk1 70-120 cm. Strong brown (7.5YR 5/6) very gravelly sandy clay loam with few, very fine, prominent white (7.5YR N8/) mottles; massive; very friable (moist), sticky and plastic (wet); strongly effervescent; carbonates occur as very fine filaments (Stage I); common, moderately thick, clay skins forming skeletal bridges and colloidal stains; gradual smooth boundary.

Btk2 120-130+ cm. Brown to dark brown (7.5YR 4/4) sandy clay loam with few, very fine, prominent white (7.5YR N8/) mottles; massive; friable (moist), sticky and plastic (wet); slightly effervescent; carbonates occur as very fine filaments (Stage I); common, moderately thick, clay skins forming skeletal bridges.

Geologic Surface: Ma2/Ya1
Soil Profile: SP-12
Classification: Haplargid
Location: Pinal County, Arizona; NW1/4, SE1/4, SE 1/4, Sec. 27, T. 3 S., R. 9 E.
Physiographic Position: Alluvial fan surface; elevation 490 m.
Topography: Gentle, < 1 % slope.
Vegetation: Creosote (*Larrea*).
Described by: Gary Huckleberry, September 14, 1993.
Remarks: Soil pit is located approximately 100 m downstream from the Magma Diversion Dam. Carbonate mottles in the Btk2 and Btk3 horizons have a vertical fabric.

Bw 0-16 cm. Light brown (7.5YR 6/4) sandy loam; weak, medium, subangular blocky structure; soft (dry), slightly sticky and plastic (wet); noneffervescent; abrupt smooth boundary.

Bt 16-23 cm. Strong brown (7.5YR 4/6) sandy clay loam; moderate, coarse, angular blocky structure; extremely hard (dry), sticky and plastic (wet); noneffervescent; few, thin, clay skins on ped faces; clear smooth boundary.

Btk1 23-45 cm. Strong brown (7.5YR 4/6) sandy clay loam; moderate, coarse, angular blocky structure; extremely hard (dry), sticky and plastic (wet); strongly effervescent; few, thin, clay skins on ped faces; clear smooth boundary.

Btk2 45-70 cm. Strong brown (7.5YR 5/6) clay loam with few, fine, prominent white (7.5YR N8/) mottles; weak, medium, angular blocky structure; extremely hard (dry), sticky and very plastic (wet); strongly effervescent; carbonates occur as very fine filaments (Stage I); few, thin, clay skins on ped faces; clear smooth boundary.

Btk3 70-135+ cm. Strong brown (7.5YR 5/6) clay loam with many, coarse, prominent white (7.5YR N8/) mottles; weak, medium, angular blocky structure; extremely hard (dry), sticky and very plastic (wet); violently effervescent; carbonates occur as many, coarse, soft masses (Stage II+); few, thin, clay skins on ped faces.

Geologic Surface: Ma1
Soil Profile: SP-1
Classification: Paleargid
Location: Pinal County, Arizona; NE1/4, SW1/4, SE 1/4, Sec. 13, T. 2 S., R. 8 E.
Physiographic Position: Upper Queen Creek alluvial fan surface; elevation 491 m.
Topography: Gentle, < 1 % slope.
Vegetation: Creosote (*Larrea*), bursage (*Franseria*), ironwood (*Olneya*), and palo verde (*Cercidium*).
Described by: Gary Huckleberry, September 14, 1993.
Remarks: Fine grained volcanics (mostly rhyolite) form discontinuous lag on surface.

A/Bw	0-10 cm. Light brown to reddish yellow (7.5YR 6/5) sandy clay loam; moderate, very coarse, platy and angular blocky structure; slightly hard (dry), sticky and plastic (wet), noneffervescent, abrupt smooth boundary.
Bt	10-35 cm. Strong brown (7.5YR 4/6) sandy clay; moderate, coarse, angular blocky structure; very hard (dry), sticky and plastic (wet), noneffervescent; common, moderately thick, clay skins on ped faces; abrupt smooth boundary.
Btk1	35-68 cm. Strong brown (7.5YR 4/6) sandy clay with few, fine, prominent pinkish white (7.5YR 8/2) mottles; moderate, coarse, angular blocky structure; extremely hard (dry), sticky and very plastic (wet), strongly effervescent; carbonates occur as fine filaments (Stage I); common, moderately thick, clay skins on ped faces; abrupt smooth boundary.
2Btk2b	68-100 cm. Reddish yellow (7.5YR 6/6) very cobbly sandy clay with common, fine, prominent pinkish white (7.5YR 8/2) mottles; single grain; hard (dry), sticky and slightly plastic (wet), strongly effervescent; carbonates occur as discontinous rinds on clasts (Stage I+), few, moderately thick, clay skins forming skeletal bridges and colloidal stains.
2Bkmb	100-115+ cm. White (7.5YR N8/) petrocalcic horizon; massive; extremely hard; violently effervescent; carbonates indurate horizon (Stage III+).

E

Geologic Surface: Ma1
Soil Profile: SP-4
Classification: Paleargid
Location: Pinal County, Arizona; SW1/4, NE1/4, NW1/4, Sec. 12, T. 2 S., R. 9 E.
Physiographic Position: Upper Queen Creek alluvial fan surface; elevation 561 m.
Topography: Gentle, < 1 % slope.
Vegetation: Creosote (*Larrea*), bursage (*Franseria*), cholla (*Opuntia*).
Described by: Gary Huckleberry, September 10, 1993.
Remarks: Located approximately 25 m from terrace scarp and 40 m from power line. Quartz gravels form discontinuous lag on surface.

A — 0-3 cm. Yellowish brown (10YR 5/4) gravelly sandy clay loam; moderate, medium, platy and angular blocky structure; extremely hard (dry), sticky and plastic (wet), noneffervescent; gradual smooth boundary.

Bt1 — 3-24 cm. Strong brown (7.5YR 5/6) gravelly sandy clay loam; weak, medium to coarse, angular blocky structure; hard (dry), sticky and plastic (wet), noneffervescent; common, thin, clay skins on ped faces; gradual smooth boundary.

Bt2 — 24-40 cm. Strong brown (7.5YR 5/6) sandy clay; massive; very hard (dry), very sticky and plastic (wet), noneffervescent; common, thin, clay skins on ped faces; gradual smooth boundary.

Btk — 40-88 cm. Strong brown (7.5YR 5/6) gravelly sandy clay; massive; very hard (dry), very sticky and very plastic (wet), strongly effervescent; carbonates occur as filaments and continuous rinds on clasts (Stage II); many, moderately thick, clay skins on ped faces; gradual smooth boundary.

Bkm — 88-150+ cm. Pink (7.5YR 8/4) very gravelly sandy clay with many, medium, distinct, strong brown (7.5YR 5/6) mottles; massive; extremely hard; very sticky and very plastic; violently effervescent; carbonates indurate matrix (Stage III+).

Geologic Surface: Ma1
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+).

Geologic Surface: Oa
Soil Profile: MGR-18
Classification: Paleargid
Location: Pinal County, Arizona; SE 1/4, SW 1/4, Sec. 33, T. 4 S., R. 11 E.
Physiographic Position: Ridge of relict alluvial fan; elevation 620 m.
Topography: 1-2 % slope
Vegetation: Bursage (*Franseria*), palo verde (*Cercidium*), creosote (*Larrea*), assorted grasses.
Sampled by: Gary Huckleberry, September 15, 1992.
Remarks: Soil pit excavated approximately 100 m northwest of the intersection of Hawkview and Whitlow Ranch roads on top of ridge next to a two-track road. Variable cobble lithologies at surface including granite, basalt, andesite porphyry, and hematite. Lag of grussy gravels (< 1 cm) at surface; no pavement. Soil colors are for dry conditions.

A 0-2 cm. Light brown (7.5YR 6/4) gravelly loamy coarse sand; weak, fine, subangular blocky structure; slightly hard (dry), nonsticky and nonplastic (wet); noneffervescent; clear smooth boundary.

Bt 2-40 cm. Red (2.5YR 4/6) gravelly sandy clay; weak, fine to medium, angular blocky structure; hard (dry), slightly sticky and slightly plastic (wet); noneffervescent; abrupt smooth boundary.

Bkm 40-45+ cm. White (5YR 8/1); extremely hard; violently effervescent; carbonates completely indurate horizon, laminar top (Stage IV).

Geologic Surface: O (Target Terrace)
Soil Profile: MGR-11
Classification: Durorthid
Location: Pinal County, Arizona; SW 1/4, NW 1/4, NE 1/4, Sec. 21, T. 4 S., R. 9 E.
Physiographic Position: Gila River terrace; elevation 471 m.
Topography: Slightly dissected; slopes < 1 %.
Vegetation: Creosote (*Larrea*), bursage (*Franseria*), and palo verde (*Cercidium*).
Sampled by: Gary Huckleberry, June 8, 1992.
Remarks: Soil exposed in pit excavated adjacent to exploratory well. Carbonates in Av and Bk1 are disseminated. Terrace tread has desert pavement with interlocking stones covering approximately 90% of surface. Black Mn varnish is common on top of clasts; orange Fe varnish is common on bottoms of clasts. Varnish color generally varies with clast lithology. Bkqm fragments are very common at surface. In 2Bkqm horizon, some granites are saprolitic, and some cryptocrystalline rocks are fractured. Largest cobble in profile has 15 cm diameter. Colors are for dry soil.

Av 0-4 cm. Light brown (7.5YR 6/4) silty clay; weak, medium, angular blocky structure; slightly hard (dry), sticky and plastic (wet); violently effervescent; clear smooth boundary.

Bk1 4-16 cm. Light brown (7.5YR 6/4) sandy clay loam; weak, fine, subangular blocky structure; slightly hard (dry), sticky and plastic (wet); strongly effervescent; clear smooth boundary.

Bk2 16-40 cm. Light brown (7.5YR 6/4) gravelly sandy clay loam with many, coarse, distinct pinkish white (7.5YR 8/2) mottles; weak, fine to medium, subangular blocky structure; slightly hard to hard (dry), sticky and plastic (wet); violently effervescent; carbonates occur as continuous 1-3 mm rinds (Stage II+); abrupt smooth boundary.

2Bkqm 40-120+ cm. White to pinkish white (7.5YR 8/1) gravels and cobbles; massive; extremely hard (dry); violently effervescent; carbonates engulf matrix and are laminar at top of horizon (Stage IV+).