SURFICIAL GEOLOGY, SOILS, AND VEGETATION PATTERNS OF THE TABLE TOP MOUNTAIN AREA, PINAL AND MARICOPA COUNTIES, ARIZONA

by

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Introduction

The diversity of alluvial fan and pediment ages and the pristine Sonoran desert vegetation of the Table Top Mountains make this region ideally suited to study relationships between geomorphic surfaces, soil development, and vegetation distribution. The Table Top Mountains and flanking piedmonts, located about 30 km (20 mi) southwest of Casa Grande and about 50 km (30 miles) east-southeast of Gila Bend in south-central Arizona, lie mostly within the Table Top Wilderness Area, administered by the Bureau of Land Management (Fig. 1). The range is dominated by the mesa-like Table Top Mountain (1333 m, 4374 ft elevation) and is surrounded by smaller hills and extensive alluvial deposits of varying ages. This study describes the surficial geology, soils, and vegetation patterns on the piedmonts flanking the mountain mass.

Methods

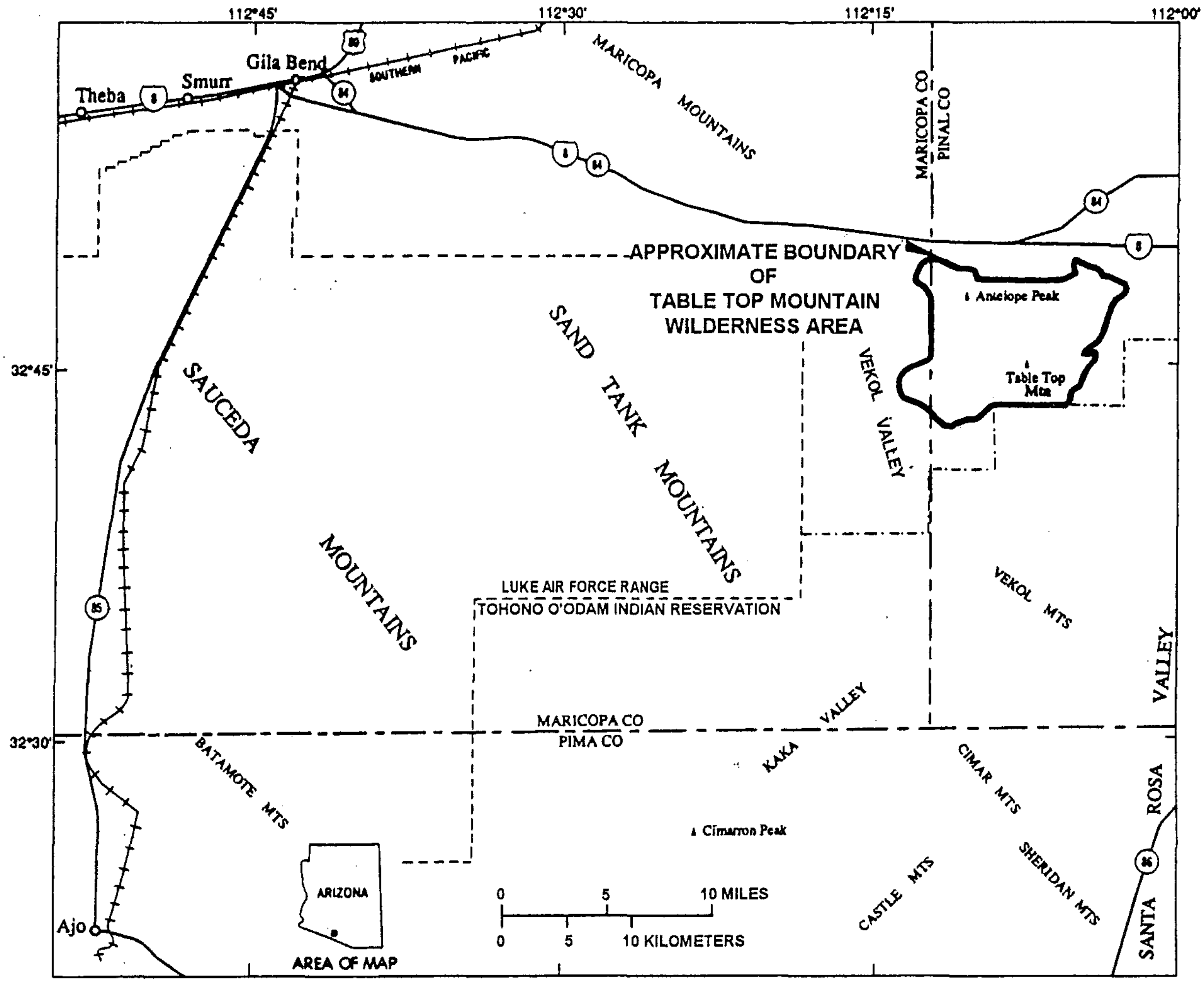
A surficial geologic map of the piedmonts flanking Table Top Mountain was prepared in three stages. First, true-color aerial photographs at a scale of 1:24,000 were examined stereoscopically to identify and delineate landform units with different surficial characteristics. These characteristics included color, roughness, degree of erosion of deposit edges (rounded or sharp edges), extent of stream dissection, and topographic relief.

Second, map unit delineations on the aerial photographs were extensively field checked and additional features distinguishing surface ages were observed. Desert pavement and rock varnish development, and especially the degree of soil development, aided in assessing relative ages of landform units. Soil trenches were excavated into alluvial fan deposits by backhoe at eight locations outside of the wilderness area, and horizon development was described using Soil Survey (1992) nomenclature modified by Birkeland and others (1991). Morphogenetic stages of calcium carbonate horizon development were described (Gile and others, 1966; Machette, 1985). Comparison of soil properties with units mapped by Hall (1991) allowed classification to the subgroup level (Soil Survey, 1992). Soils exposed in trenches represented surfaces of 6 different ages. Soil descriptions are included in Appendix A. Several additional surfaces, including pediments, active channels, and oldest units not accessible by road, were identified but not represented by backhoe trenches.

Third, map units were transferred to mylar overlaid on 1:24,000 rectified orthophotographs; some generalization was made because stereo photo pairs allowed a higher level of resolution than did the orthophotographs. The map units were correlated across the mapping area, and relative and numerical ages were estimated. Age control is non-existant in the mapping area, so soil development and other age-related features such as dissection and desert pavement were compared with radiometrically dated soils in the Desert Project study area near Las Cruces, NM (Gile and others, 1981), with soils in southeastern Arizona (McFadden, 1981; Menges and McFadden, 1981), and in the Lower Colorado River area (Bull, 1991). The four oldest alluvial surfaces are difficult to distinguish based on soil properties, and their relative ages were assessed based on topographic position and the degree of erosion.

After mapping was completed, vegetation was surveyed in circular plots (McAuliffe, 1991) to obtain cover and abundance of perennial species on surfaces of contrasting age. Plot locations coincide with soil trenches, which are indicated on the map. Raw data for logarithmic cover and density classes are included in Appendix B. Statistical analysis techniques included ordination and principle components analysis to distinguish patterns of similarity and dissimilarity among sampled plots (Bolton and Pendall, in preparation).

Figure 1. Location of Table Top Mountain surficial geology mapping area, in south-central Arizona. Bold line shows BLM Wilderness Area boundary; mapping area boundary extends approximately 3-5 km beyond the Wilderness Area, but does not extend into the Tohono O'Odam Indian Reservation.



Geologic Setting

The Table Top Mountains lie in the Sonoran Desert portion of the Basin and Range physiographic province, which is characterized by mountain ranges surrounded by deep, alluvial fill. Bedrock geology of the area has been mapped by Peterson and others (1987, 1988) and Gray and others (1992); the following is a summary of their work. The oldest rock in the study area, Proterozoic Pinal Schist, makes up the core of the range, and underlies most of the central part of the mapping area. The schist is composed of muscovite, quartz and feldspar derived from supracrustal lithologies. It makes up the bulk of the gravels in the alluvium of all ages, and a lag of metamorphic quartz derived from the Pinal Schist is common on alluvial surfaces of intermediate age. Oracle Granite of Peterson (1938), dated by K-Ar on biotite to 1328 +/- 40 Ma[1] (Balla, 1972) intrudes the Pinal Schist, and is exposed in much of the southeastern corner and in a band across the northern portion of the mapping area. The Oracle Granite is a coarse-grained granodiorite, and in places forms extensive pediments which may or may not be overlain by alluvial gravels. A thin, localized outcrop of middle Proterozoic Pioneer Formation of the Apache Group unconformably overlies Proterozoic rocks near the top of Table Top. This formation is composed of fine-grained red sandstone.

Fossiliferous Paleozoic limestone (possibly Mississippian Escabrosa Limestone, known from the Vekol Mountains to the south of the study area; Steve Reynolds, personal communication, 1994) that was not observed by previous mappers was noticed in the present study cropping out in a small area in the northeastern portion of the mapping area. This limestone is locally abundant in alluvial gravels across much of the mapping area, suggesting a formerly more extensive exposure.

In the Late Cretaceous and Early Tertiary, magmatism and compressional deformation affected southern Arizona, followed by a period of quiescence. Crustal extension in the latest Oligocene to early Miocene uplifted ranges throughout southern Arizona, including the Table Top Mountains. Sediments shed from these early ranges may have flowed into the Gila Bend "depocenter" to the west (Jon Spencer, personal communication, 1994).

Miocene basaltic andesite and olivine basalt cap the Proterozoic core of the Table Top Mountains. Several flow units make up the nearly horizontal surface of Table Top. A K-Ar date of 23 +/- 5.2 Ma was obtained on a whole-rock sample of the olivine basalt from Antelope Peak (Shafiqullah and others, 1980). These units overlie tuff units and a Tertiary conglomerate containing clasts of the Apache Group (including quartzites and limestones), Oracle Granite, and Pinal Schist. A tilted, poorly consolidated sandstone (**Tso**) was observed in the northeastern part of the study area, underlying sub-horizontal alluvial fan gravels. This outcrop may be correlated with the sedimentary member of the Early Miocene (24-20 Ma) Sil Murk Formation (Gilbert, 1991) in the eastern Gila Bend Mountains. The tilting of this sandstone may represent the most recent phase of tectonic activity in the area, although it is unclear whether the sandstone rests on the same block as the Table Top flows, or if it is separated from the horizontal flows by a fault zone.

Geomorphic Setting

The study area includes several types of landforms that have arisen from a variety of physical processes. Large features such as mountain masses and surrounding basins are the products of tectonic and volcanic activity over the past 30 to 40 My. Late Cenozoic basin filling in the Table

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

Top Mountains area probably started during the last stages of volcanism and tectonism, in Early Miocene time. Tilted sediments containing volcaniclastic lithologies (**Tso**) represent this early phase; most of this material has been buried or removed by subsequent erosion. Following uplift events that caused tilting of **Tso** units, pedimentation (at the mountain fronts) and basin filling (in the valleys) commenced again, depositing alluvium which has not been tilted. The presence of extensive pediments and sinuous, embayed mountain fronts suggest that southern Arizona has been tectonically quiescent since at least middle Miocene time (Menges and Pearthree, 1989); basin filling and pedimentation near Table Top has probably been going on at least since then.

Erosion of the upland areas of Table Top Mountains has built substantial piedmonts, or bajadas, flanking the hillslopes. When observed in detail, these piedmonts are actually a mosaic of coalescent alluvial fans and pediment surfaces of different ages. In the absence of major tectonic events, episodic climatic fluctuations have resulted in erosion and redistribution of basin fill, producing landforms such as stream terraces and inset alluvial fans. Synchroneity of fan sequences across a wide area suggests regional climatic control. Morrison (1984), working at a scale of 1:250,000, identified six Quaternary surficial units in the Table Top Mountain region, which occur as alluvial fans, pediments, and stream terraces. The present study focuses at a larger scale (1:24,000) on the geomorphic surfaces produced by Late Cenozoic climatic processes which have acted over definable time spans and which have distinct geographic boundaries. Because hillslopes and colluvial deposits (except landslides) are the result of continual erosion, they are not usually confined to time-stratigraphic boundaries, and are not included in this mapping effort.

An overview of the Table Top area is shown in Figure 2. A variety of differently-aged alluvial fans can be identified, with the oldest surfaces showing up most prominently. Slow erosion rates and cementation of surficial deposits by calcium carbonate ("caliche," or petrocalcic soil horizons) have contributed to the preservation of these late Pliocene to early Pleistocene alluvial fans in the Table Top area. The light color of these surfaces, due to the reflective caliche cap and to relatively sparse vegetative cover, makes them noticeable in aerial view (Fig. 2). One prominent Plio-Pleistocene fan, informally named Prospect Fan, is easily seen from Interstate 8 (Fig. 2). Fans of this age (**Oo**), or slightly younger (**O1**, **O2**, **Mo**), are common in the mapping area; some are indicated in Fig. 2. Indian Butte is a remnant of an even older deposit (**Tsy**); the original surface is not preserved, and alluvial gravels are mostly eroded from the knife-edge ridge (Fig. 2). Few remnants of this age surface remain in the mapping area. Middle Pleistocene (**M**) to Holocene (**Y**) surfaces are common in distal regions and along major, active streams (Fig. 2). These units are finely dissected in a dendritic drainage pattern and are not cemented by caliche at the surface.

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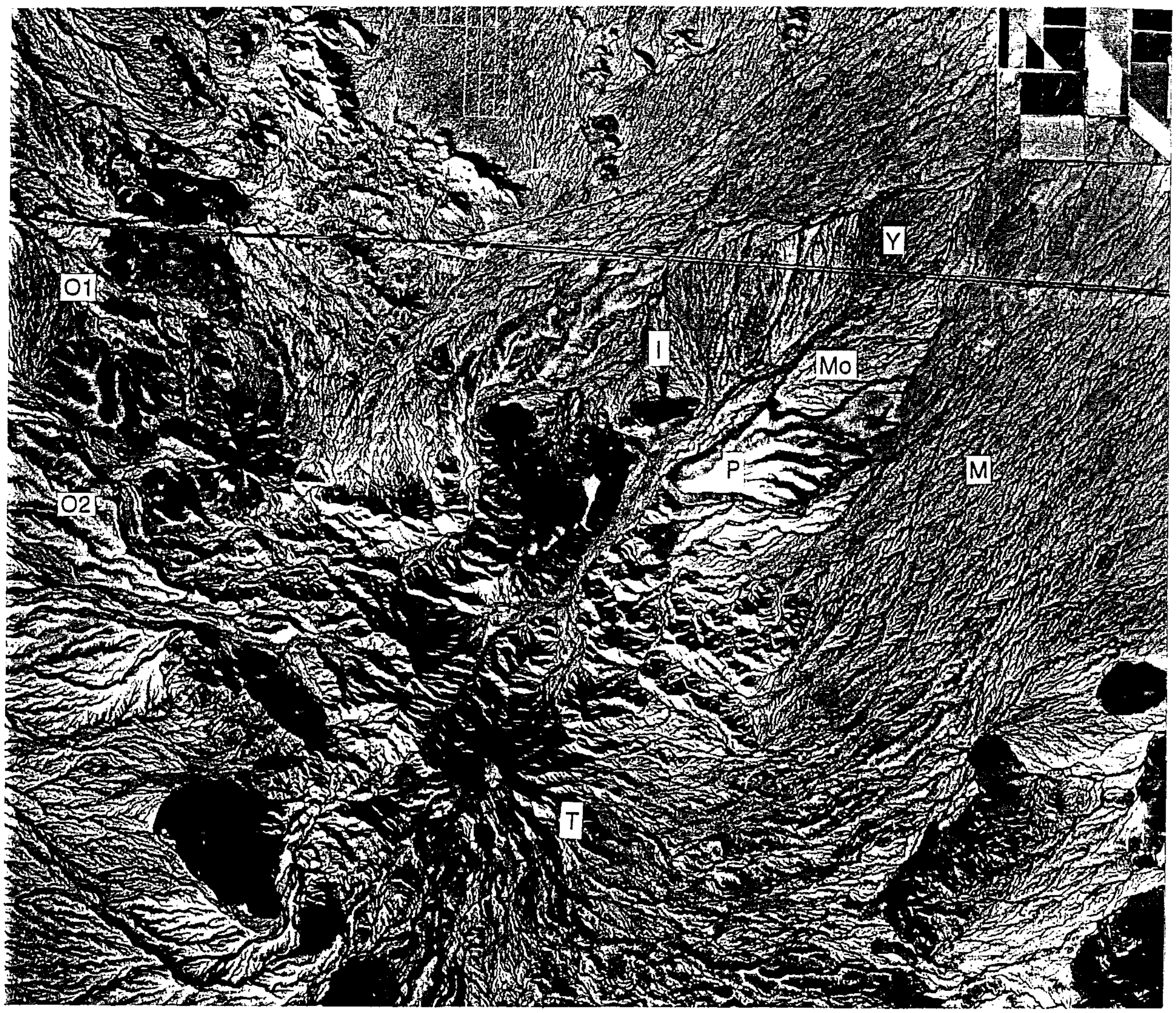
Figure 2. Aerial view of Table Top Mountain study area (approximate scale = 1:125,000). Indian Butte (I) is a narrow, eroded remnant of **Tsy**, the oldest alluvial unit with significant surficial exposures. Late Pliocene to early Pleistocene fans are noticeable by their relief, light-colored surfaces (due to the reflectance of caliche cap), and deep dissection. **Mo**, **O2**, **O1**, and **Oo** are examples of increasingly older fans, ranging from middle- to early-Pleistocene (**Mo**) to late Pliocene (**Oo**). "Prospect Fan" (**P**) is the largest remnant of **Oo**-age deposits; younger **Mo** and **O2** surfaces are much more extensive. Middle Pleistocene (**M**) to Holocene (**Y**) units are characterized by shallower, dendritic drainage patterns and are common in distal portions of piedmonts and as terraces along active streams. Table Top Mountain itself (**T**) is the eroded remnant of an early Miocene basalt flow.



Climate

The climate of the study area is currently hot and dry, with distinctly biseasonal rainfall. At Casa Grande (elevation 424 m (1405 feet)), where records have been kept since 1951, average July temperature is 33 °C (91 °F), and average January temperature is 10 °C (50 °F). Occasional freezing temperatures are recorded during most winters, but snow is rare and not persistent. Annual precipitation at Casa Grande is about 22 cm (8.5 inches), of which about half falls between July and September (Sellers and Hill, 1974). Late summer rainfall occurs as heavy thunderstorms when moist air sweeps northwards from the Gulf of California and the Gulf of Mexico. Winter precipitation usually is brought by cyclonic storms originating in the Pacific. It is usually less intense and therefore infiltrates into the soil more deeply than summer rainfall.

The climate of the Sonoran desert has not remained constant over the time period represented by the piedmont surfaces around Table Top. The transition from the relatively warm and stable Pliocene climate to the dramatic glacial-interglacial cycles of the Pleistocene resulted in major aggradation and erosion events recorded as alluvial fans and fan remnants in the study area. Analysis of packrat middens, collections of vegetation stored by rodents (*Neotoma* spp.) in crevices and preserved for tens of thousands of years, indicates that the climate as we know it today has only existed for about 4000 years (VanDevender, 1990). Middle Pleistocene midden samples (>30,000 ^{14}C years B.P.) from the western Sonoran Desert contain fragments of juniper (*Juniperus monosperma*), pinyon pine (*Pinus monophylla*), and Joshua tree (*Yucca brevifolia*), indicating cooler summers and a greater proportion of winter precipitation than today. However, precipitation probably reached a maximum during the late Pleistocene (30,000 to 10,000 ^{14}C years B.P.), and the coexistence of frost-sensitive Whipple yucca (*Yucca whipplei*) and barrel cactus (*Ferocactus* spp.) with juniper and pinyon pine suggests that late Pleistocene seasonal temperature extremes were less than those of today (Van Devender, 1990). If the ground remained thawed, precipitation falling during winter months would have infiltrated more deeply than summer moisture due to lowered evaporation rates. Due to the increased effectiveness of leaching and equable temperatures, as well as the increased proportion of winter rain, late Pleistocene climate was apparently more conducive to weathering of soil minerals than today's interglacial moisture regime.

Vegetation

The Table Top Mountains lie within the Arizona Upland unit of the Sonoran Desert. The full altitudinal range of the Arizona Upland (300-1300 m) is represented in the project area. The Arizona Upland desert differs from other deserts of the Southwest in its richness in arboreal and succulent plants and in its high species diversity of ephemeral herbs. Here the saguaro cactus (*Carnegiea gigantea*) reaches its highest population density. High species diversity has been attributed to the bimodal precipitation regime.

Preliminary studies at Table Top indicate a strong relationship between vegetation, geomorphology and soils. Previous assumptions about gradual changes in species composition as elevation changes, for example from proximal to distal parts of alluvial fans, have been shown at nearby Sonoran desert sites to be too simplistic (McAuliffe, 1994). Patchy vegetation distributions can often be seen to correspond to abrupt boundaries of geomorphic surfaces (McAuliffe, 1994). Species appear to respond individually to limiting factors, principally water and nutrients. Abrupt changes in soil type at boundaries of geomorphic surfaces are often accompanied by changes in particle size distribution, and thus water holding capacity. Soil clay content appears to be a key influence on vegetation distribution because of its high water holding capacity. Species diversity is highest along ephemeral streams, where underflow is a dependable water source, and on hillslopes, where diverse microenvironments allow a variety of plants to find niches.

On piedmonts, the most abundant perennial species include the ubiquitous creosote (*Larrea tridentata)*, triangle leaf bursage (*Ambrosia deltoidea*), foothills palo verde (*Cercidium microphyllum*), and ratany (*Kramaria grayi*). The average cover value for all plots surveyed on piedmonts is about 17%. However, the standard deviation is about 10%, showing that vegetative cover is quite variable on different aged surfaces and in different microtopographic positions. Values range from less than 10% cover on young, sandy surfaces to more than 40% cover in swales on intermediate-age surfaces. Young surfaces tend to be dominated by creosote, and to have a low diversity of other perennials (except adjacent to washes). Bursage is usually the second most abundant species, with one-half to one-fourth the cover of creosote. On the intermediate-age surfaces with clay-rich argillic horizons, the cover values of bursage and creosote are usually reversed, with bursage dominant, and ratany common. On old surfaces with exposed petrocalcic horizons, creosote has the highest cover, and species diversity tends to be higher than on other piedmont surfaces. This may be because old surfaces have the highest small-scale patchiness of soil texture and water holding capacity. Due to uneven erosive stripping and subsequent deposition of eolian sediments, there is high variability in depth of fine sediment, and thickness, induration, fracturing, and degree of weathering of petrocalcic horizons on middle-Pleistocene and older surfaces. This variability in soil thickness and potential rooting depth, particularly in fractures, may provide more "niches" than on other surfaces. Additionally, the depth of water penetration is limited by caliche, possibly concentrating water in shallow soil zones where roots of many desert shrubs are concentrated.

Microtopographic effects on vegetation patterns are evident in a comparison of vegetation growing in broad swales and on undissected interfluve areas on intermediate-age surfaces. Although when these surfaces are surveyed as a whole, bursage is similar to or greater than creosote in cover value, bursage is prevalent mainly in broad, shallow (<1 m deep) swales, and creosote dominates interfluve areas with strong desert pavement. Creosote apparently has a fairly uniform cover across the extent of this landscape unit, but in the interfluve areas it forms a virtual "monoculture." Bursage, however, attains a fairly high density in areas receiving run-on, such as swales. Total cover values in the swales is high due to the presence of palo verde and ironwood trees, in addition to bursage. The dominance of creosote on intermediate-age surfaces with moderate argillic horizons in the Table Top area is in contrast to the findings of McAuliffe (1994) on piedmonts near Tucson, Arizona. There, bursage appears to be more common than creosote on soils with argillic horizons. Apparently, at elevations above about 600 m, bursage dominates on clayey soils, but at lower elevations, creosote may be more common (McAuliffe, personal communication, 1994).

Map Units

Generalized bedrock mapping units are based on, and somewhat modified from, those in Peterson and others (1987). Map symbols for alluvial units in this report are modified from a system used by Huckleberry (1992; 1993a; 1993b; 1994) and Demsey and Pearthree (1994). The oldest basin fill unit, Tertiary sandstone with dipping and slightly faulted beds, is shown as **Tso**. Old alluvial remnants, probably pre-Quaternary, that cap bedrock ridges are grouped into the unit **Tsy**. Quaternary units are divided into units of three general ages, young (**Y**), intermediate (**M**) and old (**O**). All surfaces are composed of alluvium except where pediment (**P**) is indicated. **O** units are undivided where relative topographic position is unclear, or may be divided into three surfaces of decreasing height above streams, **Oo**, **O1**, and **O2**; weathering characteristics on the 3 **O** age units are similar. **M** units are undivided where surface features are not sufficiently distinct for more specific mapping, or may be divided into 3 major subunits of decreasing age and soil development, **Mo**, **M1**, and **M2**. The **M1** unit is further subdivided into **M1a** and **M1b** surfaces where relative topographic position and soil characteristics allow the two ages to be distinguished. **Y** units are usually divided into **Y2** (modern stream channels) and **Y1** (youngest alluvial fans or stream terraces). In places, two or more units occur in close proximity or as part of a mosaic that is too finely divided to allow mapping of discrete areas. A "+" symbol is used to indicate a mixture of two or more units, and in one case, a complex map unit (**MY**) has been defined. Solid lines delineate obvious contacts between units; dashed lines indicate a gradual transition between units; dotted lines represent the limit of mapping where agricultural fields obscure surface properties.

Generalized Bedrock Units (for more detail, see Geologic Setting)

Xp Pinal Schist (Early Proterozoic)
P€o Oracle Granite (Middle Proterozoic)
P€p Pioneer Formation (Middle Proterozoic)
Pz Paleozoic sedimentary rocks, undifferentiated
Tv Tertiary volcanic rocks
Tc Tertiary conglomerate
R Undifferentiated bedrock
RP Rock pediment

Pre-Quaternary Alluvium

Tso (early Miocene)

This medium to fine grained, moderately well sorted sandstone dips about 30 degrees to the southwest. It is poorly consolidated but lightly cemented in patches with calcium carbonate, and was exposed in a stream cut adjacent to the **Oo** surface. The sandstone is composed of feldspars and quartz with some tuffaceous material, suggesting that deposition was contemporaneous with Early Miocene volcanism (Jon Spencer, personal communication, 1994).

Tsy (late Miocene to Pliocene)

Alluvium of **Tsy** consists of poorly sorted, subangular to subrounded gravels, cobbles and boulders with subhorizontal bedding. Gravels are cemented from the surface to a depth of about 3 m with calcium carbonate. Dominant lithologies include schist, basalt, and Tertiary conglomerate. Remnants of this deposit occur at elevations of over 100 m (300 ft) above active stream channels on narrow ridges (such as Indian Butte); the original areal coverage of **Tsy** surfaces is unknown, but must have been extensive. Thickness of this unit above bedrock is usually 3 m or less. Underlying bedrock appears to have been planed to a flat pediment surface before alluvial deposition.

Plio-Pleistocene Alluvium

Map Units O, Oo, O1, O2, O+P

Late Pliocene to early Pleistocene alluvial fan remnants are fairly common and prominent features of the landscape surrounding Table Top Mountains. Old alluvium is present as alluvial fan remnants from which the original surface has been substaintially modified by erosion. The original areal extent of the fans was probably much greater than at present. Older units have been rounded off at the edges and are no longer planar. The height above active streams ranges from 10 to 100 m (30 to 300 ft). Dissection patterns are subparallel or dendritic. Deposit thickness is estimated to be at least 10 m and possibly up to 100 m, but in places, a bedrock core or pediment surface may be present not far below the fan surface. For example, "Prosect Fan" (Figure 2) in the northeast portion of the study area is highly resistant due in part to bedrock control at the fan apex and to capping by several meters of carbonate-cemented gravels, and retains some of its original morphology and orientation. The **O** unit is used where subunits could not be distinguished.

Oo (late Pliocene?)

Oo units occupy the second highest topographic position of surficial units, after **Tsy**, about 100 m above active streams. Oo fan apices occur within 800 m of the mountain front. The surfaces may be planar in longitudinal profile, but are usually strongly convex in transverse profile. Dissection by local drainages on the fan surfaces is deep (up to 25 m) and subparallel. The drainage pattern causes formation of elongated, sloping surfaces known as ballena topography (Peterson, 1981), particularly in the northwest corner of the study area. Particle sizes in the poorly sorted **Oo** deposits range from sand to boulders, and in places eolian silts have infiltrated, causing a fining of upper layers. The thickness of **Oo** deposits is uncertain, but may be up to 100 m in places. Reconnaissance of a recent landslide scar along the edge of the largest **Oo** unit did not reveal any bedrock exposures within the entire height of the scarp above the streambed. Lithologies in **Oo** deposits include schist, basalt, granite, sandstone, and limestone. Darkly to moderately varnished basalt boulders form a lag on most **Oo** surfaces. Fragments of caliche are abundantly interspersed between basalt boulders at the surface. Rock varnish on basalt is quite variable due to erosion and spallation of boulder surfaces, burial by eolian silts and subsequent exhumation, and movement downslope by hillslope processes. Soil development on the **Oo** surface is characterized by thin A and B horizons at the surface that are formed from recently deposited eolian silts and contain abundant fragments of pedogenic carbonate from the underlying petrocalcic horizon. These horizons are brown to light brown in color, loam to silt loam in texture, have weak platey (A horizon) or subangular blocky sturcture (B horizon), and are calcareous. Calcium carbonate (Stage V, Machette, 1985) cements the deposits beneath surface horizons to at least 5 m. Erosion may have removed former argillic horizons; for example, uneroded soils in southern New Mexico have argillic horizons that are about 50 cm thick overlying laminar petrocalcic horizons (Gile and others, 1981).

Vegetation on the **Oo** surfaces consists of palo verde, ocotillo, triangle-leaf bursage, brittlebush, creosote, saguaro, ironwood, ratany, and other Sonoran desert shrubs. Preliminary reconnaissance on the eroded flanks of the Oo fans revealed the presence of perennials that are uncommon on fan surfaces, such as Abutilon sp. and*******

O1 (late Pliocene?)

O1 units are transitional between **Oo** and **O2** surfaces, and can usually only be distinguished where **Oo** and **O2** are present. **O1** surfaces may be more strongly eroded remnants of **Oo** deposits, as they tend to occur on edges of **Oo** units. The elevation difference between **Oo** and **O1** is about 5 m. **Oo** units slope down gradually to more or less planar **O1** surfaces. Soils and vegetation are similar to those on **Oo** units.

O2 (early Pleistocene-late Pliocene?)

The **O2** surfaces occur at elevations of at least 10 m, but usually not more than 30 m, above active streams. The apices of **O2** fans occur at a greater distance from the mountain front than **Oo** fan apices, and are extensive in the northeastern and western parts of the mapping area. They are distinctly fan-shaped and planar and have edges that are less rounded than **Oo** surfaces, but more rounded than younger surfaces. Dissection by on-fan washes, more dendritic than parallel, is deep (3 to 6 m) and not very abundant. Thickness of **O2** deposits is probably less than about 10 m; in places a granitic bedrock pediment beneath the **O2** alluvium is exposed in stream cuts. Lithologies making up the poorly sorted gravels are similar to those in **Oo** units, and a basalt boulder lag, interspersed with caliche fragments, is characteristic of the surface. Basalt boulders are somewhat more darkly varnished than on the **Oo** surface, suggesting less erosion and spallation. Soil development on **O2** surfaces is characterized by the presence of a thin calcic or Bk horizon (about 20 cm thick) overlying several meters of petrocalcic horizons (see Appendix B, soil profile S-3). Presumably, an argillic horizon that was originally present has been stripped by erosion. The Bk horizon has developed in recently deposited eolian silts, and has a strongly effervescent matrix due to the incorporation of abundant fragments of petrocalcic material from lower horizons. Calcium carbonate development has progressed to Stage V (Machette, 1985), with brecciation of thick, laminated petrocalcic (K) horizons. Soils include Typic Paleorthids and Typic Durorthids. Description of typical **O2** soil in Appendix A, Soil Profile S-3.

Vegetation on **O2** surfaces is dominated by creosote, with smaller percent cover of bursage, wolfberry, ratany, ocotillo, *Opuntia* sp, and senna (Veg sites 86-V1, 86-V2; Appendix B).

O+P

O+P units represent pedimented surfaces of various lithologies, covered in places with **O**-age alluvium or exposed. These pediment surfaces occur in higher landscape positions than those classed as **M+P**, but are lower than the eroded pediment of Indian Butte. The pediment surface slopes at an angle of 2-3 degrees, slightly greater than the angle of younger pediments.

<u>Pleistocene Alluvium</u>

Map Units M, Mo, M1, M1a, M1b, M2, MY, M+P

Pleistocene alluvium is present as moderately eroded to very slightly eroded fan remnants, with the original extent of the deposit usually well defined. Fan edges are sharp on all but the oldest deposit, **Mo**, which has become somewhat rounded due to erosion. Fan surfaces are planar in longitudinal and transverse section. Surface topography on older (**Mo** and **M1a**, **M1b**) surfaces has been smoothed, but on younger surfaces (**M2**, **MY**) depositional bar and swale topography is still noticeable. Pleistocene surfaces slope at an angle of less than 2 degrees. Height above active stream channels is 1-3 m except for the **Mo** surface, which can be up to 10 m above channels. The thickness of Pleistocene deposits ranges from 1 m to 10 m. In many places, younger Pleistocene units bury older units, especially where the older deposits have become cemented with caliche. The age of buried caliche may be Plio-Pleistocene (**O**) or early Pleistocene (**Mo**). The caliche can be very resistant to erosion, and in some areas is responsible for the preservation of **Mo** and older surfaces at elevations far above the modern base level. Age control on **M** units is poor, but soil development at Table Top has been correlated with soils in southern New Mexico for surface age estimation. In some cases, especially where granite bedrock is present, Pleistocene surfaces are not subdivided and are grouped into a single "**M**" unit.

Mo (early to middle Pleistocene?)

Mo units are 3 m to 10 m above active wash bottoms. In places, **Mo** units may grade up toward **O2** surfaces, but are noticeably inset into the **O** age units. The morphometry and depth and degree of dissection of **Mo** fans is similar to **O2**. Dissection by streams is apparently controlled on both age units by petrocalcic horizons that armor the surface and limit downcutting episodes to periods of high runoff. Deposit thickness probably does not exceed 10 m, and may be 5 m or less in many places. Particle size on the **Mo** surface is dominated by basalt cobbles, and smaller gravel size quartz and caliche fragments mantle the surface between basalt cobbles. The **Mo** surface can be most easily distinguished from **O2** surfaces by the presence of quartz, which has been eroded or weathered from the **O2** surface. Schist cobbles are found in the deposits where they have been protected from weathering by engulfment by caliche. A continuous desert pavement may have existed at one time, but has probably been disrupted by erosive sheet washing; currently, the cobble and gravel lag covers about half the surface. Basalt cobbles are moderately darkly varnished. Soil development on the **Mo** surface is similar to the **O2** surface. Carbonate horizon development has reached Stage IV to V (Machette, 1985), with brecciation of upper horizons and a thick (10-20 cm), extremely hard laminated zone. Erosion, possibly at the Pleistocene-Holocene climatic transition, has apparently removed the upper solum down to the depth of the petrocalcic horizon. Subsequent eolian deposition has resulted in accumulation of 10 to 40cm of fine material, some of which has infiltrated into cracks in the petrocalcic horizon, and some of which forms cumulic A and Bk horizons. Gravels within these horizons consist of caliche fragments. The degree of soil development in the upper horizons, with moderate clay accumulation, suggests dust accumulation since the late Pleistocene. Soils include Petrocalcic Paleargids and Typic Paleorthids; a representative profile is described in Appendix A, Soil Profile S-2.

Vegetation on the **Mo** surface is more diverse than on other fans surveyed. Creosote and paloverde are both common, and smaller amounts of bursage, saguaro, ocotillo, brittlebush, ratany, wolfberry, *Opuntia* sp., senna, and *Trixis californica* are also present (Veg sites 83-V1, 83-V2, 83-V3; Appendix B).

M1 (middle to late Pleistocene)

The **M1** surface has been subdivided into 2 units (**M1a**, **M1b**) where field mapping and air photo resolution has allowed them to be distinguished. In other places, particularly in areas of granitic lithology, the distinguishing characteristics are more difficult to recognize and the units are grouped into a single **M1** unit. The **M1a** and**M1b** units are most easily differentiated by soil characteristics, or where they occur as adjacent stream terraces, by relative elevation. **M1** surfaces are distinguished from older and younger Pleistocene-age units by the presence of a reddish argillic horizon; the color difference usually is apparent at the surface due to mixing of lower and upper soil material by burrowing animals. The surfaces are less than 5m above active stream channels. The deposits of this age commonly form stream terraces along major washes, but in some areas they form extensive alluvial fans. Surfaces of these deposits are moderately dissected to a depth of 2m (rarely more), and the broad interfluve areas are flat and smooth. The **M1** deposits are probably up to 3 m thick, and may bury older deposits, or be buried by younger Pleistocene or Holocene deposits; where buried, the argillic horizon is removed. A well developed desert pavement occurs at the surface, madeup of interlocking quartz, granite, basalt, sandstone and limestone pebbles and cobbles. Basalt cobbles are usually darkly varnished and, together with the well preserved pavement and lack of dissection, suggest considerable surficial stability.

Interesting vegetation patterns were noted on **M1** age surfaces. In general, bursage is more common than creosote, but on interfluves, even where the argillic horizon is fairly well-developed, creosote is more common. Other species present include palo verde, saguaro, ratany, ironwood, ocotillo, and *Opuntia* sp. (Veg sites 87-V1, 87-V2, 88-B1 to 88-B5, 88-S1 to 88-S5; Appendix B). Some M1 plots surveyed have high species diversity, possibly due to inclusion of both interfluve and swale topographic positions in the surveyed area.

M1a (middle to late Pleistocene)

This older **M1** unit occurs on higher landscape positions and has a greater degree of soil development than the **M1b** unit. The topography of **M1a** surfaces is flat and relatively undissected, possibly due to the presence of interlocking desert pavement, which is dominated by quartz. Basalt is also present at the surface,and is darkly varnished. Other lithologies, notably schist, are present at depth, but apparently have been weathered from the surficial pavement. An Av horizon with moderate to strong platey structure and vesicular pores is present. Calcic horizons (Bk) overlie dark red, clayey argillic and calcic horizons (Btk). A petrocalcic horizon, with Stage III to IV development (Machette,1985) is present below a depth of 60 to 100 cm. **M1a** soils include Typic Haplargids and Petrocalcic Paleargids; a representative pedon is described in Appendix A, Soil Profile S-5.

M1b (late Pleistocene)

The **M1b** unit tends to have a more dispersed and less well varnished pavement than the **M1a** surface. Less resistant lithologies may also be present at the surface of **M1b** than **M1a** deposits. Soils are the main distinguishing feature where elevational differences are not apparent. The **M1b** soil may have a moderately well developed argillic horizon, or may have a reddish cambic horizon instead, in regions of granitic parent material. The A horizon may or may not have vesicular pores. Calcic horizons are present between 10 or 20 and 60 to 90 cm, and a plugged, but not indurated, K (petrocalcic) horizon (up to

Stage III) may be present below this. The petrocalcic may be a buried horizon. Soils in this mapping unit are classified as Typic Haplargids and Petrocalcic Paleargids. Representative pedons are described in Appendix A, Soil Profiles S-4E, S-4W, and S-8.

M2 (latest Pleistocene)

M2 surfaces occur 1 to 3m above active stream channels; thus, in many places cannot be distinguished from **M1b** surfaces on the basis of elevation alone. Dissection by streams is common, to a depth of about 1 m, and bar and swale topography is evident in most interfluve areas. Apparently, debris flows have deposited boulder bars that are often dominated by basalt particles up to 1 m or more in diameter. The bar and swale topography give this surface a rough appearance on air photos and in person. Schist is common on the surface and throughout the deposits, as are metaquartz, limestone, and sandstone; non-basalt volcanics are a minor component. In swale areas between bars, desert pavement of gravel-sized schist and quartz is incipient, appearing more like a pebble lag than a pavement. Basalt boulders on bar tops are often moderately to poorly varnished, suggesting some antiquity of these features. Soil development on the **M2** surfaces is moderate. A slightly darkened A horizon is present; the lack of desert pavement has not allowed formation of vesicular pores. A weak, and moderately reddened, argillic horizon present in some places. Where present this horizon is usually less than 25 cm thick. Calcic horizons, with Stage II carbonate as gravel rinds or coatings are present and may reach a depth of more than 1m. M2 soils include Typic Haplargids and Typic Calciorthids, and a representative pedon is described in Appendix A, Soil Profile S-1.

Bursage makes up the greatest percent cover on M2 surfaces, with creosote and palo verde the next most common perennials. Saguaro, ocotillo, and ratany are also common (Veg sites 92-V1, 92-V2; Appendix B).

MY (latest Pleistocene to Holocene)

MY units are mapped where the landscape is finely dissected by active streams but interfluve areas range in age from Holocene to late Pleistocene. **M1** and **M2** surfaces occur in areas that are too small to map individually, and may be adjacent to and at a similar elevation as **Y** (Holocene) age surfaces. A buried petrocalcic horizon may be present under broad areas of this surface. Areas of **M** age are distinguished by well to moderately well developed desert pavement and dark varnish; these often grade into **Y** age surfaces with an unvarnished pebble lag and obvious depositional features. Soil Great Groups on **MY** surfaces include Torriorthents, Camborthids, Calciorthids, and Haplargids. A representative pedon is described in Appendix A, Soil Profile S-7.

Vegetation patterns on these surfaces reflect the proximity to washes. Interfluve areas, whether **M** or **Y** in age, tend to be dominated by creosote bush, while palo verde, ironwood, triangle-leaf bursage, limberbush (*Jatropha cardiophylla*), and cacti cluster next to ephemeral drainages (Veg sites 89-V1,89-V2, 89-V3; Appendix B).

M+P

The **M+P** surfaces are pediments covered with a patchy, thin veneer of alluvium. When soil is present, its reddish color suggests a middle- to late-Pleistocene age. The pediment surface (top of the bedrock) is about 3 m above active channels, although surficial alluvium may be higher.

Holocene Alluvium

Map units Y, Y1, Y2, Ys

Two Holocene age surfaces have been observed in the Table Top area. **Y1** units are usually present as stream terraces adjacent to active washes, and **Y2** units comprise the actual washes. Extensive Holocene fans are common adjacent to Vekol Wash, and active fans mapped as **MY** surfaces are dominated by Holocene alluvium in the northwestern portion of the mapping area. In some cases, it was not feasible to separate these units and they are grouped into a single **Y** unit.

Y1 (early to middle Holocene)

Y1 units are common as stream terraces adjacent to the mountain front, and as larger fan surfaces in distal positions. Much of the younger, Holocene aged alluvium is transported out of the mapping area to distant valley floors. **Y1** terraces are about 1m above active channels, and may be up to 1.5 m thick. A pebble lag covers the surface of gravelly deposits, but in the western portion of the mapping area near Vekol wash, Holocene deposits are sandy and a lag is absent. Holocene alluvium is primarily composed of schist gravel, reflecting the erosion of the core of the Table Top Mountains. Very lightly varnished basalt cobbles are present in most areas (the notable exceptions being the far northwest and southeast corners of the mapping area), and granite, limestone and sandstone are locally present. Soil development on **Y1** units is minimal. A thin yellowish brown A horizon overlies a very weak cambic horizon, which might be slightly reddened or have weak, blocky structure. Carbonate has been leached from the upper 15cm of the deposit, and redistributed as very thin, discontinuous coatings on clasts (in gravelly material) or as fine filaments (in sandy material) to a depth of 1m or more. A buried petrocalcic horizon is frequently present below about 1m depth. The soils are classified as Torrifluvents and Camborthids. A representative pedon is described in Appendix A, Soil Profile S-6.

Creosote dominates Holocene-age surfaces, especially on distal, sandy fans. Bursage may also be common at higher elevations or on gravelly deposits. Palo verde, ratany, saguaro, and *Opuntia* spp. make up a lower portion of the cover (Veg sites 91-V1, 91-V2, 99-V1, 99-V2; Appendix B).

Y2 (late Holocene to present)

Included in this mapping unit are active stream channels (where they are wide enough to be resolved at the scale of mapping, about 12m), and associated very recent terraces. Channels tend to be braided and anastomosing, with small "islands" of low terraces (<0.3 m) present within and adjacent to the channels. All older surfaces are dissected to some degree by active channels which could not be mapped; this contributes some heterogeneity to the surface characteristics of those units. **Y2** channels represent the local base level of erosion, which varies across the mapping area. Channels with the lowest base level of erosion have their headwaters in the upland areas of Table Top Mountain, whereas on-fan drainages are often elevated, particularly where channels drain **Mo** or older surfaces. In some cases, bedrock or caliche controls the base level of these washes, and in the southwestern portion of the mapping area, relatively narrow canyons have cut into deeply cemented Quarternary alluvium. Where bedrock is exposed in stream channels, a thinly veneered pediment or strath terrace may be observed in cut banks.

Ys

Ys represents landslide deposits that have probably occurred during the late Holocene. They occur on steep slopes of old alluvial fans which are being undercut by stream action. Basalt boulders which were transported and fractured to produce fresh surfaces are lightly varnished, similar to the varnish on boulders on the youngest stream terraces. Thus, the slide areas appear light colored on aerial photographs.

Landscape Evolution and Age Correlation

The age of an alluvial geomorphic surface is generally considered to also represent the age of the material immediately underlying the surface (Gile and others, 1981). Processes of soil formation, such as translocation of calcium carbonate and other salts, illuviation (downward movement) of clay to lower horizons, and organic matter accumulation, acting over a given time period, produce diagnostic features that can help in determining the relative age of the surface. These pedogenic features are considered in the general context of landscape evolution, with other features such as topographic position, degree of dissection, and surficial morphology, to arrive at a final numerical surface-age estimate. Over time, dissection by stream channels becomes deeper; soil profiles become more complex, and then simpler as erosion removes part of the solum; and calcium carbonate accumulation becomes increasingly important. Numerical ages may be assigned to undated surfaces on the basis of comparison with dated surfaces that exhibit similar properties and have been exposed to similar climates (for example, McFadden and others, 1989). Generalized properties of each alluvial mapping unit (excluding **Tsy** and **Tso**), with approximate numerical age estimations, are shown in Table 1.

Table 1. Properties of alluvial surface units at Table Top, and ages estimated by correlation with surfaces showing similar properties in the southwestern U.S.

Table Top Surface Unit	Estimated Age	Dissection (m above channels)	Soil Horizons	Carbonate Stage[1]
Y2	<1 ka	channels	C	0
Y1	1-10 ka	<1 m	A, Bw, Bk, C	0-I
MY	1-15 ka	<1 m	A, Bw, Bk, Kb	0-I
M2	10-15 ka	~1 m	A,Bw, Bk, Btk, CBk	I-II
M1b	15-25 ka	1-3 m	Av, Btk, K	II-III
M1a	25-125 ka	1-5 m	Av, Btk, K	III-IV
Mo	125-800 ka	3-10 m	A, Bk, Btk, K	IV-V
O2	800-1600 ka	10-30 m	A, Bk, K	V
O1	>1600 ka	>30 m	A, Bk, K	V
Oo	>1600 ka	~100 m	A, Bk, K	V

[1] Machette, 1985

Three general ages of Quaternary or Late Cenozoic geomorphic surfaces have been recognized, based on similar diagnostic criteria as used in this report, in the Basin and Range Province of the southwestern U.S. (Christenson and Purcell, 1985). Young alluvial fans are Holocene in age (0 to 10,000-15,000 yrs), intermediate fans are Late to Middle Pleistocene (10,000-15,000 to 500,000-700,000 yrs), and old fans are Early Pleistocene to Pliocene (>500,000-700,000 yrs). Units of similar age have been observed from the Eastern Mojave desert in California to southern New Mexico (e.g., Bull, 1991; Gile and others, 1981) and have been recently mapped in south-central Arizona (Huckleberry, 1992; 1993a; 1993b; 1994). Surficial geomorphic units described in this study have been correlated with units possessing similar degrees of stream dissection, topographic positions, soil development and pavement characteristics (Table 2).

Table 2. Correlation of Table Top surficial geologic units with surfaces in the southwestern U.S. Estimated ages in parentheses.

Table Top (this study)	Lower Colorado River[1]	Southern New Mexico[2]	Southeast Arizona[3]
Y2 (<1 ka)	Q4 (0-2 ka)	Organ III & channels (0.1-1.1 ka)	
Y1 (1-10 ka)	Q3b, Q3c (2-8 ka)	Organ I & II (1.1-7 ka)	Golder (4 ka)
MY (1-15 ka)	Q3 (2-12 ka)	Organ I & II & I.R.[4] (1.1-7 ka)	
M2 (10-15 ka)	Q3a (8-12 ka)	Issac's Ranch (8-15 ka)	Brave Bull (7.5-25 ka)
M1b (15-25 ka)	Q2c (12-70 ka)		
M1a (25-125 ka)	Q2b (70-200 ka)	Jornada II (~100-150 ka[5])	Catalina (25-100 ka)
Mo (250-800 ka)	Q2a (400-730 ka)	Jornada I (250-400 ka) to La Mesa (~500-800 ka[5])	Twin Lakes (~500 ka)
O2 (800-1600 ka)	Q1? (>1200 ka)	Dona Ana (>400 ka)	Cordonnes, Martinez (1000-2000 ka)
O1 (>1600 ka)	Q1? (>1200 ka)	Dona Ana (>400 ka)	
Oo (>1600 ka)	Q1 (>1200 ka)	Dona Ana (>400 ka)	

The rough synchroneity of these deposits over such a broad area, and lack of evidence for major tectonism, suggest regional climatic control over their deposition. In general, during the Quaternary, climatically-driven pulses of aggradation and basin filling have punctuated longer intervals characterized by erosion or surface stability and soil development. Since the last glacial maximum, however, deposition has been more dominant and hiatuses of landscape stability have been relatively brief (Bull, 1991). Holocene age fans may be attributed to a general decrease in base level of erosion as increased aridity caused the decline of latest Pleistocene lake level high stands and high water tables (Christenson and Purcell, 1985). Although base level has probably declined with continual erosion, there is no clear evidence of formerly shallow water tables on the piedmonts surrounding the Table Top Mountains. Alternatively, two pulses of deposition during the latest Pleistocene to Holocene have been attributed to enhanced sediment yields from

[2] Gile and others, 1981
[3] McFadden, 1981
[1] Bull, 1991
[4] Issac's Ranch alluvium abbreviated by I.R.
[5] Machette, 1985

hillslopes as vegetation cover declined during the climatic transition (Bull, 1991). These pulses might be represented at Table Top by **M2** and **Y1** units, corresponding with Bull's Q3a and Q3b surfaces, and with the Golder and Brave Bull terraces near Tucson, respectively (Table 2). A greater variety of Holocene-age surfaces in southern New Mexico (Issac's Ranch, Organ I, II, and III) suggests greater recent tectonic activity in that region than in southern Arizona. However, more detailed study may reveal exposures of additional Holocene-age surfaces in the Table Top area.

Middle to late Pleistocene deposition occurred in two phases at Table Top, resulting in the **M1a** and **M1b** surfaces. In places, both surfaces are not preserved or are not distinguishable. Where they are separated by a noticeable change in relief, contrasting soil properties show that a fairly lengthy episode of landscape stability separates them. These surfaces may correspond to Bull's Q2b and Q2c units in western Arizona and southwestern California, which have been dated at 70-200 ka and 12-70 ka, respectively. However, **M1a** surfaces at Table Top lack the maximally developed argillic horizons present on Bull's Q2b surfaces, and thus may represent the younger end of the age spectrum for that unit (Table 2). In New Mexico and southeast Arizona, only one surface of middle to late Pleistocene age appears to be preserved (Jornada II and Catalina, respectively; Table 2). The considerably older **Mo** unit at Table Top is correlated with the Q2a surface (400-730 ka) in the Lower Colorado River area, with the Jornada I (250-400 ka) and/or La Mesa (~500-800 ka, dated using calcium carbonate accumulation rates; Machette, 1985) units in southern New Mexico, and with the Twin Lakes terrace (~500 ka) in southeast Arizona. However, the **Mo** soil has been truncated by erosion to the top of the petrocalcic horizon, and recent accumulation of eolian sediment has replaced the original argillic horizon. This is in contrast to soil development on the correlated surfaces, which have been subjected to less erosion. For example, the Jornada I soil has a 65 cm-thick argillic horizon in certain landscape positions, and even the Upper La Mesa surface retains an argillic horizon (Gile and others, 1981). In southeast Arizona, maximal argillic horizon development is expressed on the Twin Lakes deposit; older soils are truncated (McFadden, 1981). If soil forming factors and erosion rates are comparable in the Table Top area and the Canada del Oro Valley near Tucson, this suggests an age >500 ka for the **Mo** surface.

The age of the **O** alluvial units at Table Top is estimated to be late Pliocene to early Pleistocene (0.8 to >1.6 Ma) by correlation with old alluvial units in the lower Colorado River region (Bull, 1991), Verde Valley (House and Pearthree, 1993), and in southeastern Arizona (Menges and McFadden, 1981). However, more Plio-Pleistocene fans are present at Table Top than in other locations (Table 2). In southern New Mexico, the Dona Ana geomorphic surface is associated with the extensive basin fill of the early to middle Pleistocene Camp Rice formation (>400 ka; Gile and others, 1981). The Dona Ana surface contains a sequence of three erosional pediments (Ruhe, 1964), which may correspond to the three **O**-age units observed at Table Top. The **Oo** and **O2** units at Table Top are interpreted as constructional landforms, while the **O1** unit may be an erosional remnant of the **Oo** deposit. Age differences between **Oo**, **O1** and **O2** are difficult to estimate because soil properties are similar.

Deep incision of **O**-age units (especially **Oo** and **O1**) may have been initiated by the integration of local basins into the lower Gila River drainage network, which was a through-flowing river by about 3 to 6 Ma (Shafiqullah and others, 1980). This may explain the change in fan orientation observed in the northeastern portion of the study area. Indian Butte and the **Oo** and **O1** units of Prospect Fan have axes running in an eastery direction, possibly due to deposition into a closed basin centered toward the east. The **O2** fan and younger units in this part of the study area are oriented more toward the north or northeast (Fig. 2). Drainage orientation may have shifted toward the north in late Pliocene-early Pleistocene time, as the lower Gila River integration proceeded upstream and captured internal drainages. However, at Gillespie Dam, approximately 65 km (40 miles) northwest of Table Top, the river has apparently downcut only about 10 m since late Pliocene time (Shafiqullah and others, 1980). Downcutting rates are too low (5-9 m My^{-1}; Euge and others, 1978) to account for the incision of at least 100 m since deposition of the **Tsy** and **Oo** units. An alternative explanation for the incision and drainage patterns is climatically-induced denudation coupled with isostatic rebound following unloading (for example, Menges, 1983). Drainage integration on a local scale may have occurred concurrently with climate change during the Pliocene-Pleistocene transition. More evidence is needed (for example, dated **O**-age deposits) before a dominant process can be ascribed to the observed landforms.

Ages of pediment surfaces typically are difficult to estimate because these landforms may be thought of as developing over a long period of time. In the Table Top area, pediment surfaces are fairly common, and in some cases ages are estimated based on the degree of soil development in the alluvial veneer and on elevation. Where alluvial cover is absent, and where elevation differences are hard to distinguish, pediments are designated as **RP**, or rock pediments. Pediments are more common in areas of granite bedrock than on schist, suggesting that production of grus by deep weathering, followed by its partial removal, may be a factor in pediment formation (Moss, 1977). Beautiful granite pediments are exposed along Interstate-8 west of the intersection of State Route 84, in a broad area to the southwest of Table Top (Fig. 2), and in numerous stream cuts. Indian Butte appears to be the remnant of a Tertiary pedimented surface, which was capped during the Pliocene by several meters of gravel.

Summary

Eleven distinct alluvial deposits have been distinguished on the piedmonts of the Table Top mapping area, four of Tertiary age, five of Pleistocene age, and two Holocene units. Estimated ages of these geomorphic surfaces seem to be roughly coincident with deposits in a region stretching from the Lower Colorado River to southern New Mexico. This suggests climatic control of deposition alternating with periods of landscape stability and soil formation. Soil development appears to reach a maximum after roughly 125 to 250 ka, and then decline over longer periods of time. Weathering processes produce argillic and calcic and then petrocalcic horizons, but eventually erosion becomes dominant and removes upper horizons. Vegetation distribution appears to be controlled to some degree by the age of the geomorphic surface, but more data are needed to establish firm relationships between, for example, soil textural composition and abundance of particular species. In general, however, young, distal portions of piedmonts are sandy and primarily support creosote, while older, proximal piedmont surfaces are more variable both in soil texture and in species composition. Additional work at Table Top could include soil chemical and physical analyses as well as collection of additional vegetation cover and abundance data.

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References

Balla, J.C., 1972, The Relationships of Laramide Stocks to Regional Structures in Central Arizona: Tucson, University of Arizona, Ph.D. dissertation, University of Arizona, 132 p.

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

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

Christenson, G.E., and Purcell, C.R., 1985, Correlation and age of Quaternary alluvial-fan sequences, Basin and Range Province, southwestern United States, *in* Weide, D.C., ed., Soils and Quaternary geology of the southwestern United States, Geological Society of America Special Papers 203, p.115-122.

Damon, P.E., Lynch, D., and Shafiquallah, M., 1984, Late Cenozoic landscape development in the Basin and Range province of Arizona, *in* Smiley, T.L., Nations, J.D., Péwé, T.L., and Schafer, J.P., Landscapes of Arizona: The geological story, New York, University Press of America, p. 175-206.

Dempsey, K.A., and Pearthree, P.A., 1994, Surficial and environmental geology of the Sierra Vista area, Cochise County, Arizona: Arizona Geological Survey Open-File Report 94-6, 14 p.

Euge, K.M., Lund, W.R., Scott, J.D., 1978, Geology of the Palo Verde Nuclear Generating Station and adjacent areas, Maricopa County, Arizona, in Burt, D.M. and Pewe, T.L., eds., Guidebook to the geology of central Arizona, Arizona Bureau of Geology and Mineral Technology Special Paper No. 2, p. 115-131.

Gilbert, W.G., 1991, Bedrock geology of the eastern Gila Bend Mountains, Maricopa County, Arizona: Arizona Geological Survey Open-File Report 91-5, 13 p.

Gile, L.H., Peterson, F.F., and Grossman, R.B., 1966, Morphological and genetic sequences of carbonate accumulation in desert soils: Soil Science, v. 101, p. 347-360.

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

Gray, Floyd, Tosdal, R.M., Peterson, J.A., Cox, D.P., Miller, R.J., Klein, D.P., Theobald, P.K., Haxel, G.B., Grubensky, Michael, Raines, Gary, Barton, H.N., Singer, D.A., and Eppinger, Robert, 1992, The Coterminous Unites States Mineral Assessment Program: Background information to accompany folio of geologic, geochemical, geophysical, and mineral resource maps of the Ajo and Lukeville 1 degree by 2 degree Quadrangles, Arizona: U.S. Geological Survey Circular1082, 27 p.

Hall, J.F., 1991, Soil Survey of Pinal County, Arizona, Western Part: U.S. Department of Agriculture, Soil Conservation Service, in cooperation with Arizona Agricultural Experimental Station, 154 p.

House, P.K., and Pearthree, P.A., 1993, Surficial Geology of the Northern Verdy Valley, Yavapai County, Arizona: Arizona Geological Survey Open-File Report 93-16, 19 p., 3 sheets.

Huckleberry, G.A., 1994, Surficial geology of the Santan Mountains piedmont area, northern Pinal and eastern Maricopa County area, Arizona: Arizona Geological Survey Open-File Report 94-7, 32 p., 2 sheets.

_______ 1993a, Surficial geology of the Middle Gila River area, north-central Pinal County, Arizona: Arizona Geological Survey Open-File Report 93-4, 51 p., 4 sheets (1:24,000).

_______ 1993b, Surficial geology of the Superstition Mountain piedmont area, Northern Pinal and eastern Maricopa counties, Arizona: Arizona Geological Survey Open-File Report 93-15, 33 p., 4 sheets (1:24,000).

_______ 1992, Surficial geology of the eastern Gila River Indian Community area, western Pinal County, Arizona; Arizona Geological Survey Open-File Report 92-7, 27 p., scale 1:24,000, 6 sheets.

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

McAuliffe, 1991, A rapid survey method for the estimation of density and cover in desert plant communities: Journal of Vegetation Science, v. 1, p. 653-656.

McAuliffe, J.R., 1994, Landscape evolution, soil formation, and ecological patterns and processes in Sonoran Desert bajadas: Ecological Monographs, v. 64, p.111-148.

McFadden, L.D., 1981, Quaternary geology of the Canada del Oro Valley, southeastern Arizona, *in* Stone, C. and Jenney, J.P., eds., Arizona Geological Society Digest: v. 13, p. 13-20.

McFadden, L.D., Ritter, J.B., and Wells, S.G., 1989, Use of multiparameter relative-age methods for age estimation and correlation of alluvial fan surfaces on a desert piedmont, eastern Mojave Desert, California: Quaternary Research, v. 32, p. 276-290.

Melton, M., 1965, The geomorphic and paleoclimatic significance of alluvial deposits in southern Arizona: Journal of Geology, v. 73, p. 1-38.

Menges, C.M., 1983, The neotectonic framework of Arizona: Implications for the regional character of Basin-Range tectonism, Arizona Bureau of Geology and Mineral Technology Open-File Report 83-19.

Menges, C. M. and McFadden, L.D., 1981, Evidence for a latest Miocene to Pliocene transition from Basin-Range tectonic to post-tectonic landscape evolution in southeastern Arizona, *in* Stone, C. and Jenney, J.P., eds., Arizona Geological Society Digest: v. 13, p. 151-160.

Menges, C. M., and Pearthree, P.A., 1989, Late Cenozoic tectonism in Arizona and its impact on regional landscape evolution, in Jenney, J.P. and Reynolds, S.J., eds., Geologic evolution of Arizona: Tucson, Arizona Geological Society Digest 17, p. 649-680.

Morrison, R.B., 1984, Late Pliocene and Quaternary Geology, Ajo Quadrangle: Arizona Bureau of Geology and Mineral Technology Open File Report 84-1.

Morrison, R. B., 1985, Pliocene/Quaternary geology, geomorphology, and tectonics of Arizona, in Weide, David, ed., Soils and Quaternary Geology of the Southwestern United States: Geological Society of America Special Paper 203, p. 123-146.

Moss, J.H., 1977, The formation of pediments: Scarp backwearing or surface downwasting?, in Doehring, D.O., ed., Geomorphology in Arid Regions: Proceedings Volume of the Eighth Annual Geomorphology Symposium at SUNY, Binghamton, September 23-24, 1977.

Peterson, F.F., 1981, Landforms of the Basin and Range Province, defined for soil survey: Nevada Agricultural Experimental Station, Tech. Bull. 28, 52 p.

Peterson, J.A., Nowlan, G.A., Hanna, W.F., Pitkin, J.A., and McDonnell, Jr., J.R., 1988, Mineral resources of the Table Top Mountain Wilderness Study Area, Maricopa and Pinal Counties, Arizona: U.S. Geological Survey Bulletin 1702, 18 p.

Peterson, J.A., Tosdal, R.M., and Hornberger, M.I., 1987, Geologic map of the Table Top Mountain Wilderness Study Area, Pinal and Maricopa Counties, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-1951, scale 1:24,000.

Peterson, N.A., 1938, Geology and ore deposits of the Mammoth mining camp area, Pinal County, Arizona: Arizona Bureau of Mines Bulletin 144, 63 p.

Ruhe, R.V., 1964, Landscape morphology and alluvial deposits in southern New Mexico. Annals of the Association of American Geographers v. 54, p. 147-159.

Scarborough, R.B., and Peirce, H.W., 1978, Late Cenozoic basins of Arizona, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., The Land of Cochise: New Mexico Geological Society Guidebook, 29th Field Conference, p. 295-302.

Sellers, and Hill, 1974, Arizona Climate: University of Arizona Press, Tucson, 616 p.

Shafiqullah, M., Damon, P.E., Lynch, D.J., Reynolds, S.J., Rehrig, W.A., and Raymond, R.H., 1980, K-Ar geochronology and geologic history of southeastern Arizona and adjacent areas, *in* Jenney, J.P. and Stone, Claudia, eds., Studies in western Arizona: Tucson, Arizona Geological Society Digest v. 12, p. 201-260.

Soil Survey Staff, 1992, Keys to Soil Taxonomy: SMSS Technical Monograph No. 19, Fifth edition, Pocahontas Press, Blacksburg, 541 p.

Van Devender T. R., 1990, Late Quaternary Vegetation and Climate of the Sonoran Desert, United States and Mexico, *in* Betancourt, J.L., Van Devender, T.R., and Martin, P.S., eds., Packrat Middens: The Last 40,000 Years of Biotic Change: University of Arizona Press, Tucson, p. 134-164.

Appendix A: Soil Descriptions

Geomorphic Surface: Y1
Soil Profile: S-6
Classification: Typic Camborthid
Location: Pinal County, Arizona; SW 1/4, NE 1/4, SW 1/4, Sec. 28, T. 7S, R. 3E.
Physiographic Position: Alluvial fan, elevation 525 m (1740 feet)
Lithology: Schist and granite alluvium with minor basalt
Vegetation: See Veg Sites 91-V1, 91-V2, 99-V1, 99-V2 (Appendix B)
Described by: Elise Pendall, May 18, 1994
Remarks: Lowest horizon (90-150 cm) has wavy boundary; one side of pit appears to be a buried calcic and argillic horizon, while other side appears to be transitional to unaltered parent material.

A 0-3 cm. Dark brown (10YR 4/3) moist, yellowish brown (10YR 5/4) dry, gravelly sandy loam; weak, fine granular structure parting to single grained; non-sticky and non-plastic (wet), loose (dry); non-effervescent; abrupt, smooth boundary.

Bw 3-12 cm. Dark brown (10YR 4/3) moist, yellowish brown (10YR 5/4) dry, very gravelly coarse sandy loam; weak, fine subangular blocky structure; non-sticky and non-plastic (wet), soft (dry); non-effervescent; abrupt, smooth boundary.

Bk 12-50 cm. Dark brown (10YR 4/3) moist, pale brown (10YR 6/3) dry, very gravelly coarse sandy loam; single grained; non-sticky and non-plastic (wet), loose (dry); strongly effervescent, with Stage I carbonate present as discontinuous coatings under pebbles; clear, smooth boundary.

CBk1 50-90 cm. Dark brown (10YR 4/3) moist, brown (10YR 5/3) dry, extremely gravelly coarse loamy sand; single grained; non-sticky and non-plastic (wet), loose (dry); slightly effervescent, with Stage I carbonate present as discontinuous coatings under pebbles; abrupt, smooth boundary.

CBk2 90-150+ cm. Dark brown (7.5YR 4/4) moist, brown (7.5YR 5/4) dry, very gravelly sandy loam; weak, coarse subangular blocky structure; slightly sticky and non-plastic (wet), slightly hard (dry); violently effervescent, with Stage I carbonate as discontinuous coatings under pebbles and powdery filaments in matrix.

Geomorphic Surface: MY
Soil Profile: S-7
Classification: Typic Camborthid
Location: Pinal County, Arizona; NW 1/4, SW 1/4, SW 1/4, Sec. 23, T. 7S, R. 3E.
Physiographic Position: Alluvial fan, elevation 480 m (1580 feet)
Lithology: Schist and granite alluvium with minor basalt
Vegetation: See Veg Sites 89-V1, 89-V2, 89-V3 (Appendix B)
Described by: Elise Pendall, May 18, 1994

A 0-3 cm. Dark brown (10YR 4/3) moist, yellowish brown (10YR 5/4) dry, gravelly sandy loam; weak, fine platey to subangular blocky structure; non-sticky and slightly plastic (wet), loose (dry); non-effervescent; common, very fine roots; abrupt, smooth boundary.

Bw 3-13 cm. Dark brown (7.5YR 4/4) moist; light brown (7.5YR 6/4) dry, gravelly sandy loam; weak, medium to coarse subangular blocky structure parting to single grained; slightly sticky and slightly plastic (wet), loose (dry); non-effervescent; common, very fine roots; abrupt, smooth boundary.

CBk 13-90 cm. Dark brown (7.5YR 4/4) moist; light brown (7.5YR 6/4) dry, gravelly sandy loam; single grained; slightly sticky and slightly plastic (wet), loose (dry); strongly effervescent, with Stage I carbonate as discontinuous coatings and filaments under pebbles; abundant, very fine and few, fine, medium and coarse roots; abrupt, wavy and irregular boundary.

2Kb 90-170+ cm. Pinkish white (7.5YR 8/2) and pink (7.5YR 8/3, 7/3 and 7/4) dry; massive; hard (dry); strongly to violently effervescent, with Stage III carbonate present as void fillings and continuous coatings around pebbles; few, very fine roots.

Geomorphic Surface: M2
Soil Profile: S-1
Classification: Typic Haplargid
Location: Pinal County, Arizona; NW 1/4, NE 1/4, NE 1/4, Sec. 18, T. 7S, R. 2E.
Physiographic Position: Alluvial fan, elevation 540 m (1775 feet)
Lithology: Schist and granite alluvium with minor basalt, sandstone, and limestone
Vegetation: See Veg Sites 92-V1, 92-V2 (Appendix B)
Described by: Elise Pendall, May 17, 1994

A 0-6 cm. Dark brown (7.5YR 4/4) moist, brown (7.5YR 5/4) dry, gravelly sandy loam; weak, medium platey structure parting to single grained; non-sticky and slightly plastic (wet), soft (dry); non-effervescent; abrupt, smooth boundary.

Bw 6-19 cm. Brown (7.5YR 5/4) moist and dry, very gravelly sandy clay loam; weak, medium subangular blocky structure; slightly sticky and slightly plastic (wet), soft (dry); non-effervescent; abrupt, smooth boundary.

Bk 19-32 cm. Dark brown (7.5YR 4/4) moist, brown (7.5YR 5/4) dry, very gravelly sandy clay loam; weak, medium subangular blocky parting to fine granular structure; slightly sticky and slightly plastic (wet), soft (dry); slightly to strongly effervescent, with Stage I discontinuous coatings under pebbles; abrupt, wavy boundary.

Btk 32-52 cm. Dark brown (7.5YR 4/4) moist, brown (7.5YR 5/4) dry, with pockets of yellowish red (5YR 4/6 moist, 5/6 dry), very gravelly sandy clay loam; weak to moderate, fine subangular blocky structure; slightly sticky and slightly plastic (wet), slightly hard (dry); violently effervescent, with Stage I carbonate as laterally discontinuous filaments; clay skins bridge and coat mineral grains; abrupt, wavy boundary.

Bk' 52-106 cm. Brown (7.5YR 5/4) moist, light brown (7.5YR 6/4) dry, very gravelly sandy loam; weak, fine subangular blocky structure parting to single grained; non-sticky and slightly plastic (wet), loose (dry); violently effervescent, with Stage I-II carbonate as pebble coatings and in matrix; abrupt, smooth boundary.

CBk 106-145+ cm. Brown (10YR 5/3) moist, pale brown (10YR 6/3) dry, gravelly loamy sand; single grained; non-sticky and non-plastic (wet), loose (dry); strongly to slightly effervescent, with Stage I-II carbonate present as discontinuous pebble coatings and bridges between grains.

Geomorphic Surface: M1b

Soil Profile: S-4E

Classification: Petrocalcic Paleargid

Location: Pinal County, Arizona; NE 1/4, SW 1/4, NW 1/4, Sec. 22, T. 7S, R. 3E.

Physiographic Position: Alluvial fan, elevation 490 m (1620 feet)

Lithology: Schist alluvium with minor basalt, sandstone, and limestone

Vegetation: See Veg Sites 88-B1 to 88-B5, 88-S1 to 88-S5 (Appendix B)

Described by: Elise Pendall, May 17, 1994

Remarks: Described east end of trench, under non-eroded desert pavement. Compare to Soil Profile S-4W.

Av 0-3 cm. Dark brown (7.5YR 4/4) moist, pale brown (10YR 6.3) dry, silty clay loam; weak to moderate, fine subangular blocky structure; sticky and slightly plastic (wet), soft (dry); non-effervescent; common, fine vesicular pores; common, very fine roots; abrupt, smooth boundary.

Bt 3-19 cm. Strong brown (7.5YR 4/6) moist and dry, extremely gravelly sandy clay loam; weak, fine subangular blocky structure; sticky and slightly plastic (wet), loose (dry); non-effervescent; common, thin, clay skins bridging grains and as colloidal stains; abundant, very fine and common fine roots; clear, smooth boundary.

Btk 19-52 cm. Strong brown (7.5YR 4/6) moist, dark brown (7.5YR 4/4) dry, extremely gravelly sandy clay loam; moderate, fine to medium subangular blocky structure; slightly sticky and slightly plastic (wet), slightly hard (dry); slightly effervescent, with carbonate as filaments on ped faces; common, thin clay skins as bridges and colloidal stains; common, very fine and few, fine roots; gradual, smooth boundary.

Bk 52-95 cm. Brown (7.5YR 5/4) moist, light brown (7.5YR 6/4) dry, extremely gravelly sandy clay loam; weak, very fine subangular blocky structure; slightly sticky and slightly plastic (wet), soft (dry); strongly effervescent, with Stage II carbonate as continuous coatings on pebbles and fillings in some voids; few, very fine roots; abrupt, wavy boundary.

2Kb 95-130+ cm. Pinkish gray (7.5YR 7/2) moist, and pinkish white (7.5YR 8/2) dry; massive; very hard (backhoe cut through it and can break in hands); violently effervescent, with Stage III carbonate continuously plugging voids and coating grains.

Geomorphic Surface: M1b

Soil Profile: S-4W

Classification: Petrocalcic Paleargid

Location: Pinal County, Arizona; NE 1/4, SW 1/4, NW 1/4, Sec. 22, T. 7S, R. 3E.

Physiographic Position: Alluvial fan, elevation 490 m (1620 feet)

Lithology: Schist alluvium with minor basalt, sandstone, and limestone

Vegetation: See Veg Sites 88-B1 to 88-B5, 88-S1 to 88-S5 (Appendix B)

Described by: Elise Pendall, May 17, 1994

Remarks: Described center of trench, under eroded head of swale with disrupted desert pavement. Compare to Soil Profile S-4E.

A 0-5 cm. Dark brown (7.5YR 4/4) moist, brown (7.5YR 5/4) dry, gravelly loam; weak, fine subangular blocky structure; slightly sticky and slightly plastic (wet), soft (dry); slightly effervescent, with carbonate in matrix; common, very fine roots; fine, vesicular pores in places; abrupt smooth boundary.

Bk 5-18 cm. Dark brown (7.5YR 4/4) moist, brown (7.5YR 5/4) dry, very gravelly sandy clay loam; weak, medium subangular blocky structure; slightly sticky and slightly plastic (wet), soft to slightly hard (dry); strongly effervescent, with Stage I carbonate as discontinuous coatings under pebbles and in matrix; common, very fine and few, fine roots; clear, smooth boundary.

Btk1 18-40 cm. Dark brown (7.5YR 4/4) moist, brown (7.5YR 5/4) dry, extremely gravelly sandy clay loam; weak, fine subangular structure parting to single grained; sticky and slightly plastic; strongly to violently effervescent, with carbonate similar to overlying horizon; thin, patchy clay skins as bridges and colloidal coatings; abundant, very fine, and common, fine roots; clear, wavy and irregular boundary.

Btk2 40-70 cm. Reddish brown (5YR 4/4) moist and dry, very gravelly coarse sandy clay loam; moderate, medium subangular blocky structure; sticky and slightly plastic to plastic (wet), slightly hard to hard (dry); strongly to violently effervescent, with Stage I carbonate as filaments on ped faces and coatings under pebbles; many, moderately thick clay skins as bridges and colloidal stains; common, very fine roots; abrupt, wavy boundary.

2Kb1 70-85 cm. Pinkish gray (7.5YR 7/2) dry; massive (in places); hard; violently effervescent, with Stage III carbonate plugging horizon (in most places); few, very fine roots; abrupt, wavy boundary.

2Kb2 85-110+ cm. Pinkish gray (7.5YR 7/2) and pinkish white (7.5YR 8/2) dry; massive; very hard to extremely hard; violently effervescent, with Stage III carbonate plugging most of horizon.

Geomorphic Surface: M1b
Soil Profile: S-8
Classification: Petrocalcic Paleargid
Location: Pinal County, Arizona; SW 1/4, SE 1/4, SW 1/4, Sec. 18, T. 7S, R. 3E.
Physiographic Position: Alluvial fan, elevation 480 m (1580 feet)
Lithology: Schist alluvium with minor basalt, sandstone, and limestone
Vegetation: See Veg Sites 87-V1, 87-V2 (Appendix B)
Described by: Elise Pendall, May 17, 1994
Remarks: Uneroded, darkly varnished desert pavement covers surface.

Av 0-5 cm. Dark brown (7.5YR 4/4) moist, light brown (7/5YR 6/4) dry, gravelly silty clay loam; moderate, medium subangular blocky structure; sticky and slightly plastic (wet), soft (dry); non-effervescent; common very fine roots; abrupt, smooth boundary.

Bk 5-15 cm. Yellowish red (5YR 4/6) moist, reddish brown (5YR 5/4) dry, very gravelly sandy clay loam; weak, fine subangular blocky structure parting to single grained; slightly sticky and slightly plastic (wet), loose (dry); slightly effervescent, with Stage I carbonate as thin, discontinuous coatings under pebbles; common, very fine roots; clear, smooth boundary.

Btk 15-60 cm. Yellowish red (5YR 4/6) moist and dry, weak, fine subangular blocky structure; sticky and plastic (wet), slightly hard (dry); slightly to strongly effervescent, with carbonate as few filaments on ped faces and coatings under pebbles; common, moderately thick clay skins bridging and coating grains; abundant, very fine roots (between 15-25 cm), and few, very fine roots (between 25-60 cm); clear, wavy boundary.

2Kb 60-150+ cm. Pinkish white (7.5YR 8/2) and pink (7.5YR 7/3) dry; massive; hard, with loose lenses of sand and fine gravel; strongly to violently effervescent, with Stage III carbonate present as void fillings.

Geomorphic Surface: M1a
Soil Profile: S-5
Classification: Petrocalcic Paleargid
Location: Pinal County, Arizona; SW 1/4, SE 1/4, SW 1/4, Sec. 28, T. 7S, R. 3E.
Physiographic Position: Alluvial fan, elevation 480 m (1580 feet)
Lithology: Schist alluvium with minor basalt, sandstone, and limestone; quartz concentrated at surface
Vegetation: See Veg Sites 90-V1, 90-V2 (Appendix B)
Described by: Elise Pendall, May 17, 1994
Remarks: Trench is located at edge of M1a surface; M2 or M1b deposit may bury the M1a surface to a depth of less than 50 cm. Lowest horizon may be a third deposit due to abrupt boundary at 127 cm.

A 0-4 cm. Dark brown (7.5YR 4/4) moist, light brown (7.5YR 6/4) dry, sandy loam; weak, coarse granular structure; non-sticky and non-plastic (wet), loose (dry); non-effervescent; abrupt, smooth boundary.

Bk 4-24 cm. Dark brown (7.5YR 4/4) moist, brown (7.5YR 5/4) dry, sandy loam to sandy clay loam; weak, fine subangular structure parting to single grained; slightly sticky and non-plastic (wet), loose (dry); slightly effervescent, with Stage I carbonate as discontinuous coatings under pebbles; clear, smooth boundary.

Btk 24-47 cm. Dark brown (7.5YR 4/4) moist, strong brown (7.5YR 5/6) dry, extremely gravelly sandy clay loam; weak, fine subangular structure; slightly sticky and slightly plastic (wet), loose (dry); strongly effervescent, with Stage I carbonate as filaments in matrix and thin, discontinuous coatings under pebbles; few, thin clay skins bridging grains; abrupt, smooth boundary.

2Btkb 47-96 cm. Yellowish red (5YR 4/6) moist, reddish brown (5YR 5/4) dry, gravelly sandy clay loam; moderate, fine subangular blocky structure; sticky and plastic (wet), slightly hard (dry); violent effervescent, with Stage I carbonate as filaments on ped faces; common, thick clay films bridging and coating grains; clear, smooth boundary.

2Kb1 96-127 cm. Pink (7.5YR 7/2) to white (10YR 8/2) dry; massive; hard to very hard; violently effervescent, with Stage III carbonate filling voids in most places; abundant, weathered schist gravel allows portions to break in fingers; abrupt, wavy boundary.

2Kb2 127-165+ cm. White (10YR 8/2) dry; massive; very hard; violently effervescent, with carbonate as thick, hard, laminated coatings around schist pebbles, and powdery carbonate plugging matrix.

Geomorphic Surface: Mo
Soil Profile: S-2
Classification: Petrocalcic Paleargid
Location: Pinal County, Arizona; SW 1/4, SE 1/4, NW 1/4, Sec. 17, T. 7S, R. 3E.
Physiographic Position: Alluvial fan, elevation 540 m (1780 feet)
Lithology: Schist alluvium with basalt; quartz and caliche concentrated at surface
Vegetation: See Veg Sites 83-V1, 83-V2, 83-V3 (Appendix B)
Described by: Elise Pendall, May 16 1994
Remarks: Backhoe broke two teeth trying to dig through 2Kb horizon. Upper 25 cm is probably recent eolian cap and filling in older, petrocalcic surface.

A 0-3 cm. Dark brown (7.5YR 4/4) moist, light yellowish brown (10YR 6/4) dry, gravelly silt loam; weak, medium platey structure; non-sticky and slightly plastic (wet), soft (dry); slightly effervescent, with carbonate in matrix; top 1 mm has microphytic crust; abrupt, smooth boundary.

Bk 3-12 cm. Dark brown (7.5YR 4/4) moist, light brown (7.5YR 6/4) dry, gravelly silty clay loam; weak, medium and coarse subangular blocky structure; slightly sticky and slightly plastic (wet), soft (dry); slightly effervescent, with Stage I carbonate as coatings under pebbles; clear, smooth boundary.

Btk1 12-25 cm. Dark brown (7.5YR 4/4) moist, brown (7.5YR 5/4) dry, very gravelly silty clay loam; weak to moderate, medium subangular blocky structure; sticky and slightly plastic (wet), slightly hard (dry); violently effervescent, with carbonate as filaments on ped faces and coatings under pebbles; few, discontinuous clay skins bridging grains and on ped faces; abrupt, wavy boundary.

Btk2 & 2Kb 25-41 cm. Dark brown (7.5YR 4/4) moist, brown (7.5YR 5/4) dry, extremely gravelly silty clay loam (Btk2); weak, medium subangular blocky (Btk2) and massive (2Kb); slightly sticky and slightly plastic (wet), soft (dry) (Btk2), extremely hard (2Kb); violently effervescent, with Stage V carbonate as brecciated pieces (in Btk2 matrix) and densely laminated horizon (2Kb), more porous where schist gravels are abundant; thin, discontinuous clay films bridging grains; clear, irregular boundary.

2Kb 41+ cm. Pinkish white (7.5YR 8/2) dry; massive; extremely hard, difficult to break with rock hammer; irregular upper boundary due to dissolution and erosion.

Geomorphic Surface: O2
Soil Profile: S-3
Classification: Typic Paleorthid
Location: Pinal County, Arizona; NW 1/4, NW 1/4, NE 1/4, Sec. 21, T. 7S, R. 3E.
Physiographic Position: Alluvial fan, elevation 510 m (1680 feet)
Lithology: Schist alluvium with basalt; basalt and caliche concentrated at surface
Vegetation: See Veg Sites 86-V1, 86-V2 (Appendix B)
Described by: Elise Pendall, May 16 1994
Remarks: Upper 19 cm is probably recent eolian cap and filling in older, petrocalcic surface.

A 0-4 cm. Yellowish brown (10YR 5/4) moist, light yellowish brown (10YR 6/4) dry, silt loam; moderate, medium platey parting to weak, fine subangulary blocky structure; slightly sticky and slightly plastic (wet), soft (dry); slightly effervescent, with carbonate in matrix; microphytic crust in upper 1 mm; common, very fine roots; abrupt, smooth boundary.

Bk 4-19 cm. Brown (7.5YR 5/4) moist, light yellowish brown (10YR 6/4) dry, extremely gravelly silt loam; weak, fine subangular blocky structure; slightly sticky and slightly plastic (wet), soft (dry); strongly effervescent, with carbonate as caliche fragments (~70% by volume), pendants under the caliche fragments, and in matrix; common, very fine and few, fine roots; abrupt, smooth boundary.

K 19-49 cm. Very pale brown (10YR 7/4) and white (10YR 8/2); massive; extremely hard; violently effervescent, with Stage V carbonate as dense, laminar zone between 19-23 cm and brecciated petrocalcic material below this; no roots; abrupt, wavy boundary.

Bk' 49-57 cm. Yellowish brown to brown (10YR 5/4 to 7.5YR 5/4) moist, light yellowish brown to light brown (10YR 6/4 to 7.5YR 6/4) dry, gravelly silt loam; single grained; non-sticky and slightly plastic (wet), loose (dry); violently effervescent, with carbonate as pieces of petrocalcic horizon and in matrix; few, very fine, and common, fine roots; abrupt, wavy boundary.

K' 57-75+ cm. Pale brown (10YR 6/3) (in laminated zone 57-60 cm) dry, very pale brown (10YR 8/3) to white (10YR 8/2) to pinkish white (7.5YR 8/2) (below laminated zone) dry; massive; extremely firm (moist), extremely hard (dry); violently effervescent, with Stage IV carbonate as laminar horizon over massive but softer petrocalcic zone.

Appendix B: Vegetation Data

Table 1. Plant species codes used in vegetation cover table (Table 2, Appendix B), with Latin species names and common names.

CODE	SPECIES NAME	COMMON NAME
AMDE	*Ambrosia deltoidea*	Triangle-leaf bursage
CAGI	*Carnegiea gigantea*	Saguaro
CEMI	*Cercidium microphyllum*	Foothills Paloverde
DILA	*Ditaxis lanceolata*	Ditaxis
ECXX	*Echinocereus* sp.	Hedgehog Cactus
FEAC	*Ferrocactus acanthodes*	Barrel Cactus
FOSP	*Fouquieria splendens*	Ocotillo
JAGR	*Janucia gracilis*	Slender Janucia
KRGR	*Kramaria grayi*	Ratany
LATR	*Larrea tridentata*	Creosote
LYXX	*Lycium* sp.	Wolfberry
MUPO	*Muhlenbergia porteri*	Bush Muhly
OLTE	*Olneya tesota*	Ironwood
OPBI	*Opuntia bigelovii*	Teddybear Cholla
OPFU	*Opuntia fulgida*	Chainfruit Cholla
OPXX	*Opuntia* sp.	Opuntia
POGR	*Porophyllum gracilis*	Odora
SECO	*Senna covesii*	Senna
TRCA	*Trixis californica*	Trixis

Table 2. Percent cover of all perennial species found within each circular plot. Data was obtained by a logarithmic cover and density class method (McAuliffe, 1991), using an area of 512 m^2 on plots labeled with a "V" and an area of 256 m^2 on plots labeled with "B" or "S." Total cover is the sum of percent cover values for all species in the plot. All values reported in percent area covered.

Veg Plot #	Surface	Soil #	AMDE	CAGI	CEMI	DILA	ECXX	FEAC	FOSP	JAGR	KRGR	LATR
91-V1	Y1	S-6	6.250	0.049	0.000	0.000	0.000	0.000	0.000	0.000	0.000	6.250
91-V2	Y1	S-6	6.250	0.195	0.000	0.000	0.000	0.000	0.000	0.000	0.781	12.500
99-V1	Y1	-	6.250	0.391	0.000	0.000	0.000	0.024	0.000	0.000	0.781	25.000
99-V2	Y1	-	3.125	0.781	6.250	0.000	0.000	0.000	0.000	0.000	0.000	12.500
89-V1	MY	S-7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	12.500
89-V2	MY	S-7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	12.500
89-V3	MY	S-7	0.195	0.000	0.000	0.000	0.012	0.000	0.000	0.000	0.000	12.500
92-V1	M2	S-1	12.500	0.049	3.125	0.000	0.000	0.000	0.000	0.000	0.781	3.125
92-V2	M2	S-1	12.500	1.563	3.125	0.000	0.000	0.000	1.563	0.195	0.781	6.250
87-V1	M1	S-8	6.250	0.000	6.250	0.000	0.000	0.000	0.000	0.000	0.098	3.125
87-V2	M1	S-8	6.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.098	6.250
90-V1	M1	S-5	6.250	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.391	6.250
90-V2	M1	S-5	12.500	0.781	0.000	0.000	0.000	0.000	0.391	0.000	3.125	3.125
83-V1	Mo	S-2	1.563	0.024	6.250	0.001	0.000	0.000	0.391	0.000	0.391	6.250
83-V2	Mo	S-2	0.781	0.000	1.563	0.000	0.000	0.000	1.563	0.000	0.000	6.250
83-V3	Mo	S-2	3.125	0.000	6.250	0.000	0.000	0.000	1.563	0.000	0.781	6.250
86-V1	O2	S-3	1.563	0.000	0.000	0.000	0.000	0.000	0.781	0.000	0.391	12.500
86-V2	O2	S-3	1.563	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.563	6.250
88-B1	M1	S-4	0.195	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	6.250
88-B2	M1	S-4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.125
88-B3	M1	S-4	0.195	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	6.250
88-B4	M1	S-4	0.000	0.098	0.000	0.000	0.000	0.000	0.000	0.000	0.000	12.500
88-B5	M1	S-4	0.391	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.781
88-S1	M1	S-4	12.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.125	12.500
88-S2	M1	S-4	6.250	0.049	0.000	0.000	0.000	0.000	0.000	0.000	1.563	3.125
88-S3	M1	S-4	12.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.125	6.250
88-S4	M1	S-4	25.000	0.000	0.000	0.000	0.000	0.000	0.000	0.098	3.125	6.250
88-S5	M1	S-4	25.000	0.781	6.250	0.000	0.000	0.000	0.000	0.000	3.125	6.250

Table 2. (Continued)

Veg Plot #	Surface	Soil #	LYXX	MUPO	OLTE	OPBI	OPFU	OPXX	POGR	SECO	TRCA	TOTAL
91-V1	Y1	S-6	0.000	0.000	0.000	0.000	0.195	6.250	0.000	0.000	0.000	12.756
91-V2	Y1	S-6	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	19.728
99-V1	Y1	-	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	32.446
99-V2	Y1	-	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	22.656
89-V1	MY	S-7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	12.500
89-V2	MY	S-7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	12.500
89-V3	MY	S-7	0.000	0.000	0.000	0.195	0.000	0.000	0.000	0.000	0.000	12.903
92-V1	M2	S-1	0.098	0.000	0.000	0.000	0.000	0.000	0.024	0.000	0.000	19.702
92-V2	M2	S-1	0.000	0.024	0.000	0.000	0.000	0.000	0.000	0.000	0.000	26.001
87-V1	M1	S-8	0.195	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.098	16.016
87-V2	M1	S-8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	12.598
90-V1	M1	S-5	0.000	0.000	0.000	0.000	0.000	0.391	0.000	0.000	0.000	13.293
90-V2	M1	S-5	0.049	0.000	0.000	0.000	0.000	0.781	0.000	0.000	0.000	20.752
83-V1	Mo	S-2	0.098	0.000	0.000	0.000	0.000	0.049	0.000	0.000	0.000	15.015
83-V2	Mo	S-2	0.000	0.000	0.000	0.000	0.000	0.391	0.000	0.000	0.391	11.328
83-V3	Mo	S-2	0.391	0.000	0.000	0.000	0.000	0.024	0.000	0.006	0.000	18.585
86-V1	O2	S-3	0.000	0.000	0.000	0.000	0.000	0.098	0.000	0.049	0.000	15.381
86-V2	O2	S-3	0.781	0.000	0.000	0.000	0.000	0.000	0.000	0.195	0.000	10.352
88-B1	M1	S-4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	6.445
88-B2	M1	S-4	0.000	0.000	0.000	0.049	0.000	0.000	0.000	0.000	0.000	3.174
88-B3	M1	S-4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	6.445
88-B4	M1	S-4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	12.598
88-B5	M1	S-4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.172
88-S1	M1	S-4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	28.125
88-S2	M1	S-4	0.000	0.000	6.250	0.000	0.000	0.000	0.000	0.000	0.000	17.236
88-S3	M1	S-4	0.098	0.000	0.000	0.098	0.000	0.000	0.000	0.000	0.000	22.070
88-S4	M1	S-4	0.195	0.000	6.250	0.098	0.000	0.000	0.000	0.000	0.000	41.016
88-S5	M1	S-4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	41.504