Surficial Geology and Geomorphology of the Western Crater Range, Barry M. Goldwater Air Force Range, Southwestern Arizona

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Introduction

This report summarizes the surficial geology and geomorphology around the western part of the Crater Range, situated in the North Tactical Range on the Barry M. Goldwater Air Force Range in southwestern Arizona (Figure 1). The purpose of these investigations is to describe the geologic and geomorphic framework of the western Crater Range and surrounding areas in conjunction with an archaeological survey that was conducted for the Air Force by SWCA, Inc, and Arcadis Geraghty and Miller (Tucker, 2000). Field investigations and mapping were done in the spring of 1998. A 1:24,000-scale map showing the surficial geology of the survey area is included with this report (Plate 1). Interpretation of aerial photographs, field checking, and mapping was done primarily by J. Klawon, with field assistance and suggestions from P. Pearthree.

Numerous individuals contributed to these geomorphologic investigations. We would like to thank all of the members of the archaeological field crew, who were very pleasant company. In particular, we thank Dave Tucker, who oversaw the field efforts, coordinated our field investigations with those of the archaeological survey, and provided lots of information about the archaeology of the region. Maps were digitized and prepared for printing by Tom Biggs and Tim Orr.

Several previous geologic investigations have been conducted in this area. Kirk Bryan explored this area as part of a project to locate and evaluate potential water sources (Bryan, 1925). He described the general geology and physiography of this area, and made many astute observations about the processes that have shaped this landscape. This portion of Arizona was mapped on a reconnaissance basis by E.D. Wilson and R.T. Moore as part of their efforts to develop a 1:500,000-scale geologic map of Arizona (Wilson and others, 1969). The bedrock geology of the Ajo 1:250,000-scale sheet, which includes the project area, was subsequently mapped in somewhat more detail by Gray and others (1988). The generalized surficial geology of the Ajo sheet was mapped by Morrison (1983) at 1:250,000 scale. Bull (1991) developed a conceptual framework for understanding the impacts of climatic changes on arid region fluvial systems of the lower Colorado River region.

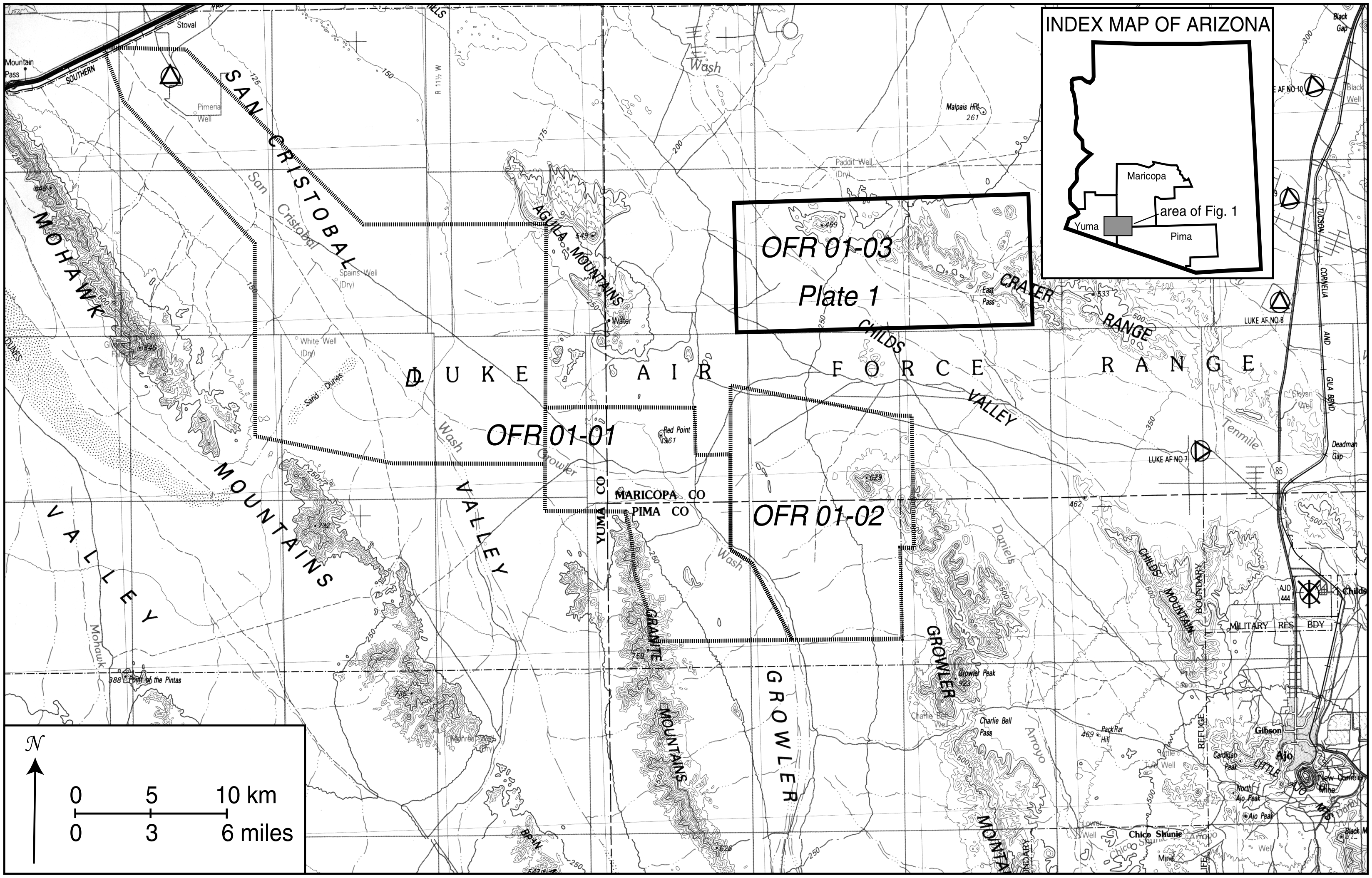

Figure 1. Location of the map area in the Barry M. Goldwater Air Force Range is outlined by the solid line. Adjacent areas where surficial geology has been mapped at 1:24,000-scale are outlined by dotted lines; letters and numbers refer to Arizona Geological Survey Open-File Reports that contain the maps.

Climate

The climate of the study area is currently hot and dry, with extreme seasonal temperature variations and two distinct seasons of rainfall. The nearest weather stations to the Crater Range are Ajo and Gila Bend. At Ajo (elevation 1747 feet asl), the average August high temperature is 103° F, and the average January low temperature is 42° F. Average annual precipitation at Ajo is 8.7 in. At Gila Bend (elevation 742 feet asl), the average August high temperature is 109° F, and the average January low temperature is 38° F. Average annual precipitation at Gila Bend is about 6 in. Occasional freezing temperatures are recorded at both stations during most winters, but snow is rare and not persistent. Slightly less than one-half of the annual precipitation at both weather stations falls between July and September (Western Regional Climate Center, 1998). Late summer rainfall occurs as heavy thunderstorms when moist air sweeps northwards from the Gulf of California and the Gulf of Mexico. Occasional intense late summer to early fall precipitation may occur in this region as a result of incursions of moist air derived from dissipating tropical storms in the Pacific Ocean. Winter precipitation generally is caused by cyclonic storms originating in the Pacific. It is usually less intense and may be more prolonged, and therefore infiltrates into the soil more deeply than summer rainfall (summarized from Sellers and Hill, 1974).

The climate of the Sonoran desert has not remained constant over the time period represented by the alluvial deposits and surfaces around the western Crater Range. 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 packrats in crevices and preserved for tens of thousands of years, indicates that the climate similar to today has only existed since about 4 ka (Van Devender, 1990). Middle to late Pleistocene midden samples from the western Sonoran Desert contain fragments of juniper, pinyon, and Joshua tree, indicating cooler summers and a greater proportion of winter precipitation than today. Precipitation probably reached a maximum during the late Pleistocene (30 to 15 ka), and the coexistence of frost-sensitive Whipple yucca and barrel cactus with juniper and pinyon pine suggests that late Pleistocene seasonal temperature extremes were less than those of today (Van Devender, 1990). 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 (Bull, 1991).

General Geology and Geomorphology

Childs Valley is located in the middle of the Sonoran Desert subprovince of the Basin and Range physiographic province. The Basin and Range province includes southern, central, and western Arizona, all of Nevada, parts of California, New Mexico, Oregon, Texas, and Utah, and much of northwestern Mexico. The physiography of the Basin and Range province is characterized by alluvial basins and intervening mountain ranges that formed as a result of normal faulting related to extension of the crust during the past 30 million years or so (Shafiqullah and others, 1980; see Table 1 for geologic time periods). Relatively narrow and low-lying, north- to northwest-trending ranges and broad, minimally dissected basins are typical of the Sonoran Desert subprovince. These characteristics imply that significant normal faulting has not occurred for millions of years in this area (Shafiqullah and others, 1980; Menges and Pearthree, 1989).

The bedrock geology of the project area has generally been mapped on a reconnaissance basis. Bedrock lithologies in the western Crater Mountains consist of silicic to mafic volcanic rocks of late Oligocene to middle Miocene age (Gray and others, 1988) with latite flows capping the majority of bedrock and basalts dominant at the western edge of the map area.

Quaternary (0 to 2 Ma)	Holocene (0 to 10 ka)	late Holocene (0 to 2 ka) early to middle Holocene (2 to 10 ka)
	Pleistocene (10 ka to 2 Ma)	late Pleistocene (10 to 150 ka) middle Pleistocene (150 to 750 ka) early Pleistocene (750 ka to 1.6 Ma)
Tertiary (2 to 65 Ma)	Pliocene (2 to 5.5 Ma) Miocene (5.5 to 22 Ma) Oligocene (22 to 38 Ma)	
Cretaceous (65 to 145 Ma)		
Precambrian (570 Ma to 4.5 Ga)		

Table 1. Time intervals as used in this report. "Thousands of years before present" is abbreviated as **ka**; "millions of years before present" is abbreviated as **Ma**; "billions of years before present" is abbreviated as **Ga.**

The geomorphology and surficial geology of this part of Arizona may be grouped into three main elements:

(1) Narrow, rugged, but not very lofty mountain ranges. The topographic fronts of the mountains are very embayed and sinuous, and outlying bedrock hills (inselbergs) are common. The very steep mountain slopes with minimal cover of colluvium attest to the predominance of erosional processes (Bryan, 1925). Erosion is facilitated by uncommon but intense rainfall and runoff, steep slopes, and sparse vegetative cover. It is likely that significantly more hillslope colluvium covered bedrock slopes in the mountains during glacial pluvial intervals of the Quaternary, especially in mountains composed of granitic or metamorphic rocks (Bull, 1991).

(2) Broad floodplains and alluvial fans associated with the major washes. The major washes in this region generally flow down the axes of the valleys about midway between the adjacent ranges. Wide floodplains associated with these washes are composed mainly of sand, silt and clay, with local gravelly channel deposits. Multiple small, discontinuous channels are typical, and well-defined channels are unusual. One or a few larger, well-defined channels exist along limited

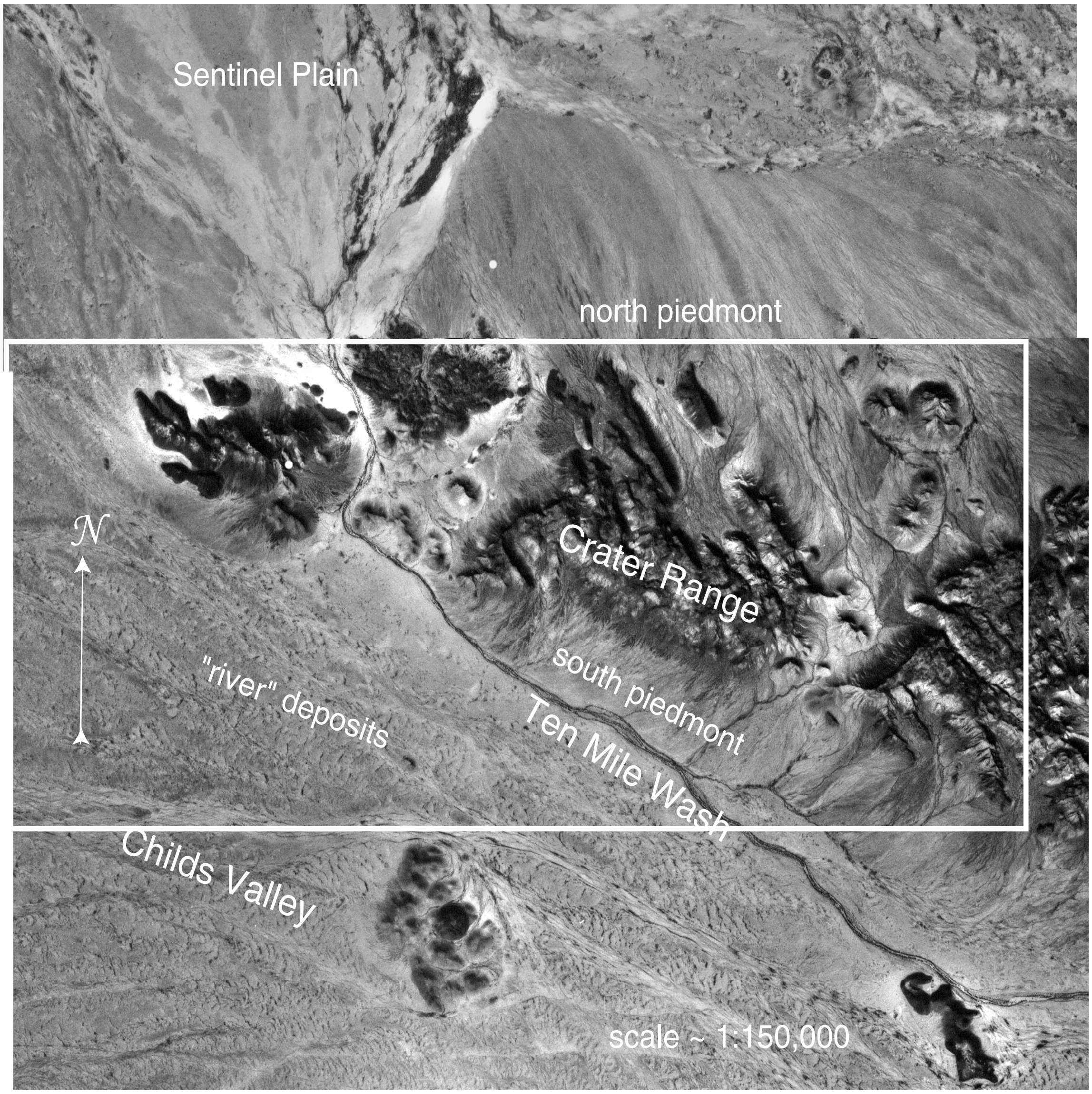

Figure 2. Composite high-altitude aerial photograph (~1:150,000-scale) of the study area. The major landscape elements are labeled, as are some specific localities in the area. The extent of Plate 1 is outlined by the white line.

reaches of the axial drainages. Locally, alluvial fans exist along these washes where floodplains are very wide and increase in width substantially downstream. Eolian reworking of floodplain and fan surfaces is common, especially in areas that have not been flooded recently.

(3) Piedmonts with minimal topographic relief. Piedmonts are the broad plains that slope gently from the mountains to the axial washes. They are covered by alluvial and eolian deposits, most of which are fairly young. Upper piedmont areas typically have tributary (converging downstream) drainage systems. Middle and lower piedmonts have weakly integrated, complex distributary (diverging downslope) drainage networks. There is little topographic relief; channels are entrenched as much as 2 to 3 m below adjacent relict fan surfaces on upper piedmonts, but less than 1 m of relief between channels and adjacent alluvial surfaces characterizes middle and lower piedmonts. Eolian deposits and landforms are very common, and they are generally prevalent on the eastern sides of valleys in this region.

Mapping Techniques and Ground Control

We employed standard surficial geologic mapping techniques to produce geologic maps of the project area. We developed a 1:24,000-scale surficial geologic map of the project area. Mapping was based primarily on interpretation of approximately 1:24,000-scale color photographs flown in 1985 that were supplied by the Air Force. Extensive field surveys were conducted to verify geologic relations in the map area.

Surficial geologic units in the project area were differentiated by the source and process of emplacement of the deposits and their relative age. Surficial deposits were grouped into four broad genetic categories. Hillslope colluvium consists of active and relict coarse sediment lobes deposited by mass wasting processes and debris flow mechanisms. Piedmont alluvium deposited by tributary streams consists of small channels and adjacent floodplains, terraces, and alluvial fans. Alluvium deposited by larger washes consists of channels, low floodplain terraces, and broad alluvial fans. Mixed eolian and alluvial deposits consist of relatively small dunes and varying amounts of exposed alluvium. Colluvial deposits and alluvial deposits in the first two categories were further subdivided based on their ages, using criteria described below. Deposits in the third category were subdivided based on the age of the associated alluvial deposits.

The physical characteristics of alluvial surfaces (alluvial fans, floodplains, stream terraces) may be used to differentiate their associated deposits by age. The initial surface features of alluvial surfaces are shaped by large-scale depositional processes. When surfaces are isolated from further deposition or reworking by large streams, they are gradually modified over thousands of years by other processes, which operate very slowly and on a smaller scale. Modifying processes include (1) small-scale erosion and deposition that smooth the original surface topography; (2) bioturbation, the churning of sediments by organisms, which obliterates depositional structures; (3) development of soils, primarily through accumulation of silt, clay, and calcium carbonate; (4) development of surficial gravel pavements (desert pavements) above zones of accumulated silt and clay; (5) accumulation of rock varnish on surface gravel clasts; (6) development of tributary dendritic (treelike) stream networks on surfaces; and (7) entrenchment of these stream networks below original depositional surfaces and subsequent dissection of these surfaces.

Alluvial surfaces of similar age have a characteristic appearance because they have undergone similar post-depositional modifications, and they are distinctly different from both younger and older surfaces. Young (less than a few thousand years old) alluvial-fan surfaces, for example, still retain clear evidence of the original depositional topography, such as coarse deposits, swales (troughlike depressions) where low flows passed between bars, and distributary channel networks, which are characteristic of active alluvial fans. Young fan surfaces also show minimal development of soil, desert pavement, and rock varnish and are basically undissected. Very old fan surfaces, in contrast, have been isolated from substantial fluvial deposition or reworking for hundreds of thousands of years. These surfaces are characterized by strongly developed soils with clay- and calcium-carbonate-rich horizons, well-developed tributary stream networks that are entrenched 1 to 10 m below the fan surface, and strongly developed varnish on surface rocks. Old alluvial-fan surfaces may also have smooth, closely packed desert pavements between the entrenched drainages. The ages of alluvial surfaces in the southwestern United States may be roughly estimated based on these surface characteristics, especially soil development (Gile and others, 1981; Bull, 1991).

Description of Map Units

Surficial deposits on the accompanying map (Plate 1) are classified by source of emplacement and inferred age. Deposits are divided by age into late Holocene (Qy2; less than about 4 ka; the abbreviation **ka** stands for thousands of years before present), early to middle Holocene (Qy1; about 4 to 10 ka), late Pleistocene-early Holocene (Qly; 7 to 15 ka), late Pleistocene (Ql; 10 to 150 ka), middle Pleistocene (Qm; 150 to 750 ka), early Pleistocene (Qo; 750 ka to 2 Ma; the abbreviation **Ma** stands for millions of years before present), and Pliocene (T, 2 to 5.5 Ma). Piedmont alluvial deposits do not have any additional letters attached to the unit labels other than age (**Qy2**, for example). Deposits associated with the major axial drainage of this area, Tenmile Wash, have the letter (**r)** added to the age designation (**Qy2r**, for example). Many areas in these valleys are covered by mixed alluvial and eolian deposits. We interpret all of the eolian deposits to be of Holocene age, but the alluvium exposed between eolian deposits may be of Holocene or late Pleistocene age. Map units indicate this mixture by the addition of the letter (**e**) to the alluvial unit designation (**Hre**, for example). As was noted above, ages of all of these deposits are roughly estimated by correlation with other similar areas, because no useful constraints have been developed for most of the deposits in these valleys. Age estimates given here are based on correlation with the surface chronosequence developed in the lower Colorado River valley by Bull (1991); see Table 2 at the end of this section. **All age estimates are approximate.**

Piedmont Alluvial Deposits

Piedmont alluvial deposits are derived from the Crater Range. The lithologic composition of clasts reflects local source lithologies. Thus, clast lithology varies somewhat along the piedmonts as bedrock source lithologies vary in the mountains.

Qy2 - late Holocene alluvium (< 2 ka)

Channels, undissected floodplains, low terraces, and active or recently active alluvial fans. On middle and lower piedmonts, deposits typically consist of sand, silt, and clay, with local channel gravel deposits; channels are small, shallow, and discontinuous. On upper piedmonts, deposits typically consist of sand to small boulders in well-defined channels, with sand and finer deposits on terraces and other areas subject to overbank flooding; braided or distributary channels networks are common. Vegetation is generally sparse, with low desert shrubs and annuals; vegetation density is higher with larger shrubs and some palo verde, ironwood, and mesquite along and near channels. Eolian landforms are evident locally, but coppice dunes around clumps of vegetation have been streamlined by recent flooding. Limited, open gravel lags on surface, but there are no pavements and rock varnish is minimal; surface color is light brown, but may be darker during seasons with above-average moisture because of growth of annuals and other ground covering plants. **Qy2** is probably correlative with units Q4 and Q3c of Bull (1991; see Table 2), which are of late Holocene age.

Qy1 - middle to early Holocene alluvium (2 to 10 ka)

Undissected terraces and alluvial fans somewhat isolated from active fluvial systems. Alluvial surfaces typically are < 1 m above adjacent washes and are partially covered by weak pavements or residual gravel deposits composed of pebbles and few cobbles with minimal rock varnish, although deposits are predominantly sand and finer. Vegetation on lag surfaces is sparse. Where Qy1 is found on the lower piedmont, there is some eolian overprint consisting of linear to semicircular coppice dunes associated with more vegetation, mainly creosote; dunes crests less than 1 m above adjacent surfaces with gravel lags. Surface color is light brown to light gray, typically somewhat lighter than **Qy2** surfaces. **Qy1** deposits are probably correlative with unit Q3b and possibly unit Q3a of Bull (1991), which are middle to early Holocene in age.

Qly - late Pleistocene to early Holocene alluvium (7 to 15 ka)

Slightly dissected terraces and alluvial fans whose surfaces are higher and have tones which are lighter or more brown than **Qy1** or **Qy2**. **Qly** encompasses surfaces which have moderate to well-developed desert pavement and varnish ranging from weak to moderate. In the upper and middle piedmont, **Qly** surfaces may be greater than 2 m above the active channel. On the lower piedmont, this difference decreases to less than one meter. Surfaces may be coarse-grained and hummocky, with distinct bar and swale topography, or fine-grained and relatively planar. Where described, the soil of **Qly** increases in carbonate development with depth; coatings increase in their thickness and continuity around clasts. Percent sand and gravel as well as induration increase with greater carbonate development. Soil clay and color development is minimal throughout the profile.

Ql - late Pleistocene alluvium (10 to 150 ka)

Weakly to moderately dissected alluvial fans and terraces that are higher and grayer than surrounding **Qy** and **Qly** surfaces. In lower and middle piedmont areas, **Ql** surfaces typically have tributary drainage networks that are incised less than 1 m; in upper piedmonts, **Ql** surfaces may be as much as 2 m above active channels. Surfaces have moderate to strong pavements composed of angular to subangular pebbles and some cobbles in upper piedmont areas, and finer grained components in the lower piedmont; rock varnish typically is strong; surface color is gray to red. Soils associated with this unit are somewhat enriched in clay and silt, and are slightly reddened. **Ql** deposits are probably correlative with unit Q2c of Bull (1991), which is of late Pleistocene age. In some areas, **Ql** deposits are subdivided based on grain size (see below).

Qlf - fine-grained late Pleistocene alluvium (10 to 150 ka)

Fine-grained alluvial fans and terraces of **Ql**. Surfaces are planar with moderate to strong varnish and moderate to strong pavements composed of angular to subangular pebbles and gravels. Vegetation is sparse on well preserved surfaces; developing drainages are occupied by greater vegetation, but appear lighter from carbonate eroding out of the soil profile.

Qlc - coarse-grained late Pleistocene alluvium (10 to 150 ka)

Coarse-grained alluvial fans and terraces of **Ql** with moderate to strong varnish and moderate to strong pavements composed of relict bars of angular to subangular gravels and cobbles that stand in relief to swales of finer-grained fill. Vegetation and dissection is similar to that of **Qlf**.

Qm - middle Pleistocene alluvium (150 to 750 ka)

Older relict fans with moderate to strong soil development and well-developed, entrenched tributary drainage networks. Modern channels are incised up to 3 m below **Qm** surfaces. Between modern channels, surfaces typically are very planar or broadly rounded with subdued bar-and-swale topography in places, moderate to strong pebble to cobble pavements, and gray to black rock varnish. Surface color ranges from dark red to light gray, and is dependent upon the degree of erosion into the underlying carbonate horizon. Underlying soil is reddened and enriched in clay and has moderate to strong carbonate accumulation. These deposits are limited in extent and are exposed only in middle and upper piedmont areas. They are probably correlative with units Q2b and Q2a of Bull (1991), which are middle Pleistocene in age.

QTs – early Quaternary to late Tertiary alluvium (1 to 10 Ma)

Poorly preserved fan remnants composed of subrounded stones and subangular to angular cobbles, fractured from the larger clasts. Typically, **QTs** is higher than any Quaternary surface and has black varnish on its clasts as well as a strongly-developed desert pavement. Surfaces appear as isolated rounded hills cemented by carbonate along their slopes and preserve little of their original fan morphology.

<u>Eolian and Eolian / Alluvial Mixed Units</u>

Mixed units are derived from Crater Range alluvium along with wind-blown additions of silt from the region. Purely eolian features are localized and appear to have formed in response to local wind patterns around bedrock topography.

Qe - late Holocene eolian deposits (0 to 2 ka)

Eolian accumulations of sand and silt located adjacent to bedrock outcrops. Surfaces appear light yellow and are somewhat stabilized by vegetation such as creosote, cacti, and grasses. **Qe** surfaces are uncommon in this area and do not seem to prefer a particular orientation on the landscape.

Qle - Late Pleistocene alluvium and Holocene eolian deposits (< 150 ka)

Mixed young eolian deposits and intermediate alluvium. Weak to moderate, pebble-cobble pavements and small coppice dunes; flat areas with pavements generally are more extensive than eolian features and rocks have weak to moderate varnish. Soil development is moderate with enrichment in clay, silt, and carbonate. Pavement surfaces are light gray on aerial photos and eolian features impart striped appearance to surfaces. The estimated age of the alluvium is late Pleistocene, with Holocene eolian features overprinting, or moving over older pavements and soils.

<u>Axial Valley Deposits of Tenmile Wash</u>

Tenmile Wash and several smaller washes to the south drain much of northern Ajo Valley, the Batamote Mountains, Childs Valley, the north side of the Crater Range, and the northern Ajo Range. The bedrock lithologies in these areas consist primarily of Tertiary volcanic rocks. The deposits associated with Tenmile Wash in the map area contain somewhat more diverse clast lithologies than do piedmont deposits.

Qy2r - late Holocene stream deposits (< 1 ka)

Deposits in stream channels and on primary floodplains of the major washes. Deposits generally consist of mixed lithologies of sand, silt, and clay, with local gravel concentrations and lags. Shallow, small, discontinuous channels are common. Vegetation typically is large creosote and low grass and shrubs, with local mesquite, ironwood, and palo verde concentrations. Variegated surface color depends mainly on vegetation density, dark brown color along channels and where vegetated, brown where more sparsely vegetated. Eolian features have been streamlined by flow. This unit also includes arroyo channels, which are steep-walled, less than 2 m deep, and have local gravel deposits.

H1r - Holocene stream terrace deposits (< 10 ka)

Deposits associated with relict channels and upper or secondary floodplains of major washes. Typically, they are flat surfaces that are on the fringes of and less than 1 m above the primary floodplain. Deposits are generally fine-grained, but surfaces have weak, discontinuous gravel lags composed of mixed lithologies. Some small, poorly defined channels. Surface color typically is light brown, and surface clasts have no varnish. Very limited low (0.5 m high) coppice dunes associated with creosote bushes and bioturbated sand and finer sediment. These surfaces probably are inundated in the largest floods. They merge almost imperceptibly into young lowermost piedmont deposits (units **Qy1** and **Qy2**).

Hre - Holocene stream terrace deposits and eolian deposits (< 10 ka)

Mixed young river terrace deposits and eolian deposits. Landforms consist of low coppice dunes and intervening flat surfaces with slight gravel lags and no pavement development, less than 1 m above adjacent floodplains. Drainage networks typically are discontinuous and channels are small. Low coppice dunes are abundant; vegetation is sparse, desert shrubs are relatively concentrated in dunes and along small channels. Predominance of eolian influence indicates that these areas have only been subject to occasional local sheet flow but not to substantial flooding for thousands of years. Thus, the alluvium in these areas is older than **H1r**.

Lre - Late Pleistocene stream terrace deposits and Holocene eolian deposits (< 150 ka)

Mixed intermediate pebble, gravel and finer textured river terraces and young eolian deposits. Surfaces are smooth and flat, ~1 m above adjacent floodplains; they have weak to moderate pebble to cobble pavements composed of mixed lithologies, with weak rock varnish on surface clasts. This unit includes varying amounts of low coppice dunes composed of fine-grained, bioturbated sediment. Creosote bushes exist on the dunes, otherwise vegetation is very sparse. Surface color is light to medium gray on photos due to weakly varnished gravel pavements. Lre soils exhibit a silty vesicular A horizon with slight soil reddening and clay and carbonate accumulations in a weakly developed B horizon (Bw). More substantial clays and nodular carbonates developing between and around <30 cm gravels compose a horizon which is noticeably more indurated than the upper soil profile. **Lre** surfaces have not been subject to substantial inundation by floods on the major washes for thousands of years.

Age Range	**Lower Colorado River chronosequence (Bull, 1991)**	**Growler chronosequence (this report)**
historical (< 100 yr)	Q4	Qy2r
late Holocene (0-4 ka)	Q3c	Qy2, Qe, H1r
middle Holocene (4-7 ka)	Q3b	Qy1
early Holocene to latest Pleistocene (7-15 ka)	Q3a	Qy1?, Ql?
late Pleistocene (15-150 ka)	Q2c	Ql
middle Pleistocene (150-750 ka)	Q2b, Q2a	Qm
early Pleistocene (750 ka to 2 Ma)	Q1	Qo

Table 2. Tentative correlation table for deposits of the lower Colorado River Valley and the northern Growler Valley. Mixed eolian / alluvial units are not included because they cannot be readily classified by age.

<u>Colluvial Deposits</u>

Hillslope colluvial deposits are locally derived and are deposited on hillslopes immediately adjacent to source areas by processes of mass wasting. Composition of the clasts is a function of the local lithology, and for this reason may vary from site to site.

R2c - Holocene colluvium (< 10 ka)

Subrounded to subangular, variably varnished stones and boulders which extend as elongate lobes from the mountain front. Surfaces occupy steep slopes issuing below near vertical bedrock outcrops and appear dark gray to black in contrast to predominantly bedrock areas, which appear light orange on mountain hillslopes. R2c deposits have sparse vegetation and are variable in age, encompassing relict to active colluvial slopes.

R1c - Pleistocene colluvium (10 ka to 1 Ma)

Relict colluvial slopes located adjacent to modern hillslopes. Typically, **R1c** surfaces consist of darkly varnished subrounded to subangular clasts with extensive carbonate litter, which imparts a white to pale yellow color to the deposit. They are limited in extent and rather localized, occurring as crescent-shaped wedges alongside bedrock knobs in the western and central parts of the project area. Overall, they are relatively planar and appear to have been modified by fluvial processes.

Bedrock units

Bedrock geologic units in the Crater Range consist primarily of gently tilted, fine-grained volcanic rocks of middle Tertiary age. Compositions range from felsic (latite) to fairly mafic (basaltic andesite). Mapping and unit descriptions are taken from Gray and others (1988).

Tba - Basaltic andesite flows (middle to late Miocene)

These youngest volcanic rocks in the map area consist of thin, mesa-capping flows 2 to 6 meters thick. This unit has been dated by K/Ar (potassium/argon) whole rock ages of 14.4 ± 0.7 Ma (Gray and Miller, 1984), 15.0 ± 2.0 Ma (Eberly and Stanley, 1978) and 15.52 ± 0.54 Ma (Shafiquallah and others, 1984).

Tc - Childs latite flows (middle Miocene)

These more felsic volcanic flows are somewhat older than the basaltic andesite. One to three cm andesine phenocrysts typically comprise 30-40 percent of rock. The fine-grained groundmass is composed of plagioclase, potassium-feldspar, olivine, clinopyroxene, apatite, and iron and titanium oxides. Individual flows vary in thickness from 3-20 m and may reach a total thickness of greater than 300 m. A K/Ar date on plagioclase yielded an age of 18.4 ± 0.9 Ma (Gray and Miller, 1984).

Thc - Holocrystalline Childs latite flows and intrusives (middle Miocene)

Light gray locally columnar jointed flows and subvolcanic intrusive bodies associated with the Childs flows.

Tsa - Sneed andesite, and associated andesitic flow tuffs and intrusive rocks (early Miocene)

Light-pinkish-tan to gray medium-grained flows, associated tuffs, and intrusive rocks (Gilluly, 1946). K/Ar date on biotite in tuffs on top of the Sneed andesite yielded an age of 22.0 ± 0.7 m.y. (Gray and Miller, 1984)

Debris Flow Features

Along the steep flanks of the Crater Range mountain front are hillslope scars which appear as linear features lighter in color than surrounding bedrock and colluvium. Generally, they run parallel to hillslope gradient, extending from the colluvial-bedrock contact to the colluvial-alluvial contact at the base of the hillslope. Although the scars vary in age, they display similar features that distinguish them from the surrounding hillslope. These features include:

Chutes: linear features which are lighter in color than surrounding material in part due to exposed carbonate, and less varnished bedrock. Colluvium may also occupy the chute if the chute has begun to fill in; in this case, weaker varnish on the colluvium differentiates the chute from the surrounding hillslope.

Levees: concentrations of boulders that line the chute on both sides and stand in relief to the surrounding colluvium. Levees are less vegetated than adjacent colluvium and also show evidence of abrasion where patches of varnish have been removed.

Toe slope deposits: cone-shaped deposits of boulders occurring at the slope break between the hillslope and alluvial fan. Toe slope deposits are discernible when they are associated with larger chutes and may be indistinct in areas with minimal sediment supply on the hillslope.

Mulitiple generations of levees are preserved in the Crater Range. Although no age determination has been made for these features, they may be grouped into young, intermediate, and old based on their morphologies. Young scars have chutes that typically have minimal vegetation and colluvium and expose carbonate and weakly varnished bedrock (Figure 3). Levees are obvious and stand in relief to the surrounding hillslope material; toe slope deposits are weakly dissected. Judging from the vegetation growing in the chutes and the presence of the scars on aerial photos from 1972, these features must be > 25 years old. Intermediate age scars commonly have chutes that are vegetated with large paloverde trees and are partially filled with colluvium Figure 4). Levees are degraded yet still apparent along the length of the chute; toe slopes are well vegetated and dissected. The oldest scars appear as faint lineaments on hillslopes, occupying slight depressions in the colluvium (Figure 5). Chutes are generally filled in and vegetated; however, in the chute, clasts have weaker varnish and vegetation density is lower than the adjacent hillsides. Levees are indistinct but may be observed in places along the chute.

Classic debris flow features are similar in morphology to those features described and observed in the Crater Range. Typically, they are characterized by chutes, levees of material which have piled up along flow boundaries, and coarse depositional lobes in down-gradient positions at the termination of the debris flow. For a debris flow to initiate, it must have a sufficiently steep slope, an abundant sediment supply, a destabilizing mechanism such as intense and/or prolonged rainfall. The Crater Range hillslopes have all of these elements. Their sediment supply is limited, however, such that flows do not always reach the base of the hillslope or leave identifiable toe slope deposits. Thus, debris flows play a minor role in contributing sediment to the landscape in the present climatic regime. W.B. Bull has postulated that in past climatic regimes that were wetter and moister in the Sonoran Desert, colluvial cover was thicker and has subsequently been stripped off during the transition to a drier climate (Bull, 1991). During this period of history, debris flow mechanisms may have been a dominant form of mass wasting as thicker colluvial covers were removed from Crater Range hillslopes. Remnants of this cover may be seen today in the relict colluvial slopes of the R1c unit.

Figure 3. Youngest debris flow scars on the south flank of the Crater Range. Debris chutes appear light-colored, exposing underlying carbonate and unvarnished bedrock. Minimal recovery of vegetation or colluvial fill has occurred since the time of scar formation. Person is circled for scale.

Figure 4. Intermediate age debris flow scar. The chute located in the center of the picture has partially filled in with colluvium and a lighter colored shrub. The most obvious debris flow route turns sharply toward the left in the bottom part of the picture.

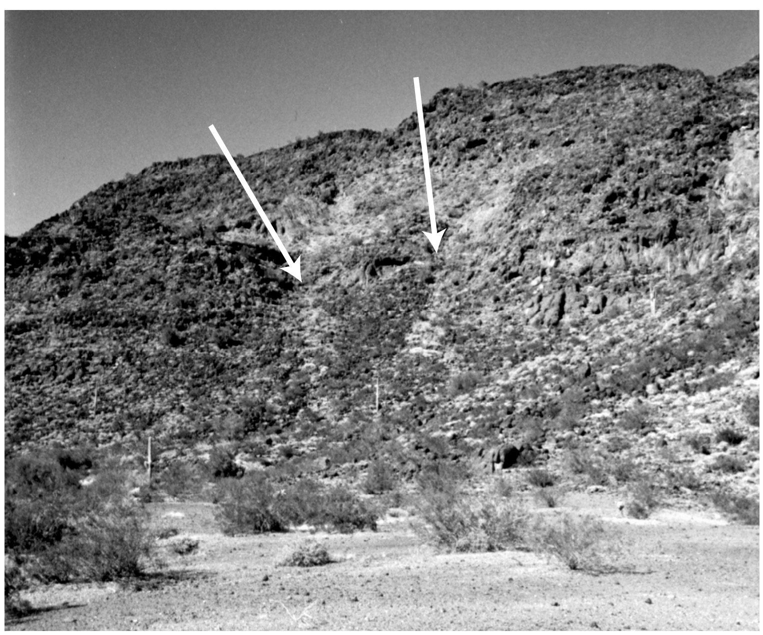

Figure 5. Oldest debris flow scars. Arrows point to two faint scars in this picture, both of which head below bedrock outcrops and can be traced into colluvial slopes. The chutes of these features have undergone an almost complete recovery since the most recent debris flow.

In summary, debris flow scars are common on the hillslopes of the Crater Range. They range from fresh scars which have undergone little recovery of natural vegetation and landscape morphology to those scars which appear as faint lineaments along the mountain front and are recognized only when one is specifically looking for them. These features can be explained by natural mechanisms and seem in all respects to be landforms created by debris flow processes.

Summary of the Surficial Geology

The surficial geology of the project area includes a diverse assemblage of deposits, ranging from coarse, poorly sorted hillslope deposits to fine-grained, well-sorted eolian deposits. These deposits have different lithologic and soil characteristics, and support different vegetation assemblages, and thus may have been utilized in different ways by prehistoric people in this area.

The southwestern and western parts of the map area are dominated by Holocene and late Pleistocene deposits of Tenmile Wash and other smaller drainages that flow through Childs Valley. These deposits have a reasonably diverse range of clast lithologies, reflecting the fact that Tenmile Wash drains a fairly large area to the southeast of the project area. Generally, the particle size is fine gravel or smaller. Tenmile Wash currently cuts through the westernmost part of the Crater Range, whereas several smaller drainages that parallel Tenmile Wash to the south flow around the end of the Crater Range. Holocene deposits associated with Tenmile Wash cover a broad strip in Childs Valley, narrow in the valley that cuts through the mountains, and then broaden into an extensive young alluvial fan on the north side of the range. Late Pleistocene deposits associated with Tenmile Wash and the parallel drainages (units Lr and Lre) form a large relict alluvial-fan complex that covers much of Childs Valley and the area west of the Crater Range. Younger Holocene eolian deposits mantle extensive portions of the relict alluvial surfaces (unit Lre). The extensive late Pleistocene alluvial-fan surfaces that wrap around the west end of the Crater Range suggest that Tenmile Wash, or at least a branch of it, formerly flowed around the western end of the Crater Range before continuing northwestward to join the Gila River.

The piedmont areas flanking the Crater Range are covered with alluvial-fan and terrace deposits ranging in age from middle Pleistocene to late Holocene. Much of the piedmont area is covered by early Holocene to late Pleistocene alluvial fan deposits. Adjacent to the mountain slopes, late Pleistocene deposits commonly contain cobbles and small boulders (units Ql, Qlc, and Qly). Farther downslope, these deposits typically consist of pebble-sized and finer material (units Qle and Qlf). On all of these surfaces, desert pavements are moderately developed, infiltration rates are fairly low, and vegetation tends to be concentrated along drainages. Adjacent to mountain slopes, vegetation is more extensive on interfluve areas. Smooth, darkly varnished middle Pleistocene alluvial-fan surfaces are not extensive around the western Crater Range. They are found mainly on the south side of the range, and the base of the mountain slopes. Clay and calcium carbonate accumulation in soils associated with Qm alluvial fans is much greater than in any of the younger units. Infiltration rates on these surfaces must be quite low, and vegetation is found mainly along drainages. Holocene channel, terrace, and alluvial-fan deposits are most extensive on middle and lower piedmonts. They are much more closely associated with the modern drainage network of the project area than are the older surfaces. Depositional landforms such as gravel bars and finer-grained swales are typically well-preserved on these surfaces. These young surfaces also typically are sites of the largest, densest vegetation in the project area, primarily because available moisture is substantially greater due to occasional stream flow.

The mountain slopes of the Crater Range consist of volcanic bedrock and hillslope colluvium derived from the bedrock. The bedrock areas consist of exposed, minimally to moderately weathered bedrock and areas of thin soil cover. Vegetation cover is typically moderate to sparse. Much of the middle and lower mountain slopes are covered with angular, poorly sorted colluvial deposits. These deposits have developed because of downslope movement of clasts from the adjacent bedrock areas. Depending on the age of the colluvium, soil development may be weak to moderate, and vegetation tends to be concentrated adjacent to drainages and swales on the hillsides.

References

Bryan, Kirk, 1925, The Papago Country, Arizona: A geographic, geologic, and hydrologic reconnaissance with a guide to desert watering places. U.S. Geological Survey Water Supply Paper 499, 436 p.

Bull, W.B., 1991, Geomorphic Response to Climatic Change, New York: Oxford University Press, 326 p.

Eberly, L.D., and Stanley, T.B., Jr., 1978, Cenozoic stratigraphy and geologic history of southwestern Arizona: Geological Society of America Bulletin, v. 89, p. 921-940.

Gilluly, James, 1946, The Ajo mining district, Arizona: U.S. Geological Survey Professional Paper 209, 112 p.

Gray, Floyd, and Miller, R.J., 1984, New K-Ar age of volcanic rocks near Ajo, Pima and Maricopa Counties, southwestern Arizona: Isochron/west, no. 41.

Gray, Floyd, Miller, R.J., Grubensky, M.J., Tosdal, R.M., Haxel, G.B., Peterson, D.W., May, D.J., and Silver, L.T., 1988, Preliminary geologic map of the Ajo and Lukeville 1° by 2° quadrangles, southwest Arizona, USGS Open-File Report 87-347, 23 p., 1 sheet, 1:250,000.

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

Morrison, R.B., 1983, Late Pliocene and Quaternary geology, Ajo Quadrangle: Arizona Bureau of Geology and Mineral Technology Open-File Report 84-1, 6 p. scale 1:250,000.

Sellers, W.D., and Hill, R.H., 1974, Arizona Climate, 1931-1972: Tucson, University of Arizona Press, 616 p.

Shafiquallah, 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 southwestern Arizona and adjacent areas: Arizona Geological Society Digest, v. 12, p. 201-260.

Tucker, D.B., 2000, Footsteps on the bajada: SWCA Cultural Resource Report No. 99-104, prepared for the 56th Range Management Office, Luke Air Force Base, Arizona, 747 p. plus appendices, 2 pocket maps.

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: Tucson, University of Arizona Press, p., 134-164.

Western Regional Climate Center, 1998, Arizona climate summaries, in Western U.S. historical climate summaries, WRCC Web Page, Desert Research Institute, University of Nevada.

Wilson, E.D., Moore, R.T., and Cooper, J.R., 1969, Geologic map of Arizona: Arizona Bureau of Mines, 1 sheet, scale 1:500,000.