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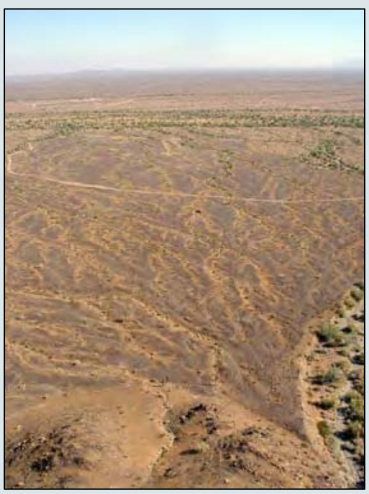

Landforms and Surface Cover of U.S. Army Yuma Proving Ground

Eric V. McDonald
Graham K. Dalldorf
Steven N. Bacon

FINAL REPORT
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September 08, 2009

Prepared by
Desert Research Institute,
Division of Earth & Ecosystem Sciences

Prepared for
U.S. Army Yuma Proving Ground,
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This report is part of a tiered series of reports that began with a general overview of Global Military Operating Environments (GMOEs) of interest to the U.S. military, particularly deserts of the world. In the first tier of these studies, U.S. military controlled properties were categorized in terms of landforms and surface cover characteristics. The second tier of studies compares characteristics of these properties to Global Military Operating Environments (such as a desert region); the third tier of this overall project will detail landscape properties in high resolution for limited areas, such as a vehicle test course, or an area of heavy dust production. This report is a comprehensive inventory of the landforms and corresponding surface characteristics at Yuma Proving Ground, southern Arizona. This report represents an early development of the methodology of applying expert-based, quantitative analyses to unclassified imagery integrated with existing USDA soil maps to map the spatial distribution of landforms, with the ultimate goal of adapting these maps to terrain hazards assessment for the U.S. military. Products of this methodology include maps of landforms, potential dust emission, desert pavement development, and slope. The report is accompanied by a suite of 8 maps.

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1.0 INTRODUCTION

The U.S. Army Proving Ground (YPG) in Yuma, Arizona is the primary Department of Defense (DoD) desert environmental test center in the Sonoran Desert of southwest U.S. Covering an area of about 3390 km^2, YPG contains a diverse array of landforms with varying surface cover and associated soil properties.

The objective of this report is to provide YPG and DoD with documentation and maps of the geomorphology within YPG (Maps 1-8). More specifically, this report provides the delineation of the constituent landforms and presents information on their geology, landform type, soil cover, degree of desert pavement development, and dust potential. To facilitate application and comprehension of material presented, data is provided in graphical format represented by map products, perspective views of individual landforms from oblique aerial photographs, and in tabular format.

This report is part of a multi-task project related to the characterization of the desert terrain at YPG, as well as of deserts in southwest Asia and other deserts of strategic interest. Building on a previous report concerning the landforms and surface cover at vehicle test courses at YPG (McDonald and Bacon, 2009), this report represents a comprehensive inventory of the landforms and corresponding surface characteristics found at YPG. Other reports (e.g. McDonald *et al*., 2009) provide science-based linkages between other deserts of strategic interest and the terrain at YPG, and further enhance the development of testing strategies that realistically simulate the conditions of military operations in the desert.

1.1 Report Scope and Format

The geomorphology and surface characteristics were mapped and documented at a fixed scale of 1:50,000 for all property within the boundary of YPG. The remainder of this introduction will include information on mapping methods for the eight different types of maps produced for this report. Following the introduction, the second section of the report presents the eight maps and describes the landform categories upon which the maps are based.

1.2 Definition of Map Units

The geomorphology, sedimentology, and physical attributes of the soils in YPG have been mapped directly into a digital geographic information system (GIS) platform, and are presented as eight individual maps. Identification of landforms and assignment of relative ages were accomplished using a variety of digital imagery as noted in Table 1-1. The following sections describe the eight different maps and the methods used to create them.

Table 1-1. Digital imagery used in mapping.

Image	Resolution	Area of YPG
IKONOS satellite	1-meter	Western half
Space Imaging satellite	5-meter	Eastern half
U. S. Geological Survey (USGS) digital orthorectified quadrangle (DOQ)	1-meter	Northern margin of western half
Google Earth	Variable	Entire area

1.2.1 Hillshade Map

The hillshade map was generated from a 10-meter digital elevation model (DEM) of YPG and the surrounding area. The map, overlain by easily recognized landmarks to facilitate orientation, allows for viewing of the desert terrain morphology without geologic and surface cover map units (Map 1).

1.2.2 Combined Geologic and Landform Map

The combined geologic and landform map is based on the identification and characterization of Quaternary (less than 1.8 million years old) landforms and associated surface features (Map 2). Relative ages of the landforms are assigned based on cross-cutting relations and surface morphology observed on digital imagery. More detailed information on landform mapping units are in the following section. The initial soils map of the U.S. Department of Agriculture (USDA), National Resources Conservation Service (NRCS), Soil Survey of the Yuma Proving Ground (NRCS, 1991) was refined in this project by adding additional landforms or the separation of existing NRCS soil units after the identification from image analysis. This task was undertaken in an effort to correlate and characterize the desert terrain in terms of Military Operating Environments (e.g., King et al., 2004), as well as other on-going projects at YPG.

1.2.3 Landform Map

Landform delineation results from the geologic map and interpretation of satellite-imagery (Map 3). The landform map depicts landforms independent of age. The landform categories used to characterize the desert terrain at YPG have been modified after the landscape and soil setting classification of King et al. (2004), which is revised and presented as Table 1-2. In this classification scheme, there are several landform mapping levels, which are a function of the mapping scale. at which the mapping was performed. The map scale used for this study is 1:50,000, a scale usually requiring the use of Landform (Level 3), which is not shown in Table 1-2; however, instead, both Landform (Levels 1 and 2) are used to characterize the desert terrain of the test courses (McDonald and Bacon, 2009), as well as the mapping of this project, so that the mapping is compatible with that of an additional on-going and overlapping project at YPG. This additional project is the third subtask related to characterizing desert terrain at YPG and consists of mapping analogous desert terrain within the World's deserts and comparing them with the desert terrain at YPG. This third subtask is referred to as the "Catalog of Analogs", and is carried out at a scale of 1:750,000, and therefore requires the use of Landform (Levels 1 and 2) for landform

Table 1-2. Landform list used to characterize geomorphic features at the U.S. Army's Yuma Proving Ground, Yuma, Arizona and the World's Deserts (revised after King et al., 2004; Table III.3).

Physiography	**Landform**
Mountains	Mountain highlands (Rocky/bedrock)
Uplands	Plateau, mesa, butte
Transitional	Badlands (eroded sediment)
	Pediments
	Recent volcanic features
	Sand sea/dunes
	Sand sheets
Piedmont Slope	Alluvial fans
Transitional	Badlands (eroded sediment)
	Pediments
	Recent volcanic features
	Sand sea/dunes
	Sand sheets
Flats/Plains	Alluvial plain
	Broad river valley
	Playa/sabkha
	Coastal
Transitional	Badlands (eroded sediment)
	Recent volcanic features
	Sand sea/dunes

characterization. A brief description and definition of each landform listed in Table 1-2 is given in the glossary section of this report.

1.2.4 Surface Cover Map

Soil data from the Soil Survey of the Yuma Proving Ground (NRCS, 1991) was integrated with the landform mapping of this study to produce the surface cover map (Map 4). The surface cover mapping units of YPG are described using the United Soils Classification System (USCS), per the standard ASTM D2487-00, and are based on NRCS (1991) laboratory data (Appendix A).

1.2.5 Soil Map

Soil data from the USDA, NRCS, Soil Survey of the Yuma Proving Ground (NRCS, 1991) was integrated with the landform mapping of this study to produce the soil map (Map 5). The soil mapping units are described using the USDA soils classification system and are based on NRCS (1991). Many areas previously mapped by the NRCS (1991) have been revised and remapped based on the new detailed geologic and landform mapping of this study.

1.2.6 General Dust Content Map

Soil data from the Soil Survey of the Yuma Proving Ground (NRCS, 1991) was integrated with the landform mapping of this study to produce the general dust content map (Map 6). This map portrays the dust content in upper 12 inches of the surface of individual landforms, which is based on NRCS (1991) soil laboratory data (Appendix A) and field observations of this study. In this report, dust is defined as the combined silt and clay content (% silt + % clay in the <2 mm, gravel-free portion of the soil) and consist of particles <0.050 mm in diameter. These are general estimates only and predict the potential of the soils to emit dust when they are highly disturbed during dry soil conditions and when most of the original soil surface has been degraded.

1.2.7 Desert Pavement Development Map

Geologic and landform mapping and field observations for this study were used to produce the desert pavement development map (Map 7). Desert pavements are surficial features that consist of a layer of clasts (rock fragments), typically one-clast thick, underlain by a fine-textured sandy silt to clayey silt horizon commonly referred to as an Av (vesicular) horizon. The Av horizon is largely composed of desert dust that has accumulated in the upper parts of the soil over a long period of time (on order of thousands of years). It should be noted that the USDA in general and the NRCS soil survey in particular, do not recognize the Av soil horizon. Soils with desert pavements are commonly referred to as reg soils in other arid parts of the world, such as in southwest Asia. In addition to desert pavements, lag layers were identified. Lag layers are similar to pavements but lack the packing and alignment of surface clasts, as well as the underlying Av horizon. Lag layers are commonly associated with young, active alluvial surfaces and bedrock surfaces. In this study, desert pavements are described as having the following degrees of development and accompanying characteristics:

- **None:** No concentration of surface clasts due to surface processes.

- **Lag**: Discontinuous cover of loose clasts at surface, no underlying dust-rich Av horizon. Implied origin is deflation of surface by eolian (wind) or sheetwash (water) processes.

- **Weakly**: Weakly developed pavement consisting of discontinuous patches of pavement with incipient varnish formation (clast color similar to original color of alluvium so that lithology is easy to distinguish). This type of surface is also underlain by an incipient to thin dust-rich Av dust horizon.

- **Moderately**: Moderately developed pavement include continuous to nearly continuous layer of surface clasts with distinct formation of varnish (i.e., clast color noticeably darker with only white-colored minerals still visible). This type of surface is typically underlain by a moderately thick to thick dust-rich Av horizon.

- **Strongly**: Strongly developed pavement consists of continuous to nearly continuous layer of surface clasts having prominent formation of varnish (i.e., clasts color distinctly darker so that lithology can only be determined along non-varnished surfaces). This type of surface is also underlain by a thick dust-rich Av horizon. These soils are commonly referred to as ‘caliche’ and ‘malpais’soils at YPG.

1.2.8 Slope Map

A 10-meter resolution DEM of YPG was used to generate the slope map (Map 8). This map shows a range of slope percentages classified into five categories. These categories are 0-10%, >10-20%, >20-30%, >30-40%, and >40%.

2.0 LANDFORM DESCRIPTIONS AND MAPS

This section describes characteristics of the mapped landforms at YPG and presents eight maps, the contents of which have been previously noted. For further information, a Glossary of Geomorphic Landforms in section 4.0 is provided after the References in section 3.0.

2.1 Landform and Soil Cover Characteristics of YPG

The morphologic and soil cover characteristics of each of the 11 landforms identified at YPG are described in each of the subsections below, and can be referenced on Maps 2 through 8. The eight maps are folded and located in a pocket on the inside of the back cover of this report. In order to show the data over the entire extent of YPG, the maps are displayed on large format (18”x 20”) paper at a scale of 1:228,000.

2.1.1 Remnant Fan

Remnant fan (Qf0) landforms typically have ridge lines that are relatively broad and rounded or narrow and sharp, and slope 0-20%. Steep slopes that lead to nearby watercourses are greater than 20%. These steeper slopes are often rilled by erosion that forms small-scale, shallow channels. The desert pavement, once well-developed on the original fan surfaces, is no longer extant, and where present, is preserved along narrow portions of ridge lines. Where intact pavement surfaces are present, dust content is approximately 30-40%. Compared to nearby alluvial fans and terraces, these landforms are extremely dissected by well-formed or incipient watercourses and active washes (Figure 2-1, Photo A).

2.1.2 Dissected Fan

Dissected fan (Qf1) landforms typically have flat upper surfaces that slope 0-10%, and steeper slopes that lead to watercourses. These surfaces generally exhibit a moderately to strongly developed desert pavement and a dust content of approximately 30-40%. Compared to nearby alluvial fans and terraces, these landforms are heavily dissected by both well-formed or incipient watercourses and active washes (Figure 2-1; Photo B).

2.1.3 Alluvial Fan

Alluvial fan (Qf2) landforms typically have surfaces that slope 0-10% and have a thin veneer of tightly-packed subangular to angular cobble- and gravel-sized clasts that form a strongly developed desert pavement. This pavement is generally underlain by a thick silt cap that contains 40-50% dust, and then by poorly-graded gravel with silt and sand. The alluvial fans are moderately to poorly dissected by active washes and exhibit moderately formed bar-and-swale topography (Figure 2-2).

2.1.4 Alluvial Fan

Alluvial fan (Qf3) landforms typically have surfaces that slope 0-10% and have a thin veneer of tightly-packed subangular to angular cobble- and gravel-sized clasts that form a strongly to moderately developed desert pavement. This pavement is generally underlain by a thick silt cap that contains 40-50% dust and then by poorly-graded gravel with silt and sand. The alluvial fans are dissected by active washes and exhibit moderately formed bar-and-swale topography that is relatively less developed than Qf2 alluvial fan surfaces (Figure 2-2, Photos A and C).

2.1.5 Alluvial Terrace

The alluvial terrace (Qf4) landforms typically exhibit surfaces that slope 0-10% and have a thin veneer of moderately-packed subangular to angular cobble- and gravel-sized clasts that intermittently form a weakly developed desert pavement. The weakly developed pavement on Qf4 surfaces is generally underlain by a relatively thin silt cap that contains less than 20% dust. This landform is composed of poorly-graded gravel with silt and sand. Alluvial terraces are generally dissected by alluvial washes and exhibit well to moderately formed bar-and-swale topography (Figure 2-3).

2.1.6 Active Wash and Alluvial Plain

Active wash (Qf5) and alluvial plain (Qpl) landforms typically have surfaces that slope 0-10% and a surface cover of loose sand and/or gravel with no desert pavement. Because alluvial plains are comprised of several composite landforms, they have a range of desert pavement development that is intermittently weakly to moderately developed. The dust content of these landforms is typically less than 10%. The alluvial plain includes areas with small-scale sand sheets and accumulations of sand around vegetation, commonly referred to as coppice dunes (Figures 2-3 and 2-4, Photo A).

2.1.7 Dune

Dune (Qd) landforms typically have surfaces that slope 0-15%. The surface cover consists of loose sand with no desert pavement. The dust content of these landforms is typically less than 10% (Figures 2-4, Photo B).

2.1.8 Badland

Badland (QTb) landforms typically have surfaces that slope 0-10%, but localized areas associated with watercourses can slope up to 20%. The surface cover is generally composed of loose sand and silts, and has a gravel lag forming weakly developed desert pavement. The dust content of the badlands ranges from 10 to 20%, but depending on underlying materials (i.e., parent material) could be higher. The most diagnostic component of the badland landform is its degree of dissection that forms a complex network of active channels and small-scale watercourses, as well as usually underlain by fine-grained sediments of the Mio-Pliocene (10-3 million years old) Bousse Formation as mapped by Olmsted (1972) (Figure 2-5, Photo A).

2.1.9 Mountain Highland

Mountain highland (Br) landform surfaces typically either have a thin veneer of loose and angular cobble- and gravel-sized clasts (lag), or they are devoid of a surface cover and are regarded as exposed bedrock. The composition and age of the underlying bedrock parent material varies over YPG. Slopes typically are greater than 30% (Figures 2-1, Photo A; 2-2, Photo C; 2-3; 2-4, Photo B; and 2-5).

2.1.10 Pediment

Pediment (QTp) landform surfaces either have a thin veneer of loose and angular cobble- and gravel-sized clasts (lag) or they are devoid of a surface cover and are exposed with characteristics similar to mountain highland landforms. Slopes are typically greater than 20% (Figure 2-5; Photo Band D).

2.1.11 Old Terrace

Alluvial terrace (QTt) landform typically have surfaces that slope 0-10%. The surface cover consists of poorly-graded loose sand and silts. The dust content usually ranges from 20-30%. This landform unit may correlate to the Plio-Pleistocene (3 million to 800 thousand years old) aged older river deposits (QTor) mapped by Olmsted (1972) in the southwest corner of YPG near the Yuma Test Center (e.g., Map 1).

2.2 Landform-based Area Statistics, Properties, and Maps

Within the approximately 3390 km^2 area of YPG, 11 different landforms were identified and mapped. Table 2-1 tabulates the total extent of each category of landform, both in nominal terms and as a portion (percentage) of the YPG area. Table 2-1 also summarizes other important characteristics related to each landform category, including geological unit, USCS symbol and description, NRCS soil type, percent mean dust content, and the degree of desert pavement development.

2.2.1 Landform Area Distribution

The spatial distribution of mapped landforms varies across YPG (Map 3). The northwestern to western half (Cibola Range) and the northeastern half of YPG exhibit Basin and Range Province physiographic characteristics consisting mostly of active washes, alluvial fans, mountains highlands, and alluvial plains. The southwestern portion of YPG near the Yuma Test Center has a wider range of landforms compared to the rest of YPG, which include alluvial plains, badlands, isolated dunes, and alluvial fans. These types of landforms are commonly associated with the edges of the broad river plain of the Colorado River. The southern portion of YPG (Kofa Range) is a broad piedmont slope composed of alluvial fans and active washes that is bounded by mountain highlands, pediments, and lesser alluvial terraces, as well as badlands near the Gila River. The southeastern to eastern part of YPG is composed mostly of a broad and flat alluvial plain at the distal ends of alluvial fans and active washes (Map 3).

The most widely distributed and common landforms in all of YPG are alluvial fans (46.6%) and mountain highlands (27.3%). Other landforms identified that are associated with alluvial fans and mountains highlands include active washes (14.3%) and alluvial plains (8.4%). The least common landforms recognized in YPG include badlands (1.4%) and pediments (1.2%), as well as alluvial terraces, old terraces, and dunes, which together, comprise 0.8% of the total area mapped (Table 2-1).

2.2.2 Percent Mean Dust Content Area Distribution

The area distribution of percent mean dust is largely controlled by the distribution of landforms in YPG and appears to by nearly uniformly distributed (Maps 3 and 6; Table 2-1). Landform surfaces underlain by 10-20% of mean dust comprise 30.4%, surfaces underlain by 40-50% mean dust include 29.0%, surfaces underlain by 0-10% mean dust include 23%, and surfaces underlain by 30-40% mean dust comprise 17.6% of the total area mapped (Table 2-1).

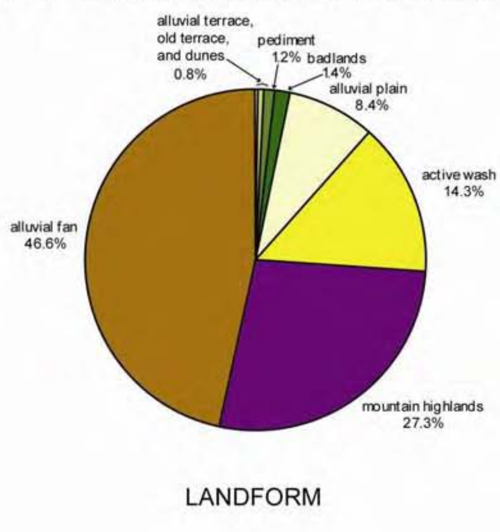
2.2.3 Desert Pavement Development Area Distribution

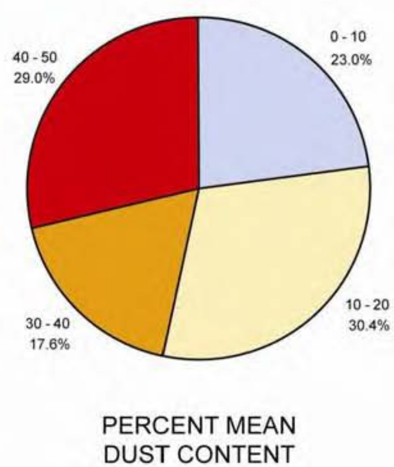
Similar to the percent mean dust, the area distribution of desert pavement develop-ment is largely controlled by the distribution of landforms in YPG (Maps 3 and 6; Table 2-1). Landform surfaces having lag (28.5%), strongly (25.5%), and none (24.4%) degree of desert pavement are common throughout YPG. Other surfaces that have moderately (17.6%) developed desert pavement were also common. The least common surfaces that exhibit strongly to moderately (3.7%) and none to weakly (0.5%) developed desert pavement were also identified (Table 2-1).

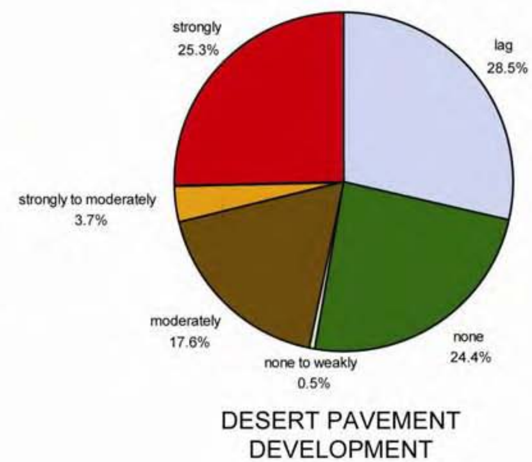
TABLE 2-1. DESERT TERRAIN ATTRIBUTES FOR YUMA PROVING GROUND.

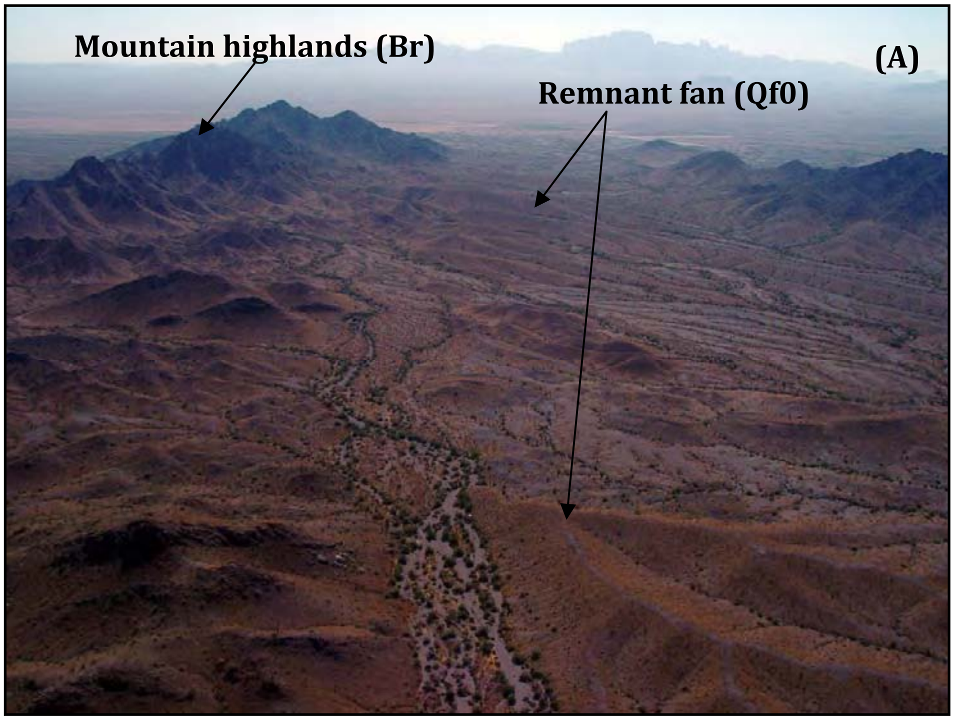
Total Area (km^2)	Portion YPG Area (%)	Geologic Unit	Landform	USCS Symbol	USCS Description	Soil Type	Percent Mean Dust Content	Desert Pavement Development
0.39	0.01	QTt	old terrace	SM, SP-SM, SP	Poorly-graded sand silt to poorly-graded sand to well-graded sand	Superstition-Rositas	0 - 10	none
6.39	0.19	Qd	dunes	SW-SM	Well-graded sand with silt	Rositas	0 - 10	none
18.30	0.54	Qf4	alluvial terrace	GM	Silty gravel with sand	Riverbend	10 - 20	none to weakly
41.21	1.22	QTp	pediment	GP, GP-GM, GC	Poorly-graded gravel with sand to Poorly-graded gravel with silt to clayey gravel	Carsitas-Chuckawalla	10 - 20	lag
43.94	1.30	Qf0	alluvial fan	GP-GM, GC	Poorly-graded gravel with silt to Poorly-graded gravel with silt to clayey gravel	Gunsight-Chuckawalla	30 - 40	moderately
47.39	1.40	QTb	badlands	GP, GP-GM, GC	Poorly-graded gravel with sand to Poorly-graded gravel with silt to clayey gravel	Carsitas-Chuckawalla	10 - 20	none
126.05	3.72	Qf3	alluvial fan	GC-GM, CL, GP-GM	Silty, clayey gravel with sand to sandy clay to Poorly-graded gravel with silt	Cristobal-Gunsight	40 - 50	strongly to moderately
285.49	8.42	Qpl	alluvial plain	SM, SP-SM, SP	Poorly-graded sand silt to poorly-graded sand to well-graded sand	Superstition-Rositas	0 - 10	none
486.22	14.34	Qf5	active wash	GW	Well-graded gravel with sand	Carrizo	0 - 10	none
553.94	16.34	Qf1	alluvial fan	GP-GM, GC	Poorly-graded gravel with silt to Poorly-graded gravel with silt to clayey gravel	Gunsight-Chuckawalla	30 - 40	moderately
856.41	25.26	Qf2	alluvial fan	GC-GM, CL, GP-GM	Silty, clayey gravel with sand to sandy clay to Poorly-graded gravel with silt	Cristobal-Gunsight	40 - 50	strongly
925.11	27.28	Br	mountain highlands	GW-GM, GP-GM	Well-graded gravel with silt to Poorly-sorted gravel with silt	Lithic Torriorthents	10 - 20	lag

Note: USCS - Unified Soils Classification System; USDA - U.S. Department of Agriculture









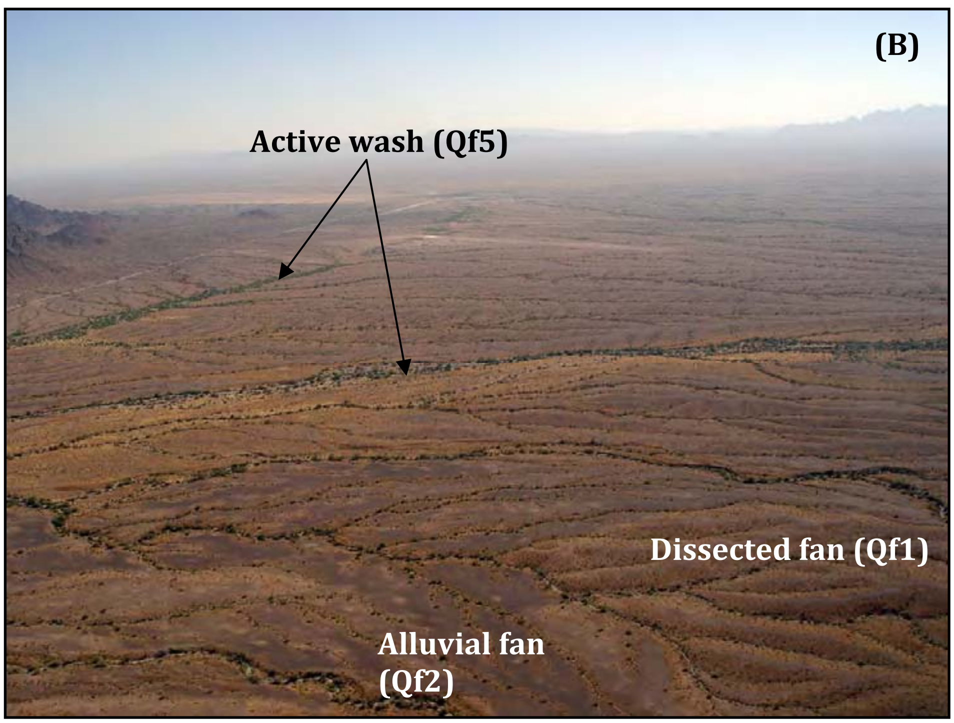


Figure 2-1. Photographs of remnant (Qf0; Photo A) and dissected (Qf1; Photo B) alluvial fans in relation to other landforms, such as alluvial fan (Qf2). Remnant fan surfaces commonly have broadly rounded to narrow, ridge lines that slope 0-20%, and steeper slopes that are often rilled by erosion, which lead to watercourses. Similar to Remnant fans, Dissected fans typically have flat upper surfaces, exhibiting strongly to moderately developed desert pavements, that slope up to 10%, and steeper slopes that are associated with watercourses.

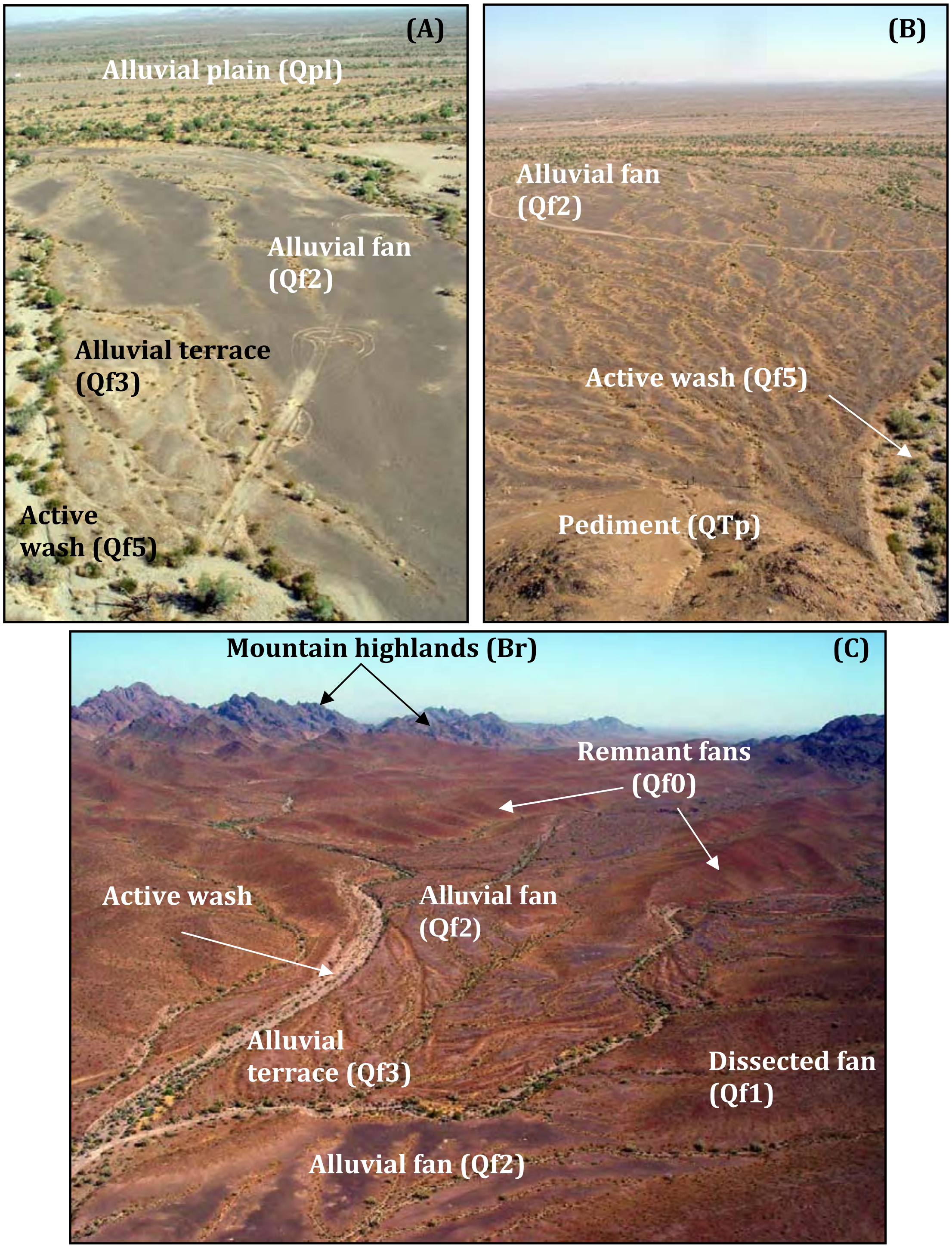


Figure 2-2. Photographs of alluvial fan (Qf2 and Qf3) landforms in relation to other landforms in the landscape. Qf2 landform surfaces have flat upper surfaces and slope 0-10%, with a thin veneer of tightly-packed subangular to well-rounded cobble- and gravel-sized clasts that form a strong to moderately developed desert pavement. Qf3 landform surfaces typically slope 0-10% and have a thin veneer of moderately-packed subangular to angular cobble- and gravel-sized clasts that constitute a moderately to strongly developed desert pavement. Both Qf2 and Qf3 landforms are generally dissected by active alluvial washes and exhibit well to moderately formed bar-and-swale topography.

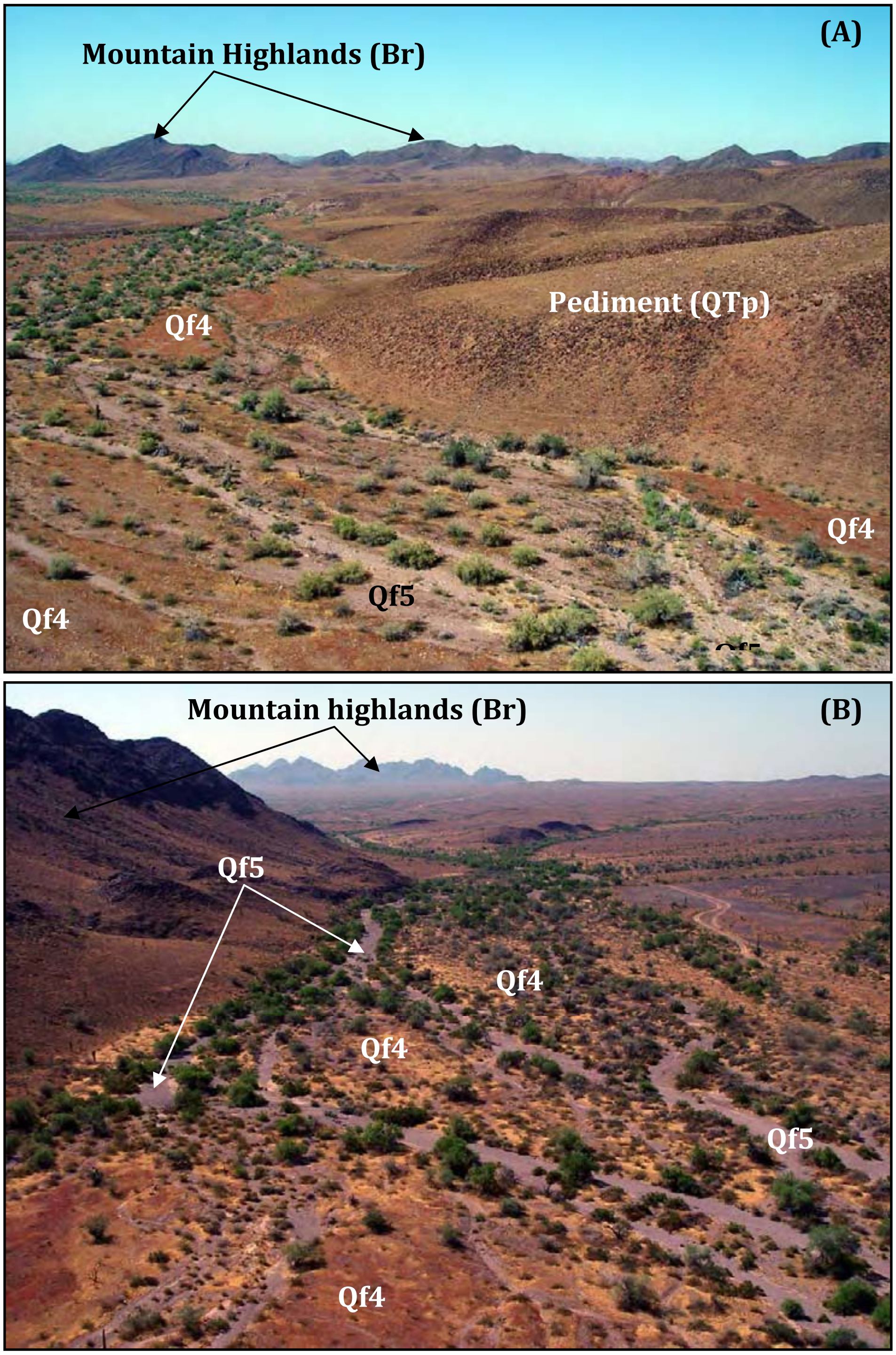


Figure 2-3. Photographs of alluvial terrace (Qf4) and active wash (Qf5) landforms in relation to other landforms in the landscape. Qf4 landform surfaces typically slope 0-10%, with a thin veneer of moderately-packed subangular to well-rounded cobble- and gravel-sized clasts that form an intermittently weakly developed desert pavement. Qf5 landform surfaces lack desert pavement and typically slope 0-10%, with a cover that varies from loose sand and/or gravel to dense gravel and cobble. Qf4 landforms are generally dissected by active alluvial washes and exhibit well to moderately formed bar-and-swale topography.

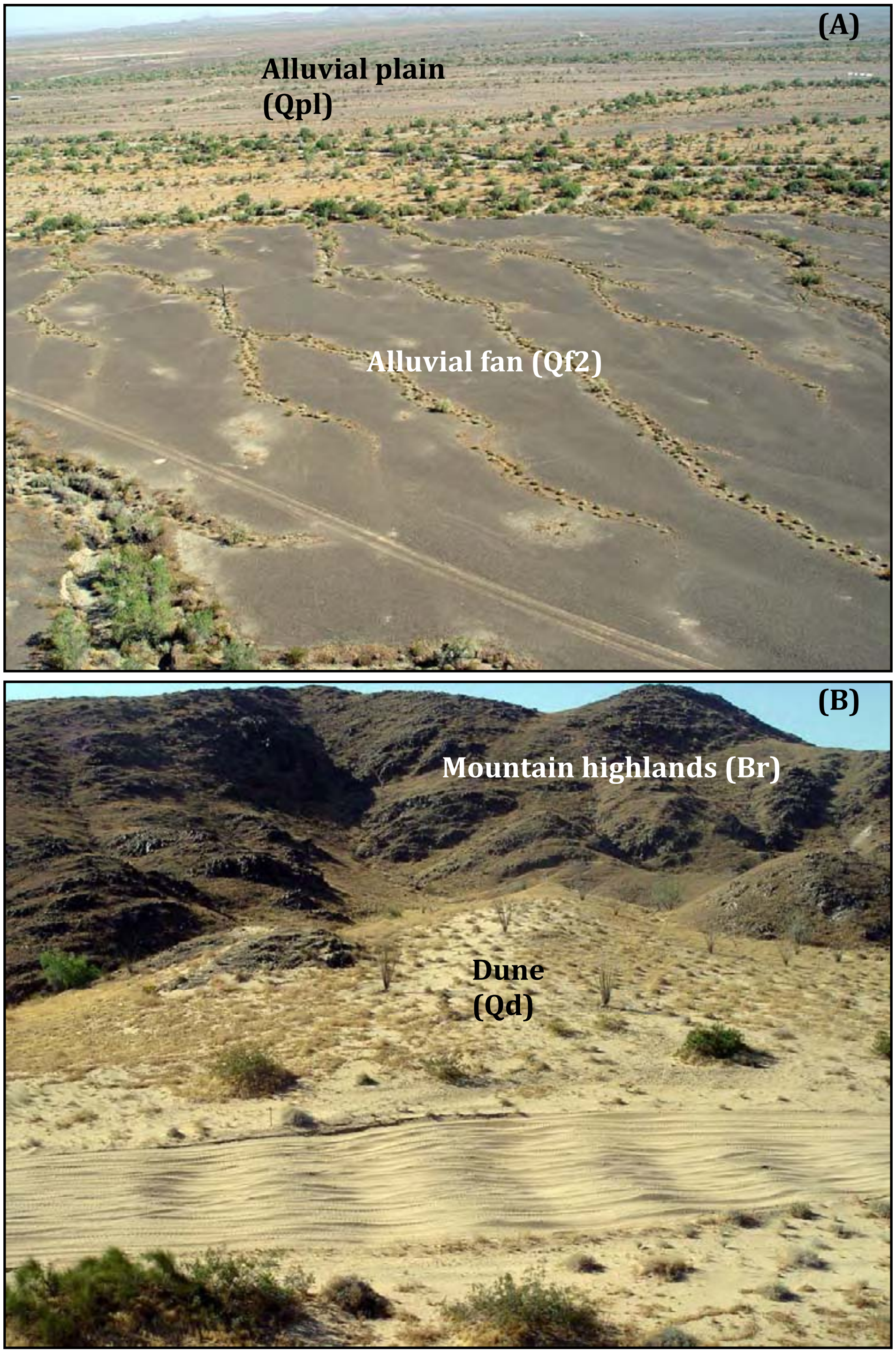


Figure 2-4. Photographs of alluvial plain (Qpl; Photo A) and dune (Qd; Photo B) landforms in relation to other landforms in the landscape. Qpl landform surfaces typically slope 0-10% and are comprised of a variety of composite landforms that are difficult to delineate at 1:50,000 scale. Qpl landform surfaces thus usually display intermittent weakly to moderately developed desert pavement. Qd landform surfaces lack desert pavement and typically slope 0-15%, with greater slope values usually found in areas where dunes locally abut elements of greater topographic relief. Qd surfaces exhibit a cover of loose sand.

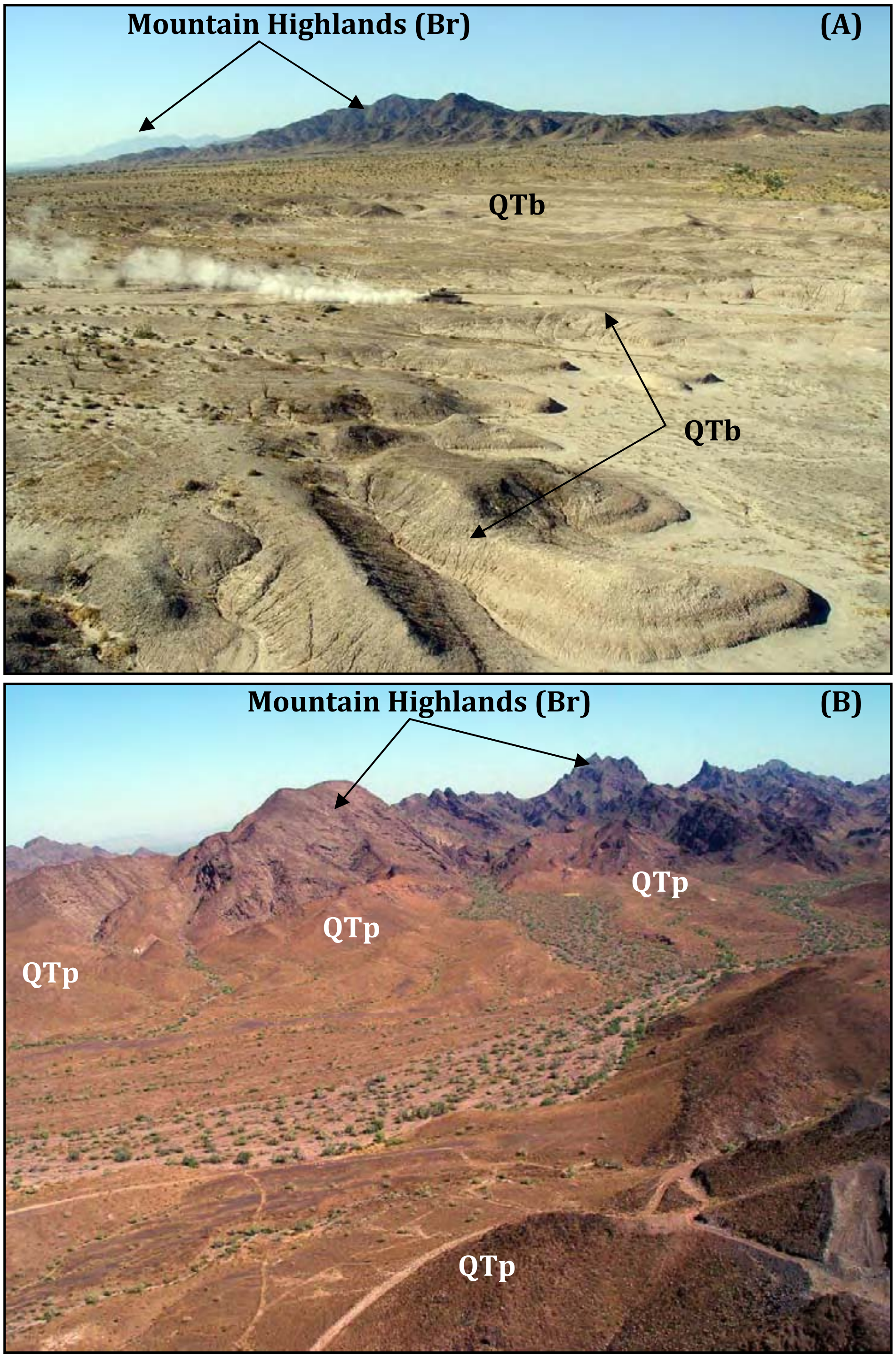


Figure 2-5. Photographs of badland (QTb; Photo A), mountain highland (Br), and pediment (QTp; Photo B) landforms in relation to other landforms in the landscape. QTb landforms typically have surfaces that slope 0-20% with a surface cover generally composed of loose sand and silts, overlain by a gravel lag forming weakly developed desert pavement. Mountain highlands (Br) landform surfaces typically either have a thin veneer of loose and angular cobble- and gravel-sized clasts (lag), or they are devoid of a surface cover; the composition and age of the underlying bedrock parent material varies. Slopes typically are greater than 30%. QTp landform surfaces exhibit characteristics similar to mountain highland landforms and their slopes are typically greater than 20%.

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4.0 GLOSSARY OF GEOMORPHIC LANDFORMS

Descriptions and definitions of landforms modified from: *Peterson, 1981; φBates and Jackson, 1984; §Easterbrook, 1998; †King et al., 2004.

Alluvial fan* – A semiconical, or fan shaped, constructional, major landform that is built of more-or-less stratified alluvium, with or without debris flow deposits, that occurs on the upper margin of a piedmont slope, and that has its apex at a point source of alluvium debouching from a mountain valley into an intermontane basin. Also, a generic term for like forms in various other landscapes.

Alluvial plain* – A major landform of some basin floors, comprised of the floodplain of a major Pleistocene stream that crossed the floor, or of a low gradient fan-delta built by such a stream. Deposits typically consist of well sorted and stratified alluvium.

Alluvial terrace – An erosional remnant of an alluvial fan that is surrounded by other landforms. Usually has a gently sloping surface and is composed of alluvial deposits. Generally an elongate landform that occurs adjacent and parallel to active washes.

Alluvial wash – An ephemeral channel or drainage network that drains a large area of the mountains and the piedmont slope. Surface is composed of recent alluvium.

Badlandsφ† – An intricately stream-dissected topography consisting of deep, narrow ephemeral washes interspaced with abundant sharp and narrow ridge tops, developed on surfaces with little or no vegetative cover. Underlying material is generally unconsolidated or weakly cemented clay or silt, sometimes with gypsum and halite.

Bedrockφ – The solid rock that underlies gravel, soil, or other superficial material.

Dissected fan – An alluvial fan that is partially eroded by gully, arroyo, canyon, or valley cutting processes, leaving relatively flat remnants or ridges separated by alluvial washes.

Mountain highland* **–** A highland mass that rises more than 1,000 feet (300 meters) above its surrounding lowlands and has merely a crest or restricted summit area (relative to a plateau).

Pediment*† **–** The footslope complex of an erosional slope; geomorphically "…an erosion surface that lies at the foot of a receded slope, with underlying rocks or sediments that also underlie the upland, which is barren or mantled with sediment, and which normally has a concave upward profile…"(Ruhe, 1975). Pediments are typically broad, gently-sloping (2°-19°) surfaces cut into bedrock, commonly marginal to mountain highlands. Pediments may be bare or covered with a thin layer of rocks on the surface.

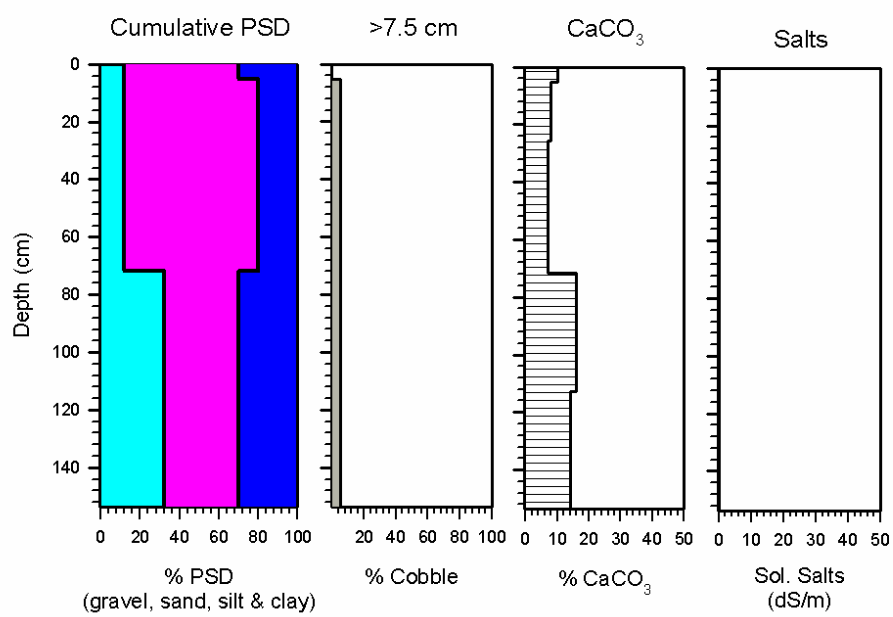
Sand sea/dunesφ **–** An area consisting of mounds, ridges, or hills of wind-blown sand, either bare or covered with vegetation. Sand seas or dunes also form aggregates of moving and fixed sand dunes in any given area, together with sand plains and the ponds, lakes, and swamps produced by the blocking of streams by the sand.

5.0 APPENDIX A: PROFILE CHARACTERISTICS OF EACH SOIL TYPE (USDA CLASSIFICATION) IDENTIFIED AT YPG ACCORDING TO NRCS (1991)

Antho family soil

Antho Pedon Soil Data

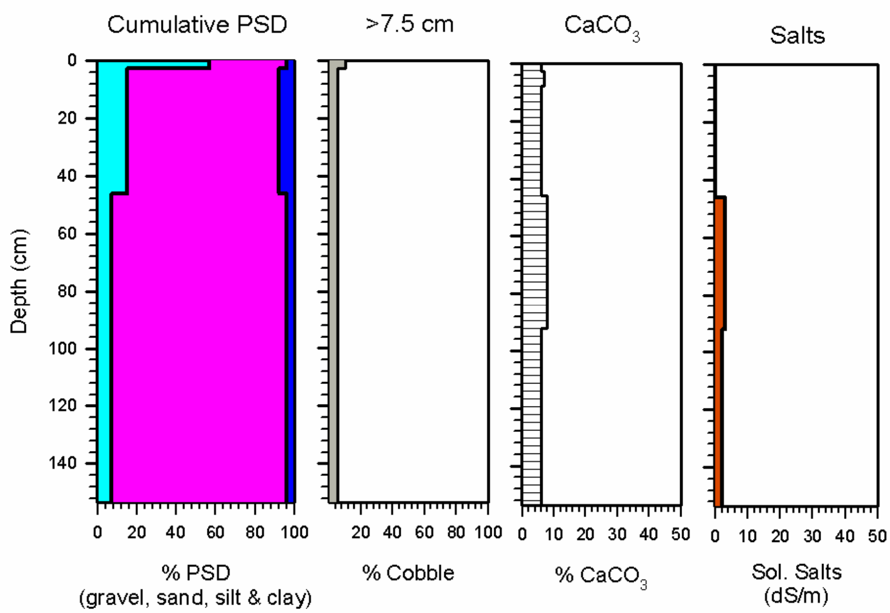
Horizon	Depth	Depth	Gravel	Sand	Silt & Clay	Cobble	CaCO3	Salts
	in	cm	-%-	-%-	-%-	-%-	-%-	dS/m
A	2	5.12	12	58	30	0	10	0
C	10	25.6	12	68	20	5	8	0
Ck	28	71.68	12	68	20	5	7	0
2Btkyb1	44	112.64	32	38	30	5	16	0
2Btkyb2	60	153.6	32	38	30	5	14	0



Carsitas family soil
(4-15% slopes)

Carsitas Pedon Soil Data

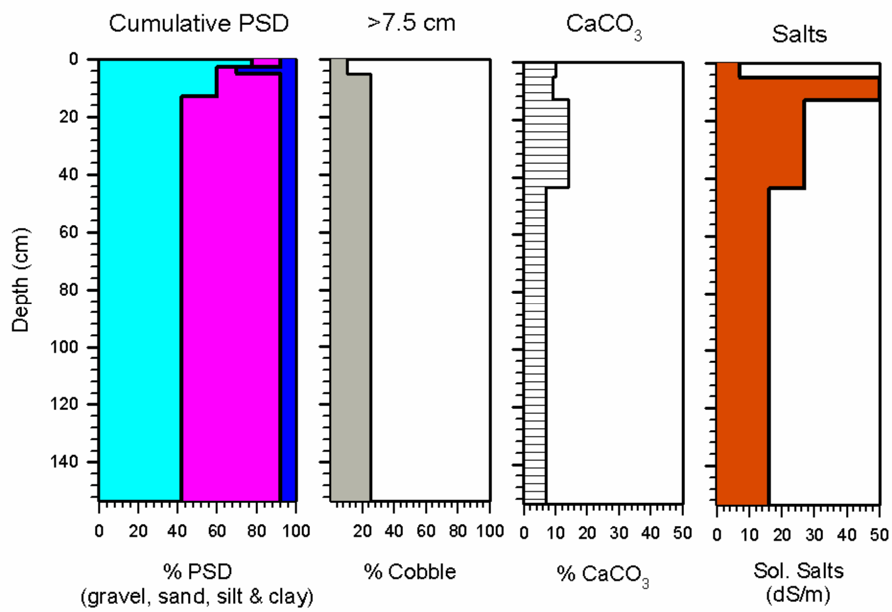
Horizon	Depth	Depth	Gravel	Sand	Silt & Clay	Cobble	CaCO3	Salts
	in	cm	-%-	-%-	-%-	-%-	-%-	dS/m
Ak	1	2.56	57	39	4	10	6	0
EB	3	7.68	15	77	8	5	7	0
Bk	18	46.08	15	77	8	5	6	0
2Bk	36	92.16	7	89	4	5	8	3
2C	60	153.6	7	89	4	5	6	2



Chuckwalla family soil

Chuckwalla Pedon Soil Data

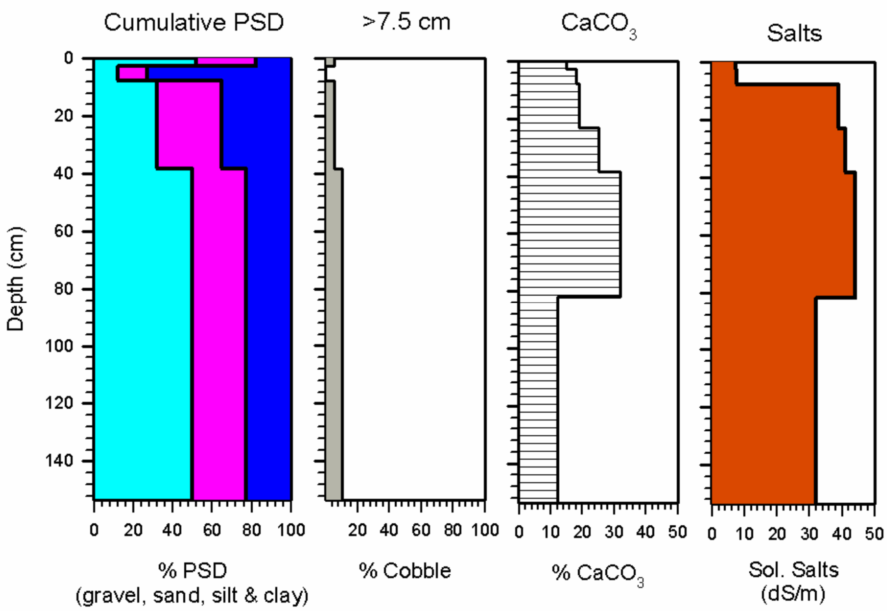
Horizon	Depth	Depth	Gravel	Sand	Silt & Clay	Cobble	CaCO3	Salts
	in	cm	-%-	-%-	-%-	-%-	-%-	dS/m
Anz	1	2.56	78	14	8	10	10	7
Ebnz	2	5.12	60	10	30	10	10	7
2Btknyz	5	12.8	60	32	8	25	9	50
2Bknyz1	17	43.52	42	50	8	25	14	27
2Bknyz2	60	153.6	42	50	8	25	7	16



Cristobal family soil

Cristobal Pedon Soil Data

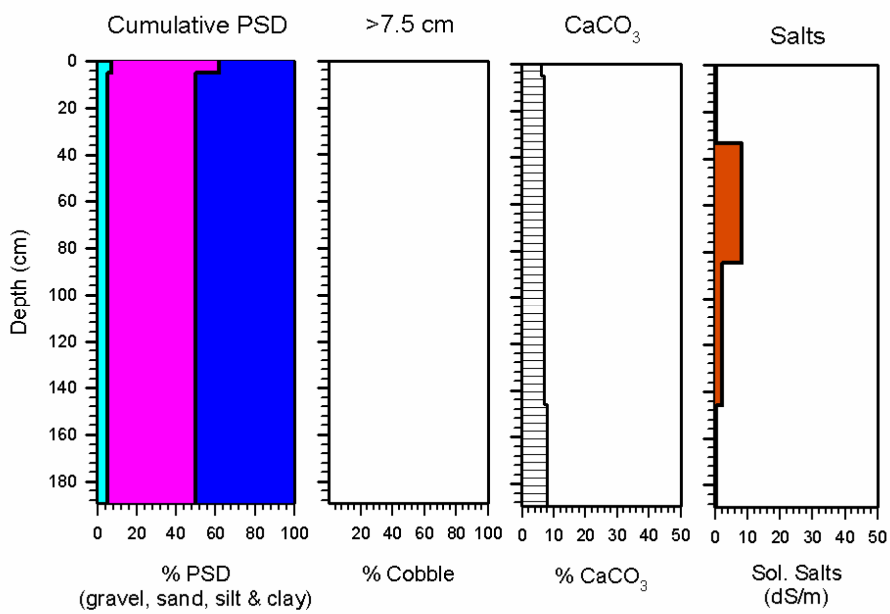
Horizon	Depth	Depth	Gravel	Sand	Silt & Clay	Cobble	CaCO3	Salts
	in	cm	-%-	-%-	-%-	-%-	-%-	dS/m
Anz	1	2.56	52	30	18	5	15	7.3
E/Btknz	3	7.68	12	15	73	0	18	7.5
Btknzy1	9	23.04	32	33	35	5	19	39
Btknzy2	15	38.4	32	33	35	5	25	41
Btknzy3	32	81.92	50	27	23	10	32	44
Btknzy4	60	153.6	50	27	23	10	12	32



Gilman family soil

Gilman Pedon Soil Data

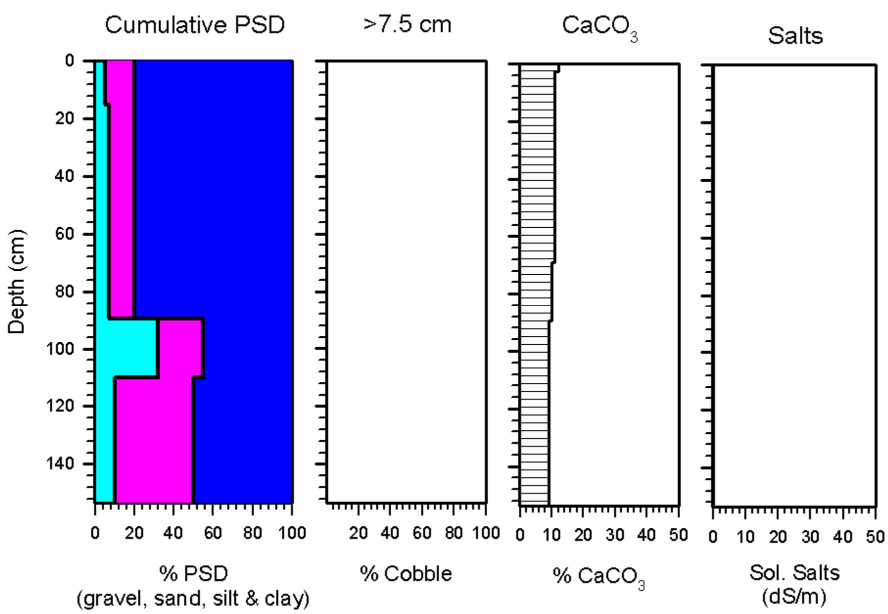
Horizon	Depth	Depth	Gravel	Sand	Silt & Clay	Cobble	CaCO3	Salts
	in	cm	-%-	-%-	-%-	-%-	-%-	dS/m
A	2	5.12	7	55	38	0	6	0.1
C	13	33.28	5	45	50	0	7	0.1
2Cknz1	33	84.48	5	45	50	0	7	8
2Cknz2	57	145.92	5	45	50	0	7	2
2Ck	74	189.44	5	45	50	0	8	0.1



Glenbar family soil

Glenbar Pedon Soil Data

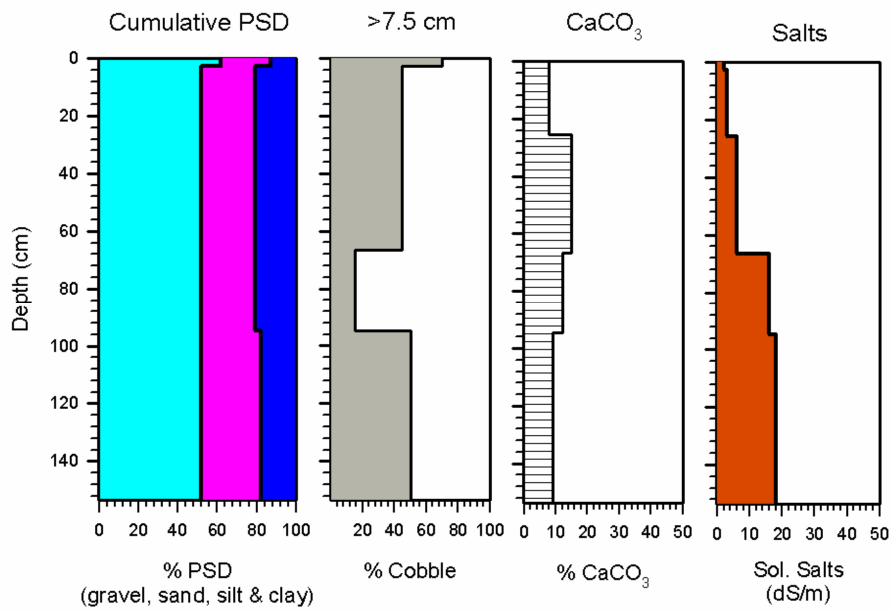
Horizon	Depth	Depth	Gravel	Sand	Silt & Clay	Cobble	CaCO3	Salts
	in	cm	-%-	-%-	-%-	-%-	-%-	dS/m
A	1	2.56	5	15	80	0	12	0
AC	6	15.36	5	15	80	0	11	0
C1	27	69.12	7	13	80	0	11	0
C2	35	89.6	7	13	80	0	10	0
C3	43	110.08	32	23	45	0	9	0
Cy	60	153.6	10	40	50	0	9	0



Gunsight family soil

Gunsight Pedon Soil Data

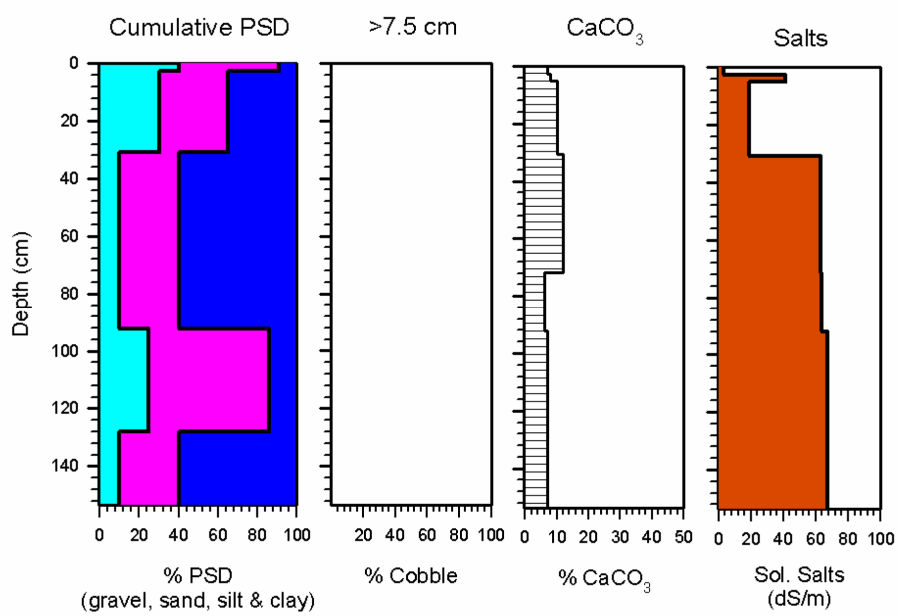
Horizon	Depth	Depth	Gravel	Sand	Silt & Clay	Cobble	CaCO3	Salts
	in	cm	-%-	-%-	-%-	-%-	-%-	dS/m
A	1	2.56	62	25	13	70	8	2
Bk	10	25.6	52	27	21	45	8	3
Bkynz1	26	66.56	52	27	21	45	15	6
Bkynz2	37	94.72	52	27	21	15	12	16
Bkynz3	60	153.6	52	30	18	50	9	18



Harqua family soil

Harqua Pedon Soil Data

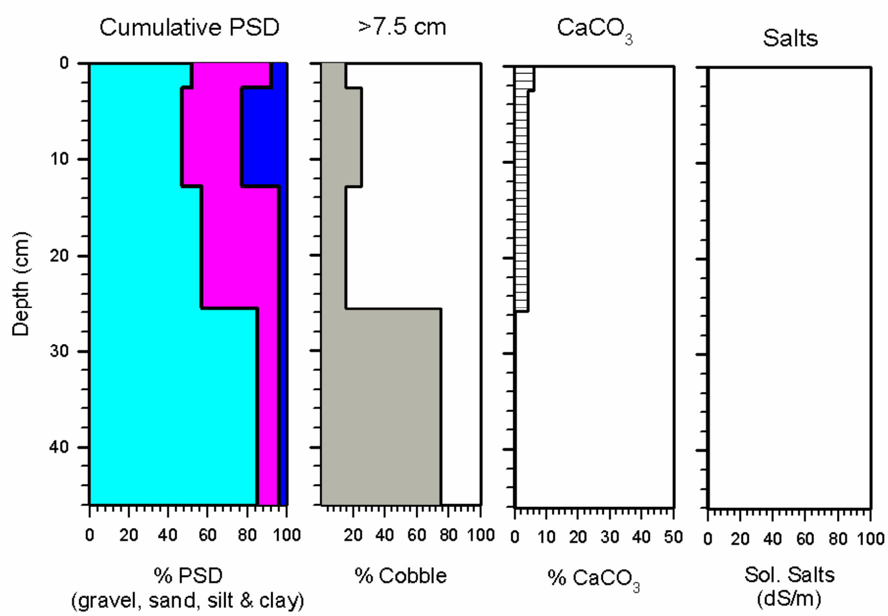
Horizon	Depth	Depth	Gravel	Sand	Silt & Clay	Cobble	CaCO3	Salts
	in	cm	-%-	-%-	-%-	-%-	-%-	dS/m
A	1	2.56	40	51	9	0	7	3
Ebzn	2	5.12	30	35	35	0	8	41
Btkzny1	12	30.72	30	35	35	0	10	19
Btkzny2	28	71.68	10	30	60	0	12	63
Bczny	36	92.16	10	30	60	0	6	64
Bctkzny	50	128	25	61	14	0	7	67
Ckzny	60	153.6	10	30	60	0	7	67



Lithic Torriorthents family soil

Lithic Torriorthents Pedon Soil Data

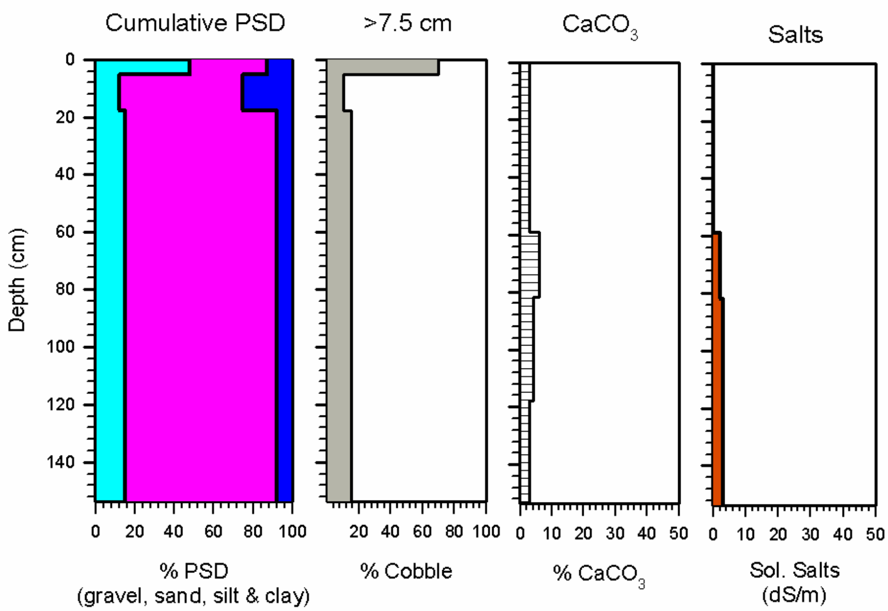
Horizon	Depth	Depth	Gravel	Sand	Silt & Clay	Cobble	CaCO3	Salts
	in	cm	-%-	-%-	-%-	-%-	-%-	dS/m
A	1	2.56	52	40	8	15	6	0
Ck1	5	12.8	47	30	23	25	4	0
Ck2	10	25.6	57	39	4	15	4	0
Ck3	18	46.08	85	11	4	75	0.1	0



Riverbend family soil

Riverbend Pedon Soil Data

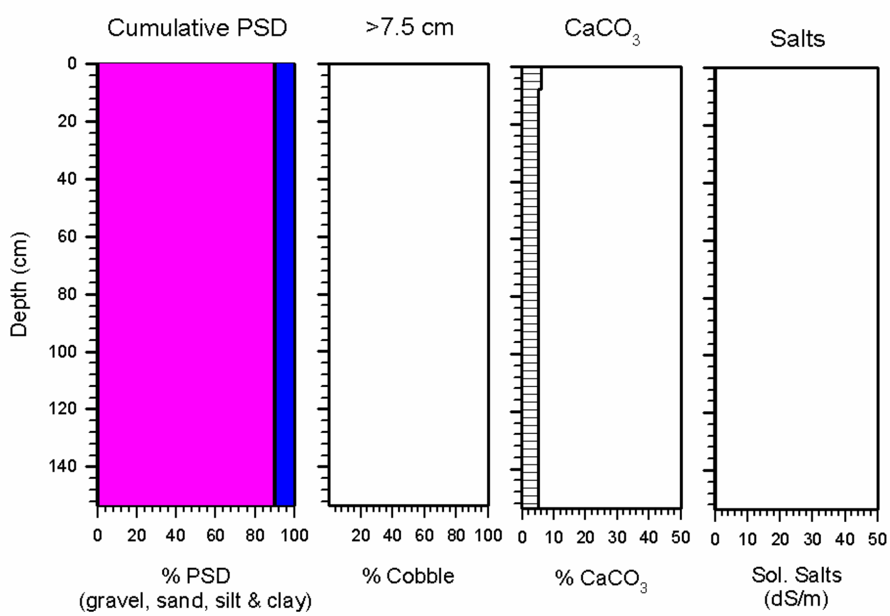
Horizon	Depth	Depth	Gravel	Sand	Silt & Clay	Cobble	CaCO3	Salts
	in	cm	-%-	-%-	-%-	-%-	-%-	dS/m
A	2	5.12	42	39	13	70	3	0.1
Ak	7	17.92	12	63	25	10	3	0.1
Bk1	23	58.88	15	77	8	15	3	0.1
Bk2	32	81.92	15	77	8	15	6	2
Bk3	46	117.76	15	77	8	15	4	3
2Btkb	60	153.6	15	77	8	15	3	3



Rositas family soil

Rositas Pedon Soil Data

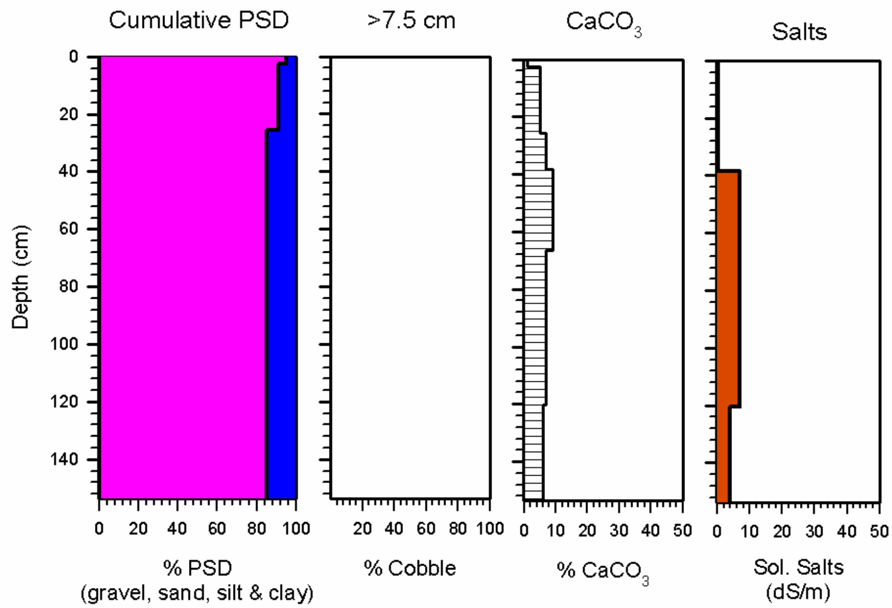
Horizon	Depth	Depth	Gravel	Sand	Silt & Clay	Cobble	CaCO3	Salts
	in	cm	-%-	-%-	-%-	-%-	-%-	dS/m
AC	1	2.56	0	90	10	0	6	0
C1	3	7.68	0	90	10	0	6	0
C2	25	64	0	90	10	0	5	0
C3	60	153.6	0	90	10	0	5	0



Superstition family soil

Superstition Pedon Soil Data

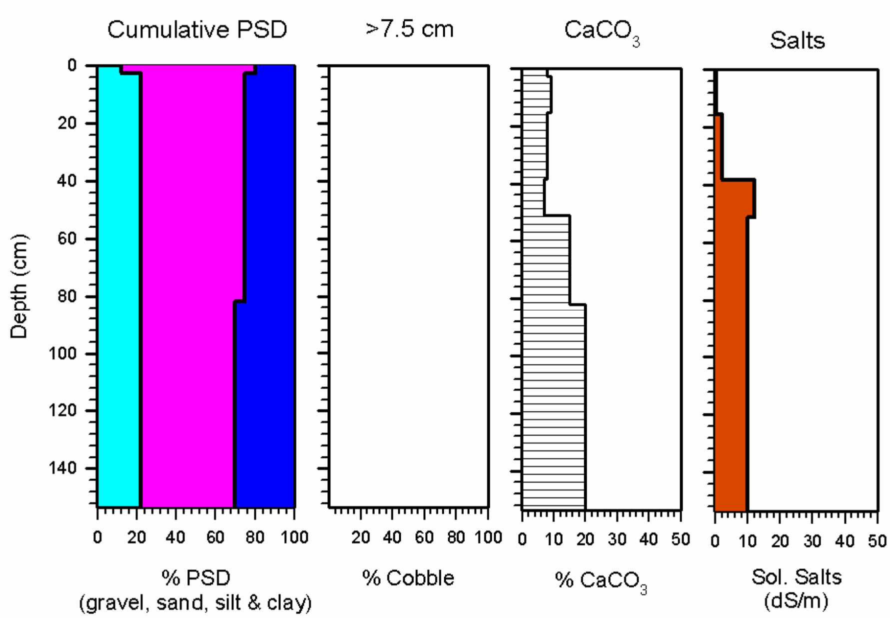
Horizon	Depth	Depth	Gravel	Sand	Silt & Clay	Cobble	CaCO3	Salts
	in	cm	-%-	-%-	-%-	-%-	-%-	dS/m
AC1	1	2.56	0	95	5	0	1	0.1
AC2	10	25.6	0	91	9	0	5	0.1
Bk	15	38.4	0	85	15	0	7	0.1
Bkz1	26	66.56	0	85	15	0	9	7
Bkz2	47	120.32	0	85	15	0	7	7
Bkz3	60	153.6	0	85	15	0	6	4



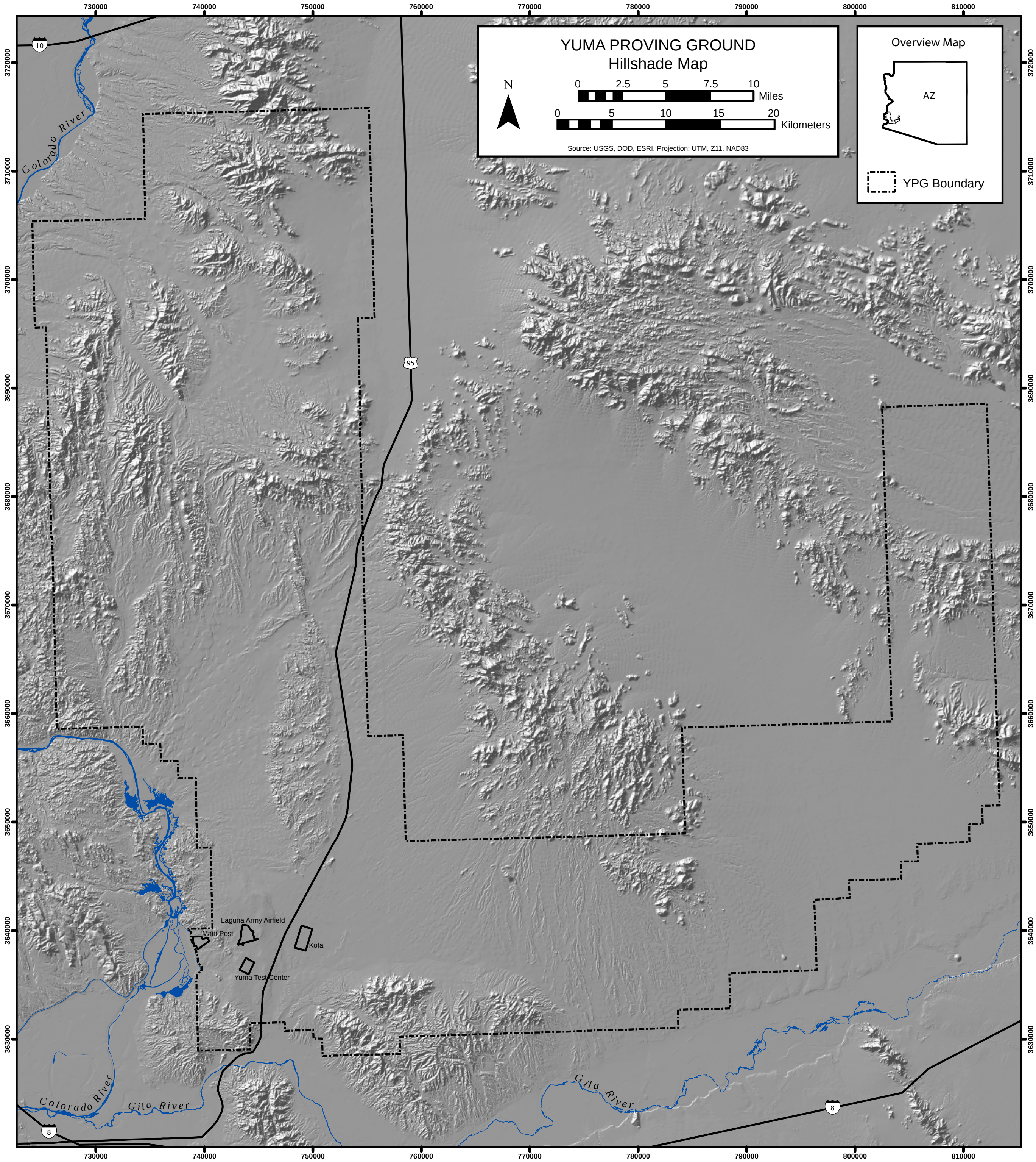
Tremant family soil

Tremant Pedon Soil Data

Horizon	Depth	Depth	Gravel	Sand	Silt & Clay	Cobble	CaCO3	Salts
	in	cm	-%-	-%-	-%-	-%-	-%-	dS/m
A	1	2.56	12	68	20	0	8	0.1
Bw1	6	15.36	22	53	25	0	9	0.1
Bw2	15	38.4	22	53	25	0	8	2
2Bt	20	51.2	22	53	25	0	7	12
2Btkz1	32	81.92	22	53	25	0	15	10
2Btkz2	60	153.6	22	48	30	0	20	10



6.0 MAPS OF YUMA PROVING GROUND



DRI
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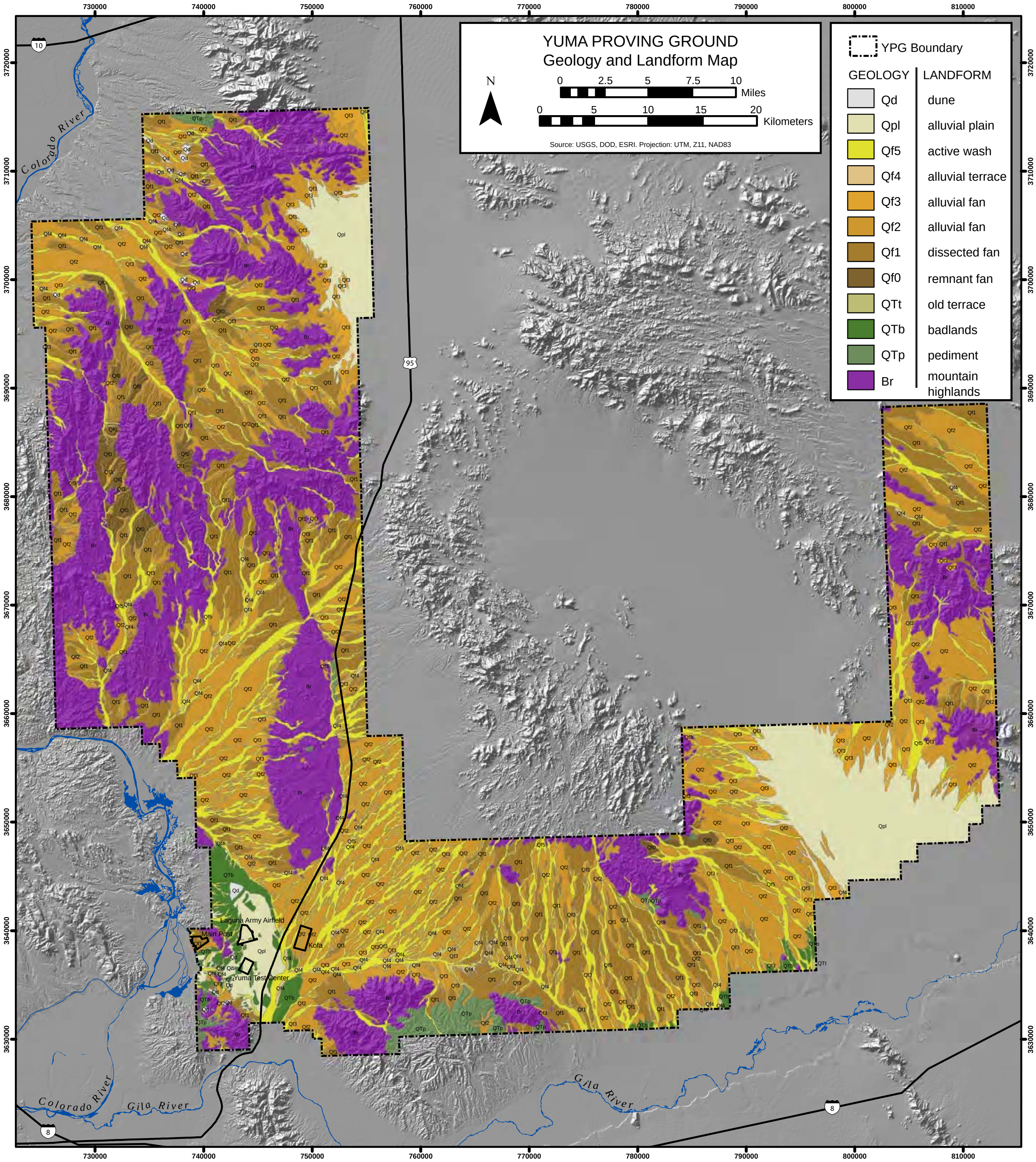
LANDFORMS & SURFACE COVER OF U.S. ARMY YPG

Hillshade Map

DATE: 9-08-2009

MAP 1

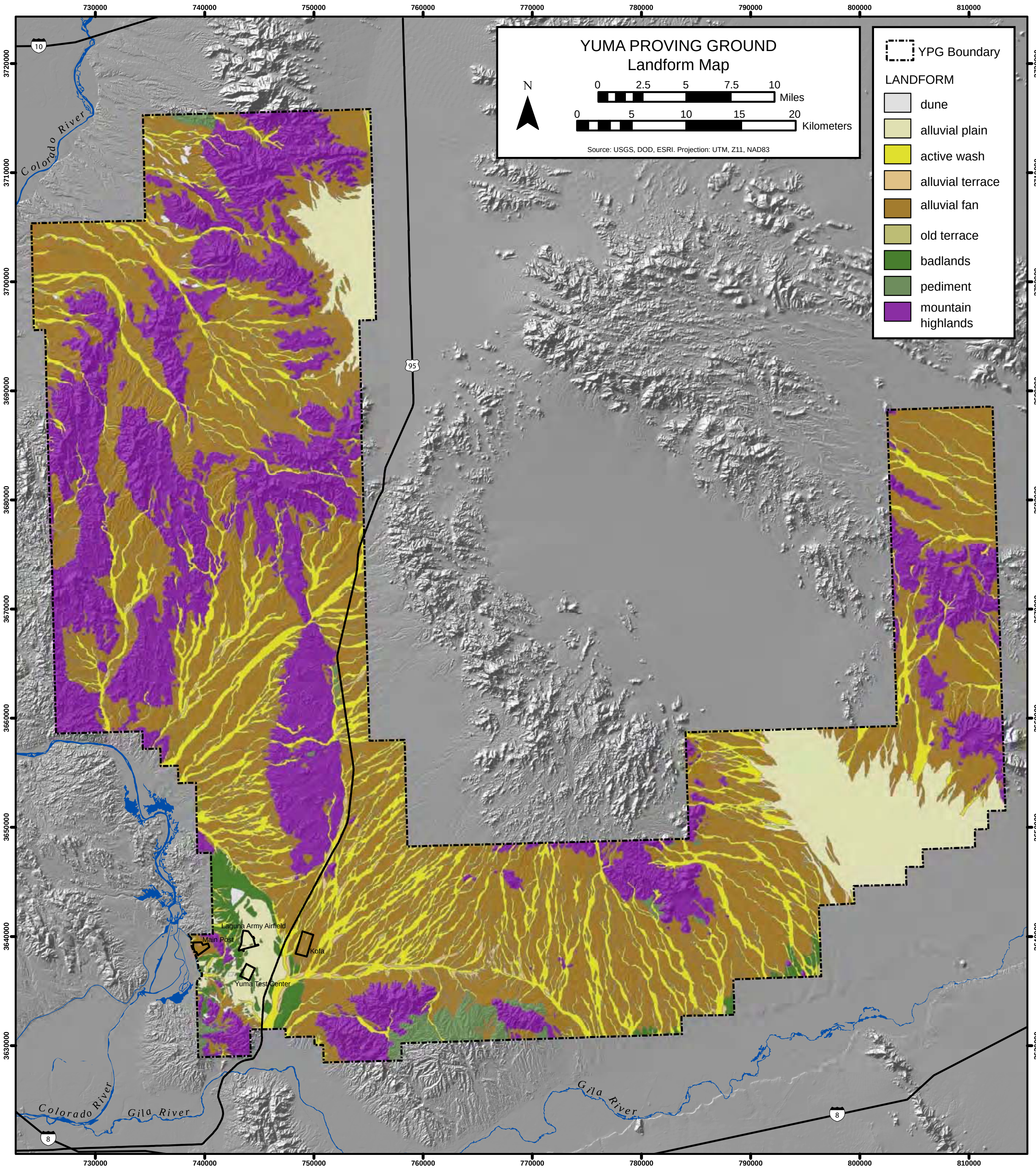


LANDFORMS & SURFACE COVER OF U.S. ARMY YPG

Geology and Landforms

DATE: 9-08-2009

MAP 2



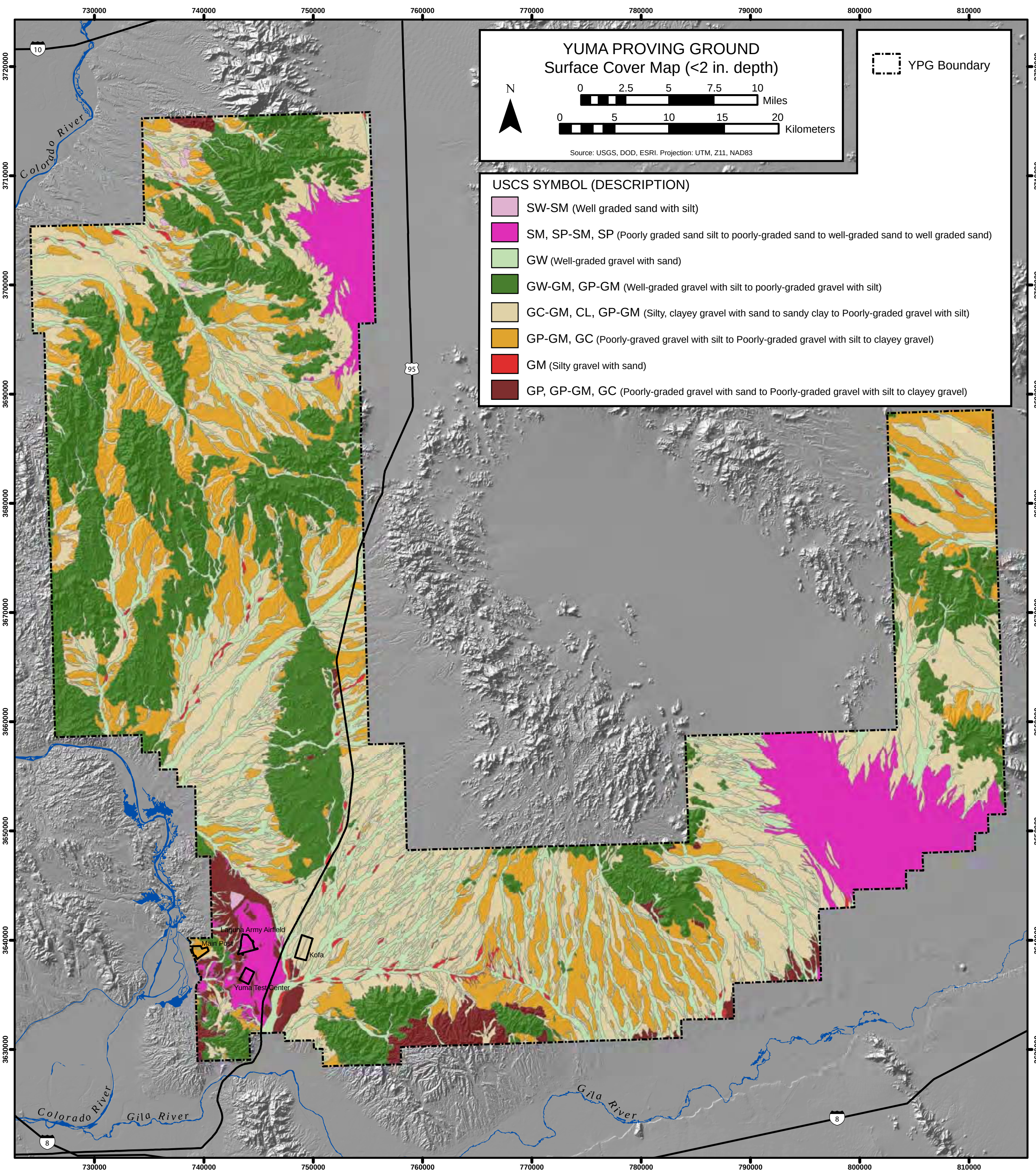
Desert Research Institute

LANDFORMS & SURFACE COVER OF U.S. ARMY YPG

Landform Map

DATE: 9-08-2009

MAP 3

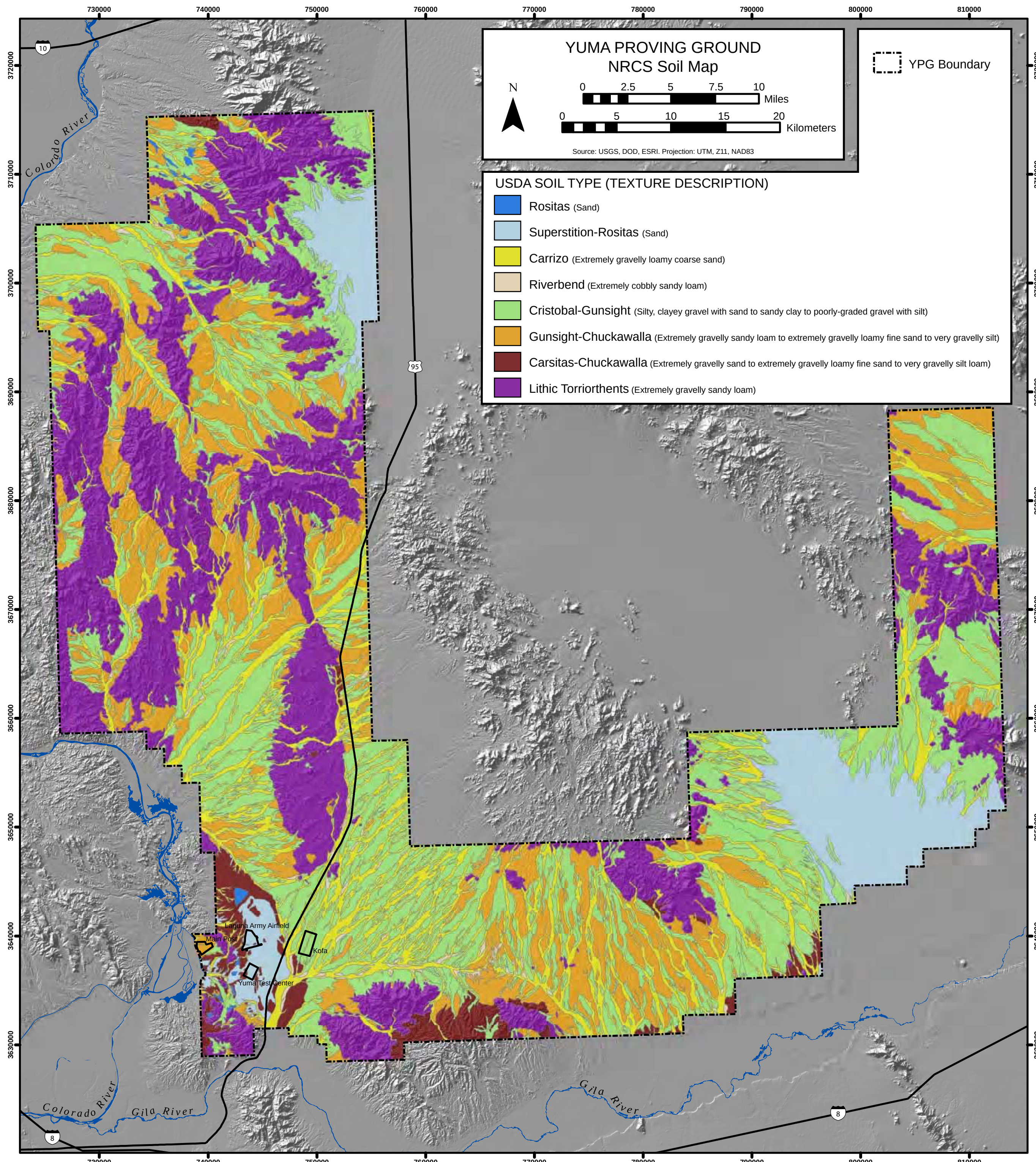


LANDFORMS & SURFACE COVER OF U.S. ARMY YPG

Surface Cover

DATE: 9-08-2009

MAP 4



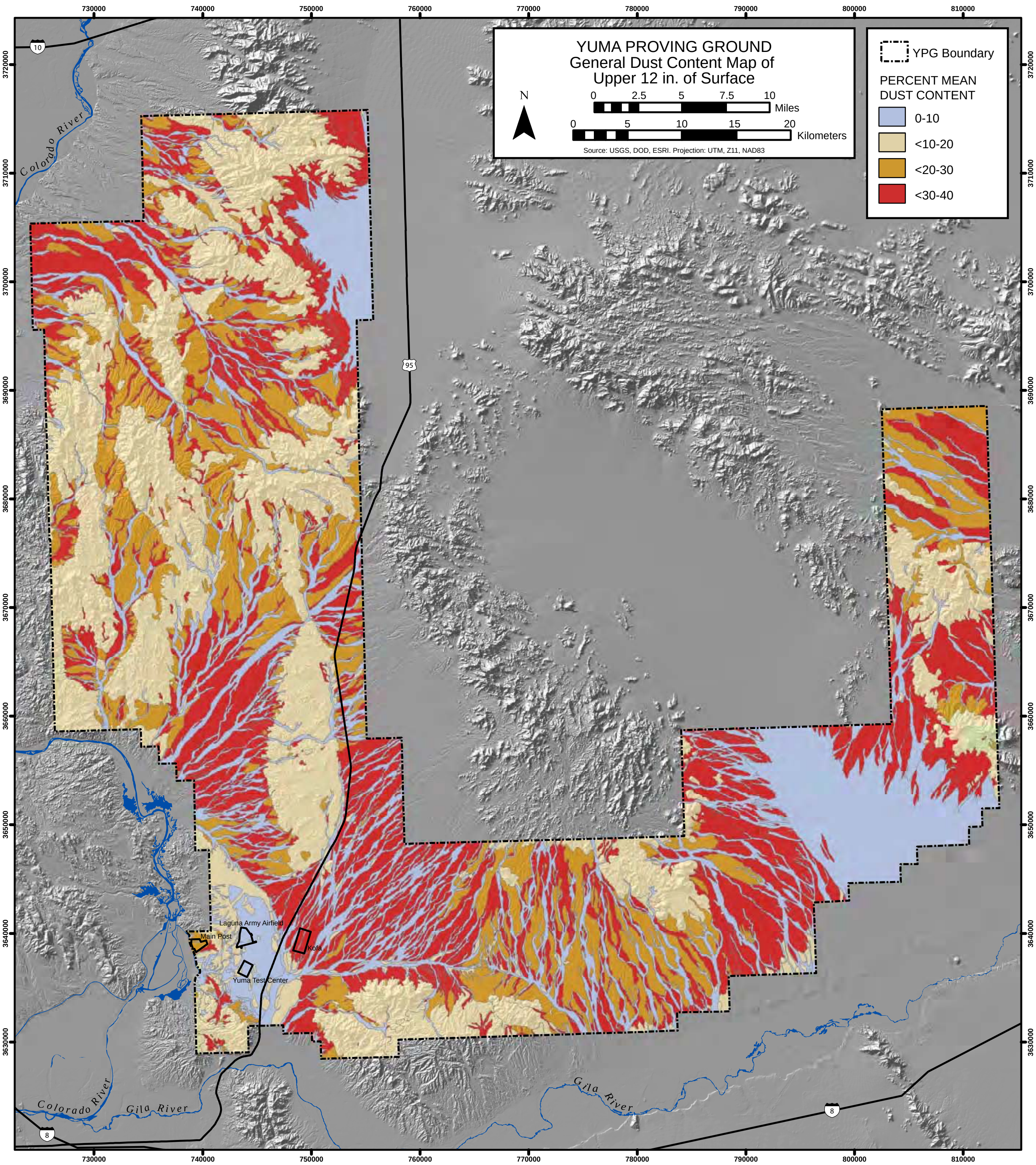
Desert Research Institute

LANDFORMS & SURFACE COVER OF U.S. ARMY YPG

NRCS Soil Map

DATE: 9-08-2009

MAP 5



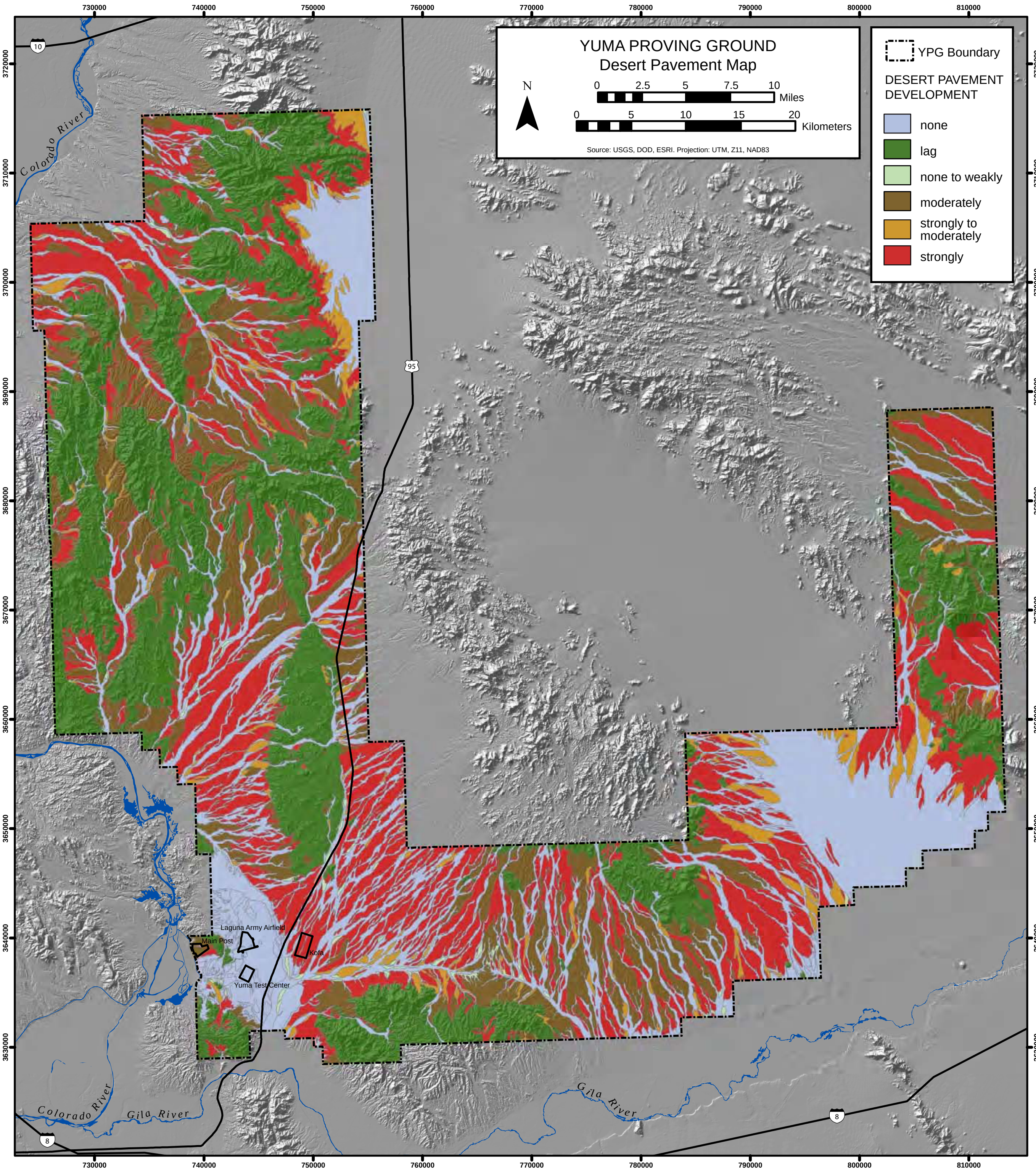
DRI Desert Research Institute

LANDFORMS & SURFACE COVER OF U.S. ARMY YPG

General Dust Content Map

DATE: 9-08-2009

MAP 6



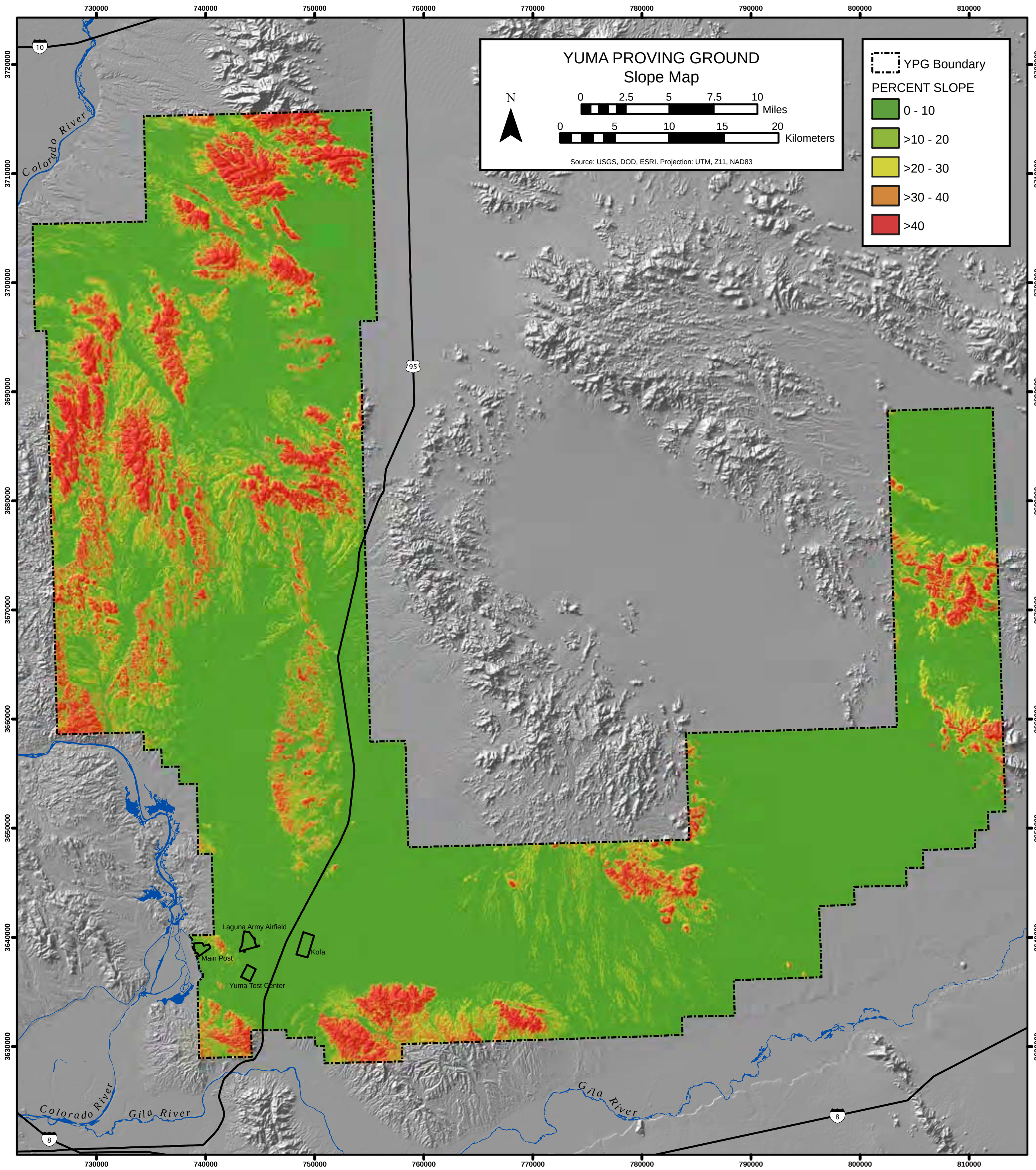
Desert Research Institute

LANDFORMS & SURFACE COVER OF U.S. ARMY YPG

Desert Pavement Development Map

DATE: 9-08-2009

MAP 7



Desert Research Institute

LANDFORMS & SURFACE COVER OF U.S. ARMY YPG

Slope Map

DATE: 9-08-2009

MAP 8