THE DISTRIBUTION OF PEDIMENTS IN THE COYOTE RANGES, SOUTHERN CALIFORNIA

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in

Geography

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by

Belinda Jean Stevens

Spring 2015

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ABSTRACT

THE DISTRIBUTION OF PEDIMENTS IN THE COYOTE RANGES,

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The Coyote Ranges lies across the boundary of the San Diego and Imperial Counties of southern California, and is bounded on the southern flank by the active right lateral strike-slip Elsinore Fault. The active San Andreas Fault system has caused the Coyote Ranges to be uplifted resulting in the formation of erosional structures such as pediments. The inaccessibility and ruggedness of the terrain have deterred detailed pediment research in and around the Ranges, which may reveal local interactions and regional correlations.

During the winters of 2012 and 2013, I performed manual mapping of pediments on aerial photographs, took documentary photographs of the sites, and made extensive handwritten field notes to capture the specific locations and geology of the pediments. Analysis of the data resulted in the categorization of more than 500 pediments, identification of pediment relationships, comparison of measured gradients, and identification of formational and/or modifying agents. Results have determined that pedimentation is not affected by geology, and some processes are active either singularly or in dual roles. It is possible that pediments within the Coyote Ranges can be used in determining the rate and timing of uplift and the identification of areas with more uplifted activity.

CHAPTER I

INTRODUCTION

Purpose of Research

The purpose of my study is to identify pediments and to map their geographic location in and around the Coyote Ranges in southern California, in order to establish a crucial basis for future research involving pediments and their informational development in the evolutionary stages of orogenesis. As part of the initial investigation, the location of the pediments must be determined, their surface configured, and underlying geology distinguished. Subsequent analysis of the data may result in categorization of the pediments, the identification of relationships with geological systems, a preliminary assessment of the age, and agents of pediment formation and/or modification. Investigation of pediments in the Coyote Ranges may have the potential to augment our understanding of the rate and timing of fault uplift and the identification of areas with more uplifted activity. The Coyote Ranges is a unique location in which the influence of faulting, deposition, uplift, and erosion may reveal local interactions and regional correlations.

The Pediment Problem Today

Pediments have been the subject of disputes and disagreements by geomorphologists since G.K. Gilbert's first recognition and description in 1877 of pediments in the Henry Mountains of Utah (Dohrenwend 1994, 321; Hadley 1967, 83; Oberlander 1974, 850; Tator 1952, 295). The pediment problems have arisen from subsequent studies and can be placed into five categories (Tator 1952, 295; Cooke, Warren, and Goudie 1993, 188):

(1) Studies have focused on the pediment landform itself, instead of the pediment's associated landforms, deposits, and erosional and/or depositional systems surrounding the pediment (Cooke 1970, 26; Oberlander 1974, 851).

(2) The vast distribution of pediment research has caused ambiguous definitions of the feature, which has given rise to inconsistent descriptions and terminology (Cooke, 1970, 26; Cooke, Warren, and Goudie 1993, 188; Dohrenwend 1994, 322- 323; Hadley 1967, 83; Tator 1953, 47-48; Twidale 1981, 423; Warnke 1969, 364).

(3) Disagreements on the origin of pediments remain unresolved (Dohrenwend 1994, 321; Hadley 1967, 83; Sharp 1940, 361; Twidale 1981, 423).

(4) Precise data that is verifiable and of practical value to other researchers is seldom presented, as pediments themselves may not provide sufficient information to reveal their genesis (Cooke 1970, 26; Cooke, Warren, and Goudie 1993, 188; Dohrenwend 1994, 323).

(5) There has been too much emphasis placed on unverifiable evolutionary hypotheses that focus on the processes and sequence of pediment changes (Cooke 1970, 26).

As indicated in (2) above, there was even disagreements about what to label the feature. Gilbert referred to the pediments as "Hills of Planation," but over the years they have been given numerous names including rock-floored piedmont slope, rock-cut surface, mountain pediment, and mesa. It was not until 1897, when W.J. McGee used the term pediment in his description of the feature in southwestern Arizona and western Sonoran Mexico terrain that the name pediment became widely accepted (Dohrenwend 1994, 321-324; Hadley 1967, 83-89; McGee, 1897, 88, 92, 110; Sharp 1940, 361-362; Tator 1953, 47-53).

However, more controversial and important than the name is the basic definition of what constitutes a pediment. Some researchers claim pediments are an erosional feature, while others regarded the structure to be a depositional form (Hadley 1967, 83-89). Pediments develop in many different climatic regimes and geomorphic settings, so it is not surprising that there are a variety of definitions describing the same structure that are similar in appearance (Dohrenwend 1994, 321-322; Oberlander 1974, 868). For example, Richard F. Hadley defines pediments as an " erosional surfaces of low relief, partly covered by a veneer of alluvium, that slope away from the base of mountain masses or escarpments in arid and semiarid environments" (1967,83). Theodore M. Oberlander refers to pediments as "ramp-like erosion surface cutting the same resistant rock that forms the adjacent upland" (1974, 850). John C. Dohrenwend's descriptive definition of a pediment is

> a gently sloping erosional surface developed on bedrock or older unconsolidated deposits. The eroded surface may be subaerially exposed or covered by a continuous or discontinuous veneer of alluvial deposits, and the bedrock may include any lithologic type with any structural attitude. (1994, 323)

For my research I prefer to use Dohrenwend's definition because it focuses on pediments as an erosional feature without any specific lithology, implication of genesis, or processes.

However, all of these pediment problems become more or less irrelevant when research on pedimentation in desert environments cannot be conducted due to the extraordinary difficulties presented by the sites (Cooke 1970, 26). Charles D. Winker and Susan M. Kidwell state that one of the struggles they faced in their field work in the Coyote Ranges was maneuvering through the range's very rugged terrain. This hardship caused access to be extremely limited, making geologic mapping arduous and consequently sparse (1996, 330). The physical conditions have made the Coyote Ranges an extremely challenging site for geological and geomorphic reconnaissance regarding field work and mapping (Dr. Bykerk-Kauffman, February 2012 personal communication).

Pediments are transitional surfaces that can be partly active, partly inactive, partly dissected, and partly buried impairing our understanding of its morphogenesis. Many actively forming pediments lie unrecognized beneath mantles of deposits, which can commonly frustrate attempts at description, measurements, and analysis of pediments (Dohrenwend 1994, 322). However, research on pediments in the Coyote Ranges has the potential to augment our understanding of the significance the structure holds within the association of the Ranges.

The pediments may have the potential to illuminate both processes, ancient and modern, which have affected the Coyote Ranges' morphology.

CHAPTER II

LITERATURE REVIEW

Location

The Coyote Ranges is centered at 32° 47’ 46.93” North, 116° 02’ 59.71” West, and lies across the boundary of San Diego and Imperial Counties in southern California (see Figure 1). It extends over 18,600 acres (29 square miles) and is approximately 13.5 miles long and 5 miles wide, with the long axis running east to west (BLM 2013; Google Earth 2013).

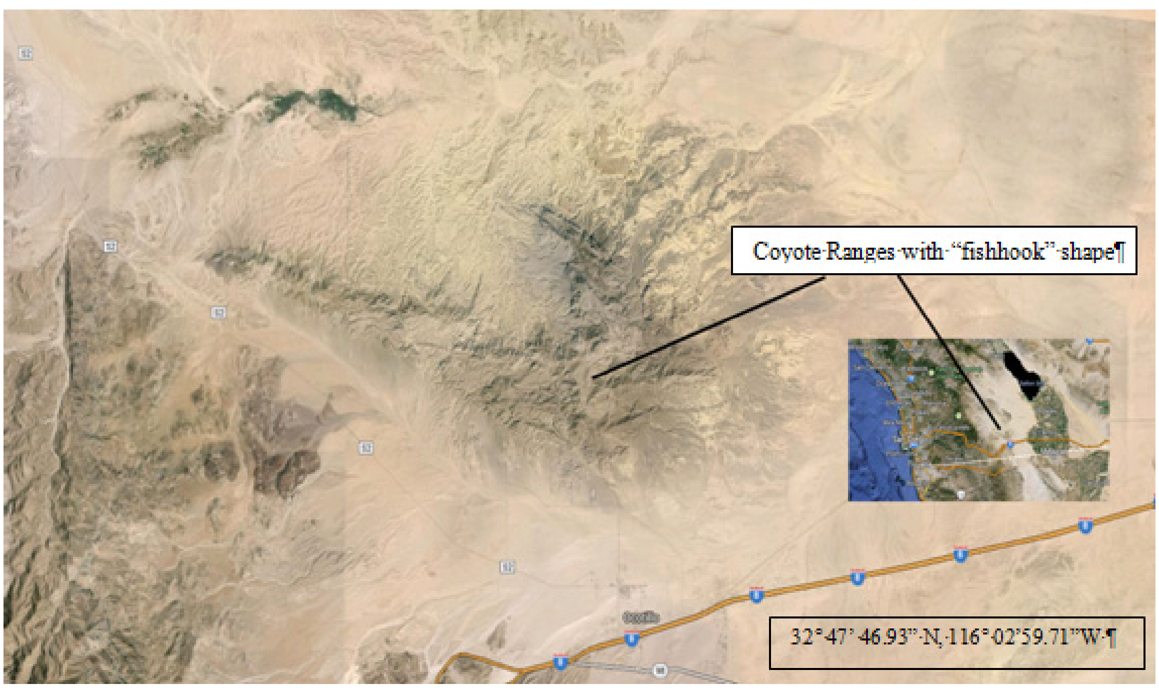

Figure 1. Coyote Range location. The Coyote Ranges are approximately 13.5 miles long and 5 miles wide with the long axis running east to west. The Elsinore Fault line runs the length of the southern flank.

The area has limited paved roads, and unimproved public roads that extend only a short distance into the Range. The U.S. Interstate 8 parallels the eastern portion of the Coyote Ranges, and the North Imperial highway (S2) parallels the southern portion (CA Parks; Christensen 1957, 3-4). The weather fluctuates considerably from sunny skies with temperatures ranging from 30 to over 100 degrees Fahrenheit, with unpredictable and sporadic rains and winds gusting up to 60 miles per hour (WU). Vegetation is sparse, but includes creosote and ocotillo bushes, a variety of cacti, and seasonal desert flowers such as lupine and brittlebush (see Figure 2) (Christensen 1957, 5).

Figure 2. Coyote Range vegetation - *left* ocotillo bush and *right* brittlebush.

The southern flank of the Coyote Ranges is bounded by the active right-lateral strike-slip Elsinore Fault, which is part of the San Andreas Fault system (Dorsey 2005, 1; Winker and Kidwell 1996, 330). Many minor faults associated with the Elsinore Fault are complex and still under study (Winker and Kidwell 1996, 330). The elevation ranges from a high of 2,408 feet, at Carrizo Peak, to a low base level of 120 feet. Due to its planimetric shape, the Coyote Ranges are also known as the Fishhook Mountain Range (See Figure 1) (BLM 2013).

General Historical Background and Geology

The Coyote Ranges' region are part of the southwestern Basin and Range geological province and is a subarea of the Salton Trough region (see Figure 3). The Salton Trough lies at the boundary between the North American Plate and the Pacific Plate where the sea-floor spreading center within the Gulf of California transitions to the transform plate boundary marked by the San Andreas Fault (CSULB n.d.). Sedimentation in the Salton Trough began in the early Miocene time when continental sands and conglomerates were deposited over the rugged paleotopography of eroded basement granitic and metamorphic rock of the Peninsular Range's batholith. Concurrently, local volcanism accompanied this time period of continental sedimentation (Dorsey 2005, 1-3). In the late Miocene to early Pliocene time, the East Pacific Rise extension (locally expressed as the west Salton Detachment Fault system) produced a large elongated basin, the Imperial Seaway, which connected the Salton Trough basin with the Gulf of California.[1] The Imperial Seaway allowed an incursion of marine clastics of claystone, sandstone, siltstone, and limestone deposits throughout the northern Gulf of California and the Salton Trough region. Synchronous with the rapid basin subsidence and marine

[1] "The west Salton Detachment Fault was a regional low-angle normal to oblique-normal fault that was active from late Miocene or early Pliocene time" (Dorsey et al 2012, 2).

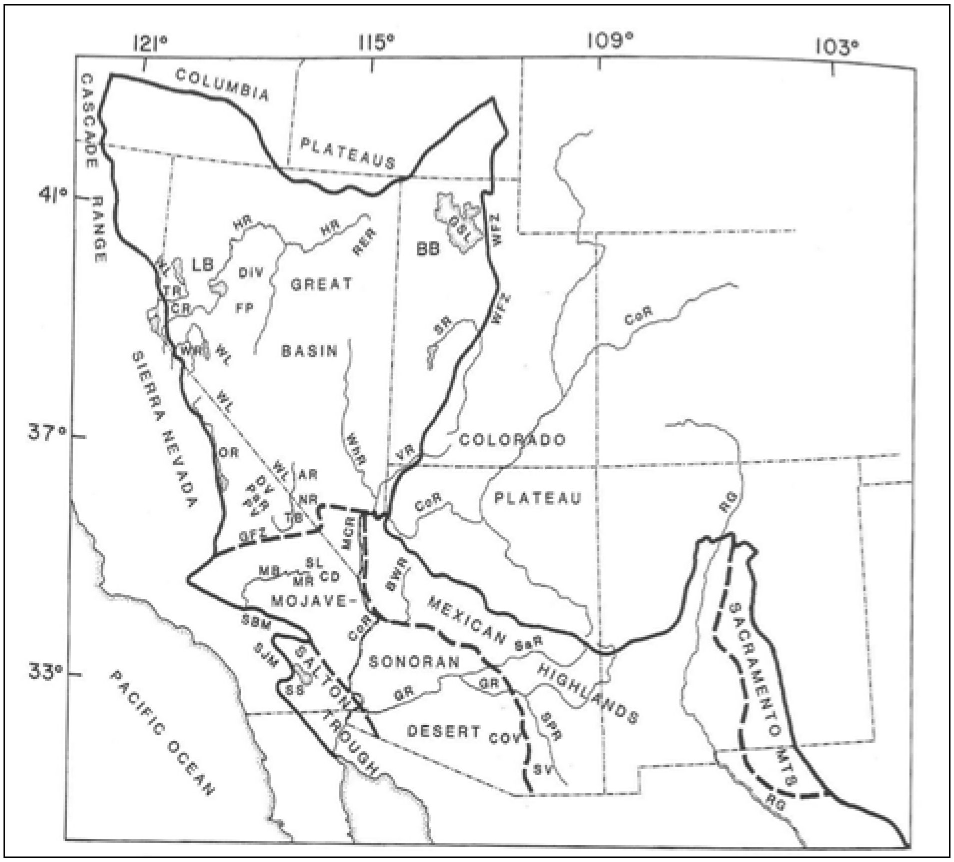

Figure 3. Basin and Range provinces and physical features. The Basin and Range Provinces extends into seven states.

Source: Dohrenwend, John C. 1987. Basin and Range. In Geomorphic Systems of North America, ed. W.L. Graf, 303-342. Boulder, Colorado: The Geological Society of America, Centennial Special Volume 2.[2]

incursion, major tectonic changes emerged, including the development of the San Andreas Fault system. The Pliocene to early Pleistocene interval records the tectonic

[2] The following names are abbreviated on the Basin and Range general map: "AR-Amargosa River; BWR-Bill Williams River; BB-Bonneville Basin; CR-Carson River; CoV-Canada del Oro Valley; CD-Cima Dome; CoR-Colorado River; DV-Death Valley; DiV-Dixie Valley; FP-Fairview Peak; GFZ-Garlock Fault Zone; GR-Gila River; GSL-Great Salt Lake; LB-Lahontan Basin; HR-Humboldt River; MB-Manix Basin; MCR-McCullough Range; MR-Mojave River; NR-Nopah River; OR-Owens River; PaR-Panamint Range; PV-Panamint Valley; RG-Rio Grande; RER-Ruby-East Humboldt Range; SaR-Salt River; SS-Salton Sea; SBM-San Bernardino Mtns; SJM-San Jacinto Mtns; SPR-San Pedro River; SR-Siever River; SL-Silver Lake playa; SV-Sonoita Valley; TB-Tecopa Basin; TR-Truckee River; VR-Virgin River; WL-Walker Lane; WR-Walker River; WFZ-Wasatch Fault Zone; and WhR-White River."

movement of the Pacific Plate northwest relative to the North American Plate. This movement caused the Colorado River to episodically debouch into the Salton Trough region between the Chocolate and Gila Mountains (Dorsey 2005, 3-5; Winker and Kidwell 1996, 296-299). The deposition of river sediments in the Salton Trough region filled the basin, and changed the sediment type from marine to nonmarine. Sediments of very fine grained clay, sand, and silt gradually caused the basin to shallow and form a topographic division between the Salton Trough and the Gulf of California (Winker and Kidwell 1996, 296). The subsidence and sedimentation for the Coyote Ranges' area ended shortly after 1 million years (Dorsey et al 2012, 19).

The interval from the Pleistocene to the current epoch has been a time of rapid uplift, inception of the Elsinore Fault, and transpressive deformation throughout the western Salton Trough region (Winker and Kidwell 1996, 313). During this time, faulting and uplift created the current rugged topography characterized by northwest-trending ridges and mountain ranges such as the Coyote Ranges (Dorsey 2005, 1, 7). Rebecca Dorsey et al's recent study of basins adjacent to the Coyote Ranges revealed that the Elsinore Fault was part of the major tectonic reorganization of the region, which ended the slip on the west Salton Detachment Fault system and initiated the modern strike-slip faults approximately 1.0-1.2 million years ago (2012, 1-21). This would suggest that the age of the Coyote Ranges is 1.0 million years old or less.

The stratigraphy of the Coyote Ranges reveal the historical interaction of the Salton Trough's three major geologic systems: the Gulf of California, the Colorado River, and the San Andreas Fault system (Winker and Kidwell 1996, 295). Early geological mapping by researchers such as Andrew D. Christensen provides a basic geological overview of the eastern Coyote Ranges, but intricate geological and structural mapping is still under study (1957, 1-188; Winker and Kidwell 1996, 297-300). The first and oldest rock unit is the Paleozoic to Mesozoic basement of crystalline granitoid and metamorphic rock of the Peninsular Ranges batholith (see Figure 4—oversized). The presence of fossilized marine bore holes and conodonts suggests the basement once existed as part of the sea floor. Composed with veins of pegmatite and layers of schist, gneiss, and marble, the basement is the Coyote Ranges' most erosion resistant lithology (Dorsey 2005, 3; Todd 2004, 7-8; Winker and Kidwell 1996, 299-303, 308). The second stratigraphic sequence upwards is the Miocene Split Mountain Group which consists of volcanic rock and nonmarine clastics, local fluvial and eolian sediments known as L-Type clastics (Winker and Kidwell 1996, 297-300) (see Figure 4).[3] The Split Mountain Group deposits filtered into the eroded basement's paleotopography, filling rivers and constructing dunes (Dorsey 2005, 3-4; Winker and Kidwell 1996, 299). The third sequence upward from the basement is the late Miocene to Pliocene Imperial Group, and represents the transition from nonmarine to marine sediments (see Figure 4). At the base of the Imperial Group lays evaporite Fish Creek Gypsum. It is the oldest evidence of the rapid transgression of marine water from the Gulf of California, as the result of regional tectonic changes (Dorsey 2005, 4; Todd 2004, 4; Winker and Kidwell 1996, 299, 306). Both the Gulf of California transgression and the progradation from the early Colorado River delta are reflected in the Imperial Group's sediments.

The late Miocene-Pliocene Imperial Group's deposition began with marine sediment from the Gulf of California. The Gulf of California predeltaic marine sediment

[3] L-Type clastics consist of sandstones, conglomerates, and sediment derived from the local environment.

Time Units			Rock Units
Era	Period	Epoch	Palm Springs Group (non-marine)
Cenozoic	Quaternary	Pleistocene	• L-Type Clastics— sandstones, and conglomerates • C-Type Clastics— fine grain sandstones, and mudstones
	Neogene	Pliocene	**Imperial Group (marine)**
			• C-Type Clastics— mudstones, and fine grain sandstones derived from the ancestor Colorado River • L-Type Clastics— coarse sandstones and conglomerates
		Miocene	**Split Mountain Group (non-marine)**
			• L-type Clastics—sandstones, conglomerates, and sediments derived from the local environment • Volcanic Rocks
Mesozoic	Jurassic		**Basement**
			• Metaplutonic rocks
Paleozoic			• Metasedimentary rocks

Figure 4. Stratigraphic column.

Source: Data adapted from Winkler, Charles D. and Susan M. Kidwell. 1996. Stratigraphy of the Marine Rift Basin: Neogene of the Western Salton Trough, California. In Field Conference Guide Pacific Section A.A.P.G. GB 73, Pacific Section S.E.P.M., edited by Patrick L. Abbott and John D. Cooper, 80:299.

is locally derived, coarse grained L-Type clastics that consists of fossiliferous sandstones, conglomerates, and rare limestones (Winker and Kidwell 1996, 299, 307). With the advancing shorelines of the Imperial Sea's, claystones, sandstones, and siltstones came marine life such as: gastropods (snails), bivalves (oyster, scallops, clams), echinodermatas (sand dollars), corals, and serpulid worms. The Group's marine to non-marine sediment transition emerged from the historical Colorado River. The ancestral Colorado River's non-marine deposits from the delta plains are very fine grained sediments known as the C-Type clastics (Dorsey 2005, 4-5; Winker and Kidwell 1996, 300) (see Figure 4).[4] Research has determined the Imperial Group's tightly compacted oyster shell coquinas beds, were formed in submerged shallow distributary channels of the ancestral Colorado River (Demere 2006, 38). The late Miocene-Pliocene fossiliferous deposition are now part of the Imperial Group's sediment. (Demere 2006, 34-35; Winker and Kidwell 1996, 308).

The fourth and youngest stratigraphic unit for the Coyote Ranges' is the Pliocene to Pleistocene Palm Spring Group. It marks the last change from marine to nonmarine delta sedimentation (see Figure 4). This Group's sediment are found to transition from C-Type to L-Type clastics, or both types interfingered together (Todd 2004, 3-4; Winker and Kidwell 1996, 299-300). The slow transition from marine to nonmarine low energy intertidal environment is recorded in the strata disturbed beds of claystone, which once housed burrowing marine animals, wavy-bedded sandstone, and shelled protozoans. Some studies suggest that the L-Type conglomerates near the top of

[4] C-Type clastics consist of claystones, mudstones, sandstones, and siltstones sediment derived from the ancient Colorado River.

the Palm Spring's Group were a result of the initiation of the San Jacinto and Elsinore Faults (Dorsey 2005, 5-7).

Pediments in General

Pediments are distributed in many different climatic regimes and geomorphic settings. Although they are most characteristic of arid and semi-arid environments (Denny 1967, 81; Dohrenwend 1994, 321; Oberlander 1974, 868; Royse and Barsch 1971, 3177; Tator 1952, 295; Twidale 1981, 423) they are not found in every desert basin (see Figure 5) (Cooke, Warren, and Goudie 1993, 191). In the western Basin and Range

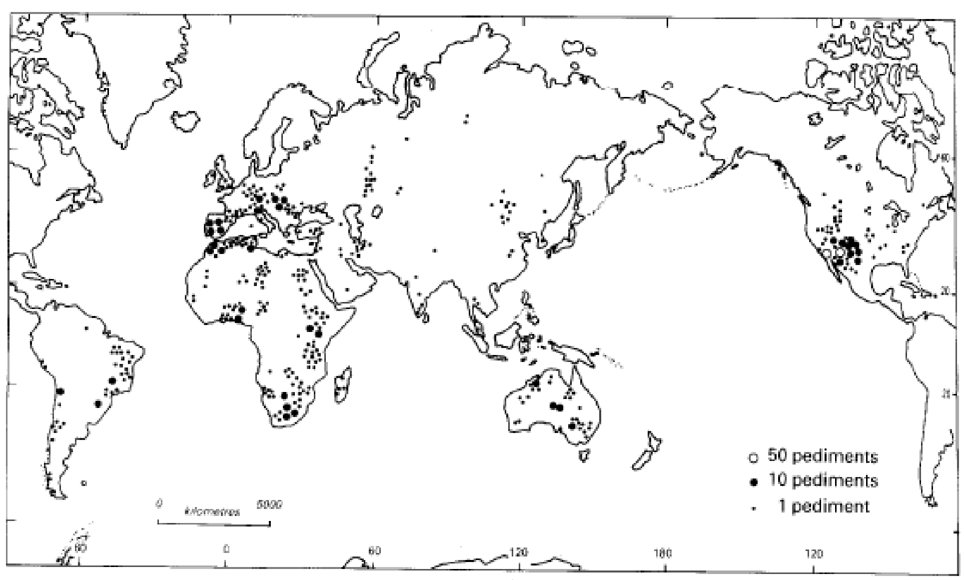

Figure 5. Pediment distribution. Pediments are found in many different climatic regimes and geomorphic settings worldwide.

Source: Cooke, Ron, Andrew Warren, and Andrew Goudie. 1993. Pediments and Glacis. In, Desert Geomorphology, 188-201. London: UCL Press. Figure 13.3.

province, including the southwestern Arizona and southeastern California deserts, areas with smaller ranges (in width, height, relief, area, and volume) are characterized by pediments. Conversely, in areas occupied by larger ranges, alluvial fans are more common than pediments. This association is interesting since pediments and alluvial fans are relatively connected; pediments are associated with erosional environments while alluvial fans are depositional in origin (Cooke, Warren, and Goudie 1993, 191). Dohrenwend reports generally larger and more continuous pediments are found in the Basin and Range province due to the greater vertical stability. The distribution of pediments and alluvial fans is related to the frequency of occurrence and style of Quaternary faulting. For instance, between the Sierra Nevada and Death Valley (southwest Basin and Range) a region of dip-slip faulting is characterized by active to moderately active tectonic mountain ranges with steep hillslopes in all rock types, low sinuosities mountain fronts, and elongated drainage basins with large alluvial fans and few or no pediments. A region of strike-slip faulting such as in the south-central Mojave Desert, is characterized by a moderately to slightly active mountain range with relatively equal drainage basins, broader valleys, and a moderately sinuous mountain front with both alluvial fans and pediments. Conversely, inactive mountain ranges with broad pediments, large embayments, and highly sinuous mountain fronts, reflect regions of post-middle Miocene tectonic stability as in the western and eastern Mojave Desert (1994, 334-335).

Pediments are part of an open erosional and depositional system; therefore, deciphering pediment morphogenesis can not be gained from studying only the pediment itself. Instead the best approach to determining the morphogenesis of pediment formation is through the study of the entire system: the Pediment Association (see Figure 6) (Cooke, Warren, and Goudie 1993, 192; Dohrenwend 1994, 324; Oberlander 1974, 851).

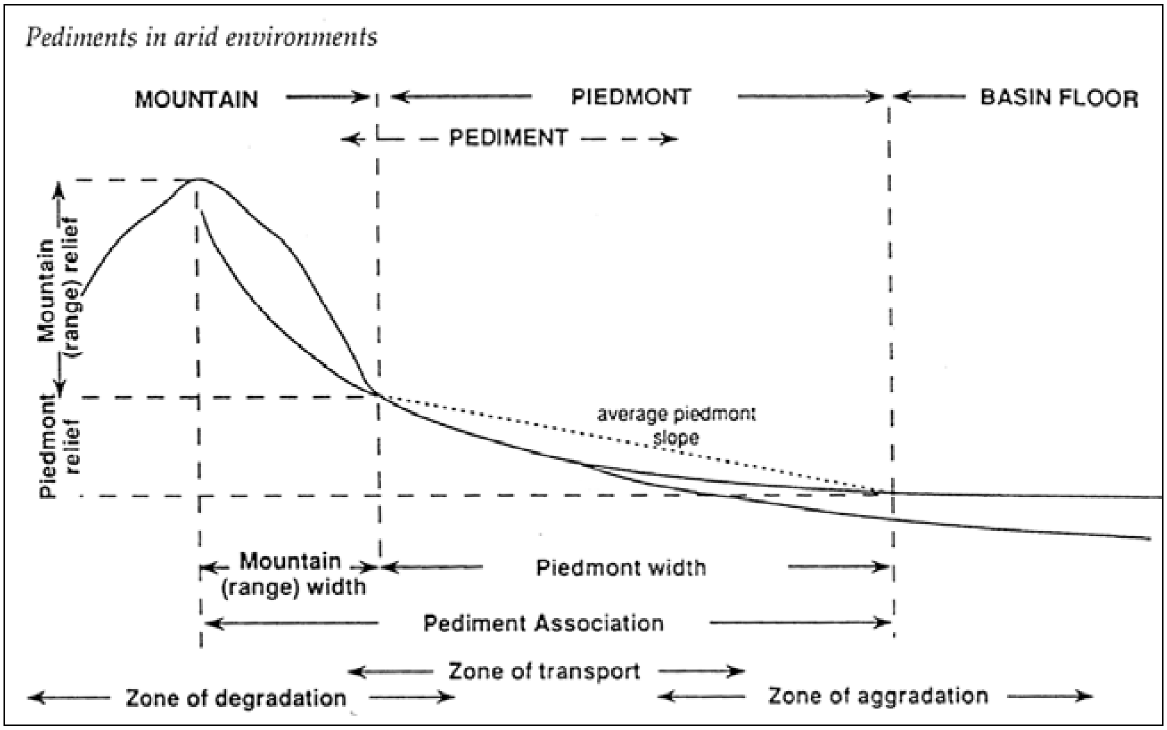

Figure 6. Pediment association. The pediment association zone boundaries are determined by the rate of debris supply and removal.

Source: Data adapted from Dohrenwend, John C. 1994. Pediments in arid environments. In Geomorphology of Desert Environments, ed Athol D. Abrahams and Anthony J. Parsons, 324. London: Chapman & Hall.

The Pediment Association includes (1) the mountain area, a zone of degradation; (2) the piedmont area, zone of pediment formation and fluvial transport, and; (3) the basin floor area, zone of aggradation (Cooke 1970, 28; Dohrenwend 1994, 323-324). The boundaries between the three zones are determined by the rate of debris supply and removal. If the rate of debris supply increases or the rate of debris removal decreases, the zones tend to migrate upslope. Conversely, if the rate of debris supply decreases or the rate of removal increases, the zones tend to migrate downslope (Dohrenwend 1994, 342).

Pediments range in size from miniature structures measured in square feet to broad pediplains covering many square miles (Cooke, Warren, and Goudie 1993, 192; Rich 1935, 1023; Tator 1952, 298). Charles S. Denny proposes a pediment's shape is related to geology through the difference in the underlying bedrock. The underlying bedrock causes a variation in a stream's bed load. As the stream traverses over pediments, the bedload movement affects pediment sizes and gradients. In addition, the more erosion resistant rocks within a stream drainage may act as a local base level and retard the dissection of pediments (1967, 102). General pediment surface profiles fall into three common shapes: concave or scooped-shape, convex or fan-shaped, or rectilinear (Cooke, Warren, and Goudie 1993, 192; Dohrenwend 1994, 327-328; Hadley 1967, 84; Tator 1952, 303; Twidale 1981, 425; Warnke 1969, 371). Pediment profiles can display one or a combination of all three general forms. The form is influenced by elements such as: (1) drainage area, (2) lithology, (3) precipitation, (4) stream discharge, (5) structural features, (6) size of regolith, and (7) soil cover (Hadley 1967, 84; Warnke 1969, 371). Ben A. Tator reported that concave longitudinal profiles have been found to be more segmented in heterogeneous rocks and smoother in homogeneous rocks (1952, 302).

Pediments are also referred to as "slopes of transportation," because alluvium is transferred across the pediment surface (Hadley 1967, 84; Twidale 1981, 423). Dohrenwend contends that classification schemes of pediments by external appearance have not been consistent or compatible with each other. Some studies have defined other types of classification. The first classification scheme is based on the general geomorphic environment. For example an apron pediment, characteristic of basin-range country, is usually located between an upland and a depositional plain, and between the watershed and base level. A pediment dome, occurs on upland slopes that are not surmounted by a mountain mass, and a terrace pediment can derive from base levels adjacent to through-flowing streams. The second classification scheme is based on relations between surface material and underlying lithology, and is often used to infer pediment forming processes. For example, a mantled pediment, is covered with a veneer of debris formed by weather and washes on crystalline bedrock. A rock pediment, forms where crystalline bedrock is exposed at the surface of former mantle pediment's weathered fronts, and a covered pediment is a sedimentary surface covered by a veneer of coarse debris (1994, 323; Bourne and Twidale 1998, 123-24; Cooke, Warren, and Goudie 1993, 191).

A pediment slope is defined as the line joining the highest and lowest points of a pediment profile along the line of a pediment association length (Cooke, Warren, and Goudie 1993, 192). The slope has become an important portion of a pediment because it is more susceptible to analytical evaluation than other pediment properties; thus, leading to numerous studies of pediment slopes and hypotheses. For example, Ronald U. Cooke proposed "the slope of pediments associated with faults is significantly steeper than the slope of pediments not associated with faults" (1970, 33). His research in the western Mojave Desert confirmed that tectonic activity may be a factor in determining the general slope of pediments (Cooke, Warren, and Goudie 1993, 193) (See Table 1). Pediment inclination measurements do not vary with region. Research from South Australia reports pediment gradients range from 1 to 6 degrees, with averages between 3 and 4 degrees (Bourne and Twidale 1998, 124). South Africa pediment gradients average about 5

Table 1. Pediment slope and faults. Research for this data was conducted in the western Mojave Desert. *Source*: Cooke, Ron, Andrew Warren, and Andrew Goudie. 1993. Pediments and Glacis. In, Desert Geomorphology, 188-201. London: UCL Press. Table 13.1c.

Pediments	No.	Mean slope	Range	Standard deviation
1. Associated with faults	31	2° 55'	39' - 5°23'	1°12'
2. Not associated with faults	22	2°10'	31'-3°50'	48'

Source: Cooke, Ron, Andrew Warren, and Andrew Goudie. 1993. Pediments and Glacis. In, Desert Geomorphology, 188-201. London: UCL Press. Table 13.1c.

degrees (Hadley 1967, 84), and the southwestern United States pediment gradient measurements range from 0.5 to 11 degrees (Cooke 1970, 28; Cooke, Warren, and Goudie 1993, 192; Dohrenwend 1994, 327; Hadley 1967, 84; Royse and Barsch 1971, 3177; Sharp 1940, 357).

Pediment gradients appear to be steeper among more erosion resistant coarser rock types and gentler on less friable substrates. As well, profiles are steeper opposite intercanyon areas than below the canyon mouths of a mountain front, and steeper along smaller streams than along larger ones due to lithological influences instead of factors concerning stream size (Tator 1952, 302). Robert P. Sharp's research in the Ruby–East Humboldt Range, Nevada found that the causes for gradient diversities includes: (1) the amount and coarseness of debris, (2) permeability of underlying rocks, (3) periodicity of precipitation, (4) volume of water, and (5) proximity to the mountain slope (1940, 357). Conversely, Jacqueline Mammerickx's research in California's Mojave Desert and Arizona's Sonoran Desert suggests that neither drainage basins backing pediments, nor lithology are decisive factors in determining the gradient of a pediment. Instead, the effects of tectonic activity and different cycles of pedimentation better explain the differences in pediment slope gradients (1964, 427-431). Cooke's study of pediment slopes in the western Mojave Desert strengthened Mammerickx's theory that lithology is not a significant factor in pediment gradient, and lithology between mountain-fronts and pediments may be different (1970, 33).

The proposed nature of the agents forming pediments varies with the researcher. Tator examines forty-three pediment studies conducted between 1880 and 1952 from regions of Africa, Australia, Mexico, Mongolia, South America, and North America and suggest the following pedimentation processes: (1) basal sapping, (2) ephemeral stream erosion, (3) escarpment retreat, (4) lateral planation, (5) rainwash, (6) rills, (7) runoff, (8) sheetflood, (9) surface wash, (10) soil creep, (11) slope retreat, (12) wind, and (13) weathering to be dominant agent(s) in their studies (1952, 308-315). Some researchers believe more than one process has been active in pediment formation, either simultaneously or at different stages of a pedimentation cycle (Hadley 1967, 85; Sharp 1940, 356). However, as pediment research expands into diverse regions, different pedimentation processes are going to dominate under diverse climatic, topographic, and geologic conditions (Dohrenwend 1994, 321-322; Sharp 1940, 362).

Pediments are characteristic of arid and semi-arid environments (Denny 1967, 81; Dohrenwend 1994, 321; Oberlander 1974, 868; Royse and Barsch 1971, 3177; Tator 1952, 295; Twidale 1981, 423), yet evidence is accumulating that pediments are ancient surfaces inherited from very different conditions than are currently operating (Cooke, Warren, and Goudie, 1993, 190; Oberlander 1974, 853). Yi-Fu Tuan relates evidence of Wisconsin glaciation that extended from the southern Rocky Mountains to Blanca Peak in south central New Mexico. In an area that is currently arid, he speculated that glaciation would have affected the climatic environment with lower temperatures and heavier precipitation. These changes probably contributed to: (1) increase volumes of streams with catchment basins, (2) greater and more constant runoffs, (3) deeper downcutting of rivers and streams, (4) the widening of valleys, and (5) increases in alluviation. Such climatic events would have affected gradational processes and landforms (1962, 63-64). Some researchers suggest some pediment formational agents may be an exaggeration. Sheetflooding for example, has rarely been observed on pediment surfaces (Cook, Warren, and Goudie 1993, 189; Rich, 1935, 1004; Warnke 1969, 366). Those opposing researchers pronounced that sheetflooding can not produce pediments, a planar surface, because a flat surface is necessary for sheetflooding to occur. Instead, a type of sheetwash would probably lower the level of an existing plane or be an agent of transportation (Dohrenwend 1994, 342; Warnke 1969, 370).

Dohrenwend suggests it is possible that some researchers are making cause-and-effect deductions from relations between a deductive process and a visible feature. Additionally, there may be some confusion between historical pediment-forming and modifying processes of today (1994, 340; Cooke, Warren, and Goudie 1993, 189-190). Some pediment modifying processes such as climate, stream activity, and uplift are forming multi-level pediments. Tator contends in semiarid environments of the southwest, multiple formational processes result from the effects of climatic fluctuation on the topography and shifting loci of stream action. In humid environments modifying agents are stream rejuvenation and the associated channel confinement. Another suggestion is that pediments result from episodic intervals of rest and uplift, with planation occurring during the pause stage (1952, 300-301). In some areas, variations in stream discharge can cause channels to cut below the bed, or into weaker sediments; thereby, forming multiple levels (Denny 1967, 100; Twidale 1978, 1140, 1142; Twidale 1981, 427). In the southwestern United States, Mammerickx announced that some deeply dissected (more than three feet deep) pediments show multiple surfaces of two, three, or more insets. She suggests the upper surface is a degraded pediment, and the lower surfaces where gullies flow are newly formed pediments (1964, 423).

Some processes such as stream activity have dual roles in pediment formation and/or modification. Victor C. Miller reflects on his research in Arizona's East Kaibab monocline, where the first attack of erosive agents was stream downcutting. Once equilibrium had been established by the major streams, lateral corrasion controlled the House Rock pediment formation (1950, 643). In South Africa, J.A. Mabbutt observed a change in pediment slopes and urged that it was due to a transition of controlling agents of a common factor - running water. The first sign indicated a change in the detrital cover caliber size from the hillslope to the pediment. The removal of the thicker grit and sand from the basal zone of some mountain faces was through forces of hillwash activity, and possibly occasional lateral stream erosion. The second sign was the further deposition of the material extended on to portions of the pediment. This possibly implied sheet flow action might have continued to control the smooth sweeping extent from the pediment to the peneplains (1955, 78-79). Sharp's research in the Rudy-East Humboldt Range in north-eastern Nevada concluded pediments were formed by lateral planation, rill, rain wash, and weathering processes. These series of actions was controlled by geology, topography, and climate conditions (1940, 370, Miller 1950, 643). Other researchers have added lithology, rock structure, and structure activity to the list of controlling agents (Dohrenwend 1994, 334-336; Tator 1952, 298; Dorsey 2005, 1). Both formation and controlling agents impact surface geomorphic processes in depositional and erosional features such as pediments (Dorsey 2005, 1).

If it were not for the factors of preservation protection, pediment remnants would have been dissected more quickly than they were. Miller lists contributing factors to the preservation of pediments in House Rock, Arizona:

> 1. A thick capping of resistant limestone gravels, ranging in coarseness up to boulders several feet in diameter.
> 2. The capping by cementation.
> 3. A veneer of coarse gravel on the dissected slopes of pediment remnants.
> 4. The coalescing of streams before reaching the pediments; thereby, reducing the number of through-pass streams and lateral stream corrasion. (1950, 641-642)

The effects of preservation factors such as veneer covering are described to be critical not only to the preservation of pediments, but the formation of one of the common pediments, covered pediments (Bourne and Twidale 1998, 127; Twidale 1981, 426-427). Researchers have reported various protective covering types including: gravel, shale, limestone, and fossils (Miller 1950, 640). However, it is not uncommon for pediment surfaces to be bare without any specific type of covering (Tator 1952, 306; Warnke 1969, 365). Twidale concludes “the development of protective factors such as veneer, introduces a discontinuous element, a stable aspect, into an otherwise continuous and continuing erosional cycle” (1978, 1172).

CHAPTER III

METHODS

Research Concerns

Andrew D. Christensen's 1957 geological research of the Coyote Ranges provides an overview of some geomorphic surfaces including pediments, but some remaining questions include (see Figure 7 plate v):

1) What is the specific geographic location of the pediments?
2) What criteria were used to classify the pediments?
3) Is there any difference between the pediments in the distinct locations?
4) Is there any evidence of pediment formational and/or modifying processes?
5) Are there any partially active, inactive, buried, and dissected pediments?
6) Can a preliminary assessment of the age of pediments be conducted?
7) Can pediments be used to determine areas of uplift?

These questions are the foundation of my pediment investigation at the Coyote Ranges, which I believe is necessary to establish a fundamental basis for future pediment research.

Methodology

My field work in the Coyote Ranges was conducted during the winters of 2012 and 2013, in segments lasting up to three weeks. I was accompanied by my mentor and colleague Dr. Bykerk-Kauffman, a structural geologist from California State

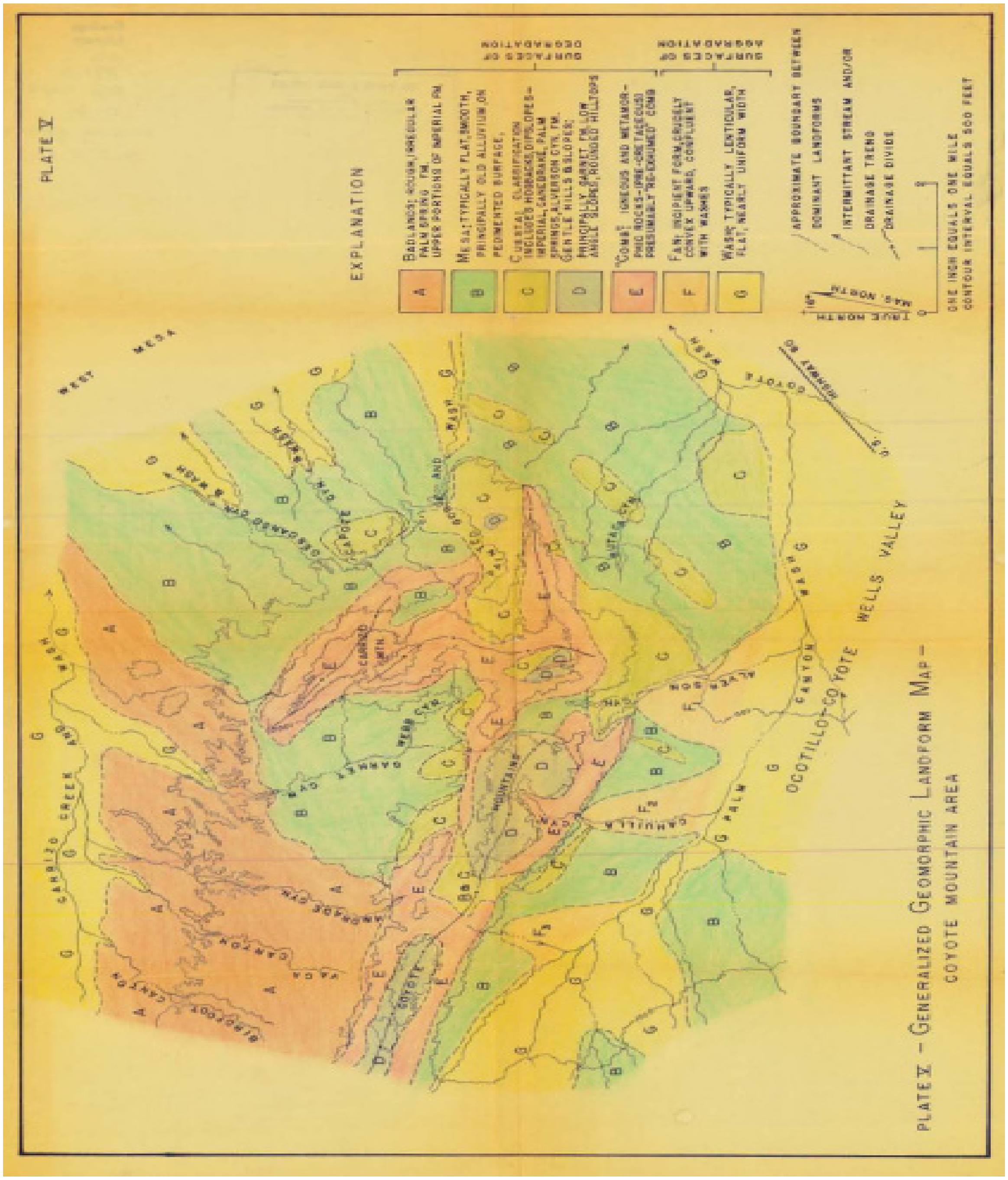

Figure 7. Christensen's generalized geomorphic landform map. Christensen's mapped eastern flank pediments are symbolized as B.

Source: Christensen, Andrew D. 1957. Part of the Geology of the Coyote Mountain Area, Imperial County, California. Master's thesis, University of California, Los Angeles.

University, Chico who has conducted geological mapping of the Coyote Ranges' structure, lithology, and landforms for over twenty years (Dr. Bykerk-Kauffman, January 2012, personal communication).[1] My research however, differed significantly from Dr. Bykerk-Kauffman's; I focused on the surface geomorphology and geology. This involved indentifying and mapping the geographic location of pediments, fault contacts, identifying pediment lithology, and any discerning structural associations. All mapping was done manually on aerial photographs of the terrain (See Figure 8). Ground photos and handwritten field notes were used to capture the aspects of specific locations. Travel within the Coyote Ranges was done mainly on foot through faulted canyons, eroded stream beds, and up the face of hills. On rare occasions, we were able to follow abandoned mining roads or game trails towards our destinations.

All of my data was transcribed into the ArcMap 10.2 computer application and projection NAD 1927 UTM Zone 11N. The ArcMap layers included : San Diego and Imperial county imagery of the Coyote Ranges (USDA-FSA), 40 foot contour lines, degree of inclination (reclassified into twelve classes) (USGS- DEM), water resources (USGS-NHD), digitized pediments, structural benches, and fault traces. Pediment profile slopes were produced using 3D Analyst tool within ArcMap, and attributes were transferred into Microsoft Office Excel to determine the degree of inclination for each pediment randomly selected. When creating the pediment profiles all efforts were used to include only the pediment from the piedmont junction to the end of the pediment surface. Over 500 pediments, including partially active, inactive, and dissected pediments,

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[1] Structural geology is a branch of geology that researches structures formed by tectonic activity.

Figure 8. Field work aerials. Field aerials were used to record geological features such as faults, pediments, bedding contacts, geology, and strike and dip measurements. The first aerial is absent of any field recording, and the second aerials has recorded data from actual field observation and measurements. The aerial information was transcribed into ArcMap for easier display of field research. These aerials are represented in figure 48 on the northern flank.

pediments, structural benches, and fault traces mapped within the Coyote Ranges were digitized as vector lines (see Figure 9). The criteria for categorizing pediment groups was the association of their geographic location. The pediment groups are: mountain pediments, oldest pediments, pediments located near faults, pediments located near streams, and peripediments (see Table 2).

Table 2. Coyote Range grouped pediments. The majority of the pediments were classified in groups 5, 6, and 7.

Group No.	Categorized Pediment Groups
1	Mountain Pediments
2	Oldest Pediments
5	Pediments located near faults
6	Pediments located near streams
7	Peripediments (no association)

Below is an explanation of each categorized pediment group:

- Group 1- mountain pediments was designed to tally the number of pediments at higher elevation levels than those encompassing the Ranges at base level.[2]
- Group 2- oldest pediments was formed for pediments that could imply relative dating by the type of pediment surface or covering.[3] [4]

[2] After digitizing and grouping all of the pediments according to their geographic location association, only two mapped pediments met the high elevation criteria. Thus, this group did not have enough data to support any calculations or interpretations for this research, and not used in slope analysis.

[3] Only two pediments were classified in group 2; thereby, limiting the data to support any calculations or interpretations for this group's category. However, an investigation was conducted in order in order to better estimate seismic hazards for the San Andreas Fault system, and to measure the slip rate of the southern Elsinore Fault paralleling the Coyote Range. The probable movement of two displaced pediments (adjacent to Alverson Canyon) and the ^{230}Th/U-series dating of alluvium deposits from the two displaced pediments and an adjacent pediment were studied (The study refers to the displacement of two alluvial fans, but in fact the landforms are pediments). The results of the pediments ages included a lag time between the alluvium deposition and the accumulation of datable carbonate of 5 ± kyr to be 39.1 ± 5.3 kyr and 46.1 ± 5.3 kyr with a ninety-five percent confidence level (Fletcher, Rockwell, and Sharp 2011, 1-11).

[4] kyr is an informal abbreviation for one thousand years (Rowlett, Russ).

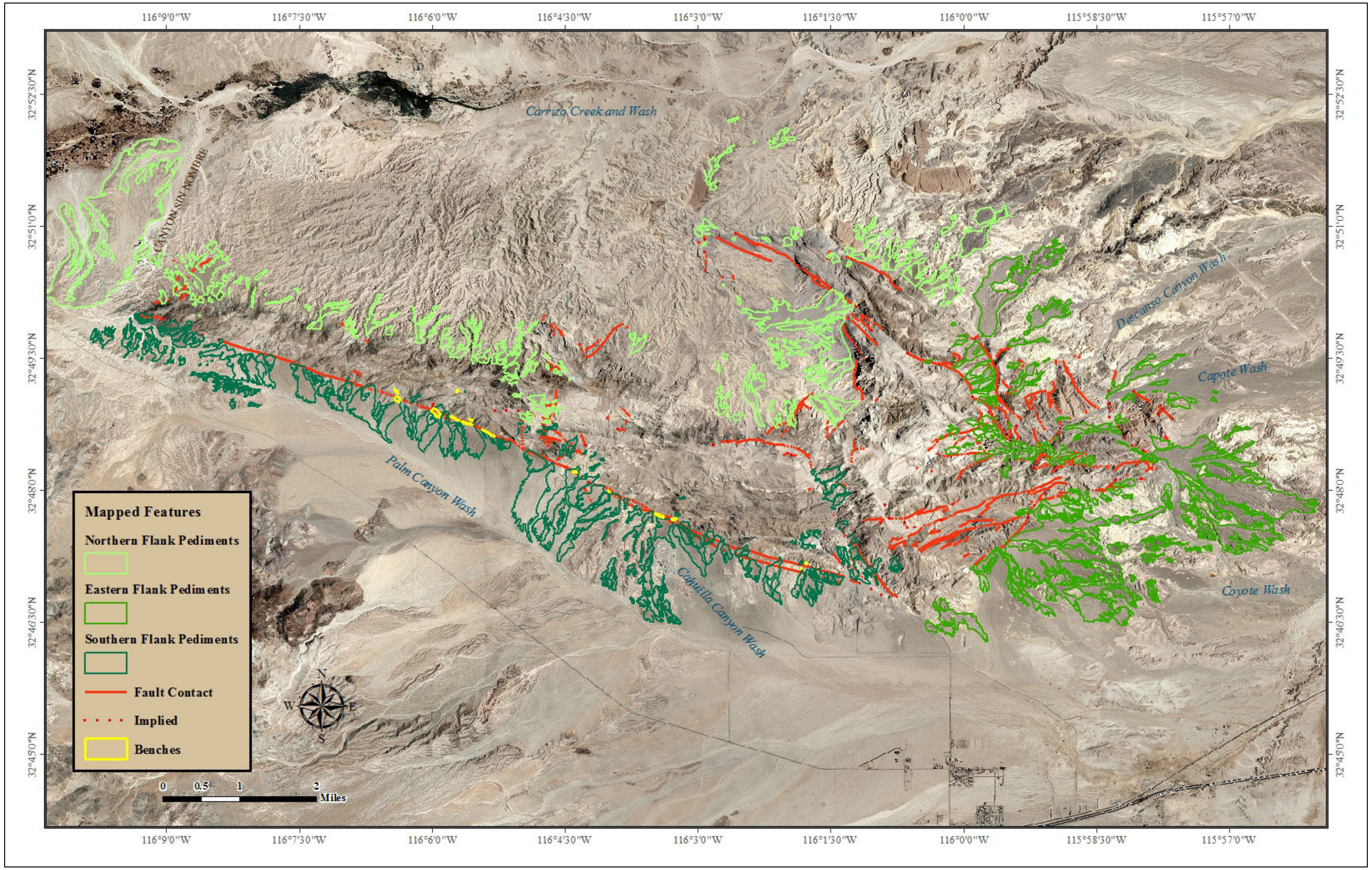


Figure 9. The Coyote Ranges. The Coyote Ranges are centered at 32° 48’ 16.34” North, 116° 02’ 46.74”West, and are approximately 13.5 miles long and 5 miles wide. The Ranges’ are littered throughout with minor faults, and bounded on the southern flank by the southern portion of the Elsinore Fault. For this study, the Ranges’ are divided into southern, eastern, and northern flanks. Different shades of green represent the three cardinal directional pediments. Fault contacts are represented in red. Structural benches are found to be along the Elsinore Fault’s line and are represented in yellow.

- Group 3 and 4 (not listed) was originally established for classifying pediments into a particular scheme based upon their external appearance. I decided that such categorizing was subject to inconsistent interpretation and not of practical value for this research, so the two groups were eliminated.
- Group 5- pediments located near faults was composed for pediments that are located near fault traces.
- Group 6- pediments located near streams was constructed for pediments that are located near streams, rivers, and washes.
- Group 7 – peripediments was created for pediments that are not geographically located near faults or stream like features.

On each of the directional maps the pediment group number is highlighted as either: 1, 2, 5, 6, or 7. The locations of the mapped pediments encompassed the Ranges, occupied open and closed basins, developed within stream channels, rivers, and washes and appeared in canyons.

In my paper reference to a particular pediment may be made in accordance to its group number, the cardinal direction of the Ranges, or a geographic location (See table 2). To render a clear explanation of pediments or other geomorphic features some illustrations includes maps, geological interpretation, and analyses of surface coverage, photography, slope profiles, and a description of unusual pediment appearance or location. Some structural and fault traces were mapped by me, but the majority were mapped by Dr. Bykerk-Kauffman, Amy Gentry, and Cavan Ewing (both graduate students from California State University, Chico). Any error upon the placement of structural or fault accuracy is due to my lack of understanding, not of the data providers.

CHAPTER IV

FIELD SITE INVESTIGATION

Geomorphic Features of the Southern Flank

The Coyote Ranges' southern flank, as defined in this study, extends west from 32° 49' 59.17" North, 116° 09' 21.55" West, to the east 32° 46' 35.03" North, 116° 00' 28.95"West (see Figure 9). For identification purposes, the southern flank pediments are color coded dark green on all figures (see Figures 9, 10, and 11). The majority of southern flank pediments are concave upwards, having higher slopes in the head, intermediate slopes in the body and a lower slope at the toes. Some pediments in plan view have a rectilinear shape and are possibly remnants of an extensive pediment that has been heavily dissected. The low slopes (2-11 degrees) of the pediment remnants contrast sharply with the steep canyon walls, cliffs, and talus of the dissected terrain. A majority of pediments that encompass the southern flank are geographically located near faults, streams or washes, or are peripediments (no association) and grouped according to their close proximity to the associated features (see Table 2, Figures 10 and 11).

The geology of the southern flank's mountain front consists of metaplutonic and metasedimentary basement rock, consisting of interlayers of schist, gneiss, marble, dolomite, and veins of pegmatite (see Figure 4). The active right lateral strike-slip Elsinore Fault trends southwest and runs the full length of the Coyote Ranges' southern flank. Some minor faults, still under study, are found to trend east and north (see Figure

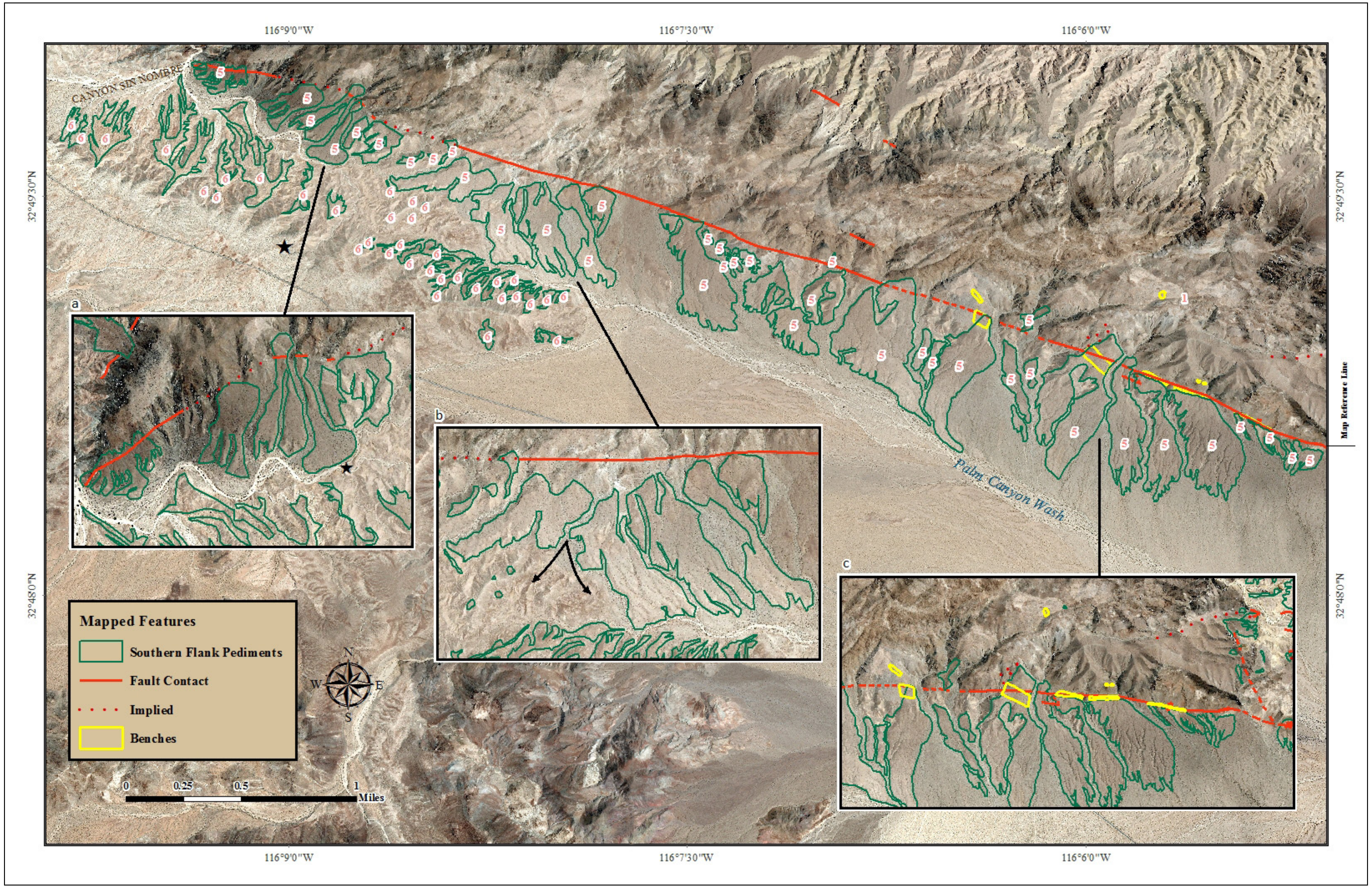


Figure 10. Southern flank pediments map. The south west end of the Ranges highlights the distribution of pediments, the association of pediments to the Elsinore Fault, the southern drainage system, and the location of structural benches. The pediment group numbers 5 and 6 are highlighted in pink.

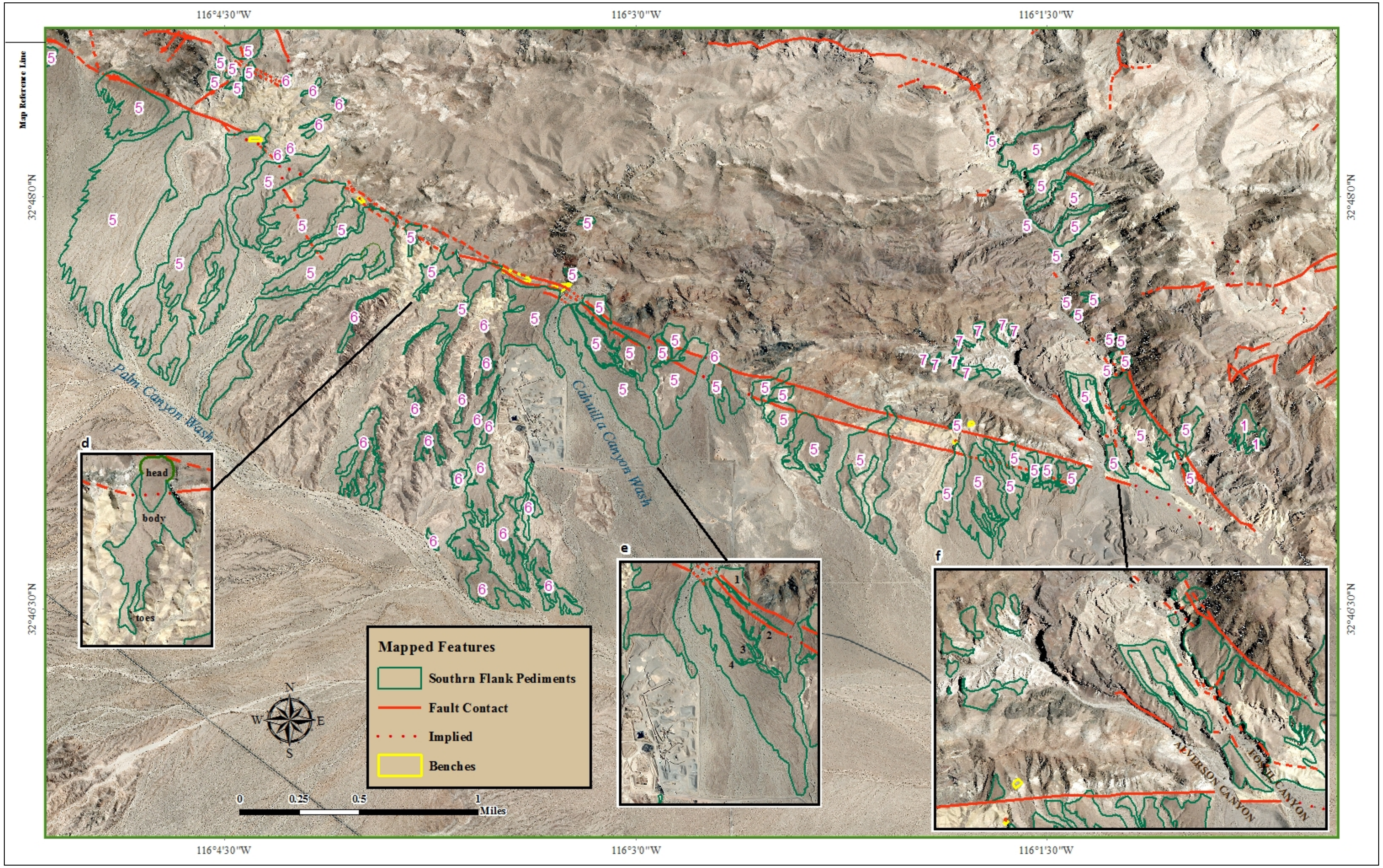


Figure 11. Southern flank pediments map. The south east end of the Ranges highlights the distribution of pediments in groups 1, 5, 6, and 7, the dissection of pediment remnants , formational and/or modifying agents such as faults, washes, modern day quarrying and construction. The pediment group numbers are highlighted in pink.

9). Most of the southern flank's drainage system flows into the Palm Canyon Wash, which runs southeast. The rest drains into the Canyon Sin Nombre Wash, which runs northwest (see Figure 9). It is possible that both the southern flank faults and drainage system have been formational and/or modifying agents of the southern flank's pediments.

In this study any pediments disturbed by local quarrying or construction are omitted. The following discussion examines the circumstances of specific pediments in the southern flank by providing descriptions and some suggestive interpretations.

Distribution

The distribution of pediments begins from the southwest (as defined in this study) end of the Ranges, extending from the base of the mountain front and from a planar landform across Palm Canyon Wash. The pediments adjoining the Range are bound at the head by the Elsinore Fault line and at the toes by the Palm Canyon Wash (see Figure 10, 11, and 12). The pediments bordering the mesa landform are bound at the head by the planar surface and at the toes by the Palm Canyon Wash (32° 49' 30.00" North, 116° 09' 02.69" West) (see Figure 10 black star, and Figure 13). The pediments bordering the mesa landform slope north towards the Coyote Ranges, and mirror the trending direction as the pediments extending from the mountain's base. Several of the southern mesa pediment surfaces have a sparse protective coverage of desert varnished gravels, which overlie an older strata of Pliocene-Pleistocene non-marine Palm Springs Group.

Within group 5 pediments extending from the Ranges' southern flank, is one pediment that exhibits a fan-shaped form at the end of its toes (32° 49'39.74" North, 116° 08'53.34" West) (see Figure 10 inset a-black star). It is possibly a combination of a

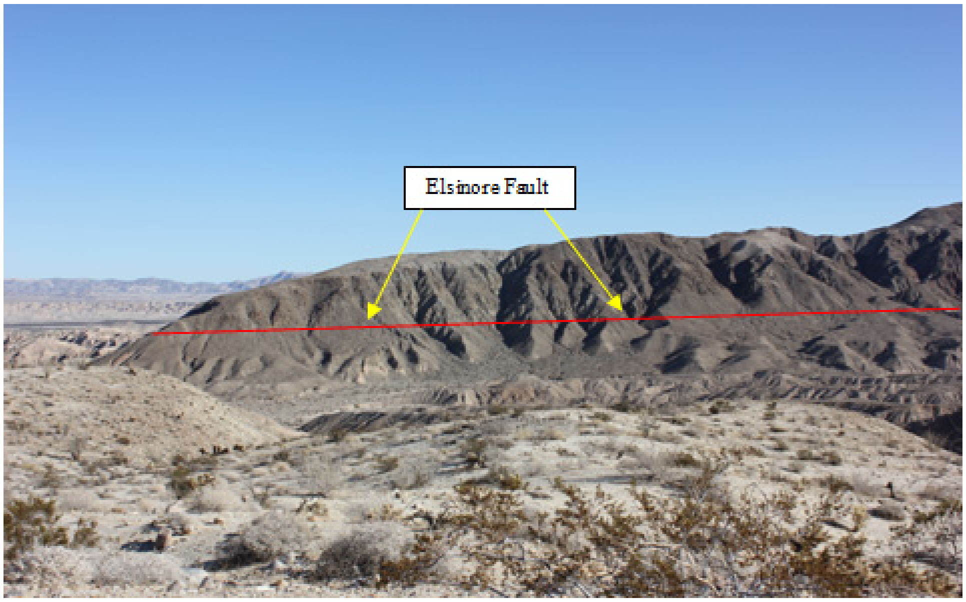


Figure 12. Southern flank pediments. The Elsinore Fault goes across the southern flank, and may be a pediment formational and/or modifying agent. Traces of the fault can be seen on the mountain front, pediments, and lithology.

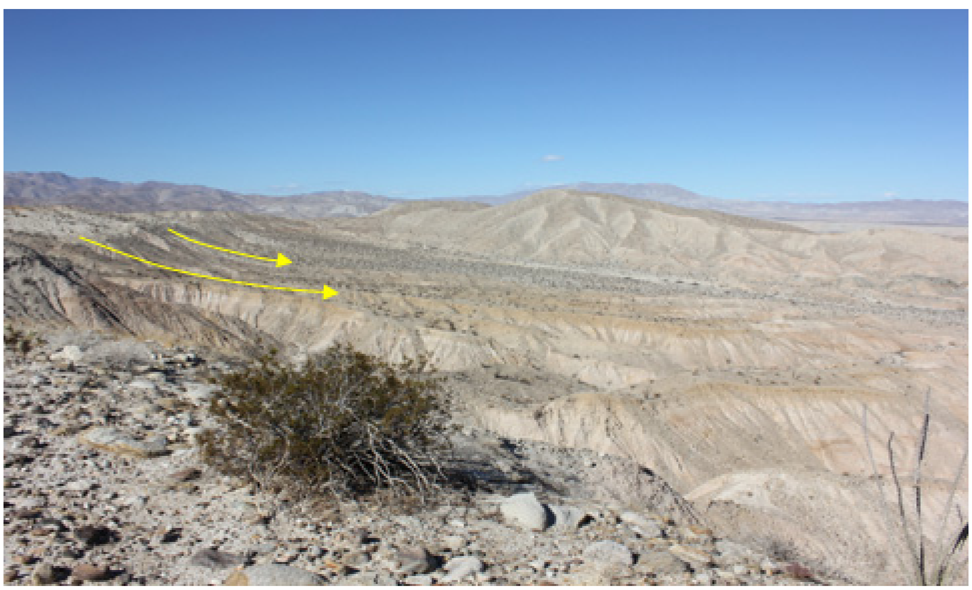


Figure 13. Stranded pediments. The mesa like pediment's have a planar head upon which the North Imperial highway (S2) road crosses. The pediments slope northward towards the southern flank of the Coyote Ranges, and measure over 11,000 feet in length

pediment and an alluvial fan, similar to Bourne and Twidale's observation in Flinders Ranges, South Australia. They claim that one of the three types of alluvial fans, a depositional feature and fluvial in origin, developed in some of the pediments toes (1998, 129). Adjacent to the fan-shaped pediment are pediments that display the various types of pediment coverage and older underling strata (see glossary-pediment sections). For example, some pediments coverage is made primarily of basement debris, and consist of migmatite, schist, and gneiss, which gives the pediments a dark appearance (32° 49' 48.43" North, 116° 08' 38.54" West). Whereas some adjacent pediments coverage includes basement debris consisting of dolomitic marble, biotite, schist, and metaquartzite, which gives pediments a lighter color appearance (see Figure 10 inset a) (Todd 2004, 7-8). Other types of southern flank pediment coverage include: (1) a sparse covering of well-sorted gravel with desert varnished, sub-angular, granitic, schist, and quartz cobbles within a sand and silt matrix overlaying a C-Type clastic older strata, and (2) well-sorted gravel with marble clasts and reworked fossilized Imperial Group marine shells, overlying a C-Type clastic older strata. Some of the pediments' coverage is dissected and the underlying strata is exposed. For example, one group 5 pediment has a coverage of mixed boulders, cobbles, and gravel overlying a C-Type clastic strata with layers of exposed tilted cemented coquina (32° 47' 38.23" North, 116 ° 03' 36.98" West) (see Figure 14). Another group 5 pediment lies beside a wash with a coverage consisting of a stratigraphic sequence that repeats approximately every seven feet. This coverage is a mix of gravel boulders, cobbles, reworked marine shells, sub-angular rocks including granite and marble clast. All of which grade down to well-sorted pebbles within a C-Type

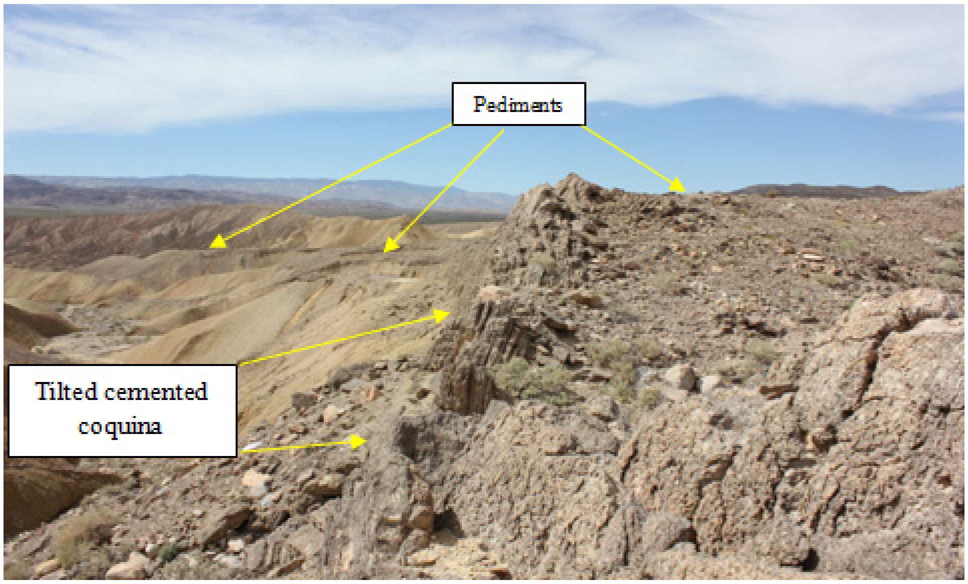


Figure 14. Pediments with coquina layers. The tilted cemented coquina layers in this southern pediment created a wall that protected the pediment gravels from erosion. The exposed coquina layer measures approximately 318 feet in length

clastic matrix (32° 49' 03.47" North, 116 ° 06' 39.12" West). Some of the pediments show evidence of modification possibly by southern drainages, faults, and washes.

The southern flank pediments reflect the course of the Canyon Sin Nombre and Palm Canyon Wash drainage (32° 49' 29.13" North, 116° 08' 19.48" West). For approximately one and a quarter miles east of Canyon Sin Nombre, pediments extending from the base of the Range trend southwest. Thereafter, pediments follow the Palm Canyon Wash drainage pattern and trend southeast (see Figure 10 inset b). Traces of the Elsinore Fault and numerous other fault paths are visible along the Coyote Range's southern flank. These faults may have produced several structural benches, and been influential in pediment formations and/or modifications (see Appendix A - glossary-structural benches).

Several structural benches were mapped along the mountain front parallel to the path of the Elsinore Fault, and lay near the heads of some pediments (see Figure 10 inset c, and 11). A few of the structural benches were devoid of any surface regolith, but had a ridge of regolith on the adjacent Ranges' slope. Other structural benches had surfaces of mixed gravel with granite cobbles ranging up to two inches in diameter (32° 48' 51.15" North, 116 ° 05' 49.97" West) (see Figure 15).

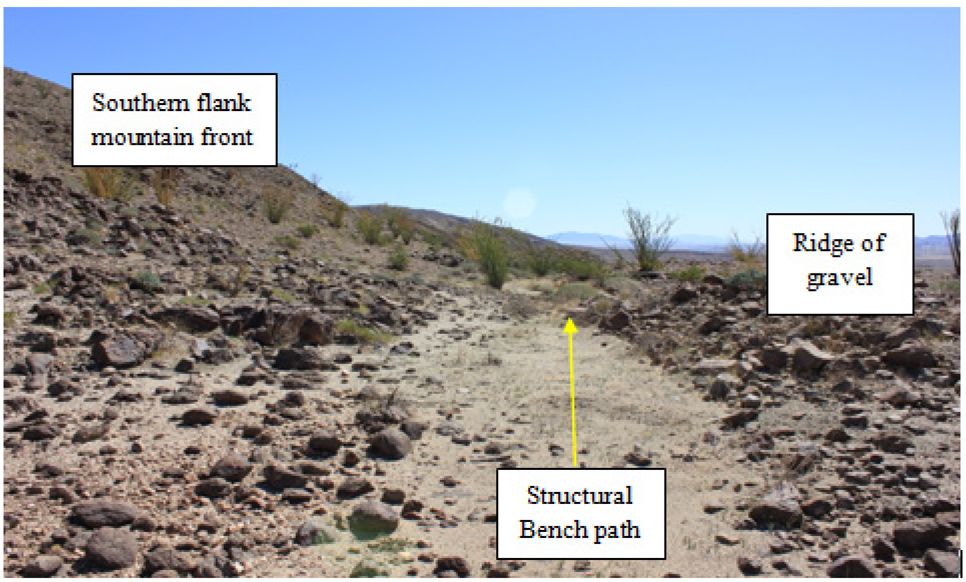


Figure 15. Structural bench. Looking east along the southern Elsinore Fault, some of the structural benches were devoid of gravel, but had a ridge of gravel on the Ranges' declining side.

A great number of the southern flank pediments may be affected by the paths of some faults. For example, one group 5 pediment does not exhibit the Ranges' common pediment concave form, but instead appears to have a higher elevated level relative to some adjacent pediments. The pediment's elevated head extends as a hill into the middle of the pediment body (see Appendix A - pediment sections). The edges of the body surround the head's sides and forefront without any separation between the body and the head portions. (32° 47' 47.55" North, 116° 03' 40.96" West) (see Figures 11 inset d, 16 and 17). Both the elevated head and the body have the same regolith coverage that includes boulders, and angular cobbles of granite, marble, and quartz clasts within a silt matrix. Approximately thirty percent of the regolith coverage displays a film of desert varnish that overlie a C-Type clastic strata. Tuan observed a similar feature in Arizona's lower San Pedro Valley, and claimed that fault contacts influenced a piedmont, cut in the Gila conglomerate, to rise as a row of knolls above the lower edge of a granite pediment (1962, 62). Mammerickx also reported faulting caused a pediment slope to be warped and uplifted in her Valyermo, California pediment research (1964, 430).

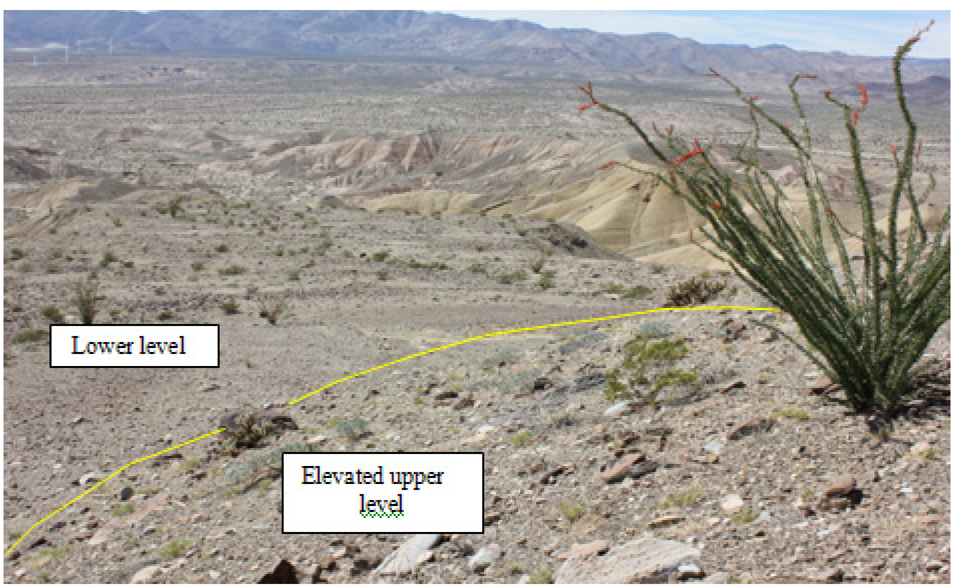


Figure 16. Warped pediment (1). The southern Elsinore fault crosses the pediment's head and possibly caused the pediment slope to be warped and uplifted without any separation between the two levels.

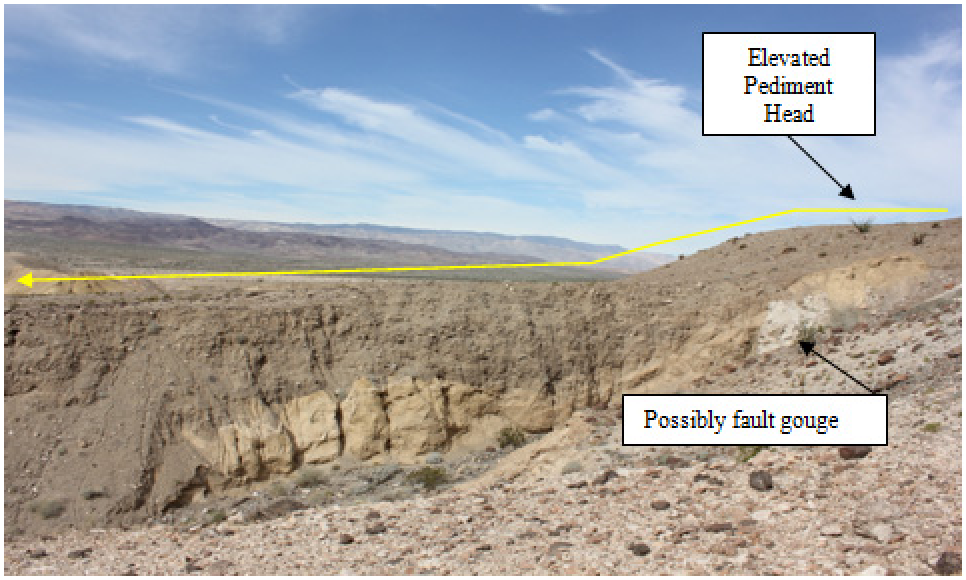


Figure 17. Warped pediment (2). The warped pediment profile displays an elevated head that might show fault gouge. The pediment has a thicker coverage than the older strata.

Numerous mountain crest drainages and washes descend from the southern flank, and may have been influential in relic and modern pedimentation. For example, at the mouth of the Cahuilla Canyon Wash, pedimentation activity can be seen in a four-tiered landform (32° 47' 36.90" North, 116° 03' 15.67" West) (see Figure 11 inset e). The lowest elevated tier lies along the wash, and the highest tier is closer to the mountain front near the trace of the Elsinore Fault. The Alverson and Fossil Canyons are two other major canyons divided by a pediment draped ridge (see Figure 11 inset f). In the two canyons, the basement is overlaid by both the non-marine Split Mountain Group, and the marine Imperial Group (see Figure 4). Both canyons show evidence of fault and stream activity and are littered with pediments along the cliffs, ridges, and near the canyon's heads. For example at the head of the Alverson Canyon, remnants of a protective regolith coverage preserves the last segments of an eroded pediment (32° 47' 26.19" North, 116°

01' 54.18" West). Beneath the remaining regolith pediment coverage is a Split Mountain Group L-Type clastics older strata (see Figure 18). In Fossil Canyon, a group 5 pediment lies beside a small mountain creek whose dissected flank has revealed an angular unconformity of an older volcanic flow, volcanic clastics, and a younger C-Type mudstone strata (32° 47' 54.34" North, 116° 01' 21.00" West) (see Figure 19).

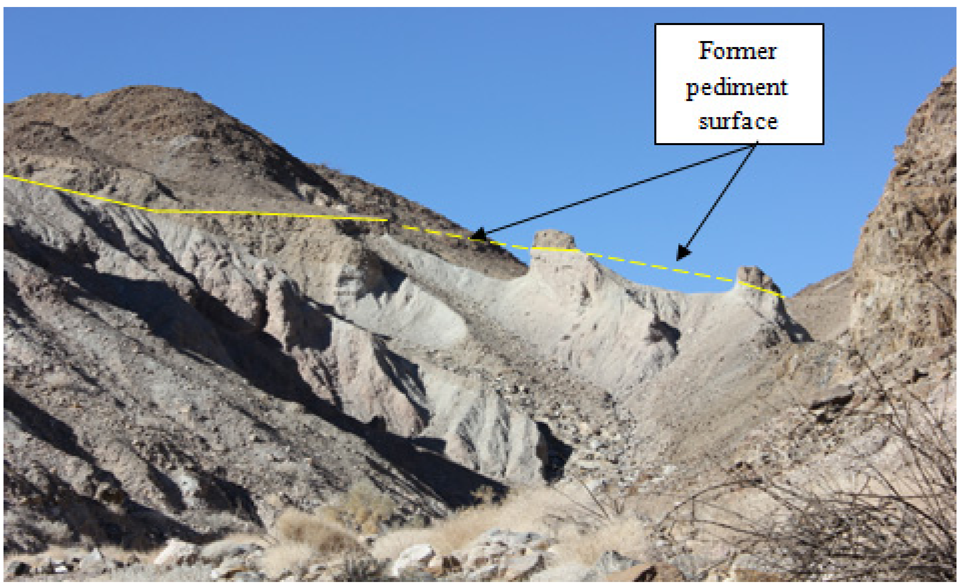


Figure 18. Pediment with dissected covering. Remnants of a pediment surface suggest a pediment once extended across the head of the southern Alverson Canyon. Note the contrast of gentle pediment slope with the steeply dissected terrain.

<u>Profiles</u>

For each pediment an individual profile was produced in 3D Analyst, an ArcMap tool. The pediments' slope attributes were transferred in to 2013 Microsoft Office Excel to determine the degree of inclination and to display the data. The selected pediment profiles are from three classified pediment groups 5, 6, and 7 (see Figure 20-29). Both west and east slope degree maps show the location of all mapped pediments,

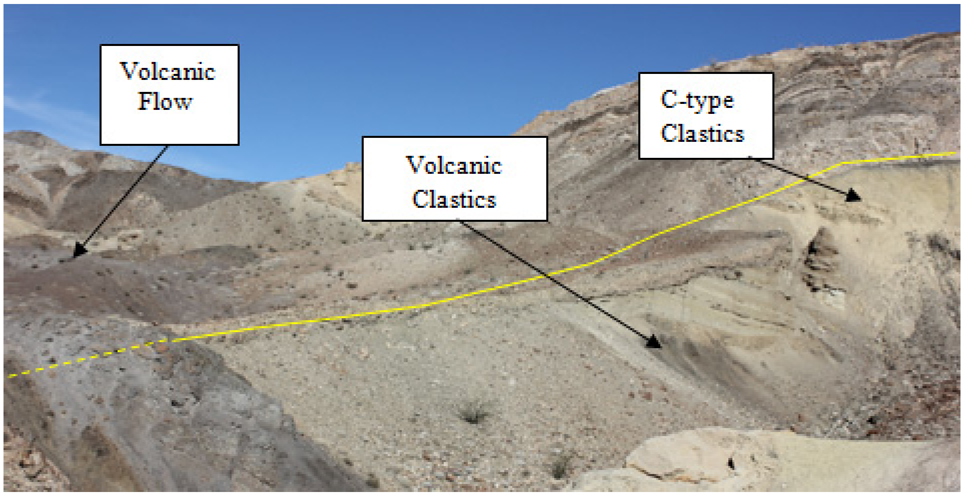


Figure 19. Pediment unconformity. The exposed pediment flank reveals an angular unconformity of dipping volcanic clastic strata and lava flows within a C-Type mudstone strata.

with individual pediment and group numbers that correlate with the selected pediment profiles below (Figures 30 and 31).

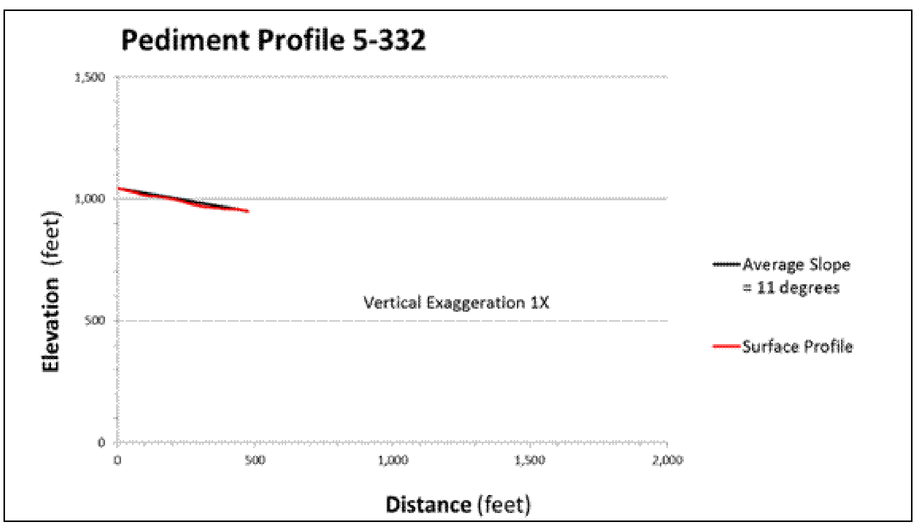


Figure 20. Southern flank pediment profiles (5-332). The profile graphs are examples from the distribution of southern flank pediments. The red surface profile line represents group 5 pediments, the blue line represents group 6, and the green line represents group 7. The vertical exaggeration is set at 1:1 for graphs of 2000 linear feet and 3:1 for graphs of 6000 linear feet.

Figure 21. Southern flank pediment profile (5-149).

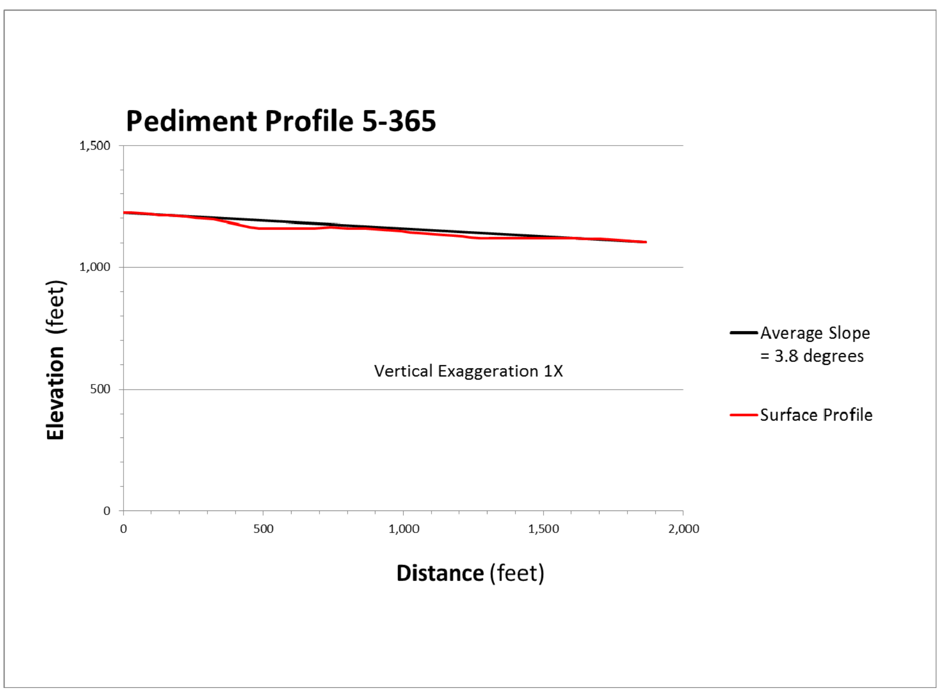


Figure 22. Southern flank pediment profile (5-365).

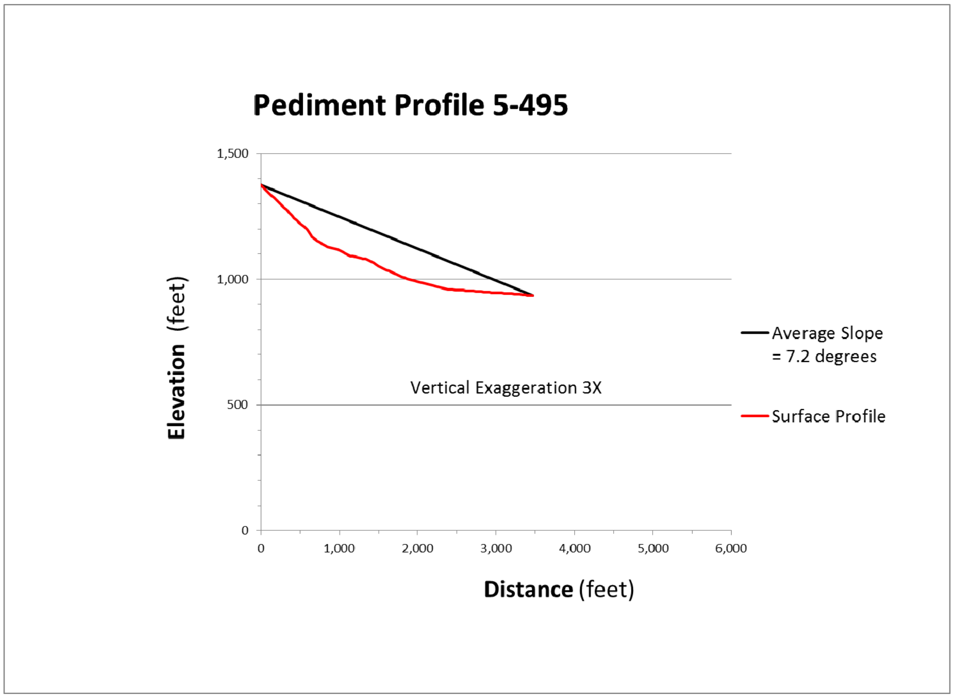


Figure 23. Southern flank pediment profile (5-495).

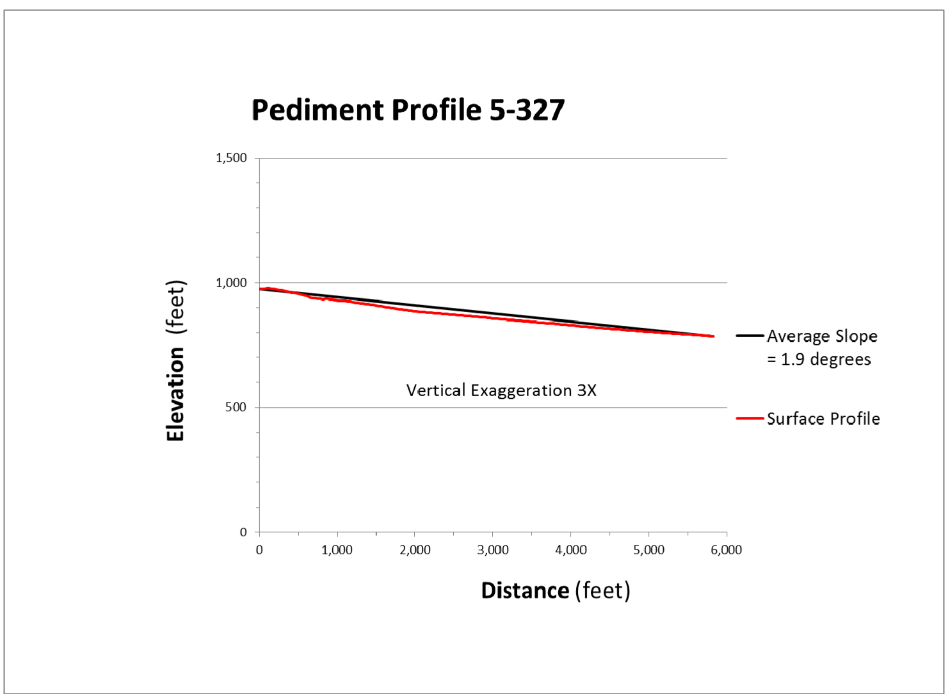


Figure 24. Southern flank pediment profile (5-327).

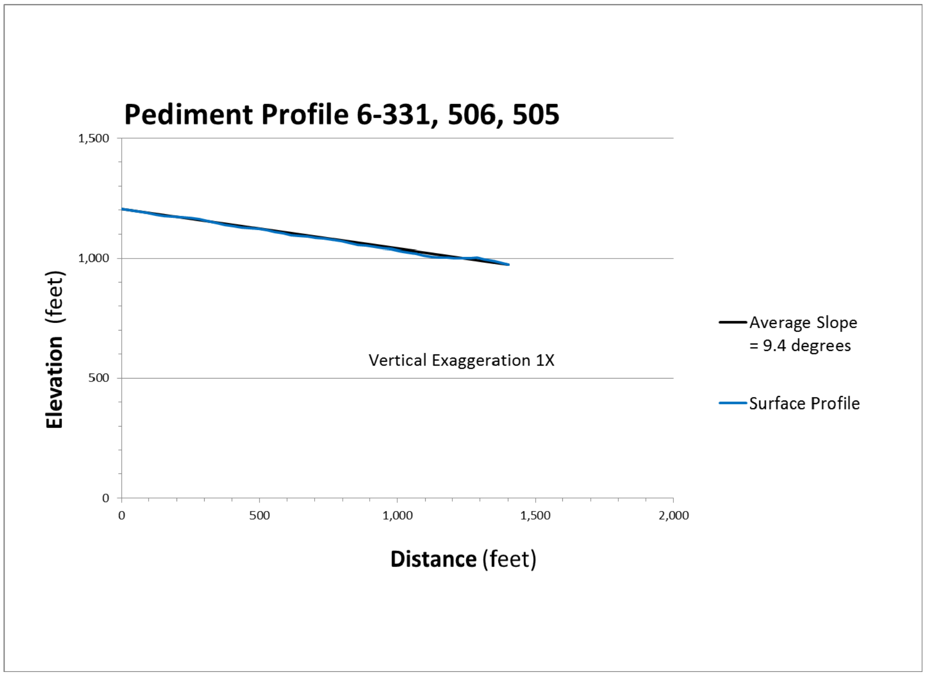


Figure 25. Southern flank pediment profile (6-331, 506, 505).

Figure 26. Southern flank pediment profile (5-510).

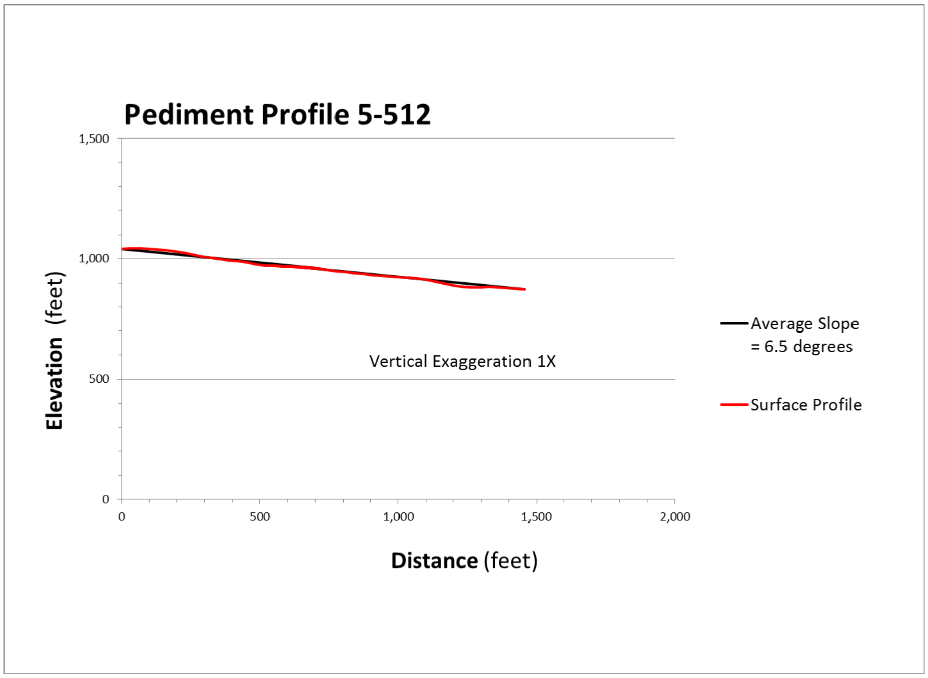


Figure 27. Southern flank pediment profile (5-512).

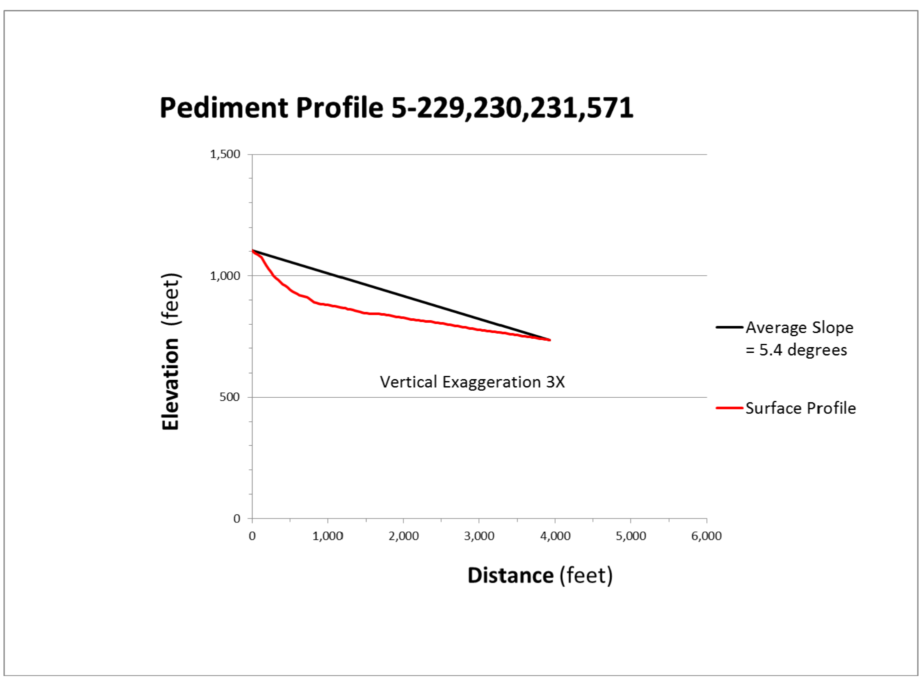


Figure 28. Southern flank pediment profile (5-229, 230, 231, 571).

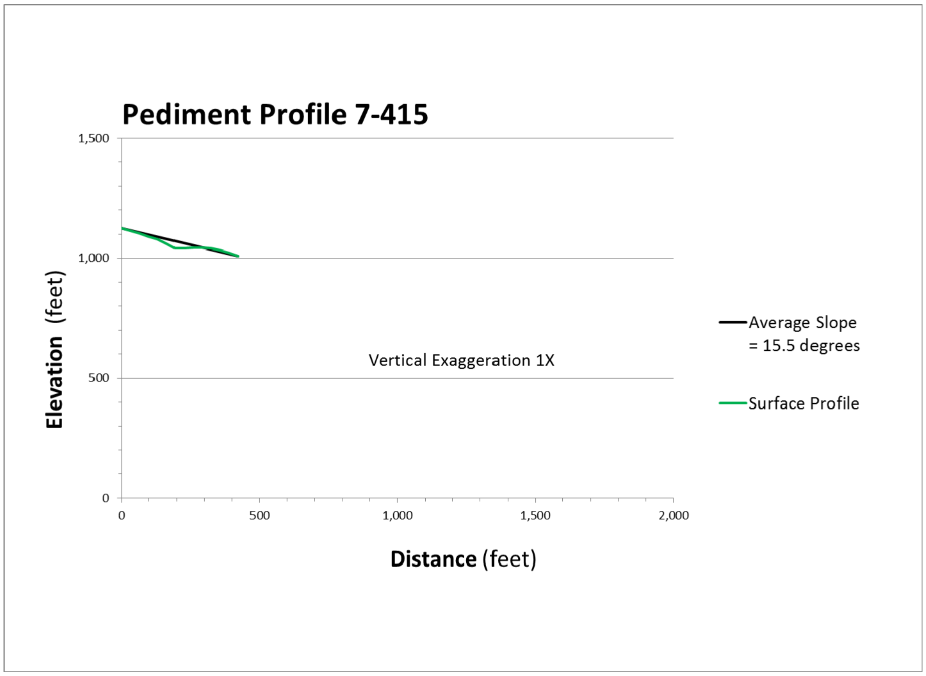


Figure 29. Southern flank pediment profile (7-415).

The selected pediments were chosen to represent the different distribution of categorized pediments (group 5, 6, and 7) from the Coyote Range's southern flank (see Figures 30 and 31):

- Group 5: 5-332 (11), 5-149 (7.2), 5-365 (3.8), 5-495 (7.2), 5-327 (1.9),
- 5-510 (2.4), 5-512 (6.5), 5-229,230,231,571 (5.4)
- Group 6: 6-331, 506, 505 (9.4)
- Group 7: 7-415 (15.5)

The southern flank pediments have low (1-5), medium (5-7), and high (7-15) slopes. The average pediment slope falls in the range of 3-8 degrees. However, the pediment surfaces often lie as remnants in highly dissected terrain. For this reason, the maps of pediments may fall in areas with slopes in excess of 45 degrees, which indicate talus, cliffs, and ridges (see Figures 30 and 31). These slopes dominate the map units;

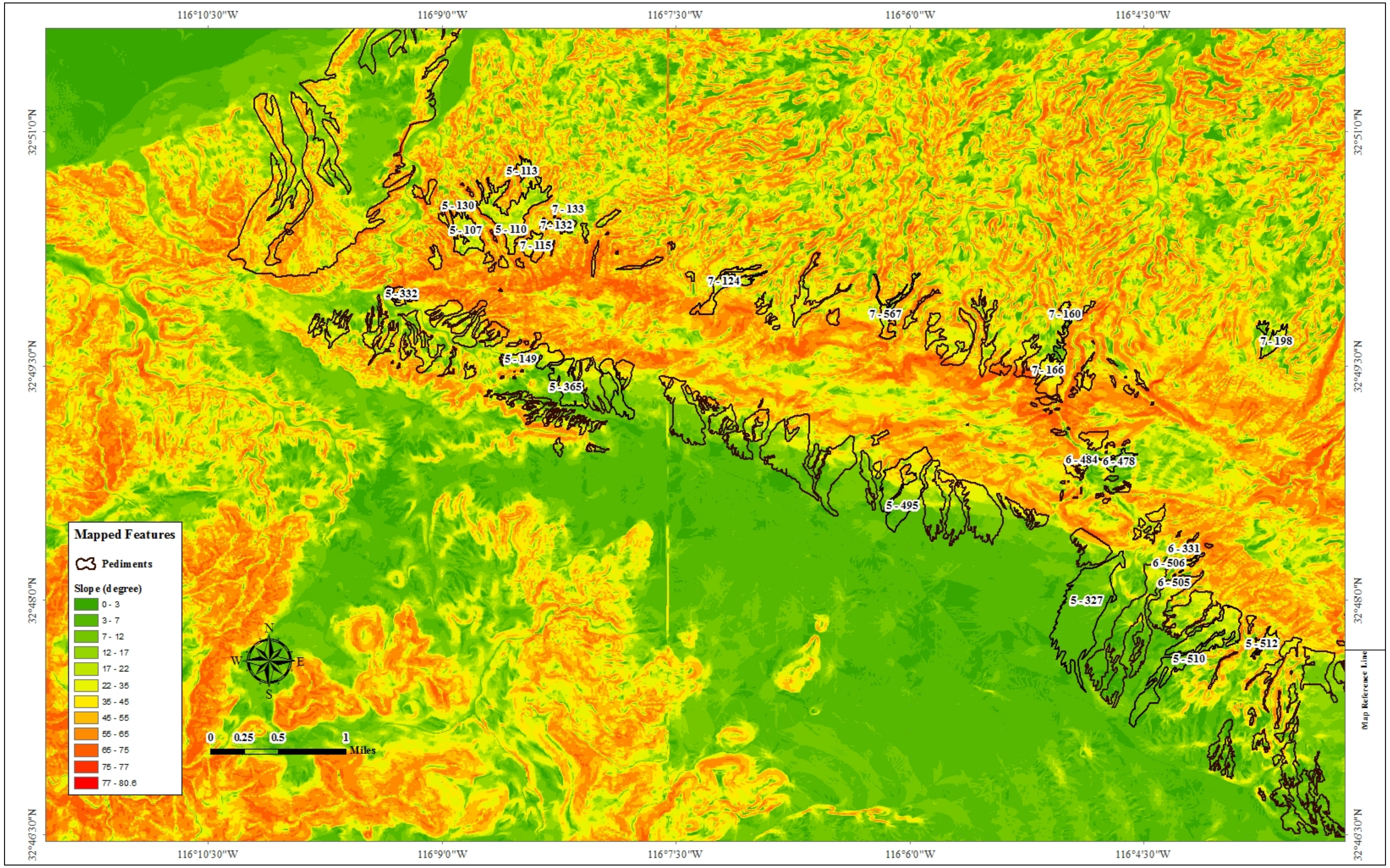


Figure 30. West slope degree map. The west slope degree map displays a portion of the Coyote Ranges' southern and northern pediment locations. The low slopes of pediment remnants contrast sharply with the steep canyon wall, cliffs, and talus of the dissected terrain. The locations of individual numbered pediments, outlined in black, correlates with selected group profiles.

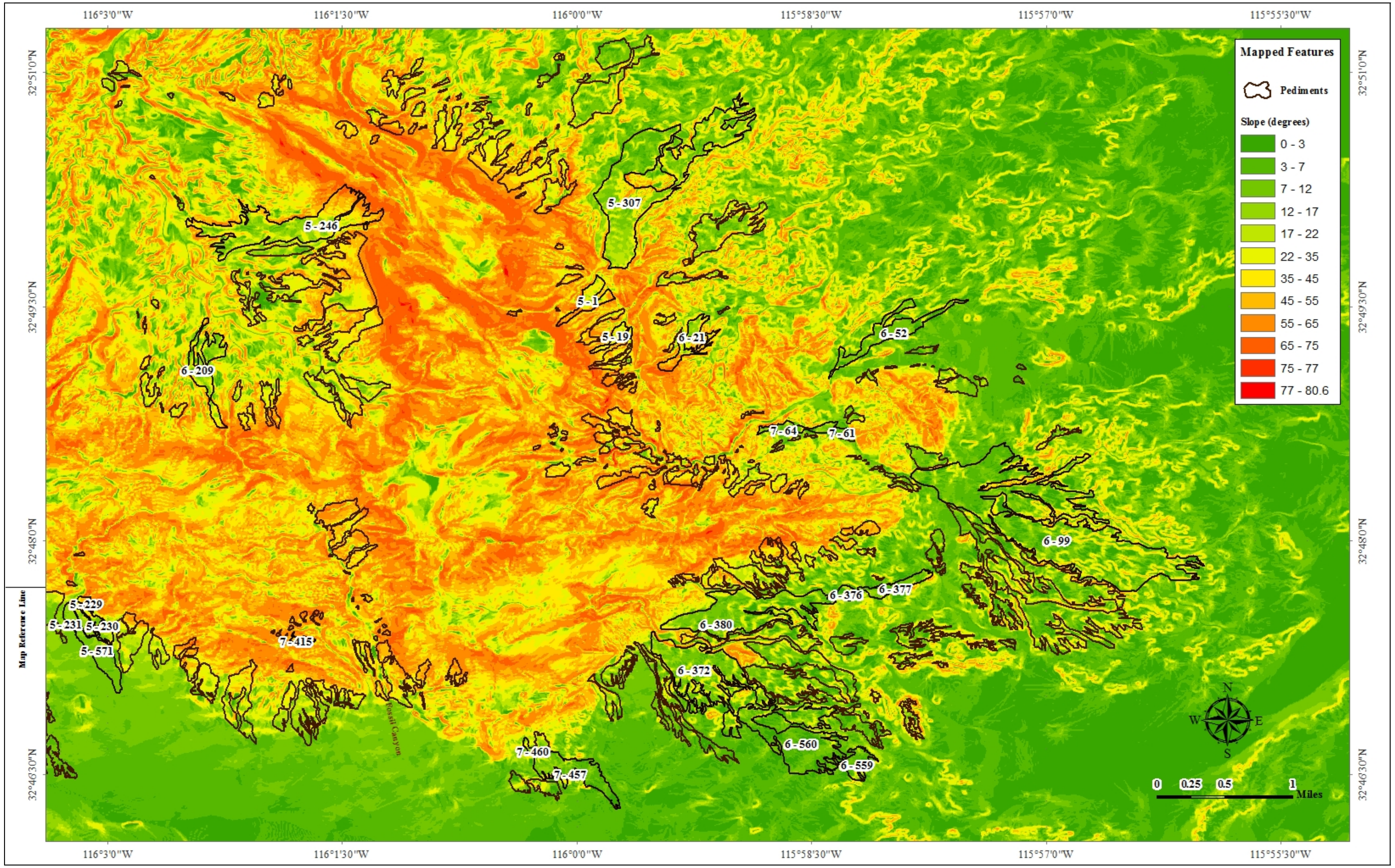


Figure 31. East slope degree map. The east slope degree map displays the remaining distribution of mapped pediments of the Coyote Range. The pediments often lie as remnants in highly dissected terrain, and appear to be in excess of 45 degrees. The high degree slope (over 17 degrees) indicates talus, cliffs, and ridges where pediments may lie. The location of the individual numbered pediments, outlined in black, correlates with the selected group profiles.

however, causal inspection suggest the pediments themselves have a gentler slope despite the apparent slope degree map (see Figure 18). Future research may possibly determine a correlation between the steepness of the pediments and their length. Mammerickx suggested that tectonic tilting, and the different cycles of pedimentation were the best reasons for pediment slope variation and length in her Mojave and Sonoran Desert research (1964, 431).

Summary

In summary, the southern flank contains concave, convex, and rectilinear shape pediments, and are grouped into categorizes 5, 6, and 7 according to the pediments association to the features (see table 2). Evidence of dissection was seen upon pediments' surface, head, flanks, and toes. Prevailing evidence of formational and/or modifying agents includes: faults, mountain tributaries, rills, gullies, washes, lateral planation, modern day quarrying, and construction. The average pediment slope falls in the range of 3-8 degrees.

Geomorphic Features of the Eastern Flank

The Coyote Ranges' eastern flank, as defined in this study, extends east from 32 46' 33.20" North, 116 00' 26.75" West, to the north 32 50' 04.19" North, 116 00' 08.31" West. The eastern pediments, for identification purposes are color coded a medium green on all figures (see Figures 9 and 32). Like the southern flank pediments, the majority of the eastern pediments are concave upwards, having higher slopes in the head, intermediate slopes in the body and lower slopes at the toes. All five categories of pediment groups are mapped on the eastern flank according to their close proximity to the associated group features (see Table 2 and Figure 32).

The geology of the eastern flank mountain front, like the southern flank, consist of basement rock but with increases of volcanic rock. The majority of the eastern flank faults trend east by northeast and north by northwest. The eastern flank's drainage system generally flows east. The low slopes (1-10 degrees) of the pediment remnants contrast sharply with the steep canyon walls, cliffs, and talus of the dissected terrain. Similar to the southern flank, the eastern faults, streams, and washes may possibly be formational and/or modifying agents of the eastern flank pediments. The following discussion examines the circumstances of specific pediments in the Coyote Ranges' eastern flank by providing description and some suggestive interpretation.

Distribution

The distribution of pediments within the eastern flank of the Coyote Ranges are found extending from the base of the mountain front, draping on the tops of some canyon cliffs, paralleling between faults, terracing along river banks, and spanning the length of washes (see Figure 32). The eastern flank is littered with minor faults that have a dominant eastward strike south of the Painted Gorge Wash area. North of Painted Gorge, the faults transition and trend northwest parallel to the Elsinore Fault (see Figure 9 and 32). In one of the eastern canyons, some group 5 pediments are bound at the head and toes by paralleling faults, and appear to be straight and uniform in length (32° 49' 09.00" North, 115° 59' 46.79" West (see Figure 32 inset a). The bound pediments' coverage alternates between both of the Palm Springs' C-Type and L-Type. Beneath the coverage, older strata sediment is from both the Imperial Group's C-Type and L-Type,

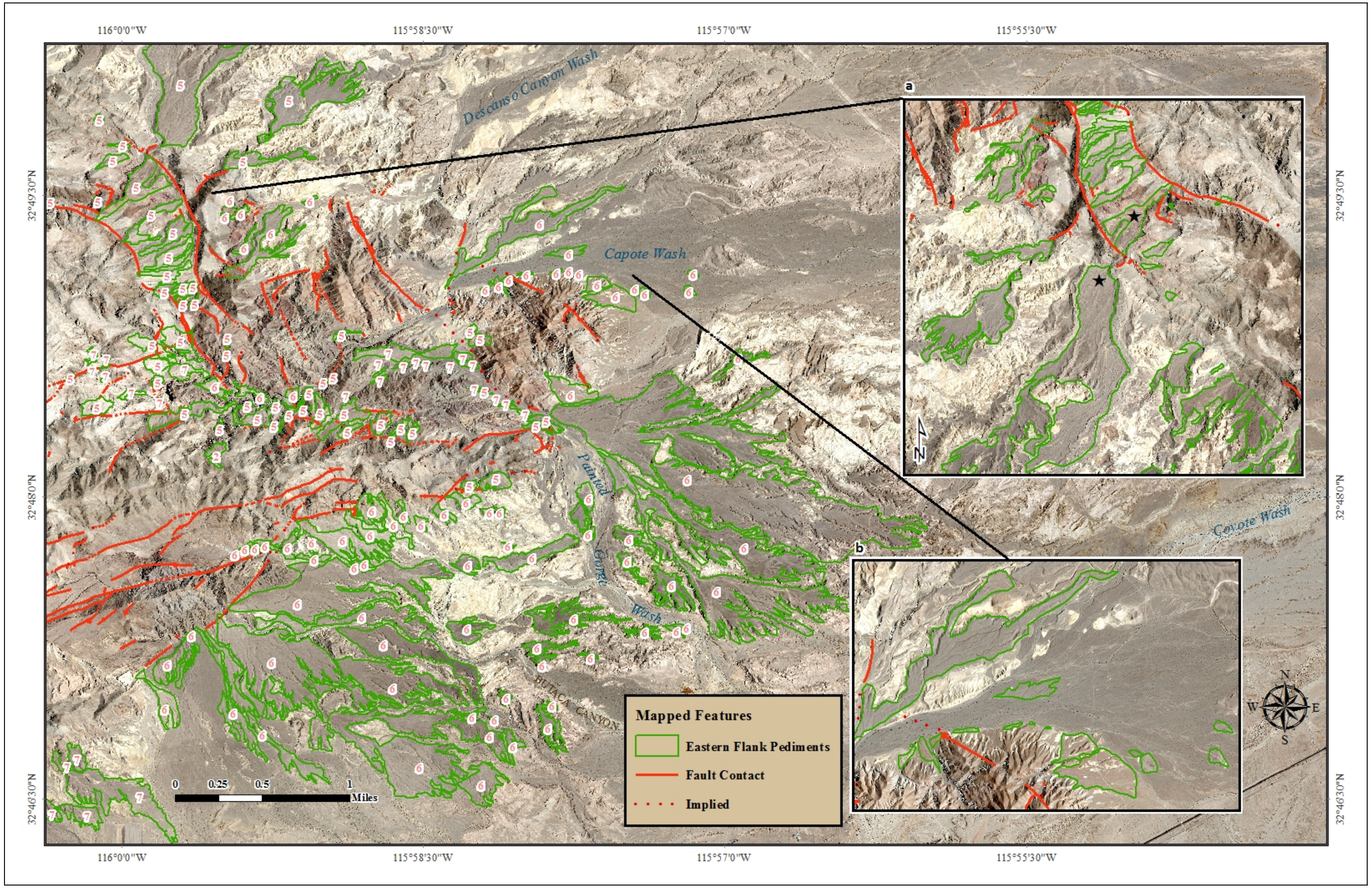


Figure 32. Eastern flank pediments map. The Coyote Ranges' eastern flank highlights the distribution of pediment groups 5, 6, and 7, faults, streams and washes. Both the faults and drainage system trends east and northwest. The pediment group numbers are highlighted in pink.

and the Split Mountain Group's L-Type and volcanic rock (see Figure 4). Tuan remarks how a straight boundary between a pediment and a piedmont was influenced by faulting in the lower San Pedro Valley of Arizona (1962, 62-63). It is possible the eastern flank faults are both formational and modifying agents. For instance, one of the pediments bounded at the head and toes by two paralleling faults appear to have once been part of a larger pediment that is now truncated (see Figure 32 insert a - black stars). Future research may determine earlier fault activity was influential in the larger pediment formation and later modified by younger faults.

In the Painted Gorge area, faulting may be also be a responsible agent in some pediments underlying heterogeneous older strata. For example, a group 6 pediment older strata includes: (1) marble, part of the basement complex, (2) sandstone, part of the Split Mountain Group, and (3) volcanic clastics, also part of the Split Mountain Group - all overlaid by regolith (32° 48' 32.90" North, 115° 59' 24.79" West) (see Figures 4 and 33). Some pedimentation on the eastern flank may have had only one formational and/or modifying agent.

Pediment formational and/or modifying agents may have been multiple or a single operation that functioned concurrently or consecutively. Some of the eastern flank pediments' terrain imply only one formational and/or modifying agent was involved. For example, an exposed group 6 pediment flank reveals an older strata that began in an ancient stream channel. The stream carved a channel into a thick basaltic flow that became filled with alluvium; thus, creating a non-conformity between the igneous and pediment sediment (32° 48' 31.08" North, 115° 59' 21.16" West) (see Figure 34). Another singular pediment formational and/or modifying agent is an eastern wash. The majority

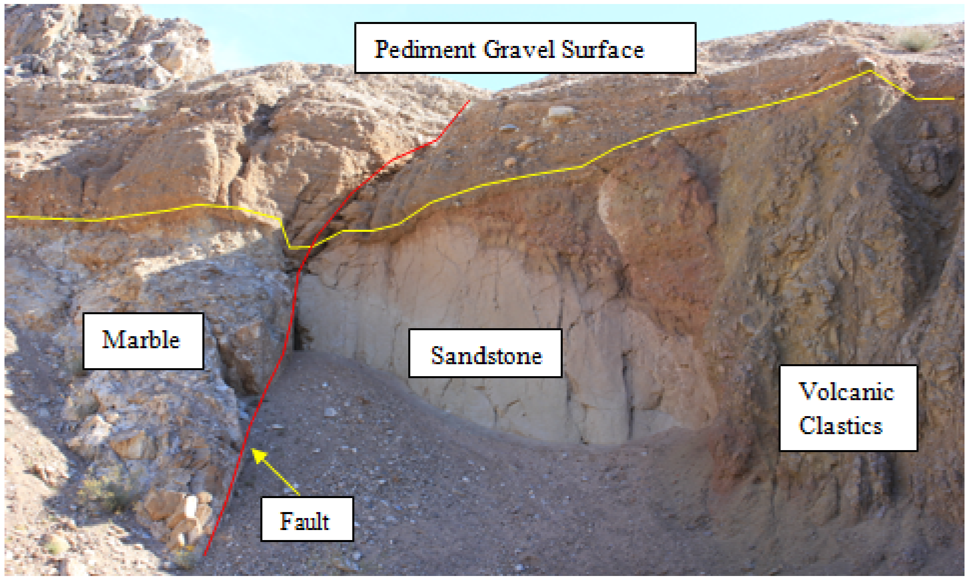


Figure 33. Pediment complicated lithology. An exposed eastern pediment older strata reveals a complicated lithology and fault trace (view photo from left to right).

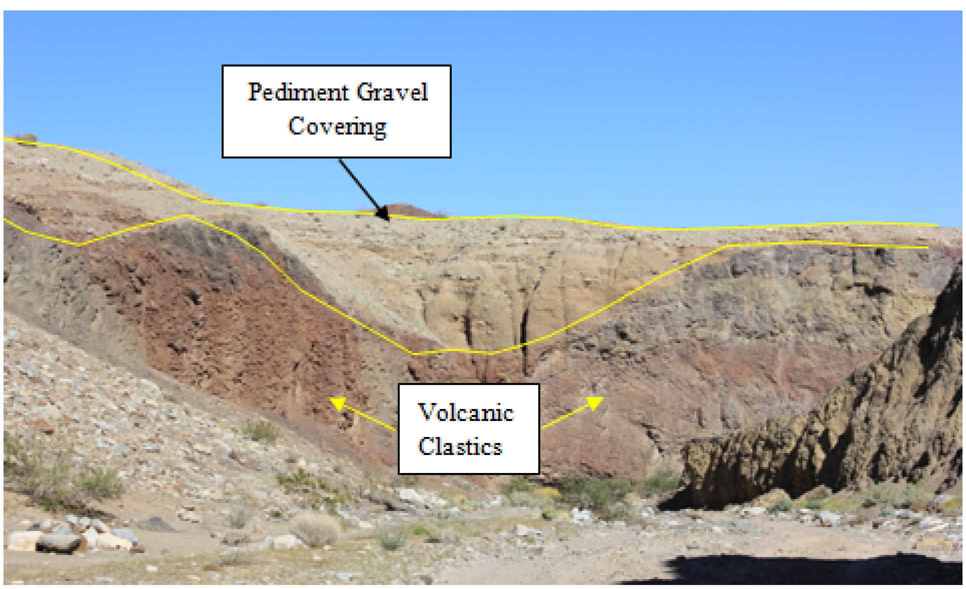


Figure 34. Non-conformity pediment. Located along a stream on the eastern flank, an exposed pediment strata reveals a non-conformably volcanic strata overlain by pediment gravels.

of washes (1) Palm Canyon Wash, (2) Butaca Canyon, (3) Coyote Wash, (4) Capote Wash, and (5) the Descanso Canyon Wash all drain eastwardly (see Figures 9 and 32).

Similar to the southern Palm Canyon Wash, which acts like a barrier for any long extending pediments, an eastern flank wash may have been a pediment modifier agent by segmentation. For instance within the Capote Wash, remnants of a pediment line the wash's southern bank and appear to have once been a part of a larger pediment that lies on the north bank of the wash (32° 49' 03.5076" North, 115° 58' 10.5739" West) (see Figure 32 inset b). Additionally, in the middle of Capote Wash lie fragments of a pediment and a few scattered knolls. On the south bank of the wash, one of the pediment remnants stands approximately 475 feet above sea level. One pediments laying within the wash stands at approximately 424 feet above sea level. The potential parent pediment on the north bank stands approximately 500 feet above sea level (see Figure 35). The all three pediment segments have the same coverage from the marine Imperial Group, and C-Type clastics older strata from the non-marine Palm Springs Group (see Figure 4). Tributaries to the eastern washes, the eastern flank rivers follow defined courses and are agents of pedimentation.

Butaca Canyon, a major shifting intermittent river extending southeast and a tributary to Coyote Wash, is another pediment formational and/or modification agent that exhibits a pediment with various levels (32 47' 40.10" North, 115 58' 58.18" West) (see Figure 36). Categorized as pediments located near streams (group 7), the multiple level pediment coverage consist of alluvial deposits overlying a C-Type mud and sand older strata. It is possible the tri-leveled pediment is the result of historical climatic conditions that contributed to increased stream activities and alluviation (Tuan 1962, 63-64).

Figure 35. Pediment remnant. This is one of several pediment remnants that may have once been a part of the parent pediment across the eastern Capote Wash. Its C-Type clastic older strata and gravel coverage matches the parent pediment. Dr. Bykerk-Kauffman stands up for scale.

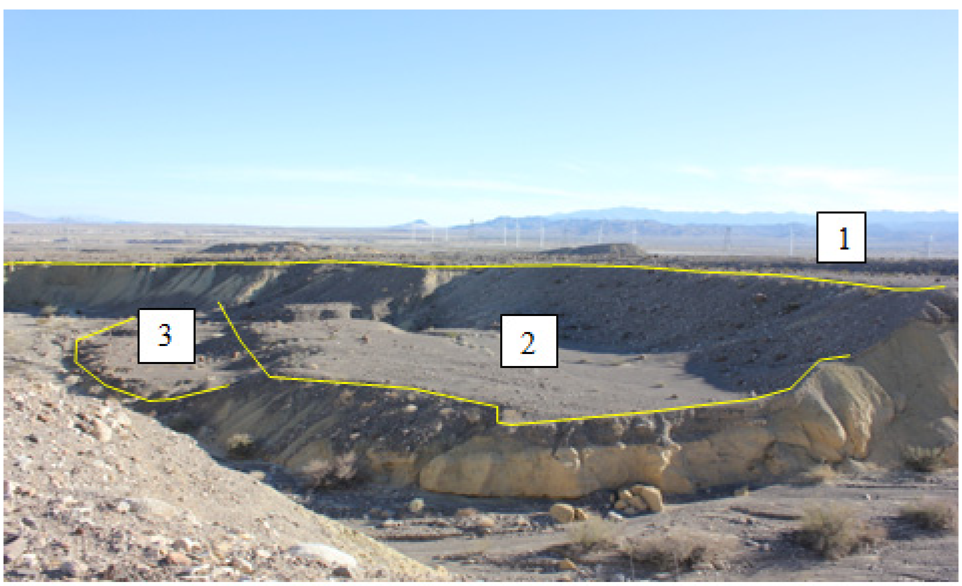


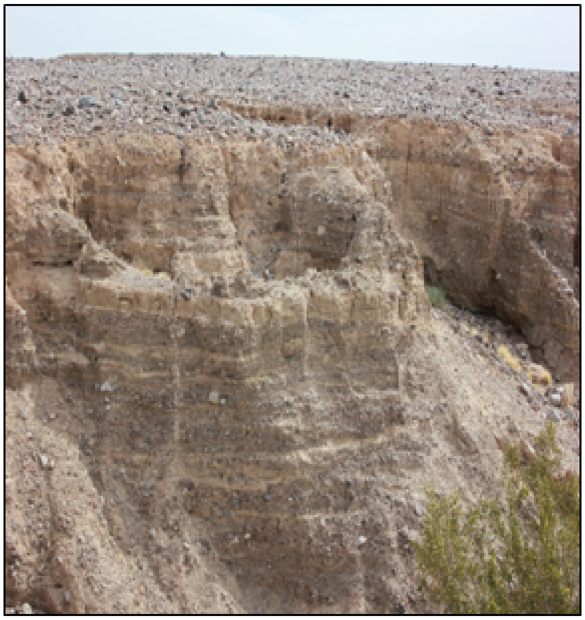
Figure 36. Multiple pediments. These tri-level pediments are located near an eastern stream, which may have been a formation and/or modification agent as a result of historical climatic conditions.

The eastern flank tributaries form intricate networks of branching creeks and channels located between more erosion-resistant landform islands, and appear to be a compelling force in dissection and pediment modification (see Figure 37). For instance, Butaca Canyon shows evidence of lateral erosion that has exposed numerous pediment

Figure 37. Eastern flank pediments. The eastern pediments formational and/or modifying agents include several washes, numerous channels, and a network of branching creeks. Eastern view shows Mexico's Mount Signal in the distance.

flanks older strata to be C-Type marine mudstone from the Imperial Group or C-Type non-marine fine sandstone from the Palm Springs Group (see Figure 4). Some of these pediments have a thick older strata of graded alluvial gravels. For example, one group 6 pediment has a repetitive strata sequence of seventeen layers from the pediment surface to the base level (32° 46' 52.51" North, 115° 57' 3.57" West) (see Figure 38).

Eleven of the seventeen pediment strata are recorded as:



20 inches of sand and coarse gravel

20 inches of sand and small pebbles

9 inches of sand and coarse gravel

3 inches of sand and small pebbles

4 inches of sand and coarse gravel

3 inches of sand and small pebbles

20 inches of sand and coarse gravel

3 inches of sand and small pebbles

9 inches of sand and coarse gravel

2 inches of sand and small pebbles

22 inches of sand and coarse gravel.

Figure 38. Pediment repetitive strata sequence. The pediment repetitive strata sequence could imply pediment formation was a gradual perpetual event. The thickness of each stratum could suggest cycles of historical climatic conditions.

Profiles

For each pediment an individual profile was produced in 3D Analyst, an ArcMap tool. The pediments' slope attributes were transferred in to 2013 Microsoft Office Excel to determine the degree of inclination and to display the data. Both west and east slope degree maps show the location of all mapped pediments. On the maps, the pediment group and individual pediment number correlates with the selected pediment profiles below (Figures 30 and 31). Below are selected pediment profiles from the eastern flank's three classified pediment groups 5, 6, and 7 (see Figures 31 and 39-47).

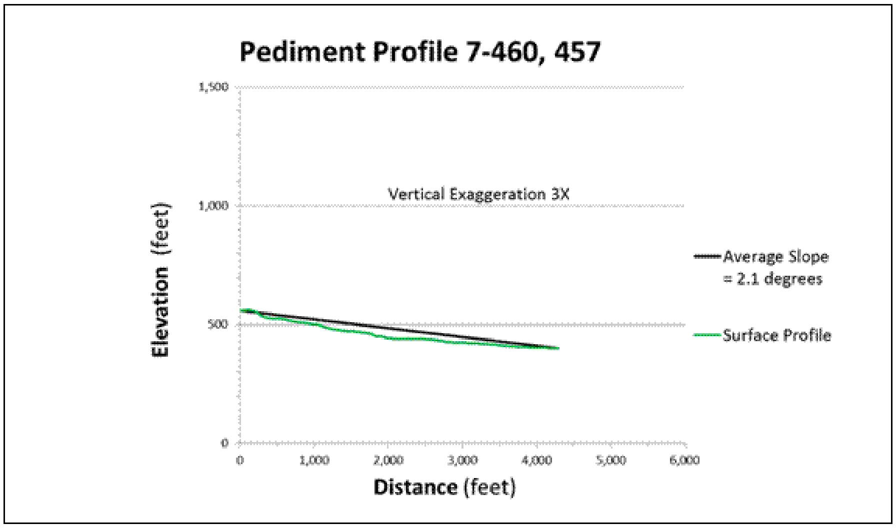


Figure 39. Eastern flank pediment profiles (7-460, 457). The profile graphs are examples from the distribution of eastern flank pediments. The red surface profile line represents group 5 pediments, the blue line represents group 6, and the green line represents group 7. The vertical exaggeration is set at 1:1 for graphs of 2000 linear feet, 3:1 for graphs of 6000 linear feet, and 5:1 for graphs of 12,000 linear feet.

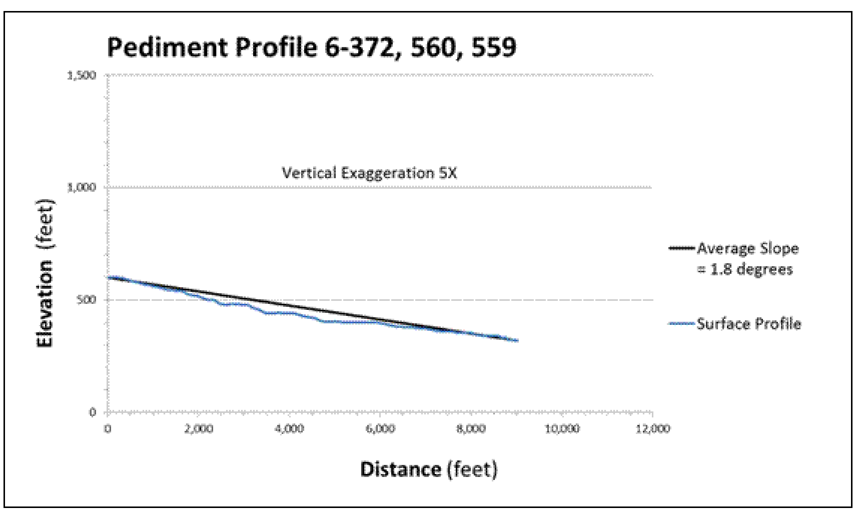


Figure 40. Eastern flank pediment profile 6-372, 560, 559.

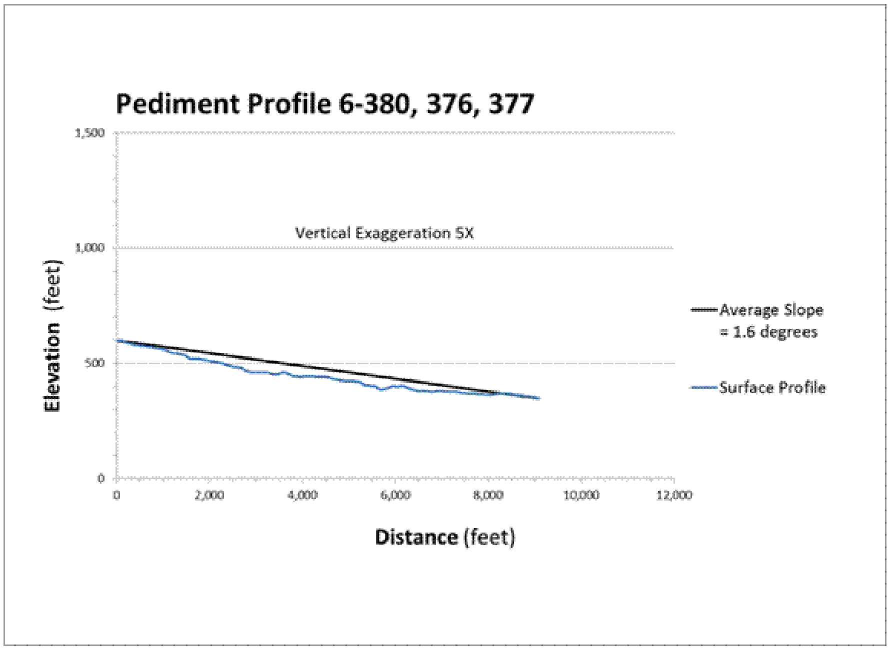


Figure 41. Eastern flank pediment profile (6-380, 376, 377).

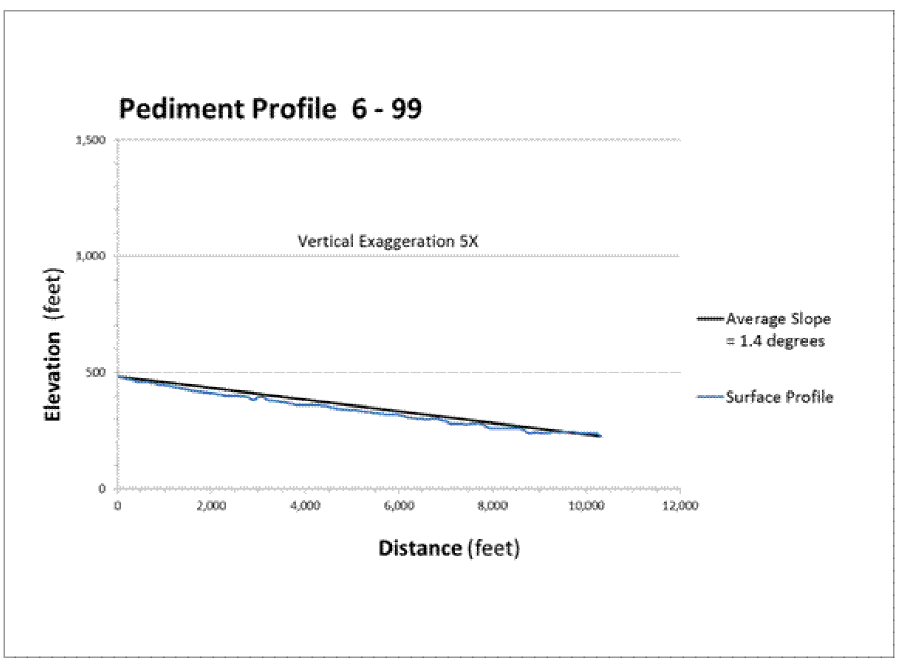


Figure 42. Eastern flank pediment profile (6-99).

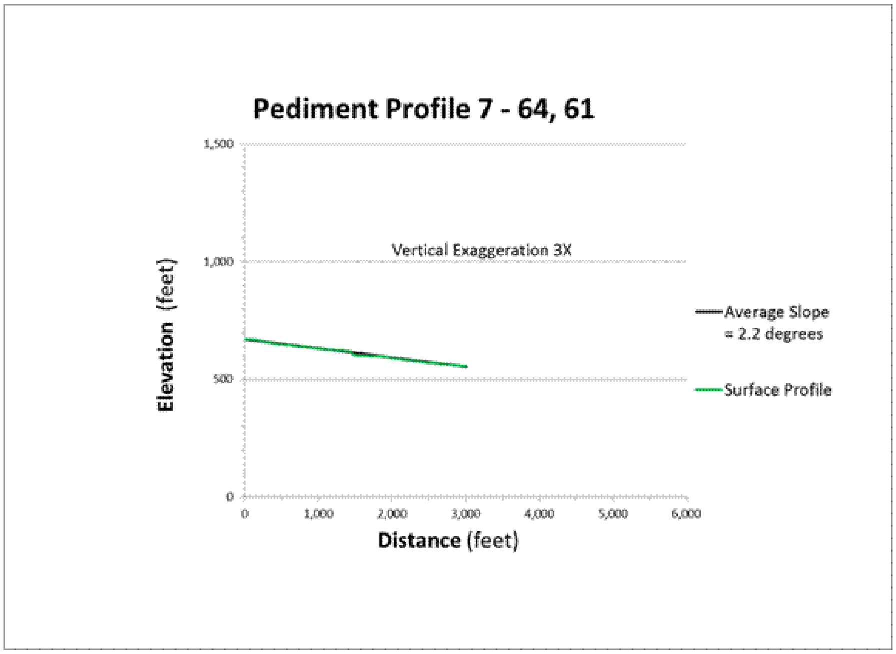


Figure 43. Eastern flank pediment profile (7-64, 61).

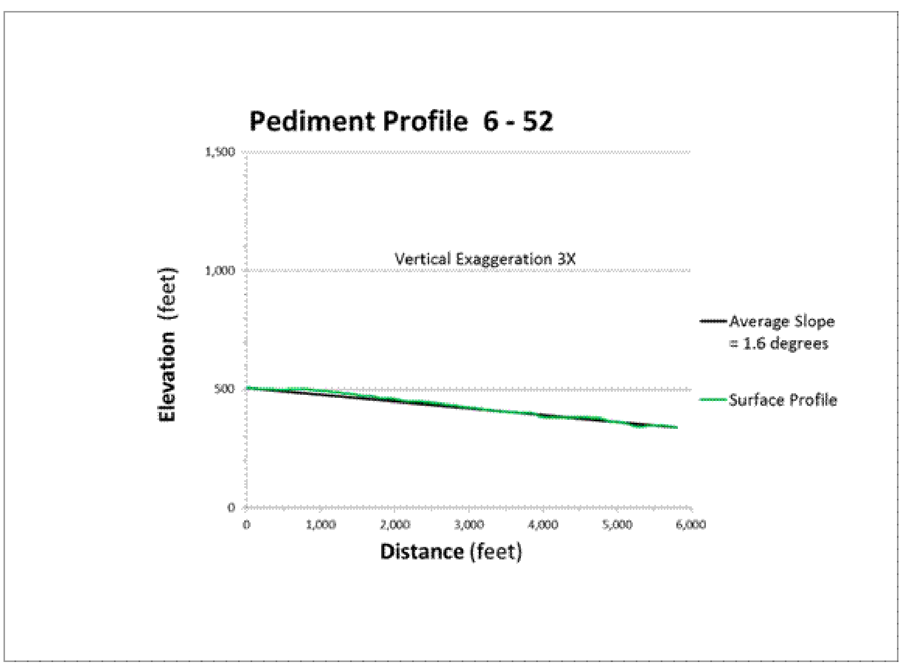


Figure 44. Eastern flank pediment profile (6-52).

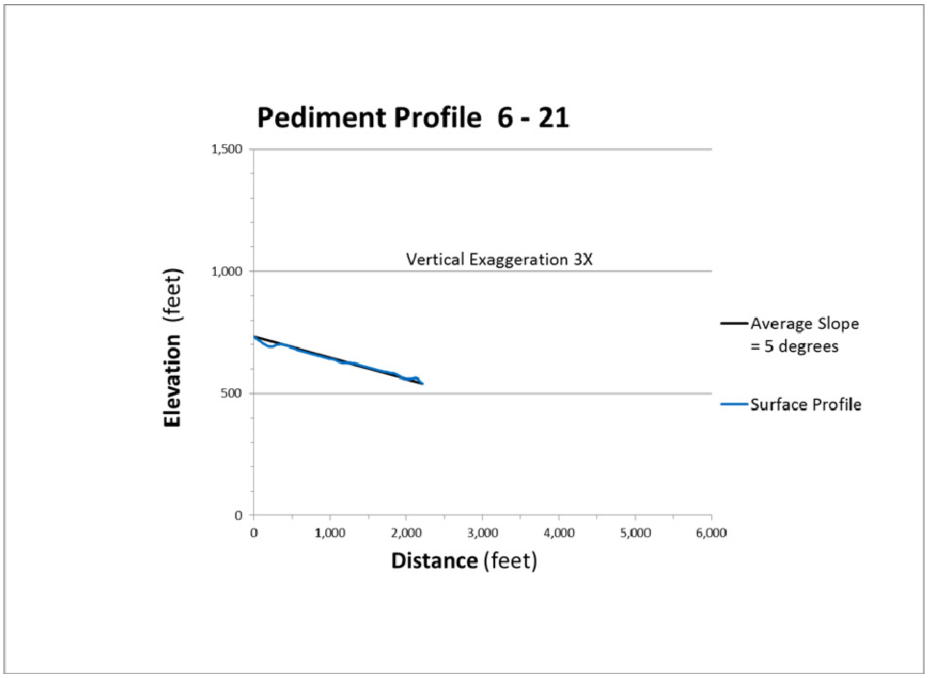


Figure 45. Eastern flank pediment profile (6-21).

Figure 46. Eastern flank pediment profile (5-19).

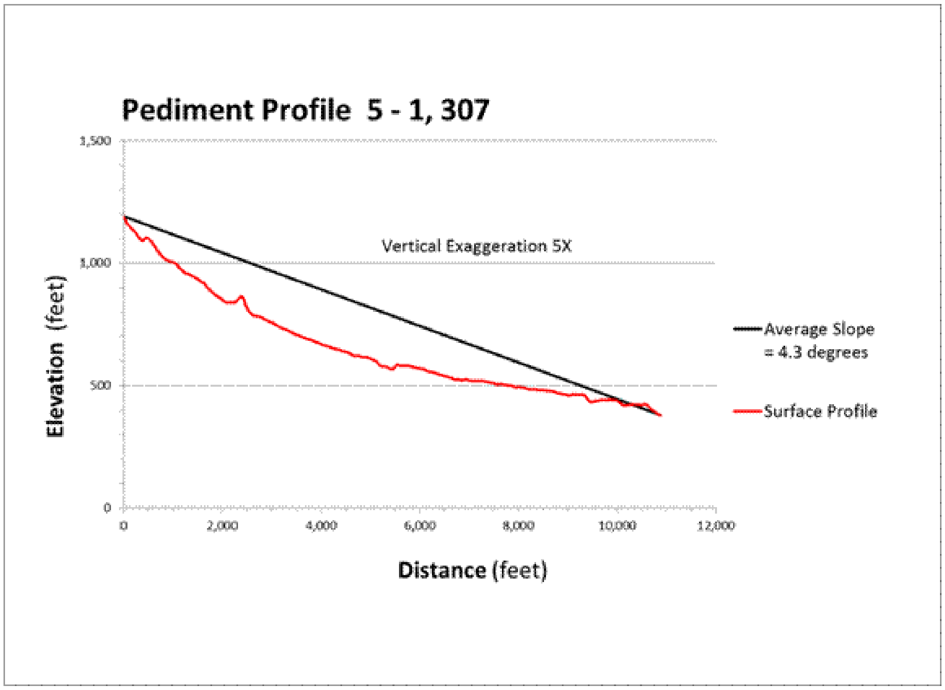


Figure 47. Eastern flank pediment profile (5-1, 307).

The Coyote Ranges' eastern flank selected pediments are as followed (see figure 31):

- Group 5: 5-19 (10), 5-1,307 (4.3)
- Group 6: 6 -372, 560, 559 (1.8), 6-380, 376, 377 (1.6), 6-99 (1.4), 6-52 (1.6), 6-21 (5.0)
- Group 7: 7-460,457 (2.1), 7-64,61 (2.2)

The eastern flank pediments have low (1-5), medium (5-7), and high (7-10) slopes. The average pediment slopes fall in the range of 1-4 degrees. Similar to some of the southern flank pediments, many of the eastern flank pediments often lie as remnants in highly dissected terrain. For this reason, the maps of pediments may fall in areas with slopes in excess of 45 degrees, which indicate talus, cliffs, and ridges (see Figures 30 and

31). These slopes dominate the map units; however, causal inspections makes it obvious that the pediments themselves have a gentler slope despite the apparent slope degree map.

Summary

In summary, the eastern flank contains concave, convex, and rectilinear shape pediments, which are categorized in to groups 2, 5, 6, and 7 according to the pediments association to the geographic features (see Table 2). Evidence of dissection was seen upon pediment's head, body, flanks, and toes. Pediments located within the interior of the Ranges showed less dissection than pediments surrounding the base of the mountain front, terracing along river banks, and spanning the length of washes. Prevailing evidence of formational and/or modifying agents includes faults, mountain tributaries, rills, gullies, washes, lateral erosion, and lateral planation. The average pediment slopes fall in the range of 1-4 degrees.

Geomorphic Features of the Northern Flank

The Coyote Ranges' northern flank, as defined in this study, extends northeast from 32 50' 05.80" North, 116 00' 12.94" West to northwest 32 50' 02.63" North, 116 09' 19.54" West (see Figure 9). For identification purposes, the northern flank pediments are color coded a light lime green on all figures (see Figures 9, 48, and 49). The majority of northern flank pediments resemble the southern and eastern flank pediments as being concave upwards, having higher slopes in the head, intermediate slopes in the body and a lower slope at the toes. Some northern flank pediments in plan view have a rectilinear shape and are possibly remnants of an extensive pediment that has been heavily dissected, much like the southern flank pediments. The low slopes (2-8 degrees) of the

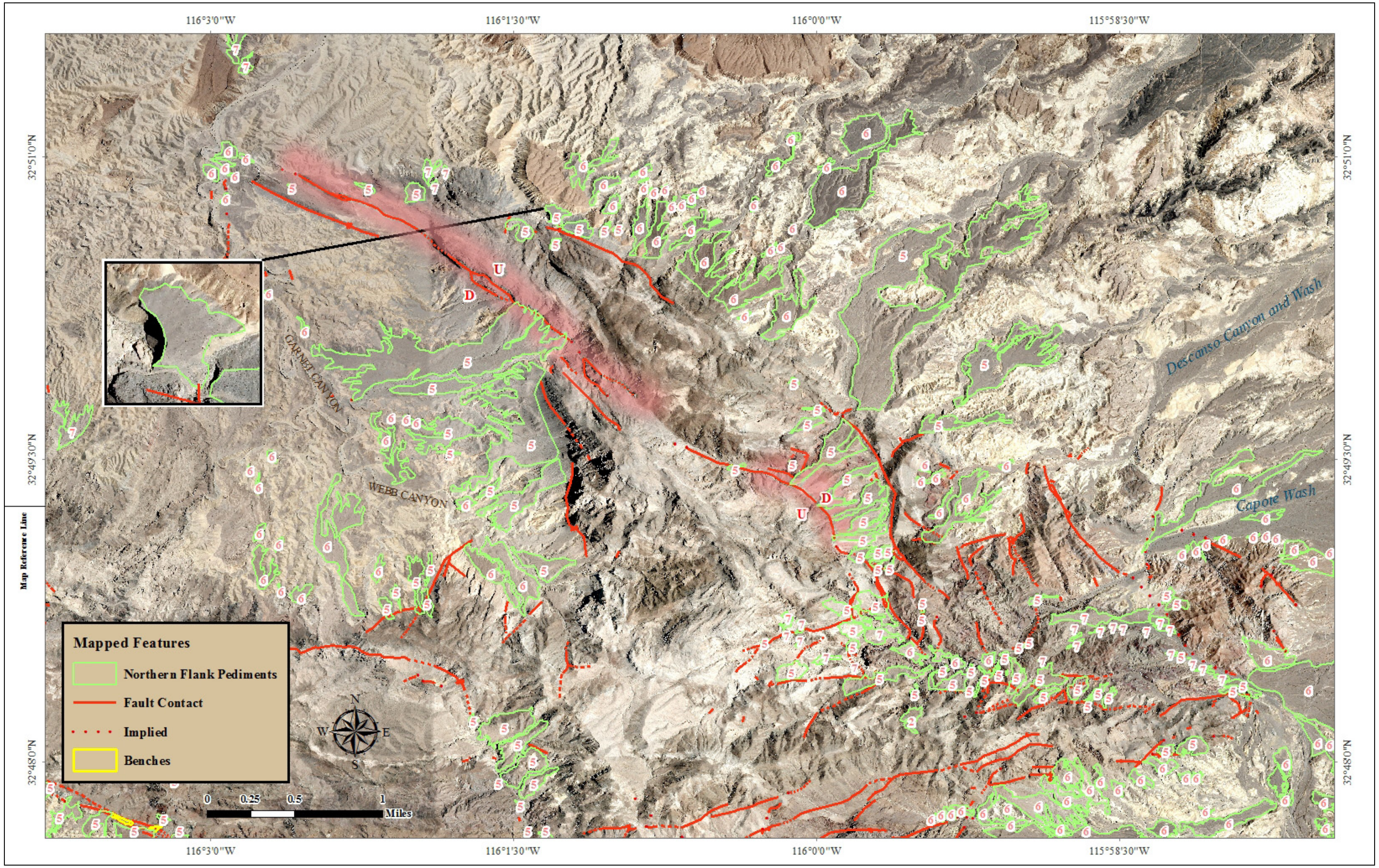


Figure 48. Northern flank pediments map. The northern flank displays a paralleling fault set, fault scarps, minor faults, an intermittent river, and washes. All could be pediment formational and/or modifying agents. The distribution of pediment groups 2, 5, 6, and 7 are highlighted in pink. The extent of fault scarps are highlighted in pink..

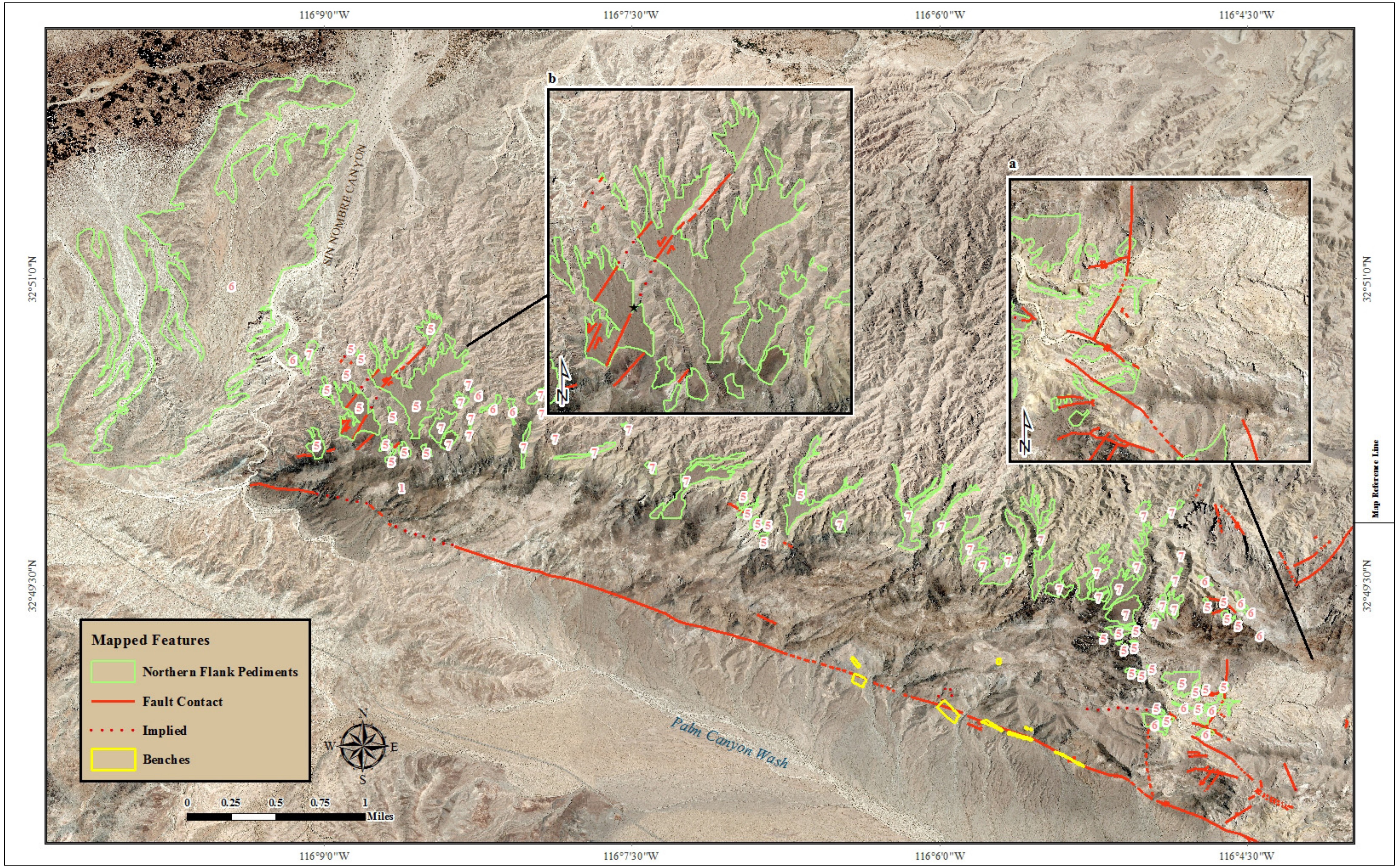


Figure 49. Northern flank pediments map. In the northern flank pediments lie within highly dissected terrain. Fault traces are found across two pediment surfaces and in a closed-in basin. The longest pediment is separated from the Ranges by Sin Nombre Canyon. The pediment group numbers 1, 5, 6, and 7 are highlighted in pink.

pediment remnants contrast sharply with the steep canyon walls, cliffs, and talus of the dissected terrain. The outline of categorizing pediments according to their close proximity to faults, stream or washes, or as peripediments groups is also duplicated (see table 2).

The geology of the northern flank mountain front consist of both metaplutonic and metasedimentary basement rock, with signs of decreasing volcanic rock and increasing presence of marble. The majority of the northern flank faults trend northwest and southwest. Fault traces are found along the mountain base, scarps, canyons, and within the open and closed basins. Most of the drainage system flows north towards Carrizo Creek/Wash, which outflows east and west (see Figures 9, 48, and 49). Similar to the other two flanks, the northern faults, streams, and washes, are possibly formational and/or modifying agents of the northern flank pediments.

The following discussion examines the circumstances of specific pediments in the Coyote Ranges' northern flank by providing description and some suggestive interpretation.

Distribution

The distribution of the northern flank pediments are found extending along washes, adjacent to faults, collectively in basins, and bordering the base of the mountain front - similar to the southern and eastern flank pediments. Unlike the eastern flank, the northern flank has fewer washes and intermittent rivers. North of Descanso Canyon and Wash, are washes where pediments' marine and non-marine older strata lie side by side (32 50' 37.48" North, 116 00' 15.77" West) (see Figures 48 and 50). In most places, the non-marine Palm Springs Group C-Type clastics pale-yellow color aids in its

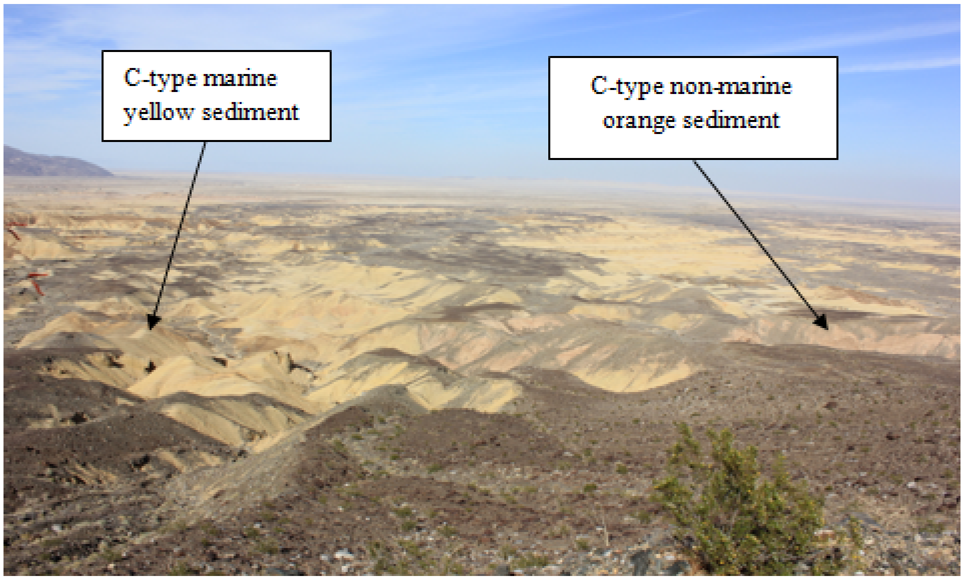


Figure 50. Northern flank pediments. The northeast flank pediments with two kinds of C-Types older strata lie side by side. Both types have a surface of desert varnished alluvium.

identification around the Ranges. However, on the northern flank the Group's C-Type clastics colors includes pale-orange to red claystones, and pale-orange silt and sandstones. The adjacent marine Imperial Group C-Type clastics colors range from pale-yellow siltstones, pale-yellow to orange or brown sandstones, and gray claystones (Winker and Kidwell 1996, 300). The northern flank pediments' older strata for both C-Type clastics usually have a coverage of alluvium and a desert varnish surface. The northern flank washes adjoins the mountain base, where faults frame the mountain's ridge.

The Coyote Ranges' northern flank has a major fault set that parallels along both the mountain ridge and a fault scarp (see Figure 48- pink highlights). The fault set trends northwest, and other faults parallel the southwest trending Elsinore Fault (see Figure 9). The ridge, resembling the outer bend in a fishhook image, runs northeast of the

Range where several dip slope landforms and pediments extend off its steep cliffs (see Figure 9, and 48). For example, one group 5 pediment formed between the mountain's steep ridge and a dip slope landform (32° 50' 41.1684"North, 116° 01' 19.0530"West) (see Figure 48 inset). The pediment has a regolith coverage and an offset non-marine C-Type clastic older strata due to a fault. Combined, both the coverage and older strata measures over 100 feet from the base level to the top of the pediment surface (see Figure 51). West of the mountain front ridge stands a fault escarpment with a marble strata.

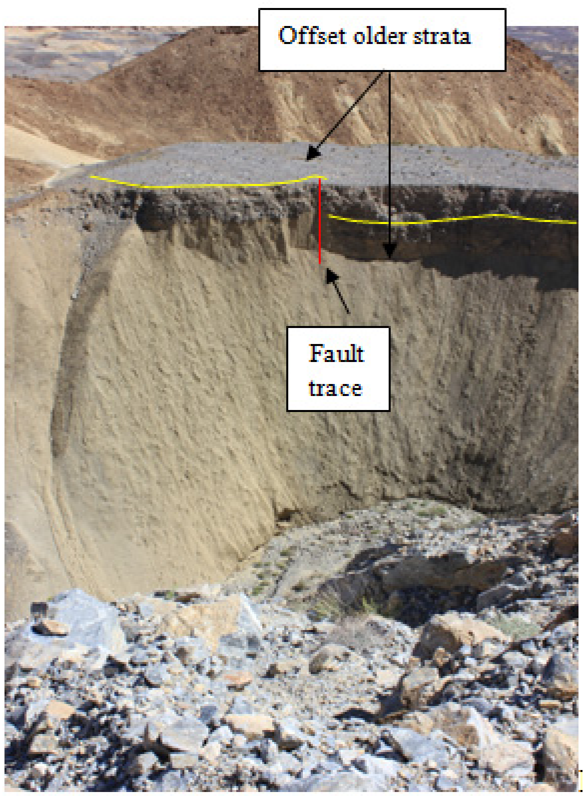


Figure 51. Pediment offset older strata. The offset of the pediment's older strata and surface follows the cessation of a fault. The landform depth measures over 100 feet from the base level to the pediment's surface.

Standing approximately 600 feet high, the fault scarp has pediments extending from its base with worm burrows and fossilized marble with oyster bore holes on the surface (Christensen 1957, 150 plate 1-a-1b; Todd 2004, 7-8) (32 50' 28.83" North, 116 01' 35.21" West) (see Figures 48 and 52). The pediments' coverage of regolith overlies either a marine or non-marine L-Type or C-Type older strata (see Figure 4). The adjacent intermittent rivers may be a formation and/or modifying agent to the scarp's extending pediments.

Figure 52. Major fault scarp. The fault scarp trends northwest, and may be a pediment formational and/or modifying agent on the northern flank.

Differing from the eastern flank's extensive anastosmosing rivers and streams, the northern flank has only two major intermittent rivers, the Webb Canyon and Garnet Canyon (32 49' 12.05" North, 116 01' 48.63" West) (see Figure 48). Originating from an open basin, the two intermittent rivers resemble the southern flank's Palm Canyon Wash. Both the Webb Canyon and Garnet Canyon intermittent rivers are connected and create a boundary for pediments' extending off the fault scarp, the mountain's base, and within the open basin area. Pediments also abound in the Range's endorheic basin.

The Coyote Ranges' only closed-in basin is centered between the southern and northern Range (see Figure 49 inset a). It measures approximately one mile long by a half mile wide, with the long axis running east to west (32° 48' 48.60" N, 116° 04' 49.17" W). Surrounded by mountains, the basin has become a catchment for pedimentation. Warnke refers to pediments within an embayment which "grow" towards each other from opposite sides of mountain ranges as Pediment Passes. The consequent stream's drainage pattern and the pediments extend west, and are referred to as a Pediment Pass with symmetrical divides (Warnke, 1969, 365). The closed-in basin pediments' older strata include both C-Type and L-Type clastics from the Imperial Group. Some of the pediments' coverage includes alluvium and surfaces' enhanced by variable desert vegetation or cemented coquina shell layers (see Figure 53). Beyond the borders of the basin, pediments continue along the mountain base of the northern flank.

The location of pediments continue to border the remaining length of the northern flank's mountain base. But unlike the southern and eastern flank, the northern flank's extending pediments are surround by highly dissected ridges, large outcrops of sandstone, and mounds of cemented coquina shell landforms. Although the northern flank is absent of any major faults such as the southern flank's Elsinore Fault, there is evidence to suggest that faulting was a modifying agent. For example on the northwest end, two group 5 pediments have a regolith coverage that overlies an older strata of non-marine C-Type clastics from the Palm Springs Group (32 50' 09.57" North, 116 08' 36.57" West) (see Figure 49 inset b, and 54). Both of the adjacent pediment surfaces

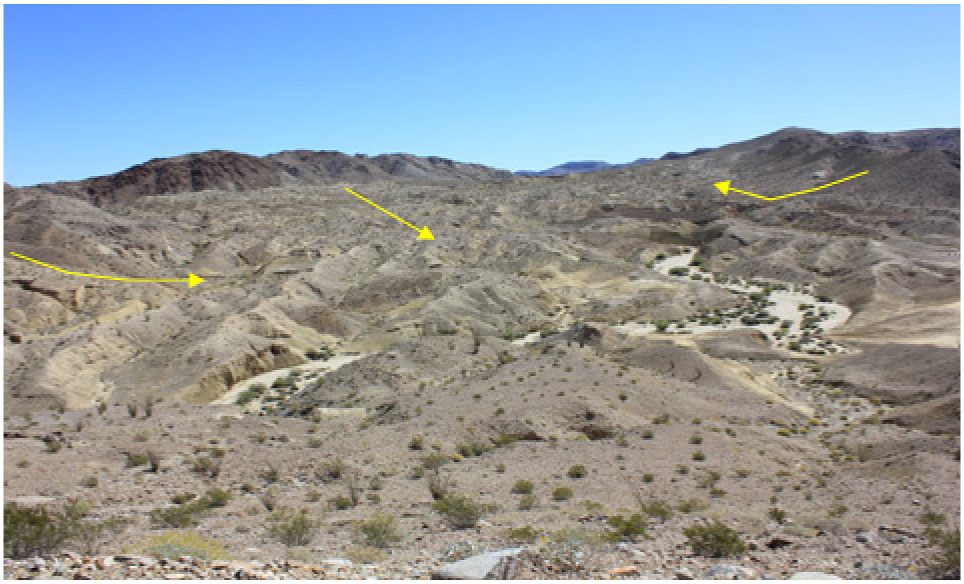


Figure 53. Pediment pass. The closed-in basin pediments “grow” towards each other from opposite sides of the surrounding mountains.

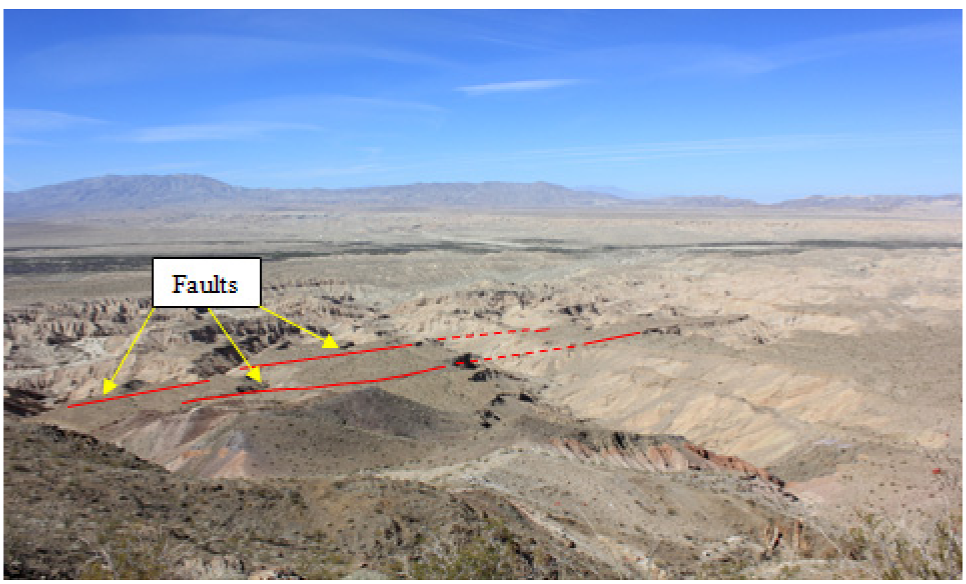


Figure 54. Pediment surfaces with fault traces. The two largest pediments on the northwest flank show evidence of fault traces across the surfaces.

show evidence of fault traces, which could imply the two pediments where once connected. One of the faults, on the largest pediment, has a left-lateral orientation of 388, 81 (Dr. Bykerk-Kauffman, March 2012 personal communication). On the smallest pediment, at the end of one of the fault lines, an exposed flank unveils an angular unconformity (32° 50' 23.2980" North, 116° 08' 45.6079" West) (see Figures 49 inset a - black star, and 55). The expose flank consist of easy erodible siltstones and sandstones from the non-marine C-Type clastics, which suggest the exposure to be recent.

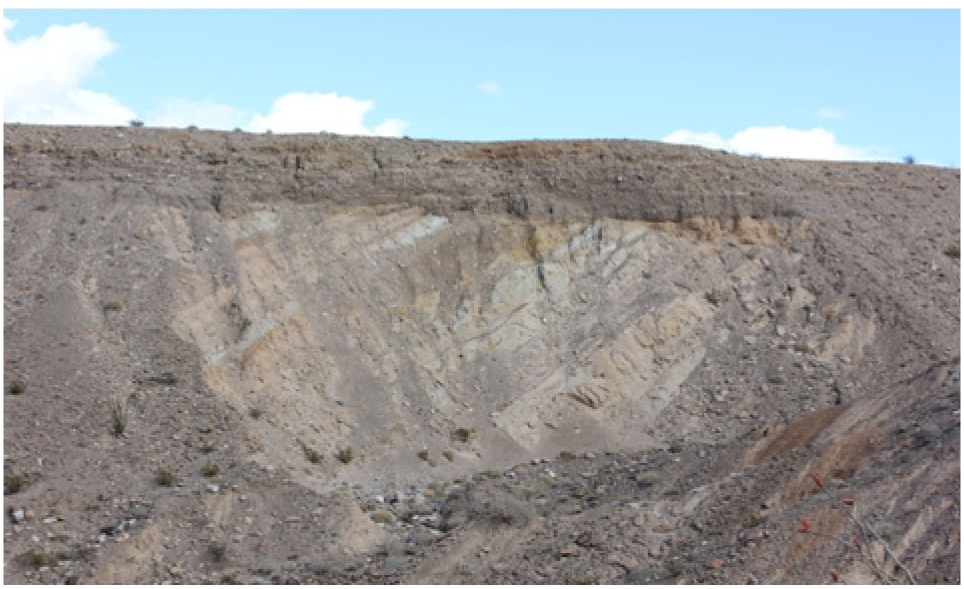


Figure 55. Angular unconformity pediment older strata. A northwestern pediment with fault traces across its surface has an exposed angular unconformity older strata of Palm Springs C-Type siltstones, sandstones, and mudstones.

The last pediment included in the northwest flank is not a part of the Coyote Ranges, but is used as a terminus of my research on pediments. It is separated from the Coyote Ranges by the Sin Nombre Canyon and is categorized in group 6 (see Table 2).

The detached pediment's highly dissected surface extends over 11,000 feet, and has a regolith coverage that overlies a non-marine L-Type clastic older strata (32° 50' 06.45" North, 116° 09' 57.89" West) (see Figure 49). It is possible that the combination of the pediment's isolation, formational and/or modifying agents such as adjacent intermittent rivers and washes, descending crest streams, faults, and its sparse protective coverage are influential in its erosion.

Profiles

For each pediment an individual profile was produced in 3D Analyst, an ArcMap tool. The pediments' slope attributes were transferred in to 2013 Microsoft Office Excel to determine the degree of inclination and to display the data. Both west and east slope degree maps show the location of all mapped pediments. On the maps the pediment group and individual pediment number that correlates with the selected pediment profiles below (Figures 30 and 31). Below the selected pediment profiles are from the three classified pediment groups 5, 6, and 7 (see Figures 56-65).

Coyote Ranges' northern flank (see figure 30 and 31):

- Group 5: 5-246 (4.7), 5-110,113 (4.5), 5-107,130 (6.4)
- Group 6: 6-209 (3.9), 6-478,484 (2.8)
- Group 7: 7- 198 (4.3), 7-166,160 (4), 7-567 (3), 7-124 (8.4), 7-115,132,133 (5.7)

The northern flank pediments have low (2-4), medium (4-6), and high (6-8) slopes. The average pediment slope falls in the range of 4-5 degrees. However, the pediment surfaces often lie as remnants in highly dissected terrain. For this reason, the maps of pediments may fall in areas with slopes in excess of 45 degrees, which indicate

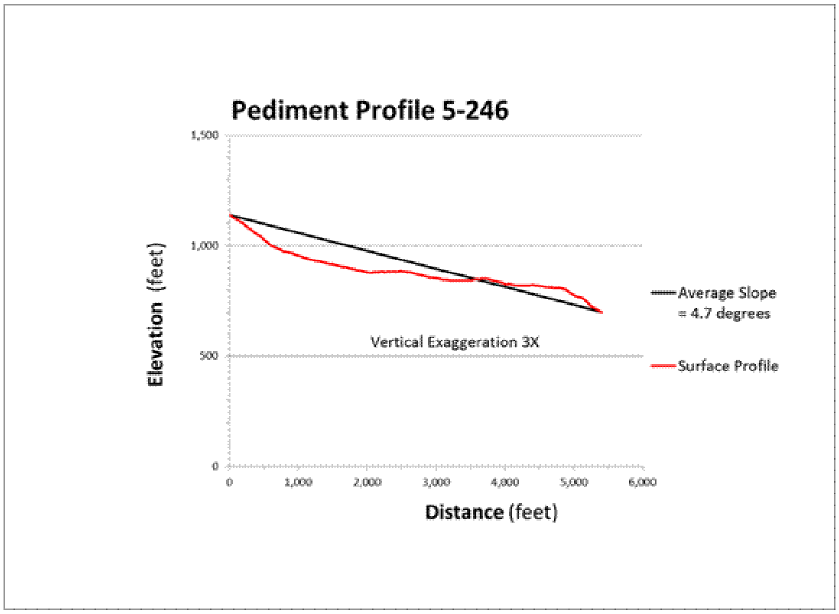


Figure 56. Northern flank pediment profiles. The profile graphs are examples of the distributed northern flank pediments. The red surface profile line represents group 5 pediments, the blue line represents group 6, and the green line represents group 7. The vertical exaggeration is set at 1:1 for graphs of 2000 linear feet, and 3:1 for graphs of 6000 linear feet.

talus, cliffs, and ridges (see Figures 30 and 31). These slopes dominate the map units; however, causal inspection suggest the pediments themselves have a gentler slope despite the apparent slope degree map.

Summary

In summary, the northern flank contains concave, convex, and rectilinear shaped pediments, and are categorized in to groups 5, 6, and 7 according to the pediments association to the features (see Table 2). Evidence of dissection was seen upon pediment's surface, head, flanks, and toes. Prevailing evidence of formational and/or modifying agents includes faults, fault scarps, mountain tributaries, rills, gullies, washes, and lateral planation. The average pediment slope falls in the range of 4-5 degrees.

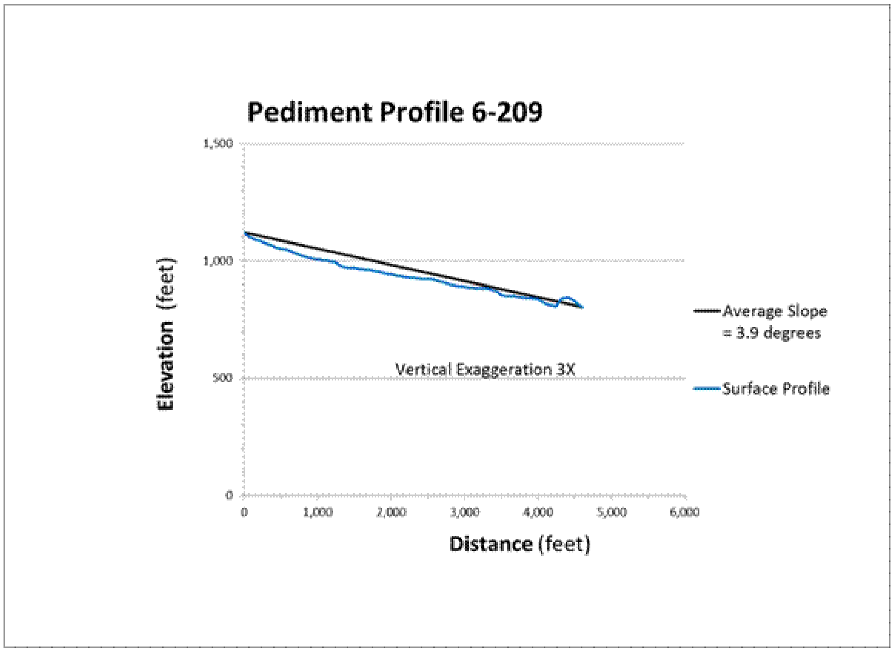


Figure 57. Northern flank pediment profile (6-209).

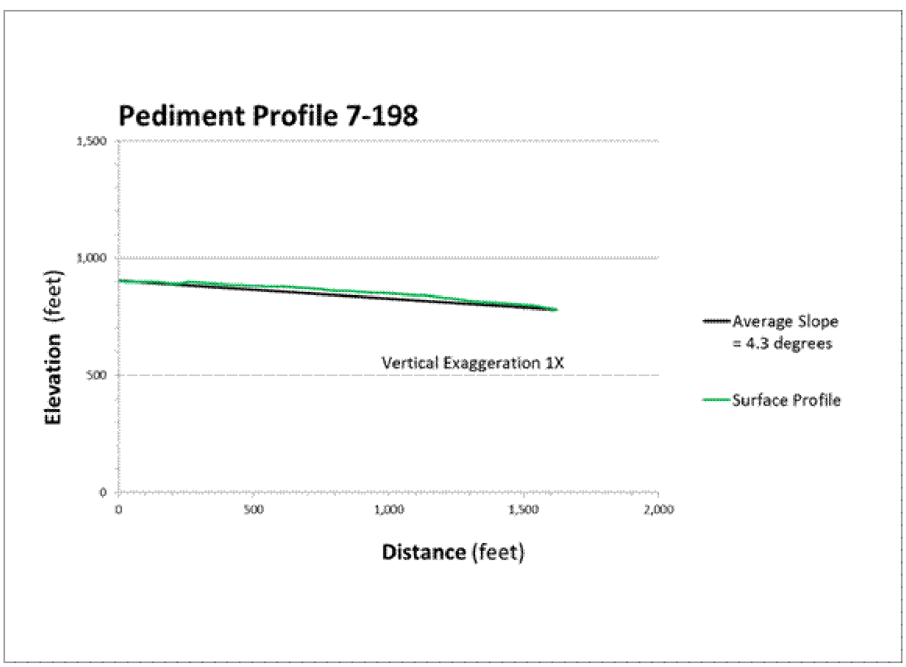


Figure 58. Northern flank pediment profile (7-198).

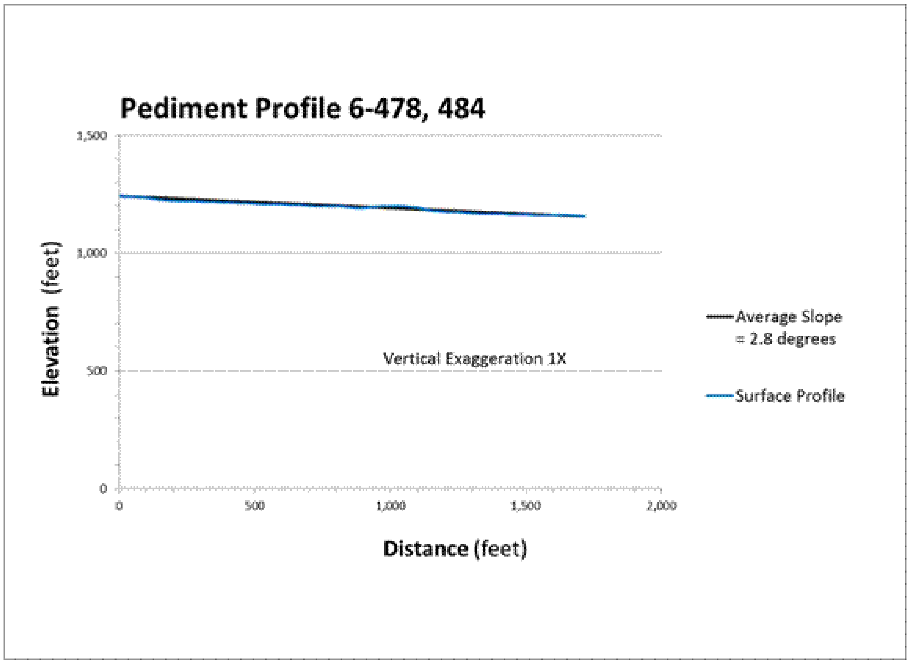


Figure 59. Northern flank pediment profile (6-478, 484).

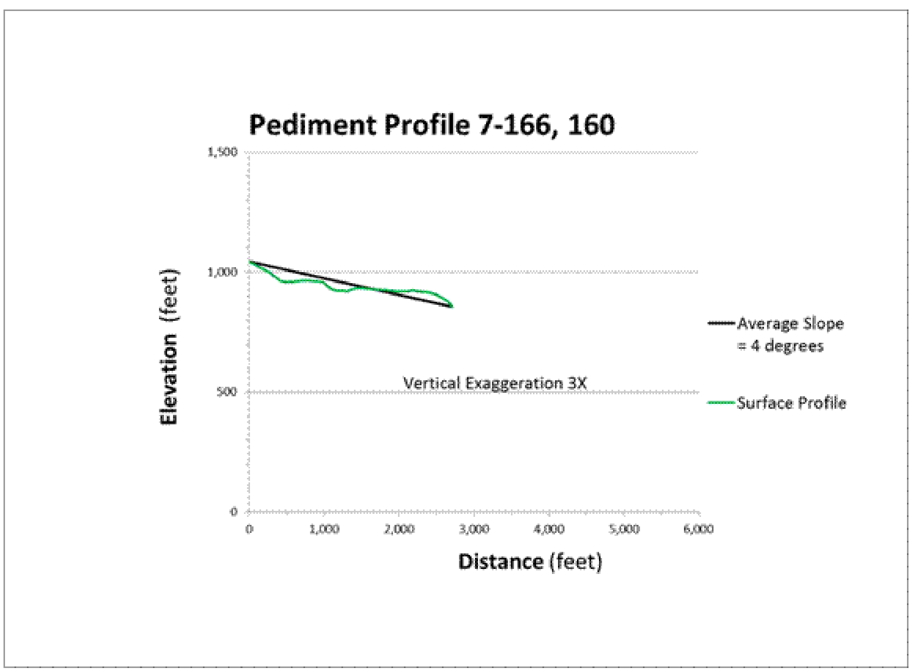


Figure 60. Northern flank pediment profile (7-166, 160).

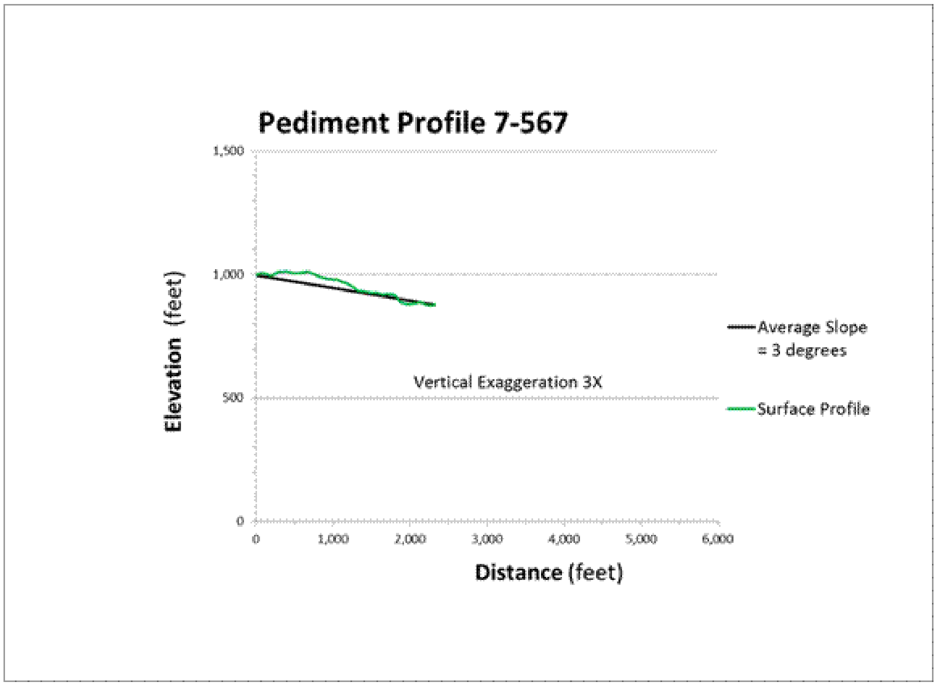


Figure 61. Northern flank pediment profile (7-567).

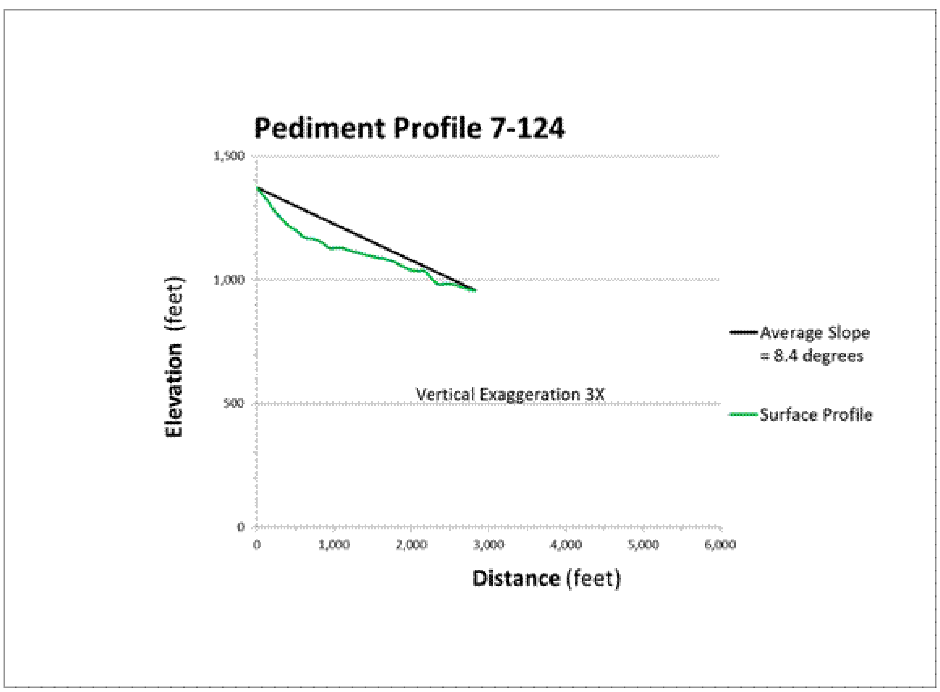


Figure 62. Northern flank pediment profile (7-124).

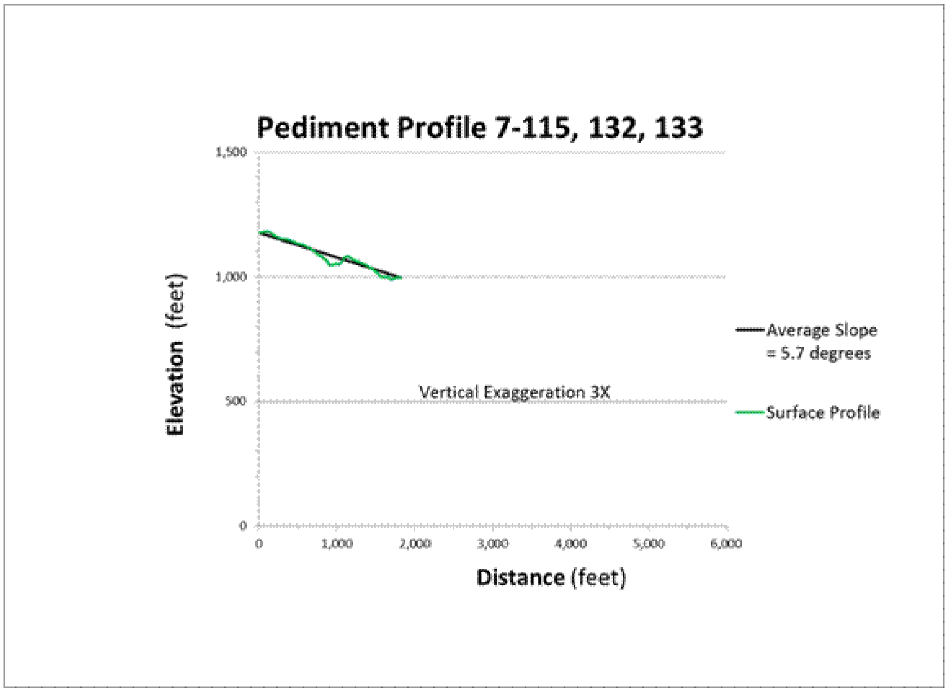


Figure 63. Northern flank pediment profile (7-115, 132, 133).

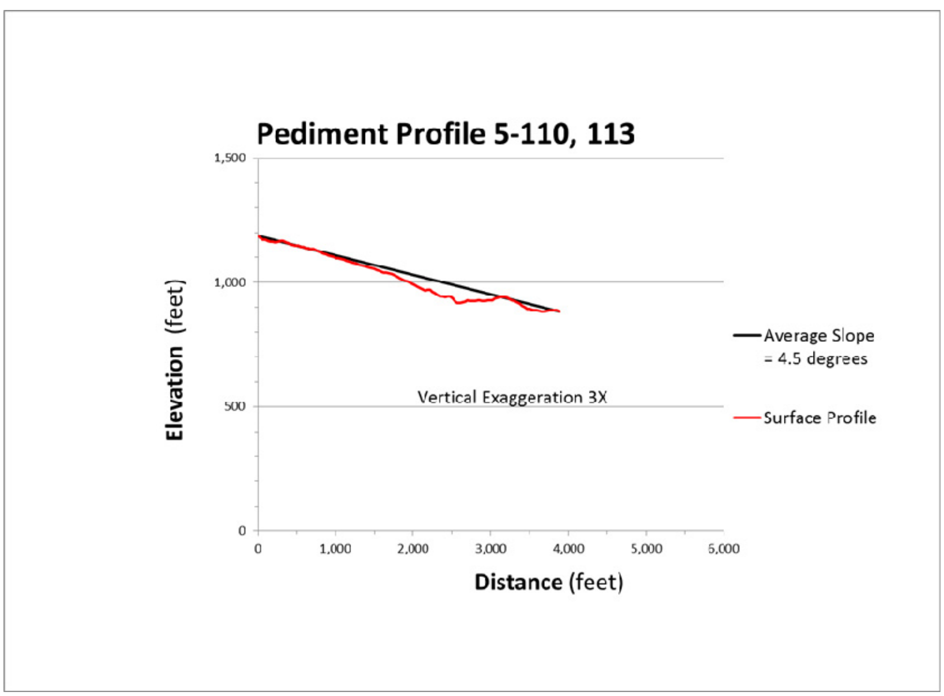


Figure 64. Northern flank pediment profile (5-110, 113).

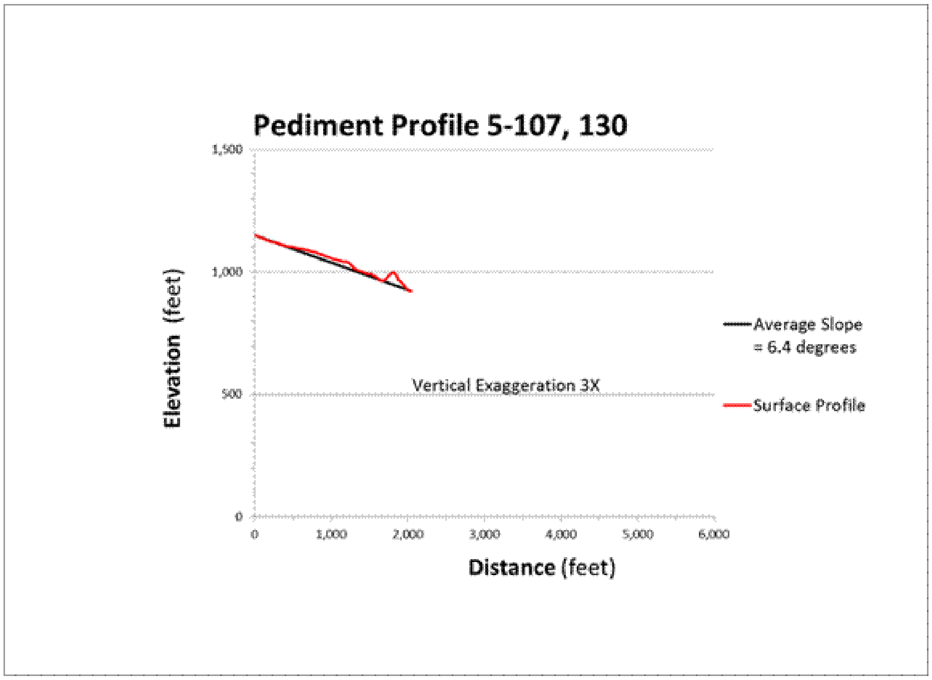


Figure 65. Northern flank pediment profile (5-107, 130). The pediments selected were chosen to represent the different distribution of categorized pediments (group 5, 6, and 7) from the

CHAPTER V

INTERPRETATION OF PEDIMENT RESEARCH

Analysis of Pediment Slopes

My research on the distribution of pediments in the Coyote Ranges lead to a total of 520 mapped pediments. From the total mapped pediments, a profile slope was produced in 3D Analyst, an ArcMap tool, for each pediment. The slope attributes were transferred into Microsoft Office Excel to determine the degree of inclination for randomly selected pediments from the southern, eastern, and northern flank's categorized pediment groups. For group 5 (pediments near faults), 60 pediments were randomly selected from 216 total categorized group 5 pediments. The group's calculated slopes ranged from 1.6 to 16 degrees, with an average of 7 degrees for 42 percent of the Ranges' total mapped pediments, excluding the southwestern mesa landform pediments. For group 6 (pediments associated near streams), 60 pediments were also randomly selected from the group's 223 total, and the same profile slope processes conducted. This group's slope ranged from .18 degrees to 14 degrees, with an average of 4.5 degrees for 42 percent of the Ranges' total mapped pediments. For group 7 (peripediments), 25 pediments were randomly selected from the group's 76 total, and the same profile slopes processes repeated. It is important to note that although fewer pediments are in this group, the number of profile slopes calculated equate to 1/3 of this mapped group. This group's slope ranged from 1 degree to 19 degrees, with an average of 6.7 degrees slope for 15 percent of the total mapped pediments within the Coyote Ranges. The outcome of the group's slope analysis suggest group 5 pediments have a steeper gradient than groups 6 and 7 (see Table 3).

Table 3. Pediment group slopes. Group 5 pediment near faults has the highest average slope. It may be possible some group 7 pediments are near faults still under study. This could explain group 7's high mean slope totals.

	Pediment Groups	Number of Pediments	Mean Slope Total	Percentage of Total Mapped Pediments
1	Associated near Faults	60	7°	42%
2	Associated near Streams	60	4.5°	42%
3	No Association	25	6.7°	15%

Group 5 pediments slope results supports Cooke, Andrew, and Goudie's pediment hypothesis that pediments associated with faults have steeper slopes than pediment slopes not associated with faults (1993, 193) (see Table 1).

The angle of the pediment slopes from the southern, eastern, and northern flanks for the three pediment groups, show the majority of pediment slopes of each category (see Figure 66-68). For group 5 (pediment near faults), the majority of the 60 randomly selected pediments degree of inclination fell within the range of 5-8 degrees. For group 6 (pediments near streams), the majority of 60 randomly selected pediment slope angle fell within the range of 2-5 degrees. For group 7 (peripediments), the majority of the 25 randomly selected pediment slope angle fell within the range of 2.01-5 degrees.

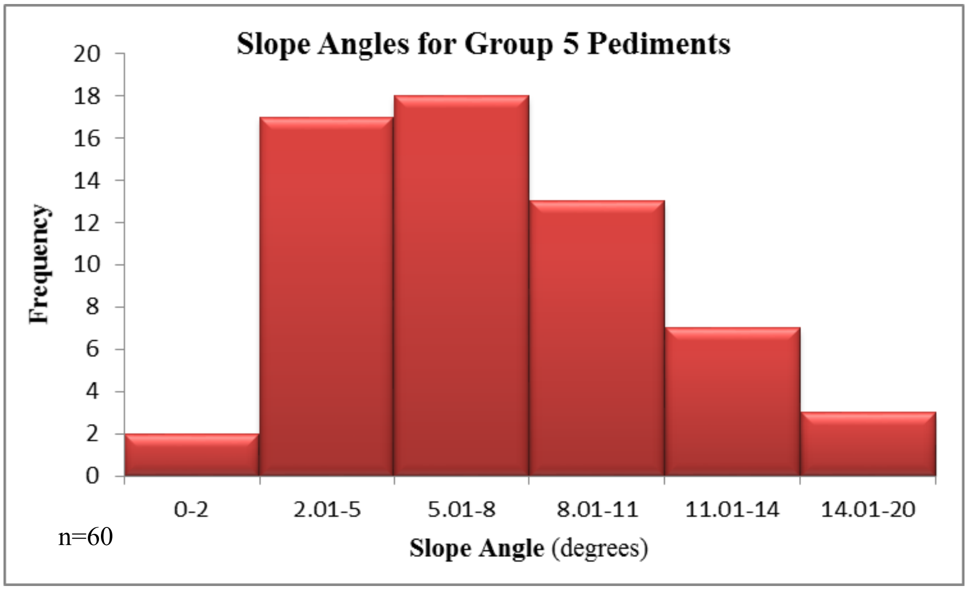


Figure 66. Histograms of pediment slopes for pediment groups. The majority of the pediment groups' slope angles correspond with the mean slope totals. Any discrepancy is due to the division of histogram bins.

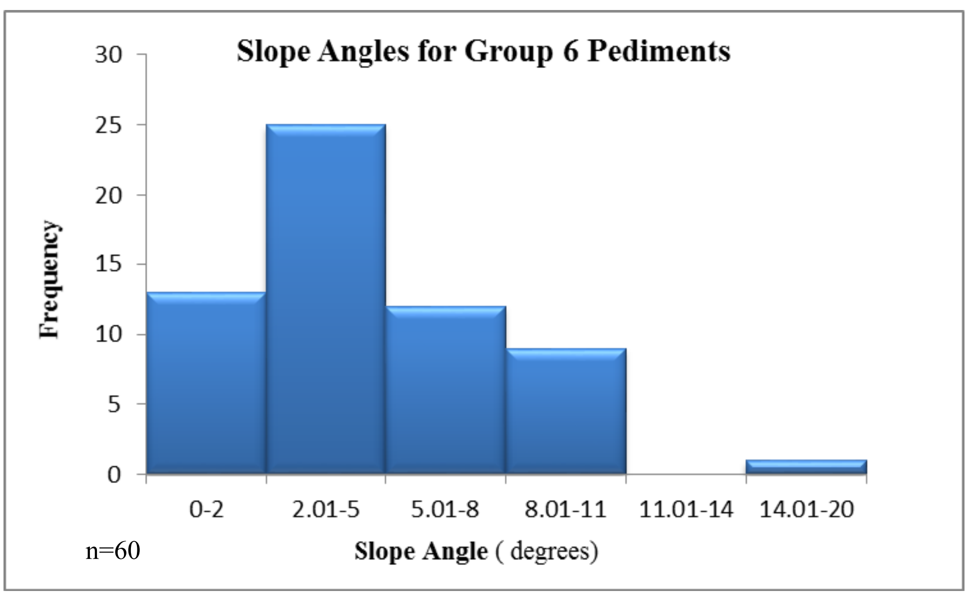


Figure 67. Histogram for pediment slope group 6.

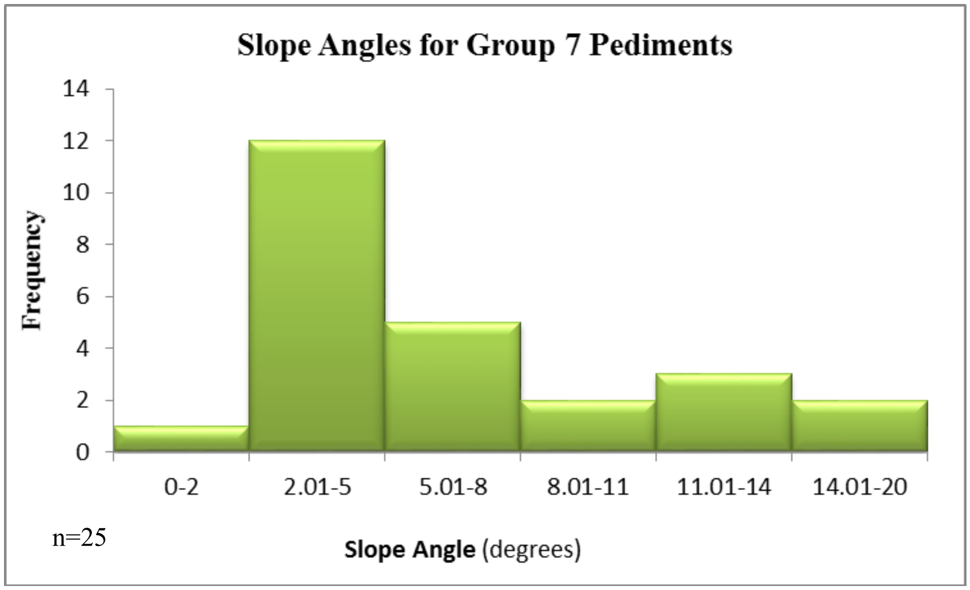


Figure 68. Histogram for pediment slope group 7.

The similarities of the pediment group's mean slope totals and the pediment slope angle totals comply with each other, except for group 7 (peripediments). The mean slope totals for group 7 was 7°, and the group's slope angle range from 2.01-5 degrees. Identical calculations were conducted for all pediment group's raw data. Therefore, the difference between group 7 mean slope total and slope angle total is due to the division of the slope angle bins. Group 7 pediments' high mean slope total may suggest that some group 7 pediments are associated near faults.

It is possible that some of the group 7 pediments are geographically located near faults that are still under study or erroneously missing from my research. All efforts were used to categorize the mapped pediments according to their geographic location association. But, if there was no visual evidence of fault traces or watercourses immediately adjacent to the mapped pediment, it was categorized as a peripediment. A few group 7 sites might imply this characterization. First, on the southern flank at the mouth of Alverson's Canyon a major fault trace has been mapped at the mouth of the canyon. But, at the head of the canyon lie pediments that were categorized as peripediment (32° 47' 26.19" North, 116° 01' 54.18" West) (See figure 11, and 18). Second, on the eastern flank a few group 7 pediments on the southeast end may be in the path of the Elsinore Fault line (32° 46' 25.44" North, 116° 00' 01.80" West) (See figure 9, and 32). Third, on the eastern flank north of Painted Gorge Wash lie several group 7 pediments that may lie near minor faults (32° 47' 44.03" North, 115° 59' 17.41" West) (See figure 32).

This might explain the close comparative mean slope totals between groups 5 and 7 pediments (see Table 3).

Discussion of Pediment Research

Researching the distribution of pediments in the Coyote Ranges has disclosed some pediment attributes reinforced in previous studies. First, the Ranges' pediment groups 5, 6, and 7 average gradients totals of 7 degrees, 4.5 degrees, and 6.7 degrees (respectively) fall into the southwestern United States pediment gradient measurements ranging from 0.5 degrees to 11 degrees (Cooke 1970, 28; Cooke, Warren, and Goudie 1993, 192; Dohrenwend 1994, 327; Hadley 1967, 84,; Royse and Barsch 1971, 3177; Sharp 1940, 357) (See table 3). Second, Cooke's and Mammerickx's claim that lithology between mountain fronts and adjacent pediments can be different was validated (930, 33; 1964, 427-431). My research provided evidence to support that the Coyote Ranges' and pediments' lithology could be different. In example number one, the southern flank's mountain front geology consists of metaplutonic and metasedimentary basement rock, with interlayers of schist, gneiss, marble, dolomite, and veins of pegmatite. Compared to a southern flank group 5 pediment that has a regolith coverage that includes boulders, and angular cobbles of granite, marble, and quartz clasts within a silt matrix that overlie a Palm Springs Group C-type clastic older strata (32° 47’ 47.55” North, 116° 03’ 40.96” West) (See figure 4, 11 inset d, 16,and 17). In example number two, the eastern flank mountain front geology continues to be basement rock, but with increases of volcanic rock. Compared to an eastern flank group 6 pediment exposed flank that reveals a complicated older strata including: (1) marble, part of the basement complex, (2) sandstone, part of the Split Mountain Group, and (3) volcanic clastics, also part of the Split Mountain Group - all overlaid by regolith (32° 48’ 32.90” North, 115° 59’ 24.79” West) (See figure 4,32, and 33). Third, lithology was not an influential element or a controlling agent in the pediment shapes. The Coyote Ranges contain concave, convex, rectilinear, and a combination shape of pediment forms within all of the Ranges’ rock units (See figure 4). The vast majority of pediment shapes were concave upwards, having higher slopes in the head, intermediate slopes in the body and a lower slope at the toes. The southern, eastern and northern flank selected pediment profiles graphs gives a good representation of the pediment shapes (See figure 20-29, 39-47, 56-65). The descriptions of specific pediments’ surface, coverage, and older strata demonstrates that lithology did not have any influence to the Ranges’ pedimentation. Fourth, evidence supported the theory that pediments could have had more than one formational and/or modifying agent either simultaneously or at different stages of pedimentation (Hadley 1967, 85; Sharp 1940, 356). The southern flank has an example of two possible formational and/or modifying agents that fit that characteristic. The majority of the southern flank pediments adjoin the mountain front, where the active Elsinore Fault line bounds the pediments' heads. Paralleling the southern flank mountain front is Palm Canyon Wash, which bounds the pediments' toes (See glossary- pediment section) (See figure 9, 10, and11). Both of these formational and/or modifying agents could have influenced pedimentation simultaneously or at different times. Fifth, Tator suggest multiple formational processes such as shifting loci of streams are forming multi- level pediments (1952, 300-301). Within the Ranges two areas show evidence of active pedimentation. In example one, on the southern flank at the mouth of the Cahuilla Canyon Wash active pedimentation can be seen in a four-tiered feature (32° 47' 36.90" North, 116° 03' 15.67" West) (See figure 11 inset e). The lowest elevated tier lies along the wash, and the highest tier is closer to the mountain front near the trace of the Elsinore Fault. In example number two, on the eastern flank the Butaca Canyon, a major shifting intermittent river extending southeast and a tributary to Coyote Wash, exhibits a multi-level pediment (32° 47' 40.10" North, 115° 58' 58.18" West) (See figure 36). Sixth, protective coverage is a critical factor to the preservation of pediments (Miller 1950, 638-642). Unlike the southern and eastern flank, the northern flank's extending pediments from the mountain base are surrounded by highly dissected ridges, large outcrops of sandstone, and mounds of cemented coquina shell landforms. Yet, are two of the northern flank's largest pediments (32° 50' 09.57" North, 116° 08' 36.57" West). Both have a regolith coverage that overlies an older strata of non-marine C-Type siltstones and sandstones from the Palm Springs Group (See figure 4). Additionally, the pediment surfaces has evidence of fault traces. Therefore, it is to the credit of the protective regolith coverage that has preserved the two pediments (See figure 49 inset b, and 54).

Conclusion of Pediment Research

The purpose of my pediment research in the Coyote Ranges of Southern California was to provide a data base on pediment locations, surface configuration, and underlying geology distinguished for future research relating to pediment development. My research focus did not entail classifying pediments in established schemes, but rather by geographic locations. The locations of 520 mapped pediments were categorized into five groups: (1) mountain pediments, (2) oldest pediments, (5) pediments located near faults, (6) pediments located near streams and/or washes, and (7) peripediment – no geographic association. From the total mapped pediments four were slotted for group1, one was recorded in group 2, two hundred and sixteen were classified in group 5, two hundred and twenty-three qualified for group 6, and seventy-six categorized in group 7. The majority of pediments were assigned into groups 5, 6, and 7. From these groups I examined: (1) the locations of the mapped pediments, (2) the geology and lithology of pediment sections, (3) the profile graphs of typical categorized pediments, and (4) the suggestive formational and/or modifying agents.

The data analysis included:

(1) The distribution of pediments to be extending from the base of the mountain, at the mouths and heads of canyons, draped on tops of canyon walls, spanning the length of washes, adjoining rivers, collectively in basins, and adjacent and paralleling between faults.

(2) Pediment sections included all of the Ranges' rock units.

(3) The average pediment slope falls in the range of 3-8 degrees for the southern flank, 1-4 degrees for the eastern flank, and 4-5 degrees for the northern flank.

(4) The majority of pediments shapes are concave upwards, but there are convex, rectilinear, and combination shapes.

(5) Formational and/or modifying agents involve faults, fault scarps, lateral planation, mountain tributaries, rills, gullies, and washes.

Some of my research insufficiencies could be the focus of future research. First, locating and mapping pediments covered by lava flows could aid in relative dating of some pediments.

Second, examining pediments near faults and highly elevated areas could identify areas with more uplift activity, and aid in establishing rate and time of fault movement. Third, comparing crest drainages and pediments may suggest a formational and/or modifying relationship between drainages and pediment lengths and gradients.

The mapped pediments of the Coyote Ranges in southern California can now be utilized to monitor, measure, record, and reveal events that can educate us on local and regional morphogenesis of the Coyote Ranges, and the evolutionary stages affecting the maturing Coyote Ranges.

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APPENDIX A

Glossary

Alluvial Fan- An outspread, gently sloping mass of alluvium deposited by a stream. It has a shape of an open fan, the apex being at the valley mouth.

Angular Unconformity- The younger sediments rest upon the eroded surface of tilted or folded older rocks. **Basal Sapping**- The undercutting and retreat of a slope caused when weathering and/or erosion are concentrated at its base (Academic Dictionaries and Encyclopedias online, s.v. "Basal Sapping," http://geography_glossary.enacademic.com/95/basal_sapping [accessed April 2015]).

Base Level – The level of the ground surface.

Buttress Unconformity- Is an unconformity where onlapping strata is deposited on a steep, high relief scarp of older strata.

Dip-Slip Fault- A fault on which the movement is parallel to the dip of the fault.

Dip Slope Landform- A slope of the land surface that conforms approximately with the dip of the underlying rocks

Faults- A fracture or fracture zone in rock along which movement has occurred (Geology.com)

Fault Scarp- The cliff or escarpment formed by a fault that researches the earth's surface.

Geology- The study of the planet earth, the materials of which it is made, the structure of those materials, and the processes acting upon them.

Knoll- A small rounded hill.

Lateral Erosion- "The action of a meandering stream as it swings from side to side, impinging against and undercutting its banks" (Dictionary or Geological Terms 3rd ed., s.v. "Lateral Erosion").

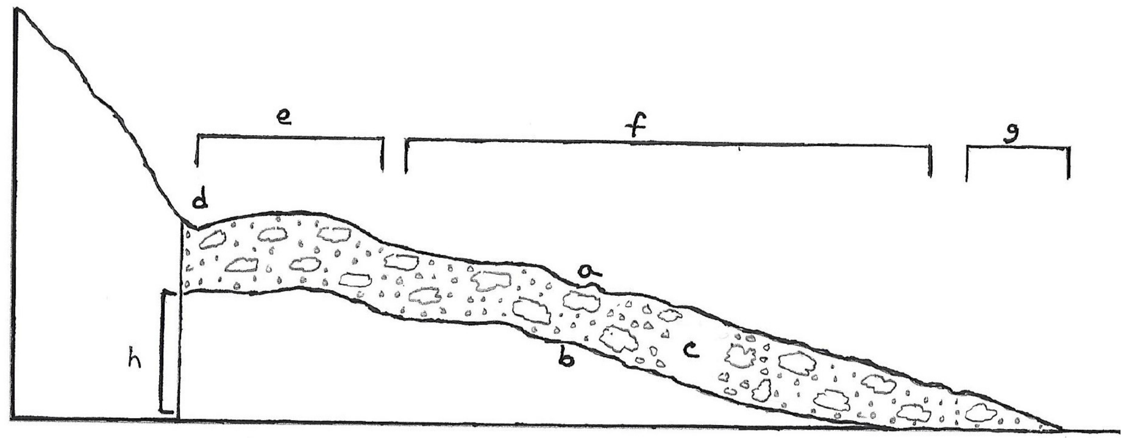
Lateral Corrasion- The process of wearing away earth surfaces laterally by running water.

Lateral Planation- The reduction of the land in an interstream area to a plain or nearly flat surface by lateral erosion.

Lithology- The description of rocks on the basis of characteristics as color, mineralogic, composition, and grain size.

Pediment- "a gently sloping erosional surface developed on bedrock or older unconsolidated deposits. The eroded surface may be subaerially exposed or covered by a continuous or discontinuous veneer of alluvial deposits, and the bedrock may include any lithologic type with any structural attitude" (Dohrenwend 1994, 323).

Pediment Sections



a) Surface- the upper top layer of a pediment.
b) Bottom- the basal bedrock surface.
c) Coverage- the pediment thickness consisting of various alluvial deposits, debris flow, colluviums, mass wasting deposits, and regolith.
d) Piedmont Junction-the slope break near the pediment head.
e) Pediment Head- the beginning slope following the piedmont junction.
f) Pediment Body- the pediment mass between the head and toes
g) Pediment Toes- the terminus point(s) of a pediment.
h) Older Strata- the underlying strata under a pediment coverage.

Pedimentation- "The range of processes bring about the formation of pediments" (Warnke 1969, 366)

Planation- The general lowering of the land.

Strata- The plural of stratum (a layer of sedimentary rock).

Strike-Slip Fault- A fault that strikes parallel with the strike of the strata involved.

Structural Bench- is a relatively planar surface breaking the continuity of a slope.