Geomorphic Evaluation of a Late Pleistocene to Early Holocene River Meander in the Desert Cahuilla, Imperial County, California

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Abstract

Geomorphic evaluation of a series of alluvial fan deposits along the southeast flank of the Santa Rosa Mountains provides insight into deposition and erosion cycles in the Desert Cahuilla. The Desert Cahuilla is approximately a 23 square mile area bounded by the Torrez-Martinez Indian Reservation on the north, Imperial-San Diego County Line on the west, Highway 22 on the south, and roughly by Highway 86 on the east. Geomorphic and paleoclimatological evidence suggests that major alluvial fan aggradational events were related to climate change during the Pleistocene. These changes were associated with glacial and interglacial transitions, and the effect of these transitions on the number and intensity of winter storm events.

The last major alluvial fan aggradation event in the Desert Cahuilla region ceased approximately 35 to 100 thousand years ago. During late-Pleistocene through mid-Holocene, alluvial fan development in the Desert Cahuilla was likely significantly influenced by climate change. A Pleistocene-Holocene climate transition involved a change from wetter and cooler to drier and warmer conditions. Resulting decreased vegetative cover and stripping of hillslope colluvium led to increased stream runoff during individual rainfall events (stream power), generally lower sediment load, and incision of alluvial fans in this region. A stream meander in the northwest Desert Cahuilla represents not only incision of the fans and fan pediments due to the change in climate, but also a stream condition of relatively low velocity and gradient, allowing development of meandering streams. Later changes, possibly due to falling base level or otherwise steepening of the stream gradient, led to higher stream velocities and development of braided and parallel drainages, cutting off the meander.

Introduction

During late 2007, I received an e-mail with the subject line, “Need a Pilot!” With a current pilots license, I responded and subsequently, on September 23, 2007, flew Phil Farquharson, Lowell Lindsay, and Diana Lindsay over an area east of Borrego Springs known as the Desert Cahuilla (Figure 1). The purpose of the flight was to conduct geologic reconnaissance in the northeast corner of the Desert Cahuilla on a parcel owned by Anza-Borrego Foundation. We photographed the area, and began evaluating the Pleistocene alluvial fan surfaces in the area.

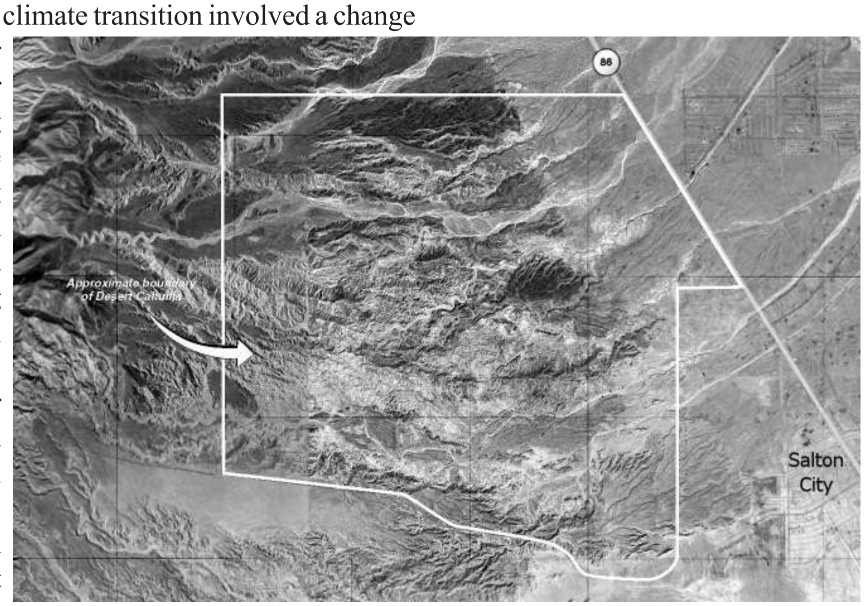

Figure 1. Desert Cahuilla Site Map.

Pleistocene alluvial fans present a fragile geologic resource that may yield information and insight into the Pleistocene and Holocene tectonic and climatic history of the region. Indeed, alluvial fans throughout the American southwest have been studied by many noted scientists. Alluvial fan surfaces provide data related to the processes involved in the formation of desert pavement and desert varnish, calcic soils unique to arid regions like the southwestern United States, and geomorphic structures and formations shaped by time and sometimes by subtle (and occasionally, not so subtle) tectonic forces.

Between late 2007 and early 2008, I made several flights to observe the Desert Cahuilla and further evaluate these sensitive alluvial fan surfaces. On one such flight, from an altitude of approximately 4,000 feet over the northwestern corner of the Desert Cahuilla, I observed what appeared to be a quarry, an easily visible topographic feature roughly circular in shape. Upon descending for a closer look, the “quarry” turned out to be a “U”-shaped meander incised into an alluvial fan pediment along the south side of a relatively large wash. We photographed the feature (Figure 2) and continued the flight. Upon further reflection, I became convinced that this old dry river meander warranted some investigation into what it might add to the story of the geological history of the Anza-Borrego Desert Region.

Figure 2. The “Meander.” (1) Late Pleistocene Alluvial Fan Surfaces (35-100 thousand years), (2) Latest Pleistocene to middle-Holocene Alluvial Surfaces, (3) Active Channel.

Geologic Setting

The Desert Cahuilla encompasses approximately 23 square miles bounded by the Torrez-Martinez Indian Reservation on the north, Imperial-San Diego County Line on the west, Highway 22 on the south, and roughly by Highway 86 on the east (Figure 1). The project area is dominated, particularly in the northern half, by alluvial fan surfaces formed on pediments composed of Tertiary-aged sedimentary rocks along the western boundary of the Salton Trough. Dibblee (1953) mapped the units underlying the area as primarily Tertiary Palm Spring Formation with Tertiary Borrego Formation along the eastern portion of the Desert Cahuilla. Dibblee (1953) described the Palm Spring Formation as terrestrial sandstones and red clays, and the Borrego Formation as the lacustrine facies of the Palm Spring Formation composed of light gray clay and sand. Rogers (1965) mapped the area to include undivided Pliocene nonmarine sediments, Tertiary lake deposits, Quaternary nonmarine terrace deposits, and Quaternary alluvium. Morton (1966) mapped Tertiary Palm Spring Formation and Borrego Formation, along with alluvium and older alluvium, both of Quaternary-age. The Palm Spring Formation was identified by Morton as consisting of interbedded nonmarine, light gray, arkosic sandstone and reddish clay, with Borrego Formation consisting of nonmarine gray clay and interbedded sandstone of lacustrine origin.

According to Dorsey (2006 and this volume), the stratigraphy of the Anza-Borrego Desert Region includes the Miocene-Pliocene Imperial Group overlain by Pliocene-Pleistocene Palm Spring Group sediments. The Imperial Group rocks include the Deguynos Formation, described primarily as deltaic and tidal flats sediments. At the base of the Deguynos Formation within the Imperial Group is the Latrania Formation comprised of sandy turbidites and megabreccia. The Imperial Group rocks are marine sediments which may be partly correlative with the Bouse Formation of the lower Colorado River Valley (Dohrenwend, et. al., 1991).

The Palm Spring Group consists of delta plain and stream sediments of the Arroyo Diablo Formation overlain by lacustrine sediments of the Borrego Formation (Dorsey, 2006). Dohrenwend, et. al., (1991) described these units as two separate formations; the Palm Spring Formation comprised of fluvial and deltaic sand, silt, and clay, and the Borrego Formation comprised of fine-grained lacustrine deposits. In this paper, I am using the stratigraphic nomenclature as described by Dorsey (2006). Along the western margin of the basin, the Palm Spring Group also includes alluvial fan deposits of the Canebrake Conglomerate. Overlying the Palm Spring Group is the Pleistocene Ocotillo Conglomerate which grades into the lacustrine Brawley Formation toward the basin center. Figure 3, from Dorsey 2006, provides a summary of the general stratigraphy of the Anza-Borrego

Desert Region.

Tectonically, the study area is located between the San Jacinto Fault Zone to the west and San Andreas Fault Zone to the east. The nearest significant fault to the project area is the Clark Strand of the San Jacinto Fault Zone located approximately 3 or more miles to the southwest (Blisniuk, et. al., 2010). Although no significant faults are known to exist within the Desert Cahuilla, several lineaments suggestive of faults can be seen in the eastern portion in aerial photography. Additionally, numerous faults seen by offsets on the order of several inches to several feet are seen in Tertiary sedimentary rocks exposed below the fan pediment in the washes in the area. In many instances, offset beds can be seen constrained between beds showing no apparent offset above and below. This may be due to extensional deformation of the sediments with some extension occurring along bedding planes and not readily visible in exposures of the sediments. Figure 4 is a photograph of offset beds in one of several roughly east-west trending washes traversing the Desert Cahuilla. Unbroken sedimentary beds are seen above the offsets. In some locations, similar offsets appear as listric faults, flattening with depth into bedding plane faults exhibiting little or no offset of discrete beds.

Pleistocene-Quaternary History

The Desert Cahuilla is underlain by Miocene through Pleistocene sediments deposited in a shallow basin environment during mid-Tertiary through Quaternary extension of the region (Dohrenwend, et. al., 1991). These sediments are, in turn, overlain by alluvial fan deposits derived from the southeastern Santa Rosa Mountains to the west of the Desert Cahuilla. The fans have been deposited on a pediment dipping east toward the center of the Salton Trough. Using the discussions of Christensen and Purcell (1985), the alluvial fans in the northern portion of the Desert Cahuilla would be intermediate age fans based on the following criteria:

1. variable depth of incision on the order of 1 to 30 feet,
2. fan surfaces generally smooth and flat,
3. fan surfaces incised but well preserved,
4. desert varnish and desert pavement can be strongly developed.

The fan surfaces in the Desert Cahuilla are flat, dissected by several prominent east-west drainages, and have a strongly developed and relatively dark desert varnish. These characteristics place the age of the Desert Cahuilla alluvial fans at middle to late Pleistocene based on Dohrenwend, et. al. (1991). Desert varnish developed on the alluvial fans in the northern Desert Cahuilla have a similar or darker appearance than that developed on alluvial fans in the southern Santa Rosa Mountains approximately 5 to 8 miles west-southwest of the Desert Cahuilla. Blisniuk, et. al., (2010) assigned a date of 35 +/-7 thousand years to the fan they studied. This suggests ages for the fans in the Desert Cahuilla range from 35,000 to as old as 100,000 years.

Bull (2000) outlines three factors in alluvial fan dynamics: 1) tectonic activity, 2) climate change, and 3) internal adjustments in the alluvial fan system. Although the region of Anza-Borrego Desert State Park is quite tectonically active, the Desert Cahuilla shows relatively little, if any,

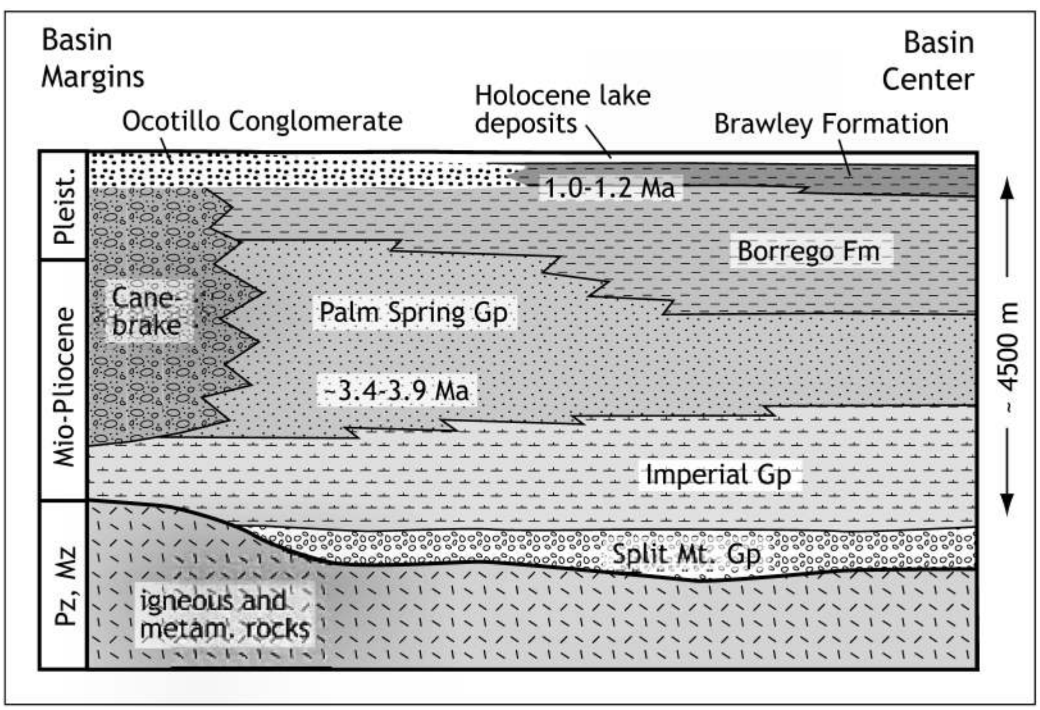

Figure 3. Stratigraphic Section. From Dorsey (2006).

notable seismicity. According to Dohrenwend, et. al. (1991), the climate south of 36ºN (roughly Las Vegas, Nevada) was cooler and wetter in the late Pleistocene, with a significant decrease in effective moisture occurring during the Pleistocene-Holocene climate transition. Bull (2000) places the Pleistocene-Holocene climate transition between 17,000 and 10,000 years ago. Coupled with changes in base level, climate changes likely were significant factors in controlling and shaping the development of late-Pleistocene and Holocene geomorphology, particularly related to alluvial fans. Harvey and Wells (2003) conclude that, in the absence of tectonic activity, climate change is the "over-riding control" of alluvial fan dynamics.

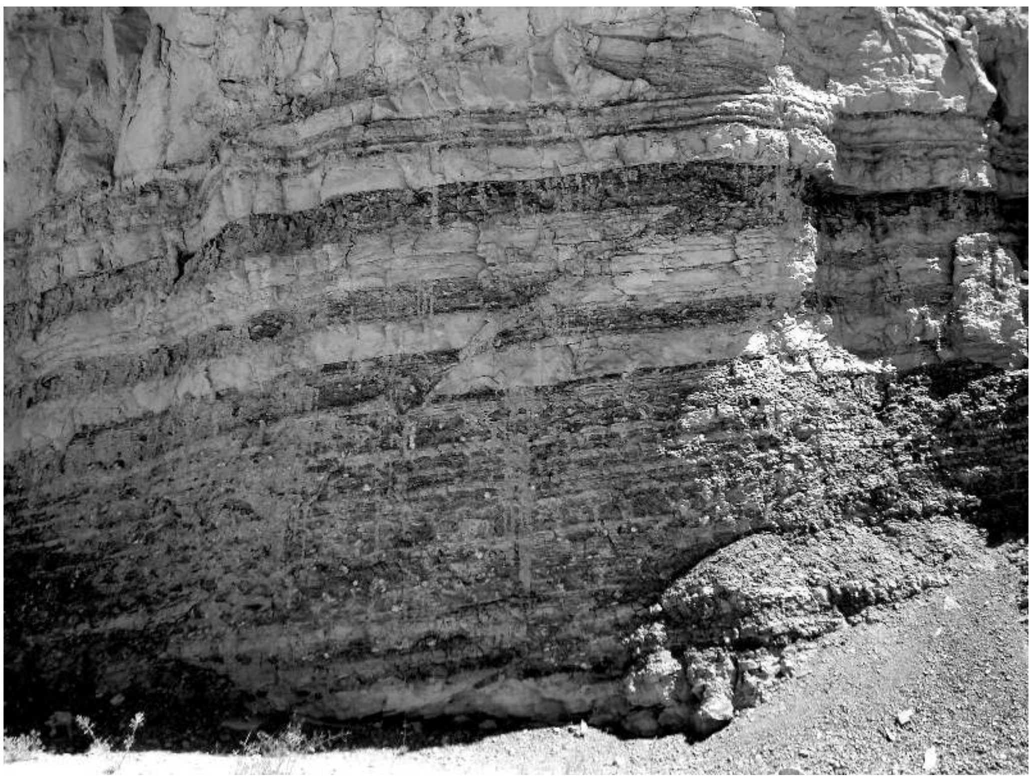

Figure 4. Offset Bedding in the Desert Cahuilla.

Stream Dynamics

Stream power (SP) is the power available to transport sediment load, and critical power (CP) is the power needed to transport sediment load (Bull, 1979). Bull (1979) defines the threshold of critical power as the point where SP/CP = 1. If this ratio is less than 1, then the stream power would be inadequate to transport the sediment load and deposition or aggradation occurs. If the stream power exceeds critical power during long time spans, vertical erosion of a V-shaped valley occurs. If a stream is close to the threshold of critical power, lateral erosion will tend to dominate. Bull (2000) describes the process by which climate change, such as occurred during the Pleistocene-Holocene climate transition, affects alluvial fan processes. As annual rainfall decreases and temperature increases, soil moisture is reduced and vegetation density decreases. This, in turn, exposes soil to erosion while increasing direct runoff. Valley floor aggradation occurs until removal of hillslope colluvium and increase in bedrock exposure causes sediment concentrations to decrease and the erosive potential of a given rainfall event increases. With the decreased sediment load, the stream power/critical power ratio increases and vertical erosion occurs. McDonald, et al. (2003) attribute channel incision and fanhead trenching to an apparent increase in summer monsoon activity in the early Holocene.

The "Meander"

The "U"-shaped meander described above is a striking feature for several reasons. This topographic feature leaves little doubt as to what geomorphic processes were involved in its evolution. It clearly represents a relatively tight, meandering turn in a fluvial drainage system. It also represents an environment in the drainage system where the flow velocity and gradient of the drainage was relatively low (SP/CP ~ 1) and thus was formed during a time when the stream was close to equilibrium. Streams with higher velocity and steeper gradients (SP/CP > 1) tend to form braided or parallel drainages. The meander is clearly incised through the surrounding alluvial fan surface down into the underlying pediment and fine-grained Tertiary sedimentary rocks. Finally, the patina developed in the bottom of the meander is obviously much lighter than the surrounding Pleistocene fan surfaces, indicating a younger age for the meander bottom. At the same time, the bottom of the meander has a noticeably darker patina than the adjacent active channel just to the north.

Several lobes of fan material within the meander can be seen in the south and southwest portions that have a patina as dark as can be seen in the meander. These observations of the meander provide a clear chronology of the order of the development of this feature in the alluvial fan system in this part of the Desert Cahuilla. The alluvial fans were deposited in the Pleistocene with aggradation ceasing between 35,000 and 100,000 years ago. As the climate became warmer and drier in the late Pleistocene transitioning into the early Holocene, runoff increased as vegetative cover decreased due to lower soil moisture. With removal of hillslope colluvium and exposure of underlying bedrock, sediment loads eventually decreased, and runoff streams began incising into the Pleistocene fan surfaces.

During incision, the position of the meander would likely have been medial to distal in the alluvial fan system, and average stream velocity and gradient would have been relatively low. Over time, possibly due to a change in base level or increase in the gradient of the drainage due to extension and lowering of the center of the Salton Trough east of the Desert Cahuilla, drainage in the location of the meander changed to braided and parallel, and the meander was cut off from the active channel by additional incision of the channel, leaving the vertical cut seen between the meander floor and active channel floor on the upstream (west) limb of the meander (Figure 2). If this occurred in latest Pleistocene to mid-Holocene time, adequate time would be available for development of the relatively weak desert varnish seen in the bottom of the meander (Dohrenwend, et. al., 1991, Helms et. al., 2003). Subsequent erosion in the meander, primarily from the southwest, incised the downstream (east) limb of the meander where it meets the active channel.

Summary

Major deposition and aggradation of Pleistocene alluvial fans in the northern portion of the Desert Cahuilla likely ended approximately 35 to 100 thousand years ago, based on fan geomorphology and well developed desert varnish on flat, smooth fan surfaces. Tectonic activity and climate change are considered two major factors in alluvial fan evolution and their relative magnitude, and thus their contribution to determining fan morphology in any particular region varies. The Desert Cahuilla, while in a region of active faulting, shows little evidence of notable tectonic activity. Therefore, climate change likely was the significant factor shaping alluvial fan geomorphology and fan processes, in particular during the Pleistocene-Holocene climate transition. Climate during this period changed from wetter to drier and warmer. Resulting increased runoff during monsoon-type storm events due to decreased vegetative soil cover, coupled with low sediment load once hillslope colluvium had been stripped, caused incision of the alluvial fans and fan pediments in the region. During latest Pleistocene to mid-Holocene in the northwest Desert Cahuilla, low stream velocity and gradient, possibly due to relatively high base level and a medial to distal position in the fan system, allowed development of a meandering drainage pattern during incision of the fans. Eventually, possibly due to falling base level or steepening of the stream gradient, drainage shifted from meandering to braided and parallel channels. One stream meander, preserved in the fan pediment, underwent soil development but was otherwise relatively undisturbed until observed in late 2007 by an unsuspecting geologist in a light aircraft at 4,000 feet over the Desert Cahuilla.

Acknowledgements

First, I'd like to thank the Anza-Borrego Foundation and Desert Protective Council for initiating the project that led to the study of the Desert Cahuilla. They facilitated the discovery and observation of the meander which is the subject of this paper. Diana Lindsay sent the e-mail initially requesting a pilot, and accompanied the author on several of the overflights of the Desert Cahuilla. Lowell Lindsay, Phil Farquharson, Mike Hart, and Monte Murbach also accompanied the author on various flights and trips to the Anza-Borrego Region, and engaged in much of the initial discussion of the meander.

Miles Kenney accompanied the author on a flight over the Desert Cahuilla and noted the rarity of the abandoned meander in an arid alluvial fan environment. Miles also assisted the author in understanding alluvial fan processes, stream processes, and Anza-Borrego Desert Region stratigraphy, and provided much "reading" material. The papers Miles provided were of immeasurable value in assisting the author to develop this paper. Tom Rockwell also provided discussion and papers aiding the author in this paper. Miles and Tom both reviewed the initial manuscript and provided valuable input.

Finally I'd like to thank my wife, Cindy, for her patience whenever I become involved in a time-consuming and sometimes frustrating project like this one.

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The crew on the first reconnaisance flight over the Desert Cahuilla, September 23, 2007.
Left to right are Phil Farquharson, Diana Lindsay, Lowell Lindsay and the author.

Geology and Lore of the Northern Anza-Borrego Desert Region

The Lows to Highs of the Anza-Borrego Desert State Park

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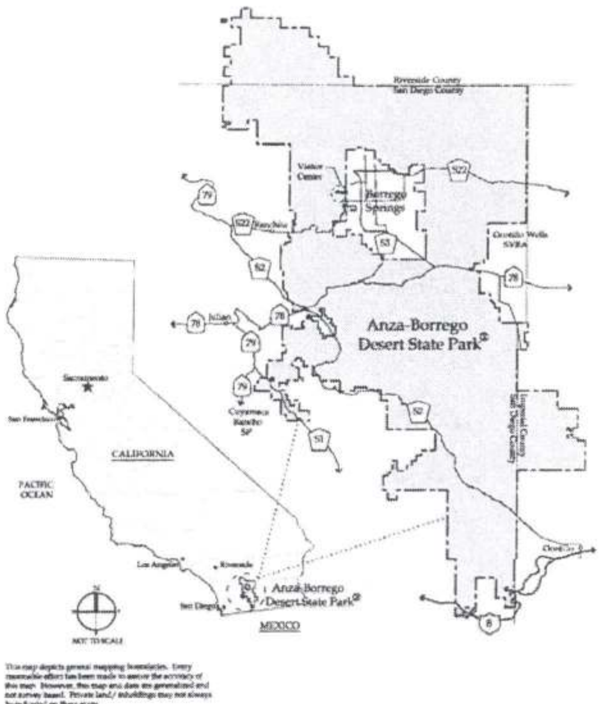

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