GEOMORPHIC RESPONSES AS INDICATORS OF PALEOCLIMATE AND CLIMATIC CHANGE

INTRODUCTION

It is, perhaps, fair to say that most geomorphologists now recognize climate as a fundamental control on the geomorphic processes operating at the Earth's surface. One would therefore expect a strong relationship between landform morphology and various climatic parameters such as precipitation and temperature, and in fact, this hypothesis now forms a major philosophical approach to geomorphic interpretation known as climatic geomorphology. Utilized primarily by European scientists (Tricart and Cailleux, 1972; Derbyshire, 1976; Budel, 1982), its underlying premise is that geomorphic processes vary spatially in type, rate, and magnitude according to the climatic regime in which they function. Landforms produced by these processes are thus assumed to vary regional and globally in accordance with climatic patterns.

There is little doubt that climate is an important parameter affecting the shape of the Earth's surface. However, as pointed out by Ritter et al. (1995), absolute observance to the principles of climatic geomorphology leads us away from the study of processes because the analyses passes directly from climate to landscape form. An alternative approach is to examine the effects of climate change on the nature of the processes operating in the near surface environment. Utilizing this methodology, the climate-process relations take on greater significance, and lead to an understanding of the response(s) of geomorphic systems to shifts in climatic regime (Ritter et al., 1995).

Given that geomorphic systems respond to changes in climate regime, it should also be

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true that delineation of the changes in the types, rates, and magnitudes of geomorphic processes will provide insights into the timing and nature of past shifts in climate, particularly effective moisture. It is this approach that has been utilized herein. Specifically, geomorphic responses in eolian, lacustrine, and fluvial systems that have resulted in erosional and depositional events have been documented for several sites in Nevada (Figure 1), and used to infer the timing and character of climatic change in the Basin and Range Physiographic Province. The results and conclusions of the specific studies are provided below.

GEOMORPHIC RESPONSES OF ALLUVIAL FAN SYSTEMS IN BUENA VISTA AND PAHRANAGAT VALLEYS, NEVADA: IMPLICATIONS CONCERNING CLIMATE CHANGE (Jerry R. Miller, John B. Ritter, Jennifer M. Husek, and Carol Thornton)

Introduction

Tectonism and climate are the primary variables considered in conceptual models of Quaternary alluvial fan evolution; however, their roles and relative importance with respect to periods of fan aggradation and entrenchment are far from resolved (J.B. Ritter et al., 1995). Early studies of Quaternary alluvial fans were conducted in tectonically active areas (e.g., Eckis, 1928) and emphasized the role of faulting in initiating source area erosion and fan aggradation (e.g., Davis, 1905; Blissenbach, 1954). Later studies related tectonism to morphologic features of alluvial fans including segmented radial fan profiles (Beaty, 1961; Bull, 1964), fan-head trenches (Denny, 1967; Hooke, 1967) and the development of fan complexes (Denny, 1967). Alternatively, Lustig (1965) argued that climate changes would alter stream regimen and vegetation density of the source area to a degree capable of affecting sediment supply. Such a geomorphic response would necessarily be widespread and characterized by synchronous periods

of aggradation and entrenchment for all fans in a region. This has been demonstrated in more recent fan studies (e.g., Pierce and Scott, 1982; Wells et al., 1987; Nemec and Postma, 1993). Importantly, if a causative link indeed exists between Quaternary alluvial fan activity and either extrinsic control (i.e., climate or tectonics), it may be possible to use alluvial fans in reconnaissance studies as a first-order indicator of either tectonic activity or climate change.

Understanding the role that extrinsic controls such as climate or tectonics play in Quaternary alluvial fan development is dependent on: (1) delineating stratigraphic relations between the alluvial fan and climatic/tectonic features or deposits, and (2) providing a temporal framework, locally constrained by radiometric dates. During this study, alluvial fans were examined in two basins of the Basin and Range Physiographic Province: Buena Vista Valley, located in north-central Nevada, and Pahrnagat Valley, located in south-eastern Nevada (Figure 1). The primary objectives of this investigation include: (1) the delineation of the surficial stratigraphy of alluvial fan deposits, (2) the correlation of alluvial fan stratigraphy to geomorphic features and deposits associated with paleoclimate and tectonism, (3) the comparison of alluvial fan stratigraphy to those developed locally as well as regionally (i.e., in the western U.S.), and (4) assessment of the driving forces leading to aggradation and entrenchment on alluvial fans in both Buena Vista Valley and Pahrnagat Valley.

Methodology

Alluvial fans in Buena Vista and Pahrnagat Valleys are comprised of time-stratigraphic units, each represented by a distinct geomorphic surface. The stratigraphy is defined here on the basis of topography, stratigraphic relationships, soil profile development, and surface

morphology. Fan deposits were initially delineated from aerial photographs in the laboratory using tonal and textural differences which were supplemented by field observations of relief between the units. Relative ages of deposits were substantiated by qualitative descriptions of soil profile development and surface morphology. Soil profiles were described for each fan deposit in soil pits and bank exposures according to the methods and nomenclature outlined by the Soil Conservation Service (1981) and Birkeland (1984). Laboratory analysis of soil particle size distribution was performed using the wet sieve/pipette techniques of Singer and Janitzky (1986). Surface morphologic properties include frequency of exposed clasts and relief of original depositional features, such as longitudinal bars on the fan surface. The relative-age methods used herein to characterize fan deposits include descriptions of desert varnish and rubification of surface clasts, as described by McFadden et al. (1989).

The Alluvial Fan Stratigraphy of Buena Vista Valley, North-Central Nevada: Implications for Climate Change on the Basis of Synchronous Geomorphic Responses on Alluvial Fans in a Semiarid Climate. (John B. Ritter, Jerry R. Miller, and Jennifer M. Husek)

Description of the Study Region

Buena Vista Valley is a north-northwest trending basin in the northern Great Basin, bordered on the west by the Humboldt Range and on the east and southeast by the East and Stillwater Ranges, respectively (Figure 2). Major external controls that might affect alluvial fan development include source area lithology, tectonism, climate and climate change, and base level. Alluvial fans sourced in the Humboldt Range are composed of sediments derived from the Triassic Prida Formation, a limestone and dolomite unit, to the north and the Rochester Rhyolite

to the south (Wallace et al., 1969; Tatlock et al., 1977). Alluvial fans sourced in the East Range are dominated by sediments derived from the Ordovician Valmy Formation, composed of argillite, chert, greenstone, and vitreous quartzite, and the Triassic Grass Valley and Raspberry Formations, which consist of weakly metamorphosed detrital rock units (Tatlock et al., 1977). Proximal alluvial fan deposits are faulted along both eastern and western margins of the basin, suggesting the area has been tectonically active since at least the middle Pleistocene. Drainage basin source areas and alluvial fans in Buena Vista Valley have experienced variable climates during the Quaternary Period. Past climates and climate changes are represented by the rise and fall of Lake Lahontan and its sub-basins. Buena Vista Valley is presently a closed basin; however, during the Pleistocene, it was a major subbasin of pluvial Lake Lahontan, which occupied the southern part of the basin during its late Pleistocene highstand (Figure 3). Base level for the alluvial fans in the study basin has varied between the elevations of the maximum highstand of Lake Lahontan (1330 m; Figure 3) and the present playa surface (1230 m). Because the alluvial fans increase in elevation from south to north in the basin and have been impact to varying degrees by pluvial lake level fluctuations, each fan has been exposed to a unique base level history (Figure 4).

Results

The eight mapped alluvial fans in Buena Vista Valley are composed of four fan-stratigraphic units including, from oldest to youngest, Qf1, Qf2, Qf3, and Qf4. Surficial geologic maps of American Canyon and Klondike Canyon alluvial fans illustrate the typical distribution

of alluvial fan units and their relation to lacustrine features and deposits in Buena Vista Valley (Figure 5).

Unit Qf1

Unit Qf1 is not present on all fans in the study area, but where present it is preserved in proximal fan areas, generally within the mountain front. Where associated with faulting, it is preserved on the upthrown block, and either buried or eroded on the downthrown block. Soils developed in Qf1 deposits are characterized by a truncated K horizon, the rubble of which is scattered across its surface.

Unit Qf2

Unit Qf2 is the dominant surficial alluvial deposit in Buena Vista Valley. Where exposed, Qf2 deposits are dominated by sheetflood deposits of well-sorted sands and gravels, but poorly-sorted debris flow deposits are also present. Soils are characterized by a Bt or Bw horizon overlying a Stage III-IV K horizon (Figure 6). In medial and distal fan areas, Qf2 is truncated by wave-cut benches and beach ridges. The ridges are constructional features with 1-2 m of relief, typically consisting of well sorted pebble- and granule-size gravels. Locally, they bury the Bt horizon of the Qf2 soil. The ridges tend to project along shore from the Zenith point of fans (point of maximum downfan deflection of fan contour), especially on those that protrude into the basin or occur at bends in the basin. Radiometric ages (AMS) from shells incorporated in ridge sediments range in age from 11,730 $\pm$ 60 to 13,560 $\pm$ 60 yrs B.P. (Table 1).

Unit Qf3

Unit Qf3 is inset into Qf2 in the proximal fan area and forms secondary fans in medial and distal fan areas. In proximal areas, Qf3 consists of both debris flow and sheetflood deposits, whereas in medial and distal areas, it is dominated by stratified, well-sorted sheetflood deposits. Soils developed in Qf3 are weakly developed, consisting of an A over Bk or Cox horizonation with Stage I carbonate morphology (Figure 7). In medial and distal areas, Qf3 abruptly truncates wave-cut beaches. Where fan channels cut across constructional beach ridge deposits, Qf3 sediments are often ponded above the ridge, locally burying the ridge, and radially splay at a point immediately downfan from the ridge. Where present, this pattern is typically repeated downfan over a series of 3 or 4 beach ridges (Figure 8). In distal fan areas, Qf3 and Qf4 deposits form distinct secondary fans. Mazama ash preserved near the top of proximal Qf3 deposits of two fans, indicates that Qf3 aggradation was well underway by 6,800 yrs. B.P. (Table 1). On at least one, the Willow Creek alluvial fan (Figure 2) which is characterized by an exceptionally well-exposed stratigraphic section in the proximal area, Qf3 deposits consist of internal cut and fill structures. A radiometric age on charcoal of 1,250+/-50 yrs B.P. indicates that proximal Qf3 deposits were entrenched and that entrenched channels were subsequently filled during the late Holocene (Table 1).

Unit Qf4

Unit Qf4 consists of the fan deposits associated with present fan channels. These channels are confined in proximal and medial fan areas and unconfined in distal areas.

Discussion

Alluvial fans in Buena Vista Valley formed during synchronous periods of aggradation, stability, and entrenchment during the late Quaternary. The similarity of particle size distribution and horizonation of soil profiles between fans Qf2 and Qf3 deposits (Figures 6 and 7) suggest that the respective units have been stable for similar periods of time. Because the Qf2 deposits are clearly truncated by beach erosional and constructional features, which in turn are truncated by Qf3 deposits, the depositional timing of units Qf2 and Qf3 relative to the filling and high stands of Lake Lahontan are also similar. The degree of soil development in Qf2 deposits, including those buried by beach ridge deposits (truncating a Bt horizon), indicate that Qf2 aggradation occurred during the early late Pleistocene, followed by a substantial period of fan stability. During the period, some minor fan entrenchment probably took place given that some beach ridges are inflected along incisions.

The abrupt truncation of wave-cut benches and beach ridges by Qf3 channels and deposits, the ponded and splayed morphology of Qf3 deposits where associated with ridges, and the apparent lack of reworking of Qf3 deposits by shoreline processes, indicate entrenchment of Qf2 fan deposits and aggradation of Qf3 deposits occurred during or following lake-recession. It follows that discharge from drainage basins in the Buena Vista Valley probably did not contribute significantly to Lake Lahontan; rather, the highstands of Lake Lahontan in Buena Vista Valley resulted from backfilling as the level of Lake Lahontan rose beyond the sill level separating it from this subbasin (Figure 3). On the basis of our correlation of Qf2 and Qf3 fan segments between fans around the basin and the synchronous nature and timing of aggradation, stability, and entrenchment, we infer that climate has controlled fan evolution in the Buena Vista

Valley. Extrinsic variables such as tectonism, base level, and basin lithology vary along the perimeter of the basin; however, their impact on fan evolution appears negligible as the Qf2 and Qf3 stratigraphy and their stratigraphic relation to beach features is consistent between fans.

The timing of fan aggradation, relative to the backfill of Lake Lahontan into the Buena Vista subbasin, suggests that it occurs during and following climate change from relatively moist to dry climates. Critical to our argument for climatically-driven fan aggradation and entrenchment is the regional synchronicity of fan aggradation and entrenchment. Tentative correlation with fans studied by Hawley and Wilson (1965) on the basis of segment morphology and surface characteristics, such as bar and swale topography and varnish cover, suggest the response was regional. Comparison of the alluvial fan stratigraphy in this region with the stratigraphies of other fan studies, conducted in both semiarid and arid climates, in the western U.S. (Figure 9) yields some interesting results. The alluvial fan stratigraphies from these studies are correlated with that developed in the Buena Vista Valley; the results are summarized in Figure 10.

The timing of fan aggradation in Buena Vista Valley is essentially contemporaneous with fan aggradation in other arid climates, including southeastern California (Wells et al., 1987; Ritter, 1987), and east central California and southwestern Nevada (Reheis et al., 1994 and in review). Wells et al. (1987) provided a process-response model for this sequence of fan aggradation and entrenchment. They proposed that increased rates of eolian deposition from pluvial lake desiccation influenced pedogenesis and infiltration-runoff relations; increased runoff from impermeable hillslopes, coupled with increased sediment availability due to a probable decrease in vegetation density, resulted in fan aggradation in spite of reduced effective

precipitation. Regional correlation of their alluvial fan stratigraphy by McFadden et al. (1989) indicates that such a response was widespread and occurred in basins underlain by different lithologies as well (Ritter, 1987).

In contrast to fans in the *arid* climates of Nevada and California, which aggraded in response to a change in climate, fans in the *semiarid* climates of Montana (Ritter et al., 1993, 1995), Idaho (Funk, 1976; Pierce and Scott, 1982), and New Mexico (Pazzaglia and Wells, 1990) aggraded during glacial climates, presumably characterized by a high effective moisture regime. In glaciated basins in southern Idaho and southwestern Montana, geomorphic surfaces underlain by fan gravels can be traced to moraines of Pinedale and Bull Lake age (Funk, 1976; Pierce and Scott, 1982; Ritter et al., 1993, 1995). More significantly, correlative surfaces in unglaciated basins in Idaho indicate that a glaciated source area was not necessary for fan aggradation to occur and suggest that maximum sediment and water discharge were associated with annual snowmelt during full glacial conditions (Pierce and Scott, 1982). In the northern Rio Grande rift, Pazzaglia and Wells (1990), have mapped and correlated Quaternary deposits in four major physiographic landscapes, one of which was composed of alluvial fans. The fans are comprised of three deposits, each temporally correlative to major periods of glaciation, including the youngest which was correlated to neoglaciation during the middle Holocene (Figure 10). Pazzaglia and Wells (1990) concluded on the basis of the regional correlation of Quaternary deposits between landscapes that while the various physiographic landscapes and their associated landforms owed their morphologic expression to tectonism, deposition within each landscape was influenced primarily by climatic fluctuations associated with glacial and interglacial events.

Conclusions

- (1) The surficial stratigraphy of alluvial fan deposits in Buena Vista Valley consists of four fan-stratigraphic units including, from oldest to youngest, Qf1, Qf2, Qf3, and Qf4.
- (2) While Qf1 may be as old as early middle Pleistocene, Qf2 is truncated by late Pleistocene beach deposits which are in turn truncated by Holocene Qf3 fan deposits. Qf4 is inset into late Holocene deposits and form the modern channel deposits.
- (3) Units Qf1, Qf2, and Qf3 correlate with Qoa, Qpl, and Qya, respectively, from the alluvial fan stratigraphy developed by Hawley and Wilson (1965). In addition, the units correlate with fan units from other studies conducted on arid alluvial fans; however, they do not directly correlate with fan units from studies conducted on alluvial fans in semiarid climates.
- (4) Stratigraphic relations with beach features and deposits, the relative timing of the fan units, and their correlation between fans in the study area as well as regionally suggest that climate change from wetter to drier conditions is the driving force behind fan aggradation. Entrenchment occurs in response to decreasing sediment supply in either a wet or dry climate.
- (5) Given the above, the fan deposits provide insights into the timing of major climatic shifts in north-central Nevada. Specifically, local discharge from drainage basins in Buena Vista Valley probably did not contribute significantly to the most recent building of pluvial Lake Lahontan. Rather, the highstand in

Buena Vista Valley is likely the result of backfilling from the Carson Sink as water levels rose above the sill separating the two subbasins.

Relations between Alluvial Fan and Axial Valley Stratigraphy in Pahrnagat Valley, South-Eastern Nevada: Implications to the Timing of Climatic Change (Carol Thornton, Jerry R. Miller, Dale F. Ritter, Nicholas Lancaster, and Kurt Cupp)

Description of the Study Region

Pahrnagat Valley is situated in Lincoln County, southeastern Nevada, approximately 80 miles north of Las Vegas (Figure 1). The geologic setting is typical of the Basin and Range Physiographic Province in that it is characterized by a series of generally north-south trending mountains, separated by alluviated valleys. Pahrnagat Valley trends in a northwesterly direction, and is bounded to the west by the East Pahrnagat Range, the southwest by the Sheep Range, and to the east (listed north to south) by the Hiko Range, the Alamo Range, and the Delmar Range. These ranges are composed of the Paleozoic Eureka Quartzite, as well as several Paleozoic carbonate formations which are unconformably overlain by Neogene pyroclastics, basalts, and lacustrine beds.

The specific area studied is located south of Lower Pahrnagat Lake (Figure 11) within the Pahrnagat Shear Zone, a series of northeast striking oblique left-lateral faults. These active faults cut undifferentiated alluvial fan deposits along the south end of the valley.

The axial drainage of Pahrnagat Valley is unusual for the Basin and Range Physiographic Province in that it is part of an integrated drainage system. Presumably, during periods of wetter climate, the valley contains a through flowing river, the White River, that is

integrated with the Muddy River, a tributary of the Colorado River. Presently, however, alluvial fans deposited by tributary streams block the axial drainage in several places, creating a series of shallow lakes, including Lower Pahranaagat Lake (Figure 11).

Results

Six alluvial-fan units were defined on the basis of topography, stratigraphic position, surface characteristics, and degree of soil development. They include from oldest to youngest, Qf1, Qf2, Qf3, Qf4, Qf5, and Qf6. Descriptions of these units are provided below.

Unit Qf1

Qf1 is a thin ($< \sim 10\text{m}$) fan unit that unconformably buries older Quaternary/Tertiary(?) alluvial fan deposits that have been eroded by the axial drainage. It is most extensively preserved in the medial and distal fan areas, and currently occupies about 35% of the total surface area of the fan complex. Where present, it has been extensively dissected and generally occurs as a series of rounded ridges, separated by younger fan surfaces. Less dissected areas exhibit well developed desert pavement. The original bar and swale topography has been replaced by single clast relief, and the larger interlocking surface clasts are typically characterized by thick, continuous coats of desert varnish. The soils developed in Qf1 are characterized by a Bt or Bw horizon overlying a thick Stage III+ K horizon.

Unit Qf2

In proximal fan areas, unit Qf2 buries unit Qf1 deposits. Farther down-fan, however, it is

inset into Qf1 and older alluvium (Figure 12). Unit Qf2 currently covers about 35% of the total fan area. The thickest exposures of Qf2 are in proximal reaches of the fan-head trench where it exceeds 15 meters. The deposits primarily consist of clast supported fluvial gravels composed of welded tuff, limestone, basalt, and occasionally quartzite and chert. Soils are characterized by a Bw horizon and an underlying Bk horizon with Stage III to III+ carbonate morphology. The surface of Qf2 is highly dissected but interfluvial ridges are not as rounded as Qf1 deposits. Surficial characteristics are similar to unit Qf1 with well-developed desert pavement consisting of interlocking clasts on the less dissected areas and thick, continuous desert varnish on the larger clast sizes. Original bar relief is no longer present.

Unit Qf3

Unit Qf3 is inset into Qf2, and is best preserved as a narrow deposit along the fan-head trench (Figure 12). The surficial characteristics are similar to Qf1 and Qf2 with a well-developed desert pavement and thick, continuous desert varnish on the larger clasts. Soils in Qf3 contain a Bk horizon with Stage II carbonate morphology.

Unit Qf4

Unit Qf4 is found primarily in the fan-head trench as small strath terraces that are generally associated with bedrock outcrops. Surficial characteristics include well-developed desert pavement and thick, continuous desert varnish on the larger clasts. The soils exhibit horizons with Stage I+ carbonate morphology.

Unit Qf5

Unit Qf5 is inset into units Qf1-Qf3 in the proximal and medial fan areas (Figure 12) and forms secondary fans in distal areas which extend onto the axial valley floor. The secondary fans originating from fan head trenches, presently form a topographic high which is responsible for creating Lower Pahranaagat Lake. Along the axial drainage, Qf5 deposits are buried by younger lacustrine sediments. A charcoal layer approximately 2 cm thick was found at Maynard Lake (Figure 11) in Qf5 fan deposits approximately 5 cm below the fan-lake sediment contact. The charcoal has been radiocarbon dated at 1,450 +/-90 yrs B.P. Bar and swale topography is present on Qf5 surfaces and soil development is very weak, consisting of A, Bk, and C horization. Secondary carbonate is present only as a soft powder on some clast bottoms below a depth of 10 cm.

Unit Qf6

Unit Qf6 consists of fan deposits associated with the modern drainages.

Discussion and Conclusions

A detailed understanding of the erosional and depositional events that have occurred in the lower reaches of Pahranaagat Valley, and a conceptual model of alluvial fan and axial drainage evolution has yet to be developed and will be provided at a later date. Specific conclusions which can be presented at this time are listed below.

- (1) Alluvial fans downvalley of Lower Pahranaagat Lake are characterized by six alluvial-fan units including, from oldest to youngest, Qf1, Qf2, Qf3, Qf4, Qf5, and Qf6. Units Qf1,

Qf2, and Qf5 represent the most extensive surficial fan units.

- (2) Preliminary interpretations of the data suggest that the erosional and depositional history of both the alluvial fans and axial drainage system of Pahrnagat Valley are intimately associated with changes in climatic regime. For example, during periods characterized by drier climate, such as the mid- to late-Holocene, the axial valley is characterized by a discontinuous flow system disrupted by secondary alluvial fans which have built across the valley floor. Shallow lakes are produced as surface waters are "dammed" behind topographic highs created by the secondary fans. Higher effective moisture conditions led to larger axial flows capable of eroding the distal portions of the secondary alluvial fan units. The result was the production of an integrated axial drainage system.
- (3) Extensive fan dissection and a lowering of base level, controlled by the elevation of the axial valley floor, appears to have occurred in the late Pleistocene or early Holocene. The development of Qf5 secondary alluvial fans had begun by 5,600 yrs. B.P. and ended by 1,450+/-90 yrs B.P. Qf5 secondary fans are responsible for the creation of Lower Pahrnagat Lake.
- (4) Lacustrine deposits which overlie Qf5 secondary fans suggest that an increase in effective moisture occurred shortly after 1450 yrs B.P. The magnitude of this climatic change was not sufficient to create an integrated axial flow system.

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