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Quaternary Evolution of the Klondike Canyon Alluvial Fan: Implications to Climatic, Tectonic, and Base Level Controls on Alluvial Fan Development

A thesis submitted in partial fulfillment of the

requirements for the degree of Master of Science in

Hydrology/Hydrogeology

by

Jennifer M. Husek

Dr. Jerry R. Miller, Thesis Advisor

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UMI Number: 1376633

UMI
300 North Zeeb Road
Ann Arbor, MI 48103

The thesis of Jennifer M. Huesk is approved:

Miller

Thesis Advisor

Department Chair

Judith A Sugar

Dean, Graduate School

University of Nevada

Reno

August 1995

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ABSTRACT

Climate change, tectonic activity, and base level alterations are considered controls on alluvial fan evolution, but varying conclusions exist on their relative importance The purpose of this study is to define the roles of these parameters on the development of the Klondike Canyon alluvial fan, Buena Vista valley, north-central Nevada.

Major conclusions of this study are based in large part on the delineation of alluvial and lacustrine deposits defined on the fan complex Four alluvial fan units ranging in age from mid Pleistocene to Holocene were delineated and mapped Major episodes of fan building appear to be related to changes in climate, perhaps a shift from wetter to drier conditions. Interestingly, stratigraphic relations between fan and lacustrine units indicate that significant fan deposition was not associated with the rise of Pluvial Lake Lahontan suggesting that Buena Vista valley filled by overflow from the Carson Sink via Chocolate Butte sill.

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Introduction

Many models have been put forth to explain the controls on alluvial fan evolution. These models focus on three driving forces which are tectonic activity, base level change, and climate change. Although these forces have been studied extensively in diverse tectonic and climatic regimes, their relative importance is still disputed (for example Ritter et al. 1993, 1994; Wells et al. 1987; and DeCelles et al. 1991).

Tectonics has often been concluded to be the primary factor in both unconsolidated and paleo-rock sequences. For example, Heward (1978) and Nilsen (1982) include tectonics in the general facies models for ancient alluvial fans. The models interpret depositional sequences to be associated with tectonic activity that rejuvenates source areas resulting in cycles of fan growth. Tectonism has also been suggested as the primary control of sedimentation in orogenic zones (DeCelles et al. 1991 and Hartley 1993). The evidence presented in these studies are angular unconformities truncating the upper boundaries of alluvial fan units, and the existence of large fan units indicative of tectonically-produced source-area relief required for their long term development. Cyclical, coarsening upward fan sequences have also been related to recurrent fault activity (Steel et al., 1977; Heward, 1978; and Nichols, 1987) that can rejuvenate the source area and enhance the production of sediments which are deposited on the fan.

Quaternary studies have also emphasized the role of faulting in primarily initiating cycles of alluvial fan aggradation. The evidence utilized in these studies includes the identification of fault scarps, folding, topographic effects or dynamic metamorphism. For example, faulting has been used by Denny (1967) and Hooke (1967) as the initiator of fan head trenches, and Denny (1967) described how a mid-fan scarp would initiate a headcut in the feeder channel forming a fan head trench. Hooke (1967) shows how a tectonic uplift can lead to coarse-grained debris flows.

Faulting has been cited as the initiator of segmented radial fan profiles by Bull (1964) and Beatty (1961). For instance, Bull demonstrated how tectonic uplift caused the stream to downcut forming a terrace, whereas farther onto the fan, the channel adjustment was manifested by deposition atop older units. The product of this process was fan segmentation. Faulting was also interpreted to be the cause of the development of fan complexes (Denny, 1967) because of the change in the loci of deposition by fanhead trenching and stream capture processes.

Base level changes have been cited as a control on alluvial fan development. Schumm (1993) notes, for example, how local changes may induce stream aggradation and degradation, and Steel et al. (1977) suggest that coarsening-upward sequences may represent aggrading base level conditions as movement of the loci of deposition toward the mountain front allows coarser-grained material to be deposited near the apex. A lowering of base level may create a fan head trench.

Schumm (1977) has suggested that these aggradational and degradational adjustments may accumulate through reactions referred to as complex response. An example of this phenomena begins with a rise in local base level. Initially the coarser-grained sediments are deposited near the apex. However, the coarse-grained sediments may build up a "barrier" that increases fan gradient. An intrinsic threshold is crossed and the stream channel downcuts forming a fan head trench

Climate change controls the sediment/water ratio by not only affecting the amount of water put into the system (Gellis 1991) but also by the type and density of vegetation present (Langbein and Schumm 1958). As a result, the effect of an increase in precipitation may lead to either an increase in sediment load, and therefore fan aggradation, or a decrease in load and fan entrenchment The first scenario applies if the source area is arid prior to an increase in effective moisture. The second applies if the source area is already humid and vegetated, because the increased precipitation would just increase the amount of vegetation.

Many recent studies of Quaternary alluvial fan evolution have used geomorphic features, paleoenvironmental data or regional stratigraphic correlation to show that climate can be a primary control on fan development. These studies include Pierce and Scott (1982), Wells et al. (1987), Nemec and Postma (1993), Ritter et al. (1993) and Ritter et al. (1994). For example, Ritter et al. (1993, 1994) used geomorphic features and paleoenvironmental data by tracing alluvial fan units directly to glacial moraines, and Wells et al. (1987) compared the age of their alluvial fan units to dated pack rat middens which provided regional timing and nature of climatic changes. A climate change is widespread, affecting many drainage basins with the same type of change, therefore the geomorphic response would be "...widespread and characterized by synchronous periods of aggradation and entrenchment for all fans in a region" (Ritter et al. 1994).

Objectives

The primary purpose of this study is to decipher the relative roles of climate change, tectonics, and base level alterations on the development of the Klondike Canyon alluvial fan. Secondary objectives are to gain a better understanding of Pluvial Lake Lahontan Lake level fluctuations and the relationships between lacustrine and fluvial processes.

Geologic and Geographic Setting

The Klondike Canyon alluvial fan is located within Buena Vista Valley in north-central Nevada, approximately 60 km southwest of Winnemucca (fig. 1). The valley covers an area of approximately 133 km^2 and is bounded on the west by the Humboldt Range and on the east by the East and Stillwater Ranges (fig 1). As is typical of the Basin and Range physiographic province, it was created by extensional tectonism which began in the Miocene. Although no fault scarps were detected on the fan, neotectonic maps of Buena Vista Valley show fault scarps in the area of Klondike Canyon with the age of early to mid Pleistocene to late Pleistocene (Dohrenwend and Moring 1991). The general location of the fault scarps are range-front. Also, tectonic rebounding associated with the drying of the pluvial lake systems is occurring (Mifflin and Wheat 1979).

Buena Vista Valley has also been subjected to significant Quaternary climatic change. These changes have been recorded by a host of parameters including lacustrine and eolian deposits (Morrison 1991, Benson and Thompson 1987, and Benson 1990), tree rings (Rose and Wigand in press, Rose 1995, and Graybill 1987), and fossil pollen

BUENA VISTA VALLEY LOCATION MAP

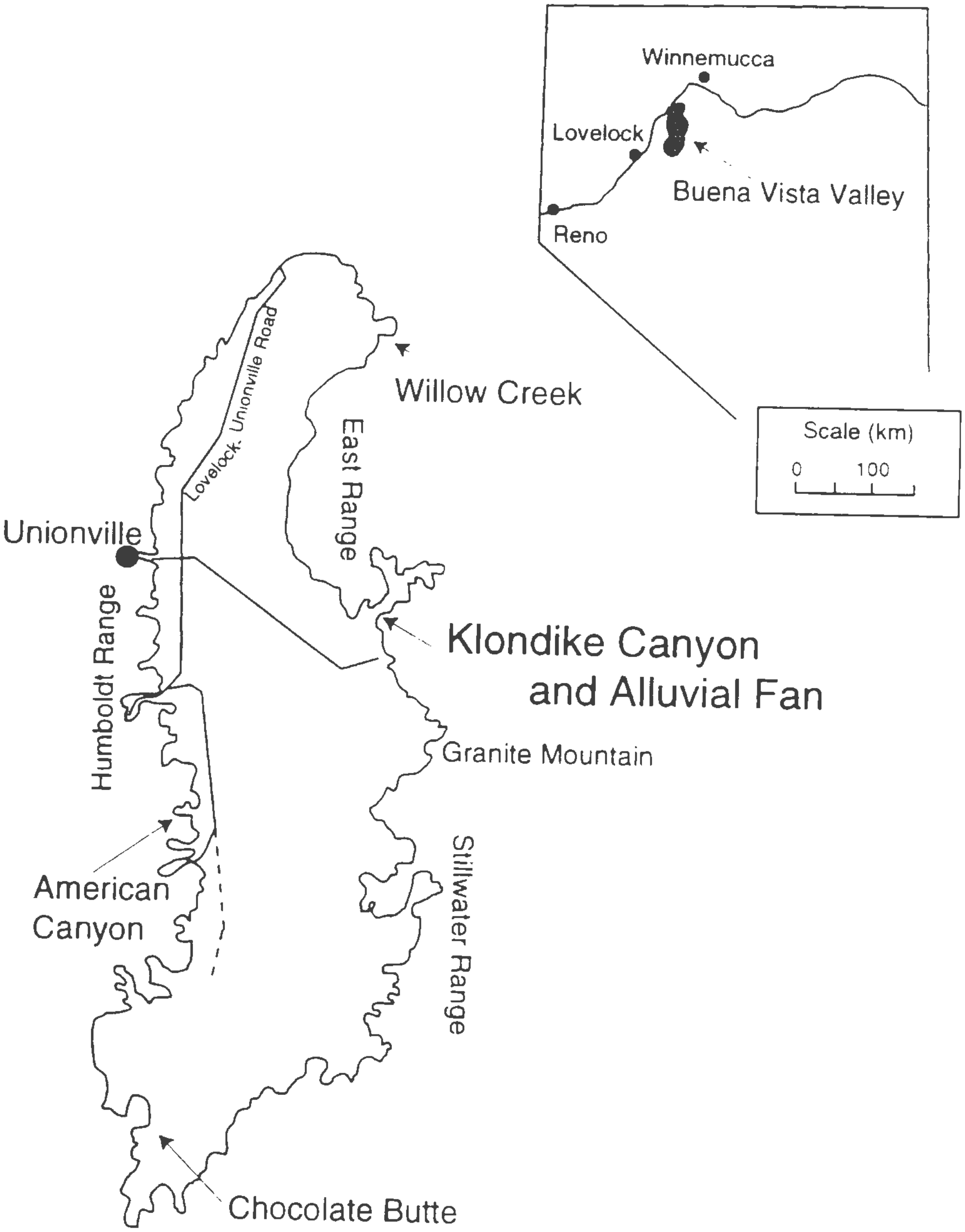


Figure 1: Location map of study area

and pack rat middens (Wigand et al. Desert Research Institute, and Rose and Wigand in press). These climatic shifts were likely to have impacted runoff and sediment yields as well as altered pluvial lake levels and, therefore, base level.

Local base level has also changed as Buena Vista is a hydrologically-closed basin and pluvial lake levels have changed considerably. (For a complete description of Pluvial Lake Lahontan cycles refer to Morrison 1991, Benson and Thompson 1987, Benson et al. 1990, and Benson 1993). Morrison (1991) declared about the Great Basin, "Few other areas in this country have equivalent exposed completeness of stratigraphic detail..., sensitivity to climatic change, and opportunity for chronometric control."

As shown above, the Klondike Canyon fan and watershed has been subjected to tectonic activity, climate change and base level alterations. It therefore provides an excellent setting to study the influence of these three variables on alluvial fan formation.

The drainage basin which feeds the Klondike Canyon alluvial fan is approximately 55 km^2. The watershed is underlain primarily by the Leach formation (plate 1) which consists of altered basic volcanics and pyroclastics with significant quantities of dark chert and siliceous argillite. Beds of dark vitreous quartzite are found at the top of the formation. Interbedded slate, limestone, and conglomerates are found at the forks of Leach Canyon (Stewart and Carlson 1978).

Methods

Interpretations derived during this investigation rely heavily on the alluvial and lacustrine stratigraphy of the Klondike Canyon Alluvial Fan Complex. Quaternary stratigraphic units were delineated on the basis of topographic and stratigraphic position, clast lithology, grain-size distribution, surface micro-relief, degree of desert pavement development, thickness of desert varnish on surface of clasts, and soil profile development. Topographic positions of the alluvial and lacustrine units were quantified using radial and cross-fan surveys obtained with a Nikon Total Station, DTM-5. Elevational data was collected using a Ashtech Global Positioning System Model XII with an accuracy capability of 2 cm horizontally and 4 cm vertically. The positions of these transects are shown on figure 2.

Surficial characteristics of the alluvial fan and lacustrine units were obtained using 25-m transects, following the methods described in McFadden et al (1989). The transect data were collected on each alluvial fan unit and two lacustrine units in areas without noticeable erosion (fig. 2). Lithology, grain size, desert varnish and rubification data were collected using the largest clast at every 1-m interval. The degree of desert pavement development and surface micro-relief was done at a reconnaissance scale

Soil profile development was described in the classification system put forth by Birkeland (1984). Each pit was located in flat-lying areas displaying stable characteristics; that is, they were devoid of vegetation and rills (fig 2). The pits were approximately 1 m in depth and hand-excavated. Soil samples were extracted from profile horizons. Laboratory analysis was conducted in the soils/sedimentology lab at the Desert Research Institute. Particle size analysis was performed using wet-sieving/pipette techniques following the procedures of Day (1965). Soil pH was acquired using an

KLONDIKE CANYON ALLUVIAL FAN: SITE LOCATION MAP

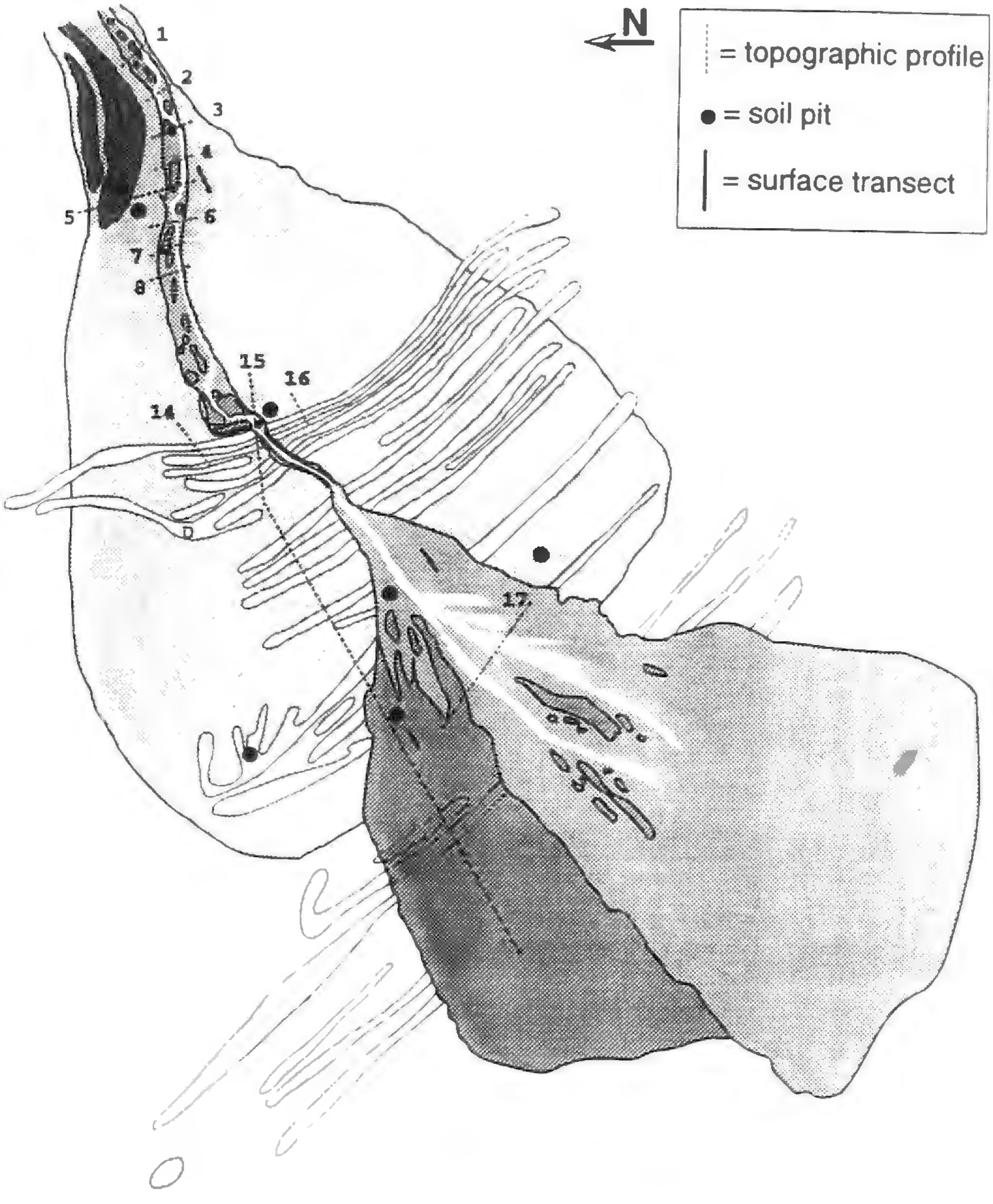


Figure 2: Surficial geologic map of the Klondike Canyon Alluvial Fan. Note the location of topographic profiles, soil pits, and surface transects.

electric pH meter in 0 01 M calcium chloride (Peech, 1965) Quantification of soil profile development was conducted using the Harden Index (Harden 1982).

The Harden Index is a method which quantifies soil development in order to compare soils from different areas. Each soil horizon in a given geomorphic unit is analyzed for color, structure, dry consistency, wet consistency, texture, clay films, $CaCO_3$ development, and pH. Each variable is compared to the parent material and is assigned a number specified by the Harden Index. For example, translocated clays are assumed to accumulate through time. Therefore, the horizon would be assigned a large number if it had significantly more clay than the parent material These numbers are then normalized, divided by the number of properties, and multiplied by the depth of the horizon in order to obtain the Harden Index Exact number increments and normalizations for each variable can be found in Harden (1982).

The measurements reported in tables throughout the documents were obtained with a hand-held planimeter from orthophotoquads. The reported number is an average of three measurements Although the planimeter has the capability for six significant figures, the measurements are reported to two significant figures and without errors.

Calibrated ages on the datable materials were obtained through BETA Analytic Inc. Samples were pretreated with acid etching and dated with AMS C^{14}. The locations of the dated material were correlated to transects using the Global Positioning System and Total Station surveys.

Results

Four alluvial fan units were delineated and mapped on the Klondike Canyon alluvial fan (fig. 3). The alluvial units from oldest to youngest are Quaternary fan unit 1 (Qf1), Quaternary fan unit 2 (Qf2), Quaternary fan unit 3 (Qf3), and Quaternary fan unit 4 (Qf4). The general morphology that characterizes each unit is shown in table 1. Other geomorphic units in the area developed during the last high stand of Pluvial Lake Lahontan. These are bars which are the linear features labeled alphabetically from A to M.

Description of alluvial fan units

Quaternary fan unit 1

Qf1 covers an area of approximately 0.22 km^2 (table 1) The unit is only locally preserved at the fan apex along the mountain front and covers the smallest area of any fan unit described. The surface of Qf1 contains a micro-relief less than one clast diameter and is devoid of bar and swale topography. Qf1 is characterized by a desert pavement exhibiting interlocking clasts. Desert varnish on clast surfaces is continuous around volcanic lithologies while rubification occurs on the bottoms and in pits of quartz clasts (fig. 4). The transect data is summarized in Table 2.

KLONDIKE CANYON ALLUVIAL FAN

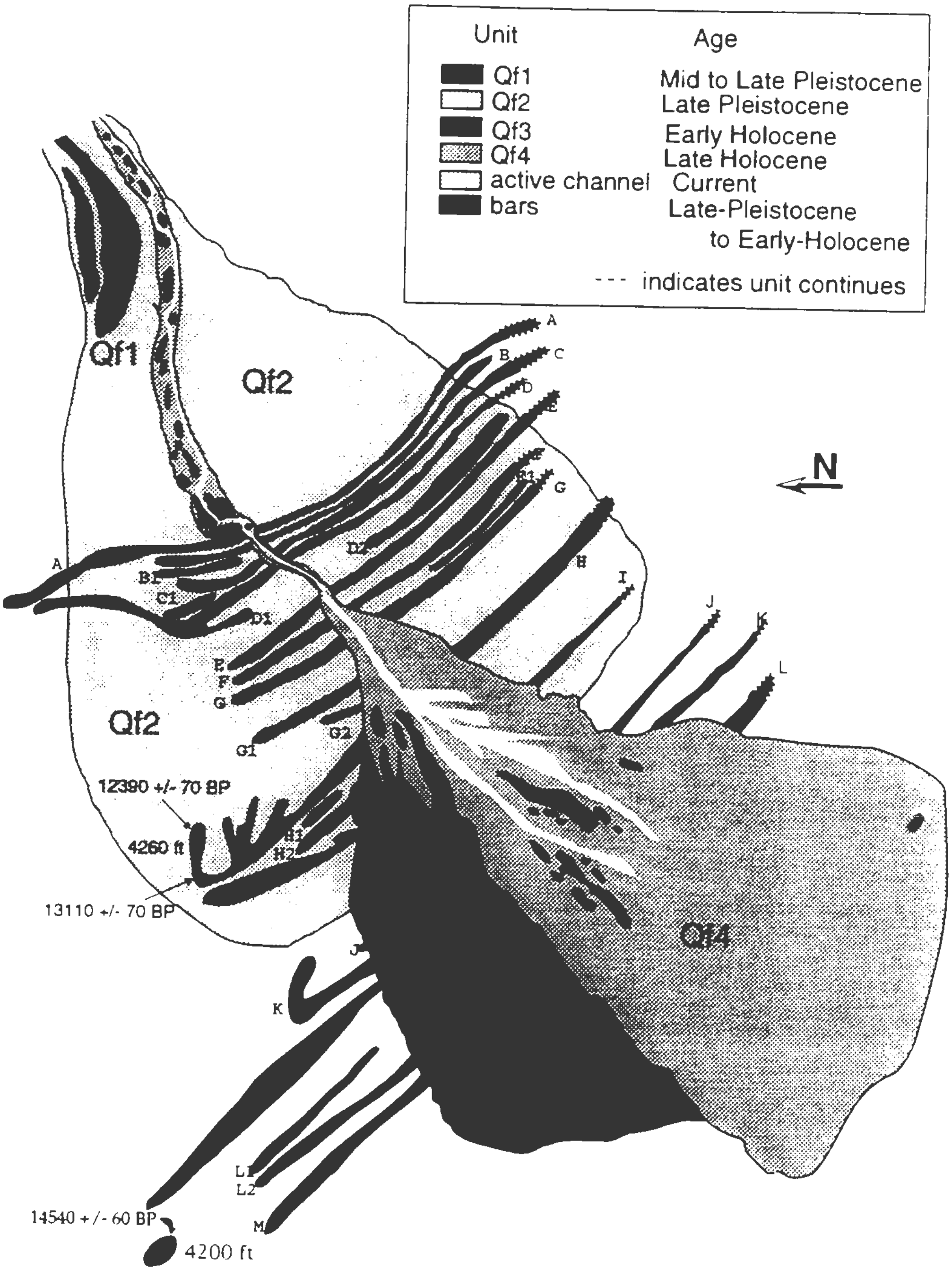
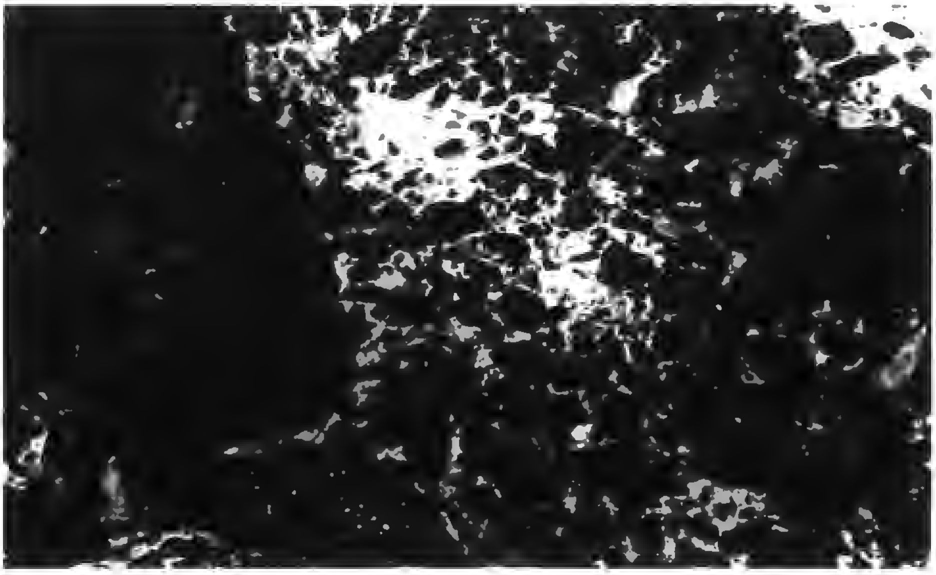


Figure 3: Surficial geologic map of Klondike Canyon Alluvial Fan based on aerial photographs. Scale = 1:30,100.

SURFICIAL CHARACTERISTICS

A.



B.

Figure 4: **A**. Quaternary fan unit 1. Note the desert pavement and desert varnish. **B**. Quaternary fan unit 2. Note the desert pavement and desert varnish.

Table 1: Summary of Alluvial Fan Unit Morphology

Fan Unit	Area (km2)	Width (km)	Length (km)	Change in Height (km)	Average Gradient
Total	26	2.7	7.4	1.5	0.20
Qf1	0.22	0.17	1.1	0.18	0.16
Qf2	18	5.0	5.6	1.2	0.21
Qf3	1.7	0.70	2.9	0.30	0.10
Qf4	5.7	2.3	4.4	0.58	0.13

Soil profiles in Qf1 sediments are characterized by Btk horizons that are approximately 20 cm thick. These horizons are associated with significant increases in soil clay (fig. 5). The Harden index (Harden 1982) calculated a profile index of 18 (fig. 6). The complete soil descriptions including laboratory results are presented in Appendix I.

The sedimentology of Qf1 was similar at each site examined. It is composed of clast-supported, well-sorted, sub-angular clasts suggestive of sheetflood deposition. Clasts range from pebbles to cobbles.

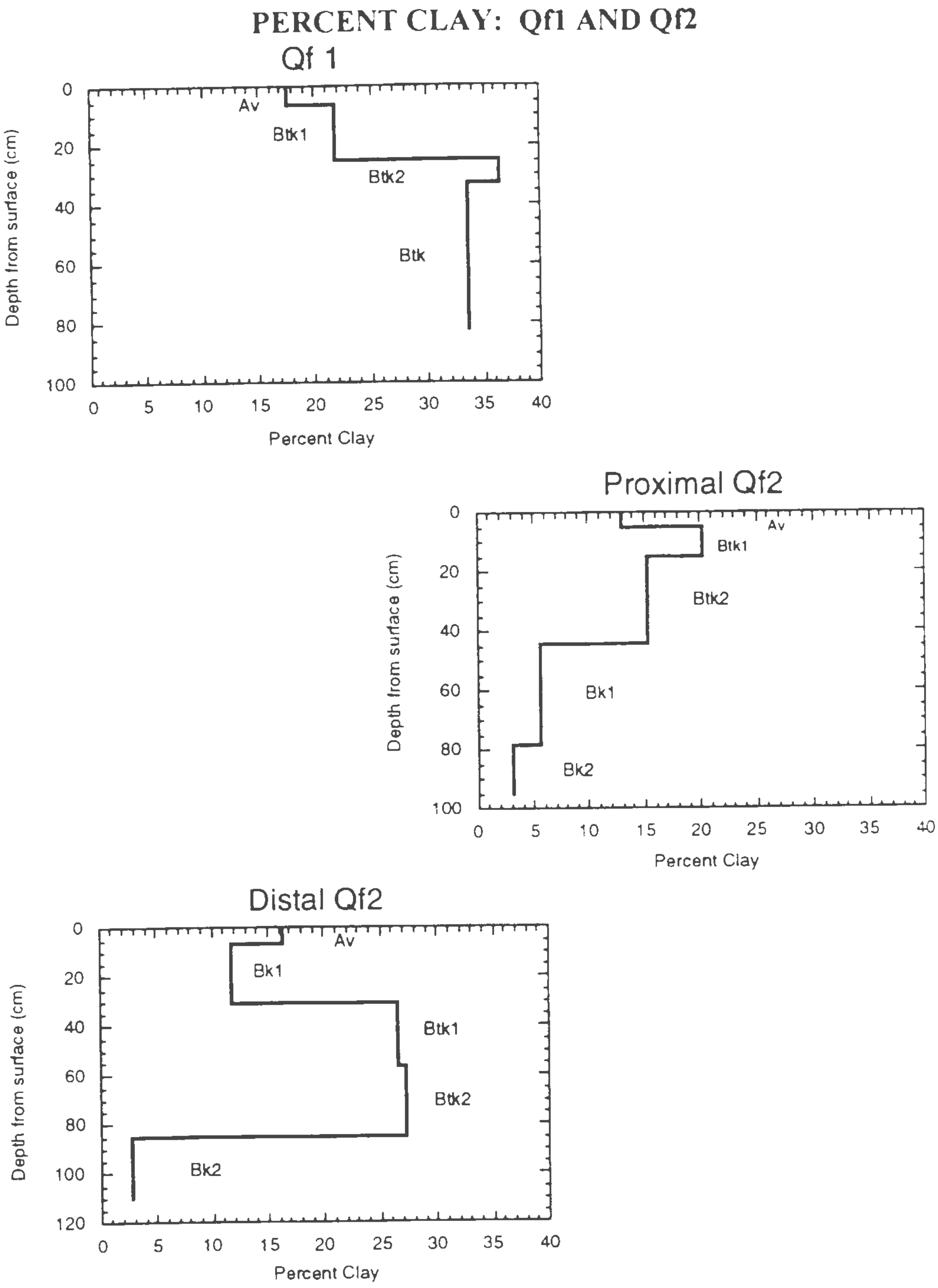


Figure 5: Clay content for Qf1, Qf2 proximal and Qf2 distal fan areas. Particle size analysis conducted by wet sieving/pipette method (Day 1965).

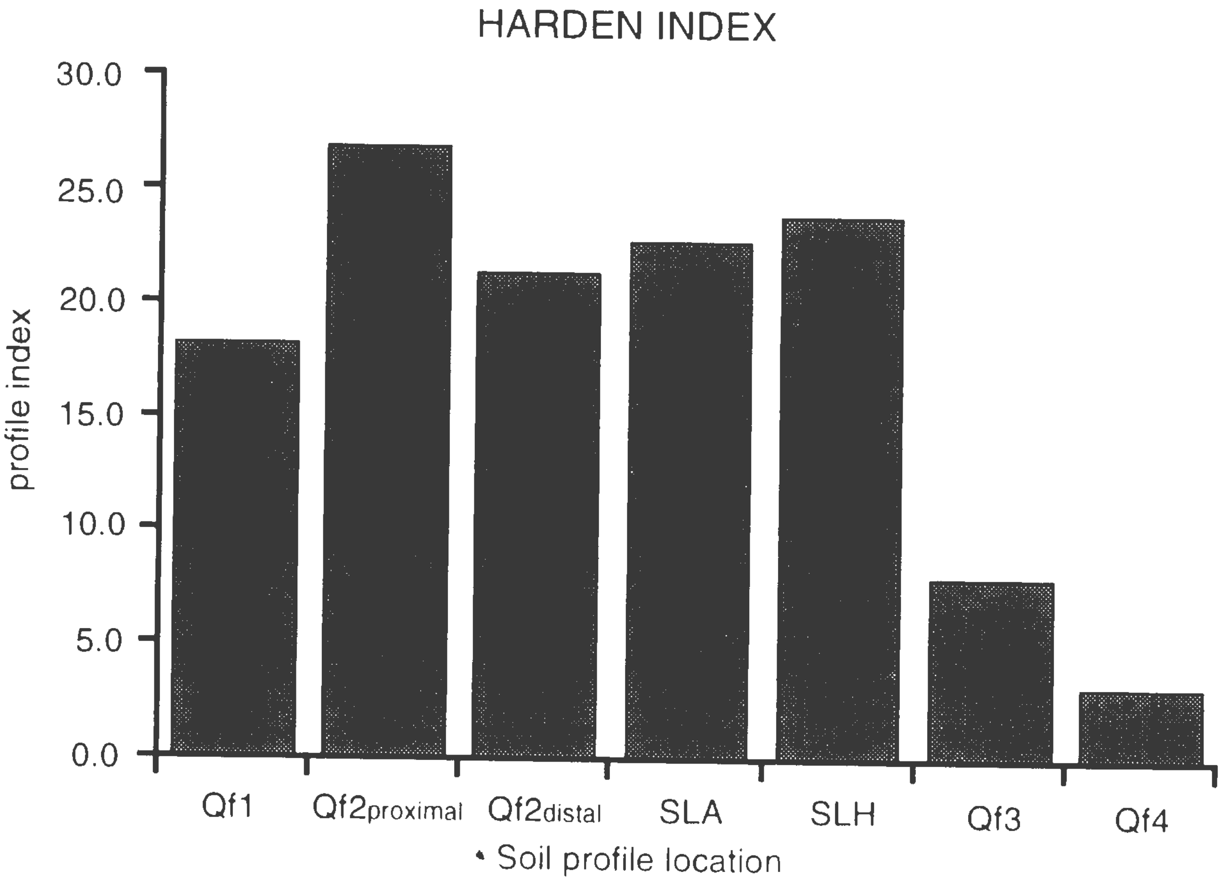


Figure 6: Soil profile level was quantified using the Harden Index.

Table 2: Surficial Characteristics of Fan Units

Unit	Maximum size of clasts	Maximum varnish	Rubification
Qf1	cobbles	100%	yes
Qf2	cobbles	100%	yes
Qf3 proximal	boulders	100%	yes
Qf3 distal	boulders	50%	yes
Qf4	boulders	20%	yes

Quaternary fan unit 2

The most extensive unit is Qf2. Its surficial characteristics and aerial extent are well-preserved in proximal, medial, and distal areas. Qf2, which is inset into Qf1 (fig. 3), has similar surficial characteristics as Qf1 (table 2 and fig. 4). In the proximal and medial areas, the surficial micro-relief is less than one clast diameter, the desert pavement is fully interlocking, and the desert varnish thickly coats volcanic clasts. The distal area has been reworked during more recent lake level high stands, and therefore does not possess a completely interlocking desert pavement. The desert varnish and surface micro-relief exhibit similar characteristics as the proximal areas. The preserved extent of Qf2 is 18 km^2.

A distinguishing feature which has eroded away Qf2 is the fanhead trench. Figure 7 shows a topographic profile of the fanhead trench. (Appendix II also contains surveys of fanhead trench) An estimated 2,700,000 m^3 of sediment have been removed from Qf2.

The soils and stratigraphy of Qf2 are very similar to Qf1. In proximal fan areas, soils exhibit a Btk horizon approximately 30 cm thick (fig. 5) Distal fan soils possess thicker horizons up to 50 cm. The complete description of the soil profiles are in Appendix I. The Harden index was calculated to be 27 and 21 for the proximal and distal areas, respectively (fig. 6). The sedimentology of Qf2 is similar to Qf1 Qf2 is clast-supported, well sorted, and sub-angular. Clasts range from pebble to cobble size Sheetflood deposition appears to have been the dominant depositional process

Quaternary fan 3

In proximal areas Qf3 is inset into Qf1 and Qf2 deposits. In medial and distal fan areas, Qf3 buries the older units. The total area of Qf3 is 1.7 km^2. Qf3 characteristics vary significantly downfan. Qf3 occurs as remnants in the upper fanhead trench and as preserved, fan-shaped deposits in the distal area. Table 2 notes some of the differences between the proximal and distal areas, but field observations revealed other differences as well. For example, surface micro-relief is small to none in the proximal areas whereas remnant bar and swale topography is prominent in distal areas (fig. 8). Boulder-size clasts are located in these bars which reach a maximum height of 50 cm. Desert pavement is characterized by completely interlocking clasts in the proximal areas and by separated aggregates of interlocking clasts in low-lying, protected areas in distal areas.

FAN-HEAD TRENCH: TOPOGRAPHIC SURVEYS

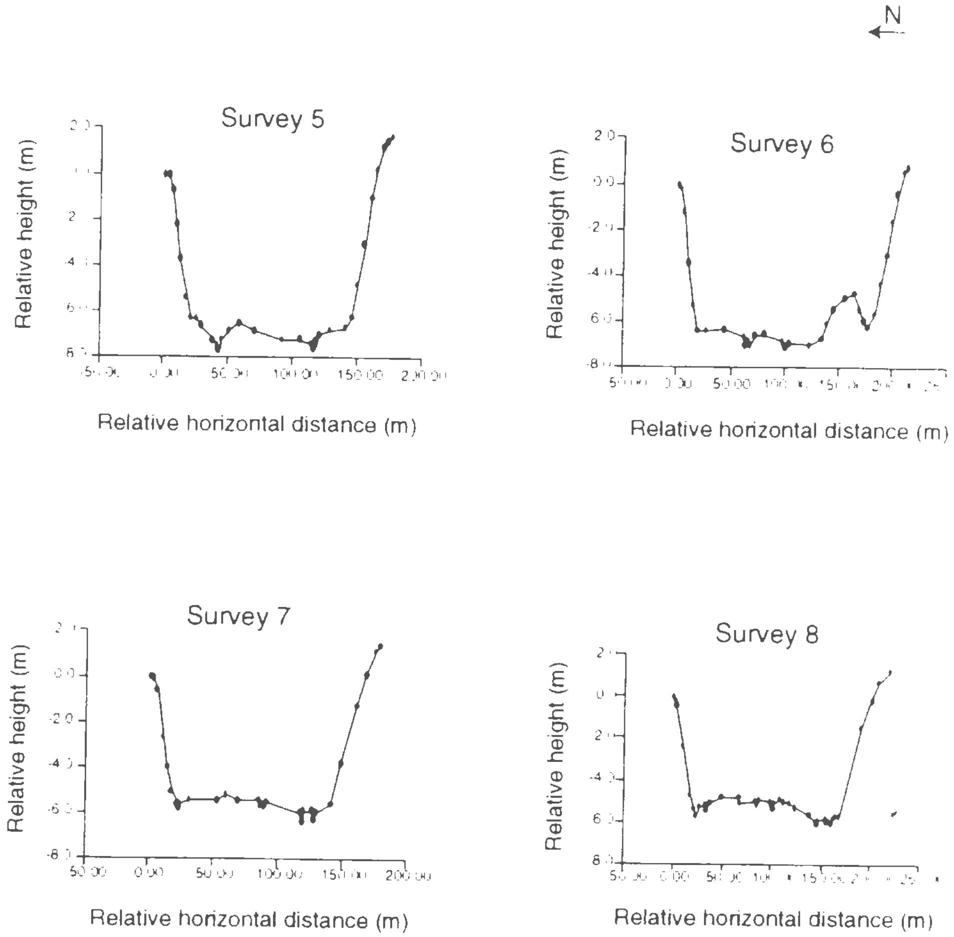


Figure 7: Field-surveyed profiles of the Klondike Canyon fan-head trench. Survey 1 is closest to the mountain front. There are 200 feet intervals between surveys moving down fan. Note the decrease in trench size away from mountain. Location of surveys noted on figure 2.

SURFICIAL CHARACTERISTICS

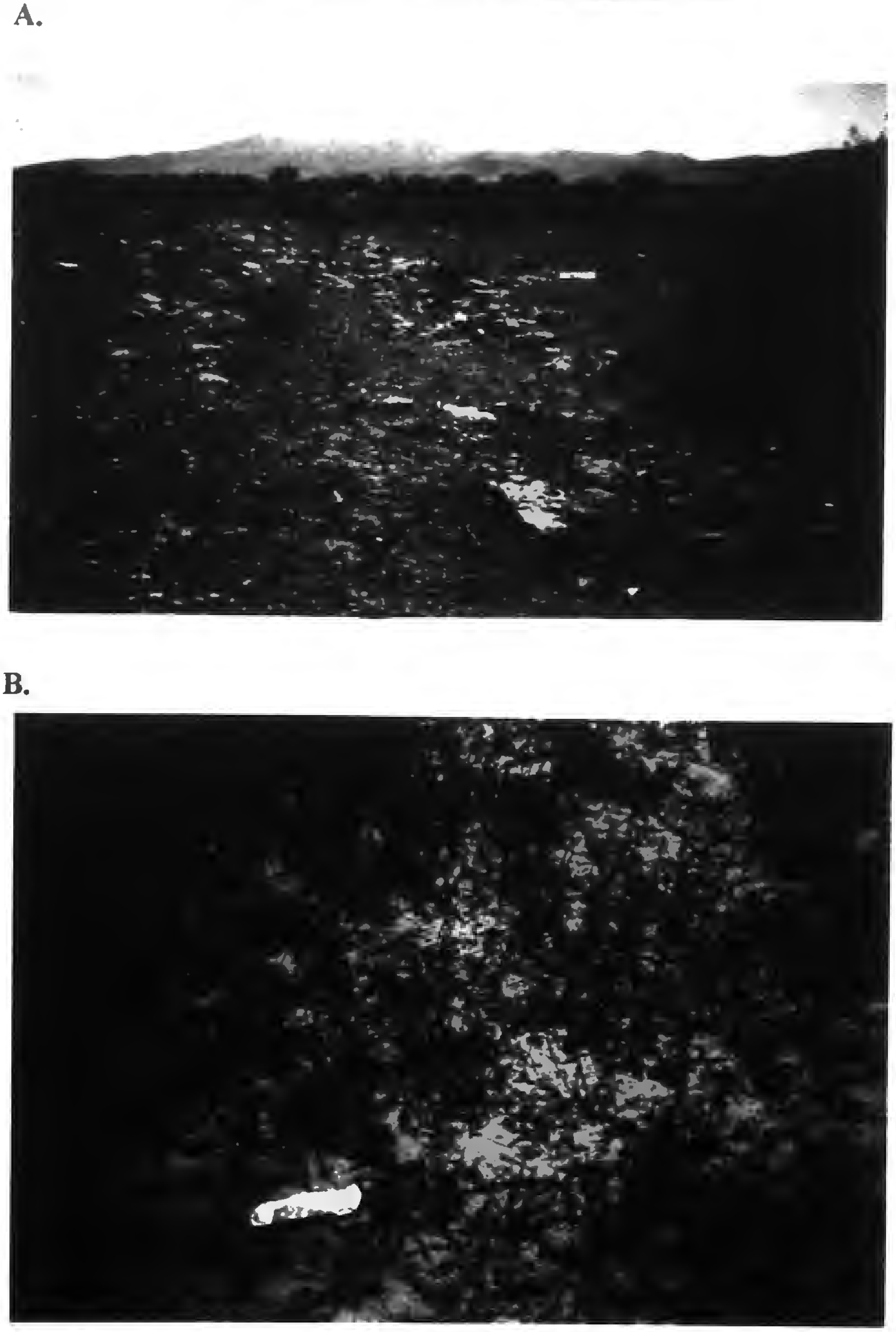


Figure 8: **A.** Quaternary fan unit 3. Note the bar and swale topography. **B.** Quaternary fan unit 4. Note the fine-grained texture.

The soil profile depicted in figure 9 is located in Qf3 distal deposits. The soil is weakly developed without significant clay accumulation. The profile displays a calcareous horizon approximately 50+ cm thick. The Harden index was calculated to be 8 (fig. 6).

Quaternary fan 4

The youngest alluvial unit, Qf4, covers an area of 5.7 km^2. It is inset into Qf3 and older deposits in proximal and medial fan areas and buries these alluvial fan units in distal areas. Within the fanhead trench, Qf4 contains few fine-grained sediments, and the pebbles are unconsolidated. In the distal area more fines (silts) overly and are dispersed within the deposits (fig. 8). Bar and swale topography is prominent throughout. Desert pavement does not exist and desert varnish reaches a maximum of 20% cover on volcanic clasts. The main clast discoloration occurs as rubification which is located only on the bottoms of clasts.

The soil profile in figure 9 is located in distal Qf4 deposits. The thickness of Qf4 in this area (fig. 2) is approximately 40 cm. The profile index produced by the Harden index is 3 (fig. 6).

PERCENT CLAY: Qf3 AND Qf4

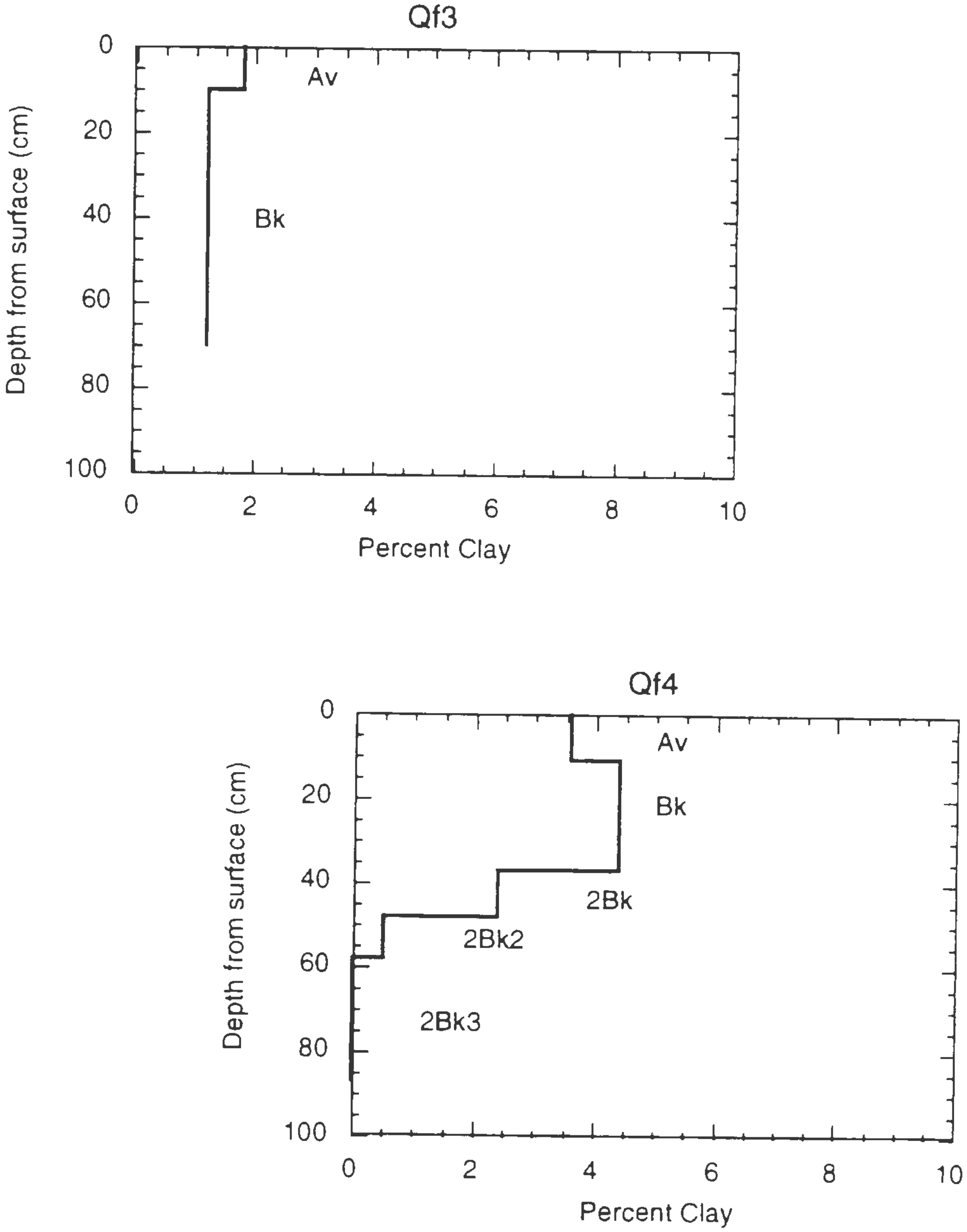


Figure 9: Clay accumulation in soil profiles from Qf3 and Qf4. See figure 2 for soil pit locations.

Lacustrine Deposits

Several lacustrine deposits or ridges overlie or are truncated by alluvial fan units of the Klondike Canyon alluvial fan (fig. 3). They have been labeled in alphabetical order from proximal to distal fan areas. The parent material of the lacustrine ridges differs from the alluvial units because of the nature of the nature of deposition. The highest lacustrine deposit was formed in relatively shallow water, because of the well-preserved desert pavement and desert varnish located on Qf2 just above the deposit. They were deposited in a high-energy environment that resulted in very well rounded, very smooth and very well sorted cobbles with very few fines The bedding is thin to medium, and while most dip towards the mountain front, the dip and strike does vary within one deposit. The deposits exhibit positive relief, are linear ridges, have constant elevations, parallel one another, and are constructional. These characteristics are consistent from bars A to M. Because of the above mentioned characteristics, these deposits have been referred to as bars.

The approximate volume of sediments contained in the bars is 4,118,000 m^3 as determined by aerial photography and topographic surveys. Observation of the map (fig 3) reveals that some of the bars are linear while others exhibit recurve spits or "hooks" on the end. All of the bars in the Klondike Canyon area are depositional features.

The best preserved bars are nearer the mountain front. The surfaces of the bars have little to no micro-relief, and the bars are capped by a completely interlocking system of desert pavement. Vegetation is absent from the top of the bars. The gently sloping sides of the bars are characterized by poorly developed desert pavement, but highly developed desert varnish. The volcanic clasts are completely covered by desert varnish and the quartz clasts exhibit rubification.

Representative soil profiles were described on bar A and bar H. Bar H is approximately 25 m lower than bar A. The soil development of the bars show no significant clay accumulation (fig. 10). The soils exhibit some calcareous accumulation. The Harden index constructed a profile index of 23 and 24 for bar A and bar H respectively (fig. 6).

The bars overly Qf2 and are truncated by Qf3 and Qf4. The bars are sitting on top Qf2 pavement and soils buried under the highest shoreline in Qf2 at American Canyon (fig. 1). Qf3 and Qf4 cut through the bars in one main channel. Then the Qf3 and Qf4 alluvial deposits are deposited over and around the bars located below the intersection point.

Stratigraphic Ages

Three C^{14} dates were obtained from the bar deposits on Klondike Canyon fan. The dated materials were identified as *Vorticifex (Parapholyx) solida* by Saxon Sharpe (pers. comm. 1994) at the Desert Research Institute. These molluscs are found in fresh water lakes of Nevada and California (Burch 1989).

The oldest date, 14,540 +/- 60 B.P., was collected from a sandy unit sandwiched between rounded, well-sorted pebbles which have been interpreted to be a constructional bar. Figure 3 shows the location and figures 11 and 12 show the stratigraphy of the dated shells.

PERCENT CLAY: SHORELINES A & H

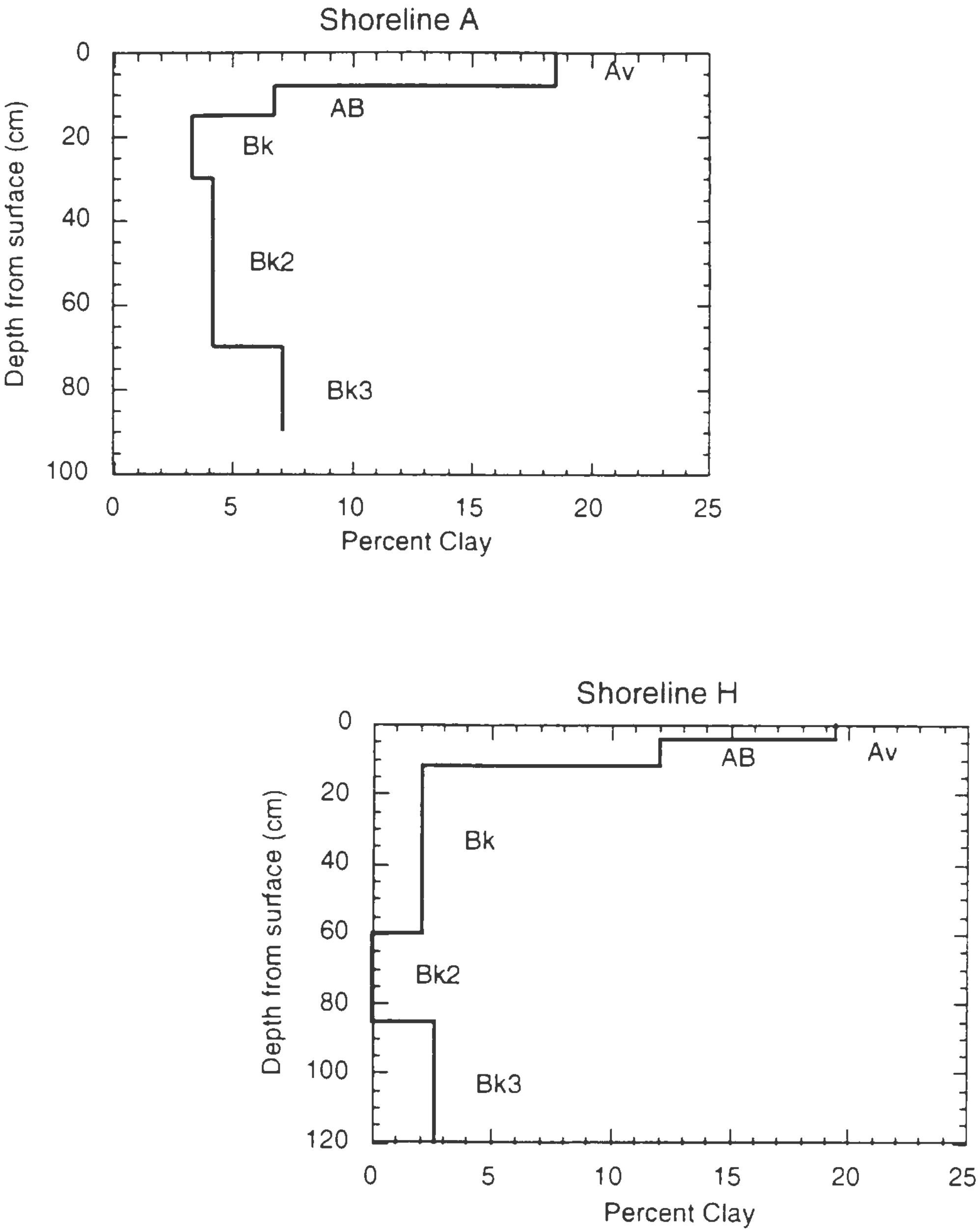
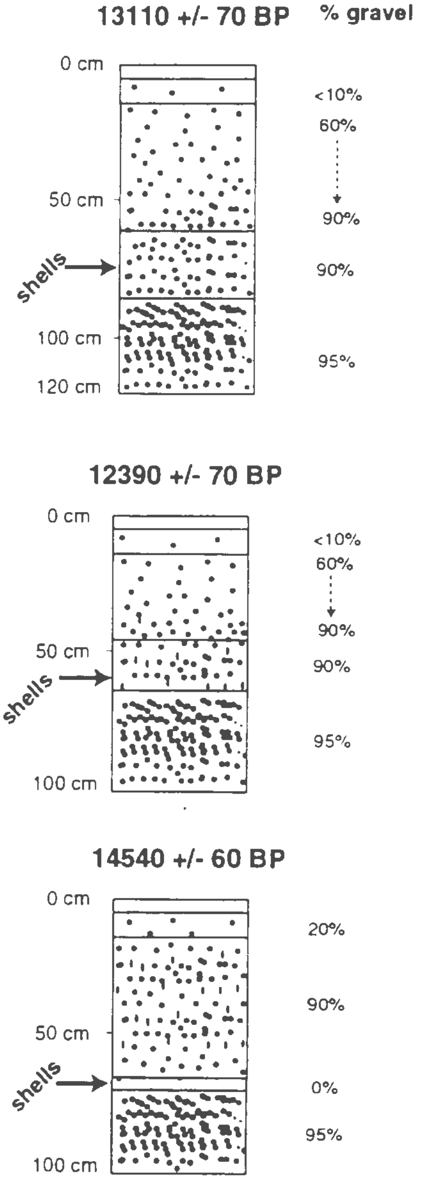


Figure 10: Clay accumulation in soil profiles developed in shorelines A and H. See figure 2 for soil pit locations.

SHELL STRATIGRAPHY



description

The uppermost layer is the Av soil horizon.

The second lyer has weel-rounded, well-sorted clasts with translocated fines.

The third layer has well-rounded, well-sorted clasts. The undulating beds cross-cut and have varying slopes. The gravel increases with depth.

The fourth layer contains the shells. It has similar bedding features The shells were located in a completely carbonate-cemented area Tufa was also located in this layer.

Down to 120 cm was more well-rounded well-sorted clasts. The bedding features were the same.

The stratigraphy of this profile is the same as the 13110 date. The two profiles are in the same unit. The uppermost layer is the Av soil horizon.
The second layer has translocated fines

The third layer has well-rounded, well-sorted clasts. The bedding features are undulating, cross-cutting, and varying slopes
The amount of gravel increases with depth.

The fourth layer contains the shells. It has the same stratigraphy as the layer above except for the cemented sediments containing the shells and the tufa.

The bottom layer has the same stratigraphy.

The uppermost layer is the Av soil horizon

The second layer has translocated fines with well-rounded, well-sorted clasts.

The third layer is dominated by well-rounded, well-sorted clasts The bedding features are undulating, cross-cutting, and have varying slopes.

The shells are found in a layer of uncemented sand.

The bottom layer has the same stratigraphy.

Figure 11: Stratigraphy of shorelines where shells were located.

SHELL STRATIGRAPHY

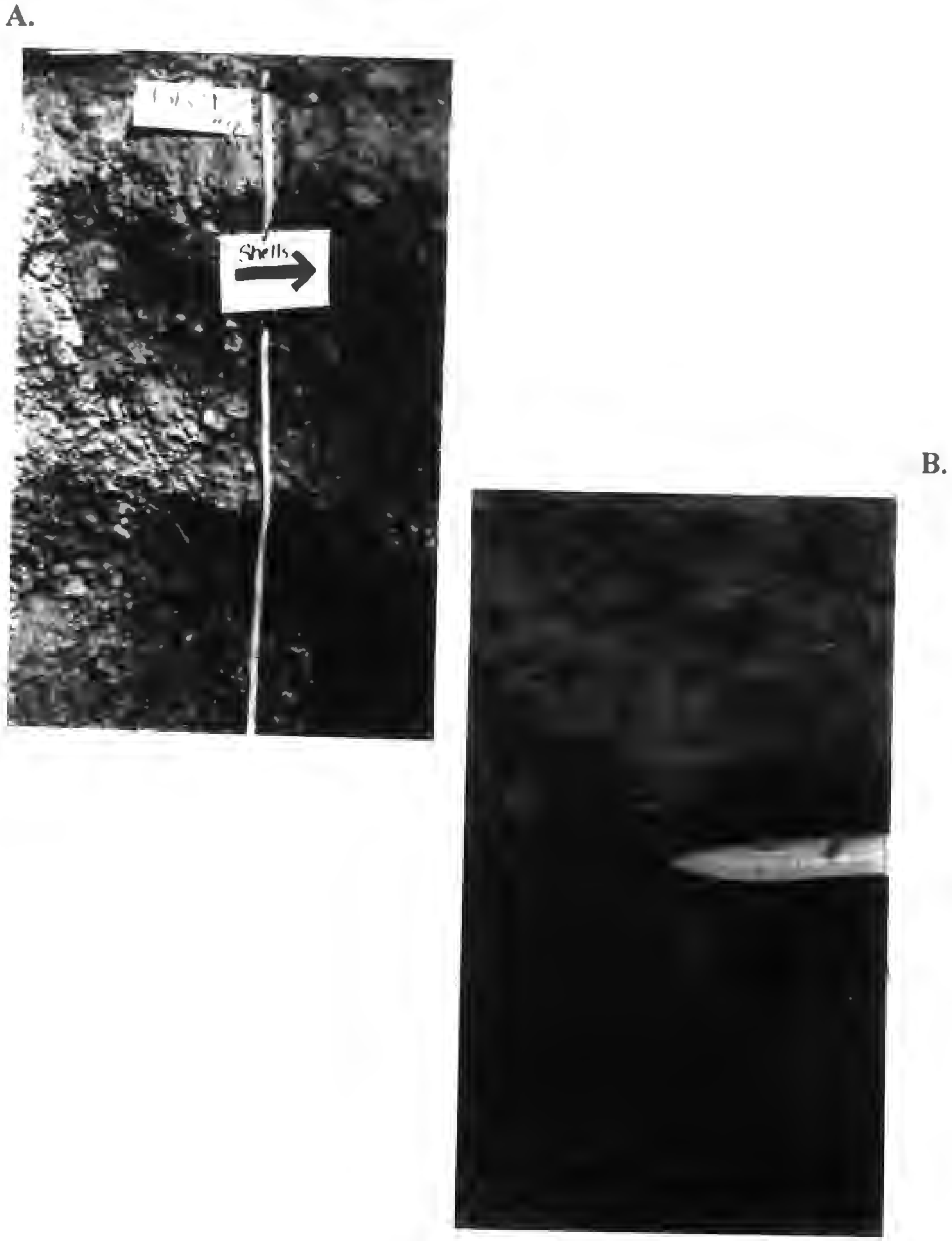


Figure 12: **A.** Bar H, dated at 12390+/-70 B.P. **B.** Remnant bar, dated at 14540+/-60 B.P. Locations of bars are shown on figure 2.

The other 2 dates, 13,110 +/- 70 B P. and 12,390 +/- 70 B P., were obtained from shells found in bar H. Their locations are approximately 75 m apart (fig. 3) within the same stratigraphic layer (figs. 11 and 12). The bar is approximately 25 m below the highest bar.

Discussion

Timing of Alluvial Fan Development

Information assembled from many different sources lead to a general model foi the timing of geomorphic events and responses for the formation of the Klondike Canyon alluvial fan. The timing of geomorphic events is critical because it is the primary indication of the relative importance of climate change, tectonic activity, and base level controls on Klondike Canyon alluvial fan evolution. These sources include surficial and soil characteristics exhibited within Qf1, Qf2, Qf3, and Qf4. They also include dates obtained from Klondike Canyon and cross-valley-correlated units. These cross-valley units were dated by Ritter and Miller (in progress) who are conducting a study of alluvial fans throughout the valley.

Relative Chronology

The relative chronology of all units can be determined by examining the map of Klondike Canyon Alluvial Fan (fig. 3). (The description of the chronology refers to the map throughout.) Qf1 is the oldest preserved unit and is poorly preserved due to substantial reworking during subsequent fan building. It is located above the intersection point and is higher in elevation than other fan surfaces. Therefore, the stratigraphic relationships with other alluvial fan units demonstrates Qf1 is older than any other unit. The soils in Qf1 are the highest in clay content (figs 5 and 9) which also resolves Qf1 to be relatively the oldest unit.

Qf2 is then inset into Qf1, and is therefore younger than Qf1. Qf2 surficial and soil characteristics suggest that both Qf1 and Qf2 are of similar ages. The soil does contain Btk horizons, however the percent clay is less than Qf1 which indicates Qf2 is relatively younger.

Soil and surficial difference between Qf2 and the lacustrine units are not founded mainly because of the different parent materials. However, the stratigraphy clearly shows Qf2 is relatively older than the bars, because the bars lie atop Qf2. It is also clear that Qf3 and Qf4 are relatively younger than the bars, because these alluvial units cut through the bars.

The relative differences in alluvial units can be studied by the soil and surficial characteristics, because the units have similar parent material which originated in Klondike Canyon. Soil and surficial differences between Qf2 and Qf3 suggest Qf2 remained relatively undisturbed for a long period of time before the rise of Lake Lahontan during its last pluvial cycle which deposited bars over Qf2 Qf2 contains 20% clay in the Btk1 horizon. Qf3 contains 2% clay which is not enough for a Bt designation. This difference in clay content reveals Qf2 is relatively older than Qf3. The complete desert pavement coverage in Qf2 compared to the scattered assemblages of desert pavement in distal Qf3 is also evidence showing the relative age difference. Another indication of the stability of Qf2 before the rise of Pluvial Lake Lahontan is a buried soil. Across the valley at American Canyon (fig. 1), an excavated pit shows that the highest bar, A, buries the soil in deposits which correlate with Qf2 (Ritter and Miller in progress). This indicates Qf2 was stable long enough for a soil with a Bt horizon to form before Pluvial Lake Lahontan reached its high stand.

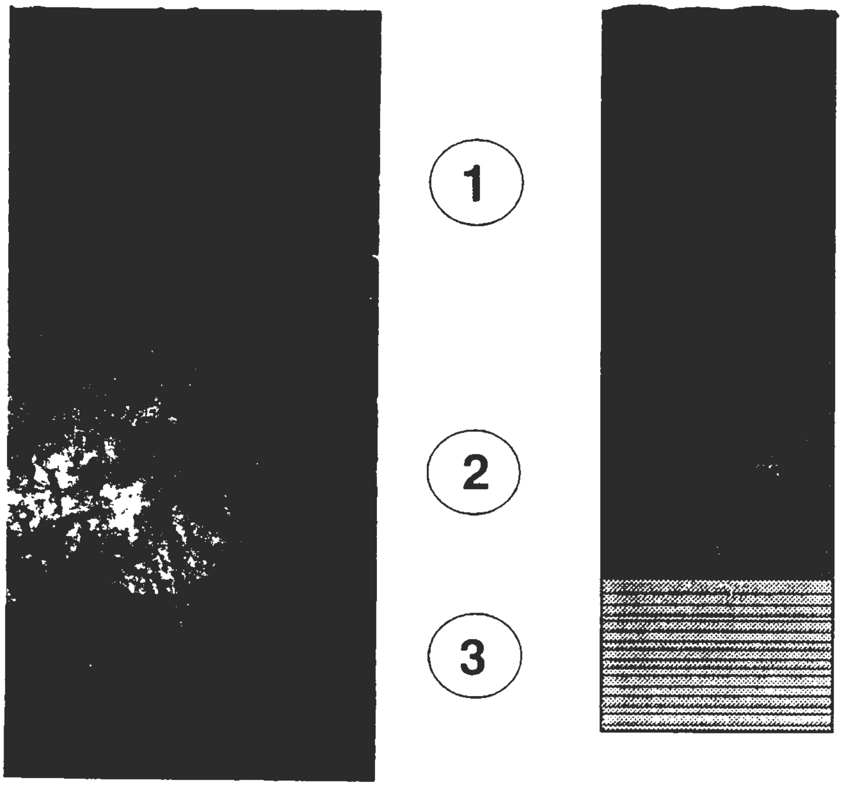
Insights into the rise of Pluvial Lake Lahontan can be extracted from the dates associated with the lacustrine bars. These dates are marked on figure three, and observation reveals that they are not in a chronological order relative to the perceived model of formation. This suggests that 1) the bar was deposited during lake level rise and a portion of the bar has been preserved through lake level high stand and fall or 2) there was a fall in lake level from at least the elevation of the older shells to at least the elevation of the younger shells and then the rise in lake level to the high stand before lake desiccation. Evidence for a remnant deposit mainly lies in the different morphology relative to other bars in Klondike Canyon because it: 1) does not parallel the mountain front, 2) is not linear, and 3) is not extensive in length. Also, analysis of the stratigraphy reveals that the sediments have not been eroded from older lacustrine units and redeposited (figs. 11 and 12). Redeposition is eliminated because 1) the shells were found in a fine-grained layer sandwiched between two gravel units, and 2) the shells are extremely fragile and would be destroyed during extended movement.

Some of the bars have different morphologies in that they exhibit recurve spits. This indicates a progradation into deeper water and possibly a longer lake-level stability (Kochel, pers. com.). The process which formed the recurve spits was currents flowing out of the southwest. Evidence lithology of the clasts in the bars. The main lithologic indicator is granite Granite is not found in Klondike Canyon and is located only at Granite Mountain which is south of the study area (Plate 1) No granite is found north of the study area at an elevation low enough for lake levels to have reached. Therefore, long-shore currents coming from the south were carrying sediments from Granite Mountain to be deposited in the bars at Klondike Canyon.

Qf3 then cut the fanhead trench in Qf2 and eroded through the bars. On the map of Klondike Canyon Alluvial Fan (fig. 3), bars J and K are dashed. This indicates that portions of the bars are buried by and protrude through Qf3. The sediments were deposited over and around the bars, but not enough material was available to totally bury them.

The processes involved in the development of Qf3 are unique in that the time-transgressive nature has been recorded due to unusual circumstances. As lake levels dropped, bars were left perpendicular to the mountain front and to flow/sediments coming from the range. When the flow from the drainage basin carrying Qf3 sediment reached the first bar, it could not overtop the protruding bar surface and ponded on the upslope side of the constructional feature. Stratigraphic sections examined upslope of the bars indicates that breaching required multiple events. For example, figure 13 shows the stratigraphy/sedimentology on the upslope side of the highest bar (A). There are three distinct units which are indicative of different depositional environments. The oldest unit has very well-sorted, fine-grained sediments which are laminar and representative of a calm environment. The middle stratigraphic unit contains coarser grained sediments with paleo-channels indicating a higher energy regime. An unconfomity marks the top of the

STRATIGRAPHY ON THE UPSLOPE SIDE OF BAR A



1. The top layer is similar to the alluvial deposits of Qf1 and Qf2. The layer is matrix supported with subangular, poorly sorted cobbles. The layer is capped by interlocking desert pavement. The deposit is indicative of sheetflood deposition.

2. The middle layer consists of medium-grained fines with a few cobbles. The most distinguishing features are the small paleo-channels. They are about 30 cm wide. The breach of the shoreline occurred during the time between 1 and 2.

3. The bottom layer is fine- to medium-grained sediments. It is thinly- to medium-bedded. These features represent a calm, settling deposition. This is indicative the environment of the mini-playas.

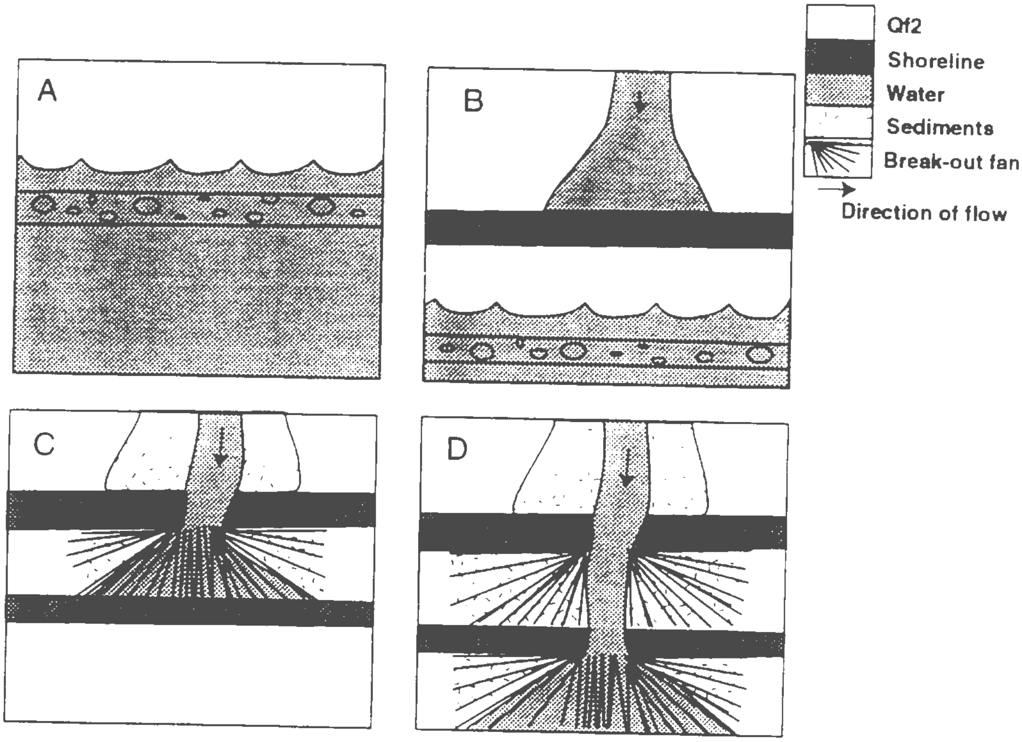
Figure 13: Diagram of stratigraphy found on the upslope side of SLA at Klondike Canyon. The stratigraphy has recorded the ponding of water, movement through the channels and deposition of alluvial materials.

middle layer when the bar was breached and the ponded water broke through. The youngest layer is then very similar to Qf2 deposits in stratigraphy and surficial characteristic, but it is the proximal Qf3 unit. A detailed explanation is given in figure 13.

Another piece of evidence for the ponding is the mini-playas on the upslope side of random bars. These mini-playas are being formed by current-day processes where water is trapped and evaporated from the surface, thereby leaving the salts to accumulate. If this ponding is occurring now, it may be indicative of the past environment.

At some time the feature was either not high enough or strong enough to hold back the ponded flow/sediments and the bar was breached. The process involved in the breaching is unclear, but it was probably an overtopping followed by downcutting. At this time the lake level was at least below the bar which was being breached, because of the features which are preserved on the down slope side of the bar. These features are "break-out" fans. They are similar to an alluvial fan in that they radiate from a single point, the breach in the bar deposition and are cone-shaped. The break-out fans were presumably formed when water broke through the bar. During the breaching process, the water/sediments then briefly moved the sediments eroded from the bar during breaching, and redeposited them in the shape of a fan. The break-out fan is, therefore, composed of sediments from the canyon and reworked materials eroded from the bar. Figure 14 shows a schematic diagram of Qf3 formation and illustrates its time-transgressive nature.

SCHEMATIC OF BREAK-OUT FANS



Channel Profile

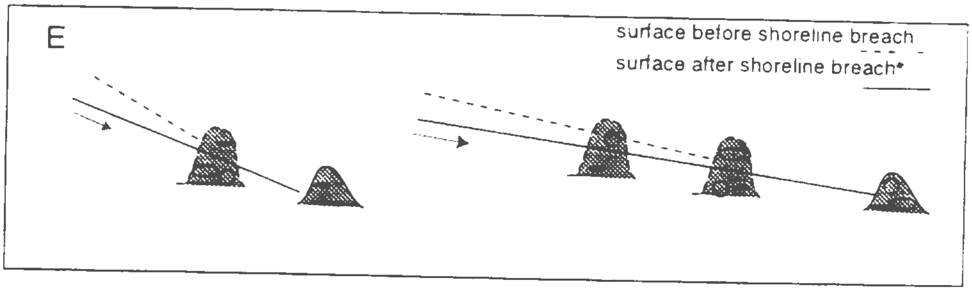


Figure 14: This schematic represents the model of multiple breaches. **A.** Time 1, a high lake level is forming a shoreline. **B.** Time 2, lake level has dropped and is forming another shoreline. Water coming from the drainage basin ponds upslope of highest shoreline. **C.** Time 3, ponded water has breached the upper ridge forming a break-out fan. Water and sediments are again ponding upslope of lower ridge. **D.** Time 4, the lower shoreline is breached forming its break-out fan. **E.** At an early time, the channel is short and has a steep gradient. With the breaching of a shoreline, the channel downcuts and acquires a gentler slope.

The processes involved in this breaching are unclear, but two important ideas are clear. First, more than one event was involved in the ponding before bar breaching event, as suggested by the stratigraphy/sedimentology of the ponded sediments. Second, lake levels had to be lower than the bar which was being breached. Therefore, a maximum age can be put on the development of Qf3. It has to be younger than the last high stand of Pluvial Lake Lahontan

The timing of the breaching of the bars can be constrained even more, because of a problem related to sediment supply during the formation of bars lower than bar A. If every bar was fully developed before any breach occurred, no sediments from Klondike Canyon could have been incorporated during bar aggradation. The estimated 4,118,000 m^3 of sediments tied up the bars in the Klondike Canyon complex would have had to come only from long shore currents. It has already been stated that long shore currents did supply granite from Granite Mountain during Pluvial Lake Lahontan, but the bars also contain volcanics from the range. Klondike Canyon is not comprised of an indicative rock type, therefore the exact origin of the sediments cannot be traced. A general reconnaissance near Granite Mountain located scoured areas, but not areas suggestive of a source of 4,118,000 m^3 of sediments. It is concluded some sediments were supplied from Klondike Canyon or the erosion of Qf2. The breaching of the bars, the development of Qf3, must therefore have occurred after the deposition of bar A, but before Pluvial Lake Lahontan had deposited the last bar.

The relative surficial and soil characteristics of Qf3 indicate that the unit is younger than Qf2. Insights into its absolute age can be obtained from other locations in the valley. For example, a C^{14} date was obtained for some charcoal by Ritter and Miller (in progress) at Willow Creek Alluvial Fan (fig. 1). The stratigraphy of the unit correlates to the Klondike Canyon Qf3. The dated charcoal which was located in a cut and fill sequence was 1,250 +/- 50 B.P. Mazama ash is also preserved in lenses within proximal Qf3 deposits in two fans. These data along with relative age correlation demonstrate that Qf3 was being deposited by at least 6,800 B.P. When taking into account the process of Qf3 development with the break-out fans, Qf3 aggradation could have occurred prior to 13,100 +/- 70 B.P. This date was obtained from the highest dated bar in the Klondike Canyon complex. The aggradation would be pre-13,100 +/- 70 B.P., because this date was obtained from the bar H at 40 m below the highest lacustrine deposit.

Qf4 followed the same fanhead trench and eroded much of Qf3. Qf4 directly cross cuts Qf2, Qf3 and the bars. No bars were located which protrude through Qf4. Qf4 exhibits surficial and soil characteristics indicating it is the youngest unit in the Klondike Canyon Alluvial Fan complex (table 2 and fig. 6). Figure 9 shows that the clay content of Qf4 is greater than Qf3 which is the opposite as predicted by the Jenny equation. One possible explanation is that Qf4 parent material contains more fines than Qf3. Klondike Canyon may have had the sediment storage stripped during the formation of Qf3 and when Qf4 was aggraded only fines were available in the source area. The surface has no sign of desert pavement and only rubification on the clasts The soil does not have any significant clay accumulation and has the lowest profile index.

Unit Age

Without dated material in the alluvial fan units, the ages can be estimated by comparing the soil development with other studies which have ages associated with the soil profile development. Table 3 is a comparison of soils data collected from Klondike Canyon with two previous studies. A comparative study of soils data for northern Nevada was not located, therefore two studies north and south of the field area were analyzed: a study by Wells et al (1987), conducted in the Mojave Desert, southeastern California, and a study by Ritter et al. (1993), conducted in Madison River Valley, Montana.

A soil correlation is attempted on the basis of Jenny's (1941, 1980) study of the factors involved in soil formation. Jenny's equation addresses the primary soil-forming factors, including present climate, vegetation, topographic relief, and parent material. Where these factors are similar between study areas, their soil should be correlative. The present climate at the Klondike Canyon and Montana site is semiarid The present climate at the California site is arid. Klondike Canyon alluvial fan is covered by xerophytic vegetation as is the California site, but the vegetation at the Montana site consists of short grasses and bunch grasses. The soils studied all formed in alluvial fan deposits. The Klondike Canyon and California alluvial fans are located on the piedmont of large mountain ranges in valleys which were once filled by pluvial lakes. The alluvial fan in Montana is located on the piedmont but originated from glacially-derived outwash Although the primary soil-forming factors are not similar in all circumstances, the goal is approximate age estimation of the Klondike Canyon alluvial fan units not an absolute age for the alluvial unit. Therefore, comparison of soils from the three studies are an initial attempt in soil correlation.

Ritter et al. (1993) noted soil development in a unit (Qf2) estimated to be late Pleistocene that are similar to the observed soils in Qf2 on the Klondike Canyon fan (Table 3). Both soils contain Btk horizonation. The soils have similar color, 10YR 3/3 and 7.5YR 4/4, respectively. They also exhibit $CaCO_3$ stages II and II+, respectively. Soils from these two studies are also very similar in the late Pleistocene in carbonate accumulation and horizonation The late Pleistocene soils described in the Wells et al. (1987) correlate with the Klondike Canyon soils in horizonation and color. Table 3 shows the other similarities between the three studies Thus, correlation of Qf2 soils and places Qf2 aggradation during the late Pleistocene.

The soil profile in Qf1 portrays the relative age difference from Qf2. Qf1 has a higher percentage of clay. The Qf1 at Klondike Canyon relates in soil characteristics to the Qf1 in Montana. However, the surficial characteristics are very similar to Qf2. These soil and surficial characteristics lead to the conclusion that Qf1 on Klondike Canyon alluvial fan is mid to late Pleistocene.

The age of the alluvial units can also be derived partially from the dates of the lacustrine bars. The highest dated bar, bar H, in Klondike Canyon is 13,100+/- 70 B.P.

Table 3: Soil Correlations

Study/Unit	Maximum $CaCO_3$ stage	Depth of Maximum $CaCO_3$	B-horizonation	B Thickness (cm)	Maximum Redness	Texture	Age estimation
Wells & Others (1987)							
Qf1	nm	nm	2Btks, 2Bk, 2Bk	55+	7.5YR 6/4-6	gls	Late Pleistocene
Qf2	nm	nm	2Bwk, 2Bk, 2Bky, 2Bk	29+	7.5 YR 6/6	gsl	Early Holocene
Qf3	nm	nm	Bwk, Bky	55+	7.5YR 7/6	gsl	Early to middle Holocene
Qf4	nm	nm	Bw	0.5	7.5YR 5/4	gsl	Middle to late Holocene
Qf5	nm	nm	none	none	10YR 6/3	gs	Latest Holocene
Ritter & Others (1993)							
Qf1	III-	39-48	Btk	6	10YR 5/3	sl	Early Pleistocene
Qf2	II	46-90+	Bt, Btk	30	10YR 3/3	cl	Late Pleistocene
Qf3a	I+	78-95	none	none	10YR 6/2	ls	Early Holocene
Qf3b	I+	24-43	none	none	10YR 4/2	sl	Early Holocene
Klondike Canyon							
Qf1	II	33-82	Btk1,Btk2	76	10YR 4/4	sil	Mid to Late Pleistocene
Qf2	II+	78-95	Btk,Bk1,Bk2	80	7.5YR 4/4	l	Late Pleistocene
Qf3	I	10-79	Bk	69	10YR 6/3	sil	Early to Mid Holocene
Qf4	I+	11-37	Bk	26	10YR 7/3	sl	Late Holocene

The highest shoreline, bar A, at American Canyon has a buried soil with a Bt horizon Therefore, the date of Qf2 is 13,100 plus the time to form the Bt horizon. Qf3 also has to be younger than 13,100+/-70 B.P. because it cuts through bar H. It has also been demonstrated how Qf3 was forming during the fall of Pluvial Lake Lahontan in Buena Vista Valley. This constrains the age of Qf3 to early Holocene

Qf4 exhibits minimal soil development, notably the lack of a Bt horizon. In the Montana and California studies, the units without Bt horizons are Holocene in age. Qf4 is relatively younger than Qf3. Therefore, Qf4 is Late Holocene.

Controls on Alluvial Fan Development

Base level Change

The anticipated role of base level change has been partially discussed in the introduction. A drop in the local base level may cause a fanhead trench to form as the channel erodes to the new base level. In fact, large fanhead trenches are located in Qf2 on most fans within Buena Vista Valley, for instance, the American Canyon and Willow Creek alluvial fans (figs. 15 and 16) within Buena Vista Valley. One may hastily conclude that the dropping of Pluvial Lake Lahontan controlled the erosion of Qf2 throughout the valley. However, Willow Creek fan is located at a higher elevation than the highest Lake Lahontan lacustrine deposit. In fact, it is approximately 75 m above the highest lacustrine deposit. Lake levels did not rise to the elevation of the Willow Creek fan, but it has the same morphology and stratigraphy as Klondike Canyon and American

AMERICAN CANYON ALLUVIAL FAN

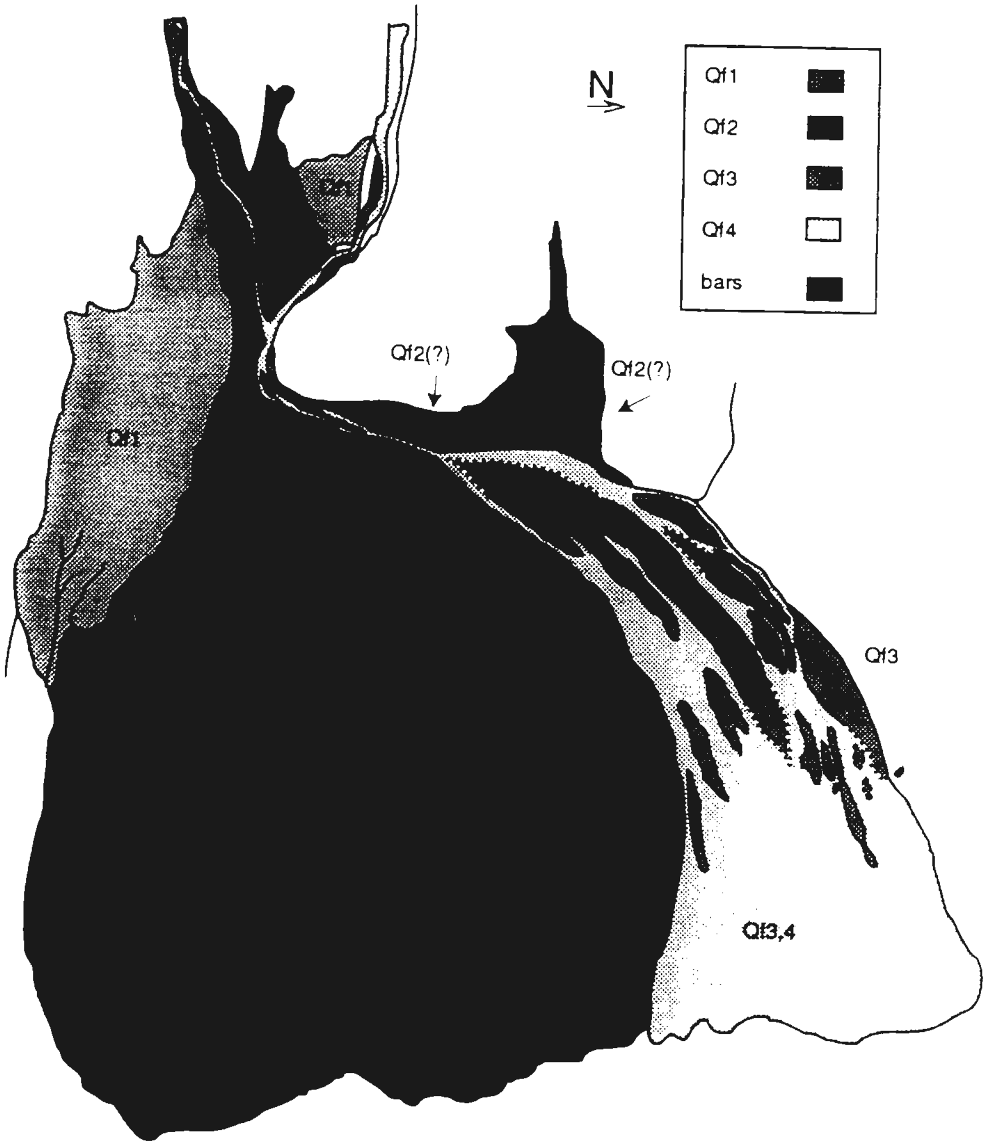


Figure 15: Map of American Canyon surficial geology based on 1:24,000 aerial photographs. Mapped and field-checked by Dr. John Ritter.

WILLOW CREEK ALLUVIAL FAN

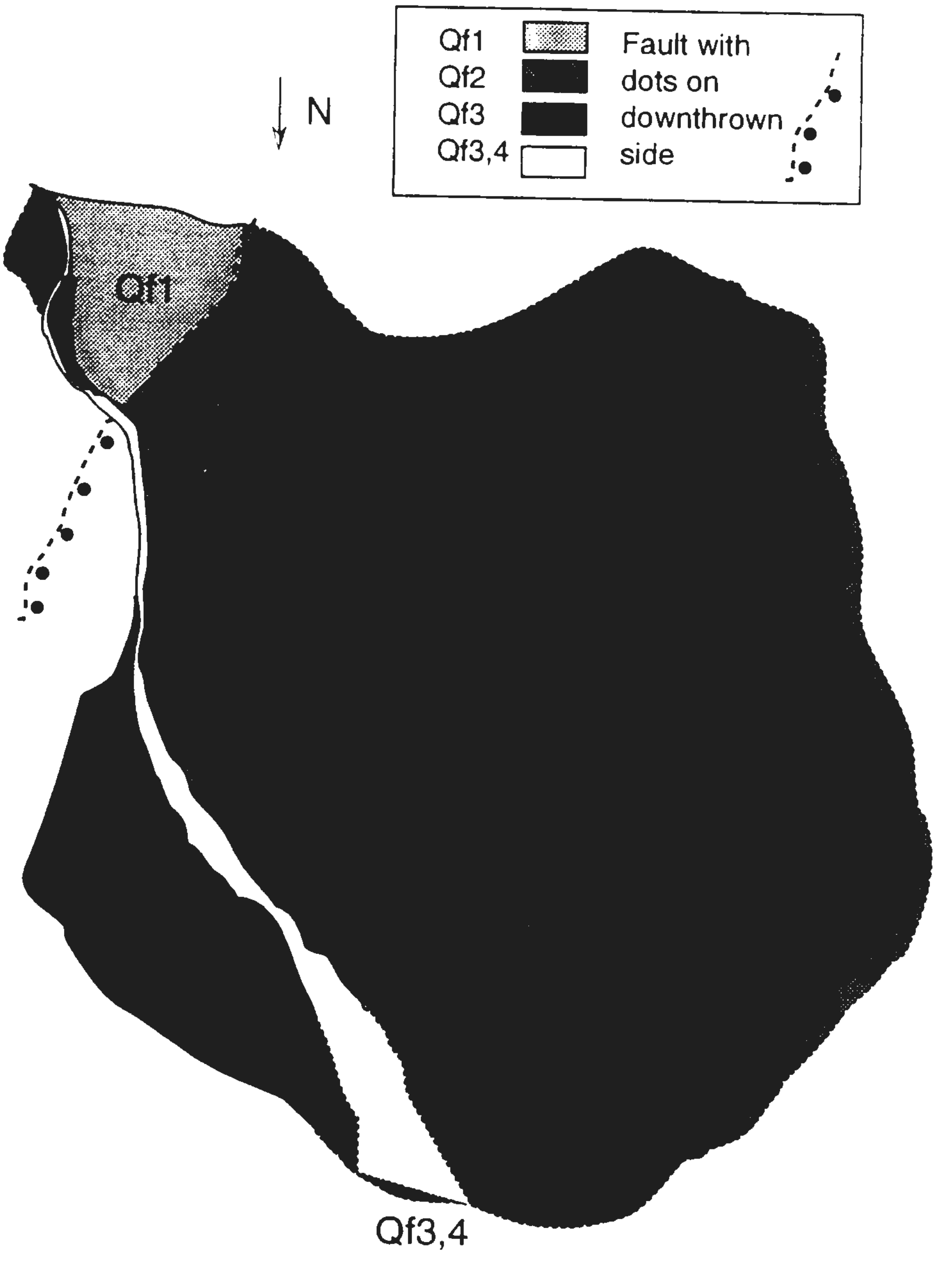


Figure 16: Map of Willow Creek surficial geology based on 1:24,000 aerial photographs. Mapped and field-checked by Dr. John Ritter.

Canyon. The similar morphologies and dissimilar base level controls terminates the conclusion that base level controlled the erosion of Qf2.

The role of base level change did, however, influence the development of Qf3 on Klondike Canyon as previously discussed in the timing of alluvial fan deposition. That is, base level control was localized to areas immediately upstream during the breaching of the bars and the formation of the break-out fans. Note that the base level was not Pluvial Lake Lahontan. Rather, the local base level was the pond on the upslope side of the bars. Evidence for this change of base level when a bar was breached are small terraces within the current channel. These terraces are not traceable for any significant distance up fan. Figure 14 schematically demonstrates this localized base level control in the channel degradation after breaching.

Another expected control of base level change is the deposition of large alluvial fan units. Qf2 is the largest preserved unit and can be located on all fans in the valley (figs 3, 15 and 16). In the section entitled "Timing of Events," it was noted that Qf2 formed well before the filling of Buena Vista Valley with pluvial waters. One piece of evidence is the well-formed, buried soils under the highest lacustrine deposit. The lack of older lacustrine deposits at the fan surface suggests that Qf2 was not associated with a prior pluvial lake cycle. In addition, there are no relations of Qf2 with any lacustrine units. Therefore, Qf2 cannot be associated with base level rise associated with Pluvial Lake Lahontan.

Climate

Alluvial fan development caused by climate change is expected to be widespread and characterized by synchronous periods of aggradation and entrenchment for all fans in a region. Lustig (1965) reasoned how climate changes would alter runoff and vegetation density of the source area thereby affecting sediment supply. The geomorphic response to the climate change whether it be an increase or decrease in sediment supply in the basin is discussed by Langbein and Schumm (1958). A climate change in the direction of increased sediment supply could cause basin-wide and even interbasin-wide alluvial fan deposition. A climate change in the direction of increased water without an initial increase in sediment supply could cause regional trenching near the apexes of the alluvial fans.

The main evidence for climate as a primary control for fan development is local and regional correlation. Within Buena Vista Valley, the fans are comprised of four units, Qf1, Qf2, Qf3, and Qf4 (figs. 3, 15 and 16). Qf1 is not preserved on all the fans, but where it is preserved it is only in proximal areas. Qf2 is the largest fan unit at Klondike Canyon as well as on all the fans in the valley. The soils in Qf1 as well as Qf2 do correlate across the valley in that strong Bt horizons are present.

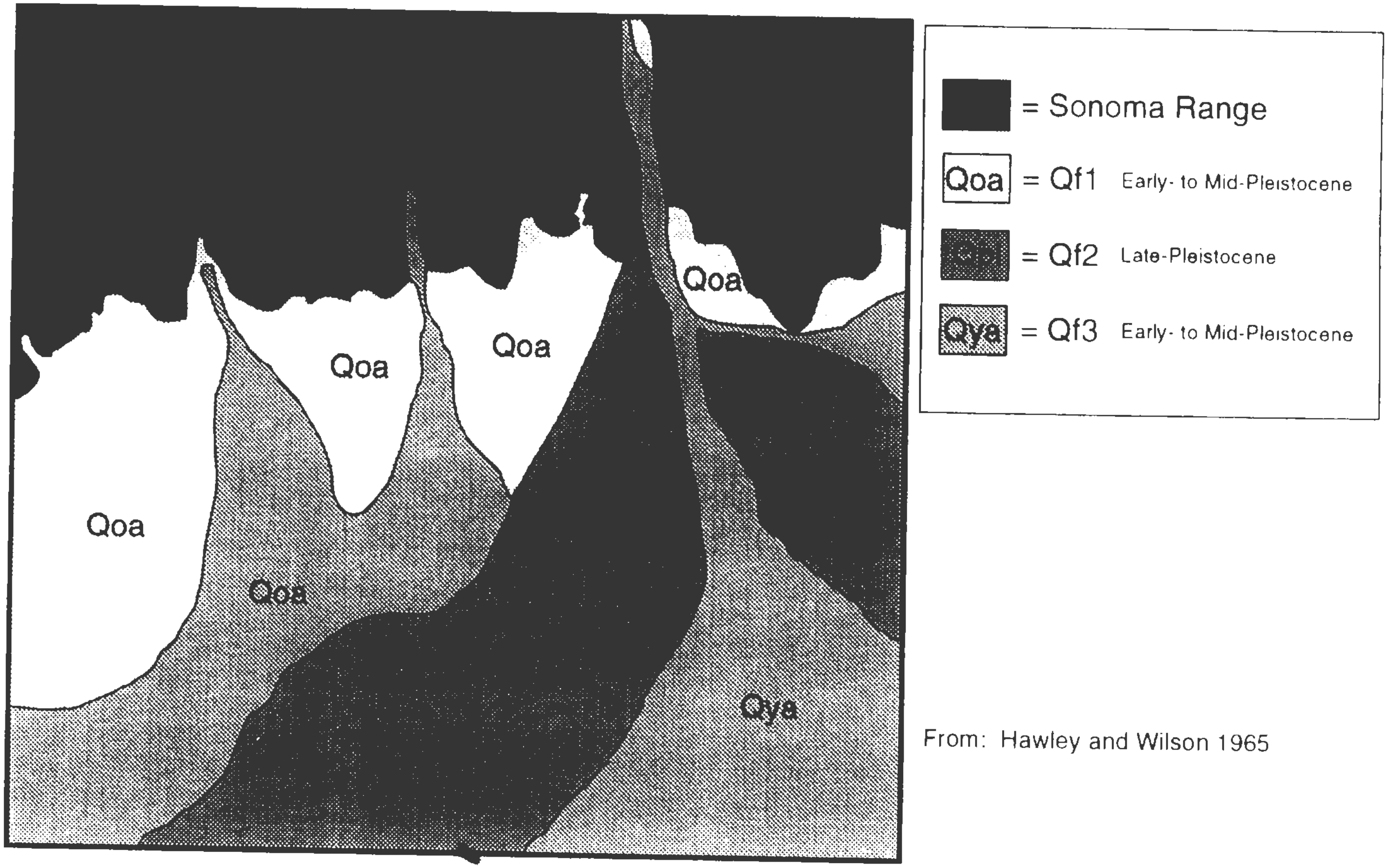
The overall stratigraphy is strongly correlative. The exactness is that Qf2 is inset into Qf1, where preserved, and is overlain by Qf3 and Qf4. Where bars, either degradational or aggradational, are preserved, they overly Qf2 and are breached by Qf3. The break-out fans can also be identified in the stratigraphic series

Fans in Buena Vista Valley are also regionally/interbasinally correlative with fans in the valley to the east, Grass Valley (Hawley and Wilson 1965). The study describes, in general, the same kind of morphology of fan units as Buena Vista Valley. For example, the study recognizes fanhead trenches. The fanhead trench in Klondike Canyon alluvial fan can be identified in the Qf2 unit on almost every fan in Buena Vista Valley. This trenching is also inter-basin. Hawley and Wilson note fanhead trenches which are narrow, steep-walled gullies incised a few feet below the alluvial apron on many fans to as much as 22 m. The correlation of these trenches is the location and quantity. This regional phenomenon can be explained by a climate change that simultaneously perturbed the basins and caused contemporaneous degradation

The correlation does not rely solely on the fanhead trenches. The alluvial fans in Buena Vista Valley have similar stratigraphic units as the fans in Grass Valley (fig. 17). That is, Hawley and Wilson have mapped three fan units which correspond with the units in Buena Vista Valley. Table 4 outlines the similarities. The sizes, shapes and unique characteristics correlate very well indicating similar development.

The regional correlation of alluvial fan units implies a regional climate change producing conditions in which fan development occurred. The different rates of tectonic activity between the Humboldt, Stillwater, and East Ranges (Morrison 1991) would produce different times for alluvial fan development to occur. This would create different morphologies and/or stratigraphies throughout the basin. Because the fan morphologies are correlative throughout Buena Vista Valley and Grass Valley, climatic controls are the most logical explanation for the alluvial fan development.

Regional Correlation of Alluvial Fans



From: Hawley and Wilson 1965

Figure 17: Map of alluvial fan units by hawley and Wilson (1965) which correlate with the fan units found in Buena Vista Valley. The regional fan correlation implicates climatic controls on fan development.

Table 4: Correlation of Alluvial Fan Development Between Grass Valley and Buena Vista Valley

Alluvial Fan/Unit	Corresponding Unit at Klondike Canyon	Shape	Size	Soils	Characteristics
Klondike Canyon					
Qf1		longitudinal	0.22 (km2)	76 cm of Btk	Preserved near mountain front
Qf2		cone	18 (km2)	30 cm of Btk	Large fanhead trench and overlain by shorelines
Qf3		partial cone	1.7 (km2)	no significant clay accumulation	Erosion through shorelines & loci of deposition farther onto valley floor
Qf4		cone	5.7 (km2)	no significant clay accumulation	Youngest fan & loci of deposition farther onto valley floor
Hawley and Wilson (1965)					
Qoa	Qf1	eroded sections	relatively the smallest preserved unit	unknown	Preserved only at mountianfront
Qpl	Qf2	cone	largest preserved unit	unknown	Contains fanhead trench & overlain by shorelines
Qya	Qf3 and Qf4	Coalesced fans		no soil development	Loci of deposition farther onto valley floor, eroded through shorelines & receiving active deposition

Tectonics

Tectonic activity initially created the topography which allows alluvial fans to evolve. The extensional tectonics in Buena Vista valley have created irregular fault scarps, some creating scarps on fan units, along the range. Hanks and Wallace (1985) note that the bars from the high stand of Lake Lahontan truncate the fault scarps located south of Klondike Canyon at the north west flank of the Stillwater Range. They estimate the age of the faulting to be 15,000 to 18,000 B P. Thus, tectonic activity associated with this scarp occurred after Qf2 and before Qf3 It is important to recognize that this faulting does not correspond to a fan building episode.

In fact, throughout the valley no tectonic signatures have been identified which correlate with fan development. In the introduction, examples of morphologic characteristics were given as to tectonic activity being associated with alluvial fan development. In Buena Vista Valley no scarps or folds have been detected which temporally correlate with the development of an alluvial fan. The only notable tectonic controls come from the random scarps which are located on fan units, for example Willow Creek. The activity has created topographic relief which have initiated the development of small alluvial cones meters in relief.

Bull (1964) showed tectonic activity was the control for alluvial fan morphology. His study centered on the fans in western Fresno County, California. The evidence for this conclusion was segmented longitudinal profiles across the fan surfaces He noted that most of the western-Fresno County fans have four segments which are straight or slightly curved. Based on their profile, he concluded that a change in stream gradient caused a change in the slope of the succeeding fan segments Bull suggested that uplift formed a steeper stream gradient that subsequently lead to deposition on the fan and the construction of a new fan segment. Repeated periods of uplift produced additional strath terraces and fan segments. This fan segmentation is therefore considered tectonically controlled.

Klondike Canyon alluvial fan is also segmented. The fans in Buena Vista Valley have four segments which are straight or slightly curved. However, the only terraces which are recognizable in Klondike Canyon are aggradational, not erosional. Therefore, fan segmentation is not suggestive of tectonic activity at Klondike Canyon. The role of tectonics in the development of the alluvial fan is best stated by Ritter et al (1994), "...because tectonism produces and maintains the relief necessary for fans to form, its primary role is long-term, controlling the duration over which fan deposition may occur along the mountain front; it does not control individual periods of aggradation and entrenchment."

Pluvial Lake Lahontan in Buena Vista Valley

The filling of Lake Lahontan

The relative age of Pluvial Lake Lahontan high stand post-dates Qf2 and pre-dates Qf3. The filling of Pluvial Lake Lahontan becomes important, because no direct relation is seen between timing of the alluvial units and the filling of the lake. In fact, details concerning timing and climatic variations which formed Pluvial Lake Lahontan are still in dispute. Many authors (e.g. Morrison 1991, Benson 1991, Hostetler and

Benson 1990, Benson and Thompson 1986, and Mifflin and Wheat 1979) have concluded that lake level rise is associated with a decrease in evaporation combined with an increase in precipitation. One factor that remains highly disputed is where the increased precipitation occurred. Benson and Thompson (1987) argue that water input to the Lahontan basin primarily is a function of precipitation in the upper drainage systems, for example Sierra Nevada. The same idea is presented by Mifflin and Wheat (1979) who indicate the importance of increased runoff to produce pluvial lakes. Hostetler and Benson (1990) note the importance of the polar jet stream splitting around the North American continental ice sheet which led to increased cloud cover, and therefore decreased evaporation, over the Great Basin particularly in the summer.

Another factor to consider when interpreting the mechanics of lake level rise are geomorphic relationships observed adjacent to and within Pluvial Lake Lahontan. Davis (1982) states on the basis of geomorphic data that sediment was supplied on the deltas which were located at the heads of estuaries during lake rise. Davis and Elston (1972) make the conclusion that during a high lake stand the streams which fed the lake aggraded. Morrison (1991) argues that during an interstatial the Carson, Truckee and Humboldt Rivers downcut. He based this on simultaneously constructed terraces particularly along the Carson and Truckee Rivers that cut narrow valleys 15-30 m deep into deltaic and lacustrine deposits.

In effect, some studies make generalizations about every valley which was inundated by Pluvial Lake Lahontan. However, it has not been convincingly shown that increased precipitation and enhanced runoff in all drainages contributed to the lake. In fact, Mifflin and Wheat (1979) state that different geomorphic reactions may occur throughout these valleys, because the Lake Lahontan basin overlaps climatic zones which differ greatly. Moreover, some evidence suggests that small streams did not react in a manner similar to larger systems, and this has led to the hypothesis that 96% of the total gauged surface inflow into the Lake Lahontan basin is contributed by the Truckee, Carson, Walker, and Humboldt (Mifflin and Wheat 1979).

In Buena Vista Valley, the smallest of the major subbasins (fig. 18), there is no geomorphic evidence on the Klondike Canyon fan for increased precipitation during the time of the filling of Pluvial Lake Lahontan. That is, alluvial fan units formed during lake level rise are lacking on the Klondike Canyon alluvial fan as well as eight other fans mapped by Ritter and Miller (pers. com.), Qf2 clearly predates the latest pluvial lake cycle and Qf3 is Holocene in age.

There are three conclusions that can be drawn from this observation. 1) There was not a large input of water from local drainage systems that surround Buena Vista Valley during the rise of Lake Lahontan in the valley. This is supported by Mifflin and Wheat (1991) who argue that the moisture-rich Sierra Nevada would have had higher values of runoff than watersheds in the Great Basin and could have made up for drier parts of the Lahontan Basin. This does not rule out a climate change in the Buena Vista region, but rather, suggests that it may not have been great enough to produce a fan building event or it may not have been the type of event to cause fan building. 2) Assuming that the input of water did not come from local sources, the influx must be related to overflow of the sill, Chocolate Butte (fig. 1), from the adjoining Carson

LAKE LAHONTAN

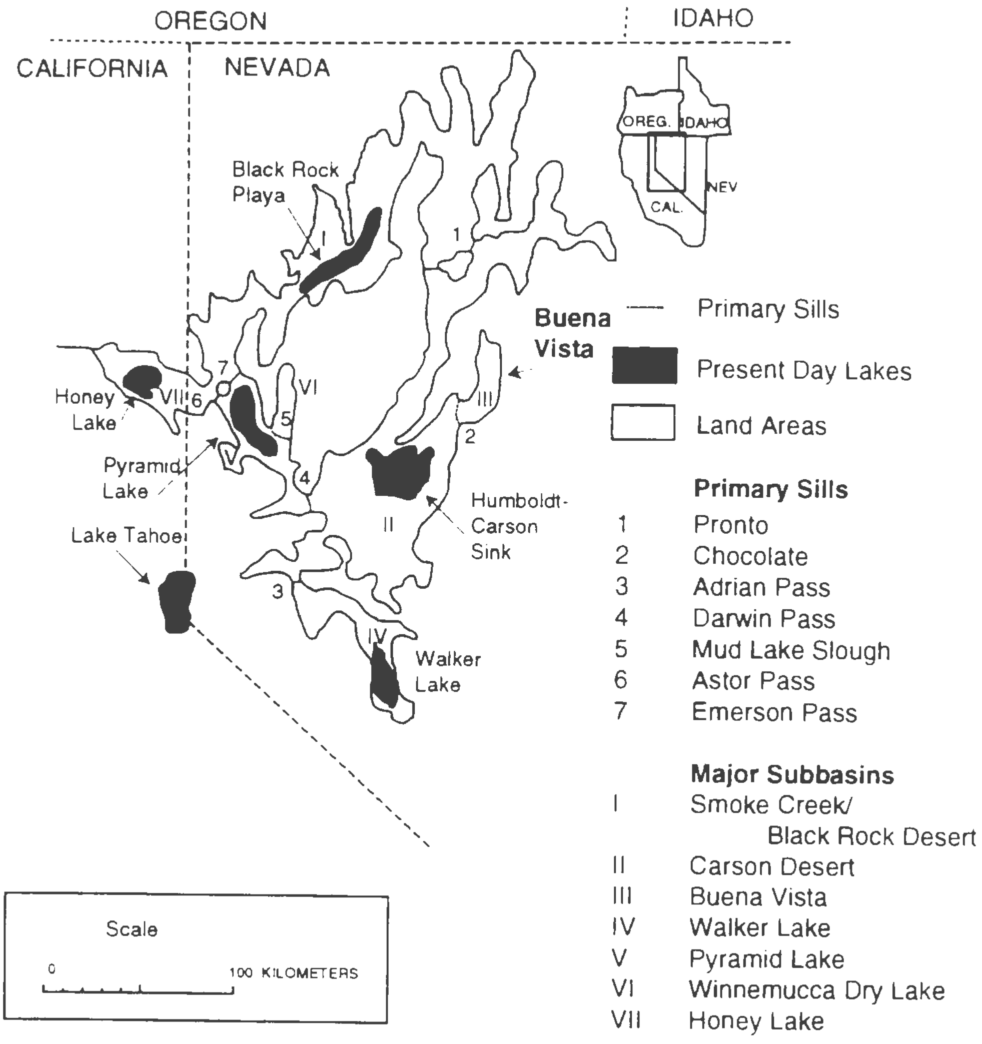


Figure 18: Surface extent of Lake Lahontan 14,000 to 12,500 B.P. and location of subbasins and sills separating subbasins. Taken from Benson and Thompson (1987).

Desert. 3) It is more difficult to model lake level curves then commonly assumed. That is, a model which would take into account a runoff proportional to drainage basin size assuming an equivalent climate change throughout the Lake Lahontan basin would not create an accurate lake level curve. Geomorphic evidence must be obtained in order to apply such a model to any valley because the valley may not have added significant runoff to Lake Lahontan.

Initial Lake Level Curve for Buena Vista Valley

This initial lake level curve based on dates from shells located in bars has been developed for the Buena Vista Valley. Table 5 shows a list of the dates which have come from this study, Ritter and Miller's ongoing study and Hanks and Wallace (1985). The lake level curve (fig. 19A) was constructed from the elevation of the bar surface vs. C^{14} dates obtained from the shells.

Preliminary inspection of the lake level curve reveals inconsistencies. The dates from Klondike Canyon, especially around 13,000 B.P., do not smoothly correlate with the dates from the west side of the valley. This may partially result from the type of bar in which the shells are preserved and collected. The bar at Klondike Canyon may have been deposited in deeper water than those on the west side. The problem is that the difference in water would have needed to be about 40 m. This would appear to represent too much variance to be explained solely by depositional setting, and therefore, other factors may be involved such as problems with radiocarbon dating. Benson (1993) points out three problems with radiocarbon dating carbonates. These

LAKE LEVEL CURVES

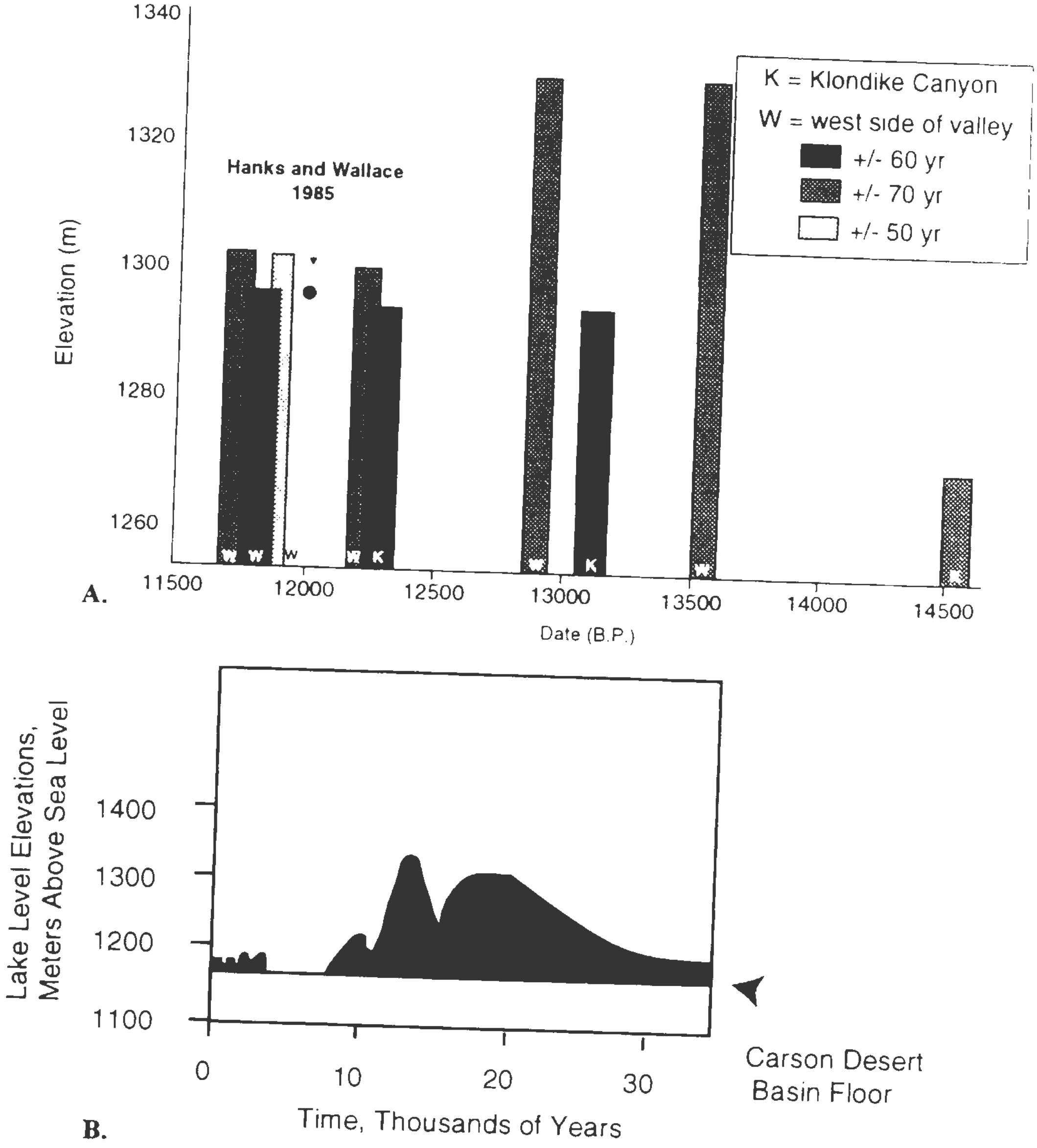


Figure 19: **A.** Initial lake level curve for Buena Vista Valley. Dates and elevations were obtained from Hanks and Wallace (1985) as well as a continuing study by Ritter and Miller. Elevations from Klondike Canyon and the west side of the valley were obtained from GPS. The lack of correlation demonstrates the error and difficulty of correlating shell dates. **B.** Lake Lahontan chronology from Morrison (1991)

Table 5: Dates and Elevations of Bars in Buena Vista Valley

Study	Location	Date (B.P.)	Elevation (m)
Klondike Canyon			
	Bar H	13,100+/-70	1295
	Bar H	12,390+/-70	1295
	Bar L1	14,540+/-60	1269
Ritter and Miller (in progress)	*West side of Buena Vista*		
	American Canyon	13,560+/-60	1331
	American Canyon	12,900+/-60	1331
	American Canyon	11,880+/-50	1303
	American Canyon	12,220+/-60	1301
	Buffalo Springs	11,730+/-60	1303
Hanks and Wallace (1985)	*East side of valley south of Klondike Canyon*		
	McKinney Pass	12,000	1296

include 1) isotopic fractionation, 2) reservoir effects, and 3) addition of modern carbon. The constructed lake level curve is very preliminary, and more work would need to be conducted to obtain an accurate lake level curve, as the one constructed here is based solely on dates obtained from bars within the valley. Correlation of Buena Vista lake

level curve with lake level curves for the entire Lake Lahontan cycle is difficult to make The primary difficulty is correlating stratigraphic units from one valley with another valley that did not have the same lake level history. Another difficulty is the responses which occur when a sill in one valley is breached. When the breaching of a sill occurs, the water level in one valley will rise, stay the same in a second, and possibly drop in a third.

Nevertheless, a comparison with Morrison (1991) shows some similarities (fig. 19), but not all the differences are explainable by standard deviations. The initial rise in Buena Vista has not been recorded. Morrison puts the rise to the high stand to be about 15,500 B.P. The remnant bar in Buena Vista has been dated at 14,500 B.P. with an elevation of 1275 m. Morrison shows the lake to be 14,000 B.P. when it was at an elevation of 1275 m and rising. Buena Vista was at its high stand from 13,500 to 13,000 B.P. and Morrison shows the high stand to be 12,500 B.P. The youngest date for Buena Vista is 11,700 B.P. at an elevation of 1300 m. By 11,700 B.P. Morrison shows the lake level to be around 1200 m.

The lake level curve by Benson and Thompson (1987) was adjusted by Benson (1991) to fit current knowledge about the errors associated with dating lacustrine carbonates (fig. 20). Benson states that all seven Lahontan subbasins coalesced approximately 14,200 ^{14}C yr. B.P. This fits the Buena Vista lake level curve, because it shows that the sill was topped before 14,500 B.P. This information was obtained from the date of the remnant bar and the source water in Buena Vista Valley. Benson concludes that the 1330-m high stand was achieved by 13,800 C^{14} yr. B.P. and receded

LAKE LEVEL CURVES

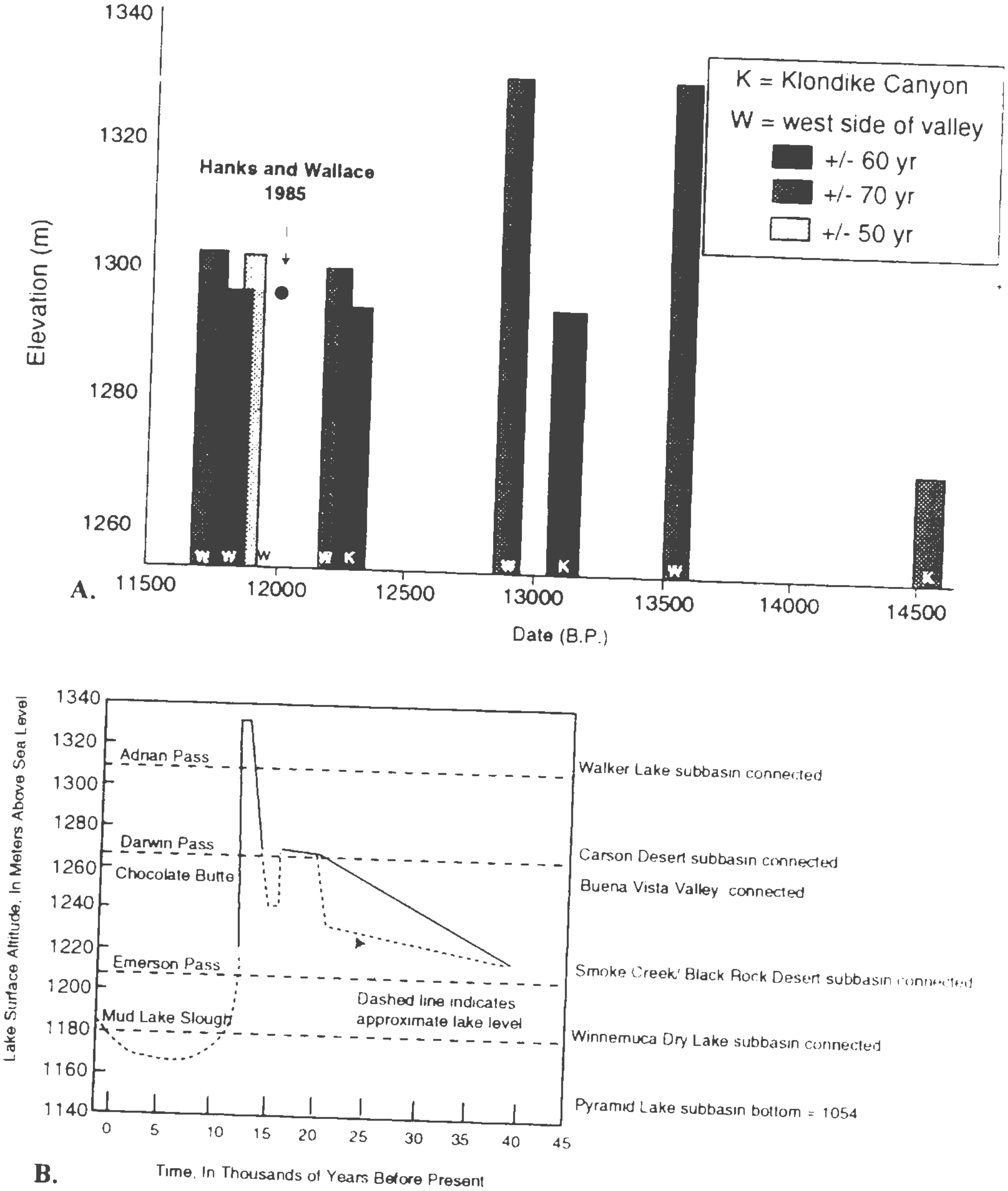


Figure 20: **A.** Initial lake level curve for Buena Vista Valley. Dates and elevations were obtained from Hanks and Wallace (1985) as well as a continuing study by Ritter and Miller. Elevations from Klondike Canyon and the west side of the valley were obtained from GPS. The lack of correlation demonstrates the error and difficulty of correlating shell dates. **B.** Central Lake Lahontan chronology from Benson and Thompson (1987).

to 1310 m by 13,700 yr B P. This does not fit the Buena Vista lake level curve because the high stand has been dated at least as late as 12,800 B P Buena Vista reached 1310 m by 12,350 B.P.

Climate Model

The temporal correlation of alluvial fan evolution and lake level rise show that the climate change associated with the fan building events cannot be directly correlated to the lake level rise. It is correlative with the drying of the lake noted on the initial lake level curve. No absolute age data have been located in Klondike Canyon alluvial fan deposits, therefore not enough information is present to warrant correlation with other climatic data such as pack rat middens and tree-ring chronologies at the present time. Hence, the climate model presented for Buena Vista Valley is based on the model presented by Wells et al. (1987) in the eastern Mojave Desert, southeastern California.

Wells et al. (1987) have dates which are correlatable to pack rat middens and fossil pollen. The climate model presented by Wells et al. suggests that alluvial fan aggradation occurred when the climate changed from a relatively wetter to a drier environment. In essence, precipitation decreased creating a time-transgressive change in vegetation. The decrease in vegetation allowed the sediments on the hillslopes to be eroded and deposited on the alluvial fan unit. Wells et al. also note that the climate change from relatively wetter to drier environment is marked by the drying of the pluvial lake in the valley. Exposed fine-grained sediment on the pluvial shorelines is presumed to have promoted slope instability.

This climate model is supported by Qf3 at Klondike Canyon. Qf3 is early Holocene and is correlative to the drying of Pluvial Lake Lahontan. This correlation is recorded as break-out fans. The time-transgressive deposition of Qf3 is transfixed in the ponded stratigraphy upslope of bar A. Qf3 deposition occurred after the high stand while the lake was drying in Buena Vista Valley. This time is characterized as a climate change from a relatively wetter to a drier environment. At this time there is not enough data proving the age of Qf1 or Qf2 to strongly support the climate model. However, this climate model is not refuted by any unit at Klondike Canyon.

Conclusions

Although climate, tectonic, and base level changes have occurred in Buena Vista Valley during the formation of the Klondike Canyon alluvial fan complex, the development of the fan can be attributed to climate change. The primary evidence is regional correlation of fan units. Hawley and Wilson (1965), Ritter and Miller (in progress), and this study have independently mapped alluvial fans within the region. Each study has independently produced similar stratigraphies. These fans occur in areas of different tectonic environments and have been affected differently by Pluvial Lake Lahontan. The fans mapped by both of the other studies occur in ranges (the Sonoma and Humboldt) with a much more rapid uplift rate (Dohrenwend and Moring 1991). The other two studies also mapped fans in which Pluvial Lake Lahontan did not reach their distal margins. Regional climate changes which have occurred throughout the

Quaternary are the most logical explanation for the deposition of equivalent units with the similar ages on numerous fans.

Qf3 developed through a series of bar breachings. The water and sediments coming from the drainage basin encountered the protruding bars. Initially the flow did not have enough mass or energy to overtop and breach the bars, and the flow ponded on the upslope side of the feature. With a given amount of flow, the bar was breached by the flow. When this breaching occurred, a small break-out fan was formed on the downslope side of the fan. It is hypothesized that multiple bars were breached in one episode and that the breaching began before the lake had completely dried. At some point, this process started again and a new set of bars were introduced to the flows producing Qf3.

A total lack of an alluvial fan unit within the Buena Vista Valley which correlates to the filling of Pluvial Lake Lahontan suggests that local sources were not a primary source of water. Many other studies (e.g. Mifflin and Wheat 1979, Benson and Thompson 1987, Morrison 1991) note the importance of higher precipitation, lower evaporation, and increased runoff for the filling of Lake Lahontan. This study does not deny that these factors played a major role during Lake Lahontan rise. Yet, in Buena Vista Valley the sill, Chocolate Butte, must have been breached by water flowing from the Carson Sink which formed the lake, because of the lack of a temporally correlatable unit to the filling of the valley.

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APPENDIX I

SOIL DATA

Unit	Horizon	Depth (cm)	Color	Structure	Dry Consistency	Wet Consistency	Texture	Clay Films	CaCO3 Stage	pH
Qf1	Av	0 to 6	10YR7/1	3f pl	sh	s,p	sil	no	no	8.53
	Btk1	6 to 25	10YR4/4	1m sbk	so	so,sp	sil	2n pf	II-	7.45
	Btk2	25 to 33	10YR5/4	1m sbk	so	so,p	sil	2n pf	II-	7.51
	Bk	33 to 82	10YR6/4	1f-m sbk	h	so,po	glc	no	II	7.27
Qf2 proximal	Av	0 to 5	10YR6/2	3f-m pl	h	s, vp	sil	no	no	7.7
	AB	5 to 15	10YR6/3	1f gr	so	ss, p	l	no	I	7.07
	Btk	15 to 44	7.5YR 4/4	2f sbk	sh	ss, p	l	2n pf,po	II+	7.01
	Bk1	44 to 78	10YR7/3	2f sbk	so	ss, sp	gsl	no	II	7.43
	Bk2	78 to 95	10YR4/4	m	lo	ss, sp	gsl	no	I-	7.33
Qf2 distal	Av	0 to 7	10YR6/2	3m pl	h	s, vp	sil	no	no	7.78
	AB	7 to 31	10YR5/4	2f sbk	h	ns, sp	l	2n pf	I+	8.07
	Btk1	31 to 56	10YR6/4	2f sbk	so	ns, sp	l	1n pf	II	7.94
	Btk2	56 to 85	10YR5/4	1f sbk	so	ns, np	gscl	no	II	8.27
	Bk2	85 to 110	10YR6/4	sg	lo	ns, np	gls	no	I	8.2
Qf3	Av	0 to 10	10YR6/3	1f pl	lo	ns, sp	sil	no	no	7.1
	Bk	10 to 79	10YR6/4	sg	lo	ns,sp	sil	no	I	7.25
Qf4	Av	0 to 11	2.5Y7/2	m	lo	ns, np	ls	no	no	7
	Bk	11 to 37	10YR7/3	sg	lo	ns, sp	sl	no	I	7.12
	2Bk	37 to 48	10YR7/3	1f sbk	so	ns,np	gsl	no	I	8.43
	2Bk2	48 to 58	10YR6/4	1f sbk	so	ns,sp	sl	no	I	8.69
	2bk3	58 to 87	10YR6/3	sg	lo	ns, sp	gls	no	I+	8.4
SL A	Av	0 to 8	10YR7/1	3c pl	h	vs, vp	sil	no	no	7.71
	AB	8 to 15	10YR6/4	m	lo	ns, np	gsl	no	I+	8.14
	Bk	15 to 30	10YR6/3	m	lo	ns, np	gls	no	II+	7.16
	Bk2	30 to 70	10YR3/2	m	lo	ns, np	gsl	no	II	6.48
	Bk3	70 to 90	10YR5/4	1f sbk	so	ss, p	gl	no	I	6.94
SL H	Av	0 to 4	10YR7/2	3f pl	h	ss, p	l	no	no	7.27
	AB	4 to 12	10YR5/3	1f sbk	so	ns, sp	gsl	no	I	7.03
	Bk	12 to 60	10YR5/4	m	lo	ns, np	gls	no	II	6.87
	Bk2	60 to 85	10YR6/6	m	vh	ns, np	g	no	II-	6.89
	Bk3	85 to 120	10YR6/6	m	lo	ns, np	gls	no	I+	6.96
	C		10YR6/3	m	lo	so,po	gsil	no	I-	7.32

Unit	Horizon C	Depth (cm)	dry color	wet color	color	normalization	texture	normalization	clay films	normalization	structure
QF1	Av	6	10	10	20	0.25	40	0 666666667	0	0	35
	Btk1	19	30	10	40	0.5	10	0.166666667	60	0 666666667	20
	Btk2	8	30	10	40	0.5	20	0 333333333	60	0.666666667	20
	Bk	49	30	10	40	0.5	10	0.166666667	0	0	20
Qf2 prox	Av	5	10	10	20	0.25	50	0.833333333	0	0	35
	AB	10	20	10	30	0.375	30	0.5	0	0	20
	Btk	29	40	10	50	0.625	30	0.5	60	0.666666667	30
	Bk1	34	20	10	30	0.375	20	0.333333333	0	0	30
	Bk2	17	20	10	30	0.375	20	0.333333333	0	0	0
Qf2 dist	Av	7	10	10	20	0.25	50	0.833333333	0	0	35
	AB	24	30	10	40	0.5	10	0.166666667	60	0.666666667	30
	Btk1	25	30	10	40	0.5	10	0.166666667	50	0.5	30
	Btk2	29	30	10	40	0.5	10	0.166666667	0	0	20
	Bk	25	30	10	40	0.5	0	0	0	0	0
Qf3	Av	10	20	10	30	0.375	10	0.166666667	0	0	15
	Bk	69	30	10	40	0.5	10	0.166666667	0	0	0
Qf4	Av	11	0	0	0	0	0	0	0	0	0
	Bk	26	20	10	30	0.375	10	0.166666667	0	0	0
	2Bk	11	20	10	30	0.375	0	0	0	0	20
	2Bk2	10	30	10	40	0.5	10	0.166666667	0	0	20
	2Bk3	29	20	10	30	0.375	10	0.166666667	0	0	0
SLA	Av	8	10	10	20	0.25	60	1	0	0	35
	AB	7	30	10	40	0.5	0	0	0	0	0
	Bk	15	20	10	30	0.375	0	0	0	0	0
	Bkw	40	10	10	20	0.25	0	0	0	0	0
	Bk3	20	30	10	40	0.5	30	0.5	0	0	20
SLH	Av	4	10	10	20	0.25	30	0 5	0	0	35
	AB	8	20	10	30	0.375	10	0.166666667	0	0	20
	Bk	48	30	10	40	0.5	0	0	0	0	0
	Bk2	25	50	30	80	1	0	0	0	0	0
	Bk3	35	50	30	80	1	0	0	0	0	0

Unit	normalization	dry consis.	normalization	moist consis.	normalization	melanization	normalization	pH
								7.32
QF1	0.583333333	20	0.25	20	0.5	0	0	8.53
	0.333333333	10	0.125	0	0	30	0.6	7.45
	0.333333333	10	0.125	0	0	10	0.2	7.51
	0.333333333	30	0.375	0	0	0	0	7.27
Qf2 prox	0.583333333	30	0.375	20	0.5	10	0.2	7.7
	0.333333333	10	0.125	10	0.25	0	0	7.07
	0.5	20	0.25	10	0.25	30	0.6	7.01
	0.5	10	0.125	10	0.25	0	0	7.43
	0	0	0	10	0.25	10	0.2	7.33
Qf2 dist	0.583333333	30	0.375	20	0.5	0	0	7.78
	0.5	30	0.375	0	0	10	0.2	8.07
	0.5	10	0.125	0	0	0	0	7.94
	0.333333333	10	0.125	0	0	10	0.2	8.27
	0	0	0	0	0	0	0	8.2
Qf3	0.25	0	0	0	0	10	0.2	7.1
	0	0	0	0	0	0	0	7.25
Qf4	0	0	0	0	0	10	0.2	7
	0	0	0	0	0	0	0	7.12
	0.333333333	10	0.125	0	0	0	0	8.43
	0.333333333	10	0.125	0	0	10	0.2	8.69
	0	0	0	0	0	10	0.2	8.4
SLA	0.583333333	30	0.375	20	0.5	0	0	7.71
	0	0	0	0	0	10	0.2	8.15
	0	0	0	0	0	20	0.4	7.16
	0	0	0	0	0	50	1	6.48
	0.333333333	10	0.125	10	0.25	20	0.4	6.94
SLH	0.583333333	30	0.375	10	0.25	0	0	7.27
	0.333333333	10	0.125	0	0	20	0.4	7.03
	0	0	0	0	0	20	0.4	6.87
	0	40	0.5	0	0	0	0	6.89
	0	0	0	0	0	0	0	6.96

Unit	delta pH	normalization	sum of norm	divide by # of properties	times depth	profile index
QF1	0	0	2.25	0.28125	1.6875	
	0	0	2.3916667	0.298958333	5.68020833	
	0	0	2.1583333	0.269791667	2.15833333	
	0.05	0.05952381	1.4345238	0.179315476	8.78645833	18.3125
Qf2 prox	0	0	2.7416667	0.342708333	1.71354167	
	0.25	0.297619048	1.8809524	0.235119048	2.35119048	
	0.31	0.369047619	3.7607143	0.470089286	13.6325893	
	0	0	1.5833333	0.197916667	6.72916667	
	0	0	1.1583333	0.144791667	2.46145833	26.8879464
Qf2 dist	0	0	2.5416667	0.317708333	2.22395833	
	0	0	2.4083333	0.301041667	7.225	
	0	0	1.7916667	0.223958333	5.59895833	
	0	0	1.325	0.165625	4.803125	
	0	0	0.5	0.0625	1.5625	21.4135417
Qf3	0.22	0.261904762	1.2535714	0.156696429	1.56696429	
	0.07	0.083333333	0.75	0.09375	6.46875	8.03571429
Qf4	0.32	0.380952381	0.5809524	0.072619048	0.79880952	
	0.2	0.238095238	0.7797619	0.097470238	2.53422619	3.33303571
SLA	0	0	2.7083333	0.338541667	2.70833333	
	0	0	0.7	0.0875	0.6125	
	0.16	0.19047619	0.9654762	0.120684524	1.81026786	
	0.84	1	2.25	0.28125	11.25	
	0.38	0.452380952	2.5607143	0.320089286	6.40178571	
SLH	0.05	0.05952381	2.0178571	0.252232143	1.00892857	
	0.29	0.345238095	1.7452381	0.218154762	1.7452381	
	0.45	0.535714286	1.4357143	0.179464286	8.61428571	22.7828869
	0.43	0.511904762	2.0119048	0.251488095	6.28720238	
	0.36	0.428571429	1.4285714	0.178571429	6.25	23.9056548

APPENDIX II

TOPOGRAPHIC PROFILES

FAN-HEAD TRENCH: TOPOGRAPHIC SURVEYS

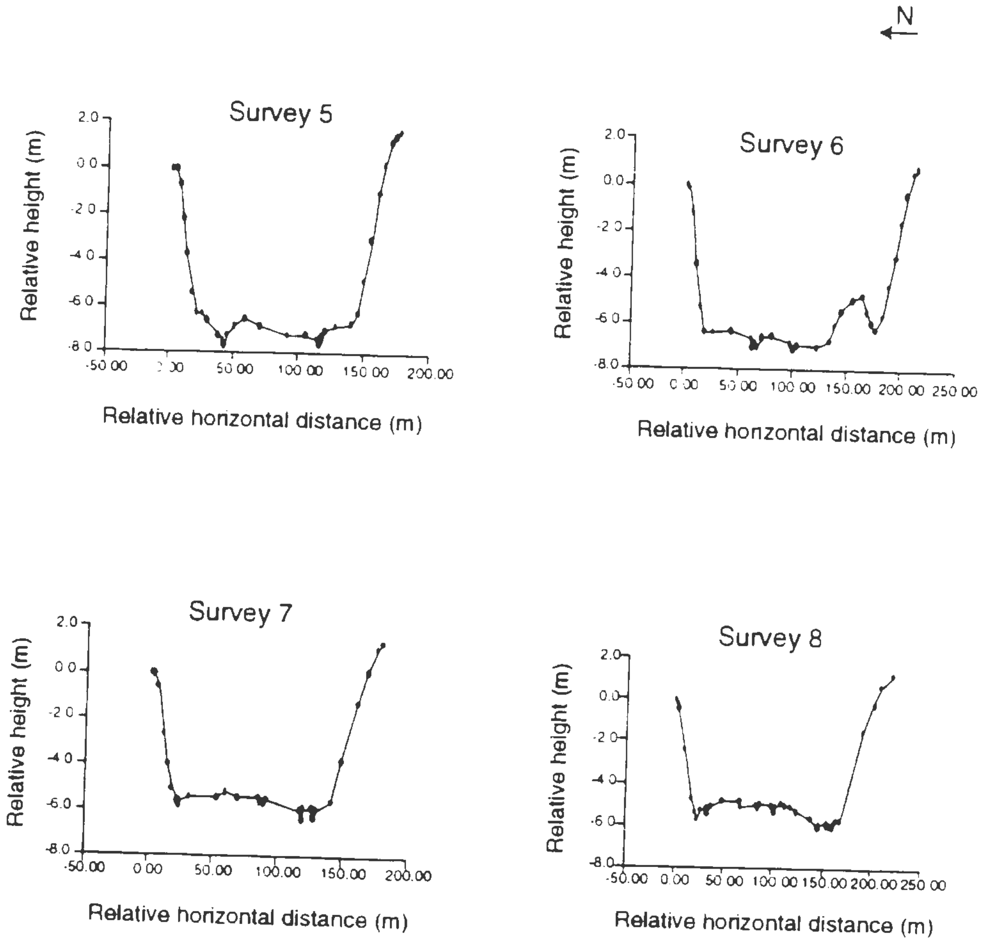
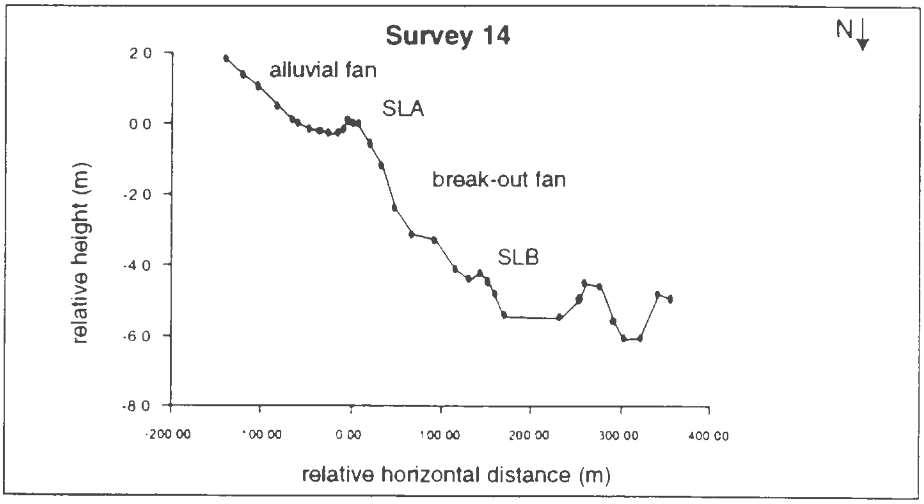


Figure 21: Field-surveyed profiles of Klondike Canyon fan-head trench. Survey 5 is closest to mountain. There are 200-feet intervals between surveys. Locations of surveys are on figure 2.

KLONDIKE CANYON ALLUVIAL FAN & SHORELINE A



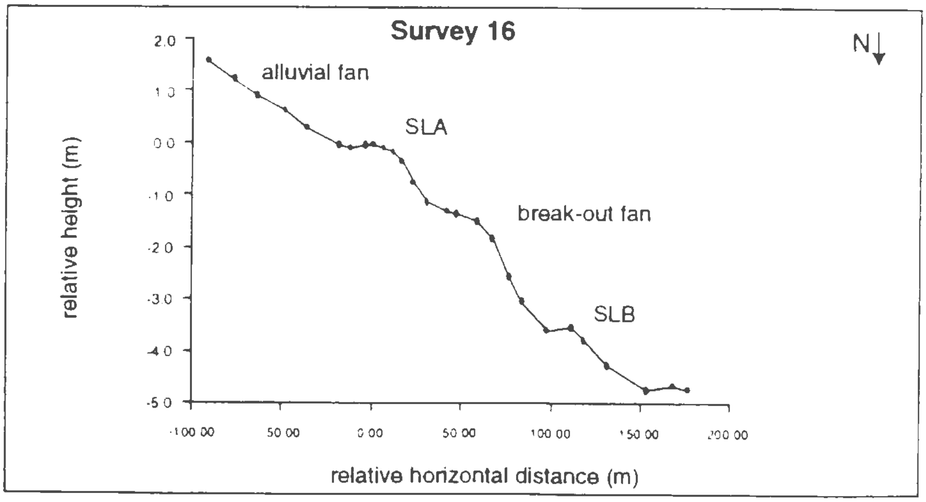


Figure 22: Filed-surveyed profiles of the contact between the Klondike Canyon alluvial fan and the high shoreline. Survey 14 is farther north than figure 16 and has a current erosional channel on the upslope side of the shoreline.

SURVEY 15

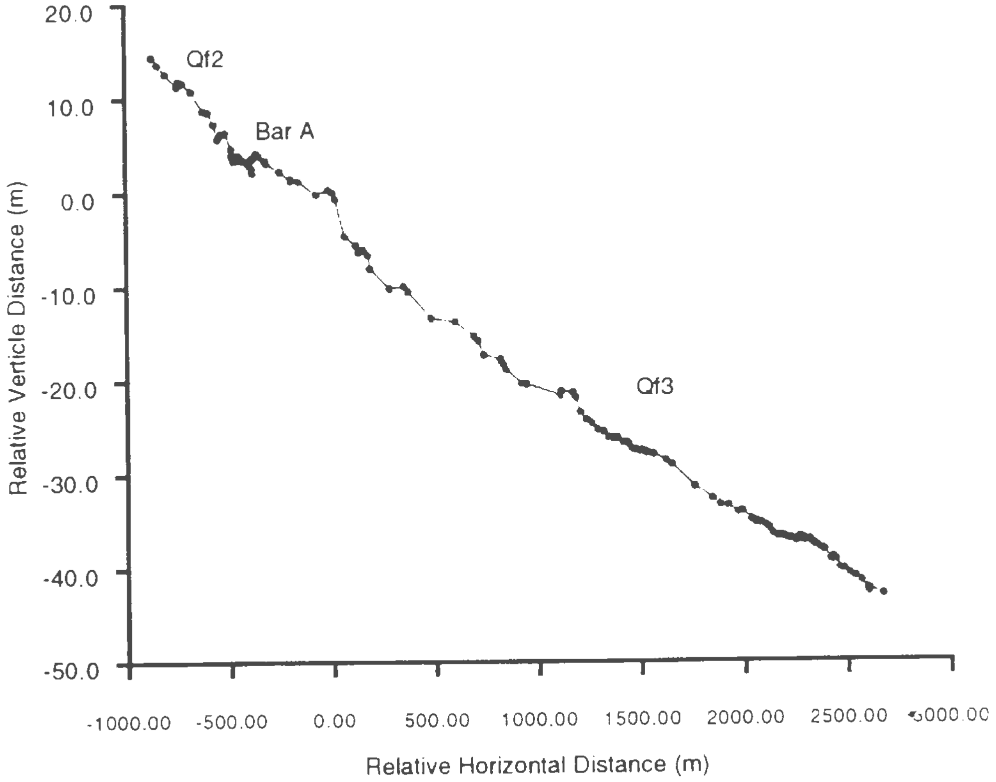


Figure 23: Profile of Klondike Canyon alluvial fan. "Bumps" on profile are shorelines. Location shown on figure 2.

Buena Vista Geology

PLATE I: GEOLOGY OF BUENA VISTA VALLEY

Q	Quaternary deposits, either landslide or older alluvial deposit
TR3	Tertiary rhyolitic flows and shallow intrusive rocks
Ts3	Tuffaceous sedimentary rocks
Tt2	Welded and nonwelded silicic ash-flow tuffs
Tgr	Granitic rocks - mostly quartz monzonite and granodiorite
Tba	Andesite and basalt flows
Kgr	Cretaceous granitic rocks - mostly quartz monzonite and granodiorite
TJgr	Granitic rocks, central and eastern Nevada - mostly quartz monzonite and granodiorite
Mzgr	Mesozoic granitic rocks, western Nevada - mostly quartz monzonite and granodiorite
Jgb	Lower and Middle Jurassic gabbroic complex - includes gabbro, basalt, and [illegible]ogenic quartz sandstone.
JTRs	Upper Triassic and Lower Jurassic shale, mudstone, siltstone, sandstone, and carbonate rock, sparse volcanic rock
TRc	Lower, Middle, and Upper Triassic limestone, minor amounts of dolomite, shale, and sandstone; locally thick conglomerate units
TRk	Lower Triassic Koipato group and related rocks - altered andesitic flow, rhyolitic tuff and flows and clastic rocks.
TRlgr	Leucogranite and rhyolite porphyry
PMh	Havallah sequence of Silberling and Roberts - chert, argillite, shale, greenstone, and minor amounts of siltstone, sandstone, conglomerate, and limestone
Msv	Lower and Upper Mississippian siliceous and volcanic rocks
Osv	Siliceous and volcanic rocks.
Ch	Upper Cambrian Harmony Formation - Feldspathic and sandstone and minor amounts of shale, limestone, and chert.