DEBRIS-FLOOD AND DEBRIS-FLOW HAZARD FROM LONE PINE CANYON NEAR CENTERVILLE, DAVIS COUNTY, UTAH

by

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ABSTRACT

Development in Centerville City is expanding into the Parsons gravel pit below Lone Pine Canyon where flooding occurred and associated debris was deposited during the wet years of 1983-84. The Federal Emergency Management Agency mapped this area as an A0 Zone (unnumbered A Zone) susceptible to alluvial-fan flooding. Centerville City officials need to know the debris-flood and debris-flow hazard in the area prior to development. To assess the hazard, the Utah Geological Survey excavated eight trenches on the alluvial fan on the Bonneville shoreline bench (about 800 feet [250 m] above the gravel pit) at the mouth of Lone Pine Canyon in May 1992. Data from the trenches were used to determine average size, type, and history of sedimentation events. This information was used to assess the potential for sediment deposition on the Bonneville shoreline bench and on the valley floor, and to suggest measures to reduce the hazard and allow safe development.

Stratigraphy exposed in the trenches shows that sedimentation events from the canyon were small (500 to 2,300 cubic yards [380-1,800 m^3]). The only deposit in the trenches suitable for radiocarbon dating was an organic-rich debris flow just below the modern soil. The flow occurred between about 1,100 and 1,400 years ago and had a volume of 2,300 cubic yards (1,800 m^3). The Bonneville shoreline bench acts as a depositional area for debris from Lone Pine Canyon. However, water associated with these events may have reached the valley floor and eroded debris from Lake Bonneville deposits below the Bonneville shoreline bench.

The greatest hazard to development in the Parsons gravel pit is flooding and subsequent deposition of material eroded from Lake Bonneville deposits below the Bonneville shoreline bench. Hazard-reduction measures may include constructing debris basins and flood-water diversion structures, and riprapping or armoring unvegetated parts of drainages below the Bonneville shoreline bench. With proper mitigation, debris-flood and debris flow hazards affecting development can be reduced and the gravel pit safely developed.

INTRODUCTION

Residential development in Centerville City is expanding into the Parsons gravel pit below Lone Pine Canyon (figure 1), along the northern boundary of the city. Minor flooding and sedimentation occurred there during the wet years of 1983-84. The Federal Emergency Management Agency (FEMA) mapped the gravel pit area as an AO Zone (unnumbered A Zone) or alluvial-fan flood-hazard area (Federal Emergency Management Agency, 1992). Centerville City officials need to know the debris-flood and debris-flow potential from Lone Pine Canyon and the size of the area affected in order to plan for the safe development of that part of the city.

At the request of Centerville City, the Utah Geological Survey conducted an geologic investigation at the mouth of Lone Pine Canyon. The purpose of the investigation was to estimate the

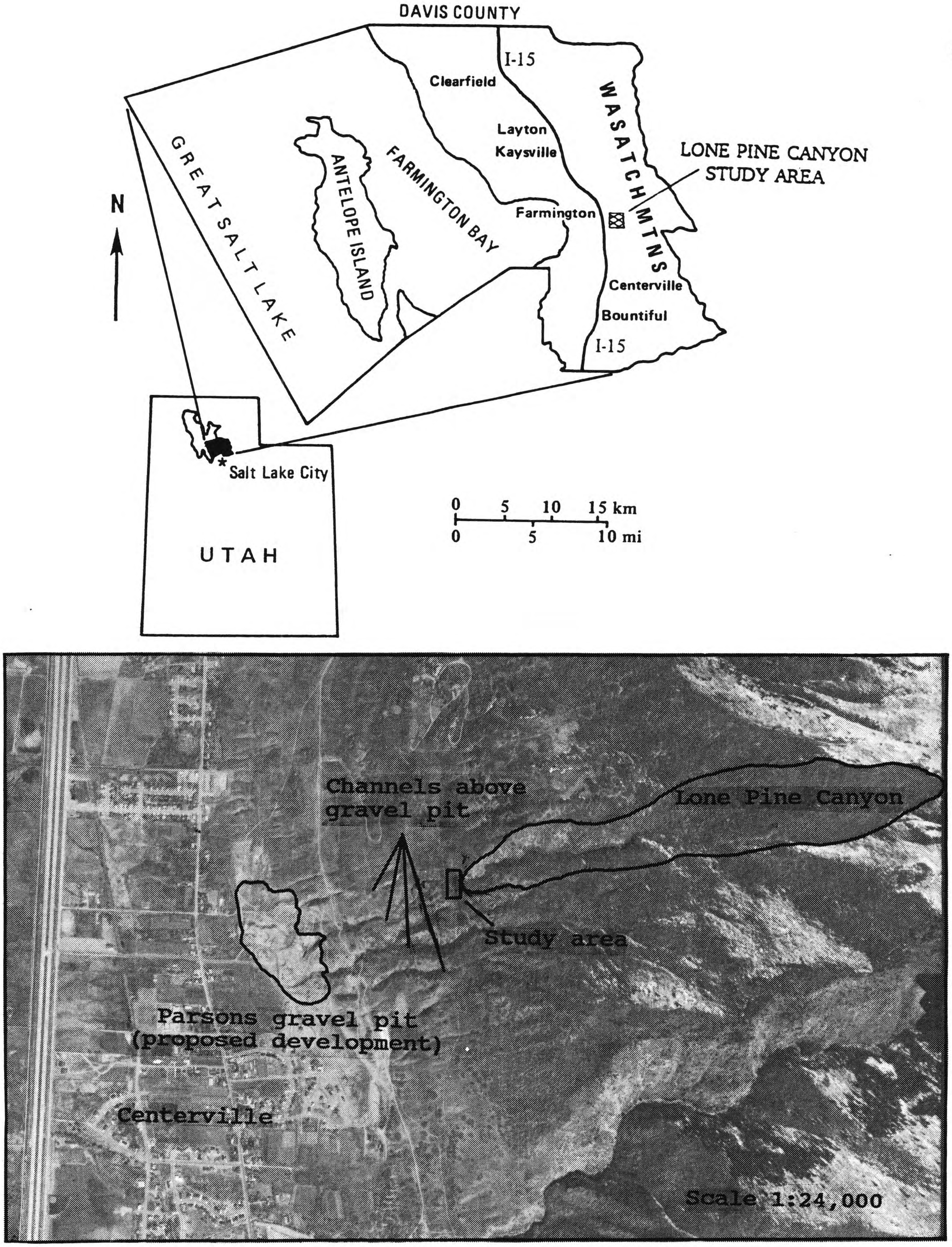


Figure 1. Location map.

potential for future debris flows or debris floods reaching the proposed development in the Parsons gravel pit where the Lone Pine Canyon drainage meets the valley floor. This principally involved determining whether sediment from the canyon could reach the valley floor or would be deposited on the Bonneville shoreline bench 800 feet (250 m) above the valley. Another goal of the study was to provide an estimate of the possible volumes of individual debris floods and debris flows for use in evaluating the need for hazard-reduction measures.

The scope of work included air photo interpretation, surficial mapping, and excavation of eight trenches to expose prehistoric sedimentation events on the fan. Stratigraphy exposed in the trenches was used to estimate the size, number, and history of sedimentation events. Centerville City provided partial funding for the investigation and J.B Parsons Company provided a backhoe to excavate trenches. By looking in detail at the size and history of prehistoric sedimentation events on the Bonneville bench, an estimate can be made about the frequency and characteristics of future events.

Trenches excavated for the study were on an alluvial fan at the mouth of Lone Pine Canyon on the Bonneville shoreline bench between the 5,160 and 5,200 foot (1,570-1,580 m) contour elevations. The site is on the northern boundary of Centerville City (figure 1). Steep slopes rise sharply east of the site to the Wasatch Range ridge crest at 8,860 feet (2,700 m). Rock outcrops are present on the slopes immediately above the canyon mouth at the

Bonneville shoreline. Mountain slopes are heavily vegetated with oak and maple. Vegetation on the alluvial fan consists of sage brush, grasses, and oak. Access to the site is on gravel and four-wheel-drive roads along and above the Davis County Aqueduct.

In this report, measurements (elevations, distances) are given in English units with metric equivalents in the text, and in metric units in the appendix. Soils were described in the field using the Unified Soil Classification System outlined in the ASTM D 2488-84, Standard Practice for Description and Identification of Soils (visual-manual procedure). These classifications and grain-size distribution precentages given in soil descriptions in the appendix are field estimates, and are not to be used for the design of structures. A glossary is included to explain technical terms.

ALLUVIAL-FAN SEDIMENTATION PROCESSES

Sedimentation on the fan at the mouth of Lone Pine Canyon is characterized by typical alluvial-fan processes, including slopewash, debris floods, and debris flows. Slopewash is the movement of material downslope by normal sheet-flow runoff from precipitation on the fan surface and surrounding slopes, and by overbank streamflow in small-magnitude flooding events or during snowmelt runoff. It is a gradual, low-energy process whereby sediments move and accumulate slowly. Because of this, slopewash deposits are composed of finer-grained material such as sand, silt, and clay.

Debris floods are debris-laden floodwaters, commonly confined to channels. Deposition occurs as channel gradient and confinement decrease. Debris floods move rapidly, and debris-flood deposits are coarser grained than slopewash deposits. Debris floods also have a lesser relative proportion of water than does slopewash, but a greater proportion than do debris flows, which are slower moving and form a muddy slurry much like wet concrete (Wieczorek and others, 1983). From 40 to 70 percent of a debris flood's volume may be boulders, cobbles, sand, and minor amounts of silt and clay. Debris-flood deposits are crudely bedded, have clast-to-clast contact, and fewer fine-grained sediments than debris-flow deposits.

Debris-flow deposits have a higher concentration of fines, are poorly bedded, and are matrix supported, commonly lacking the clast-to-clast contacts present in debris-flood deposits. Debris flows contain from 70 to 90 percent solids by weight, with larger clasts supported by the matrix of smaller material (Costa, 1984). Both debris floods and debris flows occur as relatively instantaneous geologic events, and can erode and deposit large amounts of material.

PREVIOUS WORK

The debris-flood and debris-flow potential of Lone Pine Canyon was first assessed by Wieczorek and others (1983) immediately after the wet winter and spring of 1983. Their assessment of Lone Pine Canyon was based on comparisons of 1983 events in similar-size drainages and records of events in the 1920s and 1930s along the Wasatch Front. They estimated that Lone Pine Canyon had a moderate potential for debris flows, and a moderate to high potential for debris floods.

The Federal Emergency Management Agency (U.S. Army Corps of Engineers, 1988) did a debris-flow-potential study for 15 drainages in Davis County based on the debris-flow events of 1983-84. The FEMA study devised a model to estimate debris-flow volumes using an existing FEMA clear-water flooding model by adding a bulking factor to simulate a debris flow. FEMA used debris volumes from the 1983-84 events and events in the 1920s, 1930s, and 1950s to derive the bulking factor. Canyons that had events during these years (Parrish, Ricks, and Rudd Canyons) were perennial stream drainages that produced large volumes (50,000 to 80,000 cubic yards [38,230-61,168 m^3]) of debris. Based on their model, FEMA estimated that 81,000 cubic yards (61,932 m^3) of material could come from Lone Pine Canyon.

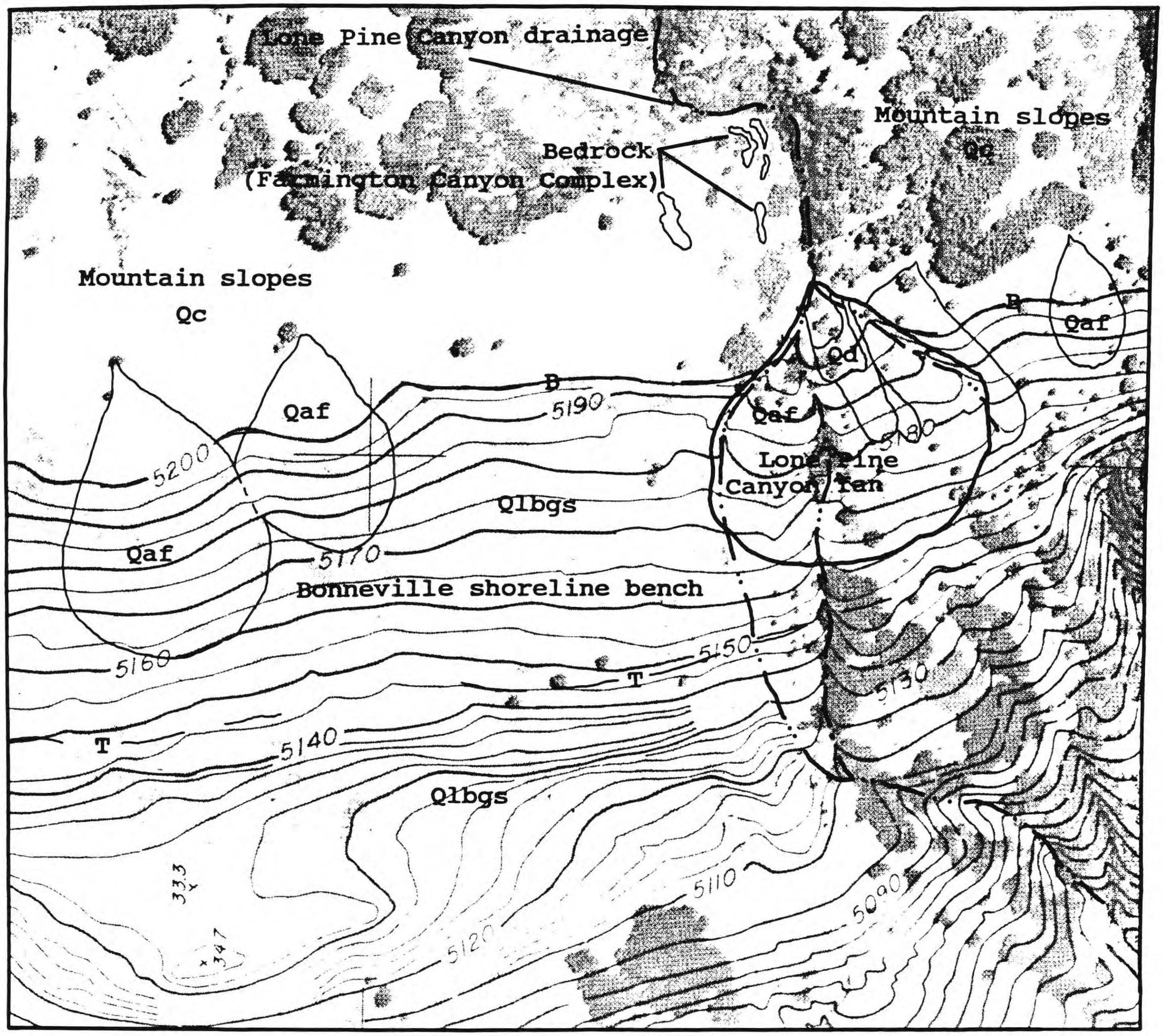
Keaton and others (1991) estimated recurrence intervals for debris flows in Lone Pine Canyon and other drainages in Davis County using the fan geometry and stratigraphy of fan sediments. Their study determined that Lone Pine Canyon had a low potential for large damaging debris flows. Keaton's group did not use the fan on the Bonneville shoreline bench in their study. Instead, they mapped and estimated debris-flow volumes from the fan on the valley floor. The Parsons gravel operation has removed this fan.

Mulvey and Lowe (1991) studied the debris-flow potential for the Lone Pine Canyon fan on the Bonneville shoreline bench, and channels leading from the bench to the Parsons gravel pit. They estimated debris-flow volumes from Lone Pine Canyon using the Pacific Southwest Interagency Committee (PSIAC) and Davis County Flood Control models. The PSIAC model calculates the average annual sediment yield from drainage basin slopes, and is commonly used to assess sediment yield from fire-damaged drainages. Sediment volumes estimated by the PSIAC model were 400 cubic yards (305 m^3) for pre-burn, and 5,100 cubic yards (3,900 m^3) for post-burn, assuming a heavy burn over the entire drainage area. The PSIAC model does not account for material scoured from the drainage channel, the source of most debris-flow material.

The Davis County Flood Control model was used as a comparison to the PSIAC model, because it estimates the volume of material contributed by the channel. Estimates using the Davis County Model determined that 76,000 cubic yards (58,100 m^3) of material could come from Lone Pine Canyon. Mulvey and Lowe (1991) concluded that the PSIAC model under-estimated potential debris-flow volumes, and the Davis County model overestimated volumes. They also concluded that the Davis County model was not applicable. This is because it was derived empirically from data on perennial streams that keep channels saturated, whereas Lone Pine Canyon is an ephemeral drainage with unsaturated soil conditions. Mulvey and Lowe (1991) suggested that a detailed study was needed to estimate debris-flow potential and volumes from Lone Pine Canyon.

GEOLOGY

Bedrock in the Lone Pine Canyon drainage is schist and gneiss of the Archean-age (2,500-3,000 million years ago) Farmington Canyon Complex (Bryant, 1989). These rocks are resistant to erosion and weather to form coarse, sandy soils. Outcrops are scattered along the drainage. The most prominent outcrops are on slopes immediately east of the study area above the Bonneville shoreline (figure 2). Much of the bedrock in the drainage is highly fractured, being part of a large pre-Bonneville-age (pre-15,000 years ago) landslide. The main scarp of the slide is at about 6,400 feet (1950 m) (Nelson and Personius, 1990) and the toe may have extended to the valley floor prior to the rise of Lake Bonneville. Landslide deposits on the valley floor were probably modified or removed by wave action in Lake Bonneville. However, the size and shape of the alluvial fan mapped by Nelson and Personius (1990) on the valley floor is larger than expected for the Lone Pine Canyon drainage. This suggests that some material from the landslide may be preserved beneath the Lake Bonneville lacustrine and post-Bonneville alluvial-fan deposits.



Explanation

Qd	-	most recent debris lobes
Qaf	-	alluvial fan
Qc	-	colluvium
Qlbgs	-	Lake Bonneville gravel and sand
B	-	Bonneville shoreline
T	-	Transgressive shoreline

Scale 1" = 200'

N

Figure 2. Geomorphic map of the study area.

Most of the study area is covered by Quaternary-age Lake Bonneville sediments, colluvium, and alluvial-fan deposits (figure 2). The Lake Bonneville sediments are composed of boulders, cobbles, sand, and a minor amount of silt. At Lone Pine Canyon, the Bonneville shoreline is an erosional feature cut into bedrock, and covered with beach sediments. The sediments are approximately 15,000 years old (Currey and Oviatt, 1985). At the Lone Pine Canyon fan, Lake Bonneville sediments are buried by 1 to 20 feet (0.3-6.9 m) of alluvium and colluvium deposited during the last 15,000 years. These deposits are composed of boulders, cobbles, sand, silt, and a minor amount of clay. Rock falls from outcrops above the bench contributed the largest boulders to these deposits.

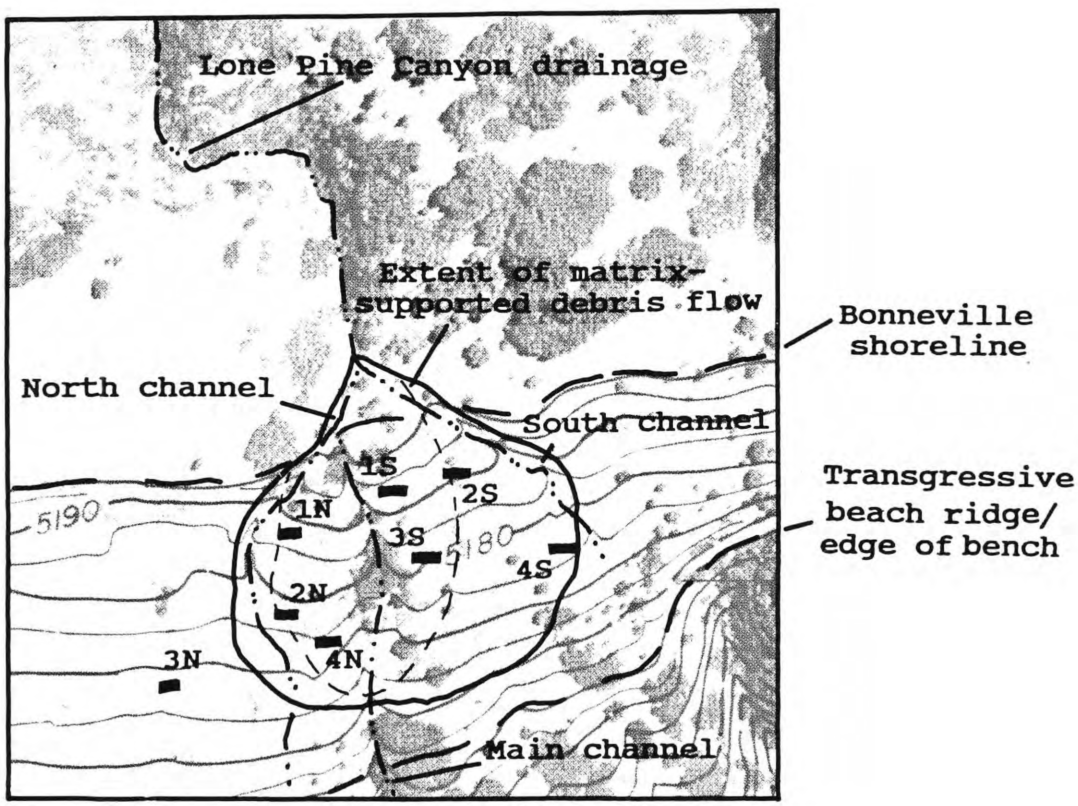
GEOMORPHOLOGY

Three principal landforms are present at the site: (1) the Bonneville shoreline beach platform or bench, (2) a transgressive beach ridge on the bench, and (3) alluvial fans (figure 2). The Bonneville shoreline beach platform forms a broad, gently west-sloping bench approximately 400 feet (120 m) wide. It is composed of rounded to subrounded boulders and cobbles, gravel, and coarse sand. The highest level of Lake Bonneville is marked by the Bonneville shoreline at the east edge of the bench (figure 2).

The transgressive beach ridge forms a line of large (5-6 feet [1-2 m]), wave-rounded boulders on the bench approximately 200 feet (60 m) west of the Bonneville shoreline (figure 2). This beach was formed as the lake stopped briefly during its rise to the Bonneville level (5,200 feet [1584 m]). The lake reworked sediments on the mountain slope into the beach ridge (figure 2). Lake Bonneville deposits blanket the steep slopes below the study site and extend to the valley floor and into the Parsons gravel pit. They are easily eroded and composed of rounded to subrounded boulders, cobbles, and sand.

Several alluvial fans are present on the Bonneville bench in the study area, with the largest at the mouth of Lone Pine Canyon (figure 2). The Lone Pine Canyon fan is the most active fan on the bench. Many large boulders (probably rock-fall clasts) are incorporated into the alluvial fan at the mouth of Lone Pine Canyon. Evidence for rock fall rather than debris flows as the source for these clasts are the outcrops above the fan. Fans with no outcrops above them do not have large boulders on their surface, fans with outcrops above them do have large boulders. The largest boulders on the Lone Pine Canyon fan are angular and are found near the mountain front near the fan apex. Rock-fall clasts reworked by wave action are rounded, whereas clasts deposited after the recession of Lake Bonneville are angular.

On the Lone Pine Canyon fan there are three distinct channels, only one of which generally carries water during runoff (figure 3). The main channel, which is the best developed, bisects the fan and is 3 feet (1 m) deep. Vegetation (oak) grows along the channel. The other channels follow the north and south margins of the fan. The northern channel carries modern flows, and it is thought to



Scale 1" = 200'

Scale 1" = 200'

Figure 3. Map of trench and channel locations.

have been excavated by local residents to divert water to a spring in the drainage below the bench (Huck Tucker, verbal communication, May 15, 1990). The third channel on the southern margin of the fan is abandoned and is 3 feet (1 m) above the modern channel at the canyon mouth. Only during extremely high flows would water enter this channel.

RESULTS OF INVESTIGATION

Type of Deposits Present

From my surficial mapping and trenching investigation of the alluvial fan at the mouth of Lone Pine Canyon, I determined that the fan is comprised principally of slopewash and debris-flood sediment. The majority of deposits are slopewash from erosion of the fan surface and from slopes immediately east of the study site. These sediments are mostly sand, with minor gravel, silt, and clay. They are massive with no erosional boundaries separating depositional events. The small grain size of the materials reflects a low-energy depositional environment.

The second most abundant type of deposits observed in the trenches were from debris floods. These deposits are composed of poorly sorted to unsorted boulders, cobbles, gravel, and sand, with a minor amount of silt. These deposits are interbedded with the slopewash sediments and have erosional contacts where they removed and incorporated slopewash material. Only one debris-flow deposit was found in the trenches. It was present on both sides of the fan, in 5 of the 8 trenches excavated.

Number and Size of Sedimentation Events

Since the waters of Lake Bonneville receded from the study site 15,000 years ago, sedimentation on the Lone Pine Canyon fan has been dominated by deposition of slopewash sediments interrupted by small debris floods (appendix). Initial deposition of material observed in the trenches began after Lake Bonneville dropped from the Bonneville shoreline during the late Pleistocene, about 15,000 years ago. Keaton and others (1991) suggest that the colder climate of the late Pleistocene increased weathering, making more debris available for transport. Evidence for this theory is thick latest Pleistocene-early Holocene alluvial-fan deposits found immediately on top of Lake Bonneville sediments at the mouths of many canyons in Davis County. In trenches 1S and 3S (two deepest trenches) the basal deposits (15 feet thick [4 m]) were coarse alluvium and debris-flood sediments. These trenches caved easily, and I did not log them in detail. However, I did observe thick alluvial deposits similar to those described by Keaton. This may support Keaton's theory for rapid late Pleistocene-early Holocene alluvial-fan sedimentation.

Commonly, when a long period of time separates sedimentation events, a soil forms on the deposits. In sediments at the mouth of

Lone Pine Canyon, no buried soils were present, suggesting that sedimentation processes on the fan have been continuous for the last 15,000 years. Most sediment deposited on the Lone Pine Canyon fan immediately after Lake Bonneville receded was alluvium. After an undetermined amount of time, slopewash processes dominated, interrupted by occasional small debris floods and a debris flow.

At least, two (north of main channel) to eight (south of main channel) debris-flood or debris-flow events occurred on parts of the Lone Pine Canyon fan in the last 15,000 years (appendix). These events are visible in the stratigraphy exposed in trenches and in deposits on the fan surface (figure 4). Because the source area and rock types are similar for all events, it is difficult to correlate individual deposits between trenches or across the fan surface or even determine the number of events represented by each deposit. Thus, the number of events given above is considered a minimum number.

Differences in numbers of events from the north to south side of the main channel are attributed to channel configuration near the canyon mouth above the fan. Immediately east of the mouth of the drainage the channel makes two 90 degree bends, first south, then west (figure 2). This preferentially directs material coming down the drainage to the south side of the fan.

Average sedimentation-event volumes were estimated from measurements of debris lobes visible on the fan surface. The lobes averaged 500 cubic yards (380 m^3), and traveled only 200 feet (61 m) from the mouth of the drainage (figure 2, table 1). These deposits were the only ones at the site whose total areal extent was visible. They are the best analog for deposits found in the trenches because their morphology, grain size, and thickness are similar. These surface deposits are considered to be representative of late Holocene sedimentation events from Lone Pine Canyon. Large boulders are common near the canyon mouth in these deposits and in one deposit in trench 1S. Because of the small size and low energy of these flows, they probably could not transport these boulders. Therefore, the boulders are interpreted to be rock-fall clasts.

Table 1. Volumes of debris lobes on the surface of the Lone Pine Canyon fan.

Area (square feet)	Thickness (feet)	Volume (cubic yards)
2,875	1.6	170
5,000	1.7	296
10,000	2.0	629
12,000	1.6	888

Only one sedimentation event (a matrix-supported debris-flow deposit) could be correlated between trenches on both sides of the main channel. It was visible in five of the eight trenches, covering half the fan surface with an average thickness of 1.6 feet (43 cm). The flow had an estimated volume of 2,300 cubic yards (1,800 m^3). It was 2-feet (60-cm) thick in trench 1N, thinning to 4 inches (10 cm) in trench 4N (appendix). A cross-sectional view of this flow is shown in figure 4 (unit C). This was the most

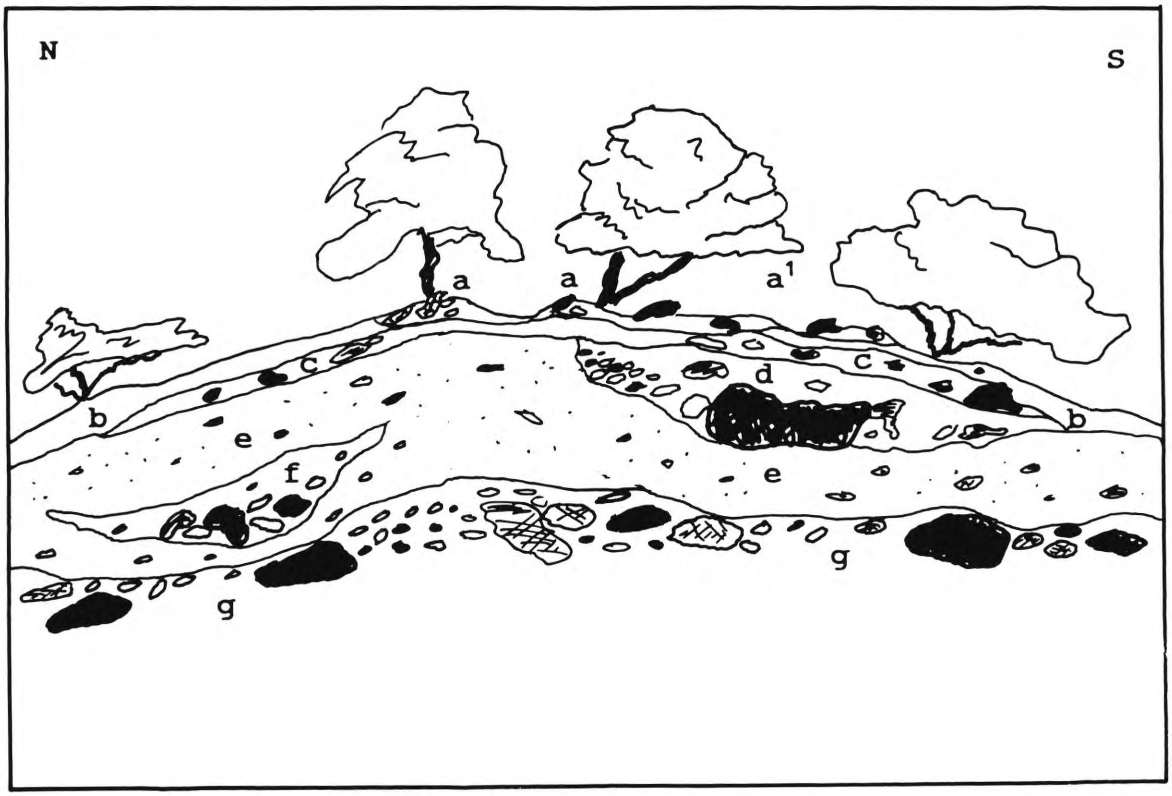


Figure 4. A. Schematic cross section of deposits in trenches on Lone Pine Canyon fan. a. debris-flood levees, a[1]. small 200 cubic yards^3/150 m^3) debris floods on fan surface, b. modern soil, c. organic-rich debris flow 1,100 to 1,400 cal B.P., d. clast-supported debris flood on south side of fan, e. slopewash deposits on fan, f. debris-flood deposit, g. Lake Bonneville deposits.

recent event exposed in the trenches. Radiocarbon ages (corrected to calendric dates) from organic material in this flow taken in trenches 1N and 3S indicate it occurred between 1,100 $\pm$ 250 and 1,400 $\pm$ 250 cal B.P. (Stuiver and Reimer, 1986) (Beta-54216 and Beta-54217; appendix). The four debris-flood lobes on the surface (figure 4, unit a) are younger than this, but their age is unknown.

I calculated the average sedimentation rate for the Lone Pine Canyon fan and determined that 175 cubic yards (130 m^3) of material are deposited on the fan surface in 100 years.

HAZARD ASSESSMENT

Potential for Debris Floods and Debris Flows

The hazard to development below Lone Pine Canyon from large debris flows similar to events in other Davis County drainages during the early 1980s is low. Lone Pine Canyon differs from those canyons because it is an ephemeral drainage without thick alluvium saturated by perennial stream flow. It is also different because historical records show no debris-flow events reaching the valley floor, even during the wet years of 1983-84.

As long as channel gradient is steep and width is narrow, debris floods and debris flows move downslope and maintain their sediment load. When the channel gradient decreases and width increases, flow slows, and debris is deposited. At Lone Pine Canyon the shoreline bench effectively reduces the channel gradient and increases its width, causing deposition on the bench. No coarse debris could be traced beyond the transgressive shoreline on the bench (5,160 feet [1,572 m]) (figure 2). If any large debris floods or debris flows had come from the canyon since Lake Bonneville receded from the site, they would have most likely buried the shoreline boulders. Based on this observation, I concluded that debris from sedimentation events in Lone Pine Canyon during the last 15,000 years was deposited on the Bonneville shoreline bench above the transgressive shoreline.

Most canyons that produced large prehistoric and historic debris flows in Davis County have perennial streams, whereas Lone Pine Canyon is an ephemeral drainage. The lack of a perennial stream in the canyon reduces the saturated soil conditions that contributed to debris flows in other Davis County canyons during 1983-84. Heavy vegetation in Lone Pine Canyon also reduces erosion.

Although most sediments from the canyon are deposited on the Bonneville bench, flood waters associated with these events flow off the bench and down to the valley floor. Evidence for this is the channels cut into Lake Bonneville deposits on the slope below the Bonneville bench. When water reaches these channels it erodes channel side-slopes and incorporates debris. The gravel pit has lowered the local base level for these channels and they are downcutting rapidly. Evidence for this is the fresh stream cuts in the upper wall of the gravel pit. The 1983 sedimentation event in the gravel pit probably was a result of such erosion.

Erosion of slopes below the shoreline bench with deposition in the gravel pit area is the greatest hazard to development. Material eroded from these slopes and deposited at their base in post-Bonneville time was about 15-feet (4.5-m) thick prior to the excavation of the gravel pit (Paul Kranbule, J.P. Parsons Companies, verbal communication, April, 19, 1992). Trenches from a 15-foot (4.5-m) excavation west of the gravel pit exposed sediments similar to slopewash deposits seen in the trenches. Boulders in this excavation and the gravel pit were rounded, indicating they were derived from Lake Bonneville deposits.

Volume of Sediment Per Event

Volumes of sediment deposited on the Bonneville bench per debris-flood event are small (500 to 2,300 cubic yards [380-1,800 m^3]). The average volume of debris deposited in the most recent events on the Lone Pine Canyon fan is 500 cubic yards (380 m^3), based on the measured volumes of the four debris-flood lobes visible on the fan surface (table 1). Although debris-flood events were difficult to trace between trenches, their thickness and extent appeared to be similar to those on the fan surface. The largest single event traced between trenches was 2,300 cubic yards (1,800 m^3). This event was a debris flow that covered approximately half the fan surface to an average depth of 1.6 feet

(0.5 m). At its deepest it was 2-feet (0.6-m) thick, and thinned to 6 inches (15 cm) in trench 4N at the toe of the fan.

In a worst-case scenario, volumes may be as large as 7,300 cubic yards (2,100 m^3). This worst-case scenario is based on the assumption that the entire fan would be covered to a depth of 2.5 feet (0.8 m), the thickest debris-flood unit in the trenches (trench 1S; appendix). The potential for a 7,300 cubic yard (2,100 m^3) event is low, based on the volumes of deposits found in the trenches and on the fan surface. There is no evidence for such an event in the past 15,000 years. However, even an event of this magnitude would probably remain on the Bonneville bench, contained by thick vegetation at the fan toe and the broad low-gradient bench.

CONCLUSIONS AND RECOMMENDATIONS

The hazard from large debris floods and debris flows from Lone Pine Canyon to the valley floor near the Parsons gravel pit is low, and with proper mitigation measures to reduce the risk, development can proceed. Evidence from trenching and surficial mapping shows the average volume of debris in the youngest sedimentation events is 500 cubic yards (380 m^3). The largest was approximately 2,300 cubic yards (1,800 m^3) and occurred between 1,100 and 1,400 years ago, covering 1/2 of the fan surface to a depth of 1.6 feet (0.8 m). In comparison, a worst-case event of 7,300 cubic yards (5,600 m^3) would cover the entire fan with 2.5 feet (0.8 m) of debris.

Deposition of sediments at the site has been relatively constant for the last 15,000 years, as buried soils indicating a period of non-deposition were not observed in the trenches.

Coarse debris from Lone Pine Canyon does not reach the valley floor, but is deposited on the Bonneville bench. Flood waters associated with these events do, however, flow over the bench and may reach the valley floor, eroding sediments from Lake Bonneville deposits below the bench. These flood waters and locally derived debris are the greatest hazard to development in the gravel pit.

Possible options for reducing the hazard from sedimentation events from Lone Pine Canyon are: (1) construction of a debris and flood-water retention structure on the Bonneville shoreline bench to catch and divert runoff from the bench, (2) construction of a debris basin on the valley floor in the Parsons gravel pit, or (3) a combination of both. Structures built to direct flood waters must be dual purpose, to contain both debris and flood waters. Also, riprap lining or armoring of unvegetated parts of the channels entering the pit would greatly reduce the volume of sediment contributed by channels between the bench and the gravel pit.

This study principally considered the debris-flood and debris-flow hazard from Lone Pine Canyon. However, several other drainages which feed into the gravel pit area may also require engineered structures to reduce hazards to acceptable levels. These are shown in figure 1. All may contribute debris and flood waters to the gravel pit area, and must be considered in an area-wide hazard-reduction program perhaps requiring diversions or larger basins.

Disturbing the natural drainage pattern should be kept to a minimum. I observed erosion along roads in Lake Bonneville sediments above the gravel pit after the July 12, 1992 cloudburst, which dropped 1.5 inches (3.8 cm) of rain in an hour on the Centerville area. As much as possible, structures should follow natural drainage patterns to reduce erosion problems. Because of the uncertainty in flood-water volumes and the need to control flood waters, a flood-volume study will be needed to determine design characteristics of flood-control structures.

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GLOSSARY

AO Zone - (unnumbered A Zone) alluvial-fan flood-hazard area designated by FEMA, and subject to sheet-flow flood depths of 1 to 3 feet (0.3-0.9 m).

Alluvium- a general term for clay, sand, gravel, or similar unconsolidated sedimentary material deposited by a stream.

Alluvial fan- a generally low, cone-shaped deposit formed by a stream issuing from mountains onto a lowland.

Alluvial-fan flooding- flooding of an alluvial-fan surface by overland (sheet) flow or flow in channels branching outward from a canyon mouth.

Bonneville level- The highest lake level/shoreline of Lake Bonneville, average elevation is 5,200 feet (1,550 m). Dates from 15,500 to 15,000 years ago.

Colluvium- a general term applied to any loose, unconsolidated mass of soil material, usually at the foot of a slope or cliff, and brought there chiefly by gravity.

Debris flood- soil materials transported by fast-moving flood waters. Solids account for 40 to 70 percent of the material by weight.

Debris flow- relatively rapid, viscous flow of water and coarse-grained surficial material. Solids account for 70 to 90 percent of the material by weight.

Flood plain- an area adjoining a body of water or natural stream that has been or may be covered by flood water.

Formation (geologic)- a rock unit consisting of distinctive features/rock types separate from units above and below.

Geomorphology- the study of landforms and the processes that create them.

Levee- ridges of material that border a debris-flow channel, generally deposited by the first pulse of material in a debris flow. Commonly composed of boulders and cobbles.

Massive- a stratum or stratified layer that is obscurely bedded, or that is or appears to be without internal structure.

Outcrop- the part of a geologic formation or structure that appears at the surface of the Earth.

Sedimentation- the act or process of forming or accumulating sediment in layers.

Slopewash- soil and rock material that is or has been transported down a slope by gravity assisted by running water not confined to channels.

Weathering- a group of processes, such as the chemical action of air, rain water, and plants and the mechanical action of temperature changes which cause rock to decay and crumble into soil.

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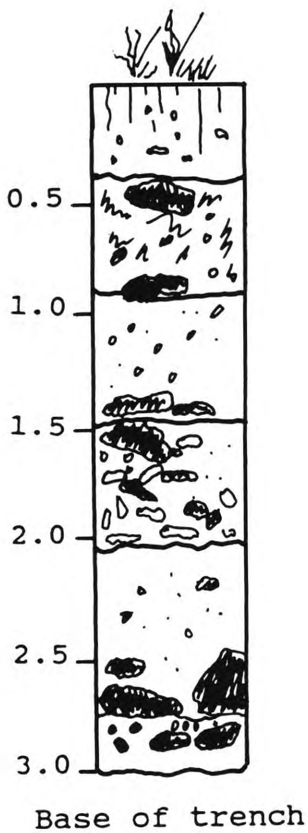
APPENDIX

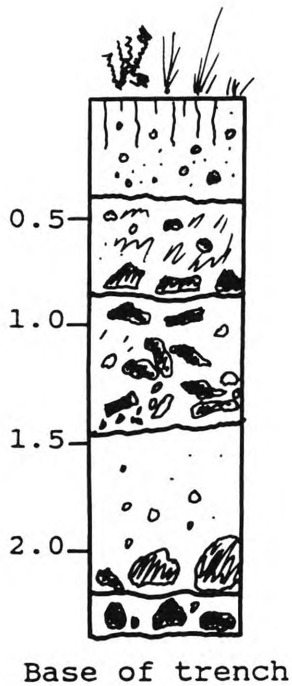
Stratigraphic columns and soil descriptions of geologic units in trenches



Trench 1N

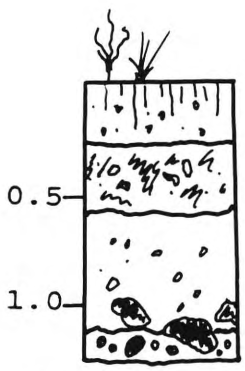
0-40 cm	Silty sand with gravel (SM); dark grayish brown 10YR 4/2 (dry), black 10YR 2/1 (wet); loose, nonplastic, dry; 60% sand, 25% gravel, 15% fines, average clast size 10-15 cm, maximum 25 cm; modern soil.
40-90 cm	Silty sand with gravel (SM); dark grayish brown 10 YR 4/2 (dry), black 10YR 2/1 (wet); medium dense, nonplastic-very low plasticity, dry; 60% sand, 20% gravel, 20% fines, cobbles present, average clast size 15-20 cm, maximum 35 cm; organic-rich debris flow; radiocarbon dated 1100 cal B.P. $\pm$ 250 yr.
90 cm-1.45 m	Silty sand with gravel (SM); yellowish brown 10YR 5/4 (dry), dark yellowish brown 10YR 3/4 (wet); medium to high density, low plasticity, dry; 70% sand, 15% gravel, 15% fines, some boulders present, average clast size 3-5 cm, maximum 45 cm; slopewash sediments.
1.45-2 m	Well-graded sand with silt and gravel (SW-SM); yellowish brown 10YR 5/4 (dry), dark yellowish brown 10YR 3/6 (wet); low to medium density, low to slight plasticity, dry; 50% sand, 40% gravel, 10% fines, average clast size 15-20 cm, maximum 35 cm; debris-flood sediments.
2-2.75 m	Clayey sand with gravel (SC); yellowish brown 10YR 5/4 (dry), dark yellowish brown 10YR 3/4 (wet); medium to high density, low plasticity, dry; 70% sand, 15% gravel, 15% fines, some boulders present, average clast size 10-15 cm, maximum 40 cm; slopewash sediments.
2.75-2.9 m	Well graded sand with clay and gravel (SW-SC); dark yellowish brown 10YR 4/6 (dry), dark yellowish brown 10YR 3/6 (wet); medium to high density, low plasticity, moist; 60% sand, 30% gravel, 10% fines, subrounded to rounded pebbles and cobbles, average clast size 3-5 cm, maximum 10 cm; Bonneville shore facies.

Trench 2N



0-42 cm	Silty sand with gravel (SM); dark grayish brown 10YR 4/2 (dry), very dark brown 10YR 2/2 (wet); loose, nonplastic, dry; 60% sand, 25% gravel, 15% fines, average clast size 3-5 cm, maximum 10 cm; modern soil, grades into bedded stream deposits.
42-85 cm	Silty sand with gravel (SM); dark grayish brown 10YR 4/2 (dry), black 10YR 2/1 (wet); medium density, nonplastic-very low plasticity, dry; 60% sand, 20% gravel, 20% fines, cobbles present, average clast size 5-10 cm, maximum 25 cm; organic-rich debris flow.
85 cm-1.4 m	Well-graded sand with silt and gravel (SW-SM); yellowish brown 10YR 5/4 (dry), dark yellowish brown 10YR 4/4 (wet); low to medium density, low plasticity, dry; 50% sand, 40% gravel, 10% fines, average clast size 5-10 cm, maximum 25 cm; debris- flood sediments.
1.4-2.25 m	Clayey sand with gravel (SC); yellowish brown 10YR 5/4 (dry), dark yellowish brown 10YR 3/4 (wet); medium to high density, low plasticity, dry; 70% sand, 15% gravel, 15% fines, some boulders present, average clast size 3-5 cm, maximum 30 cm; slopewash sediments.
2.25-2.35 m	Well-graded sand with clay and gravel (SW-SC); dark yellowish brown 10YR 4/6 (dry), dark yellowish brown 10YR 3/6 (wet); medium to high density, non to very low plasticity, moist; 60% sand, 30% gravel, 10% fines, subrounded to rounded pebbles and cobbles, average clast size 3-5 cm, maximum 15 cm; Bonneville shore facies.

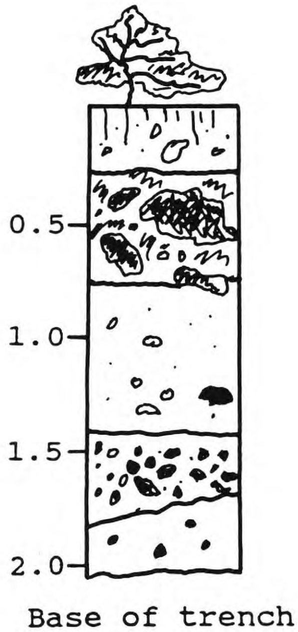
Trench 3N



Base of trench

0-28 cm	Silty sand with gravel (SM); dark yellowish brown 10YR 4/2 (dry), very dark brown 10YR 2/1 (wet); loose, nonplastic, dry; 60% sand, 25% gravel, 15% fines, average clast size 1-2 cm, maximum 5 cm; modern soil.
28-55 cm	Silty sand with gravel (SM); dark grayish brown 10YR 4/2 (dry), black 10YR 2/1 (wet); medium density, nonplastic, dry; 60% sand, 20% gravel, 20% fines, cobbles present, average clast size 2-4 cm, maximum 15 cm; organic-rich debris flow.
55 cm-1.09 m	Clayey sand with gravel (SC); dark yellowish brown 10YR 4/4 (dry), dark yellowish brown 10YR 3/4 (wet); high density, low to moderate plasticity, dry; 60% sand 15% gravel, 25% fines, average clast size 2-4 cm, maximum 15 cm; slopewash sediments.
1.09-1.20 m	Well graded sand with clay and gravel (SW-SC); dark yellowish brown 10YR 4/6 (dry), dark yellowish brown 10YR 3/6 (wet); medium to high density, none to slight plasticity, moist; 60% sand, 30% gravel, 10% fines, subrounded to rounded pebbles and cobbles, average clast size 5- 10 cm, maximum 25 cm; Bonneville shore facies.

Trench 4N



0-28 cm — Silty sand with gravel (SM); dark grayish brown 10YR 4/2 (dry), very dark brown 10YR 2/1 (wet); loose, nonplastic, dry; 60% sand, 25% gravel, 15% fines, average clast size 10-15 cm, maximum 40 cm; modern soil.

28-75 cm — Silty sand with gravel (SM); dark grayish brown 10YR 4/2 (dry), black 10YR 2/1 (wet); medium density, nonplastic, dry; 60% sand, 20% gravel, 20% fines, cobbles and boulders present, average clast size 10-15 cm, maximum clast size 40 cm; organic-rich debris flow.

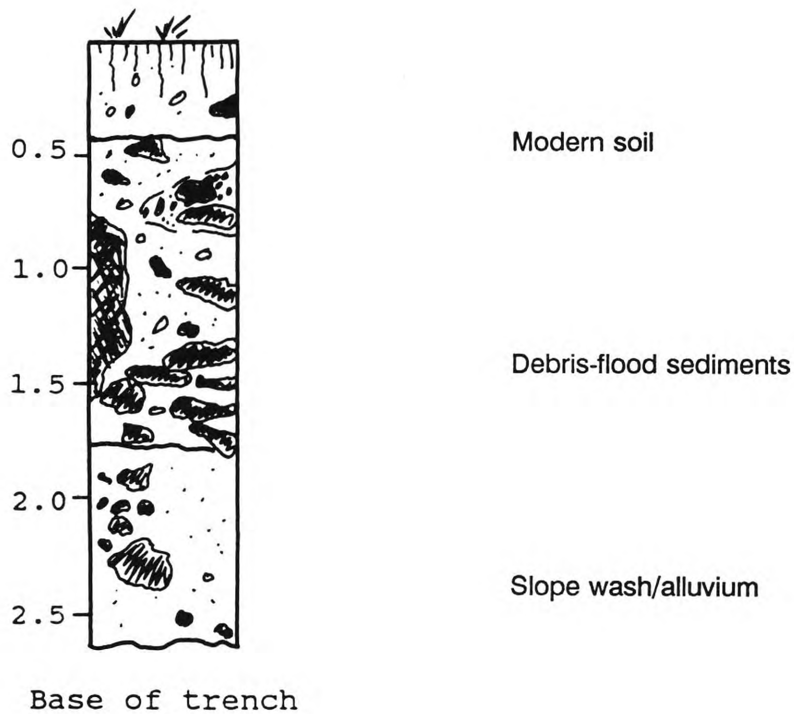
75 cm-1.40 m — Silty sand with gravel (SM); dark yellowish brown 10YR 4/4 (dry), dark yellowish brown 10YR 3/4 (wet); high density, nonplastic, dry; 70% sand, 15% gravel, 15% fines, average clast size 3-5 cm, maximum 50 cm; slopewash sediments.

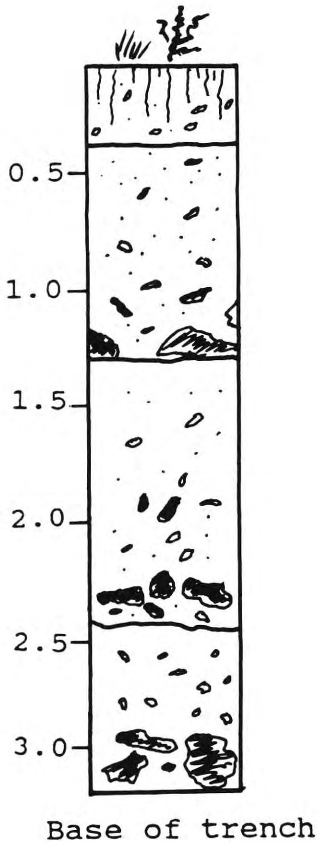
1.40-1.80 m — Well graded sand with silt and gravel (SW-SM); yellowish brown 10YR 5/4 (dry), dark yellowish brown 10YR 3/4 (wet); medium density, nonplastic, dry; 60% sand, 30% gravel, 10% fines, average clast size 3-8 cm, maximum 15 cm; debris-flood sediments.

1.80-2.05 m — Silty sand (SM); yellowish brown 10YR 5/6 (dry), dark yellowish brown 10YR 3/4 (wet); medium density, low plasticity, moist; 75% sand, 10% gravel, 15% fines, average clast size 1-2 cm, maximum 5 cm; Bonneville shore facies.

Trench 1S

Did not log in detail due to collapse danger.



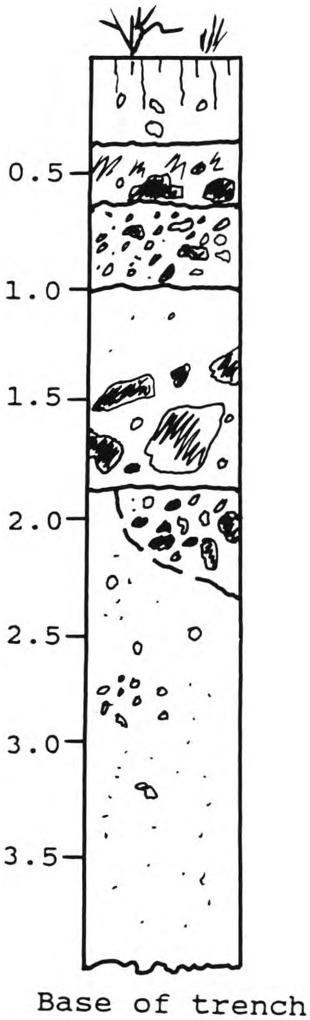


Trench 2S

0-35 cm	Silty sand with gravel (SM); dark grayish brown 10YR 4/2 (dry), very dark brown 10YR 2/2 (wet); low density, low plasticcity, dry; 60% sand, 25 % gravel, 15% fines, average clast size 3-5 cm, maximum 15 cm; modern soil.
35 cm-1.3 m	Silty sand with gravel (SM); brown 10YR 5/3 (dry) very dark brown 10YR 3/3 (wet); high density, slightly plastic, dry; 60% sand, 25% gravel, 15% fines, average clast size 5-10 cm, maximum 40 cm; slopewash sediments.
1.3-2.4 m	Poorly graded sand with silt and gravel (SP-SM); yellowish brown 10YR 5/4 (dry), dark yellowish brown 10YR 4/4 (wet); medium to high density, nonplastic, dry; 50% sand, 40% gravel, 10% fines, average clast size 10-15 cm, maximum 30 cm; slopewash sediments.
2.4-3.2 m	Poorly graded sand with silt and gravel (GP-GM); yellowish brown 10YR 5/4 (dry), dark yellowish brown 10YR 4/4 (wet); medium to high density, nonplastic, dry; 50% gravel, 40% sand, 10% fines, average clast size 15-20 cm, maximum 40 cm; debris- flood sediments.

Trench 3S

Did not log in detail due to collapse danger.



Modern soil

Matrix-supported organic-rich debris flow
* radiocarbon date location 1400 ± 25° Cal B.P.

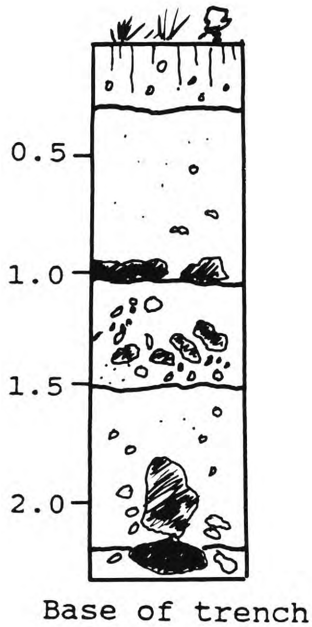
Debris-flood sediments

Debris flow

Alluvium

Slope wash/alluvial sediments

Trench 4S



0-29 cm	Silty sand with gravel (SM); dark grayish brown 10YR 4/2 (dry), very dark brown 10YR 2/2 (wet); medium density, slightly plastic, dry; 60% sand, 25% gravel, 15% fines, average clast size 3-5 cm, maximum 5 cm; modern soil.
29-95 cm	Silty sand with gravel (SM); dark grayish brown 10YR 4/2 (dry), very dark brown 2/2 (wet); medium to high density, low plasticity, dry; 60% sand, 25% gravel, 15% fines, average clast size 2-5 cm, maximum 20 cm; slopewash sediments.
95 cm-1.5 m	Well graded gravel with silt and sand (GW-GM); yellowish brown 10YR 5/6 (dry), dark yellowish brown 10YR 3/4 (wet); low density, nonplastic, dry; 50% gravel, 40% sand, 10% fines, average clast size 6-10 cm, maximum 12 cm; debris-flood sediments.
1.5-2.2 m	Silty sand with gravel (SM); yellowish brown 10YR 5/6 (dry), dark yellowish brown 10YR 3/4 (wet); high density, low plasticity, dry; 60% sand, 25% gravel, 15% fines, some boulders present, average clast size 5-10 cm, maximum 45 cm; slopewash sediments.
2.2-2.4 m	Well graded sand with gravel (SW); yellowish brown 10YR 5/4 (dry), dark yellowish brown 10YR 4/4 (wet); low density, nonplastic, average clast size 10 cm, maximum 40 cm; Bonneville shore facies.