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NEVADA BUREAU OF MINES AND GEOLOGY

# **Landslide-Induced Flooding at Ophir Creek, Washoe County, Western Nevada, May 30, 1983**

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# **Landslide-Induced Flooding at Ophir Creek, Washoe County, Western Nevada, May 30, 1983**

**By Patrick A. Glancy, U.S. Geological Survey, and John W. Bell,  
Nevada Bureau of Mines and Geology**

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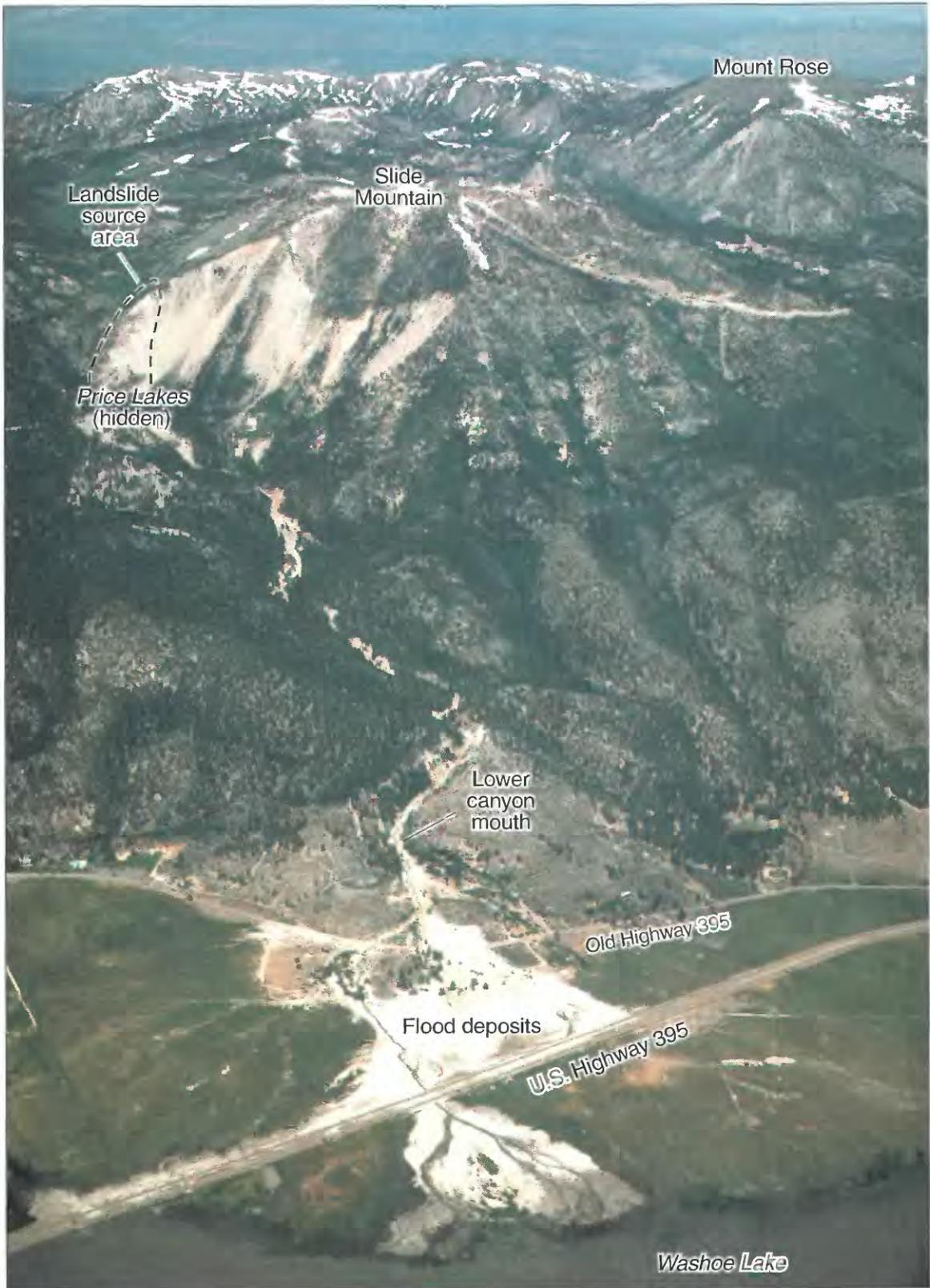
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**Frontispiece.** Panoramic aerial view of Ophir Creek and Slide Mountain, western Nevada, looking northwest. Mount Rose at upper right. Photographed from airliner by A.S. Van Denburgh, U.S. Geological Survey, August 5, 1983.



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## CONVERSION FACTORS, VERTICAL DATUM, AND PARTICLE-SIZE UNITS

Multiply	By	To obtain
acre	0.4047	square hectometer
acre-foot (acre-ft)	0.001233	cubic hectometer
cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second
cubic yard (yd <sup>3</sup> )	0.7646	cubic meter
foot per foot (ft/ft)	0.3048	meter per meter
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
foot per second (ft/s)	0.3048	meter per second
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
mile per hour (mi/h)	1.609	kilometer per hour
square foot (ft <sup>2</sup> )	0.09290	square meter
square mile (mi <sup>2</sup> )	2.590	square kilometer
yard (yd)	0.9144	meter

**Temperature:** Degrees Fahrenheit can be converted to degrees Celsius by using the formula  $^{\circ}\text{C} = 0.556(^{\circ}\text{F}-32)$

**Sea level:** In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929, formerly called “Sea-Level Datum of 1929”), which is derived from a general adjustment of the first-order leveling networks of the United States and Canada.

**Particle-size units** are expressed in millimeters (mm) and phi ( $\phi$ ) units.



# Landslide-Induced Flooding at Ophir Creek, Washoe County, Western Nevada, May 30, 1983

By Patrick A. Glancy, U.S. Geological Survey, and John W. Bell, Nevada Bureau of Mines and Geology

## ABSTRACT

Ophir Creek, a small stream on the eastern slopes of the Sierra Nevada, western Nevada, flooded severely on May 30, 1983. Flooding began at mid-day during clear, hot weather devoid of recent storm activity. It killed one person, seriously injured four others, and caused over \$2 million damages.

The flood was abruptly triggered by a landslide from the slopes of, appropriately named, Slide Mountain. The slide was the combined product of gravity, favorable geostructural orientations of bedrock, and sudden hydraulic imbalances. The aberrant hydraulics resulted from intensive melting and infiltration of heavy snowpack during several days of unseasonably hot weather. About 1,400,000 cubic yards of rock material plummeted into small Upper Price Lake, a pond astraddle the creek, on the upper flank of Slide Mountain. The force of the slide entering the lake quickly expelled about 20 acre-feet of mostly water. About 2 more acre-feet were incorporated downstream as nearby Lower Price Lake was, in turn, emptied by the sudden flow surge.

Expelled water initially flowed at probable rates of 13,000-20,000 cubic feet per second. Flow raced 0.6 mile down the steep upper canyon of Ophir Creek, gouging easily erodible channel materials. Flow compounded as it further incorporated snow, eroded debris, and additional water. It deposited about 50 acre-feet of debris just downstream of the upper canyon. The debris-charged flow then surged 1.06 miles through the lower canyon of Ophir Creek, eroding and incorporating more debris from the flatter lower canyon. Peak flood discharge of the leading flood surge progressively increased to about 50,000 cubic feet per second near the lower canyon mouth.

The leading debris-flow front overtopped the normal channel downstream from the lower canyon mouth and overran two homes, killing one person and injuring

three who were fleeing the 20 to 30-foot-high, 200-foot-wide surge. The leading front arrived at Old Highway 395, about 2.9 miles downstream from Upper Price Lake, 8 to 9 minutes after it began, after travelling at an average velocity of 19 to 22 miles per hour (28 to 32 feet per second). Upstream of the roadway, flow largely bypassed a manmade, diversionary channel. Instead, it flowed straightforwardly down the axis of the Ophir Creek alluvial fan, where lateral channel confinement decreased. The flood plain quickly widened and flattened causing spreading and slowing of the leading flow surge. This flow transformation resulted in the start of widespread debris deposition. Three more homes were damaged or destroyed and another person seriously injured downstream from Old Highway 395.

Hydraulic dynamics of the flood were complex and variable over time and enroute. The dilute peak-flow surge from Lower Price Lake quickly transformed to boulder- and vegetation-laden flow through severe erosive bulking within the canyons. At the lower canyon mouth, the surge was a watery debris flow of a dual character: (1) A coarse component consisting of boulders, cobbles, gravel, sand, and trees intermixed with (2) a fine-grained, matrix-fluid component of low clay and mud content and of low cohesion and yield strength. These components tended to separate at sites of velocity drops wherein the turbid fluid matrix flowed faster and beyond deposits of the coarse-grained fraction. Flow of the turbid fluid matrix beyond the terminus of boulder deposits displayed mixed hydraulic characteristics that prevented confident classification as either hyperconcentrated flow or debris flow.

Total sediment deposits of the flood were about 450 acre-feet. Sediment was only a component of the total floodflow, but resultant bulk volume of sediment deposits was more than 20 times the volume of Price Lakes, where the flood originated. Total floodflow

(water and debris) reaching the Ophir Creek alluvial fan was about 800 acre-feet, more than 36 times the initial volume of Price Lakes. Other contributing sources of water included snowmelt from upstream of the landslide, ground water draining from the slide mass and scar, existing streamflow overrun in the channel, tributary inflow downstream from Lower Price Lake, ground water in pores of debris eroded from the channel, ground water stored in the streambed and banks of Ophir Creek that drained to the channel following severe scour by the leading, boulder-laden flood surge, and snowpack atop the slide mass and in the canyons.

Stratigraphic and particle-size distribution characteristics of sediment deposits indicate that the coarse-grained sediments on the Ophir Creek fan were deposited by debris flows and infer that a prolonged debris-flow phase of progressively decreasing magnitude followed the leading peak-flow surge. Photographic evidence documented the progressive return to Newtonian streamflow conditions during early hours of the flood recession, which continued for several days.

## INTRODUCTION

About noon on the hot, sunny Monday of May 30, 1983, Tom Reed, his wife, and three companions were finishing the interior of Reed's newly built home on the west side of Washoe Valley in western Nevada (figs. 1 and 2). The Reeds had constructed their house on the north-bank terrace of Ophir Creek less than a quarter of a mile downstream from the mouth of the lower canyon of Ophir Creek (fig. 2), just outside of the estimated 100-year flood plain. Suddenly, a member of Reed's group commented about the abnormally loud noise the creek seemed to be making. Simultaneously, others glanced upstream and saw a wall of boulders, mud, and trees about 30 ft high and over 100 ft wide, cascading rapidly toward them from the canyon mouth. Instinctively, all five scrambled desperately in a race for life that only four of the group won. Reed's house and that of a nearby neighbor were the farthest upstream (fig. 2), and, thus, the first to be overrun by the 1983 "Memorial Day flood."

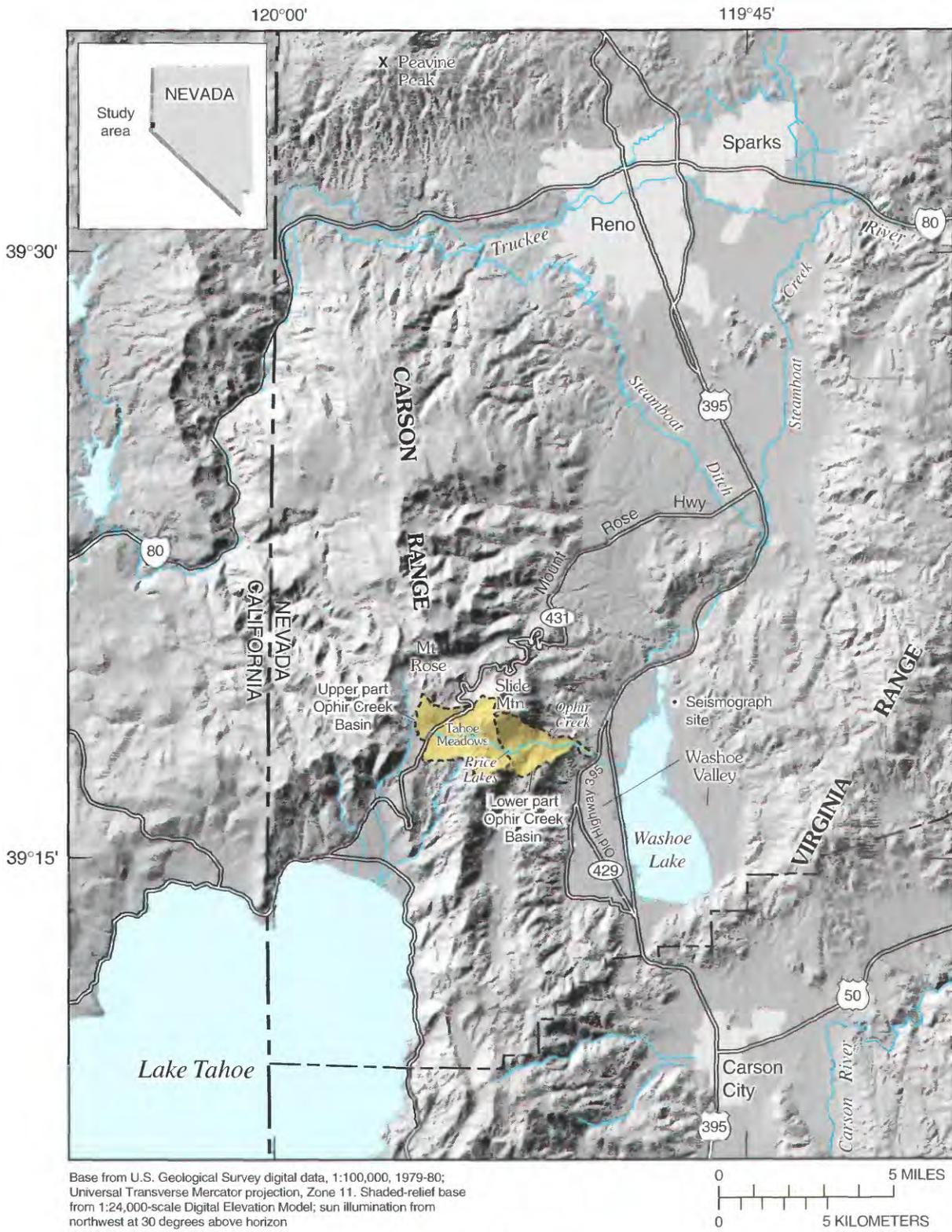
The origin of this flood was different from most floods in western Nevada, but its effects were similar to those of destructive flash floods that commonly occur almost yearly throughout Nevada, the Great Basin, and other parts of the arid West. Normally, desert flash floods are triggered by rainfall and therefore are accompanied by cloudy skies and unstable air currents.

People threatened by these "normal" floods are generally attuned to the impending hazards by blustery and unstable weather conditions, a warning that allows them to be on guard and seek safety when threatened. In contrast, this flood was triggered during and by the results of hot, clear, and calm weather, and the victims were struck immediately after a warning that consisted only of the sight and sound of the approaching deluge.

The unseasonably hot weather, which also had prevailed during several previous days, accelerated melting of an abnormally heavy snowpack. The snowmelt infiltrated the fracture system of the structurally unstable, steeply sloping, bedrock mass of Slide Mountain, which extends to the Ophir Creek channel several miles upstream from the area of human development. Apparently, the rapid infiltration of snowmelt increased hydraulic pressures within the bedrock fracture system sufficiently to unbalance the static forces that had been maintaining stability of the mountain slope. The destabilizing hydraulic forces and the force of gravity caused rapid failure of a portion of the steeply sloping bedrock mass and its overlying regolith, which triggered a rapid sequence of events that quickly culminated in disaster for the inhabited areas downstream. The destabilized mass slid downward into Upper Price Lake, a small reservoir. The force of its abrupt plunge into the lake rapidly expelled the lake contents into and through smaller Lower Price Lake, about 0.1 mi downstream. The combined contents of both lakes then cascaded downstream through two steep, narrow canyons and vigorously eroded the unstable channel bed and canyon walls enroute. This flood surge gathered mass and momentum as it progressively incorporated debris along about 2-3/4 mi of transit. When it reached the lower canyon mouth, the debris-laden flow disgorged its contents on unsuspecting inhabitants near the juncture of the mountain slopes and the valley floor (frontispiece).

## Purpose and Scope

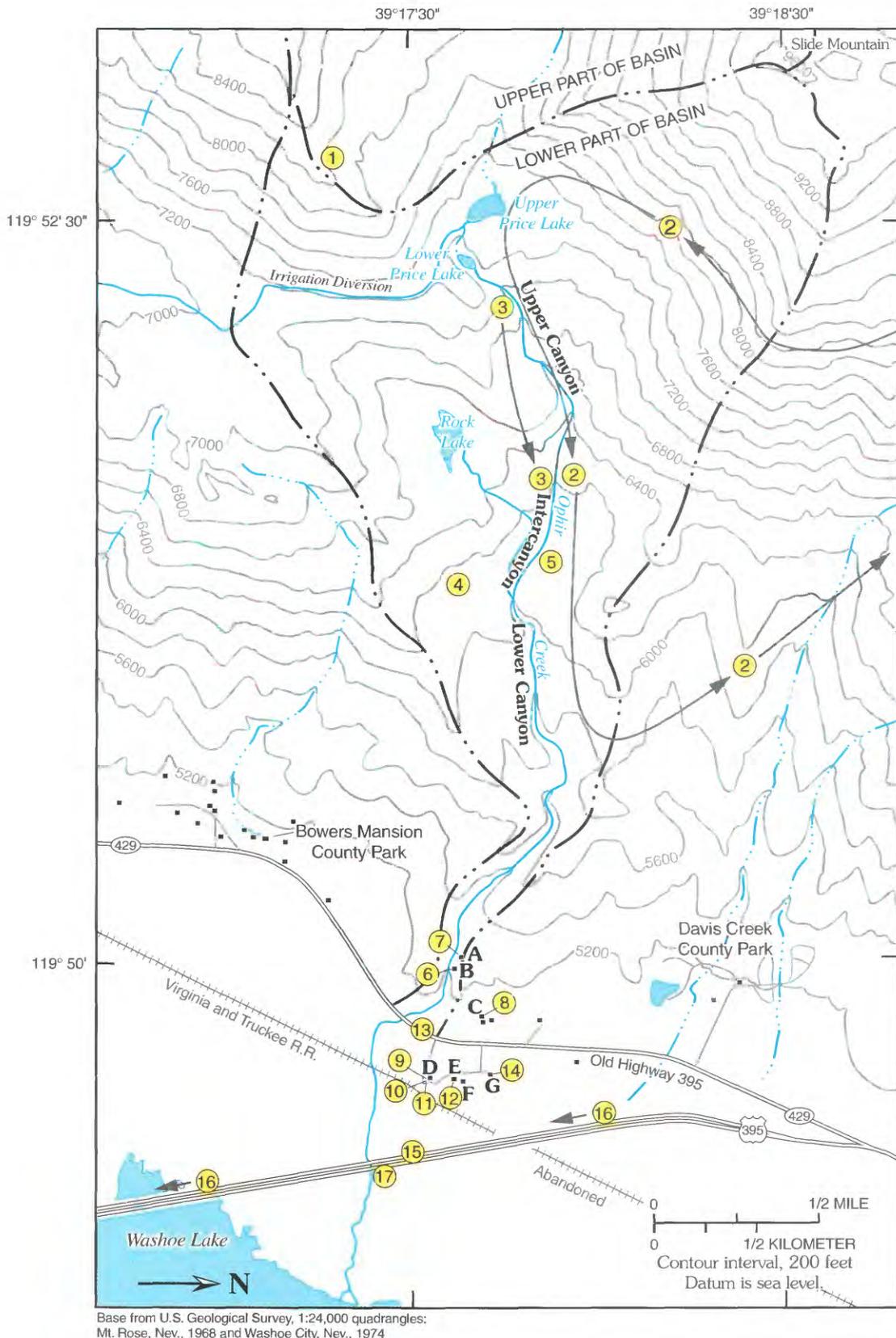
The landslide-induced flood at Ophir Creek on May 30, 1983, provided an opportunity to scientifically document an important hydrogeological event. The rapid expulsion of Price Lakes by the landslide initiated a chain of events that was witnessed by many. Resultant scientific data were more plentiful than usual for severe floods in sparsely populated areas. The available data facilitated a major objective of this investigation by allowing quantification of several hydrogeological



**EXPLANATION**

 **Ophir Creek Basin**

**Figure 1.** Ophir Creek Basin, Western Nevada, and nearby geographic features.



**Figure 2.** Locations of selected eyewitnesses and other features during the May 30, 1983, flood of Ophir Creek, Nevada.

## EXPLANATION

— · · — Boundary of Ophir Creek Basin

C.

### Homes referred to in text

- A Ogilvy
- B Reed
- C Thompson
- D Stafford (originally Price)
- E Cline
- F Turek
- G Graves

### Approximate locations of eyewitnesses during flood (appendix B)

- ① Ronald Mentgen (possible location)
- ② Doug Cook (approximate hanglider route)
- ③ James Schumacher (approximate upstream location and extent of downstream retreat)
- ④ Mark Bridgewater (location uncertain)
- ⑤ William and Elizabeth Willets (approximate location)
- ⑥ Tom Reed, John Burrue, and Tim Miller
- ⑦ Anne Ogilvy
- ⑧ Kathleen Thompson
- ⑨ Greg Stafford
- ⑩ Shirley Stafford
- ⑪ Vic Stafford
- ⑫ Kathleen "Katy" Cline (swept to freeway by flood)
- ⑬ Patricia Sommers (abandoned car)
- ⑭ Susan Graves
- ⑮ Kenneth Julian
- ⑯ Reed Dopf (moving)
- ⑰ Charles McQuerry

← Arrows show approximate travel routes of eyewitnesses during the duration of their observation

Figure 2. Continued.

characteristics to add to our understanding of hazardous flood processes, specifically those associated with rapid releases of water in fragile and easily erodible environments. Another purpose of this documentation is to improve general understanding and awareness of hydrogeological hazards and their potential consequences in a high-risk area that is experiencing rapid human encroachment and development.

The benefit of having eyewitnesses strategically located throughout a drainage basin during a flash flood is uncommon, particularly in the sparsely populated Great Basin. This flood was witnessed by at least 20 people who inadvertently were positioned fortuitously and were later able to vividly recount their observations and experiences. The sunny and warm weather that prevailed during the flood allowed witnesses to observe and note events without the distracting discomfort of inclement weather. Their observations were not obscured or distorted by wind, rain, poor visibility, or other discomforts common during floods. As a result of these factors, eyewitness accounts of high quality spanned the full duration of the landsliding and flooding. These accounts are included in this report (app. B) to provide both a broad overview and scientifically important details of the disaster from its beginning to its conclusion. Additionally, the eyewitness accounts provide detailed and varied perspectives on human reactions and responses to a natural disaster by those directly threatened and affected. Although catastrophic floods caused by reservoir spillage are not an everyday occurrence, neither are they extremely rare. Commonly, reservoirs drain rapidly during dam failures if their impounded volumes of water are small and if the dam fails quickly and completely; drainage can occur within a time period ranging from a few minutes to possibly half an hour, depending on characteristics of the small reservoirs and the nature of the failures. In contrast, the forceful and nearly instantaneous expulsion of a reservoir's contents, as occurred at Upper Price Lake during this event, is a rare phenomenon. The hydraulic-energy release for a given quantity of water may be on the order of one to several orders of magnitude greater in such cases of nearly instantaneous spilling. The downstream effects that follow such an intense energy-release rate can be devastating, as demonstrated by the effects of this flood.

In addition to documenting the 1983 event, this report summarizes information on historical floods and prehistoric landslides and debris flows within the Ophir Creek Basin (app. A). The report compares the subject flood with predictions of flood hazards made about a decade earlier, and it documents some of the natural landscape-healing processes that have occurred during the decade following the flood. The report also summarizes damages caused directly by the flood. Last, it includes conclusions regarding the potential for future hydrogeologic hazards within the lower part of the Ophir Creek Basin, an area of continually accelerating human development.

## Acknowledgments

Many individuals and organizations contributed to the preparation of this report. Information that was used directly in the text, figures, or tables is credited at appropriate places. The authors also offer their gratitude to the many people and organizations that are not cited or mentioned directly, but who assisted in the investigation and shared their knowledge with us and the readers. The authors are especially grateful to Steven Ellen, Jon Major, Michael Nolan, and David Prudic of the U.S. Geological Survey, for critical reviews of the report and numerous helpful suggestions.

## THE SETTING

Ophir Creek is a small, elongate drainage of about 4.5 mi<sup>2</sup> that drains east-southeastward down the steep, east-facing slopes of the Carson Range of the Sierra Nevada. It heads on the southeastward flank of Mount Rose (upper part, fig. 1), includes the southward-draining slope of Slide Mountain, and empties into Washoe Lake (lower part, fig. 1). The lake occupies a natural land-surface depression; its surface outflow (Steamboat Creek) is ultimately tributary to the Truckee River, about 14 mi to the northeast. The Ophir Creek Basin is about 16 mi southwest of downtown Reno, Nev., and about 10 mi northwest of downtown Carson City. Ophir Creek is one of many small streams that drain eastward from the Sierra Nevada into a rapidly developing, mixed urban-suburban corridor that parallels the eastern flank of the range for about 65 mi southward from Reno.

The 1983 flood did not involve the entire 7-mi length of the Ophir Creek drainage basin, but rather was limited to the lower 3 mi of the channel (figs. 1 and 2). The peak flood surge originated mainly from two small, adjacent point sources. These point sources of stored water were Upper and Lower Price Lakes, located about 3 mi upstream from the creek's mouth and juncture with Washoe Lake.

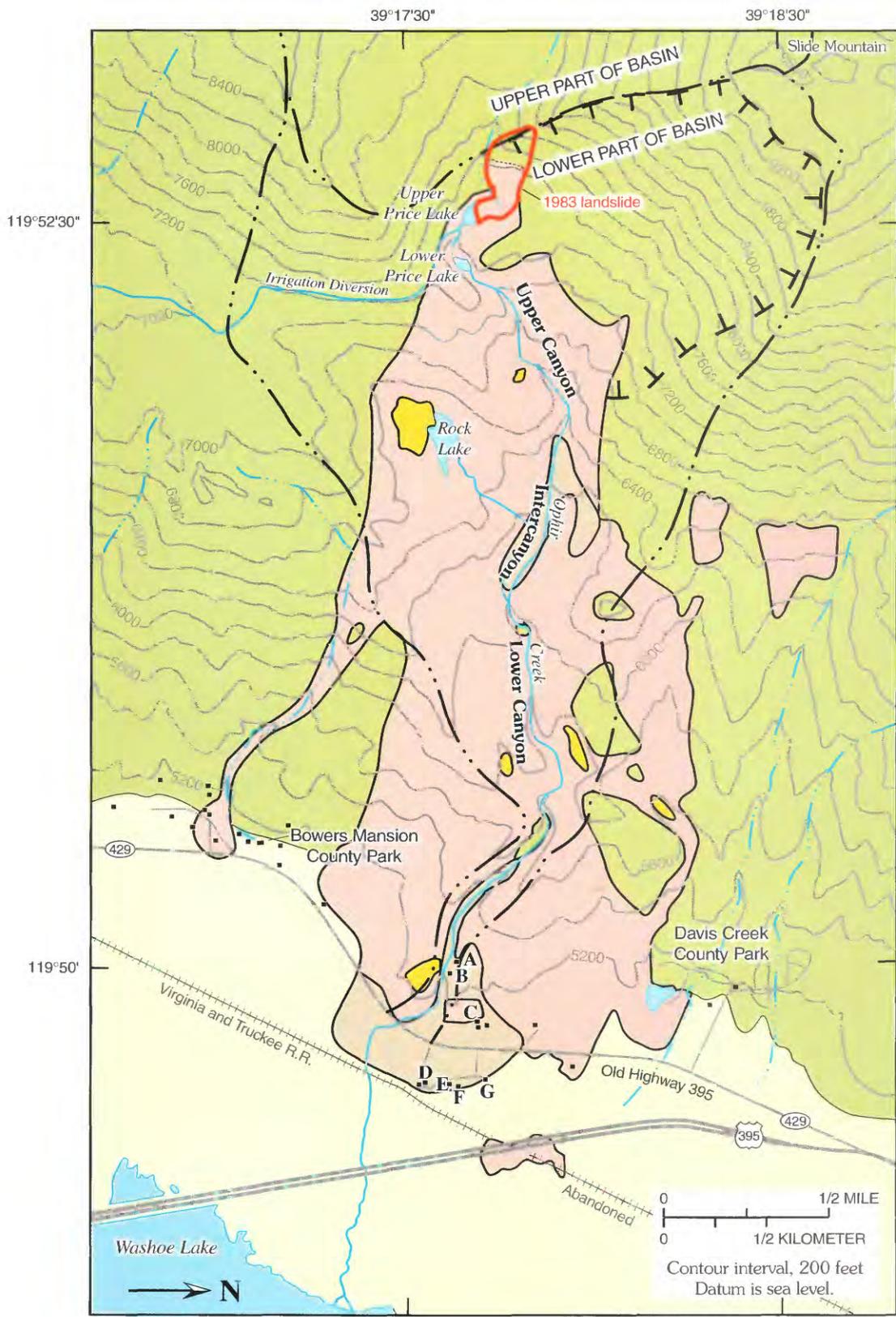
The Ophir Creek drainage (fig. 1) is currently (1990's) inhabited only along its lower 1-1/2 mi length. Although many people travel the upper part of the basin on Nevada State Highway 431, commonly called the Mount Rose Highway, most residents occupy the mountain-front alluvial fan that was constructed by numerous past Ophir Creek floods. The fan, as well as many other features described here, are collectively shown in the photographs of figure 3, the maps of fig-

ures 2 and 4, and the drainage profile of figure 6. U.S. Highway 395, a four-lane divided freeway, the primary transportation link between Reno and Carson City, crosses the distal extremity of the Ophir Creek fan diagonally on a southeasterly alignment. The old Virginia and Truckee Railroad grade, abandoned in 1950, also crosses the fan diagonally along a southwesterly alignment, a short distance upgradient from the freeway. The freeway and railroad grade cross irrigated pastures growing on fine-grained alluvial sediments that underlie the gently sloping distal part of the fan (figs. 3, 4, and 6). Ophir Creek joins Washoe Lake downstream from the freeway at a distance that varies with the stage of the lake and the varying position of its shoreline. Nevada State Route 429, better known as Old Highway 395, traverses the fan, roughly along its topographic contour, a short distance upstream from the abandoned railroad grade. This highway, which now serves mainly local residents, is situated along the more steeply sloping medial part (fig. 6) of the fan, upstream of the pasture lands. This steeper sloping medial segment of the fan is underlain by dominantly coarse-grained sediments, including numerous boulders, deposited both by Ophir Creek floods and by prehistoric landslides from the southeastern face of Slide Mountain (fig. 4). The upstream, proximal segment of the fan (fig. 6) was increasingly developed for houses a few years after the flood. The proximal and medial segments of the Ophir Creek fan (fig. 6) currently contain an increasing number of dwellings and, if the potential for future natural hazards is ignored, most of these areas, as well as the distal segment, will probably become prime candidates for future, full-scale, real-estate development. The areally larger upstream part of the Ophir Creek Basin (fig. 1) is increasingly being used by hikers, skiers, and others for year-round recreational purposes.

Although the downstream, gently sloping areas (medial and distal segments) of the alluvial fan are mostly treeless, a Sierran coniferous forest, with an understory dominated by manzanita and bitterbrush, dominates the landscape upslope from Old U.S. Highway 395 to the crest of the Carson Range. Uplands of the Ophir Creek Basin near Price Lakes, at the base of the southeastward-facing slope of Slide Mountain, are composed of hummocky-configured slopes that were formed by deposition of prehistoric landslides from the face of the mountain. Most of these hummocky uplands are steeply sloping and deeply entrenched by the channel of Ophir Creek.



**Figure 3.** Vertical aerial photographs of Ophir Creek alluvial fan, western Nevada: *A*, pre-flood view (U.S. Forest Service photograph, July 15, 1977). *B*, Post-flood view (Nevada Department of Transportation photograph, June 6, 1983).



Base from U.S. Geological Survey, 1:24,000 quadrangles: Mt. Rose, Nev., 1968 and Washoe City, Nev., 1974. Map of deposits modified from Tabor and Ellen, 1975

**Figure 4.** Areal extent of landslide and fluvial deposits prior to the May 30, 1983, flood, lower Ophir Creek Basin, Nevada.

## EXPLANATION

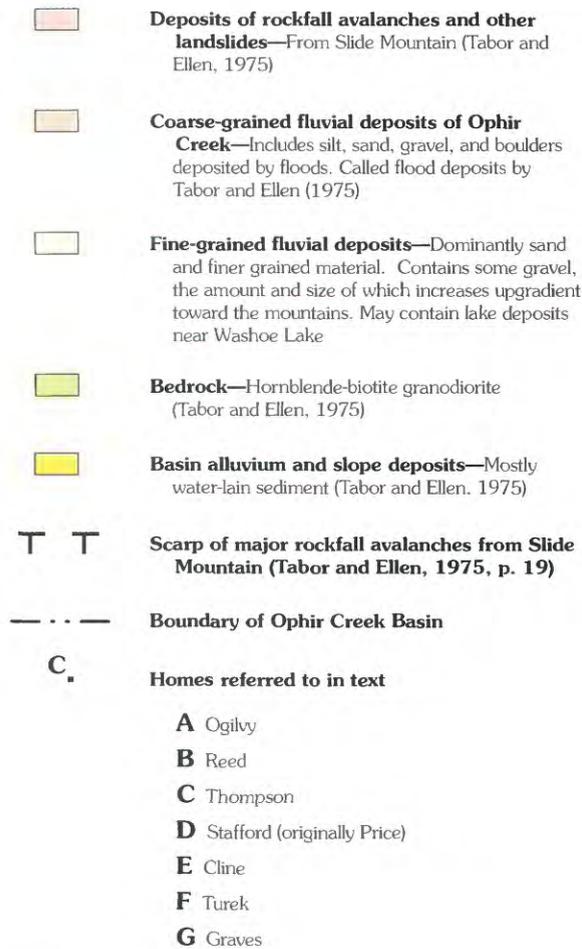


Figure 4. Continued.

Local climate is transitional between the arid Basin-and-Range climate to the east and the wetter Sierran climate to the west. On an annual basis, the Sierran snowpack is the product of the dominant precipitation component, but individual storms during any season can yield large amounts of rain. Severe regional flooding can be caused by heavy regional rainstorms or by rain on a thin or water-saturated snowpack. Summer convective storms frequently are intense and often have caused severe localized flash flooding, both in the Sierras and the adjacent Basin and Range region.

## Basin Geologic Characteristics

Ophir Creek drains the east-facing slopes of the Carson Range of the Sierra Nevada, thus its drainage basin is situated exclusively in an igneous rock terrane (Thompson and White, 1964; Bonham, 1969; and Tabor and Ellen, 1975). The bulk of the igneous

bedrock exposed in the basin is Cretaceous-age, hornblende-biotite granodiorite that was emplaced as part of the Sierra Nevada batholith. In the upstream part of the basin (fig. 1), some Tertiary-age volcanic bedrock of the Kate Peak Formation (Miocene or Pliocene age) is exposed on the southern flanks of Mount Rose (Thompson and White, 1964, pl. 1; Bonham, 1969, pl. 1). However, in the downstream part of the basin (fig. 1), including mainly drainage from Slide Mountain and the unnamed highlands to the south of Ophir Creek (fig. 4), the bedrock terrane is exclusively granodiorite and related intrusive, igneous rocks. Because the 1983 flood, which is the main subject of this report, originated within and was confined to this lower part of the basin, this geologic discussion is limited to the lower part of the Ophir Creek drainage (figs. 1 and 4).

The Carson Range (fig. 1), including Slide Mountain, and the easterly adjacent Washoe Valley, are landscape products of the tectonic evolution of Basin and Range physiography that has been ongoing regionally since mid-Tertiary time. Major faults in the granodioritic mass of the lower part of Ophir Creek Basin trend generally north-south (Tabor and Ellen, 1975). Carson Range uplift, relative to Washoe Valley downdrop, has resulted in a topographic relief of between 3,000 and 3,500 ft, along the Ophir Creek floodway, from the southeast face of Slide Mountain to the western shoreline of Washoe Lake. This steeply sloping relief manifests over a distance of about 3.5 mi, over 95 percent of it in slightly less than 3 mi.

Landslide (including rock avalanche) and fluvial deposits dominate the landscape of lower Ophir Creek Basin (fig. 4). The landslide deposits were designated as "Debris Flows of Slide Mountain" by Tabor and Ellen (1975). They are referred to as landslide deposits in this report to clearly distinguish their genesis from the frequently discussed debris flows of the 1983 flood which emplaced the flood deposits through a different rheological process. The bedrock fracture pattern within the granodiorite mass that makes up the southeast-facing slopes of Slide Mountain played a critical role in the origin of the landslide that initiated the 1983 flood. Geometric orientation of this joint-and-fracture system promoted downslope movement of the lithic mass into Upper Price Lake. Indeed, the orientation of bedrock fractures has been largely responsible for a long succession of prehistoric slides from Slide Mountain (Tabor and Ellen, 1975; app. A). The origin of this joint and fracture pattern is probably related to both the cooling (shrinkage) history of the granitic (granodiorite) batholith and subsequent Basin and Range structural stresses.

## The Drainageway

### Price Lakes

Upper Price Lake occupies a small natural depression astride Ophir Creek at the base of the southeastward-facing slopes of Slide Mountain (fig. 2). Downstream about 0.1 mi, Lower Price Lake was a small pond impounded by a man-constructed dam on Ophir Creek. There are few bathymetric data for either of the lakes. The Mount Rose and Washoe City 1:24,000-scale topographic maps (U.S. Geological Survey, 1968a and b) show the lake-surface areas to be about 4 acres (Upper Price Lake) and 1 acre (Lower Price Lake). Measurements made after the 1983 flood suggest an average depth for the southern half of Upper Price Lake of 3 to 4 ft, and about 2 ft for Lower Price Lake. The northern half of Upper Price Lake was filled by debris during the May 30, 1983, landslide and, preceding the landslide, no accurate measurements of depths (only estimates discussed below) for this part of the lake are known.

Bottom sediments in both lakes, exposed by drainage of the lakes following the 1983 landslide, appear to consist chiefly of materials deposited by the through-flowing Ophir Creek. The lake-bed-surface deposits consist predominantly of sand-size and finer grained materials. The bottom sediments of Upper Price Lake also include a substantial amount of decayed organic material. The exposed bottom of the southern half of Upper Price Lake revealed a surface of relatively low and gentle relief assumed to result from long-term, generally uniform deposition of inflowing sediment. This lack of pronounced bottom relief, and a uniform depth as exhibited by the southern half of the lake, is difficult to reconcile with rumors of a previously deeper zone to the north that is now covered by the 1983 landslide deposits.

Norman Cliff, long-term Washoe Valley resident, recalls a "deep hole" (area and depth unknown) at the northwest corner of Upper Price Lake (oral communication, 1983). Cliff's recollection of greater-than-average depth in the northwest part of the lake has been independently bolstered through conversations with several fishermen and swimmers in the Washoe County and Carson City areas who adamantly insist that a "deep hole" existed, but are unable to quantify its depth and diameter.

Mark Warren, Nevada Department of Wildlife, made a biological stream survey of Ophir Creek several years before the flood that confirmed a perennial trout population in Upper Price Lake (oral commun., 1985).

Warren believes these trout required some water habitat deeper than 3 to 4 ft for winter survival because a lake of consistently shallow depth would have frozen solid during most average winters. According to Warren, replenishing the oxygen supply necessary for fish survival would also have required a zone deeper than 3 to 4 ft that remained hydraulically connected continuously with the freshwater inflow from Ophir Creek. A former Washoe Valley resident, Warren recalls swimming and fishing in Upper Price Lake during his boyhood summers. Like Norman Cliff and the other local fishermen and swimmers, he is confident that a "deep hole" existed at the north or northwest part of the lake prior to the 1983 landslide. He estimated the maximum depth of the hole at about 15 ft. Although uncertain of the surface area or bottom configuration of this deeper-than-average zone, he agreed with the authors of this report that a surface area of 4 acres and an estimated average lake depth of 5 ft should adequately account for the overall lake volume at the maximum lake stage. Thus, on the basis of available evidence, the combined volumes of water contained in Upper and Lower Price Lakes at the time of the 1983 landslide are estimated to be about 22 acre-ft (20 and 2 acre-ft, respectively). The amount of water volume that was contained as ice at the time of the flood is uncertain (see eyewitness account of Ronald P. Mentgen, app. B).

### Ophir Creek

Immediately downstream from Lower Price Lake, Ophir Creek descends through a deeply entrenched, steep canyon (referred to as the upper canyon in this report) for a distance of about 0.6 mi (fig. 5). Channel gradients of Ophir Creek, including those of the upper canyon, are shown in figure 6. The steep gradient in the upper canyon (average, 26 percent, or 14.6°) promotes very energetic streamflow. The upstream part of the confining canyon floor and walls consists of an easily erodible and incompetent mass of a granodiorite rock slide that Tabor and Ellen (1975) mapped as a shattered slide block. Individual fragments in this mass range from huge, house-size boulders down to silt- and clay-size particles. The unstable slopes of this severely shattered mass, exceptionally prone to erosion by the high-energy streamflow, are shown in figure 7. The remainder of the upper-canyon channel boundary also consists of prehistoric landslide debris that is equally susceptible to erosion by streamflow.



**Figure 5.** Upstream view of upper canyon of Ophir Creek downstream from Lower Price Lake, western Nevada. Oblique aerial photograph by R.L. Jameson, U.S. Forest Service, May 31, 1983.

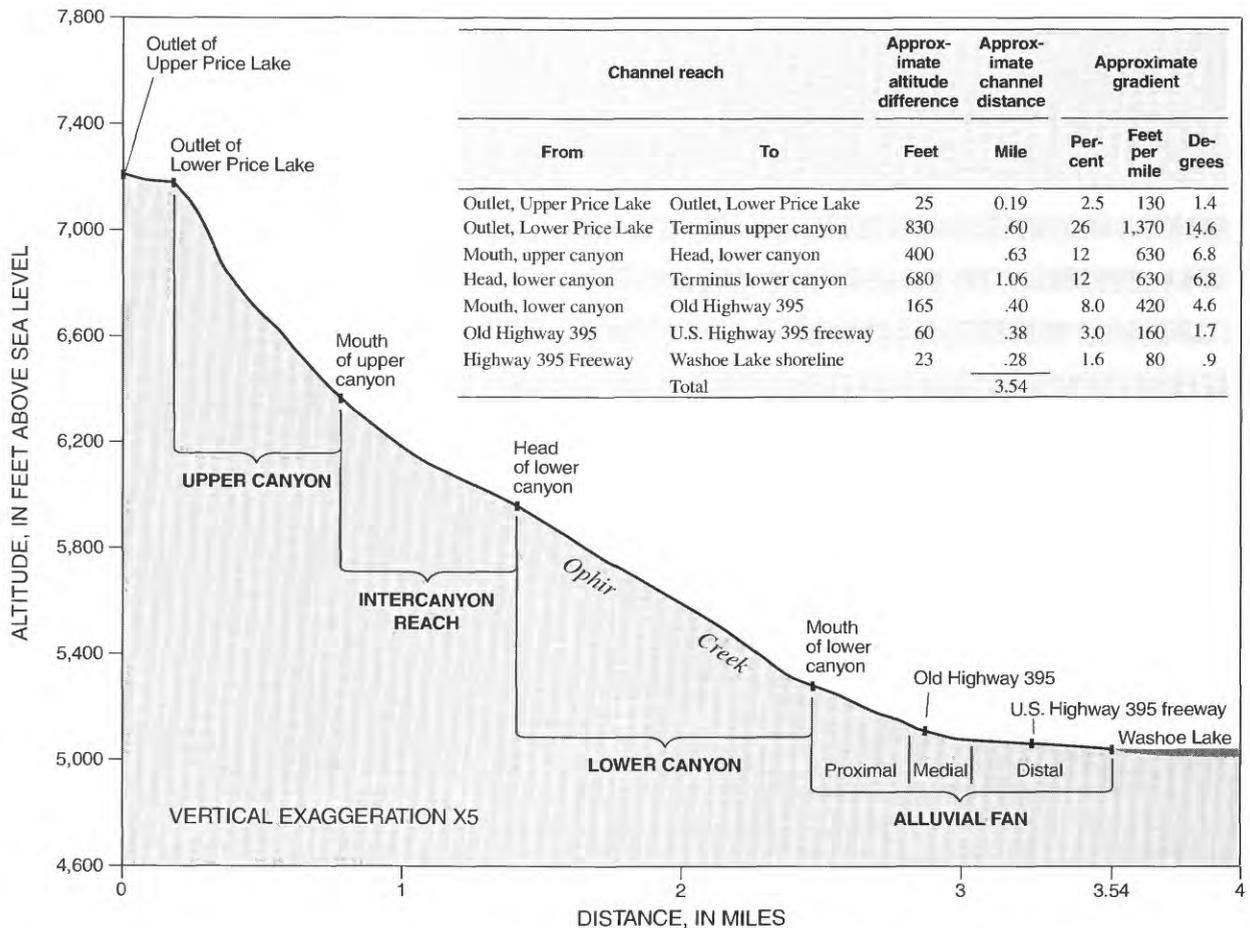
Downstream from the terminus of the upper canyon, the channel is less confined laterally throughout a reach of about 0.63 mi (fig. 6). The average gradient of this reach is about 12 percent ( $6.8^\circ$ ), about half that of the upstream canyon. This marked decrease in gradient may be partly the result of recurrent sediment deposition by intense floodflows that spread laterally after exiting the upper canyon mouth. The lateral spreading of flows decreases flow depths. The velocities of the flows diminish because of the increased frictional resistance to flow associated with decreasing depth and increasing width and also because of the decrease in channel gradient. The combined effects of spreading and slowing cause the variable floodflows to drop substantial fractions of their entrained sediment bedloads. The resultant deposits are the bouldery and dominantly coarse-grained flood deposits, as mapped throughout

this reach by Tabor and Ellen (1975). Downstream from this relatively open, and dominantly depositional reach, the channel enters a lower canyon that has a similar average gradient (about 12 percent,  $6.8^\circ$ ; or 630 ft/mi). This lower canyon was incised, mainly during late Quaternary time, by the creek for about 1.06 mi, mostly into unconsolidated deposits of prehistoric debris flows (landslides) that came from Slide Mountain (Tabor and Ellen, 1975).

The channel-bounding deposits of both the upper and lower canyons are susceptible to erosion by streamflow, particularly by severe floodflows that apparently recur frequently (Flood History, app. A). This erosive susceptibility is caused by several factors, including the generally unconsolidated character of the deposits, an abundance of fine-grained material (gravel size and smaller), and steep channel gradients that promote swift and turbulent streamflows capable of mobilizing and transporting eroded sediments. These factors are depicted by the photograph in figure 8. The incorporation of the eroded material within the floodflows increases their abrasive character and viscosity, and adds to the dynamic fluid momentum by increasing flow mass. This debris bulking can thereby increase the erosive character and sediment-transport capability of the fluid, and often promotes a progressively increasing destructive potential to the moving mixture of liquid and solid materials.

The deep channel incisions through the upper and lower canyons, particularly with regard to the relatively young geologic age of the channel-bounding deposits, attest to the severe geohydrologic instability of the terrain during flooding (figs. 5, 7, and 8). Stream downcutting is enhanced along the deeply entrenched channel because the narrow canyons restrain the normal tendency for the flows to migrate and meander laterally. In spite of this severe lateral confinement, floodflows persistently undercut the steep canyon walls. The undercutting resteepestens the slopes periodically during the recurring large floods. The net effect of these short-duration, intense, and erosive flows is to promote and perpetuate the instability of the channel of Ophir Creek.

Downstream from the lower canyon mouth, channel gradients flatten throughout the roughly 0.4-mile channel reach to Old Highway 395 (fig. 6). The upstream extent of home development is about 0.1 mi downstream from the lower canyon mouth (fig. 2). These upstream home sites (Ogilvy's and Reed's) were situated on a stream terrace mantled by



**Figure 6.** Topographic gradients for Ophir Creek, western Nevada. Gradients extracted from topographic information shown on Mt. Rose and Washoe City, Nevada, 7-1/2-minute topographic maps.

coarse-grained fluvial deposits, most of which were probably emplaced in prehistoric time. The terrace is markedly lower than the hummocky ridge of older debris-flow (landslide) deposits dissected by the canyon immediately upstream. The two home sites are only a few tens of feet north of, and 10-15 ft above, the normal creek bed. The vulnerability of this terrace to inundation by exceptionally severe floods was dramatically displayed during the 1983 flood (fig. 9).

The older debris deposits underlying and laterally bounding the creek between the lower canyon mouth and Old Highway 395 confine minor floods and normal flows of the creek to a generally predictable path. A manmade southeastward diversion of the creek channel (figs. 9 and 10), capable of containing low-to-normal flows of the creek, is located about 0.1 mi upstream from Old Highway 395. During periods of major flood-

ing, Ophir Creek largely bypasses this southeastward diversion and reverts to its preferred natural course which is generally along the axis of the alluvial fan. In general, this axial-fan route is weakly confined downstream from Old Highway 395. The fan gradient between Old Highway 395 and the U.S. Highway 395 freeway averages only about 3 percent (about 160 ft/mi, or 1.7°, fig. 6). The weak channel confinement and the rapidly decreasing fan gradient promote marked spreading and rapid deceleration of floodflows. Thus, the area in the vicinity of and downstream from Old Highway 395 is the major area of deposition for debris carried by floodflows of Ophir Creek. Because of its decreasing slope (8 to 3 percent, or 4.6 to 1.7°) and low relief, this fan surface has also become a popular area for human habitation; as a result, inhabitants have been periodically subjected to the traumatic effects of severe flooding.



**Figure 7.** Upper canyon of Ophir Creek, Nevada, severely gouged and scoured by the high-energy flow of 1983 flood. *A*, Upstream (westward) aerial view toward Lower Price Lake, photographed June 3, 1983, by Patrick A. Glancy, U.S. Geological Survey. *B*, Close-up view of south canyon wall just downstream from Lower Price Lake, July 27, 1983, photographed by Patrick A. Glancy. Note the widely ranging mix of fragment sizes and the easily erodible character of the debris comprising the canyon walls.



**Figure 8.** Heavily eroded Ophir Creek channel, western Nevada, the day after the flood. Photograph by Kenneth Ganz, U.S. Forest Service, on the morning of May 31, 1983.

Most of the surficially exposed, prehistoric landslides mapped by Tabor and Ellen (1975) do not extend downstream beyond Old Highway 395 (fig. 4). The surfaces of these older landslides are cluttered with huge boulders and have steep slopes and relatively rugged relief, which contrast sharply with the smoother, gently sloping fan surface constructed by the fluvial processes of Ophir Creek. The fluvial fan deposits bury older landslide deposits downgradient from Old Highway 395. A few remnants that have not yet been buried protrude above the fluvial deposits; they are visible as isolated patches and as the island south of the fan axis as shown in figure 4.

Coarse-grained, bouldery flood deposits (map unit "Qf" of Tabor and Ellen, 1975) begin as a narrow, laterally confined strip of riparian deposits within the lower canyon (fig. 4). Downstream from the canyon

mouth, these "coarse-grained fluvial deposits of Ophir Creek" broaden into a conical shape and terminate about 0.15 mile downgradient from Old Highway 395. Interestingly, the downstream terminus of Tabor and Ellen's map unit (reproduced in fig. 4) is roughly coincident with the downstream extent of bouldery deposits from the May 30, 1983, flood (figs. 10 and 31), suggesting general hydraulic similarities between this recent flood and an unknown number of prehistoric floods that deposited coarse-grained materials within the boundaries of Tabor and Ellen's "flood deposits." Tabor and Ellen designated the remaining unconsolidated, relatively fine-grained sediments exposed at land surface downstream from the coarser-grained "flood deposits" as "alluvial fan" deposits. That unit is designated as "fine-grained fluvial deposits" in figure 4. The sediments of this unit are dominantly sand and finer grained material. The channel gradient of Ophir Creek flattens to about 1.6 percent, or  $0.9^\circ$  (about 80 ft/mi) downstream from the U.S. Highway 395 freeway to the creek's junction with Washoe Lake (fig. 6).

U.S. Forest Service aerial photographs of July 1977 show the channel and riparian zones of Ophir Creek to have been generally well vegetated (figs. 3A and 11A). Deciduous plants were the dominant vegetal type but a scattering of conifers also was present. The dominant plants probably were quaking aspen, cottonwood, and willows. The perspective portrayed by the aerial photos suggests that vegetation was most dense within and along the channel throughout the upper and lower canyons. In the photos, the vegetated canopy appeared less dense within the laterally unconfined reach between the upper and lower canyons (fig. 11A). A moderately dense stand of riparian deciduous vegetation grew along the active-channel and irrigation-diversion routes downstream from the lower canyon mouth as far as Old Highway 395 (fig. 3A). Away from the active channel, the characteristically coarse-grained "flood deposits" (Tabor and Ellen, 1975) were dominated by shrubs and some conifers (figs. 3A and 4). Downstream from Old Highway 395, a few scattered cottonwoods and willows also grew. The shrub cover was of similar density to that covering the adjacent prehistoric debris-flow (landslide) deposits. Downgradient from the "flood deposits," the dominantly fine-grained fan surface was vegetated mainly by meadow grass downstream to the normal shoreline of Washoe Lake.

## SUMMARY OF LANDSLIDE AND FLOOD HISTORY

### Landslides

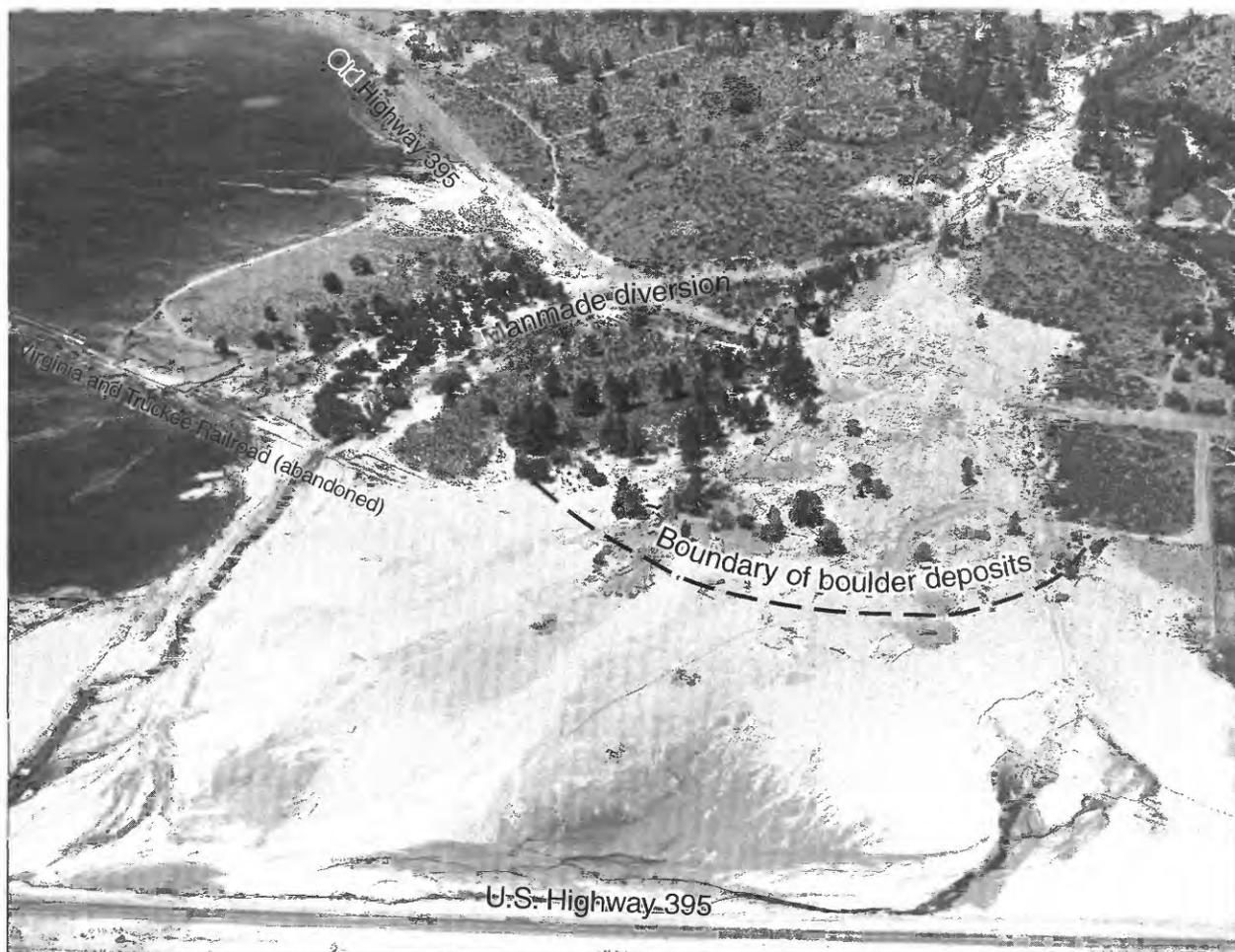
The southeastern face of Slide Mountain, including Ophir Creek drainage, exhibits abundant evidence of multiple land-slope failures (landslides) during Quaternary time. The mountain is named for the large, unvegetated bedrock scars on its southeast face (frontispiece) that resulted from several land-slope failures. The deposits of these landslides were first mapped and discussed by Thompson and White (1964) and most recently by Tabor and Ellen (1975). Tabor and Ellen

differentiated nine separate slides in the deposits surrounding Ophir Creek. The small slide that precipitated the 1983 flood is but the latest (10th) recognized land-slope failure in this series. A more detailed discussion of landslide history is in appendix A of this report.

Ophir Creek flows exclusively over and through the deposits of these slides from the area of Price Lakes to near Old Highway 395 (fig. 4). Thus, the physical character of the erodible deposits plays an important role in the erosion and sediment-transport history of Ophir Creek. The physical makeup of the deposits and the incised nature of Ophir Creek resulting from its drainage evolution were major factors influencing the flow characteristics of the 1983 flood.



**Figure 9.** Downstream view of Ophir Creek, western Nevada, just below mouth of lower canyon. Ogilvy home behind tree at left; boulder-strewn terrace to left of creek contains displaced wreckage of Reed home. Manmade diversion angles through trees at upper right, across creek from where Reed's damaged recreation vehicle rests. Oblique aerial photograph taken during afternoon of May 30, 1983, by Washoe County Sheriff's Department.



**Figure 10.** Oblique, aerial westward view of Ophir Creek alluvial fan, western Nevada, the major site of sediment deposition by the 1983 flood. Natural alignment of creek channel (lower right) was reestablished to the man-diverted route along left (southeast) part of fan by July 26, 1983, the date of this Patrick A. Glancy photograph.

## Floods

Ophir Creek has had a substantial number of floods in the recent past that are not known to have been associated with, or accompanied by, landslides from Slide Mountain. Part of a chronology of flooding in the Truckee River Basin for the period 1861-1976 describes floods in the Ophir Creek watershed (Goodwin, 1977). Goodwin's accounts of these floods were gleaned mainly from newspaper accounts and are descriptive rather than scientific and (or) quantitative (Victor Goodwin, U.S. Forest Service, retired, oral commun., 1984). Additional information was obtained from current and former residents of the Ophir Creek Basin, other eyewitnesses to past floods, and miscellaneous published accounts.

Winter floods, which are caused by regional storm systems, generally are less frequent than summer convective storms throughout the arid southwest;

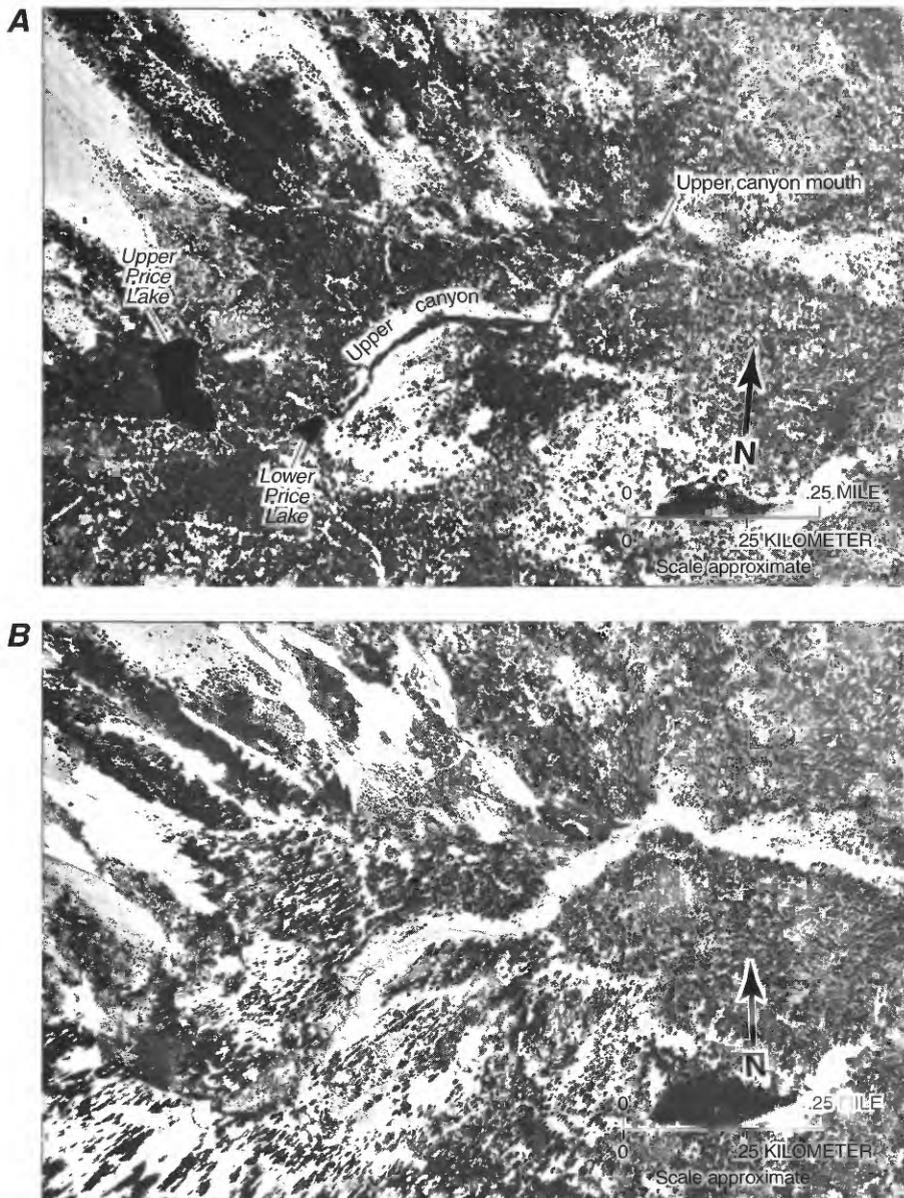
however, they can be severe and because they are usually regional, they sometimes devastate large areas. A summary of Ophir Creek winter floods is listed in table 1; a more detailed discussion of some of these floods is in appendix A of this report.

Severe floods in the arid Great Basin are caused more frequently by summer convective storms than by winter, regional storm systems. In contrast to the wide-reaching storms of the winter season, the summer convective storms are geographically localized and flooding is often restricted to small areas, often to sub-basin areas, during a given storm. The Carson Range of the northern Sierra Nevada is no exception; severe summer convective storms are a common occurrence. A summary of some summer floods known to have occurred in the general proximity of the Ophir Creek Basin is listed in table 2. Documentary evidence

of these floods is from newspaper accounts, a flood documentary (Glancy, 1969), and streamflow data of the U.S. Geological Survey.

Currently, no known records exist of flooding at Ophir Creek caused by convective summer storms. However, the potential for this type of flood is indicated

by the number of documented floods that have occurred in nearby drainages, as listed in table 2. Therefore, there is a reasonable probability that flooding from summer convective storms has occurred historically, and an almost certain probability that, prehistorically, it occurred numerous times.



**Figure 11.** Vertical aerial views of Price Lakes and upper canyon of Ophir Creek, western Nevada, before and after the flood: A, U.S. Forest Service photograph of July 15, 1977, before the 1983 flood. B, Nevada Department of Transportation photograph of June 6, 1983, after the flood.

**Table 1.** Summary of winter, or winter-related, floods of Ophir Creek, Washoe County, Nevada

[This summary does not include all historical winter-related floods of Ophir Creek, but only those for which specific data are available, or where regional flooding was so severe that Ophir Creek was very likely involved. Several other noteworthy floods may have occurred for which documentation is unavailable or, as yet, undiscovered. Most of the floods listed are discussed in greater detail in appendix A of this report]

Date	Remarks	Information source
January 1874	Possible failure of natural impoundment of Upper Price Lake	Goodwin, 1977
November 1875	Reported failure of manmade dam on Upper Price Lake	Goodwin, 1977
July 1890	Major flood caused by failures of dams on Price Lakes	Reno daily newspapers, Carson City Appeal, and Goodwin, 1977
March 1907	Large-scale regional flooding; Ophir Creek flooding likely	Goodwin, 1977
December 1937	Major flood damage to highway crossing Ophir Creek	Reno daily newspapers and eyewitness accounts
January 1943	Large-scale regional flooding; Ophir Creek flooding likely	Goodwin, 1977
November 1950	Serious flood damage to highway crossing Ophir Creek	Reno daily newspapers and eyewitness accounts
December 1955	Large-scale regional flooding; Ophir Creek flooding likely	Reno daily newspapers
Jan./Feb. 1963	Large-scale regional flooding; Ophir Creek flooding likely	Reno daily newspapers
May 1983	Largest known flood; landslide flushed Price Lakes	Eyewitness accounts and documentary field investigations

## ANTECEDENT WEATHER CONDITIONS

The May 30, 1983, flooding was primarily caused by the sudden emptying of Price Lakes by a landslide from the southeast slopes of Slide Mountain. Weather probably was closely related to and thus was a critical factor in the cause and flow characteristics of the flood.

Locally and regionally, the 1982 and 1983 water years were both very wet, at least partly as a result of a very strong El Nino climatic influence. Heavy flooding, debris flows, and landslides in northern California caused by winter storms during that time are a matter of public and scientific record (Ellen and Wieczorek, 1988). These winter storms generally moved eastward and dropped substantial amounts of rain and snow across Nevada. As they continued farther eastward, these same weather systems and others also similarly blanketed Utah, hundreds of miles eastward. Utah flooding, landslides, and debris flows during the 1982-83 water years are a matter of scientific and historical record (Anderson and others, 1984).

During modern times, the winters of 1951-52, 1968-69, 1981-82, and 1982-83 were seasons of especially great precipitation; however, severe Ophir Creek flooding occurred only in 1983. Winter precipitation data for those 4 years at Reno, the local measurement station of longest record, are listed in table 3. Also, degrees of winter wetness generally can be interpreted through comparisons of the water content in April 1 snowpacks. Water stored in snowpacks near the Ophir Creek drainage for the wettest recent years listed above

are listed in table 4. These data indicate that cumulative snowpacks for the winters of 1981-82 and 1982-83 were far greater than average, but substantially less than those of the winters of 1951-52 and 1968-69. Thus, some disparity exists between the inferences projected by Reno precipitation data of table 3 and the snowpack data of table 4.

**Table 2.** Summary of known summer floods during recent history in the Carson Range near Ophir Creek, Nevada

[This summary probably does not include all recent floods in these drainage basins; nor is it likely complete for all basins within 10-mile radius in the Carson Range. It is intended to portray the serious potential for summer floods in the general vicinity of Ophir Creek. Locations of these basins are outside the study area]

Date	Drainage basin	Approximate distance from Ophir Creek
August 15, 1941	Galena Creek	4.5 miles NNW
July 29, 1952	do.	Do.
July 20, 1956	do.	Do.
July 29, 1960	North Fork Kings Canyon Creek	10 miles SSE
August 15, 1965	Whites Creek	6 miles N
August 15, 1965	Third Creek	5 miles SW
August 15, 1965	Galena Creek	4.5 miles NNW
August 2, 1966	do.	Do.
August 25, 1967	do.	Do.
August 25, 1967	Second Creek	6 miles WSW

**Table 3.** Precipitation at Reno, about 15 miles northeast of the Ophir Creek Basin, Washoe County, Nevada, during October-May of years with historically wet winters

Period (A)-(B)	Precipitation <sup>1</sup> (inches)									
	Oct. (A)	Nov. (A)	Dec. (A)	Jan. (B)	Feb. (B)	Mar. (B)	Apr. (B)	May (B)	June <sup>2</sup> (B)	Oct.-May total
1889-90	0.36	1.74	2.30	6.71	2.11	0.39	0.30	1.44	0.01	15.35
1951-52	.96	.61	1.95	1.89	.62	2.02	1.63	.02	--	9.70
1968-69	.01	.73	1.03	4.13	1.74	.07	.10	.20	--	8.01
1981-82	.64	2.13	1.05	1.20	.41	1.14	.34	.10	--	7.01
1982-83	1.65	1.71	1.04	1.72	1.58	1.31	1.35	.21	--	10.57

<sup>1</sup> Data from official U.S. National Weather Service records (U.S. Weather Bureau, 1932, and National Climatic Center, 1921-84).

<sup>2</sup> June data were included for 1890 because the severe flood of Ophir Creek was on July 6. See appendix A.

**Table 4.** April 1 water content of snowpack near Ophir Creek, Washoe County, Nevada, for highest years of record<sup>1</sup>

[Symbol: --, no information available]

Site	Altitude (feet above sea level)	Water content of April 1 snowpack (inches)				
		1963-77 average	Historically wet winters			
			1952	1969	1982	1983
Mount Rose <sup>2</sup>	9,000	35.9	68.1	81.7	56.7	57.0
Mount Rose Ski Area <sup>3</sup>	8,850	38.5	--	--	77.9	75.6
Little Valley <sup>4</sup>	6,300	6.9	29.8	24.2	2.9	16.1

<sup>1</sup> Data from official records on file at the U.S. Soil Conservation Service. No data available for 1890.

<sup>2</sup> Located about 3.5 miles north-northwest of slide area.

<sup>3</sup> Located about 1 mile north of slide area.

<sup>4</sup> Located about 3 miles south of slide area.

In addition to the plentiful precipitation during the winter of 1982-83, and the abundant residual snowpack in and around the Ophir Creek drainage, as of April 1, 1983, cool and wet weather continued for at least an additional 6 weeks. At 14 sites monitored in the northern Sierra Nevada, the water content of the snowpack was greater than 200 percent of average on May 1 (John Capurro, U.S. Soil Conservation Service, oral commun., 1985). By May 1, water content in two of the three snow courses (table 4) had increased: Mt. Rose, 64.6 in., and Mt. Rose Ski Area, 83.6 in. Some low-altitude melting had decreased the water content from

16.1 in. to 9.7 in. at the Little Valley course (U.S. Soil Conservation Service, 1983b, p. 10). During the month of April, the Mt. Rose snow course received 6.9 in. of precipitation and the Mt. Rose Ski Area course received 9.8 in. (U.S. Soil Conservation Service, 1983b, p. 13). The first part of May continued unseasonably wet and cool; many of the snow courses in the Tahoe-Truckee area received more precipitation, some over an inch. The Mt. Rose Ski area, closest snow course to the 1983 landslide, received 0.9 in. during the month; no May data are available for the Mt. Rose and Little Valley courses (U.S. Soil Conservation Service,

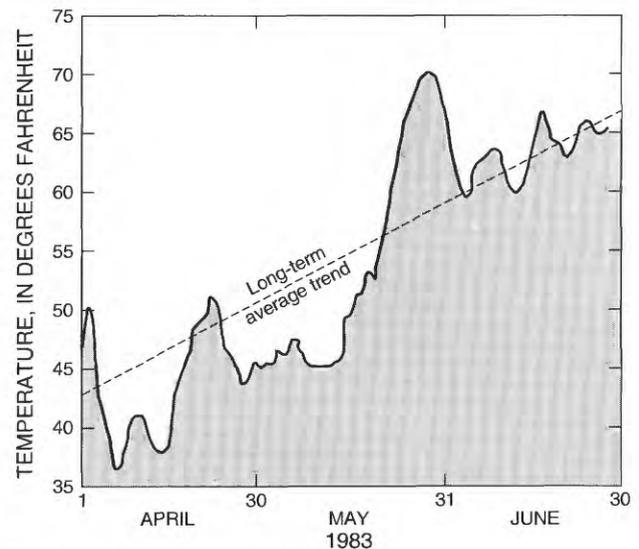
1983c, p. 4). As of April 1, the Soil Conservation Service was predicting snowmelt runoff in the Truckee-Tahoe area to be about 200 percent of the average runoff during the 1963-77 period (U.S. Soil Conservation Service, 1983a, p. 9). Ultimately, local streamflows in the Sierra Nevada were about 250 percent of average (U.S. Soil Conservation Service, 1983c, p. 1).

Although the 1982-83 winter snowpack was exceptional in and around Ophir Creek and Slide Mountain, it had been equalled or exceeded several times. Therefore, if the May 30, 1983, landslide was triggered largely by snowmelt hydraulics, some factor, or factors, other than quantities of precipitation and snowpack may have played a critical role. The most likely additional influences were the residual moisture in the rock-fracture system from the winter of 1981-82 and the melting rate of the 1982-83 snowpack, particularly the rapid infiltration of snowmelt into the bedrock fractures just prior to the landslide.

Maximum and minimum temperatures for May 1983 at the Carson City, Glenbrook, and Reno weather stations are listed in table 5; Reno is about 15 mi north-east and Carson City is about 11 mi southeast of the slide area. Glenbrook is on the east shore of Lake Tahoe, about 15.5 mi south-southwest of the slide area.

The data in table 5 show that at meteorological-data sites reasonably close to the slide area, daily temperatures abruptly rose about May 20; the nights became noticeably warmer, and the days warmed dramatically. A similar temperature trend at all three stations emphasizes that the sudden warming was areally widespread and therefore, probably also affected the Ophir Creek drainage. A graph of daily mean temperatures at the Carson City weather station for the months of April-June of 1983 is shown in figure 12 (the 1983 mean daily temperatures are the 5-day running average of daily mean temperatures). Departures of daily temperatures from the long-term, average-temperature increase, portray the extent to which daily temperatures conformed or deviated from long-term average conditions. As stated earlier, the superposed curves clearly show that unseasonably cool temperatures prevailed during most of April and particularly during the first two-thirds of May. A warming trend that abruptly shifted temperatures from below to above normal began about May 20 or 21. The heating continued and reached a peak on the 29th, at which time average daily temperature was over 10°F above normal.

The effect of this late-May heat wave on the snowpack in the vicinity of Ophir Creek and the landslide area was depicted by data collected at a snow-



**Figure 12.** Daily mean air temperature at Carson City, Nevada, April 1-June 28, 1983 (Otto Moosburner, U.S. Geological Survey, written commun., 1985).

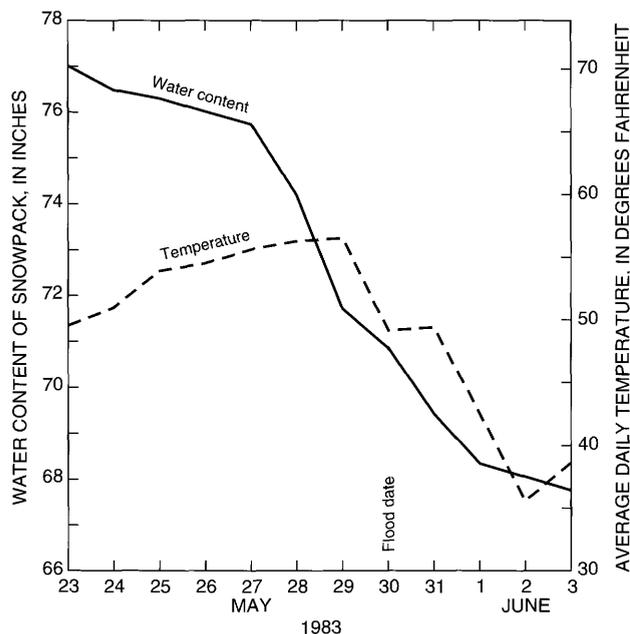
survey station located on the west flank of Slide Mountain, 1.2 mi northwest of the 1983 landslide. Daily fluctuations in snow-water depth, total precipitation, and minimum, maximum, and average air temperatures were recorded at this site (Mount Rose Ski Area). An analysis of temperature data for the days preceding and following the landslide (fig. 13) shows that a series of abnormally high, daily-average temperatures caused a sudden decrease in the snow-water (snowpack) depth. Beginning on May 23, the average daily temperature increased from 49.6°F to a high of 56.5°F on May 29. During the 5-day period, May 23-27, snowpack was depleted at a rate of about 0.325 in. of water per day (fig. 13). On May 27, the snowpack melted more rapidly; during the following 3 days (28-30), snowpack depletion intensified and averaged about 1.6 in. of water per day. The decrease of snow-water depth during this 3-day period accounts for about 35 percent of the total snowmelt that occurred prior to May 30.

Although direct evidence that the landslide was triggered by hydraulic forces related to rapid infiltration of the quickly melting snowpack is impossible to obtain, circumstantial evidence for this type of triggering mechanism is strongly supported by these weather characteristics preceding the time of the slide. Regionally, rapid melting of other unusually heavy snowpacks by this same early-season heatwave also triggered numerous landsurface failures and severe floods in Utah (Anderson and others, 1984).

**Table 5. Maximum and minimum daily temperatures at Carson City, Glenbrook, and Reno, Nevada, during May 1983**

[Temperatures exceeding 70 degrees Fahrenheit are shown in bold type. Data from National Oceanic and Atmospheric Administration (1983, p. 10)]

Degrees Fahrenheit	Day																															Average	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
Maximum	51	62	66	64	51	60	68	60	56	54	59	63	63	70	68	60	69	<b>75</b>	<b>72</b>	<b>76</b>	<b>84</b>	<b>85</b>	<b>88</b>	<b>89</b>	<b>90</b>	<b>92</b>	<b>92</b>	<b>92</b>	<b>82</b>	<b>87</b>	<b>74</b>	71.7	
Minimum	30	32	31	40	37	32	29	36	33	30	32	30	31	29	50	34	30	37	40	37	41	43	43	47	48	49	49	51	57	46	47	38.7	
Maximum	43	49	57	55	43	46	56	53	49	49	52	54	55	60	57	56	60	64	63	68	70	<b>72</b>	<b>74</b>	<b>78</b>	<b>75</b>	<b>78</b>	<b>78</b>	<b>78</b>	<b>75</b>	<b>72</b>	70	61.6	
Minimum	30	33	28	32	29	24	29	29	25	28	26	29	33	29	38	28	30	34	36	38	36	38	39	39	42	42	42	43	45	48	39	42	34.2
Maximum	50	59	64	61	53	57	65	61	53	49	58	61	61	67	65	59	66	<b>74</b>	<b>68</b>	<b>76</b>	<b>83</b>	<b>83</b>	<b>87</b>	<b>88</b>	<b>90</b>	<b>91</b>	<b>91</b>	<b>91</b>	<b>83</b>	<b>87</b>	<b>76</b>	70.2	
Minimum	29	30	30	33	33	30	30	26	32	30	35	30	29	30	41	32	29	35	38	35	39	42	43	42	42	42	45	45	49	52	44	46	36.3



**Figure 13.** Snowpack moisture and average daily temperature in late May and early June of 1983, Mount Rose Ski Area snow-survey station, western Nevada. Data from U.S. Soil Conservation Service, Reno, Nevada.

## THE LANDSLIDE

### Lithologic Character and Structure of Slide Mountain

Slide Mountain is one of the highest peaks (9,698 ft above sea level) on the eastern flank of the northern Sierra Nevada. It is composed largely of Late Cretaceous, hornblende-biotite granodiorite, which generally is uniform except for a shattered, chalky zone on the east side of the mountain (Tabor and others, 1983, p. 7, 18). The mountain is bounded on the east by a principal Quaternary trace of the Sierra Nevada frontal fault zone (Tabor and Ellen, 1975).

Structure in the granodiorite at Slide Mountain is variable, but many faults and prominent joints are northerly striking and generally steeply dipping (Thompson and White, 1964, and Tabor and Ellen, 1975). Watters (1983) showed that orientation of the jointing changes from north-northwest to north-northeast on the southeast side of the mountain in the area of principal landsliding. The location of landsliding on the southeast face of the mountain may be spatially related to this change in structural orientation; other contributing factors include steep slopes above Ophir Creek and geographic slope orientation. The highly fractured,

sheared, and chalky bedrock mapped by Tabor and Ellen (1975) in this part of Slide Mountain also likely contributes to landsliding.

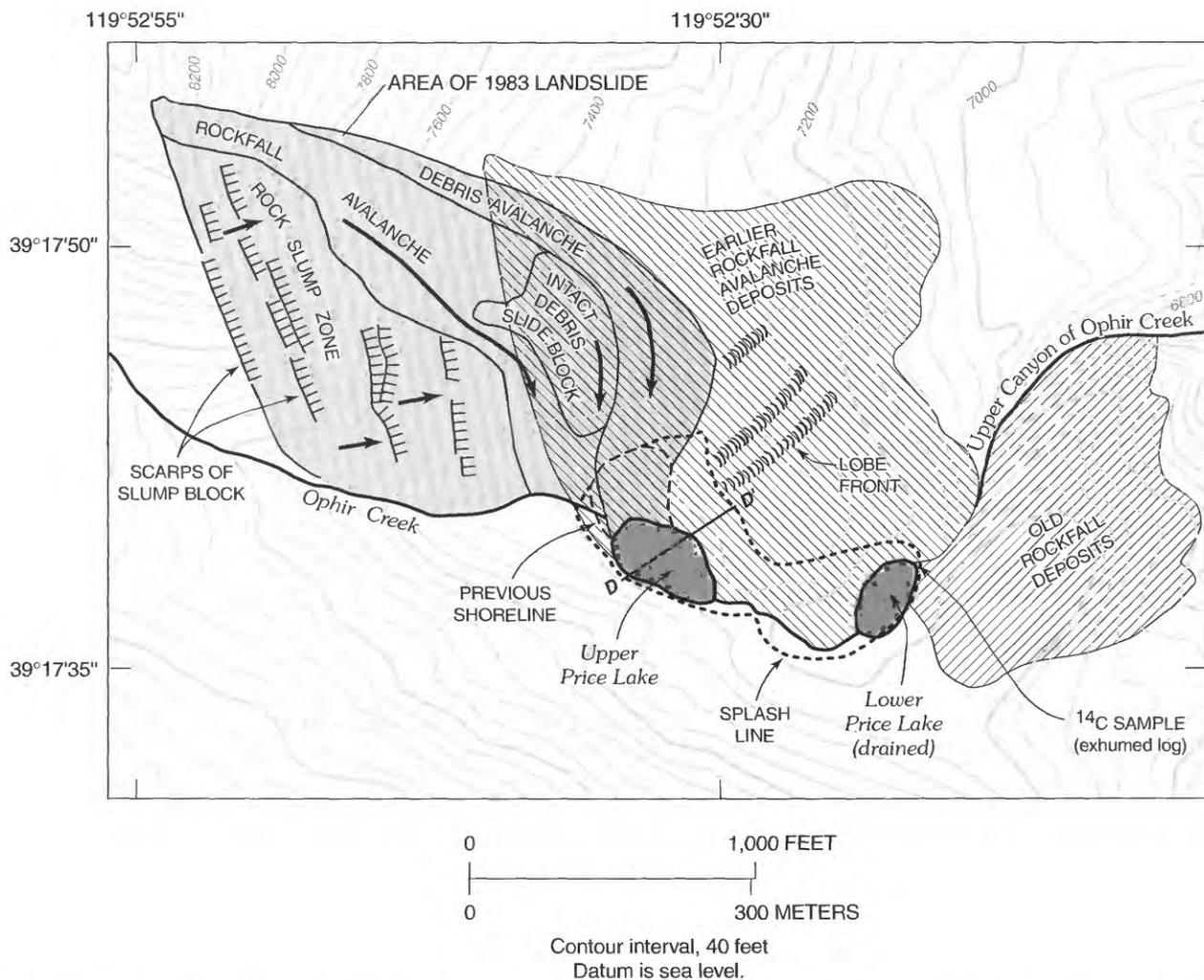
### The Landslide of May 30, 1983

The May 30, 1983, landslide was a composite of three nearly simultaneous, inter-related mass movements: rock slump, rockfall avalanche, and debris avalanche (terminology from Varnes, 1978). The location of the landslide is shown in figure 4 and a detailed map of landslide features compiled from aerial photography is shown in figure 14. The landslide components also are delineated on the photograph of figure 15. As indicated by overlapping relationships, movement of materials originated with multiple rock slumps that were followed by the rockfall and debris avalanches in the northern part of the landslide; the avalanche deposits overlie the slump blocks, indicating that they were a later phase of the sequence.

The rock slump zone consists of numerous parallel and sub-parallel, rotated, slump blocks that are 300 ft or more wide and several hundred yards long. Each block is bounded by a headscarp, as much as 9 ft in height, which appears to be joint controlled. The scarps trend north-northwestward and extend southward nearly to Ophir Creek; they transect the ridgeline and lie oblique to the hillslope. Maximum downslope movement, as determined from displaced treelines, was about 100 yd. All slumping was confined to unweathered, jointed granodiorite. The failure-surface geometry is not clearly known (Watters, 1983, p. 179-180).

The rockfall avalanche is composed almost entirely of large blocks of granodiorite (as much as 10 ft or more in diameter) that slid downward along the margin of the rock-slump zone to the base of the steep slope (fig. 16). Within the rockfall-avalanche zone, a fairly coherent slide block remains that apparently detached along its base and rafted downslope (figs. 14 and 15). This slide block is characterized by deformed and crevassed (but intact) soil and by large trees that, through motion, were tilted back toward the hillside. An analysis of pre- and post-landslide aerial photography indicates that this block moved downslope about 100 yd.

At about the time of the rockfall avalanche, a debris avalanche occurred along the northern edge of the rockfall avalanche. This finer grained component of the landslide consisted of a gravelly sand (mean particle diameter, 1 mm) derived from unconsolidated



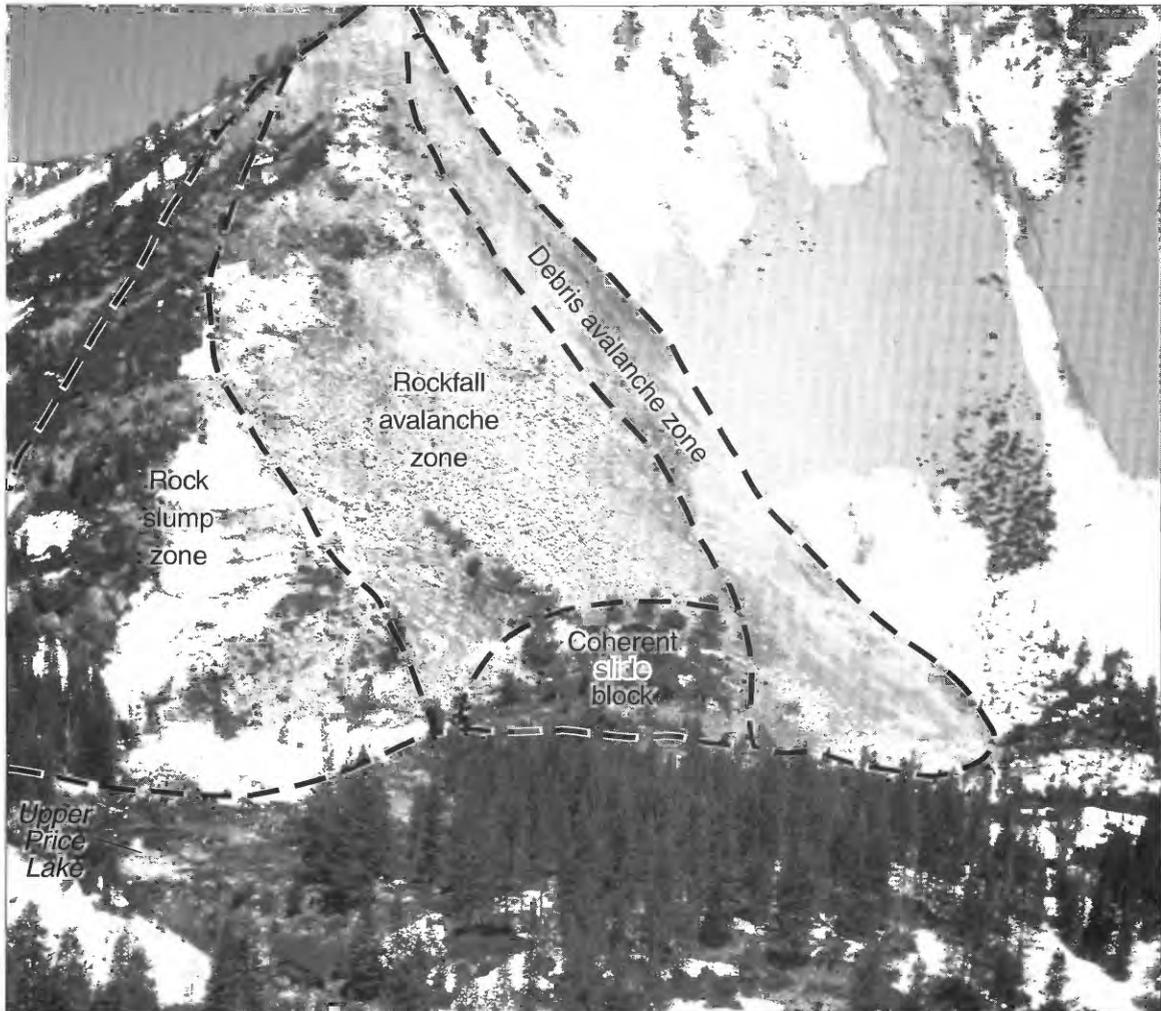
**Figure 14.** Ophir Creek landslide features compiled from pre- and post-1983 aerial photographs. Shows approximate location of cross-section D-D' of figure 21.

surficial colluvium that overlaid the unweathered bedrock. The debris avalanche overrode a fairly thick snowpack, which may have accelerated and extended the movement and given it more flow-like characteristics.

Debris from the rockfall avalanche and the debris avalanche entered the northern half of Upper Price Lake, displaced the liquid contents, and filled the cavity. The force and mass of the avalanches also deformed and compressed peaty lake sediments (fig. 17) as they overrode most of the lake-bottom area. As shown by a muddy splashline on the surrounding snow (figs. 14 and 22), the water in Upper Price Lake was rapidly displaced. Watters (1983, fig. 11; reproduced as fig. 21 of this report) showed this splash line to be about 6 ft

above the lake level of May 30, 1983, on the southwest side of the lake and about 12-14 ft above lake level on the northeast side, indicating that the force of the splash was directed mostly eastward.

Thickness of the landslide was variable. Watters (1983, p. 179) shows that the thickness of the rock-slump zone may have ranged from 30 to 100 ft. Deposits of the rockfall avalanche and debris avalanche are less than 3 to 7 ft thick in the upper portions of the landslide, but are 20 to 35 ft thick at the toe of the landslide. If an average thickness of 15 ft is assumed for the entire landslide, about 1,400,000 yd<sup>3</sup> (about 870 acre-ft) of material was displaced. The terrane of the toe of the avalanche deposits is hummocky and chaotic and includes many large trees from upslope.



**Figure 15.** North-westward view of 1983 landslide, Ophir Creek, western Nevada; scarps in rock-slump zone are visible in snow at left side of photograph. Oblique aerial photograph by Otto Moosburner, U.S. Geological Survey, on May 31, 1983.

### Possible Causes of the Landslide

Possible causes for the 1983 landslide include loss of lateral support, seismic shaking, increase in surcharge, and increases in water content and pore pressure. These causes are evaluated for validity and importance, as follows.

Downcutting by Ophir Creek near the base of Slide Mountain has occurred throughout late-Quaternary time, as indicated by successive stream incisions into earlier landslide deposits. Undercutting of steep slopes by Ophir Creek, however, does not appear to have contributed directly to the 1983 landslide because there is little recent incision adjacent to the landslide and the slide movement appears to have been parallel to Ophir Creek rather than toward the creek.

Although seismic shaking (earthquake) is a common cause for landslides, there is no evidence that shaking initiated the 1983 landslide. A seismograph located 6.5 mi east of the landslide (fig. 1), and monitored by the University of Nevada, Reno, Seismological Laboratory, did not record any abnormal seismicity at the time of the landslide.

An increase in surcharge—the uncommonly thick snowpack—may have been a significant cause because the added weight of snow may have contributed to movement of the landslide. However, snowpack had been depleting rapidly for about a week (fig. 13) and, therefore, exerted less overall downhill force at the time of failure than it would have earlier.

The most likely cause for the landslide appears to have been an increase in subsurface water content, accompanied by probable increases in hydraulic pore pressures, that were the results of the rapid melting and likely infiltration of the exceptional 1982-83 snowpack described above. On the basis of this sudden melting of a substantial part of the record snowpack, we postulate that abnormally large quantities of meltwater permeated the surface of Slide Mountain during the few days preceding the landslide. Because permeability of the granodiorite is primarily through joint and fracture openings, the infiltrating water would primarily follow these discontinuities within the bedrock mass. An abnormal increase in subsurface moisture content would tend to decrease the shear strength of the discontinuities by increasing local pore pressures and reducing the effective stresses exerted on those discontinuities. The rapid increase in moisture content also would decrease shear strength in the unconsolidated surficial deposits mantling the bedrock slope.

The existence of high subsurface moisture content in materials at the landslide is supported by observations during the first few days following the landslide. Sandy surficial deposits on the undisturbed upper slopes near the landslide were observed to be saturated and susceptible to liquefaction and flowage downslope under foot impact. An uncertain volume of ground water probably flowed out from the landslide debris immediately following the slide (see report section entitled "Flood Volume and Water Sources").

### Effects of the Orientation of Bedrock Joints

Studies of bedrock structure have shown that joint orientations in the area of the landslide are locally favorable for downslope movement (Robert D. Brown, U.S. Geological Survey, written commun., 1983; Tabor and Ellen, 1975; Tabor and others, 1983; Thompson and White, 1964; Watters, 1983). Strikes of prominent joints vary from north-northwest to north-northeast,



**Figure 16.** One of the largest granitic blocks involved in rockfall-avalanche phase of the 1983 landslide, Ophir Creek, western Nevada; block measures 25x12x8 feet. Backpack is 1-1/2 feet long. September 7, 1983, photograph by Patrick A. Glancy.



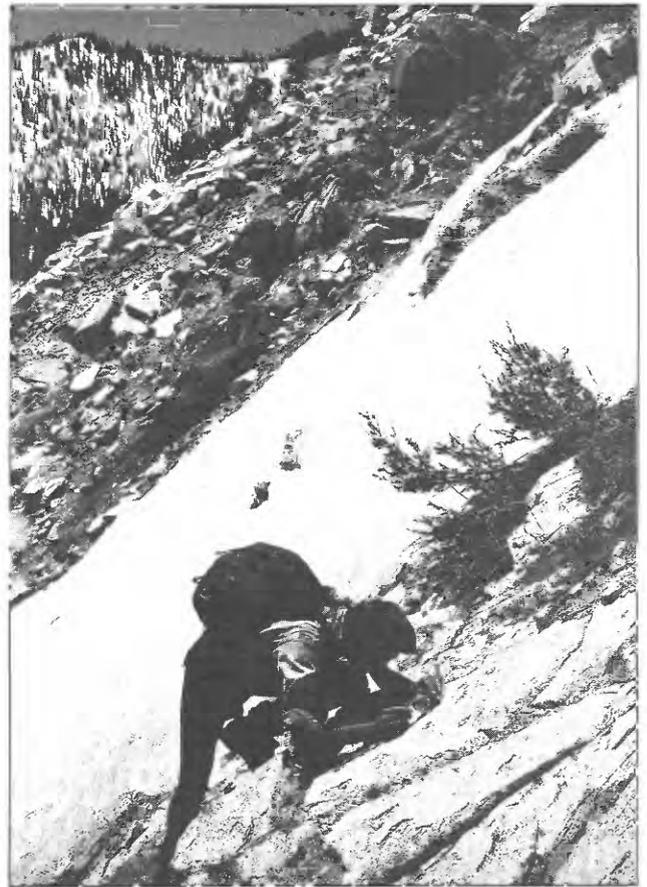
**Figure 17.** Bottom sediments of Upper Price Lake, western Nevada, deformed and uplifted by 1983 landslide. Six-inch knife (arrow) shows scale. Photograph by Patrick A. Glancy, July 27, 1983.

and variations of these trends occur at most sites. Some joints dip steeply (greater than  $80^\circ$ , fig. 18), but many dip gently (less than  $45^\circ$ ). An analysis by Watters (1983, figs. 6 and 7) showed multiple joint sets surrounding the 1983 landslide, two of which are oriented in directions favorable to landsliding. These two joint sets trend northeastward, approximately parallel to the pre-landslide topography, and dip  $30^\circ$  to  $38^\circ$  downslope (joint-set poles  $J_U$  and  $J_L$  and their corresponding planes in fig. 19). Because the estimated pre-landslide slope was about  $35^\circ$ , these joint sets probably served as the primary failure surfaces.

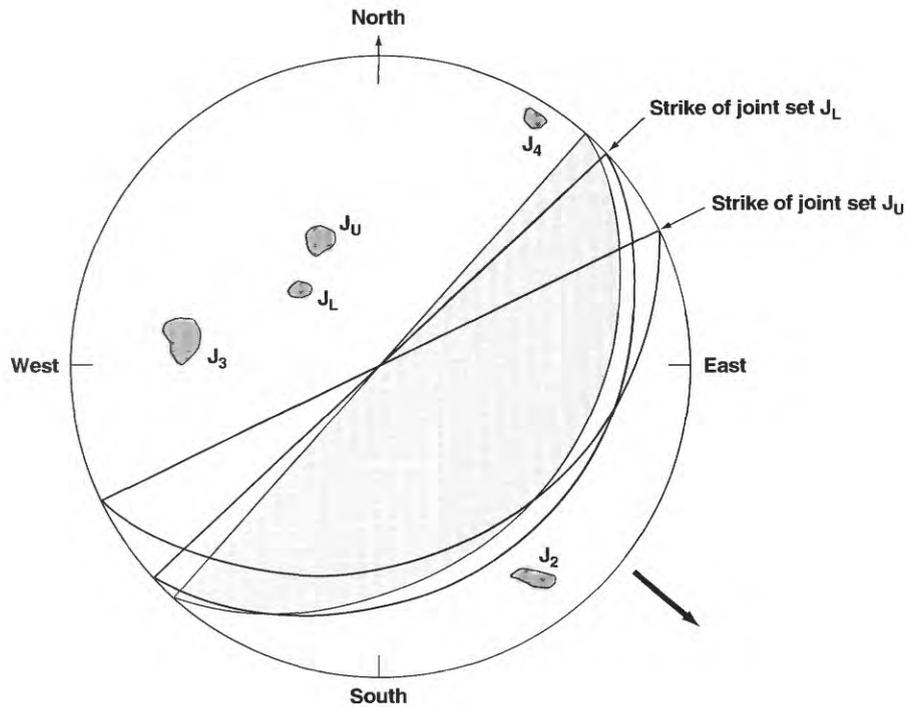
Northwest-trending joints, marked by scarps within the rock-slump zone (fig. 14), are oriented obliquely to the slope and this oblique orientation may have contributed to the partial downslope movement of the rock slide. This partial movement has resulted in a potential for reactivation of the landslide and a continuing hazard. Robert D. Brown (U.S. Geological Survey, written commun., 1983) estimated that as much as  $900,000 \text{ yd}^3$  of rock remains perched on the slope north of Ophir Creek and may move again under conducive conditions.

## THE FLOOD

The Ophir Creek flood of May 30, 1983, was the result of a rapid sequence of events that can be separated into four phases: (1) a sudden composite landslide down the steep, southeastward-sloping face of Slide Mountain that plunged into and buried the northern part of Upper Price Lake; (2) the quick downstream expulsion of the contents of Upper Price Lake by the landslide into Lower Price Lake, and the subsequent incorporation and downstream expulsion of the contents of that smaller lake into a highly energetic fluid surge; (3) swift downstream movement of the combined contents of both lakes that progressively scoured and bulked a massive quantity of sediment and debris into the flow; and (4) deposition of the sediment and debris load of the floodflow on the Ophir Creek alluvial fan.



**Figure 18.** Southwestward view of landslide area showing downslope dip of joint surfaces (foreground); northern margin of rockfall-avalanche zone in background. Photograph by John W. Bell, June 7, 1983.



**EXPLANATION**

-  **Joint-set poles**— $J_U$  and  $J_L$  are shallow ( $30^\circ$ - $40^\circ$ ) principal joint sets from upper and lower hillslope surfaces, respectively.  $J_2$ ,  $J_3$ , and  $J_4$  are other steeper, principal joint sets in bedrock surrounding landslide area
-  **Average slope of pre-slide land surface**
-  **Approximate direction of landslide**

**Figure 19.** Principal bedrock joint-set orientations in the area of the 1983 Ophir Creek landslide, western Nevada; orientations are plotted on a three-dimensional, lower-hemisphere stereographic projection. In this diagram, joint orientations are represented by drawing lines perpendicular to the joint planes and plotting the locations (poles) where the perpendicular lines pierce the lower hemisphere. The two-unshaded semi-circular planes are the joint planes for sets  $J_U$  and  $J_L$ ; the shaded plane is the average land-surface slope before the landslide (modified from Watters, 1983, figs. 6 and 7). For a discussion of stereographic projection, see Davis and Reynolds, 1996, p. 691-730.

### The Expulsion of Price Lakes

The contents of Upper Price Lake were expelled by the combined dumping and piston-like actions of the landslide. Landslide movement was at least partially witnessed by Doug Cook, the hang-glider pilot whose observations are recorded in appendix B. He recalled, "I heard a roaring sound, kind of like the sound of a jet engine . . . Out of the corner of my eye I could see a bunch of rising dust." Ronald Mentgen, another eyewitness,

related the sound of the landslide movement to the rushing sound of air moving as wind. Mentgen also observed trees moving downslope in an upright position (probably part of the intact debris slide block described in the preceding landslide section of this report).

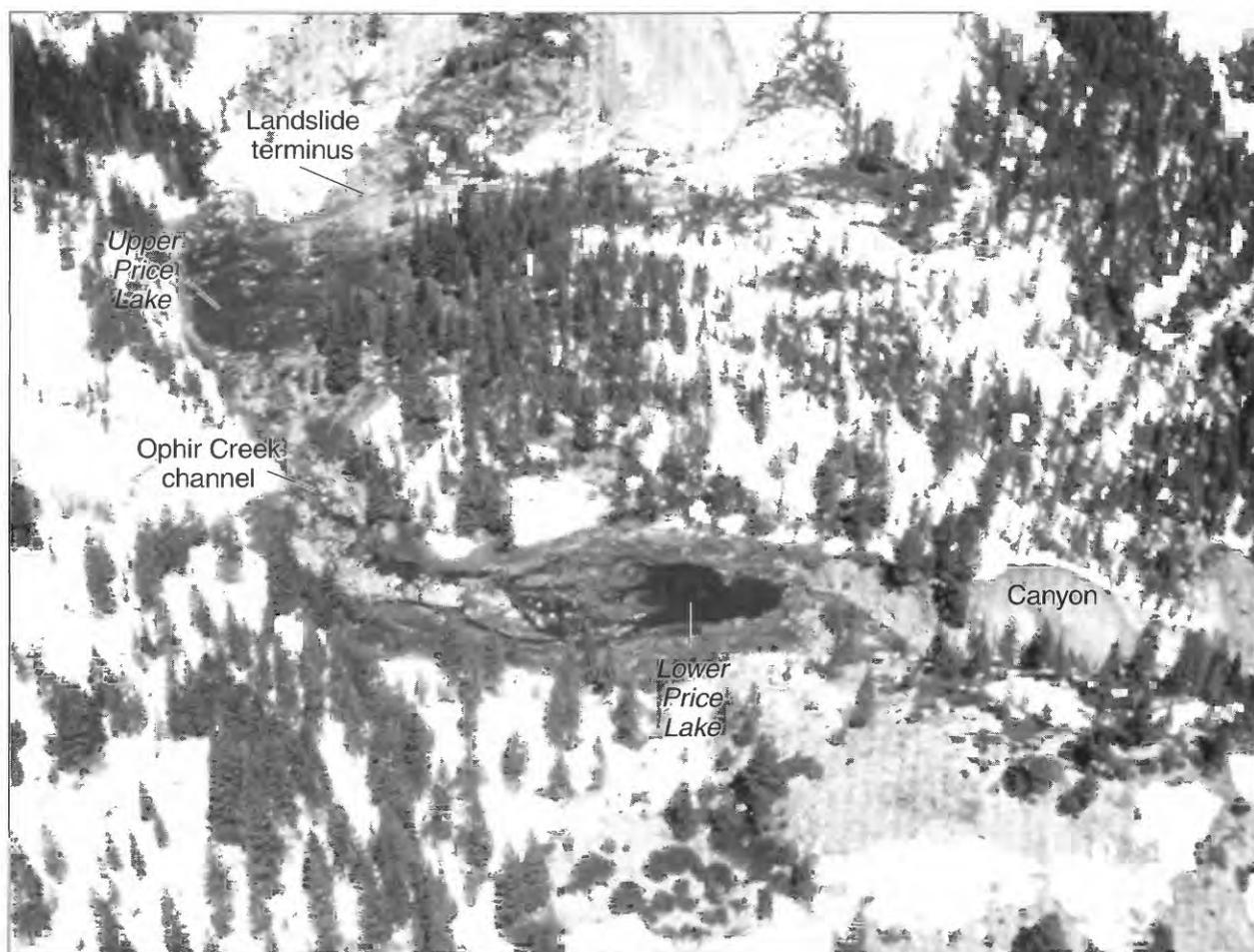
The force and movement of the landslide quickly expelled the lake contents that included ice, water, and unconsolidated sediments, and deformed the lake-bottom sediments. Postflood deformation of

lake-bottom sediments (fig. 17) indicates that the movements of the lake floor probably also caused a dumping action, somewhat analogous to the quick tilting of a pan of water to empty its contents. Cook (app. B) vividly described the visual effect of the emptying of Upper Price Lake: "When it hit the lake," he said, "it was like a huge explosion. It just blew the whole lake apart. It looked like a tidal wave at first and then the canyon gathered it up." This testimony verifies the sudden release of stored water from both lakes.

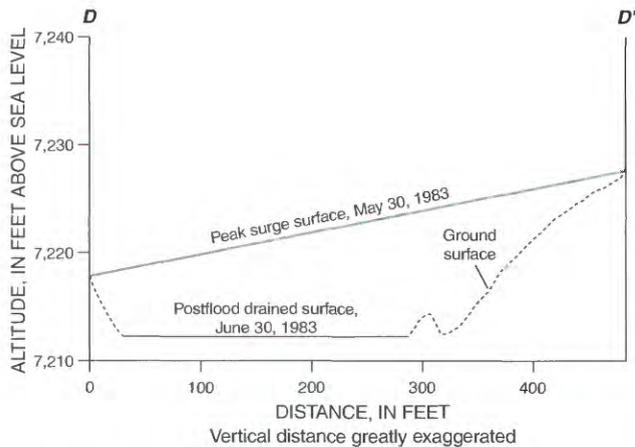
Cook's comparison of the surge of water exiting the lake to a tidal wave is corroborated by evidence left on the landscape by the departing fluid. Irregular discoloration of the snowpack near Price Lakes and along the interconnecting channel reach (figs. 20 and 22) defines the limits of the flow as it left the lakes. The fluid mixture imparted a dark color to the snow-covered landscape that is probably the result of

fine-grained, organic-rich, lake-bottom sediments expelled with the water. The residual color of these sediments is markedly darker than the fine-grained component of the debris avalanche, which consisted chiefly of light-colored, decomposed granodiorite.

Watters (1983, p. 181) described the displacement of Upper Price Lake as a wave of up to 16.5 ft in height above the lake level. He showed that the upper level of the surge line was not horizontal (fig. 21). A gradual and less dynamic expulsion of the contents of Upper Price Lake would have caused a more horizontal wave-line perpendicular to the flowpath. In contrast, the tilted crest confirms the dynamic response of the fluid to the sudden combined dumping and pushing impacts of the landslide. The oblique aerial photograph of figure 22A shows the dominance of the wave-like surge compared to a milder appearing erosive scour caused by flow through the narrow break in the dam. The dam



**Figure 20.** View of terminus of 1983 landslide and point of origin of Ophir Creek flood at Upper Price Lake. View also shows Ophir Creek channel connecting Upper Price Lake and Lower Price Lake, and the steep canyon of Ophir Creek just downstream from Lower Price Lake, Nevada. Oblique aerial photograph by Patrick A. Glancy, June 3, 1983.



**Figure 21.** Profile, looking upstream, of high-water surface of Upper Price Lake, western Nevada, when expelled by the landslide May 30, 1983. See figure 14 for approximate location of cross section. Adapted from figure 11 of Watters (1983).

probably failed concurrently with the wave-like surge, and as shown in figure 22A indicates that most of the lake contents escaped over the failed dam during the surge. Much of the entrenchment through the breach may have been caused by postflood recessional flow. Figure 22B shows the extended path of the displaced fluid downstream from Upper Price Lake into, and through, Lower Price Lake.

The tabular mass on the downstream face of Lower Price Lake dam (lower right in fig. 22B) appears to be a large piece of ice displaced from one of the lakes. This mass was gone by June 17, 1983, when the site was visited, indicating that it had melted during the intervening period. This information supports Ronald Mentgen's observation (app. B) that ice covered at least part of the surface of Upper Price Lake just prior to the landslide on May 30, 1983.

The rate at which Price Lakes were expelled probably is important to the subsequent hydraulic evolution of the flood. This rapid rate compounded the kinetic energy of the flow and increased its capacity to erode and mobilize debris along the channel of the steep canyon immediately downstream.

### The Torrent in the Canyons of Ophir Creek

The upper canyon of Ophir Creek, which extends downstream from Lower Price Lake, is steep (average gradient about 26 percent, slope of  $14.6^\circ$ , fig. 6), narrow, and relatively straight throughout its roughly



**Figure 22.** Oblique aerial views of Price Lakes, western Nevada, showing muddy surge line on snow, June 3, 1983. A, Upstream view of the outlet of Upper Price Lake. B, Upstream view of Lower Price Lake and upstream reach of Ophir Creek channel. Photographs by Patrick A. Glancy.

0.6-mi reach. The steep descent of this reach is similar to a hydraulic chute, but—unlike a rock chute—the canyon walls and streambed are highly erodible (fig. 7a). The water-dominated floodflow exiting Lower Price Lake, containing a minor amount of fine-grained sediment in suspension, changed quickly after the flow entered the steep canyon below Lower Price Lake. A photograph taken during the flood (fig. 23) by James Schumacher (eyewitness account, app. B) probably portrays the flow near peak stage in the upper canyon. The extreme turbulence of streamflow shown in the photograph is a visual indication of the magnitude of kinetic energy and power of the flow that eroded the steep channel-bounding hillslopes, thereby further steepening and destabilizing the slopes. In this manner, the flow rapidly incorporated large quantities of stream-bank materials immediately downstream from Lower Price Lake. The amount of debris thus

derived from canyon walls is reflected by the sizes and abundance of fresh erosion scars shown in figure 7. Debris incorporated in this manner included boulders from the streambed, colluvium, and landslide debris that bounded the channel, and trees and other vegetal debris that were readily stripped from the channel and its side slopes. The amount of vegetation swept away by the flow is shown through comparison of the photographs of figure 11. During transit of the upper canyon, the rapidly accumulating debris load progressively compounded the erosive action of the flood surge as it increased in inertial power and destructive force.

After a rapid journey of about 0.6 mi through the upper canyon, the now debris-choked flood surge exited the canyon mouth and spread over a flood plain that has a channel gradient about half that of the upstream canyon (fig. 6). This wider and flatter inter-canyon reach of Ophir Creek is about the same length



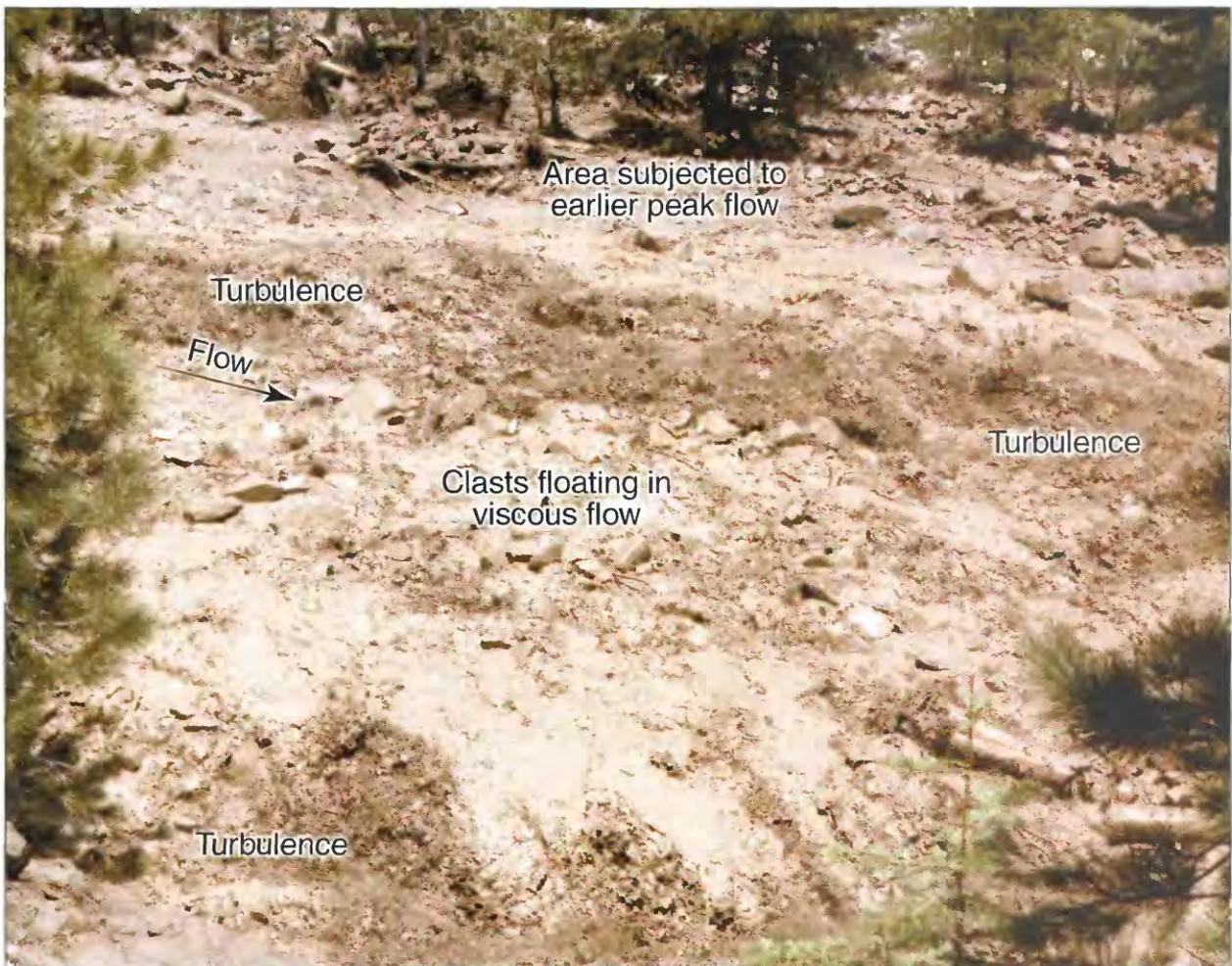
**Figure 23.** Floodflow of Ophir Creek in upper canyon, downstream from Lower Price Lake, at about 11:55 a.m. on May 30, 1983. Note the dark-colored, sediment-entrained, turbulent flow between the trees in right foreground. Photograph taken by hiker James Schumacher.

as the upper canyon (fig. 6), and was vegetated mainly by shrubs and quaking-aspen trees. The decreasing channel gradient and laterally expanding flood plain of the intercanion reach caused decreases in the depth and velocity of the flow, the combined effects of which promoted deposition of some of the coarse-grained fraction of the sediment load.

Within this intercanion reach, the leading edge of the flow encountered William and Elizabeth Willets (fig. 2 and app. B). Elizabeth's first warning of the approaching flood was the noise of its movement. Alerted by the sound, she watched trees being plowed asunder by the bulldozing effect of the boulder-laden, leading edge of flow. Although the Willets reacted instinctively and fled with haste, they barely escaped. They noted that the leading edge of flow was turbulent, boulder-laden, and laced with downed timber that was

being vigorously churned about. They also observed the preflood, bouldery streambed being uprooted by, and incorporated within, the flow, even though the stream gradient had decreased markedly downstream of the upper canyon mouth. The Willets noted that heavily debris-laden floodflow continued during their 20 to 25 minute stay in this intercanion reach of Ophir Creek.

About 10 to 15 minutes after taking the photograph shown in figure 23, James Schumacher arrived at the south edge of the flood plain, within the intercanion reach (fig. 2), where he photographed the scene shown in figure 24. Although the flow surface pictured in the photograph shows turbulent zones, particularly along the edges of the channel, the fluid appears viscous. Large particles, some probably as much as a foot or more in diameter, appear to be floating at the surface



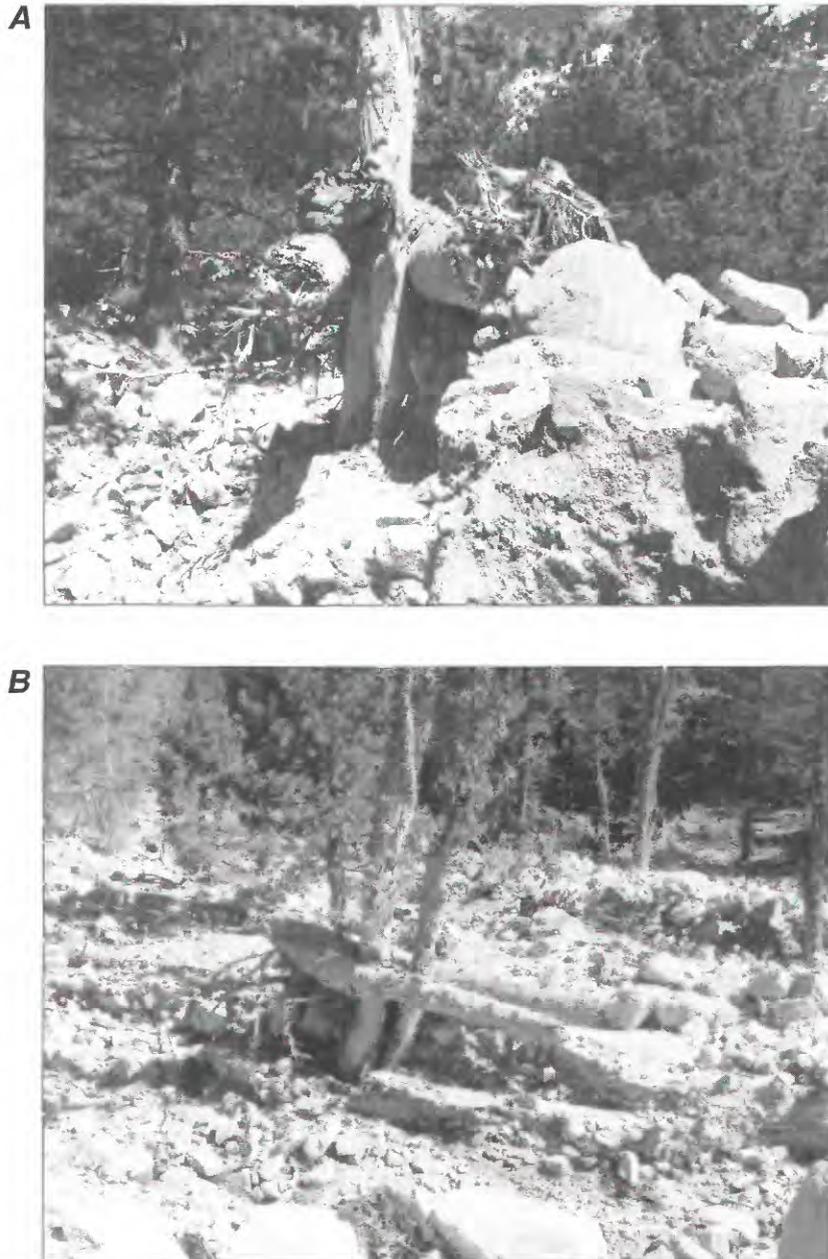
**Figure 24.** Northward view of flood downstream from mouth of upper canyon of Ophir Creek, western Nevada. Photographed by James Schumacher about 10-15 minutes after the photograph in figure 23.

of the fluid. This apparent rafting of coarse particles indicates that the flow was probably moving as a debris flow at that time. Figure 24 also shows that the flow had receded below peak stage.

A substantial fraction of the sediment load that was eroded in the upper canyon was deposited on about 15 acres between the upper and lower canyons. Much of the deposit consists of boulders and cobbles, but

trees and fragments of trees also were chaotically deposited throughout this intercanion reach. These deposits and the sense of disarray that their deposition imparted to the landscape are shown in figure 25.

The erosive character of the leading flow surge continued as the flood entered the lower canyon; large volumes of older, unconsolidated, rockfall-avalanche debris that comprise the lower canyon walls were



**Figure 25.** Coarse-grained deposits on broad flood plain between upper and lower canyons of Ophir Creek, western Nevada: *A*, trees and bouldery rubble partially bury a standing tree; and *B*, coarse debris mantling the flood-plain surface. The battered crotch of a dismembered tree snared by two living trees suggests the degree of abrasive energy that characterized the flood. Photographs by Patrick A. Glancy, July 27, 1983.

removed by lateral erosion and incorporated in the flow. The lower canyon walls show abundant severe erosion by the flood, similar to those of the upper canyon pictured and described earlier. With the exception of some loss of debris in the intercanyon reach, the continued downstream channel erosion indicates that the flow progressively increased its sediment load during transit. The average gradient of the lower canyon (12 percent, or  $6.8^\circ$ ) is about the same as that of the intercanyon reach (fig. 6). Thus, the erosive character of the floodflow probably was revitalized mainly by the lateral confinement of flow exerted throughout this narrow and steep-walled canyon.

Eyewitness Mark Bridgewater (fig. 2 and app. B) was impressed by the viscous character of the leading edge of the flood, which appeared to him as a deep, soupy mud or sludge that was moving very fast. He also noted that the flow was choked with debris, and he observed super-elevated flow around curves in the channel. The momentum of the flowing mass was vividly impressed on Bridgewater's memory by the manner in which the flow ravaged large trees along its path.

## Flow on the Alluvial Fan

The leading edge of the flood inspired both awe and fear among numerous eyewitnesses as it exited the lower canyon mouth. The witnesses seemed impressed by both its audible and visual characteristics. The combined accounts of Anne Ogilvy, the Reed party, Kathleen Thompson, the Staffords, Kathleen Cline, Patricia Sommers, Susan Graves, and Reed Dopf provide varying perspectives on the flood as they experienced it from a variety of vantage points and degrees of personal involvement (fig. 2 and app. B).

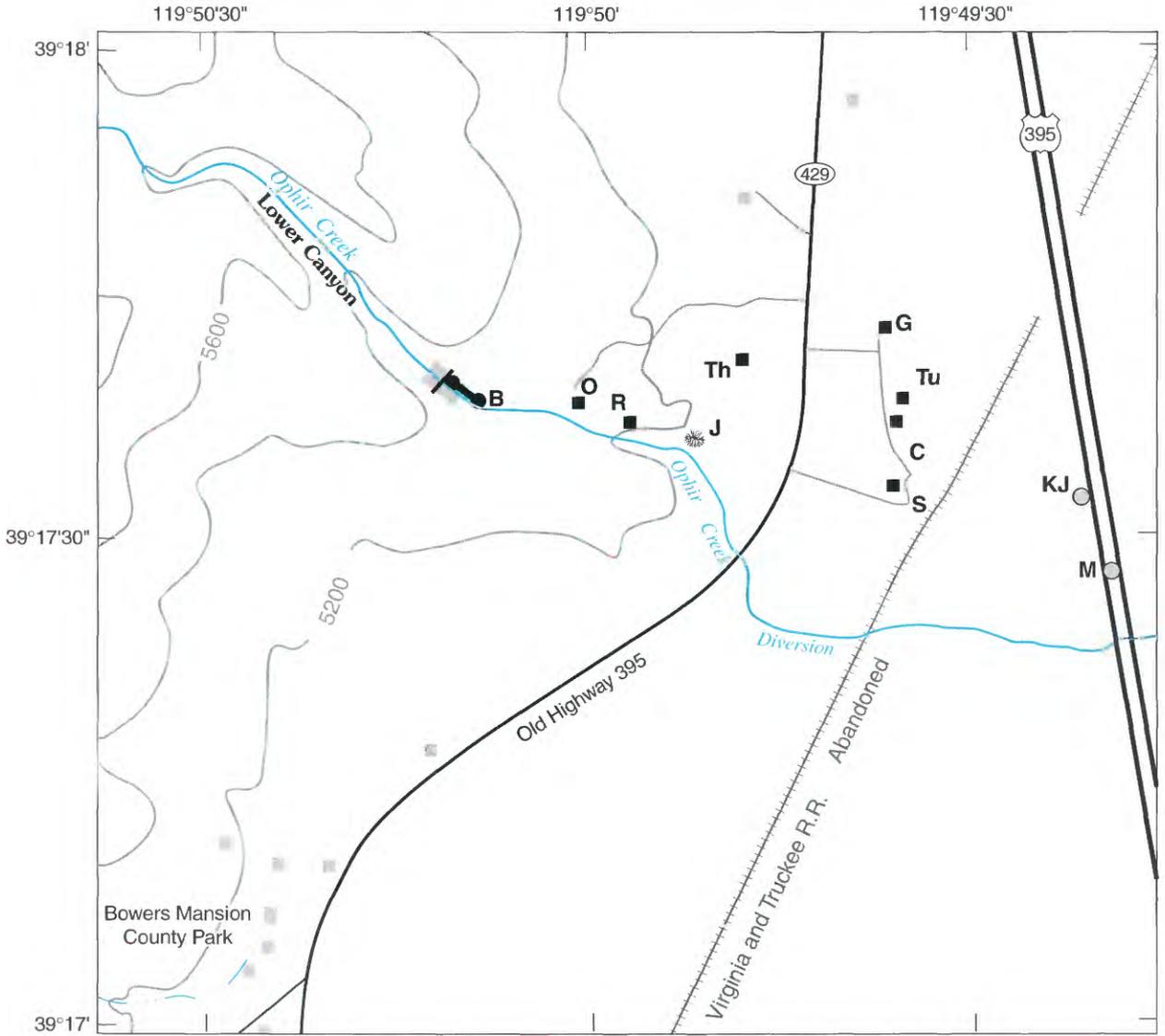
As the leading peak-flow surge emerged from the lower canyon mouth, it began to transform from a dominantly erosive flow to one of net-depositional character. Lateral cutting diminished greatly and differential deposition on the riparian landscape began. Some continued vertical downcutting of the channel was evident after the flood ended but the depth of this erosion is indeterminate because of subsequent backfilling by recessional flows. Two views of a boulder berm emplaced by the flow at the canyon mouth are shown in figure 26 (B, fig. 27). Boulder berms are characteristically formed by streamflow and hyperconcentrated flow (Costa, 1984, p. 292).

Downstream from the canyon mouth, the flood plain progressively widens and flattens from the average 12-percent gradient within the canyon to an average of about 8 percent, or  $4.6^\circ$  (fig. 6). These changes induced deposition of some of the coarse-grained fraction of the debris load (fig. 28) about 0.1 mi downstream from the mouth of the lower canyon. The leading flow surge swept across a terrace bordering the north bank of the stream channel; this terrace is about 10 to 15 ft above the normal streambed. As the surge swept downstream over the terrace, it damaged the Ogilvy home (O, fig. 27) and destroyed the Reed home (R, fig. 27). Eyewitness testimony of Tom Reed (app. B) establishes clearly that the leading edge of the flow was virtually contemporaneous with peak flow; after barely outrunning the leading edge of the flow, Reed turned and observed that the flow had already receded from the terrace to the normal flood plain where it subsequently remained. Burruel, Miller, and Valenzuela were downed by the boulder-laden flow. Fine-grained matrix fluid continued moving downstream on the terrace, overtook Linda Reed, and subsequently swept her into Thompson's back yard (figs. 27 and 29).

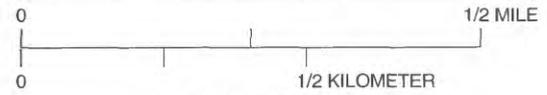
The height of the leading peak-flow surge, from the mouth of the lower canyon downstream to Old Highway 395 is indicated by several lines of evidence. A channel cross-section measurement within the canyon mouth (fig. 27) indicates the surge height was about 25 ft above the normal streambed level; it may have been several feet higher a short distance upstream because the canyon mouth is beginning to expand laterally at the site of the cross section. The surge probably lost some height as it continued to spread laterally downstream from the canyon mouth. Ann Ogilvy (app. B) estimated the surge height at 23 ft when it struck her home about 0.1 mi downstream from the canyon mouth (O, fig. 27). The Reed home, just downstream from Ogilvy's, sat atop a terrace that measures at least 15 ft above the normal streambed. Destruction of the Reed home (R, fig. 27) by the flood required a surge height of several feet above the terrace to effect destruction in the manner described by the witnesses (Reed and others, app. B), and as documented by postflood field evidence. Therefore, we conclude that the surge height at Reed's homesite was on the order of 20 to 25 ft above the normal streambed. A tree along the north bank of the creek a short distance downstream from the Reed homesite (J, fig. 27) is shown in figure 30. Bark was abraded from the tree trunk by the bouldery mass of the flood surge to a height of about 15 ft above its base;

**A****B**

**Figure 26.** Boulder berm on northern edge of flood plain of Ophir Creek, western Nevada, at mouth of lower canyon. *A*, Narrow, elongate berm aligned parallel to the direction of flow; berm composed of chaotically stacked boulders with minimum interstitial fill. *B*, Wide variation in boulder size; clast sizes range from cobble size to more than 6 feet in diameter. Photographed July 14, 1983, by Patrick A. Glancy.



Base from U.S. Geological Survey, 1:24,000 quadrangles: Mt. Rose, Nev., 1968, and Washoe City, Nev., 1974



Contour interval, 200 feet  
Datum is sea level.

**EXPLANATION**

- |           |  |           |  |
|-----------|--|-----------|--|
|           | General location of flow-rate measurement reach  |           | Homesites of residents affected by flood |
|           | Approximate site of preflood and postflood cross-sectional channel measurement depicted in figure 37 | <b>C</b>  | Cline                                    |
| <b>B</b>  | Location of boulder-berm deposits of figure 26   | <b>G</b>  | Graves                                   |
| <b>KJ</b> | Approximate vantage site of Kenneth Julian   | <b>O</b>  | Ogilvy                                   |
| <b>M</b>  | Approximate location of Charles McQuerry   | <b>R</b>  | Reed                                     |
| <b>J</b>  | Flood-scarred Jeffrey Pine tree of figure 30   | <b>S</b>  | Stafford                                 |
|           |  | <b>Th</b> | Thompson                                 |
|           |  | <b>Tu</b> | Turek                                    |

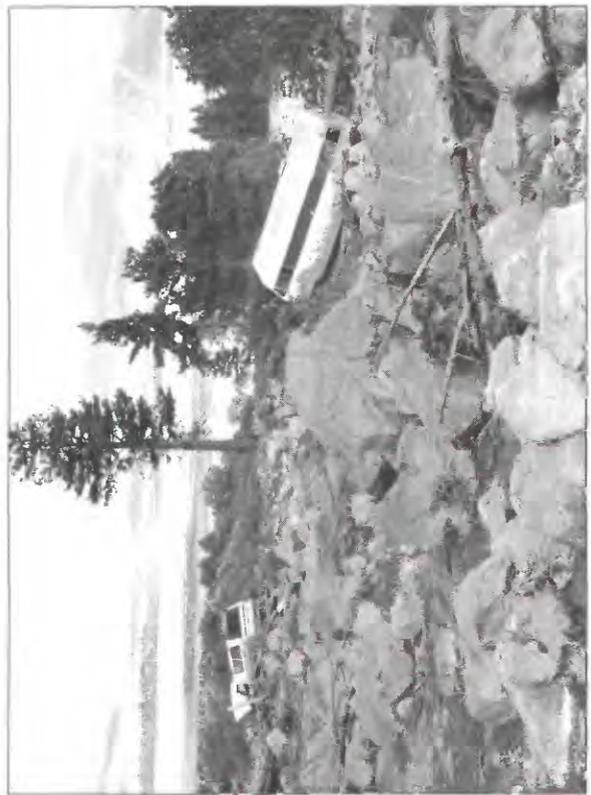
Figure 27. Flood-related reference sites on Ophir Creek alluvial fan.



A



B



C

**Figure 28.** Effects of peak-flow surge on north terrace of Ophir Creek, western Nevada, downstream from lower canyon mouth, showing (A) relation of terrace to the creek thalweg, (B) devastation of Reed's home, and (C) characteristics of boulder deposition on terrace. Photographs by Patrick A. Glancy, June 1 and 2, 1983.



**Figure 29.** Northeastward route of mud-laden matrix fluid that swept away Linda Reed after it overflowed the north-bank terrace of the Ophir Creek alluvial fan, western Nevada. Part of the severely damaged Ogilvy home shown at the lower right corner; Reed's demolished home and damaged motorhome are on terrace at right center. Oblique aerial photograph by Jon O. Nowlin, June 3, 1983.

the base of the tree is about 5 ft above the normal streambed. Thus, the boulder-laden flow front was probably on the order of 20 ft high at this site (J, fig. 27). Eyewitness Kathleen Thompson (app. B) compared the flood-surge height to that of a three-story home (about 20-30 ft tall) from her site of observation just north of the tree shown in figure 30 (Th, fig. 27).

Reed Dopf (app. B) viewed the approaching surge while driving southward on the U.S. Highway 395 freeway (fig. 2). His distant perspective was broad and detached, similar to that of hang-glider pilot Doug Cook during the landslide and initial flood stages. Dopf described the scene from his fireman's frame of reference: "As it came out of the canyon, it was just volatile.

It looked exactly like opening a fire hydrant. It was that much turbulence. It was that much motion." He further described the flow as "a tabular mass of water and rock that was coming out of there." He described it as making "a dull roar like you'd hear at the ocean. The thing that was most impressive was this deep, percussive sound."

The natural channel of Ophir Creek near the battered tree shown in figure 30 was altered by man many decades ago (J, fig. 27). Normal streamflow was diverted sharply southeastward to irrigate fields downstream from Old Highway 395, and this constructed channel diverts low and moderate flows away from their natural path, the axis of the alluvial fan of Ophir



**Figure 30.** Jeffrey pine along the north bank of Ophir Creek (fig. 29), western Nevada, abraded by the flood. Tree records a peak flood-surge height of about 20 feet and is about 100 yards upstream from Old Highway 395. Backpack height is about 1-1/2 feet. Photographed by Patrick A. Glancy June 1, 1983.

Creek. The location and alignment of this diversionary channel can be discerned in figure 3B and is labeled in figures 27 and 29. The debris-laden surge easily bypassed the artificial channel bend, however, and flowed along the axis of the alluvial fan. Unrestrained by channel banks along the fan, the flow spread laterally and engulfed the developed area that included the Stafford, Cline, and Turek homes (S, C, and Tu, fig. 27). The progressively widening flood path downstream from the lower canyon mouth is best shown by the vertical aerial photograph of figure 3B. This June 6, 1983, photograph shows the recessional realignment of the channel to the northern part of the fan and also the partial entrenchment by the receding floodflows. The photograph of figure 10 shows the postflood flow redirected to its man-aligned course by July 26, 1983.

The stream-channel and alluvial-fan gradients (fig. 6) abruptly flatten downslope from Old Highway 395 (fig. 2). During the flood, this flattening and rapidly expanding flowpath caused a correspondingly sharp decrease in flow depths and a rapid deceleration of the peak-flow surge. As the mass decelerated, the boulders and much of the associated finer grained sediment was deposited along about a 0.25-mi route. The area and limits of boulder deposition are shown in figures 10 and 31.

Testimony of eyewitness Susan Graves (app. B and G, fig. 27) indicates that boulder movement at Old Highway 395 continued for at least 10 minutes after the leading edge of the floodflow arrived. Vic Stafford (app. B) recalled that intense flow past his home (S, fig. 27) lasted about 45 minutes. Greg Stafford observed that most of the massive boulder deposition in the vicinity of the Stafford property occurred in a very short time during the early stages of the flood. Despite the intensity of the leading edge of the flow, as reported by eyewitnesses, progressive downstream flattening of the channel gradients implies that the overall velocity of fluid flow diminished enroute from the mouth of the lower canyon to the downstream limit of boulder deposition. Eyewitness accounts by Susan Graves and Tom Reed (app. B) indicate a high velocity near and upstream from Old Highway 395. The areal pattern of boulder deposits (fig. 31) suggests that the flow decelerated noticeably downstream from the tree shown in figure 30 (J, fig. 27) where flow began to rapidly spread laterally.

The extent of home damage downstream from Old Highway 395 is depicted in figures 32, 33, 34, and 35, which picture three homes and the extent of their exterior damage. The Stafford home (S, fig. 27) appears to be structurally intact, but was partially filled with fine-grained deposits to over half the height of the ground floor (fig. 32). The Cline home (C, fig. 27) was destroyed (figs. 33 and 34); Mrs. Katy Cline's escape from that house (app. B) is rendered even more incredible by evidence shown in figures 33 and 34, which portray some sense of the chaos that must have prevailed in and around the Cline residence at, or near, the time she was forcibly ejected by the flood. The Turek house (Tu, fig. 27), like Stafford's, was not heavily damaged structurally, but was substantially damaged internally by water and the deposition of fine-grained sediment (fig. 35).



**Figure 31.** Downstream extent of boulder deposition on Ophir Creek fan resulting from the 1983 flood. Turek and Cline homes are separated by new alignment of creek. Stafford home and buildings among trees to south. Vertical aerial photograph by Nevada Department of Transportation, June 1, 1983.

Fine-grained, sediment-laden fluid flowed beyond the boulder field toward the freeway (fig. 10). Some of this fluid mixture appears to have come from the upper part of the interstices between surficial boulders. The partial draining of these interstices contributed to the rough appearance of the bouldery armored surface portrayed in figures 31, 40, and 48.

Eyewitnesses Shirley Stafford, Cline, Sommers, Julian, Dopf, and McQuerry, individually located at a variety of vantage points (fig. 2), all described movement of the fluid mixture of water and fine-grained sediment that flowed beyond the boulder deposits toward the freeway (app. B). The consensus of their accounts is that the mixture was heavily laden with entrained sediment. The flow appeared to be more viscous than water, and although its velocity had decreased greatly from that of the peak flow through the canyons, it still

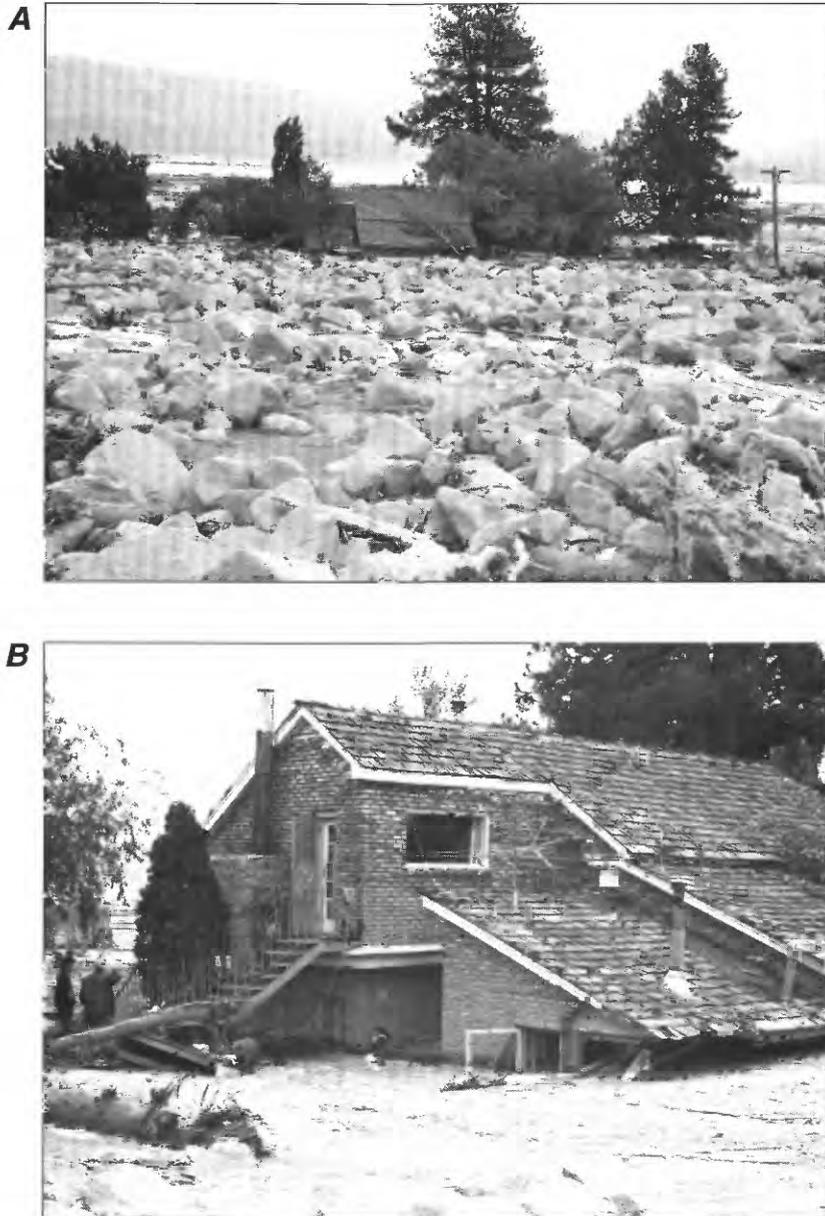
retained a level of power that impressed Shirley Stafford (app. B). As the flow moved southward, parallel to the upstream side of the freeway, she watched it roll a helpless horse over and over. Similarly, Katy Cline tried to stand up in the flow but was repeatedly knocked down. Sommers observed Cline being rafted along by the viscous flow.

### Flow Rates and Velocities

Flow rates and velocities are quantitative hydrologic variables important to the scientific characterization of flooding and the understanding of flood characteristics. These variables usually are measurable to acceptable degrees of accuracy during floods that are anticipated, rise gradually, peak smoothly, and recede over a prolonged time, are dominantly water rather than

debris laden, and are confined within a stable channel. Corresponding data usually cannot be measured directly during flash floods, which are of opposite and contrasting character: they usually are unexpected and they rise, peak, and recede before such direct measurements can be made. Also, flash floods can erode stream channels to a degree that hydraulic characteristics of

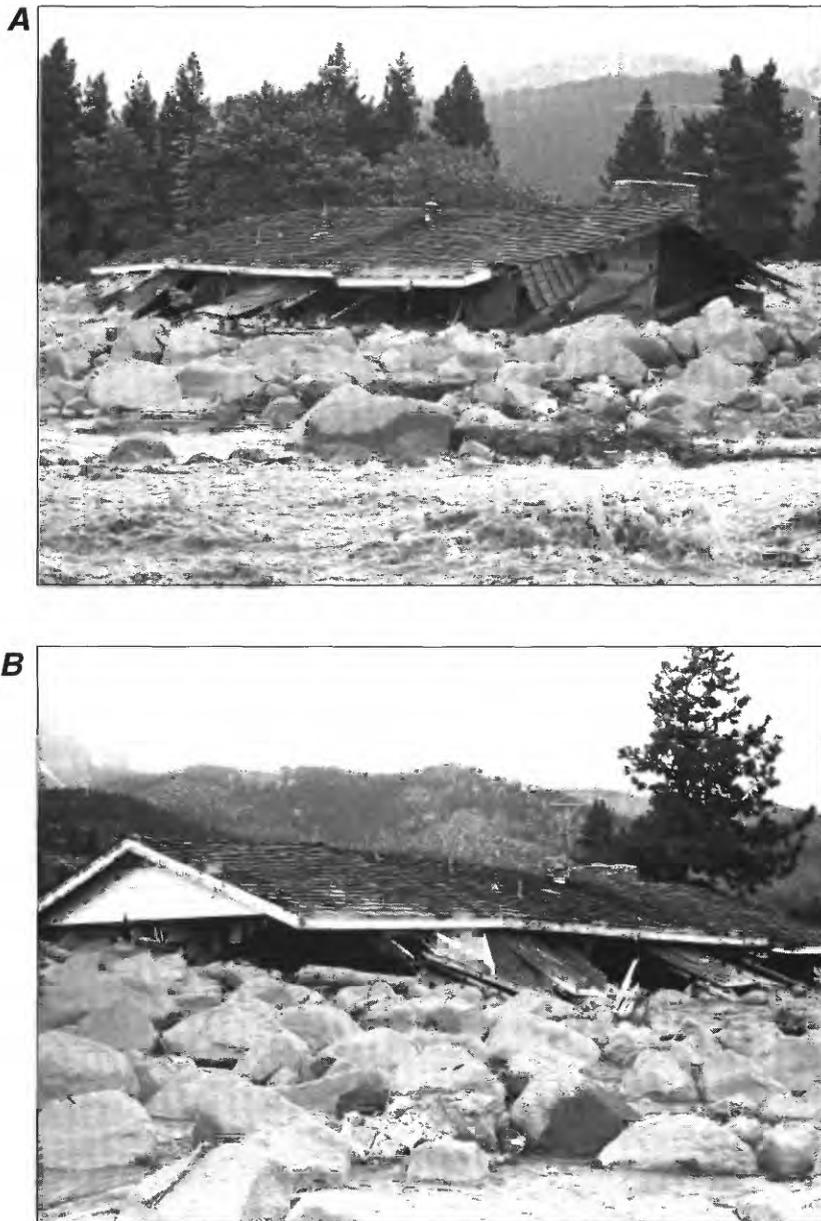
the resultant fluid are altered by high concentrations of entrained debris. Flow rates and velocities must be estimated indirectly, after flooding has ceased. Measurements made after a flood are potentially less accurate; consequently, confidence in the measurement results is inherently less than for data measured directly during flooding.



**Figure 32.** Stafford home, June 1, 1983. Photographs show damage caused by Ophir Creek flood, western Nevada: A, View downstream from just below Old Highway 395. B, Southeastward view of north end of house. Photographs by Patrick A. Glancy.

The Ophir Creek flood of 1983 was a particularly intense flash flood that, because of its unusual and unpredictable genesis, chaotic nature, and hazardous behavior, was largely unmeasurable by standard, direct, hydraulic techniques. The energetic severity of the flood produced streamflow heavily laden with

entrained sediment. This heavy sediment loading undoubtedly altered hydraulic characteristics of the fluid mixture. The distorted hydraulic character impaired indirect-measurement methods originally devised for streamflow where water, rather than sediment, is the dominant fluid component.



**Figure 33.** Cline home, June 1, 1983. Photographs show damage caused by Ophir Creek flood, western Nevada: *A*, View southwestward showing downstream side of house. *B*, View northwestward showing downstream side of house. Kathleen Cline was ejected from this side of the house by floodflow. Photograph by Patrick A. Glancy.



**Figure 34.** Downstream (eastward) view of Cline house. Distal margin of boulder deposits at top of photograph. Oblique aerial photograph taken by Washoe County Sheriff's Department during afternoon of May 30, 1983, after the leading flow surge of the Ophir Creek flood, western Nevada.

No hydraulic formulae handily quantify flow rates and velocities of streamflows that are dominated by entrained debris (debris flows), that vary rapidly in magnitude and intensity, and that flow through erosively unstable channels. Consequently, formulae devised for water-dominated (Newtonian) flows are, of necessity, often used as imperfect surrogate tools during debris-flow analyses. Resultant flow-measurement data are inherently imprecise. During the Ophir Creek study, estimates were therefore numerically rounded to reflect an appropriate level of confidence.

Keen observations by ideally located eyewitnesses were unusually abundant for the Ophir Creek flood, compared to most flash floods. Data derived from these accounts were used in numerical checks and balances on the frail results obtained by liberal applications of surrogate Newtonian-flow, indirect-measurement formulae.

In summary, several measurement methods, some less appropriate than others, were used, as available opportunities allowed, to compute flow rates and velocities. Results of the various methods, tempered by theoretical and practical considerations as well as by eyewitness accounts, were compared and weighed against each other, in check-and-balance fashion, to finalize rounded estimates of flow rates and velocities.

#### **Average Rates and Velocities**

Eyewitness observations allow an estimate of the average time of travel of the leading edge of the flood from Price Lakes to Old Highway 395. James Schumacher (app. B, fig. 2) noted the time of the landslide as 11:53 or 11:54 a.m., according to his wristwatch. Eyewitness Kathleen Thompson (Th, fig. 27) noted that her electric power supply failed at 12:02 p.m., which agrees with Sierra Pacific Power Company's timing of

**A**



**B**



**Figure 35.** Turek home on June 1, 1983. *A*, View downstream to the northeast; *B*, view cross channel to the north. Photographs by Patrick A. Glancy taken after the Ophir Creek flood, western Nevada.

the power outage in the area. Electric power failed on the Ophir Creek fan because supply lines were cut by the leading edge of the flood where it crossed Old Highway 395. Thus, the overall travel time from the beginning of the spilling of Upper Price Lake to the time of arrival of the leading edge of flow at Old Highway 395 was about 8 or 9 minutes. Eyewitness Doug Cook, who observed the landslide and the travel of the flood surge from Price Lakes to Old Highway 395 (hang-glider flight path, fig. 2), but did not document the rate of travel with a timepiece, independently estimated the travel time as ranging from 5 to 10 minutes (app. B). We believe the clock-time range of 8 or 9 minutes to be an acceptable estimate of the overall travel time. The map distance of the flowpath to Old Highway 395, 2.88 mi (summation of several distances; see fig. 6) is slightly less than the slope distance. The slope distance was computed as 2.91 mi and more correctly represents the true length of the stream-channel reach. The average flow velocity that is based on a travel time of 8 or 9 minutes and either of those distances (2.88 or 2.91 mi) would range between 19 and 22 mi/hr (about 28 to 32 ft/s).

Fluid velocities in the range of 28 to 32 ft/s are not unreasonably high considering the steep channel gradient. This average velocity range is well within the range of peak velocities (10 to 40 ft/s) characterized by Van Dine (1985, p. 51) for debris torrents in Canada. Streamflow velocities as fast as 30 ft/s have been measured with a current meter in natural river channels by the U.S. Geological Survey (Leopold, 1974, p. 58).

The average velocity of the Ophir Creek flood is greater than the 5.6 ft/s (3.8 mi/hr) that was caused by the Lawn Lake and Cascade Lake dam failures in Colorado (Jarrett and Costa, 1984, p. 31). However, the average gradient of Ophir Creek (about 14 percent, fig. 6) is about 2.8 times that of the channel in Colorado (about 5 percent; Jarrett and Costa, 1984). Overall, comparisons of release rates of ponded water, channel slopes along variable-length reaches, and characteristics of channel confinements and geometry between the two floods indicate that different average velocities would be expected.

#### **Rates Associated With Expulsion of Price Lakes**

A precise rate of expulsion of Upper Price Lake by the landslide is indeterminable because data necessary to establish the emptying rate, with a desirable degree of precision, are unavailable. Watters (1983,

p. 181) described displacement of Upper Price Lake as a large wave up to 16.5 ft high. This determination of wave height importantly verifies a rapid and dynamic emptying of the contents of the lake. The eyewitness account of Doug Cook (app. B) supports the observation of Watters regarding rapid expulsion.

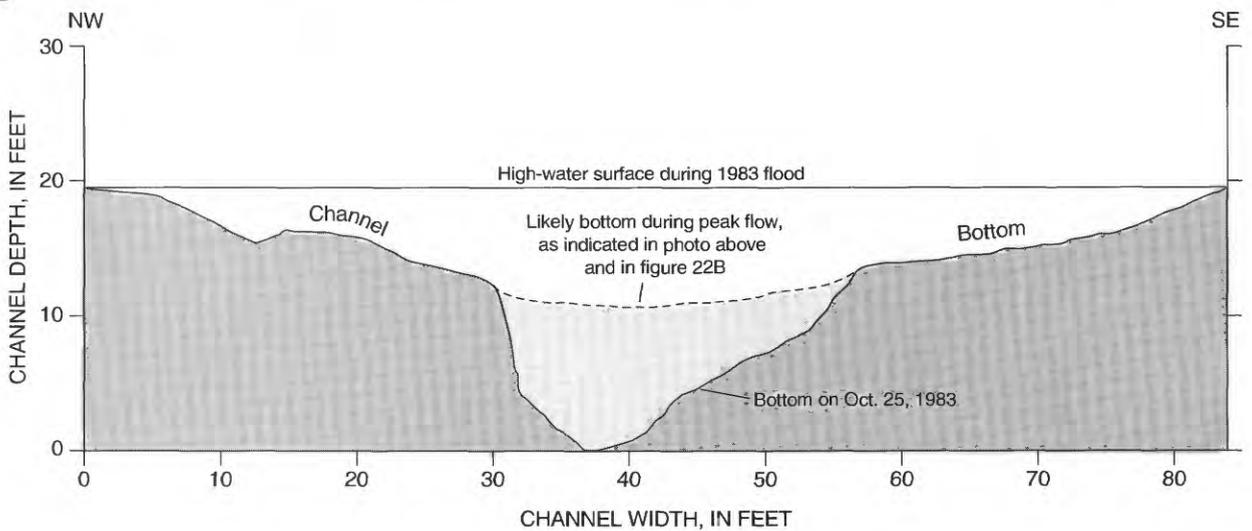
Hydraulic evidence at the outlet of Lower Price Lake was used to speculate on varying rates of fluid movement from Lower Price Lake and into the head of the upper canyon. Figures 22B and 36A show the geometry of the creek channel at the outlet of Lower Price Lake as it existed shortly after the flood. By the time the geometry was surveyed in October 1983, snowmelt runoff had deepened and enlarged the outlet (fig. 36B). A vertical cross section of the area of flow as it left the lake was determined from measurements of the channel-bottom shape and the elevation of the high-water lines left by the flow at its peak stage (fig. 36B). The October 25 measurements were modified for the channel bottom, as shown in figure 36B. This cross section is located approximately along the axis of the earthen dam that formerly impounded Lower Price Lake.

Immediately downstream from the dam, the channel bottom drops vertically at least 10 ft (fig. 36A); then the upper canyon of Ophir Creek falls steeply (figs. 5 and 6). As a result, a minimum peak-flow rate can be estimated by assuming that the flood moved at critical velocity over a spillway. The only known hydraulic parameters are the approximate size and shape of the flow cross section, which is depicted in figure 36B. A flow analysis that assumes hydraulically critical flow at the site of the measured cross section implies the following hydraulic conditions: (1) The flow cross section is assumed to be analogous to one that might have resulted had an imaginary impoundment of that size existed at the site, and (2) flow through the cross section is analogous to that which would achieve a maximum rate following instantaneous removal of the imaginary impoundment. This analogy inherently assumes that the approach velocity to the flow cross section is zero. However, field evidence, eyewitness accounts, and common sense demonstrate that the actual approach velocity during the peak surge of the flood was much greater than zero; thus, this critical-flow analysis results in a minimum estimate of the rate of flow through the section.

**A**



**B**



**Figure 36.** Outlet of Lower Price Lake, western Nevada: *A*, Upstream view of breached dam, photographed by R.L. Jameson, U.S. Forest Service, on morning of May 31, 1983. *B*, Downstream view of cross section, as surveyed about 5 months later by Robert R. Squires and Rodney L. Carson, U.S. Geological Survey, October 25, 1983.

For a rectangular channel, the critical-flow hydraulic state is given by:

$$F = \frac{v}{\sqrt{gdm}}, \quad (1)$$

where  $F$  is the dimensionless Froude number;

$v$  is the average flow velocity at the lake exit, in feet per second,

$g$  is the gravitational constant of acceleration, equal to 32.2 feet per second per second, and

$dm$  is the mean depth of flow through the vertical cross section, in feet, assumed to equal the critical-flow depth.

At critical flow,  $F = 1$ , and  $v = \sqrt{32.2dm}$ . Velocity can be readily calculated if the flow is assumed critical and if the mean flow depth representing the critical depth can be determined (Rouse, 1950, p. 71). Figure 36B shows that an acceptably reasonable and accurate estimate of  $dm$  cannot be made for the entire cross section in a single step. Therefore, the vertical cross section of flow was subdivided into a series of nearly rectangular vertical elements, to allow application of the above equation, and velocities of the individual elements were calculated. Areas of the individual elements were also calculated.

Flow rates for the individual elements were subsequently calculated using the basic flow equation:

$$Q = VA, \quad (2)$$

where  $Q$  is flow rate, in cubic feet per second;

$V$  is velocity, in feet per second; and

$A$  is area perpendicular to direction of flow, in square feet.

A summation of the individual flow rates and areas calculated for the individual elements at critical state results in a cumulative flow rate ( $Q$ ) of about 6,000 ft<sup>3</sup>/s and a corresponding cross-sectional flow area of about 400 ft<sup>2</sup>. Average velocity (assuming a zero approach velocity) during the critical-flow state through the cross section shown in figure 36B, can then be simply calculated ( $V = Q/A$ , or 6,000 ÷ 400) as about 15 ft/s. Dual links of evidence for the rapid expulsion of Upper Price Lake, described above, and the well-defined channel between Upper and Lower Price Lakes (fig. 20) assures that the flow surge into Lower Price Lake was large and swift. Thus, outflow from Lower Price Lake, through the cross section shown in figure 36, was probably hydraulically supercritical and, if so, the flow rate would probably exceed 6,000 ft<sup>3</sup>/s.

Supercritical flows can and do occur naturally in erodible channels, but probably are uncommon throughout long channel reaches or within any given reach for prolonged periods of time. Hydraulic forces on the channel boundaries caused by supercritical flow, which is rapid, turbulent, and abrasive, remold erodible channels in a manner that transforms the depth-velocity relation and causes flow to progressively revert to and remain in a subcritical state. The landslide that emptied Price Lakes may have generated supercritical flow at the outlet of Lower Price Lake for the short duration that was required to empty the lakes. If so, the average velocity probably would have exceeded the critical average velocity of 15 ft/s calculated above.

Average flow velocities in the range of 28 to 32 ft/s, which was determined by using travel time and distance, as described above, probably generally characterize the overall movement of the flow downstream from Upper Price Lake to Old Highway 395. At velocities of 28 and 32 ft/s, the application of the basic flow equation ( $Q = VA$ ) indicates that corresponding peak-flow rates through this cross section (fig. 36B, area = 400 ft<sup>2</sup>) would range from about 11,000 to 13,000 ft<sup>3</sup>/s, or about twice the assumed minimum rate of 6,000 ft<sup>3</sup>/s determined and described above.

The range of flow rates (6,000-13,000 ft<sup>3</sup>/s) estimated above for the outlet of Lower Price Lake can be hypothesized on the basis of time required to empty the contents of Upper and Lower Price Lakes. The combined contents of the lakes probably were about 22 acre-ft, or about 960,000 ft<sup>3</sup>. At a constant flow rate of 6,000 ft<sup>3</sup>/s, 160 seconds would be required to move that amount of water; similarly, at 11,000 and 13,000 ft<sup>3</sup>/s, 87 and 74 seconds, respectively, would be required. Because these hypothesized flow rates are assumed to be peak-flow rates, they would not prevail during the entire emptying of the lakes; thus, times somewhat greater than those estimated would have been necessary to empty the lakes at flows characterized by those peak-flow rates. Cook's observation (app. B) of the rapidity of lake spilling infers that the largest of the above postulated flow rates might be closest to the actual event. Even at that large rate (13,000 ft<sup>3</sup>/s), it may have taken about 1.5-2 minutes to evacuate 22 acre-ft of water. Cook's observations thus imply that a peak rate greater than 13,000 ft<sup>3</sup>/s may have occurred. At a flow rate of 13,000 ft<sup>3</sup>/s, flow would have been supercritical at the outlet of Lower Price Lake, and average velocity would have been 32.5 ft/s.

Eyewitness accounts, Watters' data (1983), and surge characteristics of high-water lines noted at the site all argue strongly for rapid expulsion of Upper Price Lake. A 1-minute duration for expulsion would require a constant flow rate from Lower Price Lake of about 16,000 ft<sup>3</sup>/s; the peak-flow rate to accomplish that magnitude of lake expulsion might have exceeded 20,000 ft<sup>3</sup>/s (an average cross-sectional peak velocity at the lake outlet of 50 ft/s). A 2-minute duration for lake expulsion would require a constant flow rate of 8,000 ft<sup>3</sup>/s and a peak-flow rate of perhaps on the order of 10,000 ft<sup>3</sup>/s (which yields an average, cross-sectional, peak velocity of 25 ft/s).

The aerial photographs of figure 22 portray a flood surge that abraded the outlet of Upper Price Lake and much of the downstream channel between the two lakes. However, at the edges of the channel, the force and duration of the flow were not sufficient to fully remove the blanket of snow mantling the channel boundaries. This residual snowpack indicates low abrasive action or a short duration of submergence, or both, at the outer channel margins. Intense erosive abrasion along the inner parts of the channel argues for high velocity but probably over a longer flow duration. The combined evidence indicates a sudden peak surge of such a short duration that much of the snowpack survived; it also indicates that highest velocities and associated shear stresses were concentrated in the center two-thirds of the channel width. The interpretation of these features is that the complete emptying of Upper Price Lake may have required more than 1 minute, and that the momentary peak surge of flow was followed by moderate to heavy flow that may have lasted over a minute. Although data are inadequate to further resolve the rate and time of emptying, they probably are adequate to conclude that most of the contents of Upper Price Lake were probably disgorged in less than 2.5 minutes after the landslide occurred.

The above discussion does not favor or verify any specific peak-flow rate for the expulsion of water from Price Lakes. However, it does imply that the peak-flow rate of expulsion was at least 6,000 ft<sup>3</sup>/s. Although eyewitness accounts implicitly suggest that the rate was greater, there is no incontrovertible hydraulic evidence to demonstrate a greater rate. On the basis of eyewitness reports that describe the rapidity and characteristics of expulsion, and in spite of limited field evidence, a peak-flow rate of about 15,000-20,000 ft<sup>3</sup>/s is indicated. Even at a minimum peak-flow rate of 6,000 ft<sup>3</sup>/s,

the flow would have been an intense surge of fluid and, as such, would have possessed an alarming amount of both kinetic and potential energy at the beginning of its downward plunge into the highly erodible, steep, and narrow canyon below Lower Price Lake.

### Rates in the Canyons

William and Elizabeth Willets witnessed the approaching flood surge from their vantage point along the flood plain between the upper and lower canyons of Ophir Creek (fig. 2 and app. B). William estimated the velocity of the leading edge at 20-30 mi/h (29 to 44 ft/s) just before it exited the upper canyon. Although wide ranging, that estimate seems reasonable, considering that the velocity of the leading edge of flow may have been near its maximum as it approached the terminus of the steep upper canyon. Willets' estimate also is reasonably compatible with the estimates of average velocities (28 to 32 ft/s) derived on the basis of overall travel time, as described above. The Willets sensed a general decrease in flow velocity as the flow spread laterally in the reach between the upper and lower canyons. Their intuitive sense is compatible with the evidence of debris deposition throughout the reach that implies both decreasing velocities and flow depths.

Direct estimates of flow rates, like that made by William Willets for the mouth of the upper canyon, are not available for the lower canyon. However, the peak-flow rate was quantified after the fact by indirect-measurement means.

Indirect determination of the peak-flow rate is quantitatively founded on the basic equation of open-channel flow:

$$Q = VA, \quad (3)$$

where  $Q$  is discharge rate of the streamflow, in cubic feet per second;

$V$  is average flow velocity through a cross-sectional area of the channel, perpendicular to the direction of flow, in feet per second; and

$A$  is the cross-sectional area of flow in the channel, in square feet.

## Slope-Area Measurement

Peak-flow rates in natural channels are commonly measured indirectly using the slope-area method (Dalrymple and Benson, 1967). The slope-area measurement method yields reliable results when prevailing streamflow conditions are within the hydraulic limitations for which the technique is applicable, and when field-measurement uncertainties are resolved or minimized.

The slope-area measurement is based on the Manning equation, an empirical expansion of the basic flow equation ( $Q = VA$ ), which defines flow rate in an open stream channel as:

$$Q = \frac{1.486}{n} AR^{2/3} S^{1/2}, \quad (4)$$

where  $Q$  is discharge rate of the streamflow, in cubic feet per second;

$A$  is cross-sectional area of flow in the channel in square feet;

$R$  is hydraulic radius of channel, in feet;

$S$  is friction slope of the channel reach, which is assumed equivalent to the slope of the high-water profile through the measurement reach, in feet per foot; and

$n$  is an empirical roughness coefficient, expressed as a numerical constant.

A comparison of the Manning equation with the basic flow equation shows that the basic components of stream discharge are still area ( $A$ ) and velocity ( $V$ ), but that velocity takes a new form:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}. \quad (5)$$

Application of the Manning equation requires hydraulically steady and uniform-to-gradually varied flow of a Newtonian fluid (water-dominated rather than debris-dominated). Minimum scour or fill, or both, along the channel boundaries, during all phases of the flow, bolster confidence that the cross-sectional area of the channel at peak flow can be accurately portrayed by postflood measurements. Also, low concentrations of debris entrained in the peak-flow results in an empirical roughness coefficient ( $n$ ) that is dominantly the product of channel-boundary roughness. For flows where channel scour and fill were minimal, a value for  $n$  can be estimated by visual inspection of channel-boundary conditions after the peak flow has subsided (Barnes, 1967).

Eyewitness accounts and postflood field investigations indicates that the Ophir Creek flood failed to meet any of the ideal hydraulic scenarios and conditions described above, which decreased confidence in results of the slope-area method of indirect measurement. The peak flow was heavily charged with debris, the entrained debris load was almost exclusively the product of channel erosion, flow was likely unsteady and probably varied rapidly, and internal frictional resistance to flow caused by turbulent motion and characteristics of entrained debris of the fluid may have been at least as important as flow resistance caused by channel-boundary roughness.

Results of recent flume studies of debris flows (Major and Iverson, 1993, p. 315) indicate that mudline elevations along channel banks record the passage of a peak roll wave, but reveal little about mean flow depth, velocity, or discharge. However, characteristics of the flume-generated flows differ from those of the Ophir Creek flood. The magnitude of the peak flow and the range of particle sizes transported by the flood greatly exceed those in the flume studies, and the characteristics of the channel boundaries of Ophir Creek seem to bear little resemblance to those of a flume. Characteristics of the mechanism and rate of fluid release and subsequent flow response also may differ greatly. Eyewitness observations of the Ophir Creek flood by Anne Ogilvy and Tom Reed (app. B), from vantage points no greater than 0.2 mi downstream from the indirect measurement reach (O and R, fig. 27), describe the leading surge of the flood as the peak flow. This surge seemed to peak almost instantaneously and receded almost as quickly. It was choked with mud, boulders, and trees. Debris deposition by this peak-flow surge is shown in figures 28, 29, and 52. Because of its brief duration, there is little likelihood that any roll waves accompanied the rise, peak, or early recession of the surge. The initial surge at peak-flow rate, downstream at Old Highway 395 was similarly characterized by Patricia Sommers (app. B). Thus, the high-water profiles along channel banks at the indirect measurement site are probably those emplaced by the nearly instantaneous initial surge. Testimony of several other eyewitnesses (for example, Vic Stafford and Susan Graves, app. B and fig. 2) recall persistent bouldery flow for up to 45 minutes after the initial peak surge. This recessional flow may have included roll waves, but at peak levels well below those of the initial surge.

Failure to meet the hydraulic requirements for a slope-area measurement reduces certainty in the results of the peak-flow measurement for this flood.

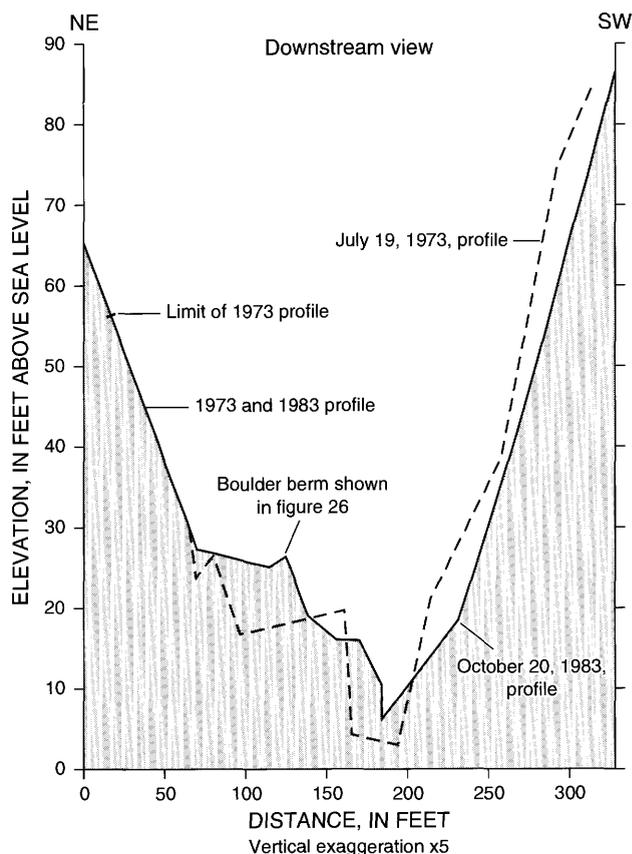
However, results of the slope-area measurement can nevertheless be usefully compared to results obtained through other measurement options. Therefore, a slope-area measurement of peak flow was made and the credibility of the results was tested through comparison with other methods. Results of several methods were evaluated and adjusted on the basis of complementary lines of evidence, and the selected result was then reported to a level of significance commensurate with the recognized level of uncertainty.

The slope-area measurement site encompassed a 250-ft channel reach within the mouth of the lower canyon (fig. 27). This site was chosen for measurement for several reasons. Its location, just upstream from the area of human occupation and associated development, was conducive to provide needed quantification of the hazard potential this flood posed to the downstream residents. Also, the general hydraulic characteristics and geometric configuration of the channel through the selected reach generally were favorable for analysis after the flood.

A quantitative analysis of the peak-flow rate and hydraulic characteristics of the debris-charged flow for a flood of this size and intensity were subject to a variety of uncertainties. The area ( $A$ ) term of the basic equation of flow (eq. 3) probably involved less, or at least more easily resolvable, uncertainties than the ( $V$ ) velocity term.

Quantification of the cross-sectional flow area was necessarily based on postflood measurements of the high-water profiles along the channel banks through the measurement reach and on the postflood geometry of the channel bed and banks. The likelihood of severe channel scour and (or) filling during this flood raised uncertainty regarding the accuracy of postflood measurements in portraying the true cross-sectional shape and size during peak flow. Another uncertainty arose because significant scour and (or) fill during peak flow might have influenced the elevation and slope of high-water lines.

An unusual and beneficial aspect of this specific channel reach was the existence of a preflood, cross-sectional channel measurement. A comparison of preflood and postflood channel topography is shown by the cross sections in figure 37. This comparison confirms that the flood did alter the channel geometry in the measurement reach to some degree. Planimetry of the two cross sections indicates that the postflood cross-sectional area is roughly 70 to 80 percent that of the preflood area; thus, effects of the flood appear to



**Figure 37.** Diagrammatic cross sections of Ophir Creek channel, western Nevada, measured near lower canyon mouth before and after the 1983 flood.

have reduced the area by about one-fourth through the process of net channel filling. Channel erosion was the dominant fluvial process during the rising and peak-flow phases and channel refilling (deposition) dominated the recessional phase of flooding. Although the exact channel configuration at the time of peak flow is unknown, the data of figure 37 imply that the postflood area may be a conservative estimate of the area at the time of peak flow.

Postflood measurements through the 250-ft channel reach included four vertical cross sections having areas that ranged from about 1,500 ft<sup>2</sup> to about 2,400 ft<sup>2</sup>. The average of these areas is about 2,000 ft<sup>2</sup>, appropriately rounded to reflect the degree of confidence in portraying the average area of the measurement reach at the time of peak flow.

The slope-area measurement of the 250-ft channel reach yielded a peak-flow rate of about 70,000 ft<sup>3</sup>/s on the basis of a visually estimated postflood, channel-boundary roughness of 0.05

(Barnes, 1967, p. 152, 153). This rate probably is excessive because (1) the frictional resistance factor ( $n$  of 0.05) accounts only for boundary friction and ignores internal friction caused by the turbulent debris-charged flow, and (2) the average flow velocity through the measurement reach at a discharge of about 70,000 ft<sup>3</sup>/s would be about 35 ft/s. This velocity seems inordinately high for the following reasons: The average flow velocity from Upper Price Lake to Old Highway 395, as described earlier, and based on distance and travel time, was in the range of 28 to 32 ft/s. Channel slope in the indirect measurement reach is about 8 percent, or 4.6°, much less than the upper canyon (slope, 26 percent, or 14.6°; fig. 6), and slightly less than the gradient downstream through the intercanyon reach and the lower canyon (slope, 12 percent, or 6.8°; fig. 6). Average channel gradient from Upper Price Lake to the mouth of the lower canyon is about 15 percent, or 8.5°. Thus, velocity through the measurement reach should likely be no more, or less than, the average velocity of 28 to 32 ft/s. A velocity of about 30 ft/s, the mid-value of the range of averages, through the indirect measurement reach would result in a peak-flow rate of about 60,000 ft<sup>3</sup>/s ( $VA = 2,000 \times 30$ ). However, a velocity of 30 ft/s also is probably excessive for the reasons stated above.

### Flow-Around-A-Bend Measurement

The indirect measurement reach is slightly curved, convex to the south. This curvature caused a super-elevation of the flow surface that probably was proportional to the velocity of the moving fluid and, thus, allowed an estimate of average velocity that is independent of those described above. The relation among fluid velocity and channel curvature, channel slope, and super-elevation of the fluid surface is specified by the following equation (Johnson and Rodine, 1984, p. 307 and 308):

$$\bar{u} = (Rg \cos S \tan B)^{\frac{1}{2}}, \quad (6)$$

where  $\bar{u}$  is the average fluid velocity;

$R$  is the radius of curvature of the channel bed;

$g$  is the acceleration of gravity (32.2 ft/s<sup>2</sup>);

$S$  is the angle of the channel slope; and

$B$  is the angle of tilt (super-elevation) of the flow surface measured perpendicular to flow direction.

The following data obtained through the slope-area measurement were used in the above equation:

$R$  is about 320 ft,

$\cos S$  is 0.996; slope ( $S$ ) used was 0.09 (average of channel slope of 0.083 and water-surface slope of 0.10); arc  $\tan S = 5.14$  degrees, and

$\tan B$  is 0.053 ft/ft (average super-elevation of 8.9 ft at average channel width of 168 ft):

$$\bar{u} = (320 \times 32.2 \times 0.996 \times 0.053)^{1/2} \cong 23.5 \text{ ft/s}. \quad (7)$$

The peak-flow rate using this average velocity (23.5 ft/s) and the area (2,000 ft<sup>2</sup>) obtained from the slope-area measurement is 47,000 ft<sup>3</sup>/s (23.5  $\times$  2,000) through application of the basic flow equation. However, because of the previously stated measurement uncertainties, the peak-flow rate was rounded to one significant figure, 50,000 ft<sup>3</sup>/s. The resultant average velocity of 25 ft/s (50,000  $\div$  2,000) probably is a reasonable estimate that is based on the various eyewitness accounts and available postflood data.

Field measurements made as part of the slope-area measurement were further utilized to check validity of the selected peak-flow rate (50,000 ft<sup>3</sup>/s) through step-backwater analysis (Shearman and others, 1986). The step-backwater analysis, an application of the Manning equation (eq. 4) utilizing field-measured data, compares computer-generated high-water lines for varying selected flow rates to high-water lines measured in the field. It thereby tests the degree to which computed results replicate field data. Results of step-backwater analyses best replicated field-measured high-water lines at a discharge of 52,000 ft<sup>3</sup>/s with the Manning  $n$  roughness coefficient ranging from 0.05 to 0.10 through the measurement reach; at that discharge, computed and measured high-water profiles were reasonably similar. The acceptable degree of replication of these profiles reinforced confidence that a discharge of about 50,000 ft<sup>3</sup>/s is a reasonable estimate of peak flow for the Ophir Creek flood of May 30, 1983, near the mouth of the lower canyon.

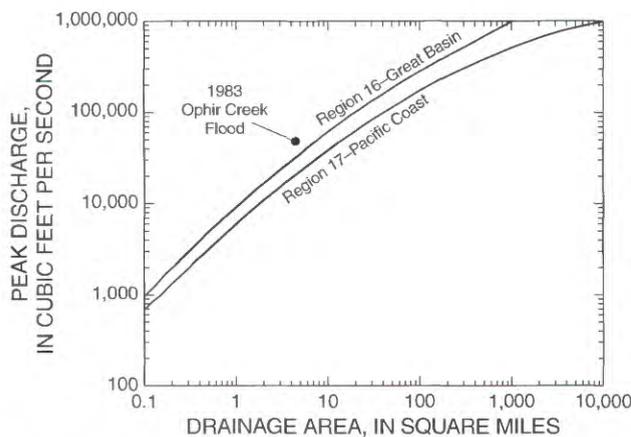
Substitution of the peak-flow rate of 50,000 ft<sup>3</sup>/s in a rearrangement of the Manning equation allowed the calculation of the Manning  $n$  (empirical roughness coefficient) as a total flow-resistance factor (combined boundary and internal resistance); the calculated value of  $n$  was 0.10. This value implies that the field-estimated boundary friction of 0.05 was roughly equivalent to the internal flow resistance. The most probable cause of internal flow resistance, based on eyewitness

descriptions of the nature of the peak-flow surge, would have been intragranular friction caused by particle collisions. However, more subtle causes, including liquid viscosity and grain friction, probably also played important, and possibly dominant, roles (Iverson and La Husen, 1993, p. 1606).

The estimated magnitude of the 1983 Ophir Creek flood (50,000 ft<sup>3</sup>/s) also can be compared to maximum floodflows that historically have been documented for this geographic region. Ophir Creek is situated generally on the boundary between the Pacific Coast and Great Basin geographic regions (Fenneman, 1931). Envelope curves for these geographic regions depicting relations of peak floods to drainage-basin areas are based on historical data collected within these regions (Crippen and Bue, 1977). Figure 38 shows the magnitude of the 1983 Ophir Creek flood (drainage area 4.5 mi<sup>2</sup>) relative to Crippen and Bue's peak-flood envelope curves for the Pacific Coast and Great Basin regions. Although the curves of Crippen and Bue are not based on floods resulting from the sudden release of ponded water (Crippen and Bue, 1977, p. 2), the relation shown in figure 38 nonetheless provides an added perspective on the severity of the 1983 Ophir Creek flood.

### Rates on the Alluvial Fan

Notable deceleration of the floodflow downstream from the mouth of the lower canyon of Ophir Creek is indicated by abundant and areally extensive



**Figure 38.** Envelope curves for maximum measured floods in relation to the 1983 Ophir Creek flood, western Nevada, (modified from Crippen and Bue, 1977, figs. 18 and 19).

sediment deposits. Estimates of flow velocities downstream from the lower canyon of Ophir Creek are based on eyewitness accounts (app. B). Kenneth Julian observed the flow front as it approached the U.S. Highway 395 freeway from his vantage point in the southbound lane (KJ, fig. 27). Average velocity of the approaching mud, which continued to flow after boulder movement ceased upstream on the alluvial fan near the Cline and Stafford homes (fig. 31), was estimated to be in the range of 4 to 11 ft/s on the basis of Julian's observations. He also noted that the fluid (mud) front was 4 to 5 ft thick and in appearance had a consistency that resembled freshly mixed concrete.

Charles McQuerry, also on the freeway (fig. 27), recorded the flow of the viscous fluid with a video camera from his vantage point (app. B). A surface velocity of about 5 ft/s was estimated for the fluid flow near the freeway, based on the rate at which vehicles and other debris were moved by the flow as they approached the freeway, as shown by McQuerry's video recording. McQuerry's precise location on the freeway during video filming is uncertain but generally was east-south-east of the Cline and Stafford homes and north of the Ophir Creek diversion beneath the freeway, as shown in figure 27.

On the basis of Reed Dopf's observations as he drove southward along the freeway (app. B and fig. 2), average velocity of the fluid (mud) front downstream from the terminus of boulder deposits near the Cline and Stafford homes to the freeway was estimated at 2-5 ft/s. Dopf also watched the muddy fluid move southward parallel to the freeway (fig. 3B) during his continued southward travel. Figure 39 shows the nearly vertical flow front of the viscous mass, laden with tree parts, as it flowed slowly near its journey's end. Dopf's ability to walk backward easily at a speed equal to that of the leading edge of the flow indicates a fluid velocity there of only a couple of feet per second.

In spite of the lack of agreement between some of the eyewitness accounts regarding specific velocities on the Ophir Creek fan, the flow clearly was moving only a fraction of the velocity ascribed to the leading flow surge throughout its journey from Price Lakes to Old Highway 395. The velocity decrease throughout the distal reach of the fan is largely caused by the flattening of the surface gradient (about 2 percent or less; fig. 6), and the spreading and directional change of the flow.

The flow rates and velocities described and discussed above are summarized in table 6.



**Figure 39.** Viscous, organic-laden leading edge of floodflow from Ophir Creek, western Nevada, advances southward at about 2 feet per second, parallel to the southbound lanes of U.S. Highway 395 freeway, as photographed by Reed Dopf on May 30, 1983.

**Table 6.** Summary of estimated flow rates and velocities of the May 30, 1983, peak-flow surge in Ophir Creek, western Nevada

[Symbol: --, no data available]

Channel site or reach (fig. 2)	Estimated discharge (cubic feet per second)	Estimated velocity (feet per second)	Information source
Upper Price Lake to Old Highway 395	--	28-32 (average)	Eyewitness accounts, map distances, and time of power outage
Outlet of Lower Price Lake	6,000-20,000, or greater	15-50, or greater	Indirect flow measurements from field evidence
Mouth of upper canyon	--	29-44	Eyewitness account
Mouth of lower canyon	50,000	average about 25	Indirect flow measurements from field evidence and verification by analytical comparisons and eyewitness accounts
0.2 mile below Old Highway 395 to U.S. 395 freeway	--	4-11	Eyewitness accounts
Parallel to U.S. 395 freeway near junction of flow and freeway	--	5	Evidence in videotape recording
Parallel to U.S. 395 freeway about 0.5 mile south of junction of flow and freeway	--	2 or less	Eyewitness account

## Discussion

The summarized discharge estimates of table 6 indicate the likelihood of a large increase in the peak-flow rate between the outlet of Lower Price Lake and the mouth of the lower canyon of Ophir Creek. This apparent amplification of the flood peak is contrary to most floods that originate from a point source; in fact, attenuation of the peak flow in a downstream direction is commonplace. The flood surge was virtually devoid of coarse-grained sediment when it passed the outlet of Lower Price Lake. It quickly amassed a significant coarse-grained component, including numerous boulders and trees, as it swept through the steep upper canyon. Rapid growth of the sediment load during transit compounded the size and intensity of the leading edge of the flow, which also was the peak of the flood. Entrainment of sediment and debris at the flow front continued downstream except for limited deposition between the upper and lower canyons. Frictional resistance of the boulder-laden front probably had a retarding effect on the flow so that the trailing fluid phase could overrun the bouldery front. The net effect of interactions between the bouldery front and the more mobile fluid phase was probably a compounding of the magnitude of the peak-flow front. The mass of debris and water probably assumed the flow characteristics of a growing, moving dam as it travelled down the channel. The erosive gouging by the bouldery front progressively increased the debris load, and the overriding tendency of the impounded fluid behind the front probably functional in concert to progressively increase the magnitude of the leading peak-flow surge. By the time it reached the mouth of the lower canyon, the peak flow probably attained its peak destructive potential—a discharge of about 50,000 ft<sup>3</sup>/s, a mean velocity of about 25 ft/s, and was dominated by a large mass of entrained boulders and trees. As the flow then swept downstream over the alluvial fan, it transformed from the erosional character that dominated flow in the canyons to a dominantly depositional mode and progressively spread laterally and decreased in velocity, volume, and destructive potential throughout its roughly 1 to 1.5-mi terminal reach.

## DEBRIS MOVEMENT

Debris mobilization, transport, and deposition were key elements of the 1983 Ophir Creek flood. Debris is the rock-derived sediment, of widely varying particle sizes, and vegetal material incorporated and transported by the flood. Visual characteristics of the

flood, as well as resulting landscape changes and impacts on man, were largely the result of debris movement. The processes and characteristics of debris movement, and the significance of large quantities of debris transport by the May 30, 1983, flood are variously discussed throughout this report. These discussions are necessary because debris movement played a key role in different aspects of the evolution of flood events. The following discussion focuses mainly on aspects of debris transport not previously discussed, and summarizes information about debris movement that appear elsewhere within the report.

### Landslide Debris

The landslide that initiated the flood furnished little debris to the water expelled from the Price Lakes Basin. Most of the landslide mass was deposited along the path of the slide upslope from the lake, on the bed of the northern half of Upper Price Lake, or around the immediate margins of the northeast lakeshore (figs. 14 and 20). Some fine-grained sediment from the slide mass may have been incorporated within the floodflow, but the amount was small compared to the total mass of the slide or to the amount of channel debris eroded downstream by the flood. Figure 22 shows that the flow exiting the lakes carried enough dark-colored, fine-grained sediment to discolor the snowpack, but the flow did not completely dissolve or erode the snowpack.

### Canyon Debris

Floodflow leaving Lower Price Lake was dilute and was transporting a relatively light sediment load; however, the flow was capable of mobilizing large amounts of debris based on water volume, flow rate, and channel characteristics of the upper canyon of Ophir Creek (figs. 5, 6, and 7). The absence of evidence of heavy sediment entrainment in the flow leaving Lower Price Lake contrasts sharply with the appearance of entrained debris as the dominant flow component as witnessed by the Willets only 0.6 mi downstream at the upper canyon mouth (app. B and fig. 2).

The rapid increase in debris transport throughout the relatively short (0.6 mi, fig. 6) reach of the upper canyon, described earlier, was the combined result of a dynamically erosive flow process through a channel highly susceptible to erosion. The leading flow surge of the flood in the upper canyon of Ophir Creek was witnessed by hang glider Doug Cook (app. B and

fig. 2). He noted that the confinement of flow caused the flow to accumulate debris. He saw trees getting plowed down, and estimated a 40 to 50 ft height for the surge. James Schumacher photographed the flow in the upper canyon (fig. 23).

The process of debris mobilization in the upper canyon is probably best portrayed as a variation of the "firehose effect" described by Johnson and Rodine (1984, p. 329). They describe this process generally as the energetic force of a high-speed stream of water that impacts, disperses, and thereby mobilizes large masses of debris, ideally in steep channels or in bedrock chutes. This description characterizes the incorporation of debris within the upper canyon of Ophir Creek immediately downstream from Lower Price Lake. However, Johnson and Rodine restrict this mechanism to the special site condition of very steep talus slopes, and they imply that this erosive process is usually the result of intense rainstorms; these restrictions do not fit the Ophir Creek flood. Thus, the Ophir Creek process might be called a "channel firehose effect" wherein an abrupt surge of high-velocity streamflow incorporates and sweeps movable debris along its path. The flow leaving Lower Price Lake, deficient in entrained sediment and possessing high kinetic energy, impacted the poorly consolidated landslide debris bounding the steep channel of the upper canyon. An action view of this process is shown in figure 23. The "firehose effect" nomenclature, as specified by the Johnson and Rodine definition, also is inadequate because the erosive streamflow never encountered and was not confined by a steep bedrock chute, as specified in their criteria; instead it was confined by a steep and relatively narrow canyon consisting of highly erodible, unconsolidated debris. The canyon walls are steep and easily destabilized by energetic streamflow, and the debris thus mobilized was progressively and cumulatively incorporated within the fluid flow by bulking. The downstream increase in mass, and also possibly in velocity, caused momentum to increase, as noted by hang-glider pilot Doug Cook. Thus, flow transformation was an ongoing process as sediment content changed rapidly during evolution of the flood.

The Willets (app. B and fig. 2) describe characteristics of the flow as it exited the upper canyon and moved through the intercanion reach upstream from the lower canyon. Their descriptions characterize the leading flood surge as strongly erosive. Postflood evidence shows the intercanion reach also to be an area of net sediment deposition. The photograph taken by James Schumacher in the intercanion reach (fig. 24),

about 10-15 minutes after his upstream photograph (fig. 23), depicts sediment transport in a somewhat different mode than that portrayed in the preceding photograph. The bulk of sediment deposited in the intercanion reach may have come to rest during recessional flow; the precise sequence of events is uncertain.

The leading flow surge entered the lower canyon of Ophir Creek after passing through the intercanion reach. Postflood evidence indicates that severe erosion continued throughout the transit of the lower canyon, thereby compounding the bulking of sediment by the floodflow. Mark Bridgewater (fig. 2) viewed progress of the leading flood surge through the lower canyon and was impressed by its speed and described its appearance as a deep, soupy mud or sludge (app. B). He also was impressed by the degree of super-elevated flow around bends and the destructive impact of the flow on trees in its path.

The 1983 flood severely altered the channel morphology of Ophir Creek, as shown in aerial photographs taken before and after the flood (figs. 3 and 11). A preflood, cross-sectional channel profile was surveyed near the mouth of the lower canyon in 1973 as part of a U.S. Geological Survey investigation of potential flood-and-debris hazards (Glancy and Katzer, 1977). The measurement was made to define the width of the channel that would be inundated and the accompanying depths of inundation that should be expected during a 100-year flood. The site selected for measurement was about 0.15 mi upstream from the proximal limit of development on the Ophir Creek alluvial fan (fig. 27). This documented channel morphology subsequently served as a baseline for comparison of channel changes wrought by the 1983 flood. The site of the 1973 topographic profile was remeasured in October 1983 to determine changes in channel morphology caused by the flood (fig. 37). Preflood sloughing of the steeply sloping south canyon wall occurred between 1973 and 1983. Although the magnitude of this sloughing was minor in comparison to channel erosion by the flood, it removed the monument marking the end-point of the 1973 profile and some channel-wall sediment. However, the alignment of the 1973 profile was substantiated using a 1973 photograph of the profile scene.

The cross-sectional profiles (fig. 37) measured at the mouth of the lower canyon before (1973) and after (1983) the flood show that a substantial quantity of debris was eroded from the south canyon wall by the flood. The south wall forms the outer bank of a gentle curve in the channel which, combined with the steep slope and poorly consolidated debris comprising the

hillslope, promoted erosion. In contrast, the north bank, located on the inside of the curve, was the site of sediment deposition by the 1983 flood (figs. 26 and 37). Recessional floodflow and the abundant spring and summer snowmelt runoff reworked the channel flood deposits south of the boulder berm, shown in figures 26 and 37, and entrenched the active channel. Interestingly, the 1973 profile shows what may have been the relict of a berm on the flood plain. If so, it may have been deposited by the major flood of July 6, 1890 (app. A). The 1983 profile does not show the maximum depth of scour that may have resulted during the 1983 flood.

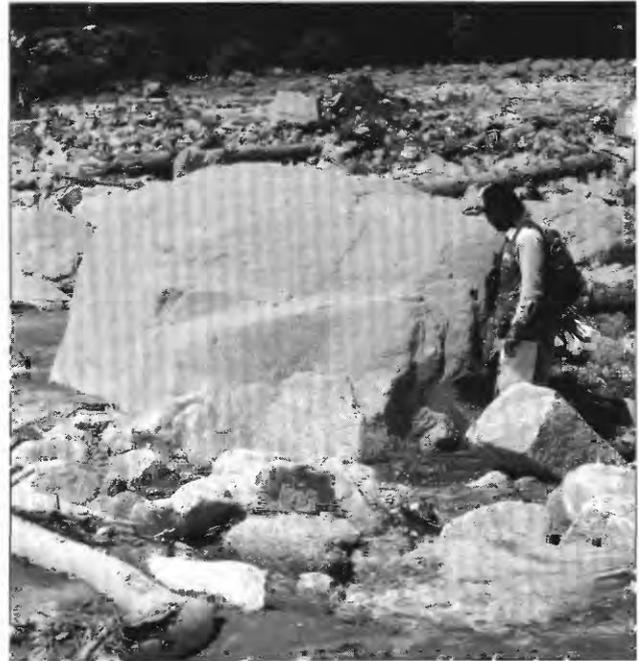
The leading flow surge began to transform from an agent of mainly erosion to one of deposition downstream from the mouth of the lower canyon. At this stage of its evolution and because of the entrained debris load, it posed a dual threat as it encountered human development—the potential to destroy by impact and (or) burial.

The 1983 flood incorporated and transported large quantities of sediment in the canyon reaches that ranged widely in its particle-size composition. Boulder movement was common, and many large boulders were moved into the human-occupied zone downstream from the lower canyon mouth. Evidence and characteristics of boulder movement are shown in many of the figures in this report. The largest boulder known to have been moved by the flood measures 6x8x12 ft (fig. 40); its point of origin is unknown, but its postflood location at the surface of deposits up to 9 ft thick atop Old Highway 395 is proof of movement. The boulder weighed several tens of tons, which attests to the phenomenal energy and power of the flood.

## Erosion

The rapid entrainment of sediment within the upper canyon resulted from the high turbulence and velocity (probably greater than 20 ft/s) of the streamflow, and the susceptibility of the channel boundaries to erosion. Both lateral and vertical channel scour were pervasive throughout the upper and lower canyons of Ophir Creek (figs. 7 and 8). The scour essentially removed the dense channel vegetation totally, as documented by photographs taken before and after flooding (figs. 3 and 11).

The volume of sediment eroded from canyon reaches was difficult to determine using preflood and postflood aerial photography. The preflood vegetal



**Figure 40.** Largest boulder known to have been moved by 1983 flood, Ophir Creek, western Nevada. Boulder, measuring about 6x8x12 feet, came to rest on downstream side of Old Highway 395. June 3, 1983. Photograph by Patrick A. Glancy.

cover within the channel masked the underlying topography and prevented an after-the-fact quantitative assessment of volume changes by comparisons with postflood evidence of erosive scarring. Also, the cross-channel profiles of figure 37 indicate that the net morphology of the streambed resulting from the flood was probably a complex product of both erosion and deposition. The total depth of channel scour by the flood was not discernible because of sediment backfilling during the recessional stage of the flood. Thus, the morphological evolution of the active channel resulting from flooding was difficult to ascertain after the event. However, an estimate of the net volume of sediment eroded was obtained from an estimate of the volume of sediment deposited by the flood.

## Sediment Deposition

Major areas of sediment deposition include (1) the relatively wide channel reach between the upper and lower canyons (intercanyon reach) and (2) the Ophir Creek alluvial fan below the mouth of the lower canyon. Sediment deposited by the flood recession is spread along the bed of the upper and lower canyons of Ophir Creek. The area of these deposits can be

measured, but their thickness is uncertain. However, these recessional deposits are believed to be volumetrically small compared to those within the major depositional zones listed above.

## Volume

### Intercanyon Reach

The intercanyon depositional reach is partially shown in figure 11. This reach was reconnoitered on August 27, 1983, to assess the volume of sediment deposition. The deposits had an irregular surface and thickness. Postflood erosion of the deposits by snowmelt runoff exposed the variability in thickness along the main channel thalweg. Figure 41 shows the typical character and thickness of these key deposits. The depositional character of the sediments includes a lack of stratification and a presence of matrix support of the coarser clasts. The average deposit thickness throughout this reach was estimated to be about 3 ft; average width of the reach was estimated to be about 200 ft; and the length of the reach, scaled from aerial photographs of June 6, 1983, is 3,000-3,200 ft. The total volume of the deposits is estimated to be 42 to 45 acre-ft (table 7).



**Figure 41.** Unstratified and unsorted debris deposited by the 1983 flood on broad flood plain between the upper and lower canyons of Ophir Creek, western Nevada. Deposit was exhumed by recessional floodflow and later spring-snowmelt runoff. Hammerhead rests on pre-flood surface. Hammer length, about 1 foot. Photograph by Patrick A. Glancy on August 27, 1983.

### Alluvial Fan

Deposits on the Ophir Creek alluvial fan (fig. 10) begin at the mouth of the lower canyon and extend downstream to Washoe Lake (frontispiece). Figure 42 shows the significant areas of deposition on the Ophir Creek fan as determined by field observations. On the basis of varying thicknesses of deposits, the depositional zone on the fan was divided into three categories. Areas were mapped and planimetered, and average thicknesses were multiplied by the planimetered map areas to determine sediment volumes (table 7).

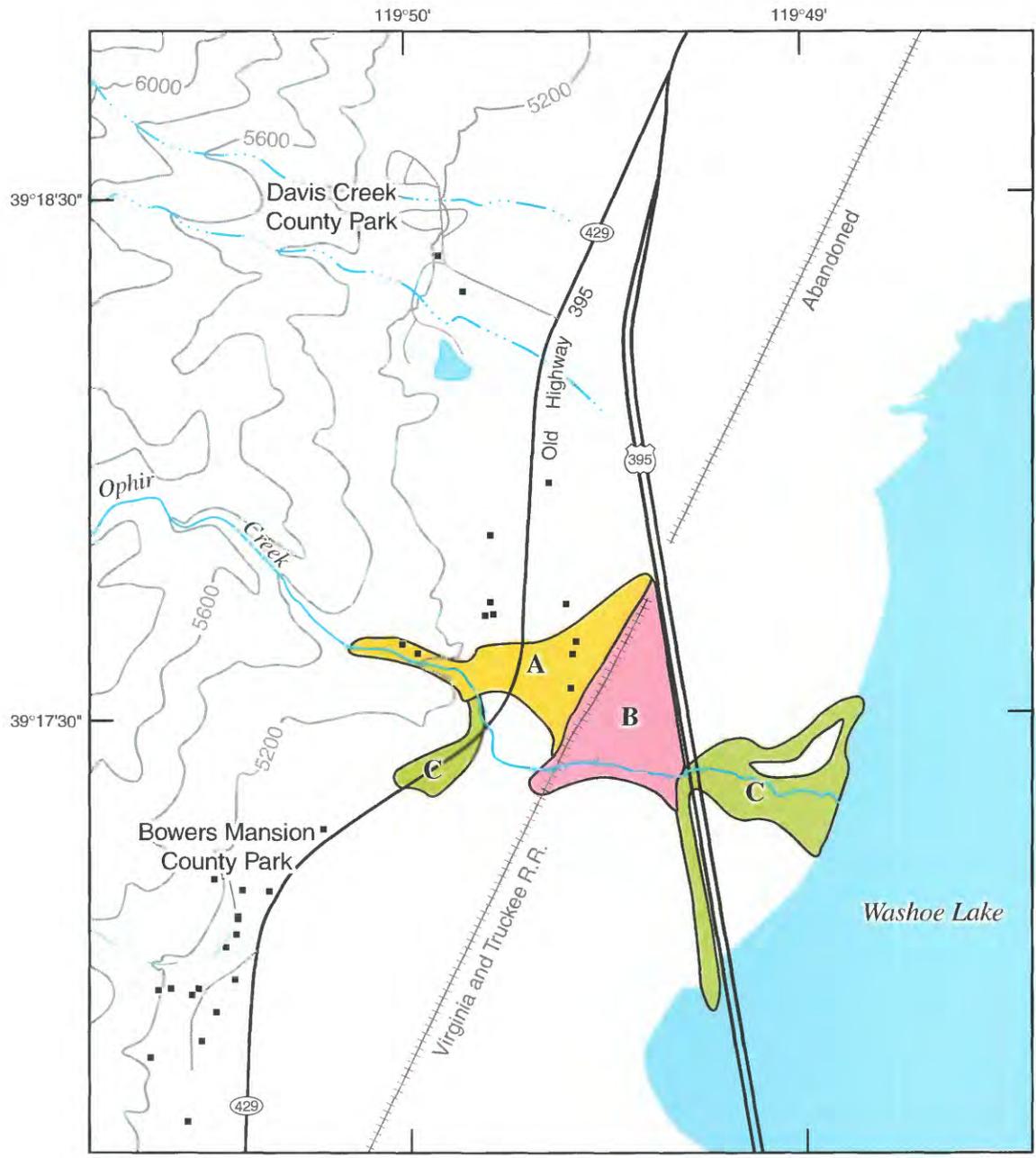
The total area of deposition on the Ophir Creek fan is about 140 acres, and the cumulative volume of sediment deposits is estimated to be about 400 acre-ft.

### Total

The approximate volume of sediment deposited by the flood is therefore estimated as the cumulation of intercanyon and alluvial fan deposits, or about 450 acre-ft. This estimate is inherently conservative because the volume of debris deposited in the canyons by flood-recessional flows was not determined.

**Table 7.** Estimated areas and volumes of sediment deposited by the May 30, 1983, Ophir Creek flood, western Nevada

Area (fig. 42)	Land-surface area (acres)	Average depth of deposits (feet)	Sediment volume (acre-feet)
Area A of Ophir Creek fan	43	5	215
Area B of Ophir Creek fan	48	3	144
Area C of Ophir Creek fan	49	1	49
Subtotal	140		400 (rounded)
Intercanyon reach between upper and lower canyons	14-15	3	42-45 (about 50)
		Total	450 (rounded)



Base from U.S. Geological Survey, 1:24,000 quadrangles: Mt. Rose, Nev., 1968 and Washoe City, Nev., 1974

0 1/2 MILE  
0 1/2 KILOMETER  
Contour interval 200 feet  
Datum is sea level.

**EXPLANATION**

**Approximate average thickness of sediment deposits in designated areas, in feet**

A	5
B	3
C	1

**Figure 42.** Major areas of sediment deposition by the 1983 flood on Ophir Creek alluvial fan, western Nevada. Sampling sites shown in figure 43 and results of analyses listed in table 8.

Additional perspective on the flooding process is gained when the volume of sediment deposited by the flood (450 acre-ft) is compared to the estimate of the volume of water released from Price Lakes (22 acre-ft). The bulk volume of sediment deposited by the flood, uncorrected for intergranular porosity, is greater than 20 times the volume of water that initiated the flood. Additional sources of water incorporated in the flood are discussed in the section "Flood Volume and Water Sources."

### Sediment Particle-Size Characteristics

Information regarding the distributions of sediment particle sizes in flood deposits improves the understanding of hydraulic-behavioral characteristics of floodflows. Sediment deposits were sampled after the flood at four sites (fig. 43) to characterize particle-size distributions within the deposits. Detailed particle-size data are listed in appendix C, and these data are summarized in table 8. Samples 1 and 2 are duplicates collected from a single site, as are 3 and 4. Photographs of the deposits yielding samples 1-4 (figs. 41 and 44) show the sediment to be unstratified and largely composed of matrix-supported cobbles and boulders.

Abundant large clasts (cobbles and boulders up to 10 ft in diameter, some weighing tons, fig. 40) within the two upstream deposits (figs. 41, 43, and 44) complicated sampling procedures and effectively prevented a true characterization of particle-size distribution within those deposits; therefore, only matrix materials (pebbles and finer grained sediment) of those deposits were sampled (samples 1-4). Samples 5 and 6 were collected from deposits that contained particles no larger than pebbles (particles less than 64 mm diameter); those

samples from the two downstream sites (figs. 45 and 46), thus, characterize the complete deposits rather than just the finer-grained matrix components.

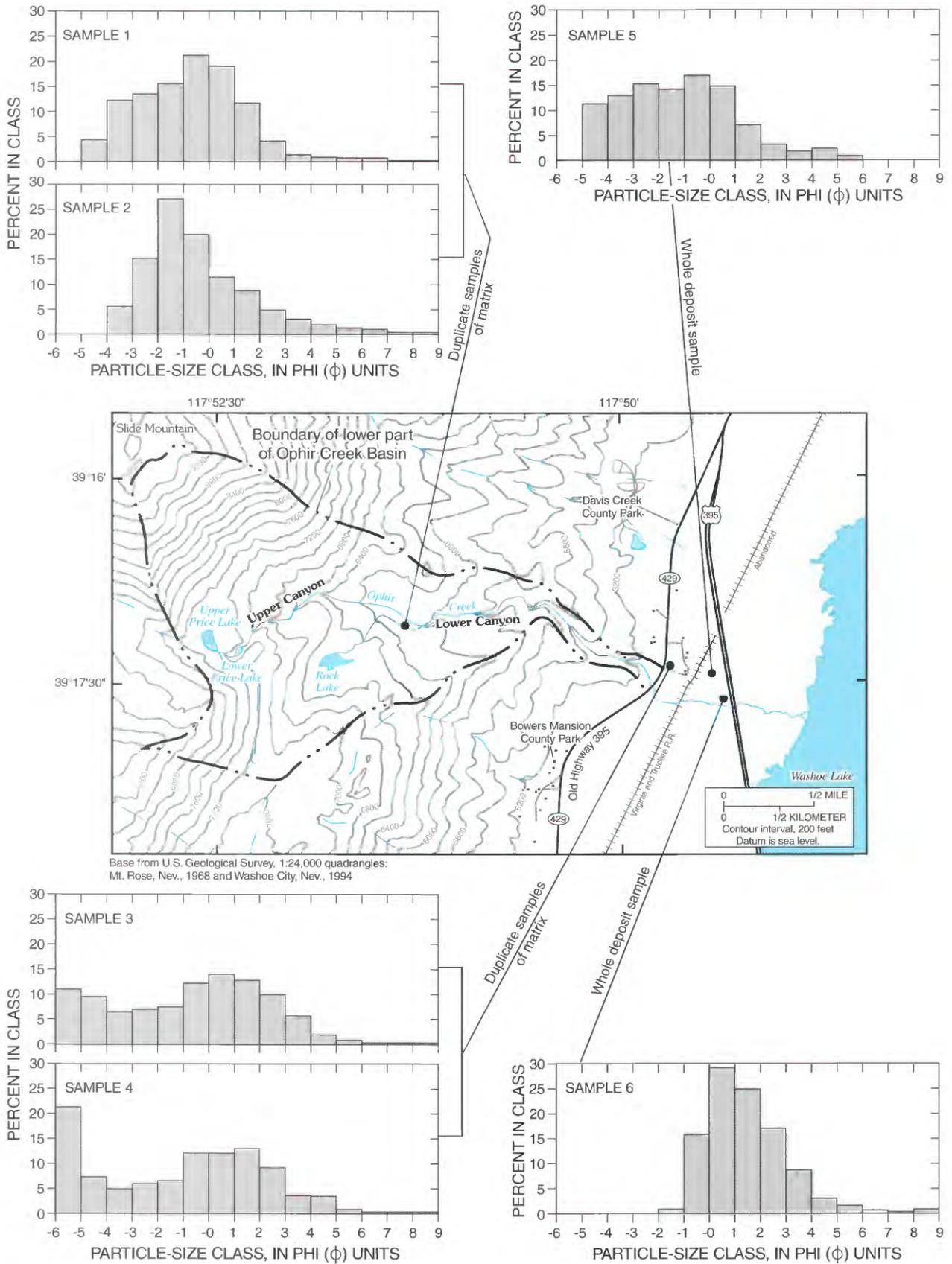
Particle-size distributions of the samples are graphically portrayed by cumulative curves (fig. 47) and histograms (fig. 43). The histograms show samples 3 and 4 to be bimodally distributed, and sample 5 appears to be weakly trimodal. If the coarser grained (cobble and boulder) components of the deposits represented by samples 1 to 4 could have been included in sampling, they might have contributed to a higher level of multimodality. The multimodal character of samples 3 to 5 also is reflected by the multiple inflections shown by their respective cumulative curves (fig. 47).

A minimal quantity of clay-size sediment (particle diameters, less than 0.004 mm) is a common characteristic of all particle-size samples (table 8 and fig. 43). The absence of clay reflects the dominance of physical weathering over chemical weathering in the source materials (granodioritic landslide deposits) and may therefore indicate a relatively young geologic age for the landslide deposits. The overall paucity of clay-size material (much less than the 3 to 5 percent lower limit) characterizes the debris transported by this flood as generally non-cohesive (Scott and others, 1995, p. 8). The total percentage of clay-size material in the proximal deposits is even less than that shown by the data (samples 1-4) because the matrix materials sampled for those deposits comprises only fractions of the total volumes of the deposits. The bulk of the fine-grained sediment of the sampled flood deposits generally can be characterized qualitatively as pebbly sand (table 8).

**Table 8.** Summary of particle-size data from sediment deposits, Ophir Creek Basin, Nevada

Sample no. <sup>1</sup> (fig. 43)	Percentage of weight in size, in millimeters (mm) and phi (φ) units					
	Pebbles (64-4 mm, -6 to -2 φ units)	Granules (4-2 mm, -2 to -1 φ units)	Sand (2-0.0625 mm, -1 to 4 φ units)	Silt (0.0625-0.004 mm, 4 to 8 φ units)	Clay (finer than 0.004 mm, finer than 8 φ units)	Mud: silt and clay (finer than 0.0625 mm, finer than 4 φ units)
1	28.6	15.1	54.8	1.1	0.4	1.5
2	20.3	26.9	47.6	3.9	1.3	5.2
3	34.3	7.6	55.0	2.7	.4	3.1
4	39.7	6.5	49.2	4.3	.3	4.6
5	39.5	14.3	43.3	2.6	.3	2.9
6	0	1.0	93.9	4.3	.8	5.1

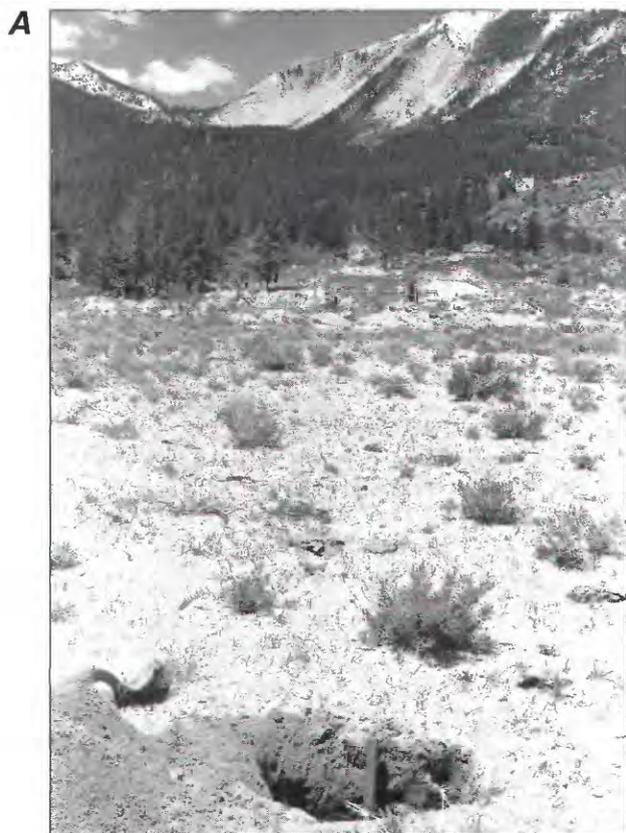
<sup>1</sup> Detailed particle-size-distribution data for these samples are in appendix C.



**Figure 43.** Locations of sediment sampling sites and histograms of particle-size distributions of sediment sampled, Ophir Creek Basin, western Nevada.

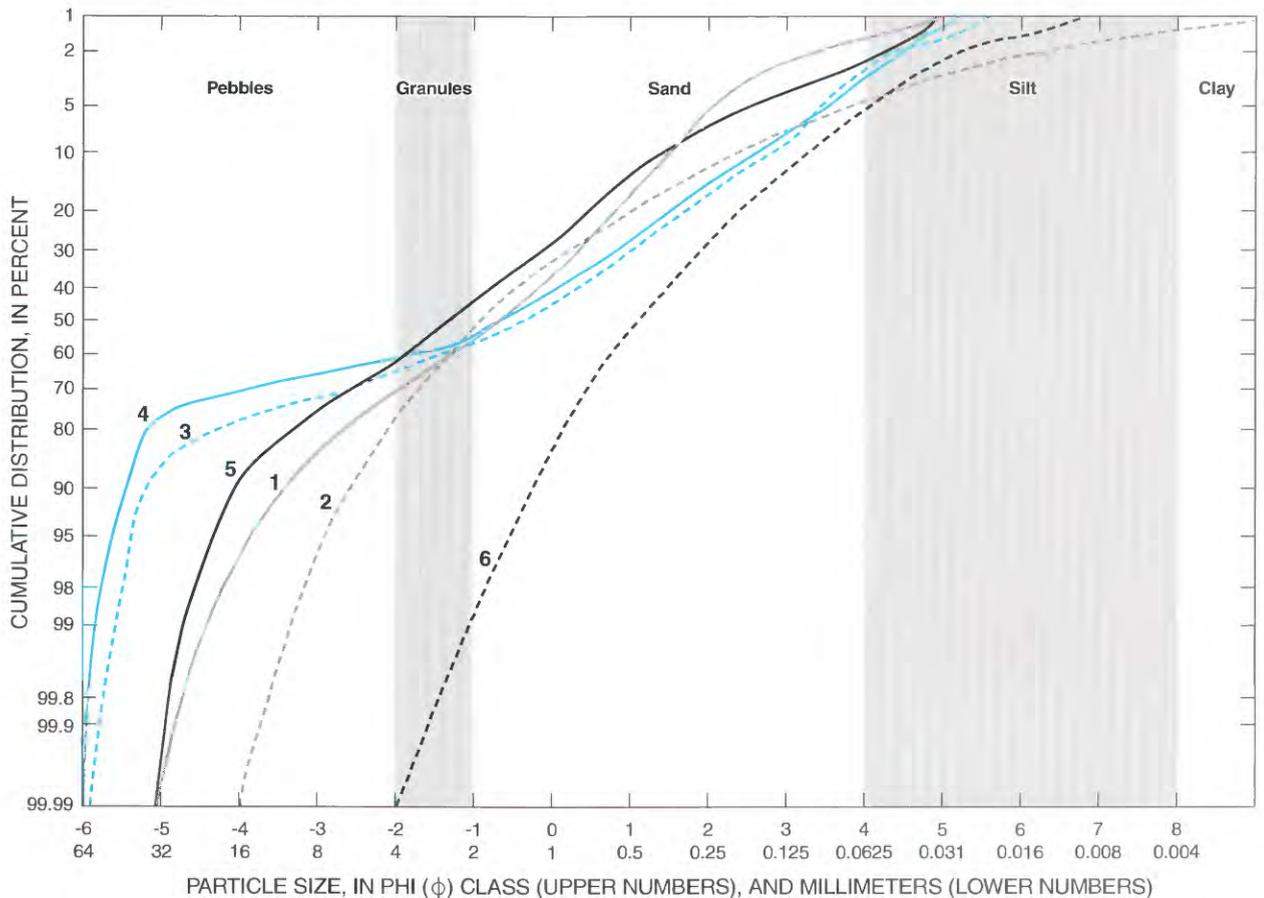
**A****B**

**Figure 44.** Freshly exhumed debris deposits of May 30, 1983, flood on Stafford property just downstream from Old Highway 395, western Nevada. *A*, Northward view of 7-foot-thick deposit. *B*, Northwestward view showing black organic-rich zone (white arrow) on pre-flood land surface, and freshly dug scars (black arrows) marking sites of sediment samples 3 and 4. Shovel length, 4-1/2 feet. Photographed by Patrick A. Glancy, November 16, 1990.



**Figure 45.** Collection site of sediment sample 5 (fig. 43). A, Westward view of Ophir Creek fan, western Nevada; Stafford home in background; sample pit in foreground. B, Sample 5 collected from back and bottom of pit. Pick length, 1-1/4 feet. Flood deposit is several feet thick.

**Figure 46.** Collection site of sediment sample 6 (fig. 43). A, Southwestward view of Ophir Creek fan, western Nevada; shovel in sample pit, 4-1/2 feet long. B, Westward view of sample pit; sample 6 collected from backside of pit about half a foot below land surface; pick length, 1-1/4 feet. Base of deposit is less than 1 foot below pit bottom. Photographed by Patrick A. Glancy on May 22, 1991.



**Figure 47.** Cumulative distribution of particle sizes for samples of sediment deposits, Ophir Creek Basin, western Nevada. Numbers 1–6 are sample numbers (collection sites shown in fig. 43). Particle-size information in tables 8, 9, and appendix C.

Graphic statistics (Folk, 1980) derived for the particle-size data (table 9) indicate that sampled sediment components of the floodflows were all poorly sorted. Implications of this generally poor sorting are discussed later with regard to flow dynamics of the depositing fluids.

## FLOOD VOLUME AND WATER SOURCES

The importance of the sudden release of about 22 acre-ft of water from Price Lakes in the initiation of the flood May 30, 1983, in Ophir Creek and the subsequent downstream flow rates and velocities of the peak flow surge were discussed earlier. However, the approximate 22 acre-ft of water released from the lakes represents only a fraction of the total volume of the flood. For example, the "Sediment Deposits" section of this report documents the cumulative volume of flood sediment deposits to be about 450 acre-ft (table 7). Few data are available to allow assessment of floodflow volumes

because of the absence of streamflow gages on Ophir Creek. However, several streamflow measurements and estimates made before, during, and after the flood (discussed below) provide a quantitative perspective on the timing and cumulative volume of floodflow.

## Volume

The flood surge at the lower canyon mouth reached an estimated peak-flow rate of about 50,000 ft<sup>3</sup>/s almost instantaneously and receded greatly within seconds, as described earlier. The exact magnitude of Ophir Creek flow just prior to the flood is unknown, but eyewitness Tom Reed (app. B and fig. 2) recalls the flow as about twice that of "normal flow." Tim Miller, a companion of Reed, noticed that the creek was flowing faster than normal, but the flow was not great enough to be frightening. Washoe County hydrologists measured the flow of Ophir Creek at about 60 ft<sup>3</sup>/s just downstream from Old Highway 395 at about 2:00 p.m.

**Table 9.** Statistics for particle-size data from sediment deposits, Ophir Creek Basin, Nevada<sup>1</sup>

Sample no. <sup>3</sup> (fig. 43)	Mean size (M <sub>z</sub> )		Median size (M <sub>d</sub> )		Sorting coefficients			
	Phi unit	Milli-meters	Phi unit	Milli-meters	S <sub>o</sub> Trask <sup>2</sup>	Standard deviation	Inclusive standard deviation	Inclusive skewness
						σ <sub>G</sub> phi unit	σ <sub>I</sub> phi unit	S <sub>k</sub> phi unit
1	-0.87	1.87	-0.70	1.70	2.6 Well sorted	2.00	1.93 Poorly sorted	-0.09 Near symmetrical
2	-.50	1.50	-.85	1.80	2.3 Well sorted	1.92	2.05 Very poorly sorted	.31 Strongly fine-skewed
3	-.80	1.80	-.20	1.20	5.36 Poorly sorted	3.40	3.06 Very poorly sorted	-.21 Coarse skewed
4	-1.45	2.45	-.80	1.80	7.54 Poorly sorted	3.85	3.49 Very poorly sorted	-.20 Coarse skewed
5	-1.32	2.32	-1.30	2.30	3.07 Normal	2.28	2.30 Very poorly sorted	.03 Near symmetrical
6	1.27	.47	1.20	.45	1.92 Well sorted	1.40	1.42 Poorly sorted	.22 Fine skewed

<sup>1</sup> Equations used to calculate grain-size statistics and rating criteria are in appendix C.

<sup>2</sup> Trask (1932) sorting coefficient considered obsolete, but included here for comparison with results of other investigations.

<sup>3</sup> Samples 1 and 2 collected at same site; samples 3 and 4 collected at same site.

on May 26, 1983 (Michael Widmer, Washoe County Public Works Department, written commun., 1983), well into the warming trend that began about May 20 (table 5). For comparison, the previous measurement recorded by Washoe County personnel, about noon on May 19, was only about 22 ft<sup>3</sup>/s. This earlier and lower flow rate coincided with considerably cooler weather that preceded the sudden heat wave of late May (table 5). They next measured it about 2:30 p.m. on June 3, 1983, at the same site, and it was flowing about 65 ft<sup>3</sup>/s. Robert Squires and Otto Moosburner (U.S. Geological Survey, written commun., 1983) also measured the flow on June 3, time unknown, at 77 ft<sup>3</sup>/s. The continuing heat wave during May 27-29 probably amplified rates of the diurnally fluctuating streamflow. However, the recollections of Reed and Miller and the measurement data of May 26 and June 3 indicate that flow during the late morning of May 30 was probably less than 100 ft<sup>3</sup>/s; we speculate that it was possibly around 80 ft<sup>3</sup>/s shortly before flooding.

The flood reportedly continued intensively for several hours (app. B), probably longer, even though the initial and most damaging surge was over in a few minutes, or less. James Schumacher's photographs of the flood (figs. 23 and 24) were taken about 10 to 15 minutes apart. William and Elizabeth Willets recall watching the flood for about 20-25 minutes between

the upper and lower canyons. Vic Stafford remembered heavy flow across his land for about 3 hours, with the most intense flooding lasting about 45 minutes. Susan Graves recalled the intense audible roar of the flood lasting at least 10 minutes. The preponderance of eye-witness testimony suggests that elevated stream discharge continued for a considerable time after the damaging leading edge of the flow had passed.

The prolonged recession of the flood was quantitatively verified by onsite hydrologic observations. Otto Moosburner (U.S. Geological Survey, oral commun., 1983) estimated the flow of Ophir Creek at about 400 ft<sup>3</sup>/s, just upstream from Old Highway 395, at 3 p.m. on May 30, 1983, about 3 hours after the peak surge. Views of the flow at about that time are shown in figure 48; however, these photographs do not show the proportion of flow through the manmade diversionary channel (fig. 27) to the south (right) of the area shown in figure 48B. The relatively heavy recessional flow shown in these figures, a few hours after the peak, was poorly confined by a braided, distributary-channel system that developed on the Ophir Creek alluvial fan. Moosburner and Squires (U.S. Geological Survey, written commun., 1983) again estimated the flow at the same site at about 250 ft<sup>3</sup>/s on May 31, at 8:30 a.m.

**A**



**B**



**Figure 48.** Northeastward panorama of boulder- and tree-laden sediment deposits interlaced by recessional Ophir Creek floodflow, at and downstream from Old Highway 395, western Nevada. *A*, Turek home at top left and Cline home near top center. *B*, Part of Cline property at extreme left and Stafford home behind trees at right. Oblique aerial photographs taken by Washoe County Sheriff's Department during afternoon of May 30, 1983.

Flow conditions too hazardous for wading prevented actual streamflow measurements during these times. Figure 49 shows the bulk of the creek flow on the alluvial fan about 27 hours after peak flow. The flow rate at that time is estimated to have been 100 to 200 ft<sup>3</sup>/s; it does not include flow through the manmade diversion to the south (fig. 27). This estimate and the measurement (about 65 ft<sup>3</sup>/s) on June 3 by Washoe County personnel indicate that "normal snowmelt flow" probably resumed sometime around June 3. This return to "normal" flow was enhanced by a cooling trend that began on May 31, as shown by the sudden drop in maximum daily temperatures (table 5). Cooler weather continued for several days and further decreased the snowmelt rate that had accelerated sharply in late May.

The information and data described above, although imprecise and sparse, were used to synthesize a flood hydrograph (fig. 50). The hydrograph was analyzed quantitatively to estimate the duration and volume of the flow (table 10). Results of this approximation indicate that overall, floodflow volume was on the order of 800 acre-ft, and lasted about 5 days. A comparison of floodflow volume to the volume of sediment deposits, adjusted for an estimated porosity of one-third (Morris and Johnson, 1967, table 5, p. D20), indicates that overall the flood was composed of about two-thirds water (530 acre-ft) and one-third solids (270 acre-ft).

A comparison of the estimate of floodflow volume (800 acre-ft) with the sudden release of roughly 22 acre-ft of water from Price Lakes that initiated the flood raises a pertinent question—What was the source of additional water that caused a flood volume of about 36 times that of the initial Price Lakes release?

## Sources

Sources of water that probably supplemented the hastily released contents of Upper and Lower Price Lakes include:

1. Increases in streamflow draining from the headwaters of the Ophir Creek Basin during the 5-day period, upstream from Price Lakes and the landslide area;
2. Ground water that drained from interstices of the regolith mantle and bedrock fractures of the slide material during and following the slide;

3. Streamflow downstream from Lower Price Lake incorporated within the faster moving floodflow;
4. Increased tributary inflow downstream from Lower Price Lake;
5. Ground water contained within interstices of debris scoured from the bed and banks of Ophir Creek;
6. Release of ground water stored within the streambed and banks of Ophir Creek to the channel after debris was scoured away by the flood; and
7. Snow stored atop the slide mass, on and around the lakes, and along the downstream channel of Ophir Creek that was subsequently swept up by the floodflow.

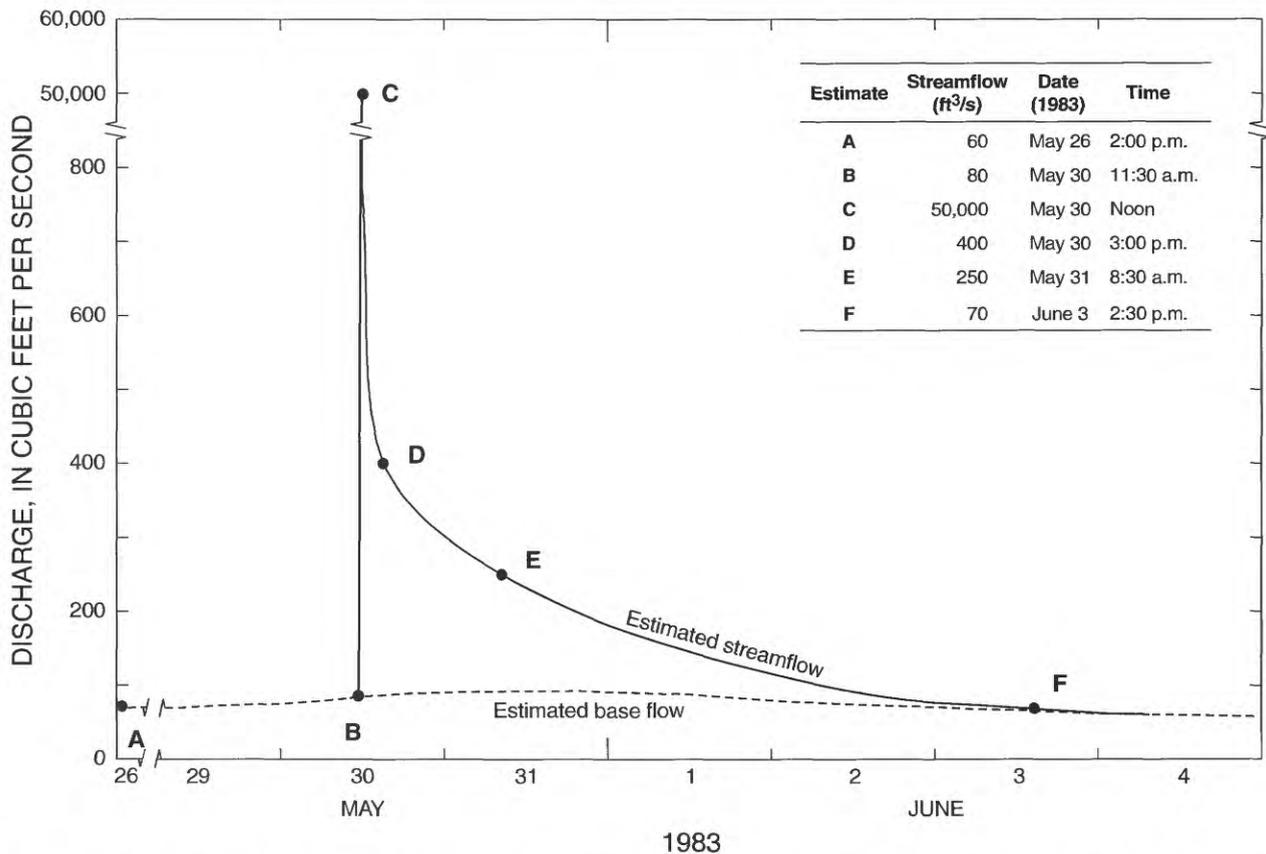
## Source 1

The flow of Ophir Creek upstream from Price Lakes was measured on the morning of May 31 to assess the magnitude of flow coming from the upstream part of the drainage. About 14 ft<sup>3</sup>/s was measured by Kerry Garcia (U.S. Geological Survey), approximately 150 ft downstream from the Mount Rose Highway (State Route 431, fig. 1) at 11:30 a.m. Garcia also noted that the heavy snowpack throughout this upper part of the Ophir Creek drainage did not appear to have been melting as vigorously during recent days as it had been downstream along the east-facing slopes of Slide Mountain (oral commun., 1983). This low-flow rate and the concurrent lack of evidence of accelerated snowmelt upbasin from Slide Mountain further confirms that the major components of floodflow originated near and downstream from Price Lakes.

The minor amount of flow coming from the drainage upstream from Price Lakes also is verified by the oblique aerial photographs that show the freshly exposed bed of Upper Price Lake on the afternoon of May 30 and the morning of May 31 (fig. 51). All drainage from the upper part of the Ophir Creek Basin is flowing across the exposed lake-bed surface. At about the same time of the photographs (fig. 51A and B), Moosburner and Squires estimated flows downstream near Old Highway 395, at 400 and 250 ft<sup>3</sup>/s, respectively. Flow from Upper Price Lake appears to have been minimal compared to that exiting the lower canyon near Old Highway 395.

**A****B**

**Figure 49.** The continuation of recessional Ophir Creek floodflow on the afternoon of May 31, 1983, about 27 hours after the peak-flood surge. *A*, Upstream view. *B*, Downstream view, about 100 yards upstream from Old Highway 395, western Nevada. Photographs by Patrick A. Glancy.



**Figure 50.** Synthetic hydrograph of 1983 Ophir Creek flood, western Nevada. Abbreviation: ft<sup>3</sup>/s, cubic feet per second. Estimate sources: A, Michael Widmer, Washoe County Public Works Department; B, authors; C, indirect measurements by U.S. Geological Survey staff; D, Otto Moosburner, U.S. Geological Survey; E, Otto Moosburner and Robert R. Squires, U.S. Geological Survey; F, Washoe County Public Works Department and Robert R. Squires and Otto Moosburner, U.S. Geological Survey.

**Table 10.** Estimated floodflow volume on alluvial fan, 1983 Ophir Creek flood, western Nevada

[Flow volumes derived from synthesized hydrograph of figure 50 and rounded to reflect confidence in estimation]

Time and date	Streamflow (acre-feet)	Base flow (acre-feet)	Floodflow <sup>1</sup> (acre-feet, rounded)
0000-Noon			
5-30-83 (pre-flood)	80	80	0
Noon			
5-30-83 (30-second peak surge)	20	.06	20
Noon-2400			
5-30-83 (recession)	400	90	300
5-31-83	500	200	300
6-1-83	300	200	100
6-2-83	200	100	100
6-3-83	100	100	0
Total (rounded)	1,600	800	<sup>2</sup> 800

<sup>1</sup>Floodflow is difference between streamflow and base flow.

<sup>2</sup>Sediment deposits of 400 acre-ft (table 7) adjusted for porosity (about 33 percent) result in volumetric proportions of about 530 acre-ft of water (66 percent) and 270 acre-ft of sediment (34 percent); proportions by weight are about 40 percent water and 60 percent sediment.

**A**



**B**



**Figure 51.** Oblique aerial views of the freshly drained bed of Upper Price Lake, Nevada. *A*, Upstream view photographed by Washoe County Sheriff's Department during mid-afternoon, May 30, 1983. *B*, Downstream view photographed by R.L. Jameson, U.S. Forest Service during mid-morning, May 31, 1983.

The combination of measured flow data in the upper basin, flow estimates on the alluvial fan, and photographic evidence of flow into and out of Price Lakes on May 30 and 31 indicates that the Ophir Creek drainage above Upper Price Lake contributed only a minor amount of water to the flood.

### Source 2

Some water contained within the slide mass drained into Upper Price Lake and added to the floodflow. The volume of ground water that potentially drained from interstices of the regolith mantle and bedrock fractures of the landslide mass was estimated as follows:

Landslide volume was approximately 1,400,000 yd<sup>3</sup>, as described earlier. Fracture porosity of the bedrock prior to sliding was probably on the order of 2 to 5 percent (D.E. Prudic, U.S. Geological Survey, oral commun., 1998). Porosity of the regolith mantle was probably about 33 percent (Morris and Johnson, 1967, table 5, p. D20). Intensive snowmelt during several days prior to the landslide assures that the lithic mass was at, or near, saturation prior to the landslide. If the entire mass is assumed to be bedrock, pore volume would range from 17 to 44 acre-ft, on the basis of a 2 to 5 percent porosity range. If the mass is assumed to be all regolith, computed pore volume would be 286 acre-ft. We assumed that two-thirds of the mass was bedrock and one-third was regolith mantle; this assumption yields a computed pore-volume range of 106 to 124 acre-ft. Not all of the entrained water would readily drain from the mass; however, additional water, under artesian pressure prior to the slide, would drain from freshly exposed slide scars. Thus, an estimated 100 acre-ft (rounded) of pore water probably drained from the slide mass during the first few hours following the slide. This drainage helped sustain the debris-flow recession pictured in figure 24.

The photographs of figure 51, however, show no evidence of large-scale drainage from the slide material or the slide scar between 3 and 4 hours after the slide to nearly a day later. If substantial drainage had been taking place for a period of days after the landslide, this flow should be apparent in the photographs showing the exposed bed and outlet of Upper Price Lake. This indicates that ground water draining from the slide contributed to the early period of flood recession but did not contribute significantly after the first few hours.

### Source 3

Downstream movement of the initial flood surge was rapid enough to overrun streamflow in the channel of Ophir Creek and incorporate it into the leading edge of the floodflow. Travel time of the leading edge of the flood between Upper Price Lake and Old Highway 395 was about 8-9 minutes, during which the flood overran streamflow estimated at 80 ft<sup>3</sup>/s. The maximum amount of streamflow incorporated by the flood under those conditions, assuming an average velocity of pre-flood streamflow of 5 ft/s, was estimated, as follows:

$$80 \text{ ft}^3/\text{s} \div 5 \text{ ft/s} = 16 \text{ ft}^2, \text{ average streamflow cross-sectional area;}$$

$$16 \text{ ft}^2 \times 2.3 \text{ mi (distance from outlet of Lower Price Lake to lower canyon mouth; fig. 6)} \times 5,280 \text{ ft/mi} = 194,304 \text{ ft}^3.$$

$$194,304 \text{ ft}^3 \div 43,560 \text{ ft}^3/\text{acre-ft} \cong 5 \text{ acre-ft.}$$

Thus, the flood may have gained up to 5 acre-ft of floodflow by overrunning and incorporating pre-flood streamflow. This volume is less than one-fourth of the estimated contents of Price Lakes. This additional flow contributed mainly to the leading flood surge and added little to the recessional flow.

### Source 4

The atmospheric heat wave undoubtedly caused snowmelt inflow to Ophir Creek from a number of tributary drainages downstream from Lower Price Lake. Because the flow rate of Ophir Creek just downstream from the lower canyon was about 80 ft<sup>3</sup>/s just prior to the flood, and because measured flow of Ophir Creek near the Mount Rose Highway on the morning of May 31 was 14 ft<sup>3</sup>/s, we infer that about three-fourths of the estimated pre-flood downstream flow entered the creek downstream from Price Lakes. Most of that tributary inflow came from the rapidly melting snowpack along the east-facing slopes of the Carson Range, particularly from the south-east-facing slopes of Slide Mountain. Most of the estimated 5 acre-ft of water that was entrained when the leading surge overran pre-flood streamflow was probably tributary inflow derived downstream from Price Lakes (source 3). An increase in snowmelt, and a resultant increase of tributary runoff, probably occurred during the hot afternoon on May 30. This increase is depicted as a gentle increase in estimated base flow of the synthetic hydrograph of figure 50. As such, it contributed little to the flow rate of 400 ft<sup>3</sup>/s (Moosburner's 3:00 p.m. estimate) downstream from the lower canyon mouth.

## Source 5

The intense scouring of the upper and lower canyons by the flood eroded sediment from the bed and banks of the stream channel that subsequently was deposited on the flood plain between canyons and on the alluvial fan below the lower canyon. Owing to the enhanced snowmelt caused by continued high temperatures (table 5) during about 10 days preceding the flood, most of the unconsolidated debris in the canyons probably was saturated. When that sediment was eroded, largely by the leading flood surge, the debris and its entrained water became part of the flood.

It is assumed that at least 450 acre-ft of material was scoured by the flood, equal to the accountable volume of sediment that was deposited. An unaccountable quantity of fine-grained sediment was flushed to Washoe Lake. An additional unaccountable quantity of debris moved through parts of the channel system and progressively backfilled the channel during the flood recession. The estimated porosity of the prescoured debris was roughly one-third of its volume, on the basis of data compiled by Morris and Johnson (1967, table 5, p. D20), and it is assumed that virtually all of the undisturbed material was saturated with water. On this basis, the entrained volume of water, at one-third the volume of accountable saturated debris was at least 150 acre-ft.

According to these assumptions, the water released by the scour of channel debris and incorporated into the flood was a major component of the floodflow, almost seven times the amount of water expelled from Price Lakes. Much of the debris and associated pore water scoured from the channel is believed to have been incorporated by the leading flood surge. Thus, much of this water became a major component of the early phase of the flood, but probably contributed little to the flood recession. The amount of water incorporated by this process that contributed to recessional flow is indeterminable.

## Source 6

Heavy snowmelt during several days preceding the flood undoubtedly recharged the shallow ground-water system beneath and adjacent to the Ophir Creek channel. Intense scour of the creek channel by the leading flood surge not only incorporated a substantial amount of interstitial pore water within the floodflow (at least 150 acre-ft, source 5), but the abrupt incision of the channel also probably accelerated drainage of ground water into the channel. The rate of this ground-water release to the channel probably was greatest

immediately following the incision, then decreased exponentially with time, as ground-water levels declined and as the abruptly incised channel was progressively backfilled by debris emplaced by the receding flood. Alluvium beneath drainages tributary to Ophir Creek were similarly saturated, and main-channel incision likely increased discharge from these deposits at the junctions of the main and tributary channels. Such an abrupt discharge of ground water may account for Elizabeth and William Willets observation (app. B) of "water gushing out of the side of the mountain."

David E. Prudic, U.S. Geological Survey (written commun., 1999), tested the hypothesis that substantial amounts of ground water may have been released and subsequently transformed to floodflow as the result of severe channel scour by the leading peak-flow surge of the flood. He tested the hypothesis through the application of a simple numerical ground-water model. Principal modelling assumptions were as follows:

1. Unconsolidated sediments beneath and adjacent to the stream channel were saturated, and the water table sloped toward the stream axis throughout the reach from approximately the head of the upper canyon to beyond the mouth of the lower canyon of Ophir Creek;
2. An approximate 2-mi reach was abruptly scoured to an average depth of 10 ft, and the ground-water head in the stream channel after the surge, was 10 ft lower than prior to the surge, and remained at this level for 3.5 days;
3. Incised channel walls were nearly vertical and did not immediately collapse into the scoured channel;
4. Ground-water flow to the stream was parallel to the water-table surface a short distance from the creek;
5. Hydraulic conductivity and specific yield of the incised sediment deposits were constant along the reach for at least 500 ft laterally perpendicular to the incised channel walls;
6. Water drained freely, coincident with a declining water table;
7. Ground-water drainage to the channel through the incised walls was not restricted by a confining layer;
8. The full 2-mi extent of incision essentially was instantaneous; that is, the time required for the complete channel scour was minimal compared to the overall 3.5-day flood duration.

In reality, many of these simplifying assumptions deviate from actual conditions, as follows. Although the channel likely scoured to an approximate average depth of 10 ft, it regraded towards the pre-flood level throughout the prolonged recessional period that began shortly after the initial flow surge. Some of the sediment backfilling the channel probably came from slumping of the vertically incised deposits because the saturated wall deposits could not retain vertical slopes during heavy ground-water discharge. Therefore, assumptions 2 and 3 are not wholly valid throughout the entire 3.5-day flood period. The assumption that ground-water flow paralleled the water-table surface is believed to have been reasonable because of the coarse-grained, permeable nature of the sediment deposits; however, some upward flow probably occurred near the stream. The depth at which upward flow contributed to the stream is unknown. Hydraulic conductivity and specific yield of the alluvium probably vary along the channel, although presumably less than they do laterally perpendicular to the channel. Furthermore, free drainage of pores accompanying decline of the water-table surface (assumption 6) is not instantaneous; however, the coarse-grained character of the deposits probably resulted in drainage over a period of only several minutes, and thus the assumption is probably not unreasonable. The brief time required to drain the pore spaces would have decreased the peak ground-water discharge immediately following the flood surge and would have prolonged ground-water discharge during flood recession.

Lateral extent of hydraulic uniformity of the deposits, perpendicular to the channel axis, is unknown. However, the lengthy canyon segments traverse mainly unconsolidated debris and landslide deposits having hydraulic properties that probably are similar to the channel bounding deposits. Assumption 8, that the entire canyon segment was instantly scoured, mainly affected the peak flow rate of ground-water discharge and the duration of the peak flow rate (peak flow of ground-water drainage probably lasted only a duration of minutes). The total volume of ground-water discharge would have been less affected by this assumption than by assumptions 2 and 4. Although the uncertainties associated with this assumption place limitations on the actual quantity, and specifically, the timing of ground-water discharge, the resultant quantitative estimates nevertheless provide valuable insight regarding the probability that ground-water discharge

supplied a substantial component of the total floodflow estimated a short distance downstream from the lower canyon mouth.

Prudic utilized a finite-difference ground-water flow model (MODFLOW-96; Harbaugh and McDonald, 1996) to estimate ground-water discharge along the scoured channel. A single layer, cross-sectional model with a 1 ft width corresponding to a 1 ft length of stream channel was constructed. The modelled boundaries were: (1) constant ground-water flow into the model area, at a perpendicular distance of 500 ft from the stream; (2) no flow across the water-table surface; (3) no flow across the base of the model layer; and (4) head-dependent flow into Ophir Creek. The river package option (Harbaugh and McDonald, 1996, p. 98-109) was used in simulating real-dependent flow into Ophir Creek. The streamflow head in Ophir Creek was assumed to be 10 ft prior to channel scour, whereas after scour, the head was assumed to be 0 ft.

The base of the model layer was assumed to be 10 ft below the pre-flood water table at a lateral distance of 50 ft beyond the stream and continued to the constant flow boundary at a lateral distance of 500 ft. Between Ophir Creek and a distance of 50 ft beyond its channel, the thickness of the model layer increased 1 ft for every 5 ft laterally, and thereby the model layer reached a thickness of 20 ft at the stream channel. The layer thickness was increased near the stream to allow drainage from sediments to the abruptly lowered head level in Ophir Creek without causing the model cell at the channel boundary to desaturate. Although the true thickness of sediment deposits contributing ground-water flow to Ophir Creek is unknown, only the upper part of the saturated deposits likely contributed flow while deeper ground water continued flowing parallel to the stream channel similar to streams west of Carson City, about 8-9 mi south of Ophir Creek (Maurer and others, 1996, p. 7). Doubling the thickness of deposits contributing to Ophir Creek is effectively equivalent to doubling the hydraulic conductivity. Thus, only hydraulic conductivity was varied within a reasonable range and according to constraints governing likely ground-water discharge to Ophir Creek before channel incision.

The 500-ft lateral distance, perpendicular to the channel, was divided uniformly into 100 cells, each of which was 5-ft long and 1-ft wide. The lateral distance of 500 ft was purposely selected to be greater than needed; thus, the outer boundary was sufficiently distant from the channel incision to eliminate any

model-boundary effects. Changes in water levels and flow for each model cell were solved using the Strongly Implicit Procedure within MODFLOW (Harbaugh and McDonald, 1996, p. 37). A closure criteria of  $2 \times 10^{-6}$  ft and an acceleration parameter of 0.70 were specified in the solution. The 3.5-day period was divided into 100 time steps. A time-step multiplier of 1.05 was used that resulted in an initial time step of 116 seconds.

Because the model simulated ground-water discharge for only a 1-ft length of channel, results were multiplied by the 2-mi (10,560 ft) length of the reach and then doubled to account for discharge from both sides of the channel. A separate steady-state model initially was done for each variation in hydraulic-conductivity to obtain water levels for each model cell prior to simulating channel scour.

Constant flow at the lateral distant boundary (500 ft) was assigned a rate that maintained a water-table gradient of 0.10 ft/ft to simulate conditions prior to channel scour. Consequently, the assigned constant flow rate varied, depending on the value of hydraulic conductivity assigned to the sediment deposits. Hydraulic conductivity was assumed to range from 20 to 100 ft/d, within the range of estimates of hydraulic conductivity for similar sediment deposits near streams west of Carson City (Maurer and others, 1996, p. 21), and for lithologically similar sediment deposits in Carson Valley (Maurer, 1986); this conductivity also is within the range of hydraulic conductivity for a clean sand (Freeze and Cherry, 1979, p. 29). The ranging hydraulic conductivity and assumed gradient resulted in a calculated range of ground-water discharge to Ophir Creek throughout the 2-mi reach of from 5 to 24

ft<sup>3</sup>/s. The lesser part of the range is similar to estimates of ground-water discharge along the Upper Truckee River (near South Lake Tahoe, Calif.) documented in late September 1996 (T.G. Rowe and K.L. Allander, U.S. Geological Survey, written commun., 1998). The greater part of the range is believed to be reasonable for spring runoff conditions, but precise measurements of ground-water contributions during these times are unavailable.

A specific yield of 20 to 35 percent, by volume, was assumed for model simulations; this range is within that for coarse to gravelly sand and fine gravel (Johnson, 1967, p. D1). Model results are summarized in table 11. The calculated volumes of water released from storage during the 3.5-day period depend on specific combinations of hydraulic conductivity and specific storage for the water-bearing deposits. Thus, the cumulative volume of water that likely drained from the sediment deposits throughout the composite 2-mi reach ranges from about 50 to 100 acre-ft; this volume is solely the quantity of water removed from storage and does not include the natural ground-water discharge of preflood conditions. Table 11 lists the lateral distance beyond the channel that a water-table decline of at least 1 ft reached during each simulation. Lateral distances where the water table declined 8 ft or more during the various simulations also are listed in the table. The maximum rate of simulated ground-water discharge occurred during the first 2 minutes following channel scour and ranged from 0.04 to 0.14 ft<sup>3</sup>/s per longitudinal foot of channel (both sides). Peak ground-water discharge immediately followed the initial flood-surge incision. If all the ground water that discharged to

**Table 11.** Summary of model results for ground-water discharge to Ophir Creek caused by flood-induced channel incision<sup>1</sup>

Estimated hydraulic conductivity (feet/day)	Estimated specific yield (percent)	Volume of ground-water discharge <sup>2</sup> (acre-feet)	Initial ground-water discharge to Ophir Creek following incision (cubic feet per second)	Lateral distance from channel (feet) attained by drawdown of:	
				8 feet or more	1 foot or more
20	20	50	400	20	100
30	20	54	570	25	110
30	25	64	580	25	105
30	30	74	640	25	100
50	25	71	850	25	120
50	30	84	890	25	115
100	30	93	1,400	30	130
100	35	106	1,520	30	130

<sup>1</sup> Incision depth estimated at 10 feet; discharge is cumulative from both sides of the channel throughout a 2-mile reach.

<sup>2</sup> Cumulative volume during 3.5 days following incision.

the channel during the first 2 minutes reached the bottom of the canyon at the same time, the maximum rate for the 2-mi reach would have been about 1,500 ft<sup>3</sup>/s (table 11). However, because of the time required for the initial surge to travel from the top of the canyon to the bottom (about 8 or 9 min.), the peak flow from ground-water discharge along the channel probably was less, but the flow probably continued somewhat longer than that estimated by the calculations. On the basis of the model simulations, ground-water discharge probably continued at rates greater than those just prior to the flood surge throughout the 3.5-day flood period. Model simulations, however, include the assumption that the channel did not refill with sediments during the 3.5-days following the surge. If it did, ground-water discharge probably was less than that simulated by the model. Data on channel backfilling rates are unavailable.

Model results indicate that an appreciable component of the overall floodflow was ground-water discharge resulting from channel incision caused by the initial flood surge. Although, the quantity of ground-water discharge is not precisely known, model simulations suggest that the total volume may have been between 50 and 100 acre-ft, with much of the discharge occurring during the first 12 hours following the abrupt channel incision as listed in table 12.

### Source 7

Snowpack atop the landslide mass, on and around the lakes, and within and adjacent to the flood plain of Ophir Creek downstream from the lakes, contributed some water to the flood. Figure 20 shows that not all of the snowpack overlying the landslide mass was incorporated into the water expelled from Upper Price Lake. Also, figures 20 and 22 show that a substantial snowpack remained peripheral to Price Lakes and the intervening channel reach after the flooding had ceased. Some of that snowpack was etched by the expelled lake

water, but most was not incorporated within the flow. Much of the snowpack along the channel of Ophir Creek canyons downstream from Lower Price Lake undoubtedly was incorporated suddenly by the erosive, leading peak-flow surge. The amount of water derived from these snowpack sources is unknown. Much of the water from the entrained snow became part of the initial flood surge. Much smaller amounts of snow, however, are believed to have been incorporated in the recessional stage of the flood because the initial flood surge effectively eroded the snowpack that had accumulated along the channel. Recessional flow would have been enhanced mainly by minor sloughing and sliding of snowpack from areas above the highwater limits of the peak-flow stage.

Although impossible to account for with precision, snowpack thus incorporated within the floodflow can be estimated indirectly, as follows:

Estimated components of flood water from Price Lakes and sources 1-6 described above, are cumulated:

Source	Quantity (acre-feet)
Price Lakes	22
1	minor
2	100
3	5
4	minor
5	150
6	50-100
Total (rounded)	350-400

Floodflow portrayed by the hydrograph of figure 50 and data of table 10 included about 270 acre-ft of sediment. Thus, sediment (270 acre-ft) plus cumulative water from seven sources tabulated above (350 to 400 acre-ft) is about 620 to 670 acre-ft. Unaccounted water, as portrayed by the hydrograph, is therefore about 130 to 180 acre-ft (800 minus 670 or 620). This unaccounted component represents a reasonable

**Table 12.** Simulated ground-water discharge during duration of the flood as the result of channel incision

Duration following incision (hours)	Discharge volume (acre-feet) at varying combinations of hydraulic conductivity, K (feet per day); and specific yield, S (percent)							
	K=20; S=20	K=30; S=20	K=30; S=25	K=30; S=30	K=50; S=25	K=50; S=30	K=100; S=30	K=100; S=35
0-12	26	30	35	39	42	48	60	67
12-36	13	14	17	20	17	21	20	24
36-60	6	6	7	9	7	9	8	9
60-84	5	4	5	6	5	6	5	6
Total	50	54	64	74	71	84	93	106

order of magnitude for floodwater derived from snowpack (1) atop the landslide mass, (2) on or around the lakes, and (3) adjacent to the floodpath of Ophir Creek downstream from Price Lakes. Because of the frail nature of all involved estimates, however, the actual snowpack component of contributing floodflow probably is in the numerically rounded range of 100 to 200 acre-ft.

Timing of the arrivals of individual floodflow components at the apex of the Ophir Creek alluvial fan, the site represented by the synthesized hydrograph, is less certain. Whether a substantial quantity of the cumulative floodflow lags behind the leading peakflow surge, as portrayed by the hydrograph, is indeterminate on the basis of the paucity and uncertainty of data that define the hydrograph.

## **DESCRIPTIONS, DISCUSSIONS, AND INTERPRETATIONS OF FLOODFLOW DYNAMICS**

The term floodflow dynamics, as described and discussed in this report, refers to the hydraulic, rheologic, and geomorphic characteristics and behaviors of the flowing fluid. Flow characteristics and behaviors of the 1983 Ophir Creek flood were related to flow rates and velocities, channel-boundary effects (geometry and roughness) and, importantly, were influenced by varying characteristics of the entrained sediment load (concentrations, lithologic composition, particle-size distribution, and possibly vegetal matter). Sediment concentration varied widely over time and from place to place during the duration and evolution of the flood, and these variations in concentration strongly influenced floodflow behavior. The lithologic composition of the debris component of the floodflow was dominantly that of granodiorite, the parent material that comprises the easily erodible landslide-related deposits forming the channel boundaries. Because these debris clasts were not exposed to chemical weathering for long periods of time and local rates of chemical weathering are low, the variably-sized granodiorite clasts are dominantly the product of physical decomposition and were only mildly altered by chemical decomposition. As a result, clay particles (as defined by both size and chemical composition) are in short supply in sediment deposits of the 1983 flood (table 8).

Classifications of flowing, water-sediment mixtures adopted to characterize the 1983 Ophir Creek flood are based on those described by Costa and Jarrett (1981), Pierson and Costa (1987), and Costa (1988).

The major classifications utilized in this report are (1) normal streamflow (herein called streamflow, or Newtonian flow), (2) hyperconcentrated flow (Beverage and Culbertson, 1964), and (3) debris flow (non-Newtonian, slurry flow). In essence, streamflow (dominantly water) has little or no yield strength and quickly flows downhill under the stress of gravity; hyperconcentrated flow has measurable, but low, yield strength (Costa, 1988, p. 114); and debris flow has measurable yield strength that can vary widely, therefore it will resist gravitational stress, and can efficiently transport large-size clasts. Hyperconcentrated flow is a transitional state between streamflow and debris flow (Pierson and Costa, 1987, p. 2).

No samples of the Ophir Creek floodflow were collected during the flood; therefore, classifications are indirectly based on photographs of flow, qualitative testimony by eyewitnesses, and physical characteristics of resultant sediment deposits. Thus, classification is inherently imprecise and depends on the authors' interpretations of the available evidence.

Flow dynamics of the 1983 Ophir Creek flood were complex and are not completely understood. In simplest terms, flow began as relatively dilute streamflow that quickly transformed to sediment-laden flow through erosive bulking of channel debris. Over time and travel distance, rheologic transformation probably progressed from Newtonian flow to hyperconcentrated flow and then to debris flow; it then regressed, probably from debris flow to hyperconcentrated flow, and ultimately back to Newtonian streamflow. Rheologic flow evolution probably was more complex than this simplified scenario, but data are inadequate to document and verify greater levels and degrees of complexity.

### **The Canyon Reach**

Streamflow initiated the flood as the contents of Price Lakes were expelled into the upper canyon of Ophir Creek. During this initial phase, flow was composed mainly of water, and an unknown amount of snow and ice, that mobilized a mixture of fine-grained sediment and organic sludge that was scoured from the beds of Price Lakes. The initial fine-grained, suspended-sediment, fluid mixture may have scoured a small amount of bedload (fig. 22) from the relatively short (about 0.1 mi) channel reach between the two lakes (fig. 6). No evidence was discovered that any significant quantity of debris from the flood-triggering landslide was incorporated within the streamflow that entered the upper canyon of Ophir Creek located

immediately downstream from Lower Price Lake. The rapid expulsion of Price Lakes was likened to a "tidal wave" by hang-gliding eyewitness Doug Cook (app. B and fig. 2).

Evidence of heavy channel scour in the upper canyon of Ophir Creek, immediately downstream from Lower Price Lake (figs. 5 and 7), indicates that the initially sediment-lean streamflow quickly began to transform by sediment bulking, thereby rapidly altering the relative proportions of water and sediment making up the fluid mixture. Hereafter in this text, this abrupt leading edge of the floodflow is referred to as the leading flow surge. Hang-gliding eyewitness Doug Cook observed the streamflow plowing down vegetation and eroding debris in the upper canyon, thereby gaining momentum enroute downstream. Floodflow, incompletely pictured by figure 23, is believed to be following near the leading flow surge and appears very turbulent. The visual impression imparted by the photograph is that of a fluid charged with sediment that may be low in yield strength; however, channelized debris flows can be quite turbulent (Pierson and others, 1990, p. 49).

The leading edge of the approaching floodflow was witnessed head on by the Willets (app. B and fig. 2) at the mouth of the upper canyon. The flow appeared to them as a vertically standing wall of brown-colored fluid, loaded with debris, which was actively eroding the channel bed. The leading flow surge appeared intensely turbulent and the fine-grained matrix fluid exhibited low yield strength as it splattered the Willets with mud from a distance of about 50 ft as they ran from it within the intercanyon reach.

The general appearance of the flow in the intercanyon area, as described by the Willets, verifies that the fluid had undergone extensive transformation during transit through the upper canyon. The fine-grained matrix fluid that splattered the Willets may have been hyperconcentrated flow but verification data are unavailable. The flow transformed from a sediment-lean fluid as it left Lower Price Lake to a muddy, bouldery, debris-charged flow throughout the steep journey of about 0.6 mi (fig. 6). At an average velocity of 28-32 ft/s, calculated for the 2.88 mi reach from Upper Price Lake to Old Highway 395, this fluid transformation would have occurred in less than 1.65-1.68 minutes; considering the steepness of the upper canyon (slope, 26 percent, or 14.6°) compared to the average gradient (13.8 percent, or 7.9°) between Upper Price Lake and

Old Highway 395, transformation from Newtonian flow to debris flow may have occurred in less than 1.5 minutes.

The leading flow surge, laden with debris, actively eroding the channel bed, and incorporating large boulders in the flow, are characteristics of debris flow. The high fluid density associated with debris-laden flow, as described, can compound the shear stress exerted on the streambed and thereby greatly amplify its erosive character (Costa, 1984, p. 274). However, the tendency to splatter mud indicates that the matrix fluid lacked cohesion or yield strength, or both. The lack of clay-size particles in all sampled debris deposits (table 8) implies that debris cohesion was low during most or all phases of the flood. The rheological behavior of the leading surge of floodflow is therefore uncertain at the mouth of the upper canyon but much evidence favors a debris-flow classification.

Eyewitness Bridgewater's description (app. B and fig. 2) of the leading flow surge, probably sighted in the lower canyon, infers a debris-flow nature. He characterizes it as a quickly moving, deep, soupy mud or sludge, choked with debris, that severely damaged large trees.

The rheological character and fluid-flow dynamics of the flood in the intercanyon reach, as depicted by the photograph of figure 24, appear different than those shown in figure 23. The flow shown in figure 23 was photographed about 10-15 minutes before that of figure 24. Although still visibly turbulent, mainly at the edges of the flow, the fluid shown in figure 24 appears viscous and seems to have yield strength because it appears to support coarse-size clasts at the flow surface. As pictured, the flow mode is probably that of debris flow. The less-turbulent central mass of the flow implies the possible formation of a somewhat rigid plug. Photographic evidence shows that the flow stage has fallen (high-water marks are above the flow surface) and the flood appears to be in the early recessional stage. This indirect evidence of possible flow transformation (apparent differences in floodflow rheology between figures 23 and 24) over time adds further complexity to the earlier described scenario of downstream flow transformation of the leading peak-flow surge.

Postflood, particle-size data collected from a sediment deposit near the downstream end of the intercanyon reach (samples 1 and 2; tables 8 and 9; figs. 41, 43, and 47) indicate a probable debris-flow genesis for the sediment deposit (Scott, 1988, and Scott and others, 1995). The deposit is unstratified, coarse clasts are randomly distributed and are supported by a fine-

grained matrix (fig. 41), and the sediment matrix is poorly sorted (1.92-2.05  $\phi$ , table 9). However, the time of sediment deposition, with regard to flood stage and flow duration, is unknown. The intercanyon reach was one of net deposition, possibly during the leading peak-flow surge and also probably later during flow recession.

### Proximal Segment of the Ophir Creek Fan

At the mouth of the lower canyon, on the proximal segment of the alluvial fan of Ophir Creek (fig. 6), the leading flow surge appeared similarly to Tom Reed and his companions as it did to the Willets upstream (app. B and fig. 2): a vertical-walled mass of boulders, timbers, brush, and muddy water churning over itself, and through this process generating a loud percussive rumble, all debris-flow characteristics. Eyewitness descriptions of the abrupt, wave-like character of the flood front create the impression that frictional resistance, both internal and external, to the flowing, bouldery mass controlled its motion and created a moving dam that maintained forward movement by overtopping and rolling over itself. The fine-grained, matrix-fluid component provided both fluidity and lubrication to the overall mass that aided downslope movement and helped prevent the coarse-grained component from locking up and stopping. The pronounced percussive rumble indicated strong inertial forces transferring downslope momentum through boulder collisions.

Downstream from the canyon mouth, the leading flow surge badly damaged the Ogilvy residence and destroyed the Reed home, destructive characteristics of both streamflow and debris flow (figs. 27, 28, and 52). Overbank debris deposits of the leading flow surge, at and immediately downstream from the lower canyon mouth, were mainly composed of mud-coated boulders and trees, some cobbles and gravel, and a relatively thin (generally less than an average 1-ft thickness) veneer of mud plaster on the landscape (figs. 28 and 52). This mud plaster indicates some cohesion within the fluid matrix (Pierson, 1985, p. 1066; and Pierson and others, 1990, p. 43); however, the minimal thickness of the plaster attests to the weakness of cohesive forces. The presence of overbank deposits of boulders on the north-bank terrace, at the Ogilvy and Reed homesites, indicates that boulders were present near the top of the leading flow surge and not just moving as bedload. A lack of fine-grained debris (particle diameters less than 64 mm) in the interstices of the boulder berm of figure 26 indicates that the fine-grained, matrix-fluid

component of the leading flood surge possessed low yield strength and, as a result, continued to flow after deposition of the cobbles and boulders. It was this gravity-separated, muddy fluid that engulfed and swept Linda Reed across and down the north-bank terrace (fig. 29) beyond the limits of boulder deposition (eyewitness accounts of Tom Reed and companions and Kathleen Thompson, app. B and fig. 2). Rheology (hyperconcentrated or debris flow) of the matrix fluid is uncertain.

The leading flow surge continued downstream beyond the north-bank terrace area and apparently lost height and velocity as it gained width. Boulder impacts demolished vegetation in the flowpath and scarred trees along the flow margins (fig. 30).

In summary, the leading flow surge, which moved at the peak-flow rate, displayed the following flow characteristics on the proximal part of the Ophir Creek fan, downstream from the lower canyon mouth to just upstream of Old Highway 395: (1) Flow was laden with boulders and vegetation that seemingly controlled the geometric configuration and speed of the flow front; (2) the abrupt flow front was as high as 25 to 30 ft, depending on the degree of lateral confinement by channel banks; (3) at the canyon mouth, the flow front moved at a velocity of about 25 ft/s, and its speed progressively decreased downstream as the flowpath widened and streambed gradient decreased; (4) the leading peak-flow surge was of short duration, probably only a few seconds; (5) the bouldery flow front was very destructive to vegetation, most homes, and people in and along the channel; (6) overbank flow produced boulder berms, boulder splays, and a thin veneer of mud plaster on the boulders and land surface; (7) the flow-front fluid was of a dual-phase character wherein the coarse-grained fraction tended to separate and deposit as the flowpath widened; (8) the fine-grained, muddy, matrix-fluid fraction had some cohesion, but low yield strength, and continued to flow after movement of the coarse-grained fraction ceased; and (9) no discernible debris-flow levees or lobes were formed when sediment was deposited by the leading peak-flow surge.

The above listed flow characteristics vary with regard to furnishing definitive evidence of Newtonian or non-Newtonian flow. The formation of boulder berms, selective boulder deposition, and a tendency for flow to separate into dual fractions (coarse-grained compared to fine-grained matrix fluid) favors a Newtonian streamflow classification. However, this is inconsistent with normal debris-flow (non-Newtonian) characteristics and is less important than the general



**Figure 52.** Mud-coated north-bank terrace of Ophir Creek just downstream from lower canyon mouth. Badly damaged Ogilvy home in background and foundation of destroyed Reed home at extreme lower right. Boulders covering terrace were deposited by May 30 flood. Oblique aerial photograph by Jon O. Nowlin, U.S. Geological Survey, June 3, 1983.

character of the flowing mass of heterogeneous components exiting the canyon mouth. John Burrue's observation of the leading flow surge (app. B) ". . . we saw a mountain of dust and trees coming out of the ground like someone was tearing things up with a big bulldozer" strongly favors a non-Newtonian mode of flow. The mixture of mud, boulders, and vegetation moving as a vertically appearing fluid front is difficult to relate to a surge of streamflow. The movement of large boulders (fig. 28) in suspension by streamflow or hyperconcentrated streamflow seems impossible, and eyewitness descriptions verify that not all boulders moved as bedload. However, the above listed characteristics that are inconsistent with debris flow testify to the rheologic complexity of the leading flow surge. On the basis of available evidence, the leading flow surge is classified as a heavily water-saturated debris flow having a fine-grained fluid matrix of low cohesion and low

yield strength. The low cohesion is a function of low silt and clay content (less than 6 percent, table 8), but principally a function of the minimal clay content.

### Medial Segment of the Ophir Creek Fan

Hydraulic transformation of the leading flow surge became more pronounced just upstream from Old Highway 395 near the battered pine tree of figure 30 (J, fig. 27). Lateral confinement of the floodflow decreased abruptly allowing the flow to spread quickly over the progressively widening surface of the Ophir Creek alluvial fan. The rapidly expanding flow width was accompanied by thinning of the leading edge of the leading flow surge. Also, the flowpath progressively flattened downstream (fig. 6). These synchronous changes along the flowpath triggered responsive changes in floodflow dynamics that are described and interpreted as follows.

Downstream from Old Highway 395, the destructive effects of the flood varied. The Cline home (C, fig. 27) was structurally destroyed (figs. 33 and 34), but the Stafford home (S, fig. 27) remained structurally intact (fig. 32). The Turek home was not invaded by debris and suffered only minor damage (fig. 35). The partially collapsed Cline home was filled with bouldery deposits, whereas the Stafford home was partly filled with fine-grained sediment and engulfed by debris deposits containing boulders. The remains of the Cline home were liberally surrounded by bouldery deposits (figs. 31, 33, and 34). Boulders also were deposited at the surface in the vicinity of the Stafford home but were most densely concentrated on the land upstream from (west of) the house (figs. 31 and 32).

The structural collapse of the Cline house, caused by the leading flow surge (Katy Cline, app. B), could have resulted from either streamflow or debris flow; another striking example of the destructive capability of the leading flow surge was the fate of Tom Reed's home upstream. However, the contrasting debris engulfment of the Stafford home, without accompanying structural collapse, is symptomatic of debris flow (Johnson and Rodine, 1984, p. 257). The contrast in damages and dissimilarities in debris deposition between the Cline and Stafford homes are in themselves puzzling, but these differences become understandable with the perspective provided by Katy Cline's experience.

Katy Cline's survival seems enigmatic as described through her recollections (app. B) and by the general postflood evidence shown in photographs (figs. 31, 33, and 34). She was apparently ejected from her home in an unconscious state during the leading peak-flow surge (Katy Cline, app. B). Her departure route was likely downward and outward through flood-induced holes in the east side of the house (fig. 33). Her recollection of the rapid filling of the house by water (no mention of boulders impacting or entering the home), combined with postflood evidence of the nature of wall failure (fig. 33), indicates that the walls were probably forced outward at the base of the house by mounting hydraulic pressure as the house filled with fluid. The east-wall failure inadvertently provided the exit pathway. Her survival immediately after her ejection is especially puzzling because evidence in postflood photographs (figs. 31, 33, and 34) implies that she travelled through a moving bouldery field of debris that should have crushed her. Equally puzzling is her earlier survival of assumed boulder movement within the home; the home wreckage was filled with bouldery

sediment (Howard C. Cline, husband of Katy, oral commun., 1996). Key evidence regarding her survival was first noted by study of the photograph of figure 34.

The heavily damaged Cline home, largely surrounded by boulders, is clearly depicted in the photograph of figure 34; the photograph also shows a partially overturned bus about 75 to 100 yds downstream from the house (fig. 31). The bus was parked beside the house prior to the flood (Howard C. Cline, oral commun., 1996), and was moved by floodflow to its postflood position beyond the downstream edge of the boulder field as shown in figures 31 and 34. The bus was muddied, but otherwise undamaged, during transit (Howard C. Cline, oral commun., 1996). The lack of damage to the bus body, and at least one other similarly transported Cline vehicle, indicates convincingly that vehicle transport occurred before the boulders arrived. Several vehicles were similarly transported from the Stafford yard, some moved all the way to the U.S. Highway 395 freeway; these vehicles also did not exhibit obvious body damage, according to our recollection and study of postflood photographs.

Katy Cline's ejection and departure from the proximity of her home is believed to have been generally coincident with vehicular movement—shortly before the arrival of boulders. The vehicular evidence and Katy Cline's survival indicate that the forward edge of the leading flow surge was dominantly a muddy fluid virtually devoid of boulders.

The above cited evidence verifies that a leading surge of mud and water struck both the Cline and Stafford homes. This leading flow surge was quickly followed by boulder- and tree-laden debris. The leading flow surge, which moved at the peak-flow rate, incorporated a mixture of boulders, trees, and mud, where it exited the lower canyon mouth; it transformed hydraulically as it moved down the Ophir Creek fan from the site of the damaged Jeffrey Pine tree (fig. 30) to the Cline and Stafford homes (fig. 31). The vertical-walled mixture of boulders, timber, and mud, viewed by many witnesses just downstream from the mouth of the lower canyon, separated into two distinct fluid phases on the medial reach of the Ophir Creek fan—(1) a leading flow surge that was either muddy streamflow, hyperconcentrated flow, or fine-grained debris flow, followed rapidly by (2) a less watery surge of boulder- and tree-laden debris.

A hypothesis of the hydraulic processes that are responsible for the transformation of the leading flow surge into a dual-phase surge is that as the super-saturated mixture of boulders, trees, and mud began

spreading laterally and decreasing in flow thickness just upstream from Old Highway 395, the rapidly widening flowpath quickly increased the area of surface resistance between the base of the flow and the land surface. This increasing streambed area caused a rapid increase in frictional drag along the base of the bouldery flow that, coupled with the downstream decrease in flowpath gradient, resulted in a general deceleration of the boulder-laden mass. The flow-front thinning is hypothesized to have promoted expulsion of the highly fluid matrix flow. The lack of cohesion within the fine-grained component of the debris flow aided the expulsion of the matrix fluid as a product of dissipation of internal pore pressure. The abundant water content of the leading flow surge that caused it to flow as a heavily saturated debris flow just upstream, allowed part of the mud-laden, matrix fluid to progressively separate and outrun the more rapidly decelerating bouldery debris, as seemingly also happened, as evidenced by Linda Reed's experience, on the upstream north terrace at Tom Reed's place (figs. 27 and 29).

The main thrust of the leading, mud-laden, flow surge (muddy streamflow, hyperconcentrated flow, or fine-grained slurry flow) was directed down the axis of the Ophir Creek fan and directly impacted the Cline home along this route with a force sufficient to initiate structural collapse of the house and eject Katy Cline. The Stafford home, located southeastward from the axial-fan route (figs. 27 and 31), probably did not receive as forceful a surge of the turbid fluid as the Cline home, and thereby escaped fatal structural damage. The mud-laden flow front had sufficient energy to raft numerous vehicles away from the approaching boulders.

The separation, or bleeding away, of the muddy matrix fluid within the leading flow surge undoubtedly decreased fluidity (increased viscosity) of the trailing bouldery debris. Separation of the watery matrix fluid increased the overall sediment concentration of the trailing mass and probably caused the bouldery debris to transform to a more coherent debris flow. Such a fluid transformation might explain inundation of the Stafford home by bouldery debris rather than a more destructive impact. The Cline house was already structurally incompetent by the time the bouldery debris flow arrived and was thus infused easily by the following boulder-laden debris. Hydraulic transformation of the bouldery mass to more coherent debris flow also explains the stratigraphic and particle-size characteristics of sediment deposits just downstream from Old Highway 395 (fig. 44 and samples 3 and 4 of fig. 47 and tables 8 and 9).

Flood deposits sampled for particle-size distribution in both the upstream intercanon reach (figs. 41 and 43) and in the medial fan area (figs. 43 and 44) display the following characteristics of debris-flow deposition: (1) lack of stratification, (2) matrix-supported coarse clasts, (3) concentration of coarse clasts at surfaces of deposits, implying inverse grading, and (4) large sorting coefficients (evidence of poor sorting) of table 9 (Scott, 1988, p. A57-A64, and Scott and others, 1995). The minimal amount of clay in the sampled debris-flow deposits (table 8) characterizes the depositing fluids generally as noncohesive debris flows (Scott and others, 1995, table 5). Times of deposition of these sediments relative to the leading peak-flow surge are uncertain.

Deposition of the sediments in the intercanon reach (particle samples 1 and 2) probably followed the leading flow surge during an early phase of flood recession. This is based on features shown in figure 24 that indicate a debris-flow phase of the flood that followed the leading peak-flow surge for a period of at least 15 minutes, and probably longer. In contrast, much debris-flow deposition on the medial fan area (particle-size samples 3 and 4) was a product of the hydraulically transformed, peak-flow surge where debris-flow deposition closely (probably within seconds) trailed the freshly separated, fine-grained, matrix flow.

Major (1996), during study of a number of flume-generated, experimental debris flows, noted that the processes of deposition were strongly influenced by the water content of the flows. Water content of the leading flow surge of the Ophir Creek flood was great enough to maintain some characteristics of streamflow until the spreading flow transformed the bouldery fraction to a more typical debris flow. However, the subsequent bouldery debris-flow phase was probably highly saturated. The high degree of saturation explains the very weakly lobate margins, low-relief surface morphology, and the generally variable margin of the downstream limit of boulder deposition (fig. 31) on the medial segment of the fan, according to comparisons with the results of Major's (1996) experiments.

The prolonged flow of debris over the medial segment of the alluvial fan, following the leading flow surge as described by eyewitnesses (Vic Stafford and Susan Graves, app. B and fig. 2), may have occurred as saturated debris flow (similar to that shown in fig. 24 in the upstream intercanon reach). If so, debris deposition probably occurred on the medial fan segment as a series of overlapping layers of debris that would probably be stratigraphically indistinguishable when exposed (fig. 44 and Major, 1996). Continued surges of

saturated debris flow, accumulating irregularly atop earlier deposits on the medial fan area, may account for the clusters and streaks of coarse clasts at the surface, as shown in figure 31.

About 0.2 mi downstream from Old Highway 395, boulder movement stopped. This downstream limit of boulder movement generally defines the downstream limit of the medial segment of the Ophir Creek fan (figs. 6 and 31).

### Distal Segment of the Ophir Creek Fan

The fine-grained, matrix fluid of the leading flow surge exhibited characteristics of both hyperconcentrated flow and debris flow after it flowed beyond the limits of boulder deposition. Hyperconcentrated-flow characteristics include: (1) separation of the matrix fluid from the coarse-grained bouldery fraction, (2) the absence of detectable yield strength in the matrix fluid, (3) Katy Cline's description (app. B) of the fluid that transported her toward the freeway more closely approximates water than a mud-dominated fluid, and (4) statistical characteristics of particle size samples 5 and 6 (fig. 43 and tables 8 and 9); sorting coefficients (sample 5, 2.3  $\phi$ ) decrease downstream (sample 6, 1.4  $\phi$ ). Mean and median particle sizes of sample 5 (both 2.3 mm) are greater than those of downstream sample 6 (0.47 mm and 0.45 mm, respectively). These downstream trends in particle-size statistics indicate sorting and selective deposition in a downstream direction, characteristics of streamflow rather than debris flow.

Characteristics of the fine-grained matrix fluid that favor classification as debris flow are: (1) eyewitness Kenneth Julian (location, fig. 27) saw "a wall of very muddy water flowing quickly . . . toward the freeway;" he observed a flow front 4 to 5 ft high . . . of a consistency resembling freshly mixed concrete (implying viscosity and yield strength greater than muddy water); (2) eyewitness Reed Dopf photographed the leading edge of the flow front near its terminus (fig. 39); as pictured, the fluid exhibits the characteristics of high yield strength and high viscosity (vertical flow front at low-flow velocity); and (3) sorting coefficients for samples 5 (2.3  $\phi$ ) and 6 (1.4  $\phi$ ) are in ranges (2.2 to 2.4 for debris flow, and 1.2 to 1.5 for hyperconcentrated flow) greater than those (0.7 to 0.9) characteristic of streamflow (Scott, 1988, p. A63).

The seeming contradiction in rheologic classification of flow downstream from the limit of boulder deposition may be the result of several factors. As described above, fluid dynamics varied both geographically and over time during the duration of flooding.

Particle-size data were collected long after flooding (app. C). The apparent conflict between statistics of particle-size samples and eyewitness accounts and photographs of flow on the distal part of the Ophir Creek fan may be the result of too few samples and sampling too near the surface of the deposits. Samples 5 and 6 were collected near the land surface (figs. 45 and 46) and, therefore, may represent flow during the flood recession, when flow dynamics may have differed from those of the initial flow surge. Also, proportions of water and sediment may have varied enroute as the fluid transporting fine-grained sediment flowed across the dry surface of the distal part of the alluvial fan. Regardless, the paucity of particle-size data, both areally and vertically within the fine-grained deposits, precludes a resolution of the apparent uncertainties of flow dynamics on the distal reaches of the Ophir Creek fan.

### Variation in the Water-Sediment Mixture Over Time

The duration of intense sediment transport is uncertain even though the onset is clearly documented by the timing of the arrival of the sediment-laden, leading, peak-flow surge. Oblique aerial photographs (fig. 53) taken by Mrs. E.H. Thom (app. B) show moderately turbulent, viscous, sediment-laden fluid with an overall appearance similar to pancake batter moving through the lower canyon and over the alluvial fan sometime between 12:15 and 1:00 p.m. (the leading flow surge arrived at Old Highway 395 at 12:02). By general appearances, described above, the fluid could be debris flow; if not, it was probably hyperconcentrated flow. Photographic resolution is inadequate to precisely verify the flow mode with confidence. The areally extensive sediment deposits on the Ophir Creek alluvial fan were largely emplaced before the times of these photographs. Therefore, sediment deposition at the time of Mrs. Thom's photographs presumably was mainly thickening the deposits. Sediment deposits in the photographs do not appear to have risen to a level of encroachment on the southbound (westward) lanes of the freeway, as ultimately occurred; southbound highway traffic appears to be moving freely, and at least half a dozen vehicles are parked on the west road shoulder. The leading flow front had likely reached and passed the site where the vertically standing flow front was photographed by Reed Dopf (fig. 39).

Mrs. Thom's photographs of the lower canyon and the proximal and medial parts of the alluvial fan clearly show that the flood is in recession and that flow



B



D



A



C

**Figure 53.** Oblique aerial views of Ophir Creek flood, western Nevada, photographed by Mrs. E.H. Thom, May 30, 1983, probably between 12:15 and 1:00 p.m. A, Northwestward, upstream view of alluvial fan. B, Southeastward, downstream view of alluvial fan. C, Eastward, downstream view of medial part of alluvial fan. D, Westward, upstream view of the lower canyon.

stage may have fallen 10 ft, or more, from the peak; eyewitness Tom Reed noted a fall of that magnitude within seconds after peak flow. Thom's photographs show flow confined to the main channel upstream from Old Highway 395, but broadly spread across the medial fan reach extending from just upstream of Old Highway 395 to the limits of boulder deposition, downstream from the Turek, Cline, and Stafford homesites (fig. 27). Near the limit of boulder deposition, heaviest flow appears to be moving predominantly southeastward. Even though sediment deposits were broadly emplaced before Thom's photographs were taken, heavy sediment transport by the flood is still evident in the photos. Evidence disclosed by these photographs confirms Vic Stafford's observations of flood severity for at least 45 minutes after the onset of flooding. Mrs. Thom's photographs verify that most sediment deposition occurred during the first hour of flooding and that heavy sediment transport continued for at least that length of time.

Numerous additional photographs (not shown in this report), both from the land and the air, were taken by observers several hours after the onset of flooding. Photographs taken sometime between 2:30 and 4:00 p.m. depict floodflows of differing character than that photographed earlier (12:15-1:00 p.m.) by Mrs. Thom. Differences from Thom's photos, most evident in the vicinity of Old Highway 395, were as follows. Flow rate had receded markedly and no longer inundated most of the flood deposits that buried Old Highway 395. Instead, numerous braided distributary channels laced the sediment deposits, and erosion of the depositional surface appeared to be the dominantly active hydraulic process (fig. 48). Many of the numerous boulders armoring the depositional surface protruded up to several feet above the flow that was occurring in the distributary channels, and many boulders had dried after their mudcaked surfaces were exposed to the atmosphere. This drying process must have taken at least an hour, implying that the widespread and heavy debris-laden flow photographed by Mrs. Thom was relatively short lived.

The 2:30-4:00 p.m. photographs show a highly turbid fluid that may have been moving as hyperconcentrated flow but was probably streamflow. These photos confirm Vic Stafford's observations (app. B) that after about 3 hours, floodflow had noticeably receded, the sediment load had decreased, and recession flow began to entrench the debris deposits to form a dominant, eastward-flowing channel between the Cline and Turek homes. Otto Moosburner, (U.S. Geological Survey, oral commun., 1996), observed

flooding near and upstream of Old Highway 395 about 3:00 p.m. The flow was turbid and gray colored, because of entrained sand, but was definitely streamflow (Newtonian flow).

Oblique aerial photographs taken by the U.S. Forest Service during the morning of May 31, 1983, show Ophir Creek flow on the alluvial fan to be largely integrated into a single channel, as described by Stafford, and flowing east-northeastward just south of the Turek home (see figs. 3B and 31 for channel position and alignment). The flow shown in the Forest Service photos is obviously streamflow but appears turbid.

## Summary

Floodflow began as a rapid surge of relatively dilute streamflow as a result of the rapid expulsion of Price Lakes. The dilute flow quickly transformed to sediment-laden streamflow through the process of erosive bulking of channel debris in the upper canyon of Ophir Creek. The initial, leading flow surge appeared as a vertically standing, churning wall of muddy fluid laden with boulders and uprooted vegetation as it exited the upper canyon mouth. The leading flow surge was moving at the peak-flow rate. The mixture of mud, boulders, and vegetation and the erosive nature of the flow front, as witnessed, favor classification of the leading flow surge as debris flow. However, the apparent lack of yield strength of the muddy, matrix-fluid component indicates that the overall fluid mass was supersaturated and may have been close to hyperconcentrated flow.

The leading flow surge probably retained its ambivalent rheologic character during transit of the intercanion reach as it deposited some of its sediment load. However, it was followed by a prolonged and more certain debris-flow episode that also deposited sediment in the intercanion reach.

The leading flow surge aggressively eroded the lower canyon and exited that reach as a debris-flow surge loaded with boulders and vegetal debris. It was very destructive to homes and people as it spread over the north-bank terrace of the proximal segment of the Ophir Creek fan. Flow deposits in this reach were largely mud-coated boulders and trees; flow spreading was distinguished by a propensity for the flow surge to separate into a mud-laden matrix fluid that continued to flow after the coarse-grained bouldery debris stopped. The lack of yield strength by the muddy, matrix-fluid component indicates that, overall, the leading flow surge rheologically resembled hyperconcentrated flow.

However, the eyewitness descriptions that the surge was laden with boulders throughout its depth confirms a debris-flow classification.

The leading flow surge transformed quickly downstream from the north-bank terrace as it moved down the medial segment of the Ophir Creek fan. It quickly spread laterally, thinned, and began to separate into a watery, but muddy, leading edge. The leading flow front, of uncertain rheological character, was quickly followed by a bouldery debris flow that further evolved as the decelerating coarse-grained component was progressively dewatered by the faster moving, escaping, fine-grained component of flow. The fine-grained matrix fluid destroyed a home, swept away its occupant, and mobilized vehicles near several homes enroute downstream toward the U.S. Highway 395 freeway. The closely following, bouldery, debris-flow phase deposited on the medial fan segment and inundated homes in its path. Debris flow seemingly continued for a half to three-quarters of an hour, possibly as multiple flow surges, and added to the debris deposits on the medial fan segment. The highly saturated, poorly cohesive debris flow, or flows, left a depositional surface of generally low relief, no debris-flow levees, and weakly lobate margins.

The leading fine-grained-fluid matrix flowed in a progressively decelerating manner over the distal segment of the Ophir Creek fan. Its precise hydraulic mode is uncertain but it seems to have transformed, possibly through selective deposition of coarser-grained sediment, from a muddy, watery, hyperconcentrated flow to a vegetally clogged, fine-grained debris flow during transit across the distal fan segment.

Sometime during the first hour after the initial flood surge, floodflow on the Ophir Creek alluvial fan progressively transformed from debris flow into hyperconcentrated flow, then into turbid streamflow, as flow rates progressively decreased. Within 4 hours following the peak-flow surge, the continually receding streamflow was actively eroding the bouldery surface of the medial fan segment, as a new channel system for the creek developed. Floodflow continued for several days, and sediment loads and associated turbidity progressively decreased as channel-cleaning processes diminished and the new creek channel evolved.

## FLOOD DAMAGE

Damage caused by the May 30, 1983, flood was extensive, varied, and complex. Results of a limited and conservative assessment indicates that damage was

about \$2 million (table 13). However, the limited nature of the assessment indicates that comprehensive damage probably exceeded \$2 million. The assessment addresses damage to homes and associated real-estate improvements, public utilities, highways, and irrigation works.

The assessment did not include several intangible components: human life and suffering are inadequately measured in terms of monetary value. Likewise, the costs of stream-channel and riparian damage, aesthetic and environmental degradation, and landscape alterations are difficult to evaluate monetarily. Public services that include police, search and rescue, onsite medical assistance and associated volunteer help, also are difficult to evaluate. Livestock losses (pets, chickens, and horses) were not assessed economically, nor were the costs of legal and other miscellaneous services.

Although incomplete, in terms of total damage assessment, this limited and conservative accounting (table 13) provides some economic perspective on this flood for comparison with other floods.

## THE 1983 FLOOD—A TEST OF FLOOD-HAZARDS PREDICTION

Flooding and related fluvial-debris hazards were predicted for Ophir Creek as part of a hydrologic-hazards investigation made during 1973 and 1974 (Glancy and Katzer, 1977; Tabor and others, 1983, p. 37-40). The estimated magnitude of the "100-year flood" for Ophir Creek at the head of its alluvial fan was 2,000 ft<sup>3</sup>/s, on the basis of the 1973-74 study. Hazards predictions for Ophir Creek were based on the expectation that flooding would occur as direct runoff of rainfall or snowmelt, or both; they did not take into account the unusual circumstance of landsliding and resultant expulsion of the contents of Price Lakes. The flood of July 6, 1890, which could be used to analyze the effects of flooding, was caused partly by the rapid emptying of Upper Price Lake. But that was not included in the analysis by Glancy and Katzer because streamflow data for that flood and the storage capacity and the rate of emptying of Upper Price Lake in 1890 are unknown. The 1983 flood provides an opportunity to compare actual impacts from a large-magnitude flood with predicted results. This opportunity is unusual because predictions of the hazards posed by debris transport are uncommon. Both the flood-hazard predictions and actual results of the 1983 flood are portrayed in figure 54.

**Table 13.** Damage caused by the May 30, 1983, Ophir Creek flood, Washoe County, Nevada

Property damage	Damage assessment (in 1983-84 dollars, rounded)	Source of information
Upper Price Lake dam and irrigation works	\$ 100,000	M.B. Twyeffort, U.S. Soil and Conservation Service, and James Lathrop, Franktown Irrigation Company
Old Highway 395	480,000	F.E. "Joe" Crowdis, Nevada Department of Transportation
Telephone lines and equipment	50,000	Dennis Woll, Nevada Bell Corporation
Power lines and equipment	50,000	F.R. Masayko, Sierra Pacific Power Company
Private real property and attached structures	<sup>1</sup> 1,105,000	D.A. DeCrona, Washoe County Division of Emergency Management
TOTAL (rounded)	\$1,800,000	

<sup>1</sup>Estimated. All other values listed represent actual costs incurred in replacing or repairing the property.

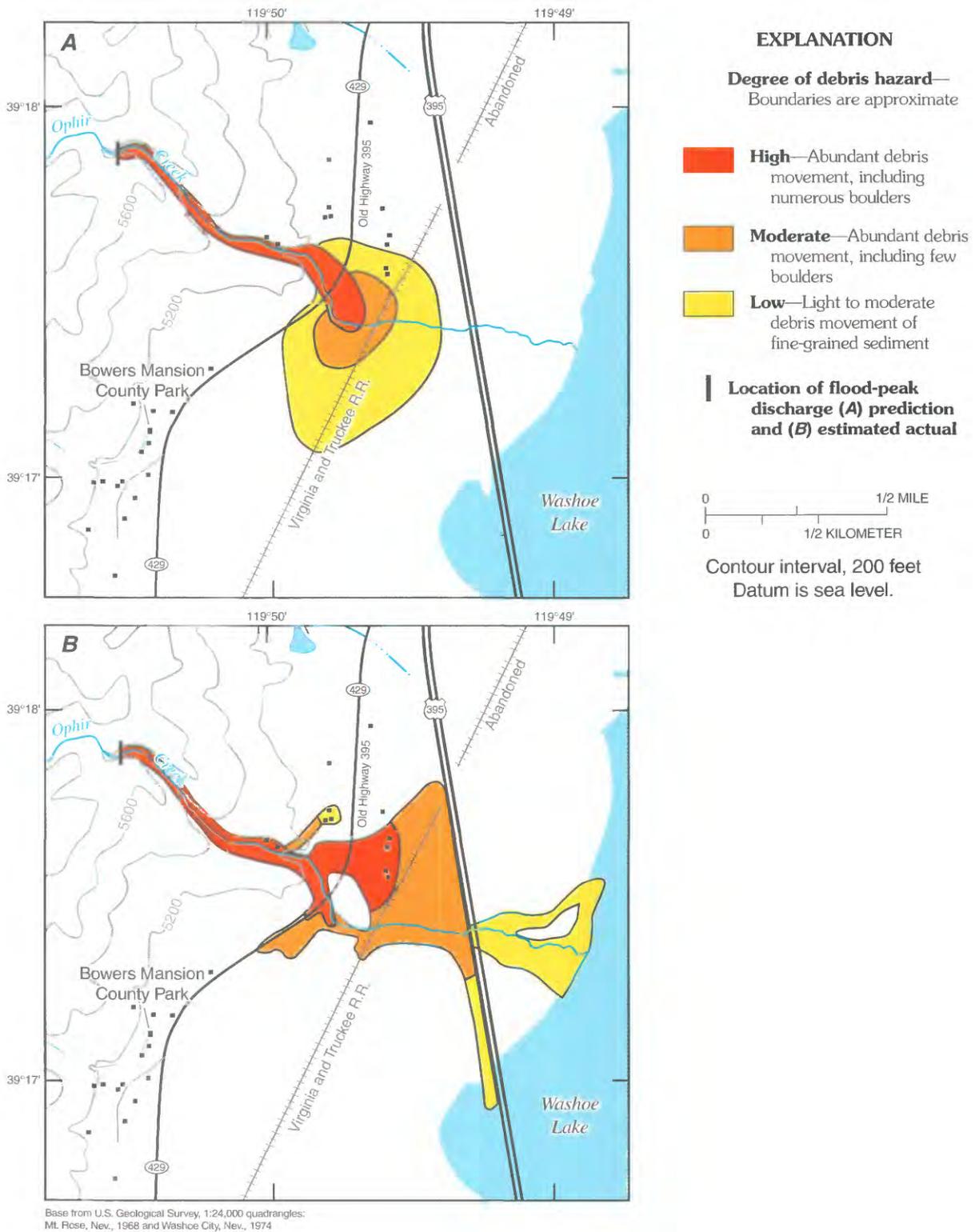
Comparisons of the predicted flood hazards and the actual flood impacts disclose the following: (1) The 1983 flood was exceptionally large; its estimated magnitude was about 25 times greater than that predicted for a 100-year flood; (2) the north-bank stream terrace, where the Ogilvy and Reed homes were located, was considered safe for the predicted flow rate of the 100-year flood, but was extremely vulnerable during the 1983 flood; (3) predicted fluvial-debris hazards are similar to those that occurred during the 1983 flood, but the areas subject to the more intensive 1983 hazards are expanded northward. A flood equal to the 100-year flood (2,000 ft<sup>3</sup>/s) was expected to follow the general route of the man-diverted channel; however, the bigger 1983 flood (about 50,000 ft<sup>3</sup>/s) largely bypassed the manmade channel and followed a more natural route down the axis of the alluvial fan; (4) the route taken by the 1983 flood subjected the Stafford, Cline, and Turek homes to hazards not predicted for a 100-year flood; (5) the severity of the 1983 flood caused streamflow and associated debris to impact a much greater area than that predicted for a 100-year flood, including debris deposition down to, on top of, along, and past the U.S. 395 freeway; and (6) the unusual size and force of the 1983 flood redefined the flood-plain boundaries of Ophir Creek for practical planning purposes. Although boulders were not incorporated within the zone classified as one of moderate hazard (fig. 54B) by the 1983 flood, the transport of fine-grained sediment (pebbles and finer grained material) was so intensive that most of it was classified as a moderate, rather than a low hazard. This classification is somewhat in disagreement with preflood predictions by Glancy and Katzer (1977), but no more so than the difference between the magnitudes of predicted and actual flooding.

Although the 1983 flood exceeded the magnitude of floods historically throughout the region for precipitation-generated floods (fig. 38), the unusual character of the canyons of Ophir Creek could promote severe floods without triggering by bedrock landslides. Massive land-slope failures resulting from severe precipitation, or effects of the precipitation, could dam the creek in the future. Such an impoundment could result in flow overtopping the naturally formed dam, thereby causing rapid release of the impounded water and flooding that could equal, or exceed, that of the 1983 flood.

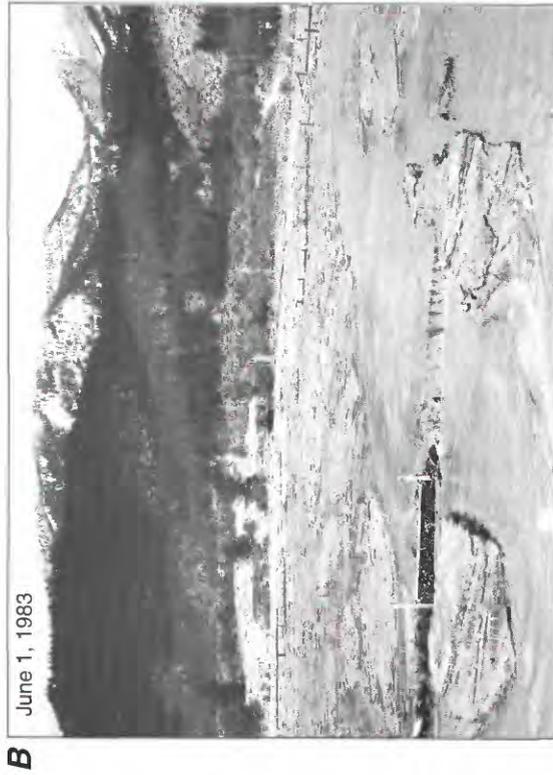
Flood- and associated debris-hazard predictions within most small drainages of the arid southwest are inherently uncertain because the streamflow data base generally is inadequate for accurate flood predictions. Also, geohydrologic processes of flooding in the arid environment are incompletely understood.

## AFTER THE FLOOD

The 1983 flood caused major landscape changes along Ophir Creek. These changes are particularly noticeable on the alluvial fan because this area is most visible from the old and new highways. The most obvious change was the extensive barren area caused by sediment deposits on the Ophir Creek fan. An early aerial view of the extent of these deposits is shown in the frontispiece. The surficial character of these deposits since has been gradually healing through natural revegetation. Healing rates were documented to provide calibration data for future paleoflood, debris-flow studies in the region. Flood and postflood changes are documented by a time-lapse sequence of upstream views of the Ophir Creek alluvial fan photographed from the freeway before and after the flood (fig. 55).



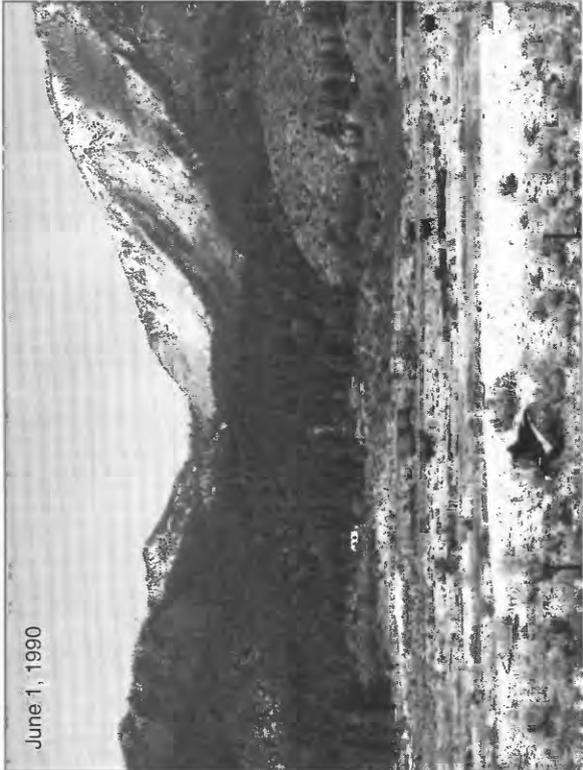
**Figure 54.** Fluvial-debris hazards on the Ophir Creek alluvial fan, western Nevada: A, As predicted by Glancy and Katzer (1977); flood peak, 2,000 ft<sup>3</sup>/s. B, As realized during the May 30, 1983, flood; estimated flood peak, 50,000 ft<sup>3</sup>/s. Abbreviation: ft<sup>3</sup>/s, cubic feet per second.



**Figure 55.** Similar upstream views of Ophir Creek alluvial fan from U.S. Highway 395 freeway, western Nevada. *A*, Irrigated pastureland before the flood, late August 1973. *B*, Barren deposits after flood, June 1, 1983. *C*, Sparse beginning of vegetation on fan deposits, June 1, 1986. *D*, Noticeably thickening vegetation on surface, August 31, 1988. *E*, Progressive thickening and growth of vegetation, June 1, 1990. *F*, Healthy growth of dominantly rabbitbrush, May 31, 1992. *G*, Shrub-dominated, nonirrigated surface on May 30, 1993. Cline home at left center and Turek home near center in *A*, *B*, and *C*; replacement for flood-destroyed Cline home at extreme left in *C* and near center in *D*. 1983 landslide area occurred at extreme left of barren face of Slide Mountain. Photographs by Patrick A. Glancy.



June 1, 1990



May 30, 1993

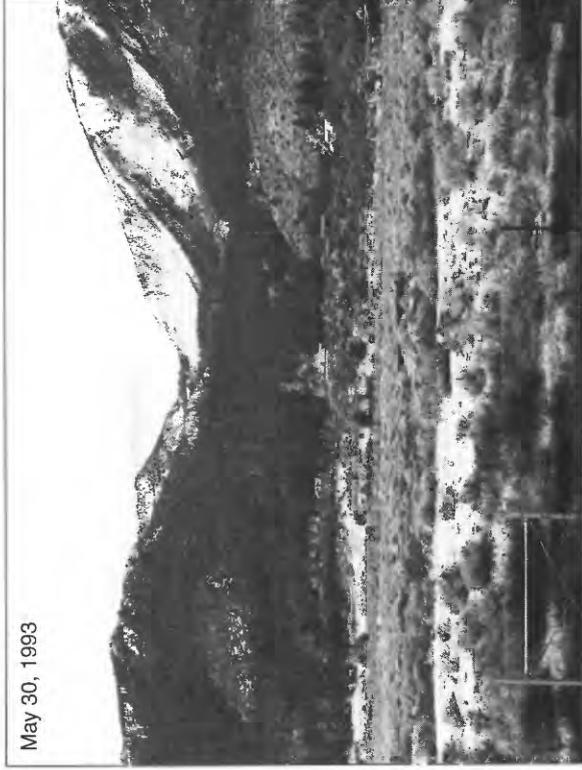


Figure 55. Continued.

Pasture land dominated the preflood view in 1973 as shown in figure 55A. The unvegetated sterile deposits left by the 1983 flood are shown in figure 55B. Later postflood photographs show that natural revegetation started slowly but accelerated after 1986. The first notable signs of revegetation were mainly annual weeds with sparse sprouts of native grass in late summer of 1986 (fig. 55C). Perennial rabbitbrush and native grasses mixed with weeds were visible by late summer of 1988 (fig. 55D), and these species had thickened noticeably by 1990 (fig. 55E). A dense cover of rabbitbrush was well established by the spring of 1992 (fig. 55F). Ten years after the flood, nonirrigated rabbitbrush dominates the area that was irrigated pasture land before the flood (fig. 55G).

As of 1996, the Reed home was not rebuilt, but the Ogilvy home has been restored and renovated. Minor debris damage to the Thompson's property was corrected, and irrigation diversions at the mouth of the lower canyon were repaired and re-established. Several new homes have been built downstream from the lower canyon mouth on pre-1983 landslide deposits, adjacent to both sides of the creek but outside of the 1983 flood zone, in the general vicinity of the Ogilvy and Reed properties. The Stafford home was torn down. A new home was built south of Staffords. Some of the boulder-laden deposits upstream and downstream from Old Highway 395 have been commercially marketed (fig. 56). Another home has replaced the one destroyed by the flood on the Cline property, and residents of the Stafford, Cline, and Turek properties have regraded their buried access roads. Old Highway 395 was exhumed and rebuilt where it was buried by debris. The channel of Ophir Creek was rediverted to the preflood route preferred by irrigators.

The destabilized canyons of Ophir Creek are geomorphically readjusting as natural processes move debris down and along the slopes. The channel reach between the canyons is slowly revegetating. A new dam was built at the outlet of Upper Price Lake to allow continued diversions of irrigation water southward to nearby Little Valley (south of Ophir Creek Basin; fig. 1), to accommodate long-vested Nevada water rights. The new impoundment behind the dam of Upper Price Lake holds only a few acre-feet of water, thereby reducing—but not eliminating—the potential flooding risks caused by any future rapid release of the contents of the lake.

Ophir Creek did not have the serious flooding that many other small drainages did during the heavy winter rain of mid-February 1986. Much of its drainage area is at a high altitude and received snow rather than rain during that storm. The creek subsequently flooded during heavy snowmelt runoff in late May to early June of 1986. The snowmelt runoff was accelerated, at least once, by a thunderstorm during late spring of 1986. The resultant flood was energetic enough to plug the Old Highway 395 drainage culvert with sediment, which caused the sediment-laden flow to overtop and blanket the road. Indirect measurements of the peak discharge of that runoff were made on July 20, 1986, about 0.1 to 0.25 mi upstream from Old Highway 395. The measurements indicated a peak flow during the night of May 31-June 1, 1986, of about 600 ft<sup>3</sup>/s.

## SUMMARY AND CONCLUSIONS

The May 30, 1983, flood of Ophir Creek was sudden, large, and severe. It was unusual because it occurred near noon on a clear, hot day that was both locally and regionally devoid of storm activity. The winter just concluded had been the second consecutive wet winter and had produced a near-record snowpack, but recent weather was unseasonably hot. The inviting weather during a holiday weekend attracted many outdoor recreationists to the eastern slopes of the Sierra Nevada. Some of these people became unwitting participants in the flood and others were astonished, and valuable, eyewitnesses.

Flooding was triggered by an unexpected landslide high on the southeast-facing slopes of appropriately named Slide Mountain, located between Reno and Carson City, Nevada. This landslide was the most recent and probably one of the smallest, of about a dozen or more, landslides from the same mountain face during late-Quaternary time (the last 100,000 years, or so). The slide probably resulted from the combined influences of gravitational force, favorable geosstructural orientations of joint-and-fracture surfaces within the granodioritic mountain bedrock, and sudden and transient hydraulic imbalances caused by ground-water movement through the bedrock mass. The triggering mechanism was probably the aberrant hydraulic pressures generated during the brief antecedent period of intensive melting and subsequent infiltration of the heavy snowpack.



**Figure 56.** Debris deposited on Stafford property by 1983 Ophir Creek flood, western Nevada. Deposits are being excavated and size sorted for commercial use, June 23, 1992. Photograph by Patrick A. Glancy.

The landslide was rapid and consisted of a composite of three nearly simultaneous interrelated mass movements: rock slumping, a rockfall avalanche, and a debris avalanche. The cumulative slide mass encompassed about 1,400,000 yd<sup>3</sup> of bedrock and associated products of bedrock weathering. The toe of the slide plummeted into the northwestern part of Upper Price Lake, a small pond that sat within and adjacent to the channel of Ophir Creek, high on the southeastern flank of Slide Mountain. Momentum of the sudden incursion of rock debris into the lake caused the rapid expulsion of the lake contents down the Ophir Creek channel. The contents were mostly water, with some entrained snow and ice and fine-grained, organic lake-bottom sediments that discolored the water but were present in small enough concentrations that they did not greatly modify the Newtonian hydraulic character of the fluid. The expelled contents of Upper Price Lake was about 20 acre-ft; an additional couple of acre-feet of mostly water were swept up by the flow surge a few hundred yards downstream as the smaller Lower Price Lake was, in turn, forcibly emptied.

The combined contents of Upper and Lower Price Lakes abruptly cascaded into the steep (average gradient, 26 percent, or 14.6°) upper canyon of Ophir Creek. The peak-flow rate entering the canyon was at least 6,000 ft<sup>3</sup>/s, but more likely in the range of 13,000 to 20,000 ft<sup>3</sup>/s, based on eyewitness observations of the chaotic expulsion of Upper Price Lake.

The fluid surge of low sediment content was erosively energetic as it cascaded into the upper canyon of Ophir Creek. It raced 0.6 mi through the deeply entrenched, steep canyon. Enroute, it gouged, bulked, and incorporated the easily erodible channel materials, and thereby progressively compounded in volume, mass, and momentum during downstream transit. Debris abraded from the channel boundaries included almost all of the riparian vegetation and large quantities of unconsolidated landslide debris of widely ranging particle sizes of late Quaternary age; it also incorporated snow and additional water as it overran normal streamflow and gouged saturated underlying channel deposits. The hydraulic character of the leading flow surge transformed dramatically during the 0.6-mi

transit of the upper canyon from that of a dilutely concentrated Newtonian fluid to a possible debris flow. Flow velocities in the upper canyon are unknown; however, because of the pronounced channel steepness, they probably equalled or exceeded the estimated average velocity of the leading flow surge throughout the 2.9-mi reach between Price Lakes and Old Highway 395 described below.

Floodflow transformed from a dominantly erosive mode within the upper canyon to one of mixed erosive and depositional mode through the wider (200 ft wide) and flatter (gradient, 12 percent, or  $6.8^\circ$ ) inter-canyon reach, also of 0.6 mi-length, just downstream from the upper canyon. Net debris deposition within this reach was about 50 acre-ft. A photograph of flow in this reach depicts the early recessional flow as probably that of a debris flow.

Downstream from the 0.6-mi long, net depositional reach, the leading flood surge entered the lower canyon of Ophir Creek and again became dominantly erosive. The erosive surge incorporated much lithic debris of mixed sizes and most of the trees and brush that mantled the flood plain throughout the 1.06-mi long lower canyon. Channel characteristics of the lower canyon are similar in lithic composition and erosive susceptibility to those of the upper canyon, but the average channel gradient of the lower canyon is much less steep (average gradient, about 12 percent, or  $6.8^\circ$ ). Average flow velocity through this canyon reach is undocumented, but probably is somewhat less than that in the much steeper upper canyon.

The peak discharge of the leading flow surge had grown to about  $50,000 \text{ ft}^3/\text{s}$ , and average flow velocity was about 25 ft/s about 0.1 mi upstream from the lower canyon mouth. There, average channel slope was measured at about 8 percent, or  $4.6^\circ$  (eq. 6), and the flood surge was probably at its peak magnitude and was composed of an incongruous mixture of vegetal matter, boulders (some over 6 ft in diameter), cobbles, sand, and fine-grained sediment that maintained fluidity because of an abundant water content.

The leading flow surge spilled out of the lower canyon mouth overtopping a north-bank channel terrace about 10 to 15 ft higher than the normal streambed. The hydraulic character of the leading flow surge at this stage of its journey was that of a highly mobile, abundantly wet debris flow of low cohesion. As a result of the lack of cohesion (minimal clay content) and abundance of entrained water, decreasing flow velocities caused by a widening flowpath and a decreasing chan-

nel gradient enabled a fine-grained matrix fluid to begin to separate and flow beyond the coarse-grained debris flow and its subsequent bouldery deposits.

The leading flow surge struck two houses occupying the north-bank terrace about 0.2 mi downstream from the lower canyon mouth. One home was badly damaged, but the occupants escaped unhurt; the other home was totally destroyed and one of its five occupants was killed as he raced for safety. Three other occupants were injured, two seriously, and only one escaped unscathed. The leading flow surge, at the homesites, reached 20 to 30 ft above the normal channel bottom and was about 200 ft wide; normal channel gradient is about 8 percent, or  $4.6^\circ$ . The flow surge, coincidentally moving at peak discharge rate, receded from the terrace almost instantaneously and left a carnage of battered dwellings among a dense field of large boulders, some as large as 6 ft in diameter, that it deposited on the narrow streamside terrace.

The leading flow surge transformed quickly downstream from the north-bank terrace as it moved down the medial segment of the Ophir Creek fan. It quickly spread laterally, thinned, and began to separate into a watery, but muddy, leading edge. This leading edge, of uncertain rheological character, was quickly followed by a bouldery debris flow that further evolved as the decelerating coarse-grained component was progressively dewatered by the faster moving, escaping, fine-grained component of flow.

The rheologically compound, leading flood surge largely bypassed a manmade channel diversion just downstream from the house-bearing terrace; it instead flowed straightforwardly along the axis of the Ophir Creek alluvial fan toward Old Highway 395 and other downgradient homes. Lateral channel confinement ends near the site of the manmade diversion; the diminished confinement allowed the debris-laden flow to spread laterally, and the height of the peak surge rapidly decreased. The spreading and thinning of the leading flow surge increased frictional drag on the boulder-laden fluid, thereby decelerating flow velocity, and the decreasing velocity promoted debris deposition on the land surface.

The flood left bouldery debris deposits up to 9-ft thick on and near the roadway. The propensity for the fine-grained matrix fluid to separate from the coarse-grained fraction at the leading edge of the debris flow caused the matrix fluid to begin to outrun the coarser grained fluid as it moved down the medial segment of the Ophir Creek fan. About 0.1 mi downstream from the north-bank terrace, the spreading and flattening

flow surge crossed Old Highway 395. Travel time of the surge from the moment of the landslide to the interruption of electrical power service by destruction of a powerline at Old Highway 395, was about 8 to 9 minutes; travel distance from Upper Price Lake to Old Highway 395 is about 2.9 mi; the resultant average velocity of the leading flood surge was later computed as between 19 and 22 mi/h (28 to 32 ft/s).

The continued widening and flattening flood plain (channel slope, 3 percent, or  $1.7^\circ$ ) downstream from Old Highway 395, caused further deceleration of the floodflow. As a result, the bouldery debris was deposited, but the fine-grained matrix fluid continued to flow. The matrix fluid engulfed and penetrated one home about 0.1 mi downstream from Old Highway 395. It swept away its occupant, vehicles parked by the home, and vehicles near a neighboring home to the south. The closely following, bouldery, debris-flow phase deposited a heterogeneous debris mass on the medial fan segment and damaged and inundated the three houses in its path. Occupants of two of the homes narrowly escaped with their lives. The occupant expelled from her home, described above, was injured during expulsion and as she was swept downstream toward the U.S. Highway 395 freeway by the viscous, fine-grained matrix fluid. She survived, but some domestic animals were killed. Debris flow seemingly continued for one-half to three-quarters of an hour, possibly as multiple flow surges, and added to the debris deposits on the medial and distal fan segments. The highly saturated, poorly cohesive debris flow, or flows, left a depositional surface of generally low relief, no debris-flow levees, and weekly lobate margins. Cobble and boulder movement ceased just downstream from the three homes, about 0.2 mi upstream from the U.S. Highway 395 freeway.

Although boulder movement ceased at the downstream limit of the homes, the finer grained matrix fluid travelled to and onto the southbound (westward) lanes of the freeway. Some matrix-fluid flow, transporting abundant vegetal debris, continued southward along the west side of the freeway. The matrix fluid was possibly hyperconcentrated flow along some of its route, but was clearly a fine-grained debris flow near its terminus; it was composed of water and fine-grained sediment, and it transported large amounts of vegetal debris. Cumulative sediment deposits of the flood downstream from the lower canyon mouth on the Ophir Creek fan, were estimated to be about 400 acre-ft.

A unique aspect of the flood was the rapidity with which water was expelled from Upper Price Lake by the landslide. Eyewitnesses and field evidence indicate that it probably took less than a couple of minutes. This rapid release rate and the following plunge down a steep, erodible channel caused the initial 20 to 22 acre-ft of water to compound its volume severalfold. Resultant sediment deposits amounted to about 450 acre-ft, more than 20 times the initial volume of Price Lakes. When the slide was confined by canyons, it cleanly scoured all vegetation in its path and badly eroded the confining channel.

The cumulative volume of floodflow, water plus debris (vegetation and sediment), was estimated at about 800 acre-ft, which greatly exceeded (over 36 times) the combined contents of Price Lakes (22 acre-ft). Additional water probably came from the following sources: snowmelt upstream from the landslide, ground-water outflow from the slide mass and scar, streamflow in the channel overrun and incorporated by the flood surge, tributary inflow downstream from Price Lakes, from ground water in pores of debris eroded from the channel bed and the release of pressurized ground water from the scoured channel boundaries, and snowpack in the canyons that was incorporated in the floodflow.

The 1983 flood in Ophir Creek was probably the largest during historical times. Although the flood of July 6, 1890, was frighteningly similar, as described in newspaper accounts, no quantitative data on the 1890 flood are known for comparison with the 1983 flood. However, the description of the 1890 flood indicates that the 1983 flood was not unique. The peak-flow rate near the mouth of the lower canyon during the 1983 flood was about 25 times greater than that predicted for a 100-year flood. Predicted areas of potential debris hazards were predicated on much less severe flooding; as a result, the alignment of actual hazardous areas were skewed from those predicted, and the predicted degrees of hazards generally were exceeded. The large number of eyewitnesses and participants in the 1983 flood temporarily focused local attention on the severity of both real and potential hydrogeological hazards on the slopes and around the eastern base of Slide Mountain. However, over time, concerns about potential hazards apparently decreased and the development and occupation of the area quickly resumed and currently (1996) continues. Natural revegetation of the

originally barren land surface created by debris deposition of the flood have been documented by photographs for more than a decade.

Ophir Creek and the southeastern slopes of Slide Mountain have been subjected to catastrophic landsliding and associated flooding for thousands of years. The most recent landslide and flood of 1983 was small in comparison to at least nine prehistoric events. Natural hydrogeological processes and specific peculiarities of the local geologic setting of the landscape all favor repetition of these types of catastrophes in the future.

Future hazardous landslides at Slide Mountain, with or without flooding, are almost certain. Flooding of a magnitude and severity greater than the 1983 flood is still possible, even if upstream manmade reservoirs are kept smaller than those in 1983, because damming of the deep canyons also can take place through natural landslide processes. Subsequent overflows of the natural impoundments caused by these unpredictable, localized landslides could result in the rapid releases of volumes of water equal to or greater than those chaotically released in 1983. The probable magnitudes, characteristics, and timing of these potential floods and landslides are unpredictable because of a lack of both general and detailed knowledge of the necessary antecedent conditions and subsequent actions and interactions of the triggering hydrogeological processes.

The prolific record of past landslides and floods at Slide Mountain emphasizes the likelihood of recurrences. This substantial history, combined with the uncertain nature and current unpredictability of these landslide-flooding events, serves notice of a continued threat to safety.

## REFERENCES CITED

- Anderson, L.R., Keaton, J.R., Sarrinen, T.F., and Wells, W.G., II, 1984, The Utah landslides, debris flows, and floods of May and June 1983: National Research Council, National Academy Press, 96 p.
- Barnes, H.H., Jr., 1967, Roughness characteristics of natural channels: U.S. Geological Survey Water-Supply Paper 1849, 213 p.
- Beverage, J.P., and Culbertson, J.K., 1964, Hyperconcentrations of suspended sediment: Proceedings of the American Society of Civil Engineers, Journal of the Hydraulics Division, v. 90, no. HY6, p. 117-128.
- Bonham, H.F., 1969, Geology and mineral resources of Washoe and Storey Counties, Nevada, *with a section on industrial rocks and mineral deposits*, by K.G. Papke: Nevada Bureau of Mines Bulletin 70, 40 p.
- Costa, J.E., 1984, Physical geomorphology of debris flows, *in* Costa, J.E., and Fleisher, P.J., eds., Development and applications of geomorphology: Berlin, Springer-Verlag, p. 269-317.
- Costa, J.E., 1988, Rheologic, geomorphic, and sedimentologic differentiation of water floods, hyperconcentrated flows, and debris flows, *in* Baker, V.R., Kochel, R.C., and Patton, P.C., Flood geomorphology: New York, John Wiley, p. 113-122.
- Costa, J.E., and Jarrett, R.D., 1981, Debris flows in small mountain stream channels of Colorado, and their hydrologic implications: Bulletin of the Association of Engineering Geologists, v. 18, p. 309-322.
- Crippen, J.R., and Bue, C.D., 1977, Maximum floodflows in the conterminous United States: U.S. Geological Survey Water-Supply Paper 1887, 52 p.
- Dalrymple, Tate, and Benson, M.A., 1967, Measurement of peak discharge by the slope-area method: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A2, 12 p.
- Davis, G.H., and Reynolds, S.J., 1996, Structural geology of rocks and regions: New York, John Wiley, 776 p.
- Ellen, S.D., and Wiczorek, G.F., 1988, Landslides, floods, and marine effects of the storm of January 3-5, 1982, in the San Francisco Bay region, California: U.S. Geological Survey Professional Paper 1434, 310 p.
- Fenneman, N.M., 1931, Physiography of Western United States: New York and London, McGraw-Hill, 534 p.
- Folk, R.L., 1980, Petrology of sedimentary rocks: Austin, University of Texas, Hemphill Publishing Co., 182 p.
- Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, New Jersey, Prentice-Hall, 604 p.
- Glancy, P.A., 1969, A mudflow in the Second Creek drainage, Lake Tahoe Basin, Nevada, and its relation to sedimentation and urbanization, *in* U.S. Geological Survey Research 1969: U.S. Geological Survey Professional Paper 650-C, p. C195-C200.
- Glancy, P.A., and Katzer, T.L., 1977, Flood and related debris flow hazards map, Washoe City quadrangle [Nevada]: Nevada Bureau of Mines and Geology Urban Map Series, Washoe Lake Folio, Map 5A1, 1 sheet, scale 1:24,000.
- Goodwin, Victor, 1977, Flood chronology, Truckee River Subbasin, Central Lahontan Basin, 1861-1976: U.S. Department of Agriculture, water and related land resources report, 302 p.
- Harbaugh, A.W., and McDonald, M.G., 1996, User's documentation for MODFLOW-96, an update to the U.S. Geological Survey modular finite-difference groundwater flow model: U.S. Geological Survey Open-File Report 96-485, 56 p.

- Iverson, R.M., and La Husen, R.G., 1993, Friction in debris flows—Inferences from large-scale flume experiments: Hydraulic Engineering '93, Proceedings of American Society of Civil Engineers, National Conference on Hydraulic Engineering, v. 2, p. 1604-1609.
- Jarrett, R.D., and Costa, J.E., 1984, Hydrology, geomorphology, and dam-break modeling of the July 15, 1982, Lawn Lake Dam and Cascade Lake Dam failures, Larimer County, Colorado: U.S. Geological Survey Professional Paper 1369, 78 p.
- Johnson, A.I., 1967, Specific yield—Compilation of specific yields for various materials: U.S. Geological Survey Water-Supply Paper 1662-D, 74 p.
- Johnson, A.M., with contributions by Rodine, J.R., 1984, Debris flow, chap. 8 of Brunnsden, Denys, and Prior, D.B., eds., Slope instability: New York, John Wiley, p. 257-361.
- Leopold, L.B., 1974, Water—A primer: San Francisco, W.H. Freeman, 172 p.
- Major, J.J., 1996, Experimental studies of deposition by debris flow—Process, characteristics of deposits, and effects of pore fluid pressure: Seattle, University of Washington, unpublished Ph.D. dissertation, 341 p.
- Major, J.J., and Iverson, R.M., 1993, Is the dynamic behavior of a debris flow recorded by its deposit?: Eos, American Geophysical Union Transactions, v. 74, no. 43, p. 315.
- Maurer, D.K., 1986, Geohydrology and simulated response to ground-water pumpage in Carson Valley, a river-dominated basin in Douglas County, Nevada, and Alpine County, California: U.S. Geological Survey Water-Resources Investigations Report 86-4328, 109 p.
- Maurer, D.K., Berger, D.L., and Prudic, D.E., 1996, Subsurface flow to Eagle Valley from Vicee, Ash, and Kings Canyons, Carson City, Nevada, estimated from Darcy's Law and the chloride balance method: U.S. Geological Survey Water-Resources Investigations Report 96-4088, 74 p.
- Morris, D.A., and Johnson, A.I., 1967, Summary of hydrologic properties of rock and soil materials, as analyzed by the hydrologic laboratory of the U.S. Geological Survey 1948-60: U.S. Geological Survey Water-Supply Paper 1839-D, 42 p.
- National Climatic Center, 1921-1984, Climatological data, annual summaries, Nevada, 1920-1983: Asheville, N.C., U.S. National Oceanic and Atmospheric Administration, v. 25 to v. 98, no. 13 (published annually).
- National Oceanic and Atmospheric Administration, 1983, Climatological data, Nevada, May 1983: National Climatic Center Report, v. 98, no. 5, 22 p.
- Nevada Division of Water Planning and U.S. Soil Conservation Service, 1981, Summary of snow measurements for Nevada, 1910-1980, and pertinent measurements in California and Oregon: Nevada Department of Conservation and Natural Resources and U.S. Department of Agriculture, 295 p.
- Pierson, T.C., 1985, Initiation and flow behavior of the 1980 Pine Creek and Muddy River lahars, Mount. St. Helens, Washington: Geological Society of America Bulletin, v. 96, p. 1056-1069.
- Pierson, T.C., and Costa, J.E., 1987, A rheologic classification of subaerial sediment-water flows, in Costa, J.E., and Wicczorek, G.F., eds., Debris flows/avalanches—Process, recognition, and mitigation: Reviews in Engineering Geology, v. VII, p. 1-12.
- Pierson, T.C., Janda, R.J., Thouret, Jean-Claude, and Bonero, C.A., 1990, Perturbation and melting of snow and ice by the 13 November 1985 eruption of Nevada del Ruiz, Columbia, and consequent mobilization, flow, and deposition of lahars: Journal of Volcanology and Geothermal Research, v. 41, p. 17-66.
- Ratay, M.S., 1973, Pioneers of the Ponderosa—How Washoe Valley rescued the Comstock: Sparks, Nevada, Western Printing and Publishing Company, 470 p.
- Rouse, Hunter, 1950, Fundamental principles of flow in Engineering Hydraulics, Proceedings of the Fourth Hydraulics Conference, Iowa Institute of Hydraulic Research, June 12-15, 1949, edited by Hunter Rouse, 1,039 p.: New York, John Wiley, p. 1-135.
- Scott, K.M., 1988, Origins, behavior, and sedimentology of lahars and lahar-runout flows in the Toutle-Cowlitz River system: U.S. Geological Survey Professional Paper 1447-A, 74 p.
- Scott, K.M., Vallance, J.W., and Pringle, P.T., 1995, Sedimentology, behavior, and hazards of debris flows at Mount Rainier, Washington: U.S. Geological Survey Professional Paper 1547, 56 p.
- Shearman, J.O., Kirby, W.H., Schneider, V.R., and Flippo, H.N., 1986, Bridge waterways analysis model: Research report, WSPRO, Updated June 1, 1988: U.S. Department of Transportation, Federal Highway Administration Report, FHWA/RD-86/108, 112 p.
- Slemmons, D.B., Jones, A.E., and Gimlett, J.I., 1965, Catalog of Nevada earthquakes, 1852-1960: Seismological Society of America Bulletin, v. 55, no. 2, p. 519-565.
- Tabor, R.W., and Ellen, S., 1975, Geologic map, Washoe City quadrangle: Nevada Bureau of Mines and Geology Urban Map Series, Washoe City Folio, Map 5Ag, 1 sheet, scale 1:24,000.
- Tabor, R.W., Ellen, S., Clark, M.M., Glancy, P.A., and Katzer, T.L., 1983, Geology, geophysics, geologic hazards and engineering and geologic character of earth materials in the Washoe Lake area—Text to accompany maps of the environmental series, Washoe County quadrangle: Nevada Bureau of Mines and Geology Open-File Report 83-7, 87 p.

- Thompson, G.A., and White, D.E., 1964, Regional geology of the Steamboat Springs area, Washoe County, Nevada: U.S. Geological Survey Professional Paper 458-A, 52 p.
- Trask, P.D., 1932, Origin and environment of source sediments of petroleum: Houston, Texas, Gulf Publishing Co., 323 p.
- U.S. Geological Survey, 1968a, Topographic map of the Washoe City, Nev., 7-1/2-minute quadrangle: U.S. Geological Survey topographic map, 1 sheet.
- 1968b, Topographic map of Mount Rose, Nev., 7-1/2-minute quadrangle: U.S. Geological Survey topographic map, 1 sheet.
- U.S. Soil Conservation Service, 1983a, Water supply outlook for Nevada as of April 1, 1983: U.S. Department of Agriculture, 20 p.
- 1983b, Water supply outlook for Nevada as of May 1, 1983: U.S. Department of Agriculture, 19 p.
- 1983c, Water supply outlook for Nevada as of October 1, 1983: U.S. Department of Agriculture, 10 p.
- U.S. Weather Bureau, 1932, Climatic summary of the United States. Section 19—Climatic data from the establishment of stations to 1930, inclusive—Nevada: United States Department of Agriculture, 34 p.
- Van Dine, D.F., 1985, Debris flows and debris torrents in the southern Canadian Cordillera: Canadian Geotechnical Journal, v. 22, p. 44-68.
- Varnes, D.J., 1978, Slope movement and processes, *in* Schuster, R.L., and Krizek, R.J., eds., Landslides, analysis, and control: National Research Council, Transportation Research Board Special Report 176, p. 11-33.
- Watters, R.J., 1983, A landslide induced waterflood-debris flow: International Association of Engineering Geology Bulletin, no. 28, p. 177-182.

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# APPENDIX A

## LANDSLIDE, FLOOD, AND WEATHER HISTORY

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## Previous Landslides

The Slide Mountain landscape shows abundant evidence of a long and continuous record of landsliding, especially large-scale rockfall avalanching. The barren, precipitous southeastern face of the mountain (frontispiece) is a large, composite, landslide scar from which the mountain derives its name. The deposits of these slides were first mapped by Thompson and White (1964, pl. 1). They differentiated the deposits by age into the general categories of "older" and "younger" slides from Slide Mountain, although they acknowledged "intermittent sliding over a long range of time is clearly demonstrated by differences in weathering and erosion of the debris and by alluvial burial of the lower parts of the oldest slides" (Thompson and White, 1964, p. A23). They calculated a conservative estimate of the total volume of granodiorite that slid away from the southeastern face of the mountain to be on the order of 125 million yd<sup>3</sup>. About a decade later, Tabor and Ellen (1975) prepared a more detailed map of the Slide Mountain landslide deposits. Their investigation revealed evidence of at least nine rockfall-avalanche and debris-flow (landslide) deposits extending from the large main scar downgradient along the axis of Ophir Creek. The characteristics of these deposits are described in detail by Tabor and others (1983, p. 18-21). The landslide deposits mapped by Tabor and Ellen, which they called the "Debris Flows of Slide Mountain," include most of those mapped earlier as the "older and younger slides from Slide Mountain" by Thompson and White (1964). (Area mapped by Thompson and White is greater than that of Tabor and Ellen.) Figure 4 depicts the areal extent of Tabor and Ellen's "debris flows" (dominantly rockfall-avalanche deposits; S. Ellen, U.S. Geological Survey, written commun., 1994). The figure does not differentiate the separate episodes of movement as interpreted by them; however, it separates areally the rockfall-avalanche deposits from the dominantly fluvial deposits of Ophir Creek that they also mapped as part of their investigation.

Some of the larger avalanche deposits extend along the entire length of the combined upper and lower canyons of Ophir Creek and onto the floor of Washoe Valley (about 3.4 mi; fig. 6); they are the products of massive and catastrophic movements of rock and debris. Other smaller landslides also are recognizable, some of which are located just west of the area mapped by Tabor and Ellen in the main slide-scar area; they include a series of relatively young lobate deposits

located north and east of Upper Price Lake (fig. 14). Some of these young avalanche deposits appear to have created, or contributed to the creation of, the depressions which contain Upper and Lower Price Lakes.

A partially exhumed log, 3 ft in diameter, was discovered at the base of the steep slope beneath the outlet of Lower Price Lake during investigation of the 1983 flood (fig. 14). It appeared to have been exhumed by heavy cascading streamflow during the expulsion of the lake. A carbon-14 sample of the log yielded an age of  $999 \pm 55$  years. The log was probably buried by earlier rockfall avalanche deposits (fig. 14) and may date the age of some of those deposits. It is uncertain which of the relatively young rockfall-avalanche deposits contain the tree because the undifferentiated deposits shown in the map of figure 14 appear to have been emplaced by multiple events. The apparent age of the tree does agree, within the range of uncertainty, with the 1,100-year-old age obtained by Tabor and others (1983, p. 20) from debris buried by their rockfall-avalanche "unit 5."

Tabor and others (1983, p. 18-21) describe the physical characteristics of the deposits that mantle the land surface of most of the Ophir Creek Basin downstream from Slide Mountain and the flow processes responsible for those deposits. Of the nine deposits they differentiated, the oldest eight were emplaced primarily as rockfall avalanches (p. 18), whereas the youngest appears to be the product of a debris flow (Tabor and others, 1983, p. 20). The rockfall-avalanche deposits typically consist of a poorly sorted mixture of granitic blocks in a silty sand matrix. Locally, they consist almost entirely of granitic blocks up to, or greater than, 9 ft in diameter (Tabor and others, 1983, p. 18). Discrete units are characterized by hummocky, chaotic terrane with bulbous frontal lobes locally in excess of 90-ft high. The deposits have partly filled the canyons occupied by Ophir Creek, a normally small stream, which has incised into the successive deposits. Debris-flow deposits (of fluvial genesis) of lesser volume and extent are recognizable along, and confined to, the canyon beds.

The general age of landsliding is late Quaternary. The oldest mapped, and most areally extensive, rockfall-avalanche deposits are considerably older than the deposits of succeeding flows; those earliest deposits are estimated to be several hundreds of thousands of years old (Tabor and others, 1983, p. 20). Several of the succeeding avalanches and flows appear to postdate Tahoe-age (60,000 - 120,000 years ago) glacial till that surficially is exposed on the south side of Upper Price

Lake. At least four rockfall-avalanche deposits and one debris-flow deposit generally are younger than 1,100 ± 200 years, based on the age of a sample of carbonized wood discovered by Tabor and others (1983, p. 20) in deposits beneath their "unit 5." Younger deposits, including those confined within the creek canyon and downstream on the alluvial fan, include deposits of debris flows or water-dominated, debris-laden floods, or both.

Slemmons and others (1965, p. 533) mention an alleged historical (1852) landslide from Slide Mountain. Newspapers and other documents on file at the Nevada Historical Society, Reno, Nev., also indicate that a rockfall-avalanche occurred in 1852, and that a probable debris flow happened in the early 1860's. The rockfall-avalanche report seems to be substantiated, but the volume of displaced rock as reported in newspaper accounts seems to have been over estimated. The Washoe Weekly Times newspaper of June 10, 1865, describes the avalanche as happening in late November or early December of 1852; the November 27, 1894, issue of the Virginia City Territorial Enterprise cites Paiute Indian accounts of a large earthquake and related landslide at Slide Mountain "a great many years ago." On the basis of these historical accounts, and possibly others, Slemmons and others (1965, p. 533) concluded that an earthquake of unknown intensity near Pyramid Lake (about 45 mi northeast of Ophir Creek) was responsible for the slide. However, the mapping of Tabor and Ellen (1975) and the accompanying text (Tabor and others, 1983) indicate that the bulk of the landslide debris in the Ophir Creek drainage to be significantly older than the earliest historical records. Scientific evidence for any landslides during 1852 is lacking. The newspaper accounts seem to be largely based on unsubstantiated non-scientific information; the size and severity of a landslide, as they describe it, seems grossly overestimated. If a slide occurred in 1852, its deposits probably are contained within the sequence of smaller, multiple-landslide deposits identified as having occurred during the last 1,100 years.

Several other accounts of relatively recent landslides at Slide Mountain have been printed and reprinted from time to time, including a humorous fictional account titled the "Great Landslide Case" in Mark Twain's book, "Roughing It." Ratay (1973, p. 335-336), describes several accounts of Slide Mountain landslides. Although interesting, the accounts are not known to have been verified by any documented factual data nor by any known scientific evidence.

The numerous episodes of mass debris movement chronicled above portray a complex and persistent Quaternary-age history of catastrophic events along Ophir Creek. Debris deposits from these numerous events range up to hundreds of feet thick in many places, and they may overlie and conceal evidence of additional earlier events. Tabor and others (1983, p. 18) indicated that some of the slide deposits may have been cut by post-depositional faulting, which implies that tectonic activity may have played some part in landscape instability. All in all, the overwhelming evidence of prolonged landscape instability clearly characterizes the lower Ophir Creek drainage as an exceedingly hazardous area.

## **Previous Floods**

### **Floods Caused by Winter Storms**

Severe winter floods, caused by regional storm systems, generally are less frequent than summer convective storms in the arid southwest; however, they can be severe and, because they are regional, sometimes devastate large areas. The following floods and some others are summarized in table 1 of this report.

#### **January 1874**

Goodwin (1977) attributes the January 1874 flood to rain on snowpack. Reportedly, this flood triggered some sort of failure of a natural earthen dam that impounded "Price Lake" (he did not specify Upper or Lower), and the downstream rainfall-runoff flooding of Ophir Creek was thus intensified by the untimely release of some unknown amount of impounded water. Damage caused by this Ophir Creek flood was apparently minimal, or unknown.

#### **November 1875**

A flood in November 1875 was the result of heavy rainfall runoff caused by a regional, early winter storm (Goodwin, 1977). Goodwin states that this Ophir Creek flood also was intensified by partial failure of William Price's impoundment of "Price Lake." Resultant damage was reportedly inflicted on Price's logging flume, located adjacent to the downstream creek channel, and to the Virginia and Truckee Railroad trestle where the railroad crossed Ophir Creek on the valley floor.

## July 1890

The greatest historical flood of Ophir Creek, before that in 1983, was on July 6, 1890. The flood probably resulted from the failure of a dam at Price Lakes (Goodwin, 1977). Apparently, the 1890 flood was at least partially the product of heavy runoff of snowmelt following a winter of abnormally heavy snowfall in the Sierra Nevada. Because there are no known records of mountain snowpack during the winter of 1889-90, the only meaningful quantitative comparison of the 1889-90 and 1982-83 winters is the precipitation recorded in nearby Reno (table 3). Cumulative precipitation there for the 1889-90 period (October 1889-June 1890), before the July 6, 1890, flood, was 15.35 in. Cumulative precipitation for the 1982-83 winter (October 1982-May 1983), before the May 30, 1983, flood was 10.57 in. In comparison, mean annual

precipitation recorded at Reno for the 113-year period of 1871-1983 is 7.27 in. The heaviest calendar-year precipitation recorded in Reno during the period was 13.73 in. during 1890; the second heaviest was 13.23 in. in 1983. In contrast, the minimum calendar-year accumulation during that period in Reno was only 1.55 in. during 1947.

The July 6, 1890, flood was described within a few days, in varying degrees of detail, by several daily newspapers of northwestern Nevada. The most detailed and vivid description was that published by the Carson City Morning Appeal on Tuesday, July 8, 1890. The article is reproduced verbatim here to retain the journalistic flavor of its time and to allow reader comparisons of the unedited text with eyewitness accounts of the 1983 flood of appendix B in this report. The Appeal report of the 1890 flood is as follows:

### "A BROKEN DAM"

#### Wm. PRICE RUINED BY A BURSTED RESERVOIR

##### How the Flood Came Down the Ravine

On Sunday afternoon at about quarter of 5 o'clock, Price's reservoir at the foot of Slide Mountain burst, and the water rushing down the Canyon submerged the V. & T. track at Franktown, causing a delay of the passenger train, which returned to Carson for the night.

##### SCENE OF THE BREAK

Slide Mountain takes its name from the fact that some years ago about half the mountain caved away and fell into the valley.

The land slide occurred in the night, and it was believed that a band of Mormon emigrants camping at the foot of the mountain were buried in the debris, but the story has never been authenticated.

The convulsion of nature left a hollow place that was utilized by W. E. Price as a site for water storage. He turned a mountain stream into the depression and dammed the lower end.

This gave him a lake three miles long, half a mile wide and seventy-five feet deep. Below this he made another reservoir covering about five acres of land, with the water fifteen feet deep.

These two reservoirs are situated about three miles from the V. & T. R. R. track at an elevation of about two thousand feet.

Leading from the reservoirs is a ravine through which a flume runs. The flume was used for fluming ice and water from the reservoirs. Mr. Price's is at the foot of the flume and here are his barns[sic], residence and ice houses. The improvements and reservoirs are valued at \$25,000.

## A FEARFUL SIGHT

Some of Price's men were in the ravine at work on the flume, when they heard a roar like a train of cars coming. As they looked up the ravine they saw a wall of water thirty feet high and one hundred feet across coming down the ravine. From base to crest it was white as marble, and at the summit it carried a load of logs and boulders.

As the ends lashed and writhed against the sides of the narrow ravine it licked up everything in its path. Fallen trees, underbrush and rocks were sucked into the swirl, and above all was a roar that shook the earth.

## A RACE FOR LIFE

There were three men in the ravine at a point where the sides were too steep to climb, and the only means of escape were down the path about three hundred yards.

The instant the wall of water flashed in sight at the turn of the ravine they dropped everything and fled down the rocky path.

The water was several hundred yards away but gaining at a fearful pace. There was a narrow point in its path where the rocks jutted out from the sides. Here it paused for a few seconds as the accumulation of logs and boulders were caught in the jam, but weight of the water piled up behind soon amounted to thousands of tons, and with a crash the temporary obstruction fell away and the water cleared a hundred feet at one leap.

The three men who were just ahead were nephews of Price, and they think that this temporary checking of the downward sweep of the flood saved their lives.

They reached a spot where they could climb to higher ground, and they barely did so when the water shot past them with a rush and only a few feet below them.

Reaching the hill they tried to sound the alarm to those below, but they were too far away.

## A COURIER SENT DOWN

At this point, however, they found a band of gypsies and one who had a fast horse was sent down to warn Price of his danger. He had to go a round-about way about two miles and reached the ranch too late to be of any service.

Price, however, had seen the water coming and got his family out of the house in time. The foot of the ravine is about half a mile from the house and the water spread out as soon as it ceased to be confined, spreading over about twenty-five acres of land.

It swept away the barn, rose above the lower floors of the house, went through the ice house and then covered the railroad track with debris for about five hundred yards.

The down passenger train which contained an extra quota of ladies and children en route to Reno to attend some school exercises[sic], was delayed until nearly midnight when all efforts to clear the track failed and the train returned to Carson.

## CLEARING THE TRACK

When the news of the break reached Carson, men were sent down on a construction train to clear the track. It was covered with logs and boulders and the water was flowing over it. In about an hour the water stopped and the men were able to work, but suddenly there came another rush of driftwood, water and boulders and covered the track again. When the second rush came, it was supposed that the upper lake dam had broken.

The water subsided and came down again at intervals all night and the men who were at work, about thirty, gave up exhausted about three in the morning. There was also a gang of twenty Chinamen higher up the creek cutting a new channel to divert the torrent by removing boulders, but did not succeed, and in the morning the boulders were blown out with giant powder. This accomplished the desired result and by noon the track was clear.

At the present time it is not known for certain whether the big reservoir is broken or only partially so.

Big waves came down at intervals but smaller than at first. The place is inaccessible except by the ravine and no one dared go up.

The dam was never regarded as strongly constructed and Price has always feared high water. The water which escaped had flowed into Washoe Lake and now men are guarding the Washoe dam for fear of a break.

Several years ago a dam broke near the present one and nearly wiped out Franktown."

The foregoing account is remarkable for the similarities it depicts between the 1890 and 1983 floods. Although the cause of the sudden releases of water from the Price Lakes appear to be different, the downstream effects of these releases seem very similar.

The newspaper account contains some obvious factual errors and other points worth noting. The article implies that the numerous landslides of Slide Mountain were a single event during relatively recent (possibly historical) times; in fact, separate landslides during possibly hundreds of thousands of years have influenced the form of the landscape surrounding the southeastern base of the mountain. The original land-surface depression, currently known as Upper Price Lake, appears to have been a natural sagpond formed along the backside of a slide mass as it moved into the Ophir Creek drainage. Therefore, it was probably a perennial pond before W.E. "Billy" Price increased its storage capacity by increasing the height of the earthfill impoundment at its outlet. The 3-mi length, 0.5-mi width (960 acres), and 75-ft depth attributed to the lake are physically impossible; more realistic dimensions, as described earlier in the "Price Lakes" section of this report, are 4 acres in area with an average depth of 5 ft.

Eyewitness descriptions of the 1890 flood were attributed to workmen who were apparently caught in the lower part of the upper canyon below Lower Price Lake. Their point of escape probably was near the mouth of the upper canyon at the broader channel reach, about 0.6 mi below the outlet of Lower Price Lake (fig. 6). At their speediest, few men can sprint faster than 100 yards in 10 seconds, or 30 ft/s. Because of the rough terrain along the canyon floor, the likelihood that all three were not excellent sprinters, and their required run was about 300 yards, they probably did not average much more than 20 ft/s, or 14 mi/h. They described the flood front as "several hundred yards away but gaining at a fearful pace." This indicates that the flood velocity in the upper canyon may have been on the order of 25-30 ft/s.

The eyewitness description of how the 1890 flood front paused for a few seconds at a narrow spot in the canyon differs from accounts of the 1983 flood, wherein no witnesses noted any stopping or slowing of the debris-laden flood front during its downstream transit. Momentum of the 1983 flood was likely greater than that of the 1890 flood because, although the release of water by the dam failure of 1890 was rapid enough to cause an abrupt vertical front to form at the

leading edge of flow, the rate of release of the lake contents during 1983 probably could not have been equalled or exceeded by a simple collapse of the earthen impoundment. The probable release rate of lake waters during the 1983 flood is discussed elsewhere in this report.

The Nevada Appeal article did not allude to the cause or mechanism of failure of the earthen impoundment other than to concede it was poorly engineered and constructed. However, Goodwin (1977) attributes the dam failure to a strong, down-canyon wind that induced heavy wave action apparently against and over the poorly constructed impoundment. The impounded lake allegedly was filled to capacity by the abnormally heavy snowmelt runoff. According to Goodwin (1977), Lower Price Lake, a reservoir created by another of Price's dams just above the upper canyon, existed before the 1890 flood; its dam too may have failed. The newspaper account includes confusing speculations about which surface-water impoundment actually failed and caused the 1890 flood.

The alleged dispatch of the horse-mounted gypsy to sound a warning downstream also has a parallel in the 1983 flood, wherein Douglas Cook attempted to outrace the leading flood surge by hang glider to warn downstream residents; ironically, airborne technology of nearly a century later was equally as ineffective as the mounted rider at outdistancing the onrushing flood waters.

Descriptions of damage caused by the 1890 flood generally replicate that of 1983, although dollar costs were much greater for the recent flood. There were no fatalities in 1890, but there were fewer human targets along the floodpath. Price's home, owned by the Victor H. Stafford family in 1983, seemed to suffer a nearly identical fate in both floods. In 1890, traffic was halted on the railroad, whereas freeway traffic was halted or delayed in 1983.

The 1890 report of flood waters periodically subsiding and regenerating is difficult to interpret. Canyon walls that were destabilized by the initial onrush of the flood could have periodically caved, temporarily dammed, and subsequently released varying volumes of heavy snowmelt runoff. Or periodic debris-flow surges during the flood recession may have contributed to oscillating flow rates.

The 1983 flood and subsequent snowmelt runoff exhumed older fluvial deposits of Ophir Creek near the mouth of the lower canyon. Figure 57 shows some of these older deposits, including two interstratified zones

of organic-rich sediments. These older sediments are located along the south side of the canyon in the general vicinity of the channel profiles of figure 37. The thickness of this exposed stratigraphic section increases moderately a short distance (50 to 100 ft) upstream from the exposure shown in figure 57; the thicker exposure contains three organic-rich strata. Wood fragments were collected August 26, 1983, from the bottom and middle strata to assess their age by carbon-14 analysis. The approximate ages of the wood fragments are as follows: bottom strata, 130 years; middle strata, 100 years. Because the ages of wood fragments are at least as old as the debris deposits, and probably somewhat older, the overall deposit is interpreted to be a likely product of the July 6, 1890, flood.

#### **March 1907**

A major rain-on-snow flood affected both the Carson and Truckee River Basins on March 16-21, 1907 (Goodwin, 1977). The severe regional nature of this flood virtually ensures that Ophir Creek also was affected, but no specific information on Ophir Creek flooding has yet been discovered.

#### **December 1937**

A heavy rainstorm that caused serious flooding throughout western Nevada, including major flooding of the Carson and Truckee Rivers, also caused intense flooding of Ophir Creek on December 11, 1937 (Nevada State Journal, December 12, 1937, p. 1). Although no quantitative data are available regarding the magnitude, quantity, or duration of streamflow, some perspective on the severity of the flood is contained in a front page photograph of the December 14, 1937, Nevada State Journal. It shows Old Highway 395 where it crosses Ophir Creek littered with debris, including boulders up to several feet in diameter. The photo caption states, "The lost was found last night by Nevada highway department crews when they uncovered the Reno-Carson City highway near Bowers Mansion and opened the road to travel for the first time since Saturday [December 11]. All these boulders were washed onto the road when the normally-diminutive Ophir Creek went on a flood-drunk binge. A four by seven foot culvert was filled rapidly with dirt and rocks and the near-river took out across the highway, leaving a trail of debris that required men and equipment three days to remove." The damage to the highway was characterized as "A 100-yard washout" in an earlier edition



**Figure 57.** Old fluvial deposits near the lower canyon mouth of Ophir Creek, western Nevada, which were exhumed by the 1983 flood. Note dark organic-rich zones exposed within the vertical stream bank—one about a foot above the present streambed, the other about a foot below land surface. Photographed by Patrick A. Glancy on September 8, 1983.

of the newspaper (Nevada State Journal, December 12, 1937, p.1). Edward Parmenter, Nevada Division of Water Resources, retired, was a Civil Engineer with the Nevada Highway Department at the time. He recalls that the flood closed the highway by damaging an approximately 150-ft length of the roadway; he also noted that flow rates were adequate to erode the black-topped surface of the highway (Edward Parmenter, oral commun., 1983). There are no known reports of dam failures at Upper or Lower Price Lakes during this flood.

#### **January 1943**

Rain fell below 8,000-ft altitude throughout the Sierra Nevada and the Sierra-front foothills during January 20-22, 1943. The rainfall was very intense at some times, and caused regional flooding along the eastern Sierra front. Although no specific information on

flooding at Ophir Creek has been discovered, the severe regional character of the storm and resultant flooding implies that Ophir Creek was similarly affected (Goodwin, 1977).

#### **November 1950**

Gustav "Gus" Bundy, a former resident of the property just north of Ophir Creek and just upstream of Old Highway 395, remembered an intense flood during the Thanksgiving period of 1950 (oral commun., 1983). He recalled that, as a result of heavy rainfall, Ophir Creek rumbled boulders along its bed so loudly during the night of heaviest flooding that the sound awoke him from sleep. He also remembered that the highway was closed for some time and that the former "Billy" Price residence downstream from Old Highway 395 received considerable deposition of flood debris from the creek.

Bundy's recollections are supported by an article in the Reno Evening Gazette of November 20, 1950 (p. 13). The news report was summarizing impacts of regional flooding resulting from a series of late November storms that climaxed on November 19 and 20; it characterized Ophir Creek flooding, as follows: "In Washoe County, Ophir Creek overflowed and caused considerable damage north of Bower's Mansion. The creek received the full force of the rain runoff early Sunday morning (Nov. 19), with boulders and sand filling the ditches and plugging the culvert."

"The stream cut deeply into the roadbed and washed 12 to 24 inches deep across the highway, stopping traffic. Highway maintenance crews manning road graders and a scoopmobile were in operation."

"The road was closed shortly before noon Sunday and was reopened at 5 p.m...."

No known quantitative streamflow data are available for either the 1937 or 1950 floods. However, as described by eyewitnesses and the newspaper reports, the 1937 flood probably was more severe.

### **January-February 1963**

Historically, western Nevada has had widespread flooding from regional storms on occasions other than those specified above for Ophir Creek. A particularly notorious regional flood occurred in both the Carson and Truckee River Basins during late January and early February of 1963. Cumulative rainfall on snowpack in the lower elevations of the Lake Tahoe Basin was 11.42 in. in a few days; similarly, 2.34 and 7.30 in. accumulated in Reno and Carson City, respectively (Reno Evening Gazette, February 1, 1963, p. 1). As a result, intensive flooding caused by the rainfall and melted snowpack was universal in all northern Sierra Nevada drainages. Flooding was so widespread that Ophir Creek did not get specific recognition in newspaper accounts, but some flooding of that drainage very likely took place.

### **Weather Data and History**

A systematic network of snowpack measurements was initiated in the Sierra Nevada, and locally in the Lake Tahoe area, in 1910 (Nevada Division of Water Planning and U.S. Soil Conservation Service, 1981, p. 1). Shortly thereafter, this network expanded statewide. As part of the operation and management of this network, summaries of snowpack measurements

are periodically published by the Natural Resources Conservation Service. Monthly water-supply forecasts are published during January-May each year. An edition also is published in October of each year that summarizes the past year and predicts the water-supply outlook for the coming water year. The autumn predictions are largely based on summaries of precipitation, runoff, and reservoir storage for the preceding year. These snowpack records, combined with precipitation records collected by the U.S. National Weather Service, provide a valuable data base to compare weather conditions between different places and over varying time periods. Specifically, they allow comparisons of the varying degrees of wetness between winters, both locally and regionally.

Before 1910, systematically collected weather data consisted mainly of precipitation and temperature information collected at towns and settlements throughout the local area. Most of the measurement sites were at low altitudes and no systematically collected, quantitative data were available regarding snowpack accumulations in the higher altitude parts of the Sierra Nevada where most precipitation falls and accumulates. Locally, the precipitation records for Reno, about 15 mi to the northeast, provide the best information on the degree of winter wetness that likely prevailed in the Ophir Creek area prior to 1910. These Reno data indicate that the wettest winter of historical record in the region was probably the winter of 1889-90. Cumulative precipitation during the period October 1, 1889-June 30, 1890 (about 1 week before the July 6, 1890, Ophir Creek flood discussed above in this appendix), was 15.36 in. (table 3). The notorious character of this severe winter is further borne out by its name "The Winter of White Death," which was bestowed by ranchers and others of the time. That name singularly characterizes it as a winter of unusually heavy snowfall and cold temperatures that killed large numbers of livestock across northern Nevada. Therefore, the precipitation data of table 3 and general historical notoriety strongly indicate that the 1889-90 winter was the wettest, or certainly one of the wettest, in the recorded history of the northern Sierra region. Further comparisons of precipitation at Reno between the 1889-90 and 1982-83 winters are given in the part of this appendix describing the flood of 1890.



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# APPENDIX B

## EYEWITNESS ACCOUNTS OF THE LANDSLIDE AND FLOOD

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The May 30, 1983, landslide-induced flood was witnessed and experienced by an unusually large and diverse group of people, compared to most other Nevada floods that have occurred in small drainages. Some of the eyewitness accounts described herein were printed in local newspapers and others were obtained through personal interviews. The accounts are summarized in this report because most provide some valuable scientific information regarding the physical character of, and processes involved in, the landslide and flood. Also, they provide an important humanistic dimension and perspective to this natural disaster. Figure 2 shows locations of the eyewitnesses during the time they observed the event. Locations of a few of the observers, as noted in figure 2, are only approximate. However, the few tenuous locations represent the authors' best judgment of the vantage points of the observers based on their recollections and testimony. One observer, Mrs. E. H. Thom, witnessed the flood from a circling aircraft; thus, her locations are not shown in the figure. A possible flight path for Doug Cook, who observed the slide and flood during a hang-glider journey is estimated on the basis of his testimony; this assumed path probably is a reasonable approximation of his actual route over the terrain.

**Ronald P. Mentgen** (interviewed by P.A. Glancy on July 21, 1983)

Mentgen was cross-country skiing in the upper part of the Ophir Creek Basin during the morning of May 30, 1983. His route was generally southeastward from the Mount Rose Highway (Nevada State Route 431) and generally was downslope across the Tahoe Meadows area (a broad, gently sloping, grassy area adjacent and downstream from Nevada State Route 431 and upstream from Price Lakes; fig. 1). He arrived at the crest of a ridge several hundred feet vertically above Upper Price Lake, which overlooks the lake and the southeast face of Slide Mountain, about 11:30 a.m. (fig. 2). He observed that the northern half of the lake was ice-covered, and he then retreated a short distance behind the ridgecrest and sat down to eat lunch. From that position he was unable to see the lake, but he could still see part of the southeastern slopes of Slide Mountain. While eating lunch, he heard a rushing sound suggestive of wind, and, glancing toward Slide Mountain, he observed trees moving downslope in an upright position. He noted that the trees moved in one smooth pulse. His vantage point did not permit him to observe

the slide mass entering the lake. After not less than 2, nor more than 5 minutes, he returned to the ridgecrest and noted that Upper Price Lake was essentially drained, but that some very turbid "coffee-colored" water continued to drain down the creek from the lake outlet.

### **Douglas R. Cook**

The following account by Doug Cook was summarized from a newspaper article and an interview of Cook by P.A. Glancy on June 23, 1983. All direct quotations are from the North Lake Tahoe Bonanza of June 1, 1983 (p. 1 and 2). Cook is the only known witness to the emptying of Upper Price Lake by the landslide.

Doug Cook recalled launching his hang glider from the Slide Mountain ski resort parking lot (north-east of Price Lakes; not shown in fig. 1) on the east-facing slope of Slide Mountain between 11:00 and 11:30 on the morning of May 30, 1983. Cook is a seasoned glider pilot of over a thousand successful launches, many from this same ski-area site. He became airborne at an altitude of about 8,200 ft and, taking advantage of thermal air currents associated with the unseasonably warm day, managed to quickly gain about 500 ft of altitude. He then soared a distance of about 1.5 mi southwestward around the southeast-facing slopes of the mountain toward the barren slide-scarred slopes above and north-northeastward of Upper Price Lake. More rising thermal air currents over this terrain allowed him to gain nearly another 1,000 ft of altitude, and he thus became positioned about 2,000 to 2,500 ft above and over the lake at an altitude approximately equal to that of the mountain summit, or about 9,700 ft. At that stage of the flight he recalls, "I heard a roaring sound, kind of like the sound of a jet engine really close . . . I thought I was going to get hit. Out of the corner of my eye I could see a bunch of rising dust."

Looking down toward the source of the rising dust, Cook witnessed the landslide moving down the mountain face and finally halting in Upper Price Lake at the base of the slope.

"When it hit the lake," he said, "it was like a huge explosion. It just blew the whole lake apart. It looked like a tidal wave at first and then the canyon gathered it up."

Cook was unaware that the flood also dislodged the contents of Lower Price Lake about 0.1 mi downstream from Upper Price Lake. "As far as I could see it

was Upper Price Lake spilling into the canyon. I don't remember it hitting Lower Price Lake." It is likely that most of the lower lake was covered with ice and snow and not discernible by Cook as a body of standing water prior to its expulsion by the onrushing "tidal wave." He noted that the confinement of the flow in the upper canyon of Ophir Creek caused the deluge to accumulate debris as it flowed downgradient. He did not note any pauses or subsequent surges of the mass during its transit. "It didn't have a chance to dissipate before it got down there. I saw trees just getting plowed down and it was gaining momentum. At this time it was between 40 and 50 ft high, weaving down the canyon."

"I was really concerned because of the fact that I know a lot of people go to that area and a lot of people fish there and if they were down there it would be all over." Cook also recognized the impending crisis to unsuspecting residents downstream. He began to race with the flood surge to try to warn downstream victims, but soon realized the futility of outrunning the flood with a great enough time margin to allow him to sound adequate warnings.

During his chase he witnessed the "snake's head" (leading flood surge) enter a gorge (probably the lower canyon) and he turned his craft and glided back to the ski area. "I left my glider there and ran down to the launch area and started telling all my friends to look down there and watch. Then all of a sudden we saw that big, brown wave cross Bower's Mansion road (Old Highway 395) and we saw a school bus and cars being washed out."

On questioning by Glancy, Cook first estimated the time span between the entry of the slide into the lake and the floodflow crossing Old Highway 395 (NV State Route 429) as about 5 minutes. On suggestion, he conceded it could have taken 8 or 9 minutes, but was adamantly unwilling to extend the travel time beyond 10 minutes. The approximate route of Cook's hang glider traverse is shown in figure 2.

**James Schumacher** (interviewed by P.A. Glancy during early June 1983)

Schumacher and a friend were hiking uphill toward the Price Lake area along the forest trail south of Ophir Creek during the morning of May 30. They had ascended beyond the mouth of the upper canyon and were climbing up the nose of the steep ridge that forms the south canyon wall (fig. 2). They were approaching Lower Price Lake, and although their

actual proximity to that site is not certain, they were probably within a 0.25-mi map distance from the lake. Suddenly, they heard a roaring sound that they later realized was that of the moving landslide. Their location was out of sight of the slide or of Price Lakes. At the request of Schumacher's friend, he noted the time of the roaring sound by his wristwatch as about 11:53 or 11:54 a.m., depending on the accuracy of the time-piece.

Schumacher quickly walked a few tens of feet northward to the canyon rim to view the possible source of the roaring sound and, instead, caught a glimpse of the flood roaring down the canyon below. The sight he witnessed is shown in the photograph of figure 23. It shows a glimpse of highly turbulent and turbid streamflow thrashing about in the canyon. The photograph is believed to depict the earlier stages of the flood, possibly the leading edge of the flood surge or possibly the early recession of the leading edge. Based on the extreme turbulence shown in the photo, the flow may have been water dominated during this early stage.

The couple then decided against continuing uphill toward the slide area and retraced their route downhill. The trail swings northward sharply at the mouth of the upper canyon and descends onto the relatively open flood plain of the creek. The flood plain broadens through this short reach that is unconfined by the canyon walls. Schumacher again photographed the flood in progress from a site where the trail formerly descended to the flood plain at the upper canyon mouth (fig. 24). He recalls the period between the times of the two photographs as about 10-15 minutes (oral commun., 1983). His approximate positions when he took the photographs are shown in figure 2.

Figure 24 shows a different hydraulic character than that shown in figure 23. The fluid appears to be a sediment-dominated mixture in the later photo, and the debris-choked mass seems to be moving as an integral block, or plug, bounded by frothing fluid turbulence along the edges of the flow. Boulders moving at the surface of the flow appear to range in size up to 1 or 2 ft in diameter. The flow character depicted by this photograph is probably that of a debris flow.

**Mark Bridgewater** (interviewed by P.A. Glancy on the afternoon of June 1, 1983)

Mark Bridgewater and his wife were hiking along the forest trail south of Ophir Creek, from Old Highway 395 to Price Lakes, on the morning of May 30,

1983. His first recollection of the slide was an audible rumble, reminiscent of the sound of a jet aircraft. He was in a position to see the movement of the slide almost immediately after he heard the initial rumbling sound. He watched the triangular-shaped rock mass slide downward almost as an integral unit. Its velocity appeared to accelerate with time and travel distance. The edges of the moving mass were the zones of visual turbulence. There was a small amount of airborne dust kicked up by the slide movement. His vantage point did not allow a view of the slide entering Upper Price Lake.

Bridgewater first sighted the flood after it had flowed about a mile, according to his estimate. He is certain he first saw the flood less than 10 minutes after he first noticed the slide movement. Bridgewater estimates his vantage point was about a mile above and away from the channel site when he first spotted the flood (fig. 2). It is unclear whether he was observing it in the upper or lower canyon segment, but most likely in the lower canyon. The leading edge of the flood did not appear as a vertically standing wall from his angle of view, but instead appeared as a deep soupy mud or sludge that was moving very fast. He was particularly impressed by the superelevated surface of the mass as it negotiated curves in the channel, and by the debris-choked nature of the fluid. Effects of the debris colliding with large conifer trees in its path were most impressive to Bridgewater; the flow would flex the large trees so violently during impact that their top 6 to 8 ft would abruptly break from the main trunk.

**William and Elizabeth Willets** (interviewed by P.A. Glancy on February 24, 1985)

The Willets had been hiking up the north side of Ophir Creek from the Davis Creek Park campground about a mile north of Ophir Creek (fig. 2) during the late morning of May 30. After hiking about 1.5 mi southwest from the campground, they reached a meadowlike area where some smaller tributaries join Ophir Creek from the north; this site is part of the wide floodplain area between the upper and lower canyon segments of Ophir Creek (fig. 2). They were hoping to ford the creek and continue hiking up the south side, but the flow of the creek was greater than they had seen it on previous visits. Bill approached the swiftly flowing stream and made his way across a small overflow channel to an island adjacent to the main channel.

Elizabeth was watching his attempts to cross the creek when she heard a loud roaring noise upstream. She looked toward the source of the noise and saw large trees falling down the upper canyon walls into the channel. She then sighted a huge wave of water and debris approaching. The leading edge of the flow front appeared vertical. She screamed to Bill to warn him of the approaching hazard, and he quickly leaped back across the small channel that separated them. He then glanced upstream and saw the approaching flood front, which appeared so close and seemed to be moving so rapidly that he instinctively crouched to the ground and covered his head with his hands for self protection. After a brief moment, he realized the flood had not yet struck so he looked upstream again, reassessed the situation, and then they both scrambled away from the creek channel. They both noted that the approaching flood mass was brown colored and that the front of it was carrying numerous large trees that were being tossed about like toothpicks. They also noted that the moving mass was plowing large boulders from the creekbed and incorporating them as it flowed.

As they raced northward, the flood front exited the upper canyon mouth and began to spread out over the wider flood plain where they were fleeing. As the flow spread laterally, it reached to within 50 ft of them and splattered them with mud. The velocity of the approaching fluid appeared to decrease during the lateral spreading of the flow, and they managed to outrun it.

They continued toward higher ground and ultimately climbed a small hill, still within sight of the flood. Bill estimates that the velocity of the approaching flood front when first sighted in the canyon was on the order of 20 to 30 mi/h. As they looked back upstream from their hilltop vantage, Elizabeth noted "water gushing out of the side of the mountain." Bill observed, "It looked like a good waterfall." During the 20 to 25 minutes they remained in the area after the arrival of the initial flood front, heavy debris-laden floodflow continued to come down the channel within their field of view. They could still hear the flow roaring after they hiked across the ridge to the north.

### **Tom Reed and Others**

The following experiences of occupants of the Tom Reed residence on the proximal (upstream part) of the Ophir Creek fan are summarized from (1) newspaper stories in the Reno Gazette-Journal (June 1, 1983,

p. 3A; and May 28, 1984, p. 1C) and the Nevada Appeal (June 1, 1983, p. 8A); (2) an interview of Tom Reed by P.A. Glancy on June 1, 1983; (3) a discussion between Raymond Isernhagen and Glancy in 1985; and (4) an interview of Kathleen Thompson by Glancy on June 15, 1983. All direct quotations are extracted from the newspaper stories.

Tom and Linda Reed were completing construction of their new home situated on the north-bank terrace of Ophir Creek, about 0.2 mi upstream from Old Highway 395 (Nevada State Route 429). During the late morning of May 30, 1983, Tom was performing interior work on the home with the assistance of three friends, Joseph Valenzuela, Tim Miller, and John Burrue. Reed recalls that the flow of the creek appeared to be about twice that of normal flow. Miller also noticed the creek was flowing faster than normal, but the flow was not great enough to be frightening. Burrue recalled, "I was in the back part of the house watching the river and suddenly it started making a real roaring noise."

"I heard the creek make a rumbling sound and I asked Tom if it always did that. Then Tom and I both looked out the back window and we saw a mountain of dirt and trees coming out of the ground like someone was tearing things up with a big bulldozer."

Valenzuela also noticed the oncoming debris-laden flood front and exclaimed, "Oh my God!" Reed immediately and urgently yelled to the rest of the group to run for safety. He recalled that, at first sighting, the onrushing surge appeared to be about a hundred yards upstream. Tom was reportedly the first out of the house, followed by Burrue and Valenzuela; Miller was last. Linda was preparing lunch in a motorhome parked next to the house (Raymond Isernhagen, neighbor, oral commun., 1985). She apparently ran about the same time the men were abandoning the house.

They ran eastward, roughly parallel to the direction of the onrushing flow front, along a well-used path that Reed recalled led toward a high mound about a hundred yards ahead (eastward), which he hoped would provide refuge. Miller only managed to run about 20 ft before he was overtaken and swept up by the flood. He estimates he was transported 350 to 375 ft within about 4 seconds. [NOTE—The time of travel may be about correct, but the distance was probably closer to 100-200 ft.]

Burrue remembers tripping on the brush and falling along the path shortly after exiting the house. "I got up and looked. There was the house. It was moving

toward me." He then ran between two parked trucks. The flood surge slammed the two trucks together and Burrue was almost pinned and crushed between them. He was somehow overrun by one of the moving trucks. "The right front tire rolled on my back and I couldn't breathe. Then another wave of mud washed it off me, but when it did, the truck swirled to my left and I went further under it and it pinned my leg."

Burrue also recalled, "I couldn't breathe. The mud was coming up to my nose. Then it (the mud) peaked out and started going down."

Reed recalls looking backward only once during his race and noted that his house was racing with him, and gaining; this realization spurred him on to greater speed and he managed to make it safely to the high ground. On arrival, he turned and noted that the flood-front surge had passed and the flow following the peak surge had already receded from the higher terrace, along which they had raced, back into the normal flood plain of the creek. Numerous flood-deposited boulders, wreckage of his home, and vehicles were scattered about over the terrace. He was unable to see the other members of his group.

Reed was near Miller, whose urgent screams quickly attracted him, and he pulled Miller's broken, but live, body from the mud. He next discovered Burrue trapped in the mud beneath the pickup truck, extracted the jack from the truck, jacked the truck up, and pulled Burrue to safety. After searching, he was unable to locate his wife, and after a long period of further searching, he discovered Valenzuela's body.

Linda Reed also was overtaken by the flood surge, apparently by the fine-grained, muddy, matrix fluid that continued flowing after the accompanying boulders came to rest on the terrace. She was swept along by the muddy matrix fluid that drained from the terrace toward the northeast and away from the main creek channel (fig. 29). The mud-choked flow flushed Linda around the north side of the mound to which Tom had escaped, and swept her into Gordon Thompson's backyard, about 0.1 mi east-northeast of the Reed residence. Thompson, and his wife Kathleen, witnessed Linda being tumbled into their yard on the crest of the muddy surge, through a hole in their chain-link fence. Despite being so rudely dumped in the yard and obviously dazed, caked with mud, and badly bruised, she managed to crawl to the Thompson's wooden deck. She rested for a few minutes on the Thompson's back porch before walking down to Old Highway 395, where she obtained medical assistance.

The men helping Tom Reed had originally planned to bring their wives and children along to picnic and socialize while they worked. If things had occurred as planned, the tragedy could have been much greater.

**Anne Ogilvy** (interviewed by P.A. Glancy on June 15, 1983)

Ms. Ogilvy lived in a house on a high flood-plain terrace along the north bank of Ophir Creek, about 0.1 mi downstream from the mouth of the lower canyon (fig. 2). Her house was the farthest upstream on the flood plain and less than 100 yd upstream from but slightly north of Tom Reed's home and, thus, farther from the main creek channel (fig. 27).

A grove of large conifer trees were fortuitously located a few tens of yards upstream from her home. They trapped a large amount of organic debris from the leading edge of the flood and thus developed a formidable buttress that partially deflected the momentum of the peak flow just enough to prevent total destruction and (or) burial of her home.

Ms. Ogilvy's first warning of the approaching flood mass was the sound of a "great rumbling, like 10 or 12 army jets" which she dismissed as overhead flying aircraft. Momentarily, from her southward view toward the creek, she witnessed "great boulders accompanied by lots of mud" coming toward her. The approaching mass was higher than her doors and windows, and was at least 8 ft above the stream-terrace surface on which the house was located, which in turn was at least 15 ft above the bottom of the normal stream channel. She immediately dashed out a door to the north away from the channel. By the time she was out the door, the upstream part of the home, separated from the main building by a breezeway, was partially destroyed by the impact of the debris. She luckily found a safe site just a few feet beyond the north side of the house that remained out of the flood path.

Ms. Ogilvy was aware of only a single surge of debris that collided with her house. This suggests rapid recession of the peak-flow surge that prompted her to abandon the building. Her experience also suggests that the peak flow was almost coincident with the leading edge of the flood. However, a substantial and sudden increase in the flow of the creek just prior to the peak surge of debris could have occurred within the normal channel out of Ms. Ogilvy's sight.

**Kathleen Thompson** (interviewed by P.A. Glancy on June 15, 1983)

Kathleen and Gordon Thompson live about 0.2 mi east-northeast of the Ogilvy and Reed homes (fig. 2). Their home is about 0.1 mi north of the main channel of Ophir Creek and is at a sufficient altitude above the creek that it was well out of the path of the main floodflow. However, they did receive some of the mud-laden fluid runout from the peak-flow surge that engulfed the upstream north-bank terrace where the Ogilvy and Reed houses were situated. As described in the Tom Reed section, the Thompsons observed Linda Reed being swept into their back yard on the crest of the mud-laden runout from the peak-flow surge that destroyed the Reeds' home.

Mrs. Thompson noted that their electric power supply failed at 12:02 p.m., the same time that Sierra Pacific Power Company recorded a power outage caused by the destruction of their main powerline by the peak-flow surge as it crossed Old Highway 395. She also observed the peak surge of mud and debris as it raced down the main channel to the south of their home. She recalls its height as equivalent to that of a three-story house, that is, about 30 ft above the channel bottom.

**Greg Stafford** (interviewed on July 21, 1983, by P.A. Glancy)

Near noon on May 30, 1983, Greg and his brother Mark Stafford were traveling in a pickup truck up the driveway from their father's (Vic Stafford) home toward Old Highway 395 (Nevada State Route 429). The Stafford home originally was built in the 1870's by William "Billy" Price, after whom Price Lakes were named. The driveway heads up the alluvial fan of Ophir Creek (fig. 2). When they had nearly reached the junction with the public roadway, they observed a rising dust cloud near the canyon mouth about 0.3-0.4 mi upstream. The dust was immediately followed by a churning mass of mud laden with boulders, trees, and rootballs. Although Greg and Mark at first believed this disturbance might be from heavy construction, they quickly realized the true nature of the hazardous situation. In an instant, Greg shifted the truck into reverse and quickly retreated back down the driveway.

Upon rearrival at the house, they shouted to all family members in the yard to quickly get into the house and go upstairs. Everyone, including several

small children, reached safety by the time the debris-laden flood mass arrived. Shirley Stafford (Mark's wife) and two adult friends ran south to high ground and later climbed a tree for safety.

Before the flood ended, it had buried the home with debris nearly to the top of the ground floor (fig. 32). The yard surface was transformed into a tightly packed mass of boulders, some of which measured as much as 6 ft in diameter. Much of this heavy coarse-grained debris may have arrived within seconds after the family members reached the upstairs part of the house.

Although the people escaped serious injuries, several horses ultimately became snared in the mud; some were rescued, but others were lost. Chickens and some other small animals were not very lucky—most died. Several vehicles were swept toward the U.S. Highway 395 freeway.

**Shirley Stafford** (interviewed by P.A. Glancy on February 20, 1985)

Shirley and Mark Stafford and their young children were visiting Mark's parents at the Vic Stafford home just before noon on May 30, 1983 (fig. 2). The Stafford pasture land, on the lower Ophir Creek fan east of the house, was being used for livestock grazing as part of a horse-boarding enterprise. Mark and his brother, Greg, had just driven up the driveway in a pickup toward Old Highway 395. Shirley and two young adult friends were tending to horses at the barn and corrals just south of the house. Mark and Shirley's children were playing in the yard next to the house.

Suddenly, the pickup roared wildly backwards into the yard at high speed. Shirley was instantly irritated at what she thought to be a display of reckless driving. Greg and Mark leaped from the truck shouting for everyone to take cover. Mark ran toward several horses grazing in the pasture to the east. In less than a minute after the arrival of Mark and Greg, the leading flood surge struck the property.

Heeding the warning, Shirley and her friends dashed to slightly higher ground a short distance to the south of the barn. They were safe from the initial flood surge, but the runout of mud from the mass of freshly dumped boulders quickly began to ooze around their feet, and they climbed trees for added safety, fearing that another and larger debris surge might be coming. After just a couple of minutes, when things did not seem to worsen, the three decided to walk eastward and

try to assist Mark in his attempt to rescue the horses. Shortly thereafter, they joined Patricia Sommers who was fleeing barefoot toward the U.S. 395 freeway after abandoning her car on Old Highway 395.

After a few minutes, the four joined Mark Stafford near the freeway. Several of the horses were becoming bogged down in the laterally expanding and deepening mud that was draining from the boulder field deposited around the Stafford home and neighboring homes to the north.

During their attempts to rescue the livestock, they also rescued Mrs. Cline (Stafford's neighbor to the north) who was being swept toward the freeway by the viscous, muddy flow. Mrs. Cline was soon evacuated by helicopter to a Reno hospital. Helicopters also were used to rescue livestock after several became mired in the layer of fine-grained debris that continued to deepen in the pasture land. Ultimately, two horses were lost but several others were rescued.

Shirley was particularly impressed by the momentum of the flood as it continued southward parallel to the freeway; she witnessed a large mare being rolled helplessly over and over by the moving fluid.

**Vic Stafford** (interviewed by P.A. Glancy on June 1, 1983)

Stafford recalls seeing and hearing the approaching flood front during the time his sons were hurriedly driving their truck back to the Stafford home to warn their families of the danger (fig. 2).

He remembers that, after the initial debris surge, there was continuous heavy movement of water and debris across his land for about 3 hours. He recalls the flood being quite severe for about 45 minutes. After about 3 hours, the flow had noticeably receded and the sediment load had diminished enough so that the receding flow began to incise a channel into the newly replaced debris deposits between the Cline and Turek homes, about 0.1 mi north of the Stafford home.

**Kathleen "Katy" Cline** (interviewed by P.A. Glancy on February 22, 1985)

The Cline home was located on the alluvial fan of Ophir Creek about 0.1 mi north of the Stafford home and about 0.1 mi east of Old Highway 395 (fig. 2). About noon on May 30, 1983, Mrs. Cline, a senior citizen, and her daughter had just stepped from their house to the yard. Suddenly they heard a loud roaring

sound from the direction of Ophir Creek, upstream from Old Highway 395. Katy glanced in the direction of the sound and saw trees flying through the air as the leading edge of the flood surge thundered across the upper part of the Ophir Creek fan. She promptly urged her daughter to escape northward to safety with the family pets; she planned to get her purse from the house and follow her daughter. Inside the house, she grabbed her purse and decided to telephone her sister to request help. During the conversation, the telephone suddenly went dead and immediately the flood gushed into the house. Katy was swept off her feet and into the bathroom by the onrushing torrent. As she rose to the surface of the rapidly rising fluid, she managed to grab the top of the bathroom door and hung tightly to it with all her strength. Within seconds, the muddy fluid had risen nearly to the ceiling, and Katy lost consciousness regarding events that immediately followed.

Mrs. Cline's next recollection was that of being submerged and swept along by the floodflow. She reported sensing an inner voice that urged her to lift her head above the surface to breathe. She repeatedly obeyed this suggestion and filled her lungs with air. At this time, she was apparently outside the house but without knowledge or comprehension of how she exited the bathroom or the house.

Figure 33 shows the downstream side of the Cline house after the flood. The character of the damage indicates structural failure near the base of the wall, probably resulting from hydrostatic-pressure buildup as the house filled with fluid. It is likely that Mrs. Cline was flushed down and out through the lower wall openings as the house quickly drained after the wall had yielded to the hydrostatic pressure.

Without knowing her whereabouts, Katy was swept generally eastward (downstream) by the debris-choked floodflow. She continued to gasp for breath during the brief periods that her head emerged. The flow was turbulent and overpowering. During her journey, she recalls seeing a truck nearby. She struggled to reach the truck, but surging waves kept resubmerging her and impeding her efforts. She recalls trying to stand up but being knocked down repeatedly by the flow.

After floating and thrashing along for some time, she caught a glimpse of some horses trapped by wire (probably fencing) and recalls sorrow at being unable to assist the animals. About this time, she became aware of her ebbing strength and increasing discomfort from the cold of the icy fluid that she had been immersed in for several minutes.

Suddenly, Mrs. Cline heard a female voice (Shirley Stafford) shout, "There's Katy, there's Katy over there!" Mark Stafford and his group pulled Katy to safety after much difficulty. She had been swept along for 0.3 to 0.5 mi, she was caked with mud and badly bruised, and her left leg was seriously injured. She was subsequently flown to a Reno hospital.

**Patricia Sommers** (interviewed by P.A. Glancy on August 1, 1983)

Sommers had been visiting Bowers Mansion County Park on the morning of May 30, 1983. She was driving back to Reno along Old Highway 395 (Nevada State Route 429) about noon. She had just driven across the diverted channel of Ophir Creek where it passed beneath the highway through a concrete box culvert at the south margin of the Ophir Creek fan (fig. 27), and she did not notice any unusual flow in the channel. About 0.05 mi beyond and a couple of seconds later, as her car came to the crest of a small rise, she noted the power lines shaking and waving ahead of her where the line paralleled the upslope side of the roadway. She quickly stopped the car and, in the next instant, a thundering surge of debris cascaded across the roadway just ahead of her car, tearing down the power lines in the process.

She attempted a U-turn but midway into the turn, her car's engine stalled and died. She looked quickly back along the highway toward Bower's Mansion County Park and saw a deluge of muddy water and debris cascade across the road where she had just crossed. She was consumed by a sense of panic when she realized her entrapment, particularly when she considered the possibility that another surge of debris might engulf her.

In a state of anxiety intensified by the roar of the deluge, she abandoned her car and dashed downstream toward the freeway for safety. As she ran, she lost her shoes but continued without them. After scrambling about 0.1 mi downstream across rocky, brushy, and tree-covered high ground untouched by the flood, she met up with Shirley Stafford and her two friends who also were heading toward the freeway.

The group moved southeastward, skirting the southern edge of the floodplain. After a distance of a few hundred yards or less, they came to the man-diverted channel of Ophir Creek that was now clogged with some of the debris that Sommers had earlier observed flowing both eastward across the highway

behind her and southward down the sloping roadway toward Bowers Mansion. Sommers tried to cross the debris-clogged channel but quickly sank to her waist in the quicksand-like mixture. She had to be extricated by one of Shirley's friends.

The group was finally able to cross the man-diverted channel after the bulk of the flood bypassed the diversion and flowed on through the Turek, Cline, and Stafford properties to the north. As they hiked eastward toward the freeway, flow of the fine-grained debris component of the flood continued and the zone of inundation was gradually expanding eastward and southward. Piles of organic debris accumulated along the southern border of the highly viscous fluid. After walking several hundred yards eastward and nearing the freeway, they joined Mark Stafford, who had been trying to rescue livestock. Suddenly they heard someone moaning in distress. Stafford climbed atop one of the piles of debris and spotted a human form being rafted along by the flowing mud. With great difficulty, he pulled Katy Cline out of the mud.

**Susan S. Graves** (interviewed by P.A. Glancy on July 1, 1983)

Ms. Graves was inside her residence, just east of Old Highway 395, along the north part of the alluvial fan of Ophir Creek at the time the flood was approaching (fig. 2). Her first indication of the impending deluge was feeling the house begin to vibrate because of ground shaking. In a few seconds, the vibrations became so intense that doors began to swing wildly on their hinges. During a period of at least 30 seconds of continuing and intensifying vibrations, Ms. Graves moved to a position that allowed her to view the leading edge of the debris flow across Old Highway 395. She estimates that it moved at a speed of about 20 mi/h. She was most impressed by the sound, particularly the fierce sharp cracks of breaking tree trunks and power poles, and recalls that the intense roaring of the flood lasted for at least 10 minutes after it first crossed Old Highway 395.

The Graves property was mostly outside the flood plain and sustained minor damage. The family raises Arabian horses and, during the period of the flooding, they worked to control and calm the panicked animals.

**Kenneth Julian** (interviewed by P.A. Glancy on February 27, 1985)

Mr. Julian was driving southward along the U.S. Highway 395 freeway during the late morning of May 30, 1983 (fig. 2). About the time he passed the turnoff to Old Highway 395, just north of Ophir Creek, he noted a number of cars parked some distance ahead along both the northbound and southbound lanes. As he approached the parked cars, he saw that many of the passengers were outside the cars looking westward; some were taking photographs. He then looked westward and saw a wall of very muddy water flowing quickly eastward toward the freeway. The muddy fluid was transporting numerous trees, many as large as 2 ft in diameter, with their bark stripped away. When he first sighted the flow, it was near the Cline and Turek houses, about 0.25 mile upstream (west) of the freeway. He stopped his car a short distance south of the other cars that were parked on the shoulder of the southbound lanes. He estimates the muddy flow reached the freeway about 2 minutes after he first sighted it; he is adamant that it could not have been more than 5 minutes. Based on Julian's observations of time and travel distance, the velocity of the leading edge of the flow averaged between 4 and 11 ft/s. Julian noted that the front was 4 to 5 ft high and of a consistency resembling freshly mixed concrete.

When the flow front reached the freeway, it was abruptly diverted southward, parallel to the roadway. Its velocity diminished noticeably as it flowed southward. Julian watched the front move southward past him. To the best of his recollection, his position was near the culvert where Ophir Creek normally flowed beneath the freeway. About 50 to 100 yards behind the leading flow edge, he noticed an approaching round object that was bobbing above and below the fluid surface. At first it resembled a ball, but when it came opposite him, about 10 to 20 yards away, he identified it as a human head. He could clearly see the victim's eyes. One or both hands of the person weakly and slowly raised above the fluid surface. The victim gazed into his eyes and spoke, "Help me!" Julian was shaken by the request because the person was far out of reach and the moving fluid of unknown depth appeared too treacherous to attempt to enter.

By this time, most of the parked southbound traffic had departed, probably in fear of being permanently delayed if the flow overtopped the roadway. Julian looked for assistance but no one was nearby.

He remembered a rope on the backseat of his car, and reluctantly raced from the victim to the car and back again with the rope, but during the interim, the person disappeared. Julian frustratedly walked back and forth for about 20 minutes searching for the victim, but never sighted the person again.

Shortly after losing sight of the victim, Julian observed a woman being pulled from the flow by several people upstream from the freeway. This was Mrs. Cline being rescued by the Stafford party. He is certain the victim he sighted could not have been Katy Cline because the victim was clearly moving downstream ahead of Mrs. Cline. Amid the floating debris that included vehicles and household goods, Julian identified at least two sleeping bags and a canteen. Because of the heavy mud coating the person, Julian could not determine whether the victim was male or female.

Julian remained at the site for a prolonged time and reported his sighting to several members of the rescue parties that arrived later. He also later reported the sighting to Washoe County Sheriff's personnel.

The mystery of Julian's sighting remains unsolved. His recollection of the events and the details are impressive and compelling. According to Julian's information, it seems possible that some unknown victim remains buried within the debris along the freeway somewhere south of the Ophir Creek crossing.

**Reed W. Dopf** (interviewed by P.A. Glancy during early July 1983)

Dopf, a professional fireman, was driving southbound in his motorhome on the U.S. Highway 395 freeway through Washoe Valley shortly before noon on May 30, 1983, accompanied by a male friend and their families. His friend, looking westward from the front passenger seat, suddenly exclaimed, "I think I just saw an avalanche!" Dopf allowed the vehicle to decelerate while both men looked over the landscape; they both soon witnessed a rising cloud of dust winding its way down Ophir Creek. They parked, got out of the vehicle, and speculated further about the cause of the rising trail of dust that was persistently working its way down-slope. After some undetermined lapse of time, they saw the leading edge of the flood burst from the lower canyon mouth, rumble about 0.3 mi farther down its channel, and then spill across Old Highway 395, about 0.7 mi to the west of their vantage point on the freeway (fig. 2).

Dopf recalls, "As it came out of the canyon, it was just volatile. It looked exactly like opening a fire hydrant. It was that much turbulence. It was that much motion." He also described the emergence of the flood front as appearing, ". . . just like it was coming out of a sluiceway. It would have been white water had it not been so dark (colored)." He also describes the overall mass of fluid as "a tabular mass of water and rock that was coming out of there."

Dopf was likewise impressed by the character and intensity of sound that accompanied the flood, and he described it as making "a dull roar like you'd hear at the ocean. The thing that was most impressive was this deep, percussive sound." The percussive sounds were undoubtedly the huge boulders pounding together within the mass of water and debris. He did not recall sensing any ground vibrations, such as those described by several observers in the vicinity of Old Highway 395, although he concedes he may have been "unaware of ground shaking because of other audible and visual distractions." Dopf noted that the percussive sounds continued only until the leading turbulent flood peak had dissipated.

As the turbulent, boulder-laden, leading wave of the flood came to a standstill, a mud-laden fluid flowed out of the massive boulder deposits and moved down-gradient toward the freeway. Dopf believes it took 5 to 10 minutes for the leading edge of this fine-grained fluid mixture to travel the approximately 0.25-mi distance from the downstream edge of the boulder field to the freeway. His estimate of the traveltime suggests that the fluid moved at an average velocity of between 2 and 5 ft/s, much slower than the estimated 25 to 30 ft/s velocity of the boulder-laden flood front as it exited the canyon and crossed Old Highway 395. This greatly attenuated velocity of the muddy, runout fluid partly explains how it was possible for Patricia Sommers and the Stafford group to have time to hike downstream and pluck Mrs. Cline from the slow-moving flow.

After the muddy flow reached the freeway, Dopf and friends slowly drove southward watching the leading edge of the mud-choked mass slowly flow parallel to the roadway. He describes the moving fluid front as a vertical wall of mud about 2 to 3 ft high with a leading edge comprised largely of tree limbs, branches, and twigs. The visual character of this moving debris is shown in figure 39. He observed that he could easily walk backwards at a speed equal to that of the leading edge of the flow, which indicates a fluid velocity of only a couple of feet per second. Dopf is confident that

the slow-moving, organic-choked, fine-grained, viscous mixture took a full 20 minutes to move southward and into some ponds along the roadway, a distance of about half a mile. That estimate also indicates an average velocity of 2 ft/s, or less.

**Charles McQuerry** (interviewed by P.A. Glancy on August 1, 1983)

Mr. McQuerry was driving along the U.S. Highway 395 freeway shortly after noon on May 30, 1983. He arrived at the site of flooding along the freeway (fig. 2) sometime after the large boulder deposit had been emplaced upstream by the initial flood surge (fig. 10). With his video camera, he filmed the viscous, muddy fluid flowing along the edge of the roadway. His videotape record includes a brief glimpse of a vehicle and a floating propane tank moving southward, parallel to the roadway, very near the site where the flow first arrived at the freeway. We estimated a surface velocity of about 5 ft/s for the flow, on the basis of the movement rates of the vehicles and propane tank as shown by the videotape recording.

McQuerry described his recollection of the flow rate as fast enough to require a fast walk or slow trot to keep pace with the floating objects. That rate generally confirms a surface velocity of about 5 ft/s. He also sensed a vibration of the roadway, but was not positive whether the source of shaking was coarse debris moving in the vicinity of the boulder deposits upstream or flow along the freeway.

**Mrs. E.H. Thom** (interviewed by P.A. Glancy on June 13, 1983)

Mrs. Thom, along with her husband, son, and daughter-in-law took off in a light airplane from Reno Cannon International Airport between 11:30 and noon on May 30, 1983. They were on a sight-seeing trip toward Lake Tahoe. Their first view of the flood scene was about 12:10 p.m., according to Mrs. Thom's recollection. The mud-laden floodflow was just reaching the upstream edge of the U.S. Highway 395 freeway when they arrived overhead. After circling and reconnoitering the flood scene, Mrs. Thom photographed the recession of the floodflow during repeated circular flights (fig. 53). Most of her photographs were probably taken between 12:15 and 1:00 p.m.



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# APPENDIX C

## **PARTICLE-SIZE DISTRIBUTION OF SAMPLES AND EQUATIONS USED IN CALCULATIONS**

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**Appendix C. Particle-size distribution of samples from sediment deposits<sup>1</sup>**

Sample no. <sup>2</sup> (fig. 43)	Date collected	Percent of weight finer than sizes shown, in millimeters (mm) and phi units (φ)																
		mm	64	32	16	8	4	2	1	0.5	0.25	0.125	0.0625	0.031	0.016	0.008	0.004	0.002
		φ	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9
1	08-27-83			100	96	84.4	71.4	56.3	35.8	17.3	6.1	2.5	1.5	1.0	0.7	0.5	0.4	0.3
2	08-27-83				100	94.6	79.7	52.8	33.0	21.5	12.8	8.1	5.2	3.4	2.3	1.5	1.3	1.1
3	11-16-90	100	88.8	79.3	72.8	65.7	58.1	46	31.2	18.5	8.6	3.1	1.5	.7	.5	.4	.3	
4	11-16-90	100	78.8	71.2	66.3	60.3	53.8	41.9	29.9	17.1	8.2	4.6	1.1	.5	.4	.3	.2	
5	05-22-91		100	88.7	75.7	60.5	46.2	29.2	14.4	7.5	4.4	2.9	1.0	.5	.3	.3	.2	
6	05-22-91					100	99	83.4	54.6	30	13.4	5.1	2.7	1.4	.9	.8	.5	

<sup>1</sup> Sediment analyses done at U.S. Geological Survey, Cascade Volcano Observatory Sediment Laboratory, Vancouver, Wash. Samples 1-4 were collected from the matrix material of the debris deposits because of the inability to obtain a representative volume of the debris that included boulders more than 10 ft in diameter. Samples 5 and 6 were collected from the whole debris deposits. Sand and coarser grained fraction analyzed by wet sieving; distribution of fines (silt and clay) analyzed by pipette using chemical dispersant and distilled water.

<sup>2</sup> Samples 1 and 2 collected at same site; samples 3 and 4 collected at same site.

**EQUATIONS USED IN CALCULATING STATISTICS OF PARTICLE-SIZE DISTRIBUTIONS**

The statistics of the grain-size distribution are described by the graphically derived measures of Folk (1980) with cumulative frequency plotted on probability paper as weight percentage of grains finer than the limit of each phi φ class.

Mean grain size (Mz) is defined as the graphic mean.

$$M_z = (\phi_{16} + \phi_{50} + \phi_{84}) / 3 \text{ and can be expressed in } \phi \text{ units or millimeter size.}$$

Median grain size (Md) is defined as that size on the cumulative curve for which 50 percent of the sample is finer.

$$M_d = D_{50} \text{ and can be expressed in } \phi \text{ units or millimeter size.}$$

Sorting Coefficients (σ<sub>G</sub> and σ<sub>I</sub>):

Standard deviation (σ<sub>G</sub>) is defined as the graphic standard deviation. (It includes the central 2/3 of the sample.)

$$\sigma_G = (\phi_{16} - \phi_{84}) / 2 \text{ and is expressed in } \phi \text{ units.}$$

Standard deviation (σ<sub>I</sub>) can also be defined as the inclusive graphic standard deviation. (It includes 90 percent of the sample.)

$$\sigma_I = (\phi_{16} - \phi_{84}) / 4 + (\phi_5 - \phi_{95}) / 6.6 \text{ and is expressed in } \phi \text{ units.}$$

Proposed criteria for verbally expressing σ<sub>I</sub> degrees of sorting are:

- 0.35φ, very well sorted,
- 0.35-0.50φ, well sorted,
- 0.50-0.71φ, moderately well sorted,
- 0.71-1.0φ, moderately sorted,
- 1.0-2.0φ, poorly sorted,
- 2.0-4.0φ, very poorly sorted, and
- over 4.0φ, extremely poorly sorted.

An older (obsolete) measure of sorting is the Trask Sorting Coefficient (Trask, 1932) and is derived graphically, with cumulative frequency plotted on probability paper as the weight percentage of grains finer than the limit of each metric class, as

$$S_o = (D_{25} \div D_{75})^{1/2} \text{ and is computed only using particle diameters expressed in millimeters.}$$

Proposed criteria for verbally expressing  $S_o$  degrees of sorting are:

- <2.5, well sorted,
- =3.0, normally sorted, and
- >4.5, poorly sorted.

Skewness is defined as the Inclusive Graphic Skewness ( $Sk_I$ ).

$$Sk_I = \frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2(\phi_{16} - \phi_{84})} + \frac{\phi_5 + \phi_{95} - 2\phi_{50}}{2(\phi_5 - \phi_{95})} \text{ and is expressed in } \phi \text{ units.}$$

Proposed criteria for verbally expressing  $Sk_I$  degrees of skewness are:

- from +1.00 to +0.30, strongly fine skewed,
- +0.30 to +0.10, fine skewed,
- +0.10 to -0.10, near symmetrical,
- 0.10 to -0.30, coarse skewed, and
- 0.30 to -1.00, strongly coarse skewed.







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