Lahars from the 1992 Eruptions of Crater Peak, Mount Spurr Volcano, Alaska

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ABSTRACT

Lahars, which are flows of volcanic sediment and water, are commonly the most immediate hydrologic hazard resulting from volcanic eruptions. Lahars often change character as they flow downstream, and a single flow can behave as a debris flow at one time and place and as streamflow at another time and place. Crater Peak, a vent on the flank of Mount Spurr volcano, erupted on June 27, August 18, and September *16–17,* 1992. Lahars generated during these eruptions illustrate the effects of clay content on lahar behavior, processes of flow transition, and thresholds of glacier slope and surface roughness, below which lahars are not generated.

On June 27, snow, ice, and rock avalanches were triggered by the eruption and flowed down several steep gullies on the south flank of Crater Peak. These flows became debris flows and entered the Chakachatna River in three places. During the August 18 eruption, at least four pulses of hot pyroclastic flow covered a small area on the middle part of Kidazgeni Glacier and flowed down three gullies on the south flank of Crater Peak, but no lahars resulted and no flows entered the Chakachatna River. On September 16–17, pyroclastic flows covered and traversed a larger area on Kidazgeni Glacier and eroded snow and ice along steep, crevassed icefalls then coalesced near the toe of the glacier to form a debris flow that deposited most of its sediment along a more gently sloping reach. The debris flow then eroded more material as it descended a narrow gully, and the resulting deposit at the mouth of that gully dammed the Chakachatna River.

Comparison of the behavior of the 1992 Crater Peak lahars with lahars that resulted from the 1980 eruption of Mount St. Helens, Washington, indicates that if less than 1 percent clay-size material is present in the flow, coarse-grained material is deposited on relatively steep slopes, and debris flows do not extend as far downstream as do debris flows with larger proportions of clay-size material.

INTRODUCTION

Lahars often present the most serious of all volcanic risks in populated areas. The hazard these flows of sediment and water represent depends on their character. Lahars can range from Newtonian, sediment-laden streamflow to non-Newtonian debris flow and can change as they move downstream. The character of the flows depends on initiating mechanisms, nature of the material incorporated in the flow, water content, and changing channel and valley geometries. Although numerous lahars have been documented, especially since the devastating eruptions of Mount St. Helens, Washington, and Nevado del Ruiz, Columbia (see Janda and others, 1981; Pierson and others, 1990; Scott, 1988; 1989), documentation of the range of factors that produce lahars remains incomplete.

Lahars were produced during two of the three 1992 eruptions of Crater Peak, a vent on Mount Spurr volcano. During the June 27 eruption, avalanches of snow and volcaniclastic debris flowed down Crater Peak creek *(informal name)* and Wilton's Walk gully *(informal name;* fig. *1)* and evolved into debris flows. During the September 16–17 eruption, pyroclastic flows eroded and incorporated snow and glacier ice on Kidazgeni Glacier, and they transformed into debris flows that eventually dammed the Chakachatna River at the mouth of Bench gully *(informal name;* fig. 1). During the August 18 eruption, pyroclastic flows extended down the gullies on the upper flanks of Crater

Peak and onto Kidazgeni Glacier and produced small meltwater flows that did not evolve into debris flows.

In both eruptions in which debris flows were generated (June 27 and September 16–17), the volume and character of the flows changed as older volcaniclastic material was entrained and as sediment was deposited along the flow path. Most of the sediment was deposited near the base of the volcano, and the lahars did not extend far downstream.

Lahars generated during the July 9, 1953, eruption of Crater Peak (Juhle and Coulter, 1955) affected the same drainages that were affected during the 1992 eruptions and were about the same size. They flowed down Crater Peak creek, across an area known informally as "the Bench," and down Bench gully and an unnamed stream draining from Kidazgeni Glacier, 2 km downstream from Bench gully (figs. 1 and 2). The Crater Peak creek lahar deposited debris that formed a fan in the channel of the Chakachatna River that dammed the river and formed a lake. The lake still existed in 1995, although it was not as large. Smaller fans were deposited at the mouths of Bench gully and the unnamed stream 2 km farther downstream. Apparently, considerable tephra was deposited on Kidazgeni and Straight Glaciers, but little, if any, tephra was deposited on Crater or Barrier Glaciers. The summit crater of Crater Peak was filled with snow and ice prior to the 1953 eruption. The snow and ice were completely removed by the 1953 eruption.

Currently no structures or people are at risk from flows down the south flank of Mount Spurr. However, hydroelectric and hydrothermal development and extensive coal mining have been or are being considered in the region. The significant hazard presented by lahars from Mount Spurr is integral to land-use planning for areas surrounding the volcano.

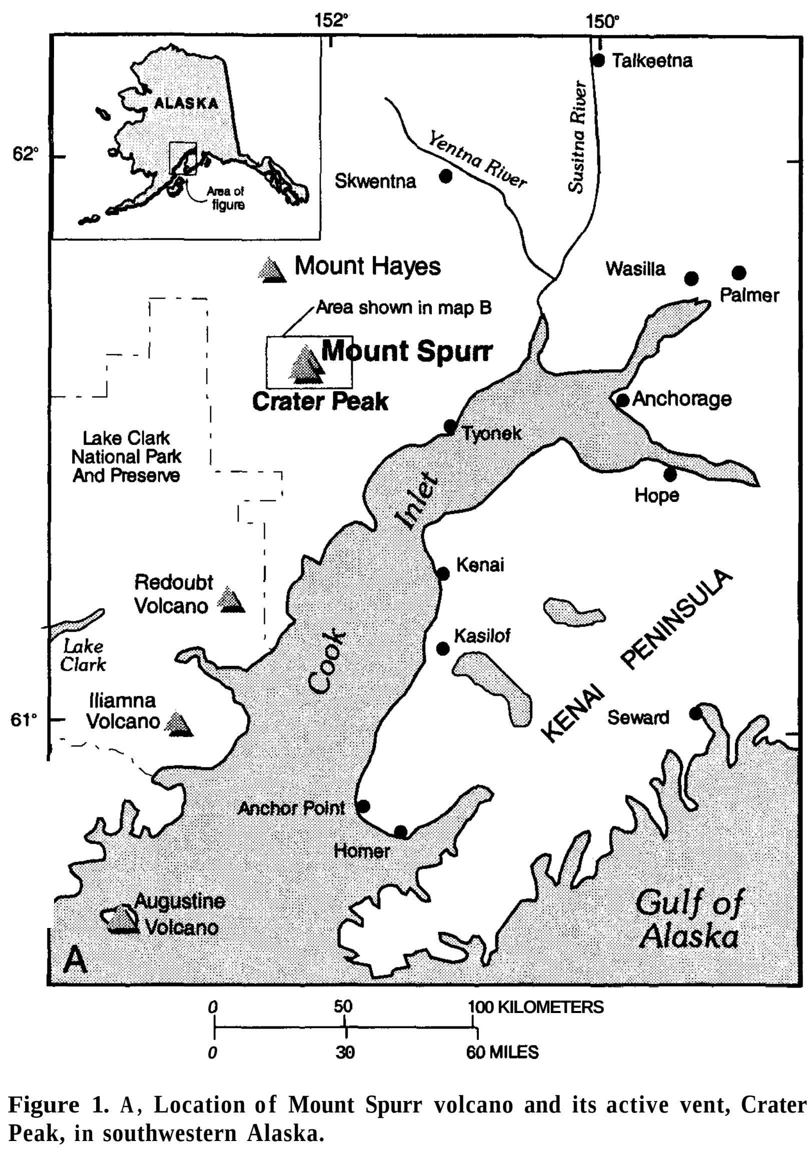


Figure 1. A, Location of Mount Spurr volcano and its active vent, Crater Peak, in southwestern Alaska.

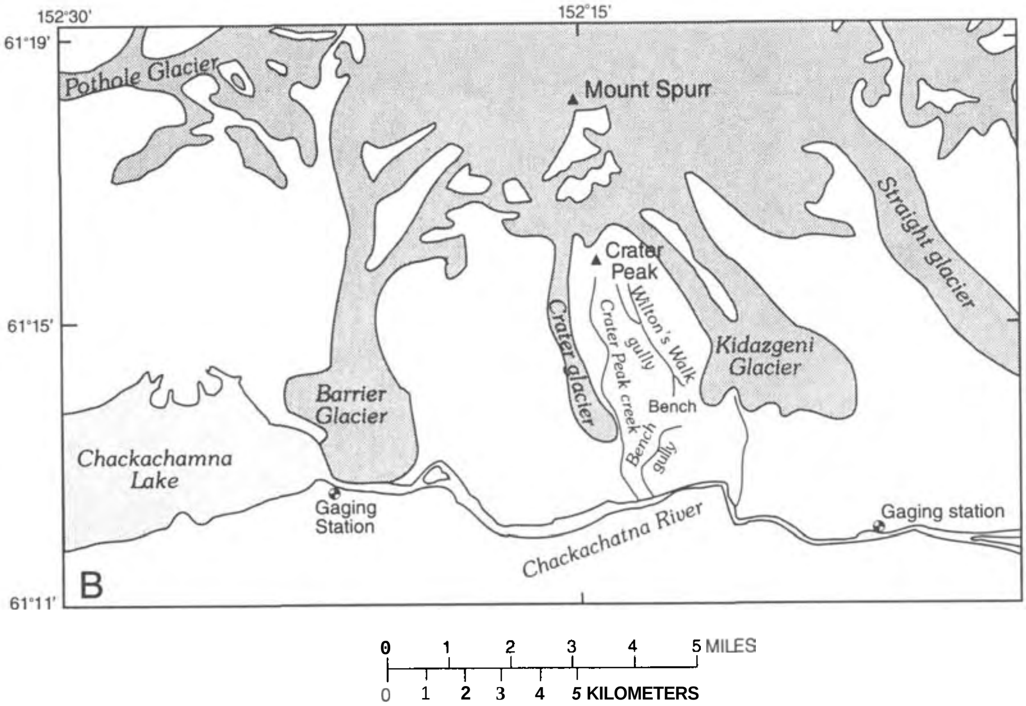


Figure 1. Continued. **B,** Hydrologic features affected by 1992 eruptions of Crater Peak.

Figure 2. A, South flank of Mount Spurr volcano, southwestern Alaska, on September 2, 1952.

Figure 2. Continued. *B*, South flank of Mount Spurr volcano, southwestern Alaska, on August 29, 1954. Lahar deposits from July 9, 1953, eruption of Crater Peak visible in center of photograph.

PHYSIOGRAPHY AND HYDROLOGY

About 67 km3 of snow and ice, covering 360 km^2, are stored in the glaciers on Mount Spurr. The main caldera of Mount Spurr is filled by snow and glacier ice and is the source of Kidazgeni Glacier, which flows around the east side of Crater Peak, and of Crater glacier *(informal name)*, which flows around the west side of Crater Peak (fig. 1). Prior to the 1953 eruption of Crater Peak, the crater at its summit was filled with snow and ice that extended a short distance down the flanks (Juhle and Coulter, 1955). Barrier Glacier is the largest glacier in the Chakachatna River drainage and partly obstructs the river southwest of Mount Spurr; this obstruction resulted in the formation of Chakachamna Lake. Barrier Glacier heads on the west flank of the main caldera of Mount Spurr, about 5 km northwest of Crater Peak.

The Chakachatna River drains the west, south, and east flanks of Mount Spurr, including the areas most affected by the 1992 eruptions of Crater Peak. The largest of numerous canyons and small gullies on the flanks of Crater Peak is Crater Peak creek, a deep, V-shaped gorge cut into pyroclastic and laharic deposits from the Crater Peak vent (Nye and Turner, 1990). Several hot springs are present along the creek. Stream slopes of all of these drainages are steep, ranging from 0.3 to 1.1 meters per meter (m/m) in Crater Peak creek within the first 3 km from the rim of the crater (fig. 3). At an altitude of about 520 m, Crater Peak creek is bounded by the toe of Crater glacier on the west and by a late Pleistocene debris-avalanche deposit on the east. At this point, channel slopes decrease and range from 0.04 to 0.09 m/m. Wilton's Walk gully, which drains the south-southeast flank, ranges in slope from 0.3 to 0.8 m/m upstream from the point where it drains onto the Bench, a gently sloping plain underlain by late Pleistocene debris-avalanche deposits and late Holocene outwash from Kidazgeni Glacier. Slopes across the Bench range from 0.04 to 0.2 mlm. The east flank of Crater Peak is drained by a stream that flows on and along the margin of Kidazgeni Glacier, and then through a breach in the Kidazgeni lateral moraine onto the Bench. The Bench is drained by Bench gully, a steep (0.1 to 0.6 m/m) gully that flows onto an alluvial fan in the Chakachatna River valley.

Mean annual precipitation near Mount Spurr ranges from less than 1,000 mm near the coast to more than 2,000 mm along the crest of the north end of the Aleutian Range (National Weather Service, 1972); on Mount Spurr, most of the precipitation falls as snow. The snowpack reaches its maximum depth in late May or early June.

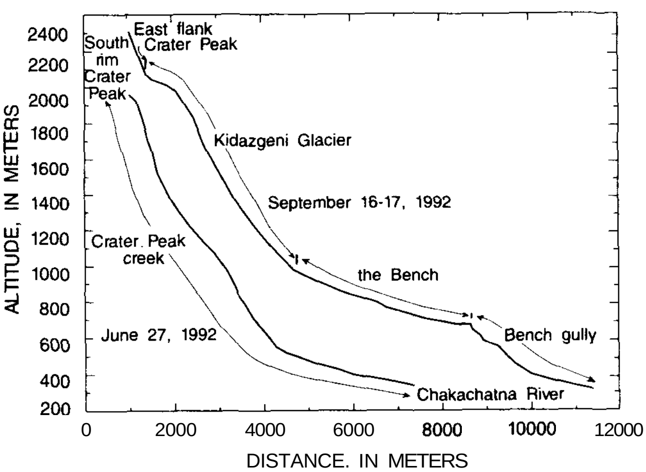


Figure 3. Longitudinal profiles for paths of June 27, 1992, lahar and September 16–17, 1992, lahars produced during eruptions of Crater Peak vent, Mount Spurr volcano, southwestern Alaska.

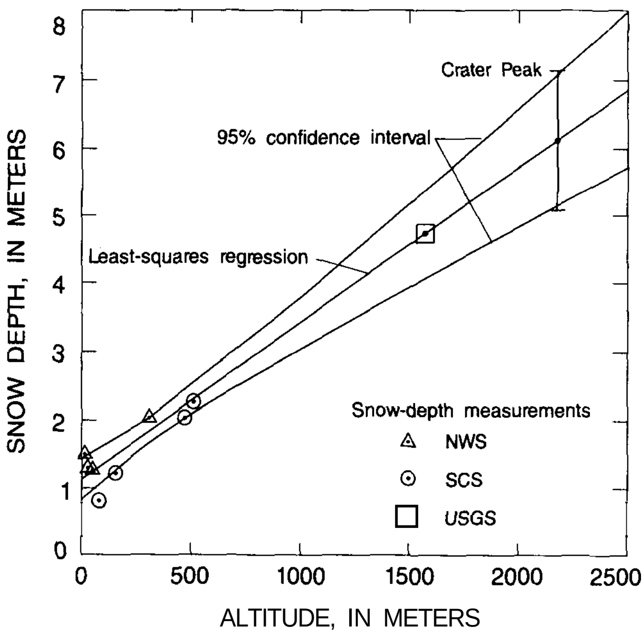


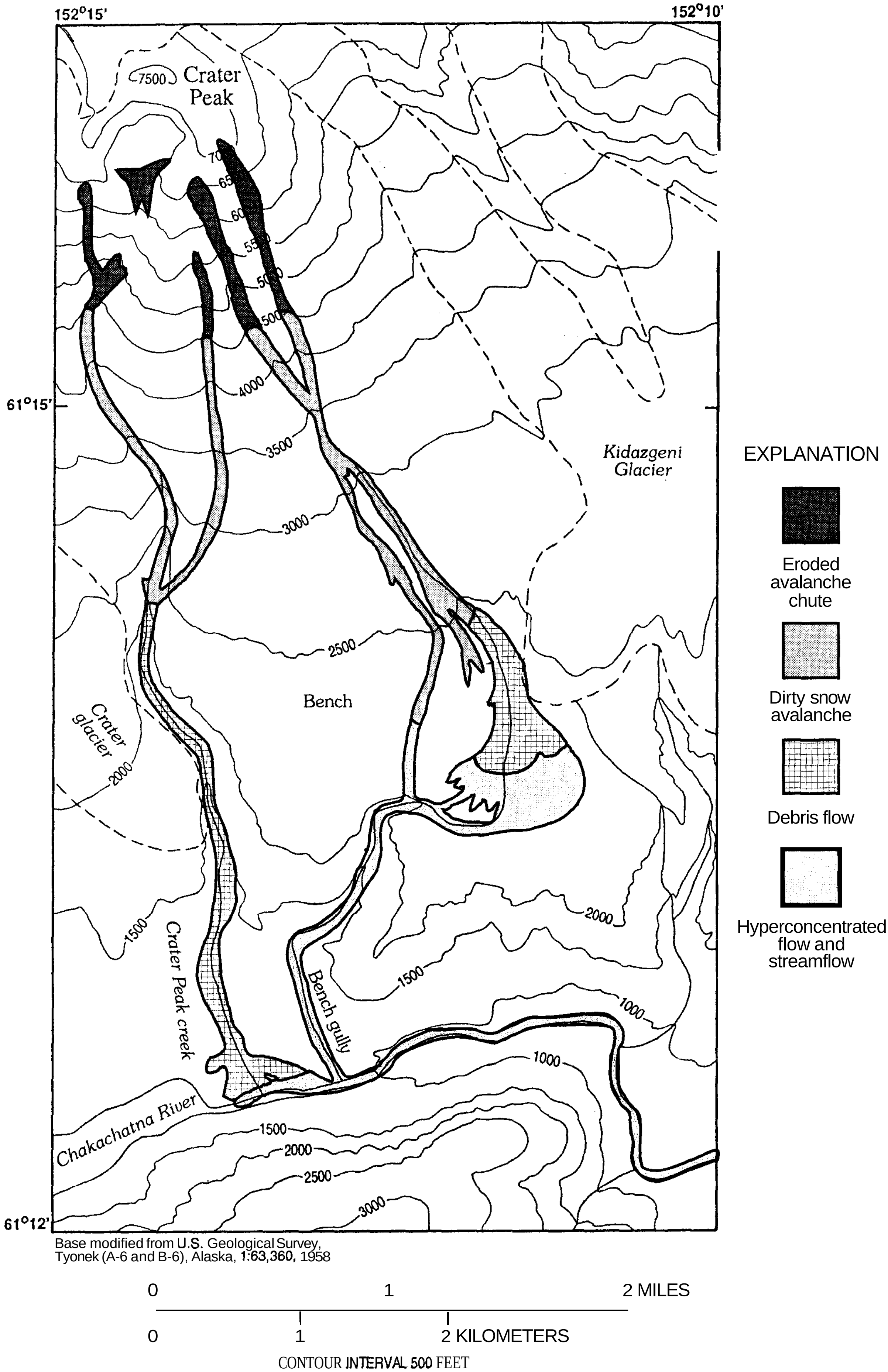
Figure 4. Maximum snow depth versus altitude for four climatological National Weather Service (NWS) stations and four Soil Conservation Service (SCS) snow courses closest to Mount Spurr volcano, southwestern Alaska, and one snowpack measurement from a site on Double Glacier, about 75 km south of Crater Peak that was taken by U.S. Geological Survey (USGS) scientists. Maximum snow depth was measured during March of 1992 at the low-altitude (NWS and SCS) sites and on April 10, 1991, at Double Glacier site. Extrapolation of regression based on these data indicates that snowpack on south rim of Crater Peak was 611 m thick.

The mean annual discharge from the 2,900 km2 basin upstream from the mouth of Chakachamna Lake was 107 m^3/s from 1959 to 1972, when a streamflow gaging station was operated there. Annual high flow is generated from glacier melt, and streamflow is generally greatest during August; the August mean monthly discharge is 340 m^3/s (Scully and others, 1978). A flow with a probability of being equaled or exceeded once every 10 years has a magnitude of 595 m^3/s (Lamke, 1979). The largest flood measured on the Chakachatna River had a peak discharge of 13,300 m^3/s, and it occurred on August 11, 1971, when part of the Barrier Glacier ice dam was eroded. Barrier Glacier .extends most of the way across the Chakachatna River valley. The Chakachatna River occupies a narrow canyon between the toe of Barrier Glacier to the north and the bedrock valley wall to the south. During the period from 1959 to 1971, Barrier Glacier had advanced faster than ice was removed from its toe, and the outlet to the lake became progressively smaller. During high flow generated by a regional rainfall, the toe of the glacier was eroded laterally, which enlarged the outlet of the lake and resulted in the release of about 2.9 x 10^8 m^3 water (Lamke, 1972; Scully and others, 1978).

JUNE 27, 1992, LAHARS

The June 27 eruption occurred near the time of the maximum snow accumulation on Crater Peak. The snow depth on relatively flat surfaces, such as glaciers near 2,000 m altitude, is estimated to have been about 6 m of snow, on the basis of regional extrapolation (fig. 4). The water equivalent of that snowpack is estimated to have been 2.2 m on the basis of an average density (0.36 g/cm^3) for the five snowpack measurements (made during April 1991 and March 1992) used to construct figure 4. However, snow was not evenly distributed prior to the eruption, and snow in the avalanche-source areas was probably deeper than 6 m; gullies were filled with snow that had avalanched or blown from the ridges. A small perennial snow and ice layer was present on the east inside wall of the crater prior to the eruption.

The eruption triggered large avalanches of snow, ice, and rock that flowed down the four major drainages on the south and southeast flanks of Crater Peak (fig. 5). Massive tephra deposits blanketed an area of about 0.08 km^2 on the crater rim, upstream from the source areas for the avalanches, but no specific evidence of pyroclastic flows was observed (see Miller and others, this volume, fig. 1). The avalanches apparently occurred during the later part of the erup-


152°15'
152°10'
61°15'
61°12'
7500
Crater Peak
Kidazgeni Glacier
Crater glacier
Bench
Crater Peak creek
Bench gully
Chakachatna River
4000
3500
3000
2500
2000
1500
1000
EXPLANATION
Eroded avalanche chute
Dirty snow avalanche
Debris flow
Hyperconcentrated flow and streamflow
Base modified from U.S. Geological Survey, Tyonek (A-6 and B-6), Alaska, 1:63,360, 1958
0
1
2 MILES
0
1
2 KILOMETERS
CONTOUR INTERVAL 500 FEET

tion, as the avalanche deposits were not extensively covered by fallout tephra, whereas adjacent areas were blanketed by fallout tephra deposits. The avalanches eroded snow, ice, and rock from a reach beginning near the south crater rim at 2,100 m to 2,000 m altitude, down to 1,400 m altitude (fig. 6), and they deposited material along the channel margins from 1,400 m to 600 m in altitude in Crater Peak creek, and to at least 800 m in altitude on the Bench. When fresh, the avalanche deposits had a characteristic dark color, caused by wet rock, relative to adjacent surficial material, and they contained abundant snow and ice particles. After the snow and ice melted and drained away, the avalanche deposits were light-colored, fluffy, and marked by rare small kettle-like pits. These deposits were scoured from the center of the channels by later flows.

The snow, ice, and rock avalanches and the later flows that scoured the center of the channels apparently evolved into debris flows downstream. Debris flows left extensive deposits below an altitude of 430 m along Crater Peak creek, and across the Bench from 800 m to about 700 m in altitude (fig. 5). The massive debris-flow deposits were overlain by well-sorted, waterlaid gravel that had been reworked either by streamflow that followed the debris flows or by flows generated locally as the debris-flow deposit dewatered.

Canyon walls and valley-floor alluvium were eroded along the steep, V-shaped Crater Peak creek canyon. Spring snowmelt probably had saturated the valley-floor alluvium prior to the eruption, and the eroded material combined with the dirty-snow avalanche to produce the debris flow that left deposits from an altitude of 430 m down to the Chakachatna River. A 0- to 2.5-m-thick, 100- to 200-m-wide diamict (a nonsorted deposit having a wide range of grain sizes) covered the lower 1 km of the channel and the alluvial fan at the mouth of Crater Peak creek (fig. 7). Most of the diamict was deposited below the break in slope between 520 m and 550 m in altitude. This lower reach, within 2 km of the mouth of Crater Peak creek, has a channel slope between 0.04 and 0.09 m/m (fig. 3).

At a location 0.5 km upstream from the mouth of Crater Peak creek, the debris flow had an estimated peak discharge of 2,000 m^3/s. This estimate was made using the superelevation of the flow around a bend to estimate the velocity of the flow (Chow, 1959, p. 448). Mid-channel bars in the Chakachatna River at the mouth of Crater Peak creek were veneered by deposits of sand and gravel, but the river was not blocked as it had been during the 1953 Crater Peak eruption. The debris flow did not extend beyond the alluvial fan at the mouth of Crater Peak creek.

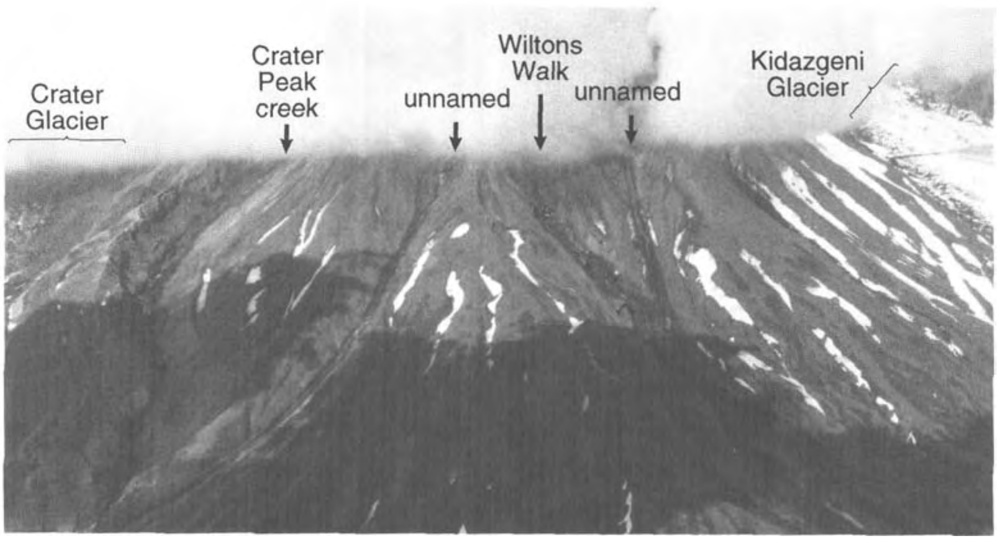


Figure 6. Four large drainage channels on south-southeast flank of Crater Peak vent of Mount Spurr volcano, southwestern Alaska, on June 29, 1992, 2 days after an eruption of Crater Peak. Dark deposits in channels are snow, ice, and rock avalanche deposits. Dark areas covering lower slopes are cloud shadows.

◀ **Figure 5.** Distribution of deposits from June 27, 1992, Crater Peak (Mount Spurr volcano, Alaska) avalanches and lahars associated with eruption. Dashed lines show approximate boundaries of glaciers.

In Wilton's Walk gully and two unnamed channels, neither the dirty snow avalanches nor the subsequent flows eroded significant amounts of material from the poorly defined channels. As the flows spread across the Bench, coarse sediment was deposited as a diamict sheet in proximal areas, indicative of a debris flow, but the deposit was thinner, bedded, and better sorted along its margins, indicative of sediment-laden streamflow. Individual units that could be correlated to the dirty snow avalanche or to the later erosive flows upstream could not be distinguished within the diamict on the Bench. The two types of flow evident upstream may have combined to form a single deposit on the Bench or the later erosive flows may not have left deposits on the Bench. Nearly all of the sediment in the flow was deposited on the Bench, and only relatively clear water flowed down Bench gully and into the Chakachatna River. At the mouth of Bench gully, the surface of a fan was covered by thin, waterlaid deposits.

AUGUST 18,1992, WATERY FLOWS

Several small pyroclastic flows descended the Wilton's Walk gully on the southeast side of Crater Peak on August 18, but they stopped short of the debris-flow deposits emplaced during the June 27 eruption. Four or more overlapping pyroclastic flows descended the east flank of Crater Peak and covered 0.1 to 0.2 km^2 of the western half of the west arm of Kidazgeni Glacier (see Miller and others, this volume, fig. 1). Eight to twelve cm of fallout tephra was deposited beyond the margins of the pyroclastic-flow deposits, but none was deposited on the pyroclastic-flow deposits (see Miller and others, this volume; Neal and others, this volume).

The pyroclastic flows ran onto a relatively smooth glacier surface, except at the highest area of contact with Kidazgeni Glacier, near the extreme northeastern sector of Crater Peak, where some glacier ice was

Figure 7. June **27,** 1992, debris-flow deposit resulting from eruption of Crater Peak vent (Mount Spurr volcano, Alaska) near mouth of Crater Peak creek, 100 m upstream from Chakachatna River. Notebook in center of photograph is 20 by 11 cm and rests on pre-eruption surface. Deposit is about 2.5 m thick.

Figure 8. Small meltwater channel along west margin of Kidazgeni Glacier, which is covered with wet, dark tephra deposits from August 18, 1992, eruption of Crater Peak vent, Mount Spurr volcano, Alaska. Northeast rim of Crater Peak is in left background. Photograph taken August 20, 1992.

mechanically entrained by the flows. Glacier slopes ranged from 0.21 to 0.26 m/m. Channels scoured by small watery flows were observed downstream from the multipulsed pyroclastic-flow deposits along both the east and west margins of the lower part of the west arm of Kidazgeni Glacier (fig. 8), but no debris-flow deposits were observed in direct association with either the pyroclastic flows or the watery flows. The water flows were probably generated by melting of small amounts of snow and ice in and under the pyroclastic-flow deposits. The small amount of snow and ice on Crater Peak prior to the August 18 eruption was confined to small patches in gullies. Water flowing down the east margin of the west arm of Kidazgeni Glacier ponded in depressions near the glacier terminus; water flowing down the west margin of the west arm of Kidazgeni Glacier flowed through a small gap in the lateral moraine onto the Bench. Cobble-size bed material was mobilized by these flows, and minor bank erosion occurred within a kilometer of the glacier, but the overall effects were comparable to those from annual glacier-melt generated flows.

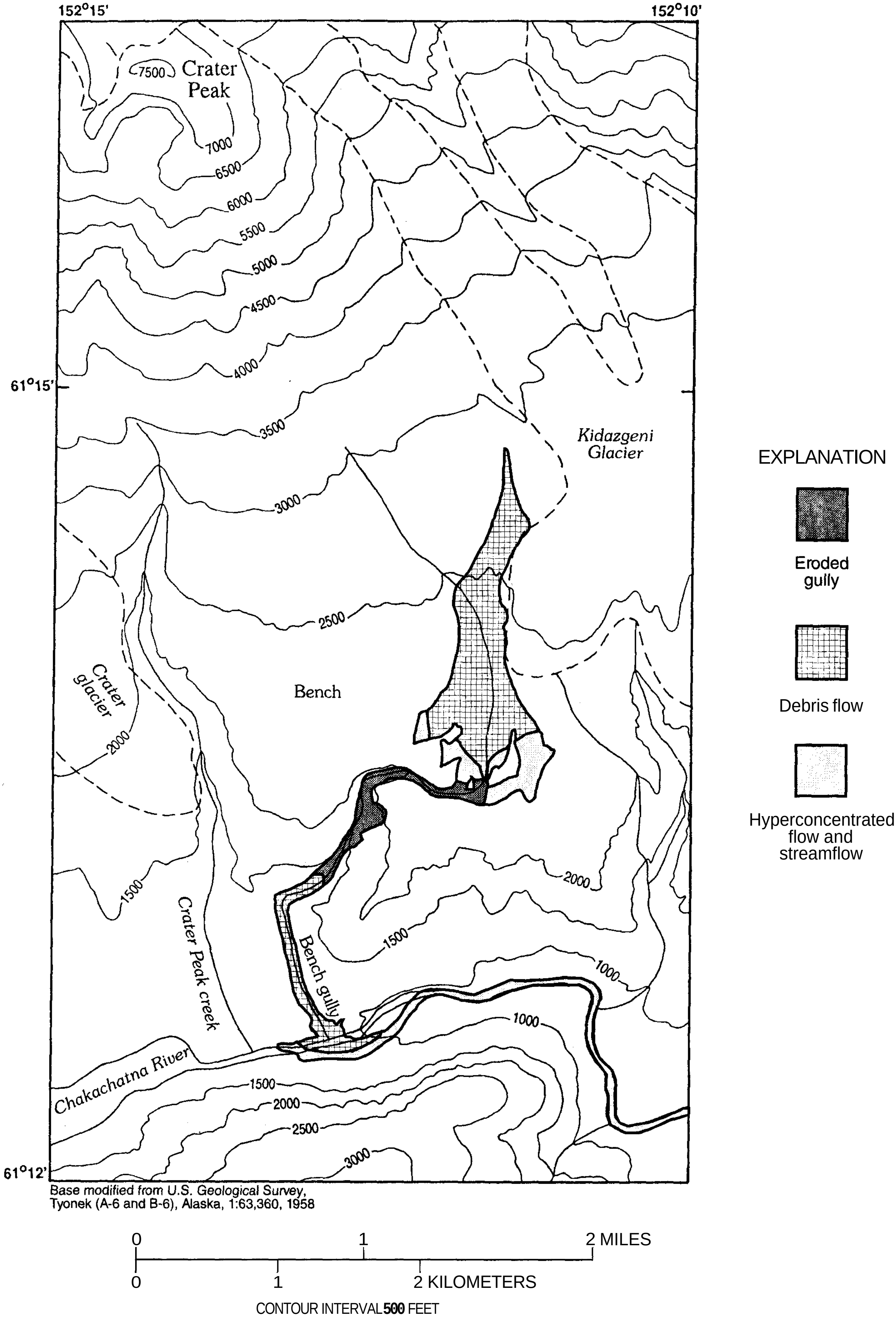
SEPTEMBER 16–17, 1992, LAHARS

Pyroclastic flows generated during the September 16–17 eruption flowed down the northeast flank of Crater Peak and onto the west arm of Kidazgeni Glacier, near the upstream end of a steep icefall (see Miller and others, this volume). These pyroclastic flows were thicker, and they traversed a more extensive and steeper area of the glacier, covering about 0.3 km2 of Kidazgeni Glacier having slopes ranging from 0.25 to 0.38 m/m. Much of this area was broken by crevasses. Because of the steeper slope, thicker flow, and greater surface roughness, the September 16–17 pyroclastic flows probably showed greater shear at their base than the flows that occurred during the August 18 eruption, and they eroded considerable snow and glacier ice. As the pyroclastic flows incorporated water melted from eroded snow and ice, they were transformed into a lahar that deposited both massive diamicts and bedded streamflow deposits along channels scoured into the glacier surface (see Waitt, this volume).

The lahar fanned across the Bench surface, widening from about 100 m on the proximal Bench to about a kilometer on the distal Bench (fig. 9). Most of the debris-flow phase of the lahar was deposited as a continuous, 1- to more than 2.5-m-thick diamict on the Bench surface. Steep bouldery flow-front lobes formed a few hundred meters upstream from the headcut of Bench gully, which drains the Bench surface. The flow-front lobes are depleted in sand- and gravel-size sediment. Deposits of planar- or cross-bedded pebbles and sand cap the surface of the diamict (fig. 10), and they extend downfan from the bouldery flow-front lobes as splay deposits (fig. 11). In some places, the splay deposits extend only a few tens of meters into brushy vegetation; in other places, they extend hundreds of meters into gullies and channels that are tributary to Bench gully (fig. 9).

One lobe of the debris flow extended far enough downstream to flow into Bench gully in a channel 10 m wide, where it combined with the more watery flows. An estimated 10,000 to 100,000 m^3 of material was eroded from the banks of Bench gully by the debris flow and subsequent incision during and following the night of September 16–17 when arcuate failures of 10- to 20-m-high banks as thick as 10 m occurred along a 1,500-m-long reach between the Bench and the Chakachatna River. Large bank failures were still occurring during the afternoon of September 17. An estimated 50,000 to 100,000 m^3 of coarse debris was deposited as a 0- to 3-m-thick diamict over the 50,000 m^2 alluvial fan where Bench gully enters the Chakachatna River. This sand and gravel diamict contains boulders as large as 1 m in diameter, similar on a gross scale to the diamict on the Bench. Subsequent watery flows, probably during the waning stages of the lahar, reworked the surface of the fan and incised a channel 3 to 4 m deep and less than 100 m long along the centerline of the fan.

The diamict formed a temporary dam across the Chakachatna River, and so the river rose to depths of 0.5 to 1 m directly upstream from the fan (fig. 12). A 20-m-wide channel was eroded along the distal margin of the fan by the Chakachatna River; through this channel pulsed a flood wave with an estimated peak discharge of 800 m^3/s just downstream from the debris fan. Peak discharge estimates (800 m^3/s and 400 m^3/s) were made using the slope-conveyance technique, which applies the Manning's equation to a single cross section to estimate the flow velocity (Chow, 1959, p. 98). The estimated discharge is larger than the largest measured, meteorologically generated flow on the Chakachatna River, but it was less than one-tenth of the peak discharge that resulted from erosion of the Barrier Glacier ice dam in 1971 (Lamke, 1972; Scully and others, 1978). Deposits downstream from the fan that mark the passage of the flood wave consist of medium- to coarse-grained, planar-bedded sand. The peak attenuated quickly from 800 m^3/s at the downstream margin of the fan to about 400 m^3/s at a location 6 km downstream, where flood deposits were fine- to medium-grained, planar-bedded sand.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Kidazgeni
Glacier
Bench
Crater
glacier
Crater Peak creek
Bench gully
Chakachatna River
EXPLANATION
Eroded
gully
Debris flow
Hyperconcentrated
flow and
streamflow
Base modified from U.S. Geological Survey,
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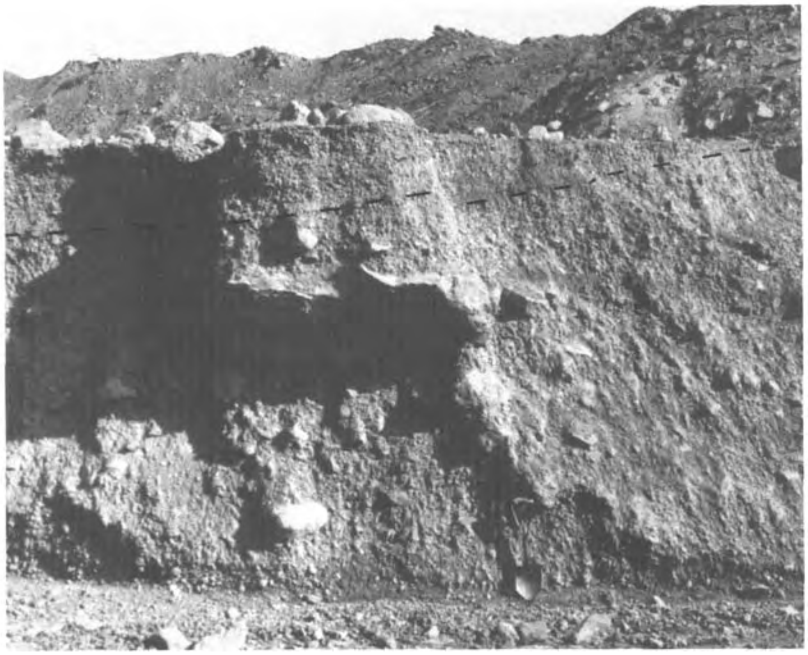

Figure 10. September 16–17, 1992, lahar deposits resulting from Crater Peak vent eruptions, Mount Spurr volcano, Alaska. Deposits are on proximal part of the Bench; they consist of a massive diamict (below dashed line) overlain by planar- and cross-bedded sand and gravel (above dashed line). Shovel in center of photograph is 0.6 m long.

Figure 11. September 16–17, 1992, splay deposits resulting from Crater Peak vent (peak issuing steam in the right background) eruptions, Mount Spurr volcano, Alaska. Deposits crop out along distal part of the Bench just upstream from head of Bench gully and consist of boulders depleted of fine material in the center and right foreground and well-sorted sand and gravel that form flat surfaces in left foreground.

◄ **Figure 9.** Distribution of deposits from lahars resulting from September 16–17, 1992, eruption of Crater Peak vent, Mount Spurr volcano, Alaska. Dashed lines show approximate boundaries of glaciers.

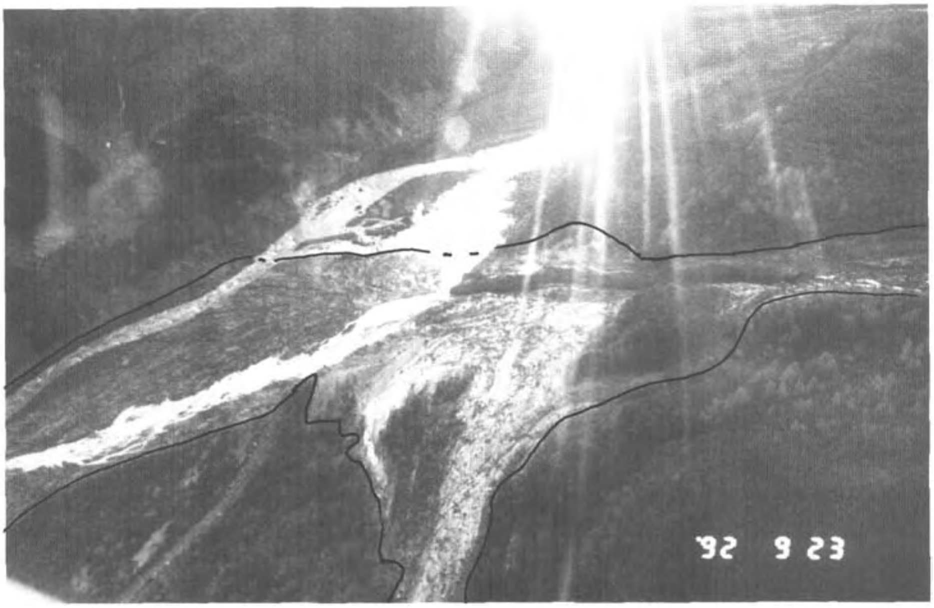

Figure 12. Alluvial fan at mouth of Bench gully, including eroded debris-flow dam (upper left outlined area) across Chakachatna River (light colored river in center). Extent of debris-flow and sediment-laden streamflow deposits indicated by solid lines, dashed where inferred. Channel at toe of alluvial fan (shown at bottom of photograph) is about 20 m wide. View is upstream.

GRAIN SIZE, LAHAR TRANSFORMATION, AND LAHAR GENERATION

The behavior of debris flows depends, among other factors, on the grain-size distribution of the material contained in the flow, especially the proportion of clay (Scott, 1988; Scott and others, 1992). Cohesive lahars from Mount St. Helens, Washington, both those that occurred in 1980 and at earlier times, and lahars from Mount Rainier, Washington, maintained fairly constant rheologic and sedimentologic properties when they contained more than 3 percent clay particles (those smaller than 0.004 mm in diameter). The May 18, 1980, North Fork Toutle River lahar from Mount St. Helens contained more than 3 percent clay, and it flowed as a coherent debris flow more than 100 km along slopes ranging from 0.007 to 0.002 m/m. The May 18, 1980, South Fork Toutle River lahar and the March 19, 1982, North Fork Toutle River lahar, both from Mount St. Helens, contained less than 3 percent clay and were noncohesive. They changed from debris flow to hyperconcentrated streamflow along 63 and 58 km channel reaches, respectively, that ranged from 0.01 to 0.002 m/m in slope. However, these transformations occurred as the lahars were diluted when they overrode streamflow. Eventually, the flows were diluted to such an extent that they became sediment-laden streamflow.

The size of the March 19, 1982, North Fork Toutle River lahar on the flanks of Mount St. Helens was similar to the June and September 1992 lahars from Crater Peak. However, as the 1982 lahar spread onto the fan at the base of the north flank of Mount St. Helens, it traversed highly erodible 1980 pyroclastic-flow and debris-avalanche deposits, and it not only bulked in volume but also incorporated sediment with a higher proportion of clay-size material (Pierson and Scott, 1985, fig. 9).

The 1992 lahars at Crater Peak contained less than 1 percent clay (fig. 13) and transformed from debris flow to sediment-laden streamflow as they moved downvalley. The flow transformations that were observed within the May 18, 1980, South Fork Toutle River lahar and the March 19, 1982, North Fork Toutle River lahar were quite different than those of the Crater Peak lahars. First, the Crater Peak lahars did not leave extensive deposits of massive, moderately sorted, sand deposits, which are indicative of hyperconcentrated streamflow (Scott, 1988, table 4). Secondly, the Crater Peak lahars moved through dry channels and overbank areas and the transformations could not have resulted from the lahar overriding streamflow. Thirdly, the lahars did leave matrix-poor levees at the distal margins of the flow. Fourth, transformation of the Crater Peak flows resulted in the debris flow coming to rest on slopes as steep as 0.04 to 0.09 m/m. The extremely low proportions of clay in the 1992 Crater Peak flows may have caused these differences.

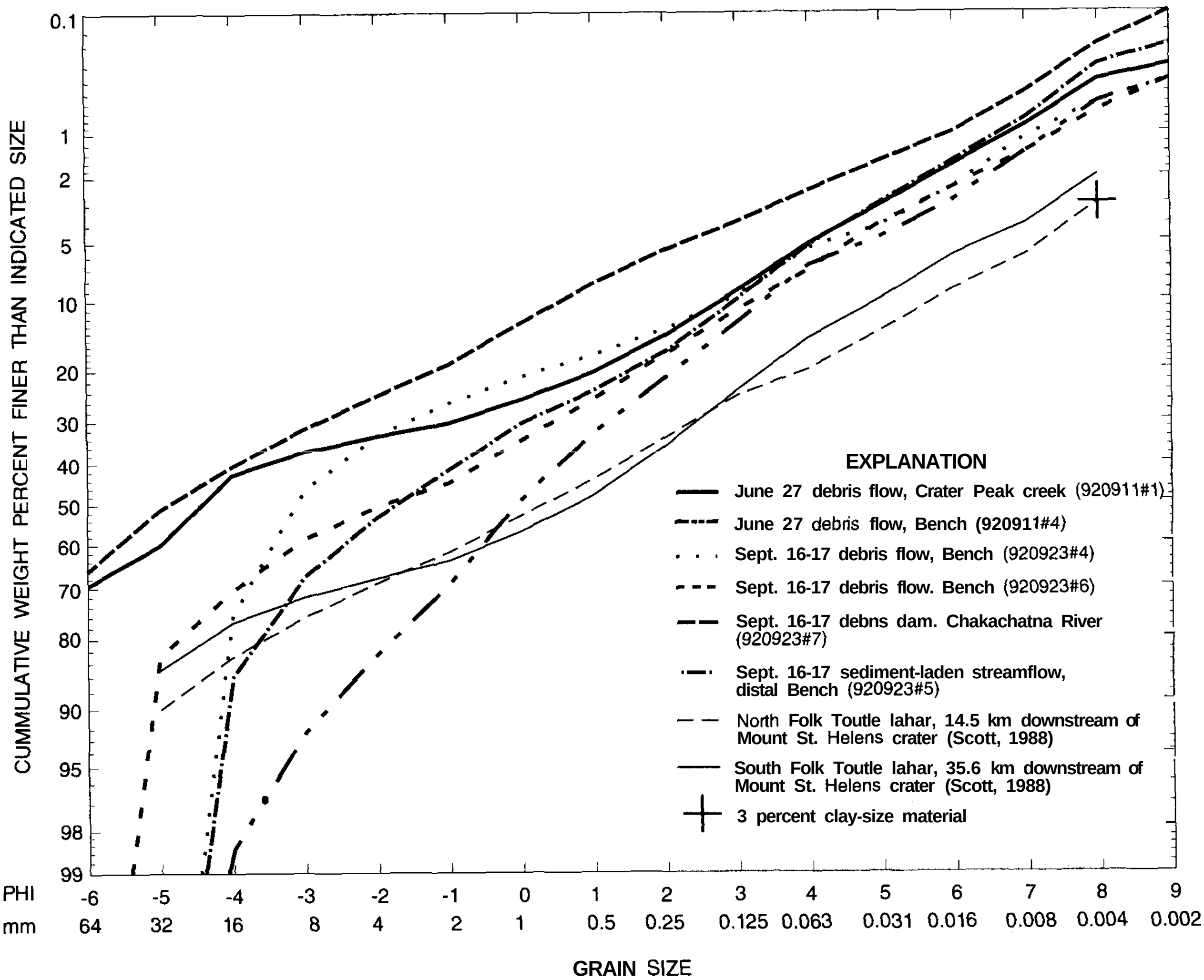

Figure 13. Grain-size distribution of matrix-only samples of June 27, 1992, debris flows and of September 16–17, 1992, debris flows, debris dam, and sediment-laden streamflow deposits from eruptions of Crater Peak vent, Mount Spurr volcano, Alaska. None of the samples include material coarser than 64 mm in diameter. Material coarser than 64 mm in diameter composed as much as 50 percent of the Mount Spurr debris-flow deposits but was not present in sediment-laden streamflow deposits. Also shown are grain-size distributions of two lahars from May 18, 1980, eruption of Mount St. Helens (Scott, 1988). Large plus sign is at a point representing 3 percent clay-size material, the percentage of clay-size material thought to distinguish cohesive and noncohesive lahars.

The distal lobes of the 1992 Crater Peak lahar deposits are composed of concentrations of coarse boulders devoid of fine-grained matrix. These lobes are unlike the contemporaneous Crater Peak lahar deposits in the proximal Bench or the 1980 South Fork Toutle River lahar deposits, in which coarse boulders are supported by a finer grained, poorly sorted, but clay-poor matrix. The distal lobes appear to have lost the fine-grained sandy matrix during or after deposition of the large boulders. Slurry flows, that is flows that show plastic flow behavior in the field yet become partially liquefied when remolded, commonly consolidate at a rate at which pore fluid can drain out, but most sediment remains in the deposit (Pierson and Costa, 1987, p. 7). This phenomenon is due, in part, to viscous forces, which are dominant over inertial forces in finer grained or slower moving slurry flows. Such was true of the Toutle River lahars, which all contained more than 1 percent clay. The Crater Peak lahars, being generally coarser grained, would have been more dependent (than the Toutle lahars) on inertial forces to sustain plastic fluid flow that characterizes debris flow (Pierson and Costa, 1987, p. 7). When the Crater Peak deposits came to rest, viscous forces were insufficient to hold the matrix in place between the boulders, and the matrix was probably eroded by pore water as it drained rapidly from the deposits.

Distal lobes were not formed by most of the Mount St. Helens lahars or by the June 27 Crater Peak creek lahar; these lahars were diluted when they overrode streamflow as they flowed downstream and where they entered larger rivers.

Several alternative hypotheses could also explain the boulder levees and lobes that are devoid of matrix:

1. The fine-grained matrix could have been washed from the deposits by waning, watery stages of the lahar. This process probably did account for some of the general reworking of the diamict and the levees. Channels were eroded into the surface of the diamict upstream from the levees and on the glacier. However, these channels were commonly devoid of boulders larger than about 1 m, and they were observed only as discrete channels on the diamict, whereas the matrix-poor boulder levees were common near the distal margins of the diamict.

2. The fine-grained matrix could have been washed out by later rain. The June 27 deposits were not sampled and photographed until September 11, so they would have been reworked to an unknown degree by intervening rainfall and runoff, even though the deposits appeared unaltered where they were sampled. The September 16–17 deposits were sampled and photographed on September 23. Minor amounts of snow and little or no rain fell during the intervening period, and no reworking by surface runoff was observed on fresh, vertical cut banks within the diamict.

3. The lahar could have transported large concentrations of boulders that were deposited together as the flow traversed the Bench. This process apparently did occur, but it was responsible for deposits unlike the matrix-poor levees. Large (larger than 2 m) boulders were observed in the diamict whose flat surfaces were covered by sand and gravel similar to the reworked matrix deposits. The bases of these boulders were not observed, but similar deposits present in a debris-flow deposit on an alluvial fan at Olancha Creek in southeastern California rest directly on rooted vegetation. As the flow at Olancha Creek spread out over the alluvial fan, increasing in width, it probably became progressively shallower. As its depth became roughly equal to the diameter of the largest boulders, those boulders became grounded, while finer material, although still coarse, continued to flow downfan. At Olancha Creek, very large boulders (larger than 2 m) were grounded near the head of the fan, and grounded boulders are progressively smaller downfan.

At Crater Peak, small flows generated by water draining from the diamict reworked the surface of the deposit (fig. 10). Larger flows, generated from water draining from the distal margins of the diamict, coalesced to form flows large enough to erode unconsolidated deposits farther downstream, for example, along Bench gully. Similar flow transition was observed in debris flows having extremely low (less than 1 percent) proportions of clay-size material in Olancha Creek, California (D.F. Meyer, unpub. data) and in Ophir Creek, western Nevada, by P.A. Glancy (oral commun., 1993) of the U.S. Geological Survey.

At Mount St. Helens and at Mount Rainier, cohesive lahars commonly originate as debris avalanches (Janda and others, 1981; Scott, 1988; Scott and others, 1992). Noncohesive lahars have a variety of origins, and some of them are generated by erosion of enough volcaniclastic material that flow concentrations exceed 60 to 80 percent sediment by weight. The higher concentrations are characteristic of coarser material. Some of the initiating flows are water flows generated by lake breakouts (Scott, 1988), pyroclastic flows that have eroded glacier ice (Scott and others, 1992) as did the September 16–17 Crater Peak lahar, and wet snow avalanches similar to the initiation of the June 27 lahar (Waitt and others, 1983; Pierson and Scott, 1985; Waitt, 1989). However, flow dilution (the incorporation of water in the stream channel that is overridden by debris flow) may play an important role in the transformations from debris flow to hyperconcentrated streamflow and from hyperconcentrated streamflow to sediment-laden streamflow (Pierson and Scott, 1985). The Bench at Crater Peak, where both the June 27 and September 16–17 lahars changed from debris flow to hyperconcentrated flow and from hyperconcentrated flow to sediment-laden streamflow, was not a stream channel. These transformations took place on a broad, vegetated plain (fig. 11), and it was not likely that any water was overridden or incorporated into the flow. Similarly, the Nevada and California debris-flow transformations occurred on alluvial fans, and these flows did not override significant streamflow.

Comparison of the August 18 and September 16–17 Crater Peak lahars confirms an observation of the 1989–90 lahars from Redoubt Volcano that ice is most effectively incorporated into pyroclastic flow when its surface is steep and rough. Most of the ice removed from Drift Glacier on Redoubt Volcano was from the steep, narrow canyon on the north breach of the volcano. Where pyroclastic material was deposited on the relatively flatter piedmont lobe of Drift Glacier, little melting occurred (Trabant and Meyer, 1992; Trabant and others, 1994). The August 18 pyroclastic flows were deposited primarily on smooth areas of Kidazgeni Glacier and no lahars were generated. The September 16–17 pyroclastic flows traversed steep, highly crevassed areas of the glacier and generated lahars.

OTHER HYDROLOGIC EFFECTS OF THE 1992 CRATER PEAK ERUPTIONS

Increased meltwater runoff can be expected from all glacier areas where ash deposits are less than about 24 mm in thickness because of decreased albedo, whereas ash thickness of more than a few centimeters can be expected to reduce meltwater runoff because the low heat conductivity of the materials insulates the ice from diurnal temperature fluctuations (Driedger, 1981). The only known ash deposit with thicknesses more than a few centimeters is on the Kidazgeni Glacier and Straight glacier (informal name, fig. 1). Prior to the 1992 eruption, thick, ablation-reducing ejecta from the 1953 eruption of Crater Peak mantled Kidazgeni Glacier below the junction of the east and west arms as well as the lower few kilometers of Straight Glacier.

The effects of the 1992 eruption on Barrier Glacier (fig. 1) and its debris-covered piedmont lobe, which dams the Chakachatna River to form Chakachamna Lake, are not expected to be significant. However, these effects need to be considered because release of Chakachamna Lake would be a significant hydrologic hazard. The flow of Barrier Glacier is not likely to have been affected by a change in the heat flow to the bed of the glacier, because the glacier is more than 5 km from Crater Peak, the active vent. Furthermore, almost no ash was deposited on the glacier, and no pyroclastic flows occurred on or near the glacier. The ice-flow speed of the piedmont lobe fluctuated in the past (G.C. Giles, U.S. Geological Survey, written commun., 1967); however, the single flood release from Chakachamna Lake probably was caused by lateral erosion of the ice dam during rainfall-generated high flow (Lamke, 1972).

Fallout tephra deposits from the three Crater Peak eruptions in 1992 blanketed much of the heaviest populated areas in south-central Alaska (see Neal and others, this volume). After the August 18 eruption deposited several millimeters of ash on Anchorage, both air and water quality were affected. Water use was greater than at any previous time, as businesses, homeowners, and the municipality washed away the ash. (Charley L. Bryant, Anchorage Water and Wastewater Utility, Municipality of Anchorage, written commun., 1992)

CONCLUSIONS

The interaction between snow and glacier ice and the pyroclastic flows and lahars produced by the 1992 eruptions of Mount Spurr volcano confirm the conclusions drawn from similar occurrences during the 1989–90 eruptions of Redoubt Volcano (Trabant and others, 1994) and the 1985 eruption of Nevado del Ruiz Volcano (Pierson and others, 1990). First, flows generated by mechanical disruption and entrainment of snow and glacier ice by pyroclastic flows are generally larger and more likely to be debris flows than when hot pyroclastic material is deposited more passively over flat surfaces. Second, bulking of lahars by erosion of debris downstream of the initiation point can produce greater hazards than those created by the initial flows. The lahars contained extremely low proportions of clay-size material and came to rest on relatively steep slopes, a behavior more similar to debris flows observed in Nevada and California than to flows observed at other volcanoes.

During the August 18 eruption, when pyroclastic material was, for the most part, deposited passively on glacier ice, small meltwater flows were produced. During the September 16–17 eruption, more energetic pyroclastic flows traversed a larger and steeper area of the glacier that was broken by crevasses. These flows eroded and melted enough glacier ice to produce large floods downstream. This observation indicates that the largest potential for incorporation of snow and glacier ice by volcanogenic flows is at places where ice surfaces are highly crevassed, steep, and exposed to large volumes of volcanogenic materials.

During the June 27 eruption, the eruption triggered snow, ice, and rock avalanches, but significant amounts of snow and ice were not melted by interaction with hot volcaniclastic material. In many ways, the June 27 lahar was similar to the March 19, 1982, lahar at Mount St. Helens, which began as a snow avalanche, and bulked by eroding volcaniclastic material both on the flank of the volcano and on the 1980 debris-avalanche deposit. The June 27 Crater Peak lahar bulked on the flanks of the volcano, but it was deposited at the base of the volcano where it entered the Chakachatna River valley.

The character of the lahars generated during the 1992 eruptions changed rapidly as they flowed down the flanks of the volcano and into the Chakachatna River valley. Where abundant, readily erodible sediment existed along the channel margins, such as along Crater Peak creek and Bench gully, the lahars incorporated additional sediment and sometimes bulked to debris flows. However, the flows contained very little clay-sized sediment, and most of the gravel in the flows was deposited on fans having slopes between 0.04 and 0.09 m/m, which is much steeper than depositional areas of lahars having more clay-sized sediment. Because the flows deposited most of their sediment on relatively steep slopes, the hazards resulting directly from the lahars did not extend far beyond the base of the volcano.

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