

THE 1980 ERUPTIONS OF MOUNT ST. HELENS, WASHINGTON

LAHAR MOVEMENT, EFFECTS, AND DEPOSITS

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ABSTRACT

Lahars occurred on May 18, 1980, on nearly all streams draining the cone of Mount St. Helens and were formed in three major ways: (1) The most voluminous lahar originated by slumping and flowing of water-saturated parts of the debris avalanche in the headwaters of the North Fork Toutle River. This lahar, which had the characteristics of a mudflow, modified more than 120 km of channel, including the main Toutle River and sections of the Cowlitz and Columbia Rivers. (2) Lahars with the highest velocities originated by catastrophic ejection of mixtures of lithic debris, ash and lapilli, water, and entrapped air; most such flows were confined to the immediate vicinity of the cone, but some were transitional to or were replaced downstream by mudflows that traveled much longer distances. (3) Finally, minor lahars were formed by melting of debris-laden ice and snow, and some were triggered by the heat of pyroclastic flows and recently deposited tephra. Although the largest 1980 lahars were devastating in their impacts on channels and flood plains, the effects were less than those of some earlier Holocene lahars of Mount St. Helens.

Flow velocities ranged from less than 1.5 m/s in downstream reaches, conveying the massive mudflow that originated on the North Fork Toutle River, to more than 40 m/s for highly mobile flows, debouching from steep canyons near the cone.

Lahar deposits are generally thin compared with depths of initiating flows. Thick fill was deposited locally, however, especially by mudflows. Even where lahars caused minimal channel deposition or scour occurred, overbank deposits are commonly more than 1 m thick. Present channels are unstable and are adjusting rapidly to the altered geomorphic and hydrologic conditions. Continued erosion will release much sediment from previously stable, pre-May 18 channel and flood-plain deposits, as well as from sediment deposited on and after May 18.

INTRODUCTION

Most major streams that originate on Mount St. Helens were significantly modified by lahars during and shortly after the May 18 eruption (U.S. Geological Survey, 1980; fig. 271). The lahars included both mudflows and debris flows at ambient or slightly elevated temperatures. The timing of the lahars can be constrained by tephra chronology (Waitt, this volume; Waitt and Dzurisin, this volume), by direct observation (Cummins, this volume; Rooth, 1980; Rosenbaum and Waitt, this volume), and by time-sequential aerial photographs. The number and timing of lahars differed significantly between valleys.

Following Mullineaux and Crandell (1962), the term "lahar" is applied to the broad range of debris flows and mudflows that resulted from the volcanic activity on and subsequent to May 18. Debris flow and mudflow represent closely similar forms of rheological behavior. The term "mudflow" is commonly used to describe the flows in which the mud content (silt plus clay) is sufficient to give the deposits a cohesive matrix and a typical muddy appearance. The total mud content may, however, be only a subordinate part of the poorly sorted deposit. Debris-flow deposits are less cohesive, more granular, and generally better sorted.

By far the most extensive and destructive lahars were those formed in the headwaters of the North

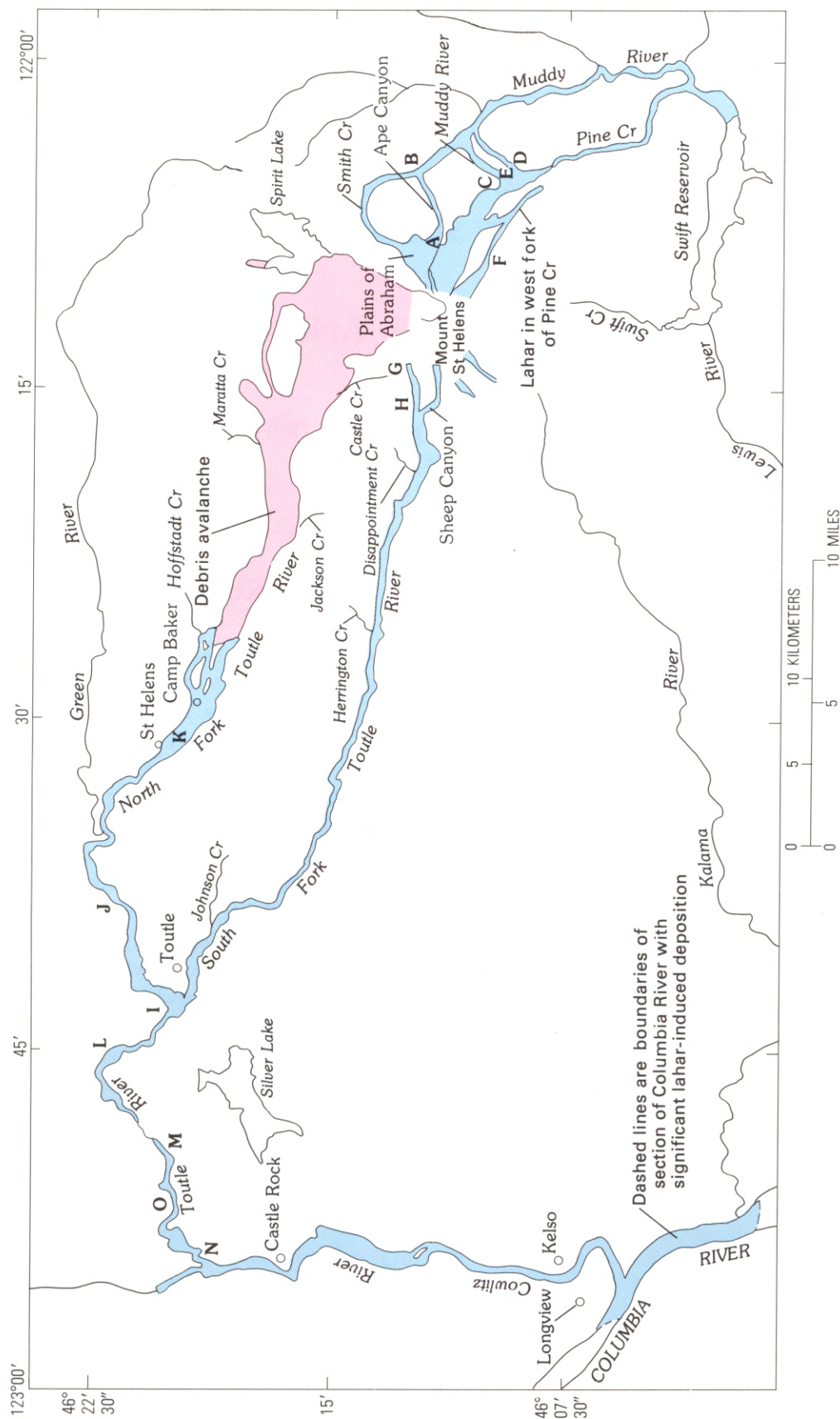


Figure 271.—Location map showing streams draining flanks of Mount St. Helens and areas impacted by lahars (shaded). Capital letters designate locations discussed in text.

Fork Toutle River; these flows ultimately deposited more than 50 million m³ of sediment along the lower Cowlitz and Columbia Rivers (Lombard and others, 1981; Peter Haini, written commun., 1980).

Destructive lahars also swept down the South Fork Toutle River. Rapidly flowing lahars originated in the headwaters of Pine Creek and the western tributaries to Muddy River, and smaller lahars and pyroclastic flows occurred in the headwaters of Swift Creek and the Kalama River (fig. 271). The impact of these lahars on bridges, roads, and other public works is discussed by Schuster (this volume).

Cohesive, clast-studded mudflow deposits extend to the highest flow marks throughout the lahar-impacted reaches of the North Fork Toutle River and the main Toutle River, as well as the lower Muddy, South Fork Toutle, and lower Cowlitz Rivers. In contrast, the highest limits of flow along the upper Muddy and South Fork Toutle Rivers are marked by abraded rock surfaces and trees. This abrasion, together with the granular texture of deposits laid down by the peak flow, suggests that the largest lahars along the upper Muddy and South Fork Toutle Rivers were debris flows or avalanches.

The most striking lahar-induced modification of valley morphology is widespread deposition, even though the lahar deposits are commonly less than 10 percent of the depths of the peak flows. Large amounts of scour were caused by the lahars along steep narrow canyons.

The May 18 lahars were voluminous and destructive. From socio-economic perspectives they were devastating. Nonetheless, from geologic and hazard-assessment perspectives, these lahars had less impact on the landscape than did some earlier Holocene lahars of Mount St. Helens (Mullineaux and Crandell, 1962; Crandell and Mullineaux, 1973, 1978). Velocities and length-descent ratios for the May 18 lahars generally fall within the range reported for earlier lahars at Mount St. Helens and at comparable volcanoes. The long runout of the main lahar from the North Fork Toutle River, however, is somewhat anomalous.

This report summarizes initial findings on the timing and physical characteristics of lahars formed during and shortly after the May 18 eruption, and on the consequent changes in valley morphology. The lahars are described in clockwise order, starting with upper Smith Creek and ending with the North Fork Toutle River (fig. 271).

ACKNOWLEDGMENTS

Special thanks are extended to Barry Voight, Harry Glicken, and John Cummins for information and much helpful discussion. We are also grateful for enthusiastic field assistance from Martha A. Sabol, James M. Duls, Jr., Lawrence A. Freeman, and Lyn J. Topinka. Janis L. Markman helped with many logistical problems. Weyerhaeuser Company provided detailed topographic maps of the Mount St. Helens area and access to their St. Helens tree farm.

UPPER SMITH CREEK

The upper Smith Creek basin was severely impacted by the 0832 PDT (Pacific Daylight Time) May 18 directed blast and the consequent blast pyroclastic flows that developed in channels (Hoblitt and others, this volume; Moore and Sisson, this volume; Waitt, this volume). The deposits of the blast pyroclastic flow in the upper Smith Creek area are commonly more than 2 m thick; they are overlain by silty gray ash with abundant accretionary lapilli, layer A3, which in turn are overlain by coarse pumiceous air fall, unit B (stratigraphic terminology from Waitt, this volume, and from Waitt and Dzurisin, this volume). The relation between the channelized blast pyroclastic flows and the massive mudflows that moved through Smith Creek remains to be established. The lahars that occurred on May 18 in upper Smith Creek tributaries

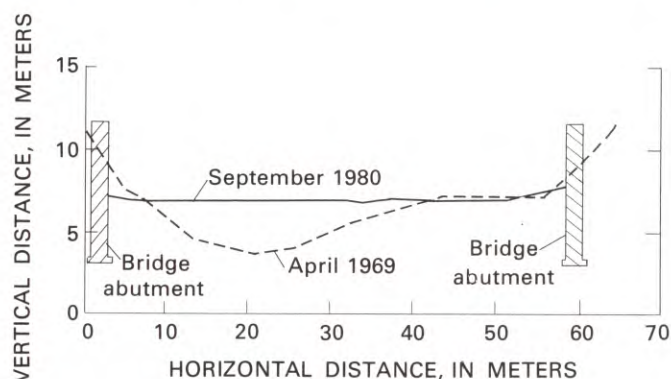


Figure 272.—Preeruption and posteruption cross-sectional profiles of the Muddy River at Muddy River bridge, 8.2 km upstream from the confluence with the Lewis River. Preeruption survey data from U.S. Forest Service site plans approved April 8, 1969.

that drain directly from the northeastern flank of Mount St. Helens were pumiceous mudflows less than 1.5 m thick. These mudflows, which overlie deposits of the blast pyroclastic flow, occurred during or shortly after the formation of unit B.

Deposits of both the blast pyroclastic flow and the later, smaller mudflows contain abundant angular-to-subangular pebbles and cobbles of a distinctive blue-gray dacite probably derived from the 1980 cryptodome that intruded the north flank of Mount St. Helens (Moore and Albee, this volume). The thin pumiceous mudflows in the upper Smith Creek tributaries that drain directly from Mount St. Helens locally reworked some of the blast pyroclastic-flow deposits from earlier eruptions.

MUDDY RIVER

Voluminous air-mobilized lithic avalanches, lithic mudflows, debris flows, and pumiceous mudflows at ambient or slightly elevated temperatures, as well as hot pumiceous pyroclastic flows, were generated in the headwaters of the western tributaries to Muddy River on May 18 (fig. 271). The lahars deposited more than 13 million m³ of water and sediment in Swift Reservoir between 0900 and 1200 (Cummins, 1981). Thin lithic and pumiceous mudflows and debris flows apparently were also generated by rapid melting of snow and ice.

INITIAL EVENTS

The number, types, and sequence of lahars differed between tributaries. On the eastern flank of the volcano, the maximum flow was associated with enormous, highly mobile lithic debris flows and avalanches that swept down the Plains of Abraham, Ape Canyon, upper Muddy River, and some eastern tributaries to Pine Creek (fig. 271). This assemblage of flows, here informally called the upper Muddy River lahar, moved across some areas that had previously been eroded by the directed blast during the 0832 eruption. Deposits of this lahar are in turn overlain by silty gray ash with abundant accretionary lapilli, layer A3, which started to fall within minutes of the 0832 eruption. Thus, the upper Muddy River lahar was generated during the explosive phase of the 0832 eruption.

Trimlines and abrasion marks on trees suggest that the upper Muddy River lahar was 10–20 m deep. A lobe of this lahar surged across a 75-m-high hill near the head of Ape Canyon (A in fig. 271). If the kinetic energy of a frictionless, 20-m-deep flow were converted to the potential energy of the lahar deposits on the crest of this hill, the flow velocity must have exceeded 32 m/s. Similarly, the more than 80-m runup on the eastern valley wall of Smith Creek, opposite the mouth of Ape Canyon (B in fig. 271), requires velocities exceeding 40 m/s. That these velocities were attained close to the volcano is reasonable, because the deposition that began in Swift Reservoir as early as 0900 on May 18 requires an average velocity greater than 13 m/s.

Sediment deposited by the upper Muddy River lahar covers a large area, but it is commonly less than 2 m thick. The sediment consists primarily of angular blocks and lapilli of lithic debris in a fine sand or silty sand matrix, and contains less mud and pumice than do the deposits of later lahars in this same area. The intermediate diameter of the largest clasts is about 0.5 m. The blocks consist of types of andesite, dacite, and less commonly basalt from the modern volcanic cone, as well as 1980 cryptodome dacite (Moore and Albee, this volume) and hydrothermally altered dacite and andesite from ancestral Mount St. Helens (C. A. Hopson, written commun., 1980). The timing, lithology, and high velocity of the upper Muddy River lahar suggest that it was caused by the explosive ejection of a mixture of rock, ash, and water from the former summit of the volcano. The high mobility of the initial lahar may indicate that air was trapped in the ejecta as they fell back to the cone.

The upper Muddy River lahar spilled into the steep northeast-trending canyon of Muddy River (C in fig. 271), the similar unnamed canyon containing Hoo Hoo Lake (D in fig. 271), and into two forks of Pine Creek. In Pine Creek, flow was concentrated in the eastern fork. At the low hill that forms a common drainage divide for Muddy River, Hoo Hoo Lake, and Pine Creek (E in fig. 271), the upper Muddy River lahar attained less than 30 m of runup and velocities were probably less than 20 m/s. Despite significantly reduced velocity, this lahar still scoured vegetation, soil, colluvium, and older lahar deposits along all but the westernmost spillover route.

The lahar along the main southeast-trending Smith Creek–Muddy River valley below Ape Canyon

PINE CREEK

Sizable debris flows and mudflows occurred in the headwaters of the west fork of Pine Creek. The most voluminous of these flows occurred at about the same time as the upper Muddy River lahar with which it interfingers (fig. 271). Peak flow of the Pine Creek lahar, which had the character of a mudflow, was 10 m or less in depth near locality F (fig. 271). The resulting deposits are 0.5–2.5 m thick. The matrix of the lahar on the west fork of Pine Creek contains more mud than that of the upper Muddy River lahar. The amount of cross-valley banking of mudlines due to radial acceleration at a stream bend near locality F in figure 271 suggests that the initial lahar of May 18 on the west fork of Pine Creek had a velocity of about 31 m/s (Fink and Malin, 1980). Despite high initial velocity and volume, however, this lahar did not reach the confluence of the forks of Pine Creek. Heavily sediment-laden water that flowed out from or immediately followed this lahar nonetheless caused significant erosion and deposition along reaches of the west fork of Pine Creek not directly impacted by the mudflow.

A smaller lahar occurred after the May 18 air fall but before the May 25 air fall. This lahar was characterized by larger average grain size and apparent shear strength, but was of lower velocity than was the initial lahar (Fink and Malin, 1980). A still smaller



Figure 273.—Trench enlarged and deepened by water torrents at west fork of upper Pine Creek. Trench eroded by though older unconsolidated lahar deposits overlain by about 0.5 m of May 18 lahar deposits.

LATER EVENTS

(fig. 271), here informally called the lower Muddy River lahar, destroyed two major road bridges (fig. 272) and buried 20 km of U.S. Forest Service roads on the flood plain of the Muddy River. This lahar also destroyed the Eagle Cliff bridge across the Lewis River near the head of Swift Reservoir. Peak flow was 10–20 m deep and transported cobbles and boulders near the surface. Most new deposits are less than 0.3 m thick near the margins of the inundated area and 1–2.5 m thick near former channels. Locally the channel was scoured to bedrock. The high flow-marks on riparian trees and bedrock surfaces along the lower Muddy River are formed of cohesive mud that commonly contains spherical cavities and pebbles. Many trees close to the axis of maximum flow, however, were sheared off and pushed in front of the advancing lahar. A massive logjam accumulated on the Muddy River in the tortuous, narrow canyon immediately upstream of the confluence with the Lewis River. Along the margins of the inundated areas, the riparian vegetation was toppled and abraded into long, tapering “bayonet trees.”

Several mudflow deposits as much as 2.5 m thick stratigraphically overlie deposits of a pumiceous pyroclastic flow that was observed surging down the headwaters of the Muddy River shortly before 1600 on May 18 (Roeth, 1980). Deposits of this flow consist predominantly of pebble-size pumice and fill gullies that were eroded several meters deep into the upper Muddy River lahar and pre-May 18 deposits. Where the pumice flow deposits overlie the earlier deposits, they display prominent flow ridges 0.2 m high that are parallel to its lateral margin. The overlying mudflow deposits display silt- and clay-rich matrices, dispersed cobbles and boulders of andesite, dacite, and less commonly basalt, prominent flow ridges, and varying amounts of included pumice and other surficial tephra. Relationships between these mudflow deposits and various surficial tephra layers suggest that at least one of these flows occurred during the waning phases of the May 18 eruption, that one occurred following May 18 but prior to the end of the eruption on May 25, that another occurred between May 25 and the end of the eruption on June 12, and that several thin flows of limited extent occurred later in the summer.

debris flow occurred after May 25 but before mid-July. Throughout the summer and early fall, small torrents of water laden with pumice and lithic debris, similar to torrents observed in the upper Muddy River, occurred during periods of rain or intensive melting of snow and ice in the headwaters of the west fork of Pine Creek. These torrents progressively enlarged and deepened a trench eroded through the May 18 and older unconsolidated lahar deposits. By early September this trench was locally more than 6 m deep (fig. 273). As in the upper Muddy River, much of the sediment that was eroded from this area by subsequent high streamflow or lahars was derived from older lahar deposits exposed in the unstable walls of this trench.

SOUTH FORK TOUTLE RIVER

INITIAL EVENTS

The lithologic character and sequence of lahars on May 18 in the headwaters of the South Fork Toutle River were similar to those in the headwaters of Muddy River. Large volumes of water-saturated lithic debris ejected during the initial phases of the eruption flowed rapidly down most of the western flank of the volcano between Toutle Glacier and the headwaters of Sheep Canyon. Water-saturated ejecta collected in South Fork Toutle River and developed into a single, sharp-crested mudflow peak that was observed by witnesses many kilometers downstream. In the area between Disappointment Creek and Sheep Canyon, peak flow occurred within minutes of the 0832 eruption, because peak mudflow deposits rest on directed-blast deposits but underlie layer A3.

The flow down the upper South Fork Toutle River locally ran up 110 m on the precipitous north valley wall (G in fig. 271). This flow scoured preexisting soil and colluvium, and left only a scattering of clasts and a thin (less than 0.3 m), discontinuous gray veneer of debris-flow deposits on the valley wall. In the field, May 18 runup deposits are difficult to distinguish from lithologically similar, older deposits that crop out on the valley wall at that point.

On the north valley wall of the South Fork Toutle River about 1 km upstream of Sheep Canyon (locality H; figs. 271, 274), May 18 lahar-scoured surfaces and thin lag deposits occur as much as 54 m above the

general depositional surface of the lahar. These deposits were not formed by cross-valley banking of mudlines due to radial acceleration around bends, or by cross-valley surging of a tributary flow; therefore, they indicate that flow of the initial South Fork Toutle River lahar was highly turbulent and was charac-

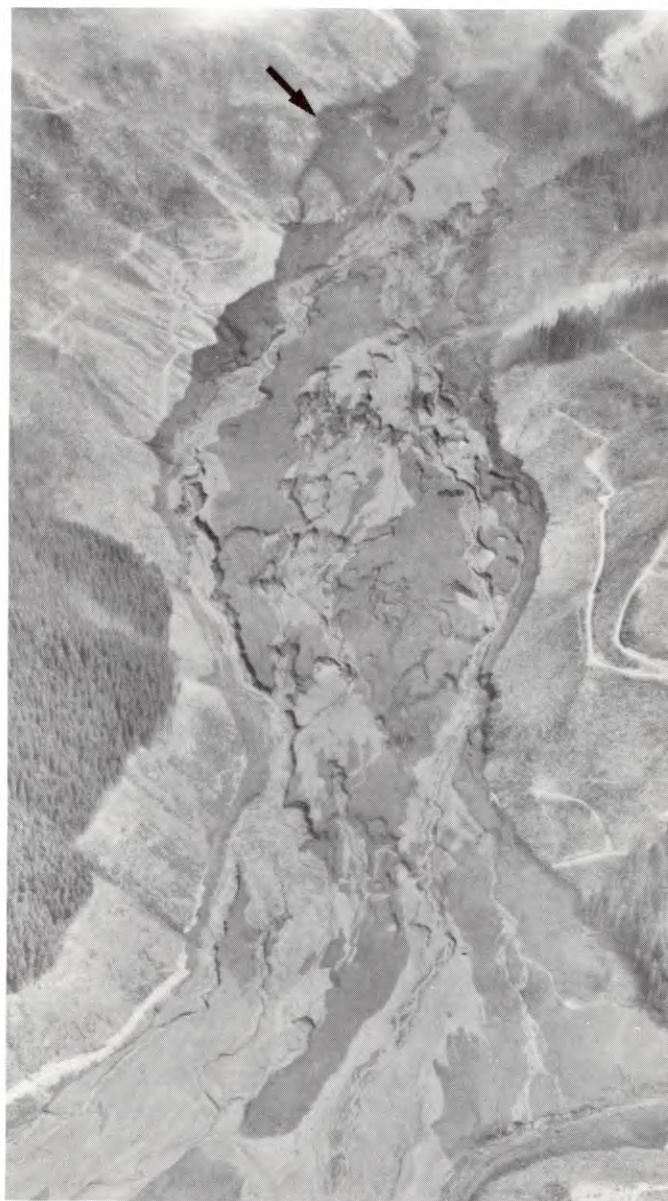


Figure 274.—Oblique aerial photograph of upper South Fork Toutle River, looking east and upstream. Arrow indicates runup of lahar on north valley side slope (see locality H in fig. 271). Initial May 18 lahar deposits appear as dark-gray areas; later May 18 pumiceous mudflow deposits appear as light-gray areas in valley bottom. Inundated valley in bottom center of photograph is 1.0 km wide. Photograph by Austin Post, May 19, 1980.

mudflow and debris-flow deposits. The base of the May 18 lahar deposits in these areas is often difficult to recognize, except where the May 18 and older deposits are separated by a zone of roots, toppled vegetation, or partially decayed organic matter. This difficulty reflects striking lithologic similarities between the May 18 and older lahar deposits. Between Disappointment Creek and Johnson Creek, however, deposits of the peak May 18 lahar are more typical of a mudflow, because their matrices contain abundant silt and clay. Streamlined longitudinal "whaleback" bars of subangular cobble gravel that have a locally intact framework and a silt- and clay-rich matrix occur at several different levels. Crests of the higher of these bars are within about 2 m of the high mudline; this correspondence suggests a close association of the bars with the mudflow peak. Sediment composing these bars typically displays either a nonconsistent internal variation in properties or a crude normal (upward-fining) size gradation. Gently sloping berms at levels below the peak mudflow are underlain by better sorted, less cohesive sediment that is typically associated with granular debris flow. Fine sediment in the upper parts of both bars and berms typically is better sorted and stratified than sediment in their coarse basal parts. This vertical sequence of deposits suggests that waning phases of the South Fork Toutle River lahar at any given point may have been characterized by a somewhat rapid transition between mudflow, debris flow, and heavily sediment-laden streamflow ("hyperconcentration" of Beverage and Culbertson, 1964). The peak South Fork Toutle River lahar apparently was transformed to highly sediment-laden streamflow. Massive mudflow deposition took place between Johnson Creek and the confluence of the North Fork and South Fork Toutle River. Little mudflow deposition occurred below the confluence; downstream, the main South Fork lahar is typically represented by less than 1 m of relatively well sorted silt and fine to medium sand with weakly developed internal stratification. At the head of the constricted canyon reach below the confluence, however, this water-laid runoff deposit is overlain by 2.5 m of South Fork mudflow deposits, suggesting local ponding of the mudflow phase. Water-laid deposits recording of the lahar past the town of Tower (L in fig. 271), Tower Road bridge (M in fig. 271), and old U.S. Highway 99 (N in fig. 271). Downstream from the confluence, the South Fork Toutle River deposits rest

terized by considerable cross-valley sloshing. This suggestion is consistent with observations of an eyewitness 6 km downstream (Rosenbaum and Waitt, this volume). Other eyewitness accounts, as well as the character and spatial distribution of the lahar deposits in South Fork Toutle River downstream of locality H, suggest that flow became less turbulent and slowed rapidly. One party of survivors, within 8.5 km of the summit of Mount St. Helens at the time of the eruption, drove downstream and crossed a bridge 18.5 km from the summit 10–12 min after the eruption (R. B. Waitt, written commun., 1980); this timing suggests that the average velocity of the lahar in this reach was not more than 31 m/s. Cross-valley banking of mudlines due to radial acceleration around valley bends suggests an average velocity between 7 and 29 m/s (Wigmosta and others, 1980). Residents who observed the arrival of the South Fork Toutle River lahar near the town of Toutle described the flow front as a 2- to 3-m-high tangle of logs and other woody debris that advanced downstream at 3 to 4 m/s. Compilation of eyewitness accounts of the timing of peak stage between locality H and the confluence of the North Fork and South Fork Toutle River suggests an overall average velocity of about 7 m/s (Cummins, this volume). Depth of the South Fork Toutle River lahar also decreased markedly in a downstream direction. Near locality H (fig. 271) the flow was at least 15 m deep. At the stream gage immediately below the confluence of the North Fork and South Fork Toutle River, flow rose 6.4 m to a stage that exceeded the peak of 72 prior years of record by 0.3 m (Cummins, this volume). Peak discharge of that lahar at the Cowitz River at Castle Rock (fig. 271) was marked by only a 0.98-m increase in stage. At Longview (fig. 271), passage of this peak was reportedly marked by the arrival of a large mass of floating woody debris, but by no increase in stage and little increase in turbidity. Pronounced downvalley reductions in both velocity and depth of the South Fork Toutle River lahar are compatible with the downstream decrease in discharge computed by Wigmosta and others (1980). Dramatic downvalley changes in texture and composition of the deposits of the initial South Fork Toutle River lahar indicate changes in the nature of the flow. Near the volcano, deposits of the initial May 18 lahar are generally less than 1.5 m thick and possess a granular matrix that is transitional between typical

upon distinctively different older alluvium and lahar deposits that display larger average grain size (cobbles and boulders), greater rounding, a larger proportion of dacite and andesite from ancestral Mount St. Helens, and fewer rocks from the modern cone. Neither deposit contains large amounts of pre-Mount St. Helens (upper Eocene to Oligocene) metavolcanic rocks, even though most of the drainage basin is underlain by those rocks.

The magnitude of mudflow-induced modifications of channel geometry can be substantiated more completely throughout the Toutle River system and lower Cowlitz River valley than on the south and east flanks of the volcano, because the preeruption valley configuration is documented by numerous bridge contract plans and detailed (1:9600) topographic maps. Comparisons indicate that the initial May 18 lahar on the South Fork Toutle River substantially modified the valley and channel configuration of that river. Vegetation adjacent to the original channel was either sheared off or toppled and abraded into long, tapering "bayonet" trees. Bank erosion, as well as deposition along both the thalweg and flood plain, was readily discernible nearly everywhere. However, amounts of erosion and deposition were highly variable (fig. 275, A and B).

Most of the 0.8-km-wide valley bottom in the vicinity of Sheep Canyon and Disappointment Creek displays a veneer of May 18 lahar deposits that is generally less than 1 m thick. However, vertical-walled gullies commonly more than 4 m deep were incised into the May 18 and older lahar deposits by the waning phase of the May 18 lahar. Continued erosion of these gullies and the main river channel is an important source of downvalley sedimentation.

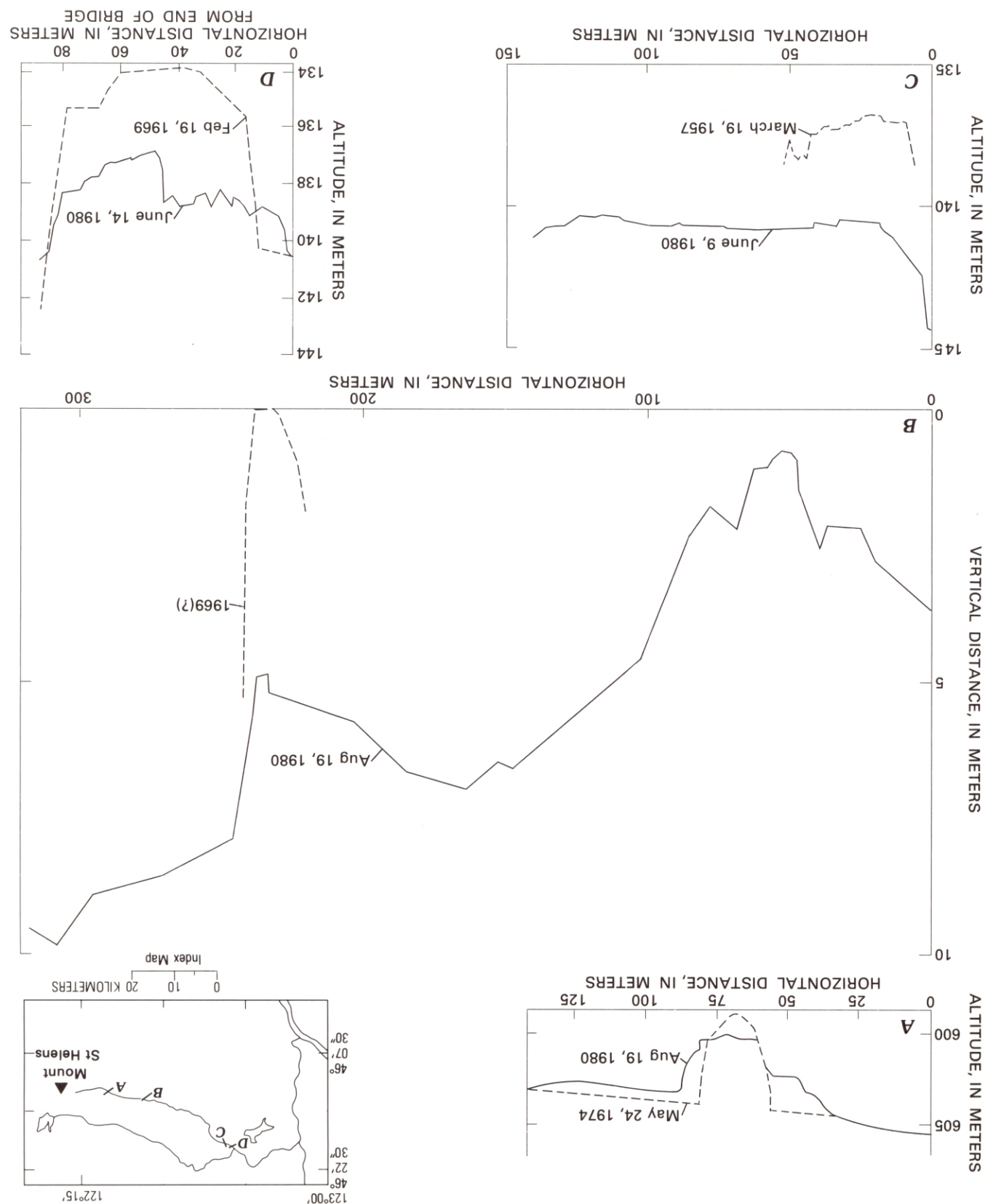
The surge of the South Fork Toutle River lahar through the confined canyon between Herrington Creek and Johnson Creek caused strikingly less channel modification than that in upstream and downstream alluvial reaches. The lahar scoured away soil and colluvium from the valley sides, and then deposited a thin veneer of mudflow deposits up to the peak flood mark. Flat-topped berms and "whaleback" bars rise from 2 to 5 m above the general level of the channel.

Through the broad alluvial reach between Johnson Creek and the North Fork Toutle River, fill from the May 18 lahar is from 2 to 4 m thick (fig. 275, C and D).

LATER EVENTS

A second lahar was observed in the upper reaches of the South Fork Toutle River at about 1400 on May 18. This lahar probably accounts for the anastomosing pattern of light-gray deposits seen in aerial photographs to be resting on the initial darker gray May 18 lahar deposits in areas upstream from Disappointment Creek (fig. 274). These deposits appear to have originated in the headwaters of the main South Fork Toutle River canyon, not in the unnamed tributaries and Sheep Canyon that drain the northwestern flank of the volcano. The deposits that underlie the anastomosing light-gray areas in the photographs are highly pumiceous debris-flow deposits 0.05–0.25 m thick. The pumice in these deposits is white to light gray, well rounded, and predominantly less than 0.5 cm in intermediate diameter. Nonetheless, pumice clasts as much as 3 cm in intermediate diameter are abundant. A probably correlative low berm of highly pumiceous debris-flow deposits was observed at several localities adjacent to the low-water channel in downstream reaches of the South Fork Toutle River, prior to being eroded by high streamflows in November 1980. The pumiceous debris flow was probably generated by accelerated melting of the heavily debris- and tephra-laden Toutle and Talus Glaciers, which drain directly into the main upper South Fork Toutle River canyon. Melting may have been induced by the accumulation of hot tephra or by a small pyroclastic flow during the afternoon of May 18.

Figure 275.—Preeruption and posteruption cross-sectional profiles of South Fork Toutle River. A, At site of Weyerhaeuser bridge no. 5700–1, 1.0 km downstream from Disappointment Creek. Note both erosion and deposition near thalweg. Preeruption profile from Weyerhaeuser Company. B, At site of Weyerhaeuser bridge no. 4100–3, near mouth of Herrington Creek, 8.7 km downstream from preceding section. Preeruption profile from Weyerhaeuser Company. C, Near Toutle, at site of discontinued (1957) stream-gaging station (no. 14.2410), 2.2 km upstream from confluence with North Fork Toutle River. Note channel aggradation and widening. Nearly all the indicated change occurred on May 18. Preeruption profile determined from information collected during discharge measurement. D, At Cowlitz County highway bridge, 1.2 km upstream from confluence with North Fork Toutle River. Note extensive fill. Preeruption profile from Cowlitz County Department of Public Works.



Unlike the upper Muddy River and Pine Creek areas, no extensive lahars seem to have been generated in the upper South Fork Toutle River during eruptions after May 18. However, channel incision and gullyng of lahar deposits, caused by heavy rains in November and December, have contributed significant quantities of coarse sediment to downstream reaches of the South Fork Toutle River. A substantial part of this sediment was eroded from pre-May 18 lahar deposits.

NORTH FORK TOUTLE RIVER

The destructive lahar that flowed through the North Fork Toutle River during the afternoon of May 18 differed from the lahars in other valleys on that day in that it originated on water-saturated parts of the hummocky debris avalanche (Voight and others, this volume), not high on the volcano. This lahar also differed from the other lahars by its greater volume, lower velocity, more sustained flow, coarser and more poorly sorted deposits, and greater length of flow. Despite these differences, the deposits of this lahar display surface morphology, gross lithologic character, and vertical textural changes that are similar to those of other May 18 lahar deposits. An additional similarity is the thinness of the deposits in most reaches relative to the depth of the responsible flow.

Observations from helicopters and subsequent aerial photographs show that the through-flowing mudflows started predominantly on the surface of the avalanche deposit and not on the cone (pl. 1; Voight and others, this volume). Observers in rescue helicopters flying over the distal parts of the hummocky avalanche deposit during the late morning and afternoon of May 18 saw numerous grayish-brown mudflows moving over the irregular surface of the avalanche (Harry Glicken, written commun., 1980). Numerous individual flows of contrasting texture and color were observed to originate from slumping and flowing of water-saturated parts of the avalanche deposit, to pond in closed depressions, and to break out of those depressions as larger, more homogeneous flows. Unponded parts of the flows were only a few meters deep and flowed downvalley at rates of 12 to 15 m/s. The impact of this complex sequence of flows differed greatly from point to point. Some areas experienced progressive deposition; others experienced

alternating erosion and deposition; and still others, particularly toward the distal end of the avalanche, experienced progressive erosion.

Back-calculated stability analysis of the 0832 landslide that started the avalanche indicates that the entire potential detachment plane must have been subjected to a pore pressure equivalent to 480 m of liquid water. Thus, most of the slide mass was probably water saturated and some parts may even have been subjected to artesian pressures (B. Voight, written commun., 1980). Additional water was provided by rapid melting of the finely pulverized portion of the 0.13 km³ of glacial ice that was removed from the mountain and incorporated into the debris avalanche (Brugman and Meier, this volume). However, much of the melt water was released long after the lahars were started; occasional large blocks of glacial ice, which were visible in the avalanche for many weeks following emplacement, played no role in mobilizing the lahars of May 18.

The peak lahar did not leave the distal end of the avalanche deposit until about 1330. By this time, the peak of the South Fork Toutle River lahar had already passed into the Cowlitz River, and lahar-induced deposition in Swift Reservoir was almost complete (Cummins, 1981).

Leaving the avalanche deposit, the North Fork Toutle River lahar took two routes—one followed the downstream channel of Hoffstadt Creek and the other followed the main channel of the North Fork Toutle River. The timing of flows down these two routes is uncertain, but both flows converged into a single flow about 4 km above the townsite of St. Helens (fig. 276B). One voluminous lahar having the initial texture of a mudflow then continued downstream. It swept away bridge decks and girders, but left piers in place. A portion of this lahar flowed up the Green River and deposited mudflow deposits, coarse woody debris, and steel-bridge girders in rearing ponds of the Green River fish hatchery.

Along the alluvial reach between the distal end of the avalanche and the mouth of the Green River, the North Fork Toutle River lahar substantially modified the drainage pattern and overall valley morphology, even though most of the resulting deposits are only 1 or 2 m thick. Between the Green River and locality J (fig. 271), the lahar surged down a confined bedrock canyon but caused only minor change in overall valley morphology, even though 1–1.5 m of overbank mud-

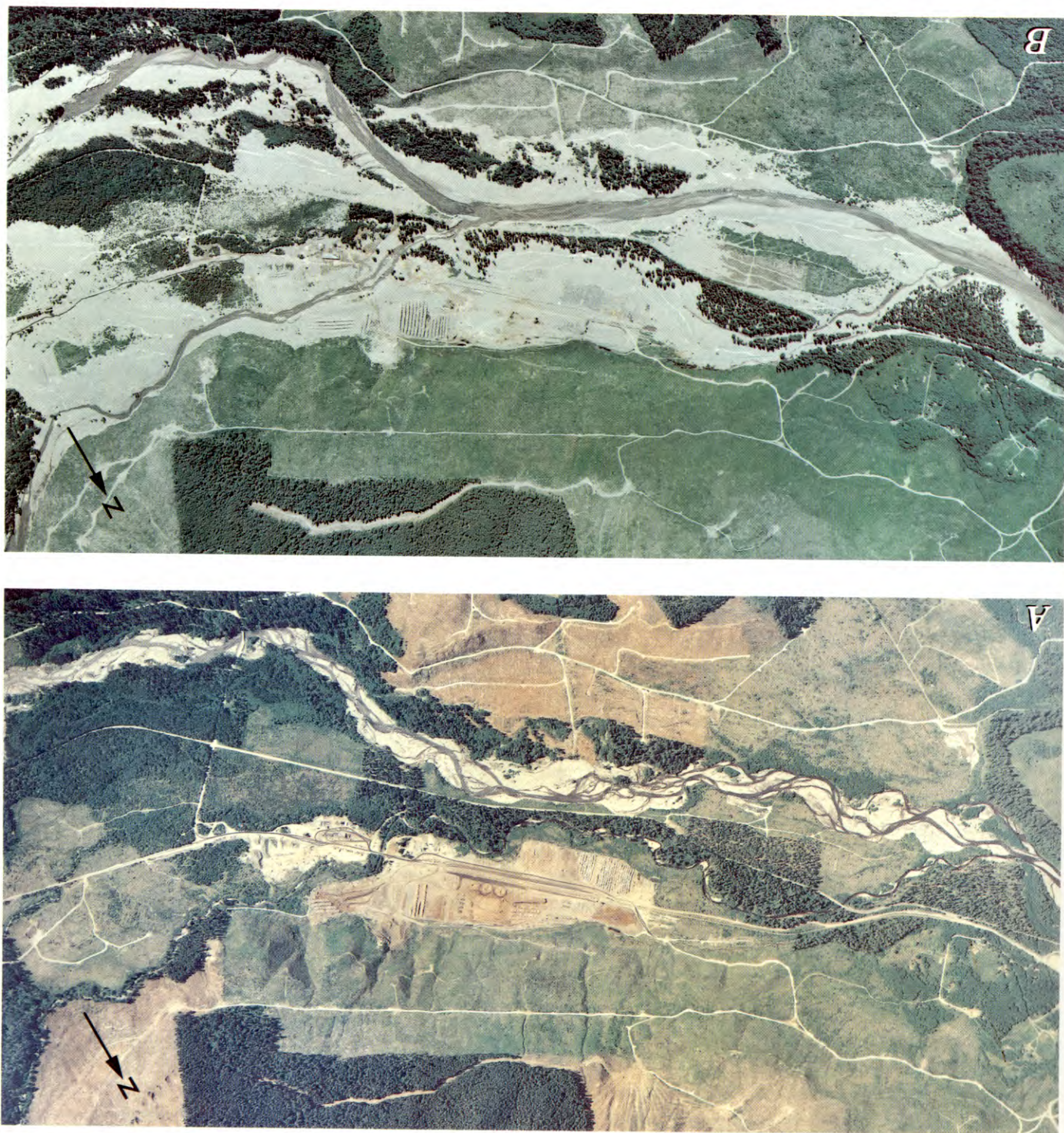


Figure 276.—Vertical aerial photographs, scale 1:24,000, showing valley of North Fork Toutle River near Camp Baker (near center of photograph). Flow from right to left. A, preeruption photograph, June 5, 1978; B, posteruption photograph, June 19, 1980. Width of mudflow inundation in center of photograph is 1.0 km. Note change in position of Hoffstadt Creek, which joins the North Fork Toutle River at Camp Baker in B. Photographs from Washington Department of Natural Resources.

flow deposits are present locally (fig. 277A). Between locality J (fig. 271) and the Toutle River stream-gaging station near Silver Lake (near I in fig. 271), a reach that includes the confluence of the North Fork and South Fork Toutle River, the North Fork Toutle River lahar again caused massive changes in channel pattern and valley morphology. Overbank deposits commonly are 3 m thick, and the sites of some former channels have more than 5 m of new deposits. Nonetheless, the channel in late summer was commonly incised as much as 1 m below the preeruption surface (fig. 277B).

In the broadly inundated areas between Camp

Baker and the townsite of St. Helens (K in fig. 271), the contrast in heights of mudlines on upstream and downstream sides of standing trees suggests that flow velocities were commonly 4–5 m/s; however, close to the axes of maximum flow along both Hoffstadt Creek and the North Fork Toutle River, numerous trees were either sheared off or toppled and abraded. Increased depth of flow probably contributed to the increased damage, but local flow velocities higher than those suggested by mudlines on surviving trees may have been an additional factor.

Leaving the St. Helens area, the North Fork Toutle

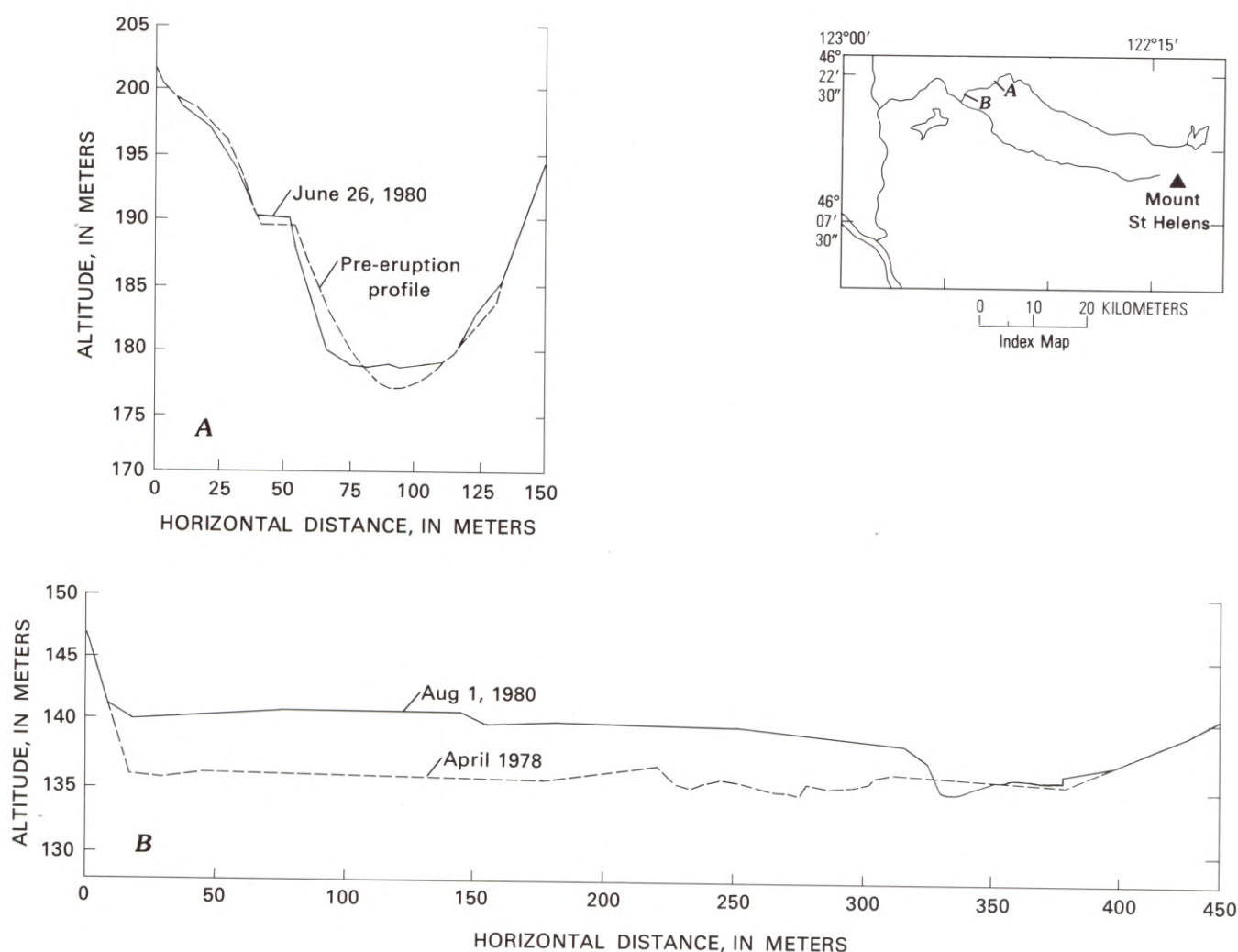


Figure 277.—Preeruption and posteruption cross-sectional profiles of the North Fork Toutle River. A, At State Highway 504 bridge near Kid Valley, 6.7 km downstream from the Green River. Little change in profile occurred. Preeruption profile from Washington State Department of Transportation. B, 0.5 km upstream from confluence with South Fork Toutle River. Note extensive fill on most of flood plain. Preeruption survey from Tudor Engineering. Observed depths of fill in adjoining areas are 1–1.5 m less than that suggested by comparison of preeruption and posteruption surveys, which appear to have used different altitude data.

Figure 278.—"Bayonet" trees on inundated area along North Fork Toutle River. Note sharpening of trees to points in downstream direction.



mudline elevations, partially decomposed logs from the former forest floor (fig. 279), as well as some mobile homes and small wooden-frame houses, floated passively on the mudflow; they were ultimately deposited in a relatively unmodified state on the new flood-plain surface (fig. 280).

Lahar deposits overlying the massive avalanche deposit and in the broad alluvial reach above the town of St. Helens are predominantly subangular pebble and cobble gravels with abundant silt and clay in the matrix. The deposits are mostly from 0.5 to 2 m thick and display rather flat surfaces, except where they have been incised by gullies and channel erosion. Upper surfaces of most thin lahar deposits on the avalanche are rather smooth, but some show distinct,ropy flow structures similar to those of pahoehoe lava; local relief on the flow structures is typically 7.5 cm or less. On steeply sloping channel margins, both on the avalanche and at numerous downvalley locations, veneers of cohesive mudflow deposits at and immediately below the peak flow levels show multiple recessional surge lines that are generally separated from one another by less than 0.3 m. Where the margin of the peak flow rests on a smooth, gently sloping surface, such as a road, an abrupt flow front at least 3 cm high is commonly present. Large (0.5–2 m in diameter) angular clasts of such noncohesive materials as avalanche deposits, colluvium, weathered older lahar deposits, and weathered tephra, occur commonly on the surface of the lahar

area (Cummins, this volume). The nature of the impact of the North Fork Toutle River lahar on flood-plain vegetation and the contrasting height of mudlines on the upstream and downstream sides of standing trees suggest that at any given cross section, the velocity of the lahars dropped markedly away from the thread of maximum flow. Sheared trees, as well as topped and abraded trees (fig. 278), are restricted to the near-channel parts of the inundated area. Considerable splashing is commonly evident at the top of mudlines on the upstream sides of standing trees adjacent to the zone of topped abraded trees. The difference in height between mudlines on the upstream and downstream sides of standing trees is greatest in the areas showing signs of splashing, and decreases to zero over distances of a few tens of meters transverse to the direction of flow. In areas of inundated forest that have consistent

augmented by a massive logjam in the same general fluence, but it may also reflect or have been through the constricted canyon reach below the confluence of the North Fork and South Fork Toutle River. This ponding may indicate restricted discharge fluence of the North Fork and South Fork Toutle ponding of the lahar may have occurred near the confluence of the North Fork and South Fork Toutle than the computed at-a-point velocities. Sustained the North Fork Toutle River was considerably slower downstream progression of peak stage of the lahar in River, timed visual observations suggest that additional documentation of these high velocities. However, as with the lahar in South Fork Toutle flows. Videotapes of television newsreels provide 31 m/s for the Toutle River and Pine Creek mud- (1980), who computed velocities ranging from 7.0 to by Wigmosta and others (1980) and Fink and Malin ton, 1969). Similar computations have been reported valley slope of the flow surface (Johnson and Hamp angle of the channel, and $\tan \beta$ is the presumed cross-radius of curvature for the stream bend, ϕ is the slope velocity, g is the acceleration due to gravity, ψ is the the formula $v = (g \psi \cos \phi \tan \beta)^{1/2}$ where v is mean 6.0–8.0 m/s. Velocities at bends were computed from stream mudlines on standing trees imply velocities of stream bends and contrasting upstream and down-North Fork Toutle River, however, supererelevation on lahar was about 12 m/s. Throughout the rest of the Green River, the mean flow velocity for the peak suggest that immediately below the mouth of the (supererelevation) due to radial acceleration on bends canyon. Velocities implied by cross-valley banking River lahar flowed into a more constricted bedrock

deposit and sporadically within the deposits themselves. These fragile clasts are commonly found more than 1 km from their most probable sources.

Where either expansion or contraction of a reach caused a major change in flow competence, large streamlined longitudinal "whaleback" bars of poorly sorted boulder or cobble gravel are commonly present. These features, which vary greatly in height and length, are as much as 60 m in length and 4 m in height. Height-to-length ratios are generally less than 0.05. As with similar features along the South Fork Toutle River, these large bars were apparently closely



Figure 280.—Locally passive nature of mudflow is shown by relatively intact condition of house, which apparently floated on mudflow surface to this position.



Figure 279.—"Nurse" log lying beneath mudline showing locally passive nature of mudflow near edge of flood plain. Note marks on standing tree caused by abrasion of the log as it floated up with rising stage and then lowered during falling stage.

associated with the mudflow peak. The basic morphology of these bars is depositional, but localized erosion during recessional flows extensively modified some bars.

Differences in sorting and degree of admixture of old alluvium indicate that significant erosion accompanied the bar-forming phase of flow. The lower parts of the bars where viewed in cross section contain a larger proportion of rounded and subrounded cobbles and boulders, as well as sand derived from the underlying alluvium, than do the upper parts. The basal 5–15 cm of the deposits typically contain more silt and clay and are browner and more compact than the overlying deposits. Locally, a faint platy structure is evident in this basal layer.

Above the compact basal layer, the deposits typically are massive or exhibit crude normal size gradation. The gradation tends to be concentrated in the uppermost 0.2 m of the deposit and gives the appearance of a mud-rich "skin." Uncommonly, poorly defined stratification is discernible in these bars; individual strata show crude normal size gradation, are generally less than 2 m thick, and are nearly parallel to the surface of the bar. Fragile clasts of older surficial deposits and soils are present at the surface of the bars and locally within the bar deposit. Also resting on the surface or embedded only a few centimeters into the tops of the bars are rounded to subangular boulders and blocks commonly more than 1 m in diameter. The surficial boulders and blocks are composed of the same general suite of lithologies found within the deposits

and include high-density pyroxene andesite. The large clasts of low-density hydrothermally altered ancestral dacite (C. A. Hopson, written commun., 1980) and vesicular 1980 cryptodome dacite (Moore and Albee, this volume) are more abundant near the peak flow marks than elsewhere in the deposits. Compared to the South Fork Toutle River mudflow, that on the North Fork Toutle River was less commonly overridden by

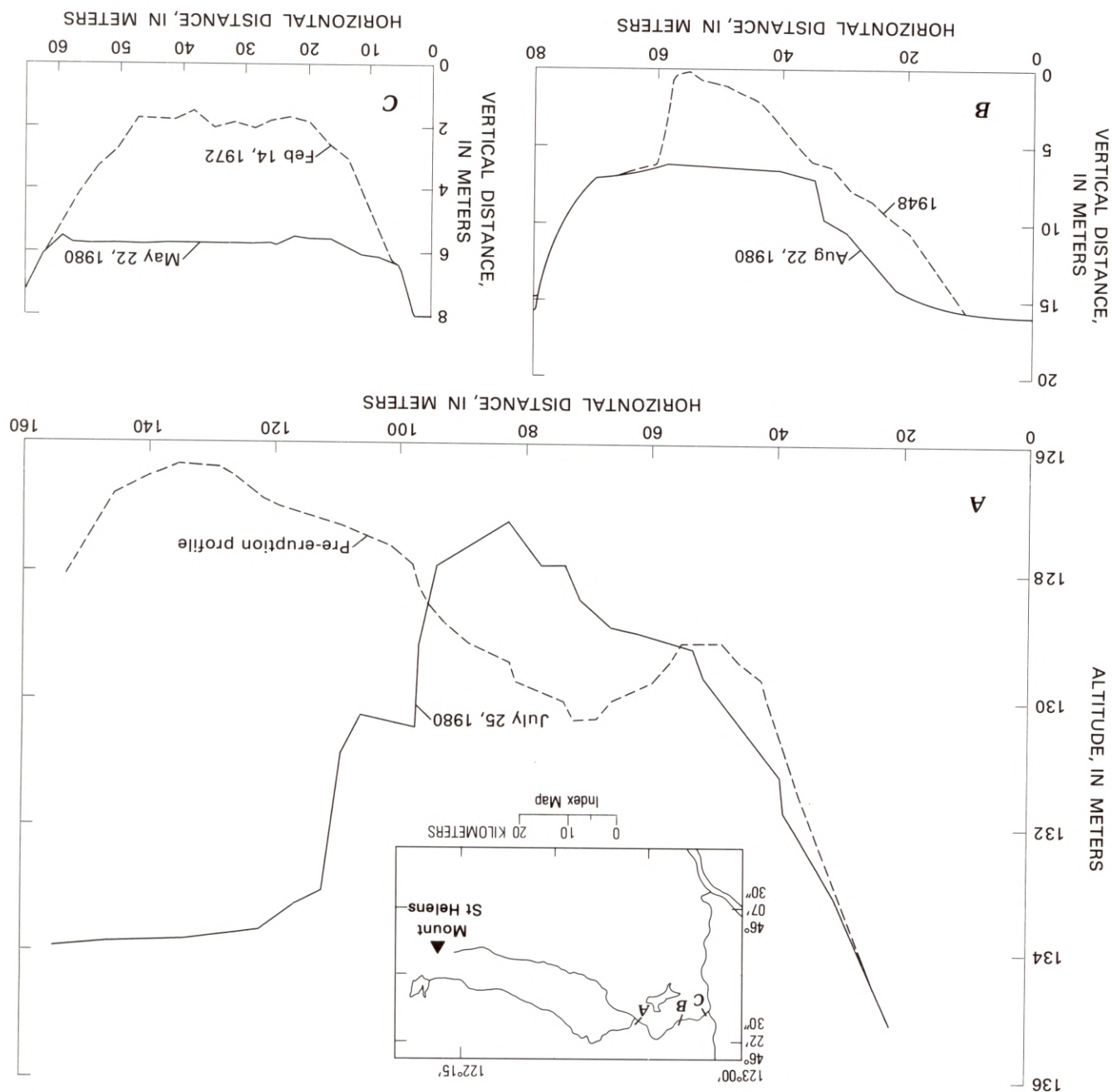


Figure 281.—Pre-eruption and post-eruption cross-sectional profiles of Toutle River. A, At Coal Bank Bridge, State Highway 504, located near I in figure 271. Note thick accumulation of mudflow deposits on right side of profile. Pre-eruption profile from Washington State Department of Transportation. B, At Tower bridge, M in figure 271. Note thatweg aggradation and formation of berm on left side of profile. Pre-eruption profile from Cowlitz County Department of Public Works. C, At State Highway 99 bridge, N in figure 271. Pre-eruption and post-eruption profiles, U.S. Geological Survey.

associated streamflow, but as on the South Fork Toutle River, debris-flow transport after peak mudflow is locally evidenced by low lateral berms of less cohesive sediment.

TOUTLE RIVER

Downstream from the confluence of the North Fork and South Fork Toutle River, the number and variation of flows were reduced. The deposits mainly represent the larger, more sustained flows from the North Fork Toutle River. At several localities (*I*, *L*, and *M* in fig. 271), coarse-grained but cohesive mudflow deposits from the North Fork Toutle River can be observed resting on stratified noncohesive sand and silty sand deposited by the downstream runout of heavily sediment-laden water from the initial South Fork Toutle River lahar. Along much of the Toutle River, the average thickness of May 18 lahar deposits is less than 1 m because the river flows primarily through narrow bedrock canyons. In these constricted reaches, the flows eroded considerable amounts of colluvium and alluvium, but lahar-deposited bars and berms are locally prominent (fig. 281, *A* and *B*). Large-scale lahar deposition along the lower Toutle River was concentrated in the wide alluvial reaches near the town of Tower (*L* in fig. 271) and immediately upstream from the Cowlitz River (figs. 271 and 281C).

Peak flow velocities through the lower Toutle River were apparently substantially lower than those along either the North Fork or South Fork Toutle River. Once again, computed average at-a-point velocities were substantially higher than was the average velocity at which the peak stage progressed downstream. For example, in the Hollywood Gorge area (*O* in fig. 271) cross-valley banking implies average flow velocities of about 3.2 m/s, whereas timed observations suggest that the peak stage was propagated downvalley at an approximate rate of only 1.5 m/s (Cummins, this volume; written commun., December 1980).

COWLITZ RIVER

Unlike the peak South Fork Toutle River lahar, which underwent striking changes in volume and rheological character in a downstream direction, the

peak mudflow associated with the North Fork Toutle River lahar underwent little change as it flowed through the Toutle and lower Cowlitz Rivers. Mudflow deposits accreting to the banks of the lower Cowlitz River and representing the peak flow are generally similar in texture to those found lateral to the channel of the Toutle River. Rocks from Holocene eruptions of Mount St. Helens constitute most of the pebble-size and larger clasts, even though those rocks underlie a small percentage of the drainage basin. A secondary mudflow berm at a level about 1–2.5 m below peak flow level occurs discontinuously along the Cowlitz River. A thin (0.1–0.5-m) layer of fine-grained water-deposited sediment occurs at the surface of this lower mudflow berm and is evidence of overriding streamflow. The uppermost mudflow deposits in the secondary berm are characterized by abundant splintered and shattered wood fragments—a significant proportion of them charred. Clasts of low-density hydrothermally altered ancestral dacite are also abundant on and near the surface of the secondary mudflow berm.

Throughout the mudflow-impacted reaches of the lower Cowlitz River, several levels of progressively better sorted debris-flow deposits occur below the earlier mudflow levels. The geometry of the debris flow and superimposed streamflow deposits suggests that both types of flow occurred simultaneously. The most prominent of the debris-flow berms on the Cowlitz River is locally overlain by texturally uniform 0.1- to 1.0-m-thick fine-grained sediment with current-produced bedding. Thus, a relatively uniform thickness of streamflow deposits was deposited before recessional incision was accomplished by either continuing debris flow or restabilized streamflow. Similar stratigraphic relations exist in other areas where both types of flow were observed to occur simultaneously. The recessional episode of debris flow was characterized by abundant immersed and partly immersed boulders as much as 0.9 m in intermediate diameter. Lower debris-flow units are generally finer grained and occur in association with sand layers that contain abundant, current-produced, internal sedimentary structures. Immersed and partly immersed boulders are much less abundant than are those in the higher units. The deposits of the lower berms thus were probably produced by flows transitional to normal streamflow.

Depths of flow at the mouth of the Toutle River were sufficiently great to allow large volumes of mud

ably non-Newtonian flow behavior. On flat surfaces Many flow features indicate highly viscous, prob-

and elsewhere. Although the largest 1980 lahars were devastating in their impacts on channels and flood plains, the im-

Lahars formed in three major ways: (1) The largest lahar originated by slumping and flowing of water-saturated parts of the debris avalanche. (2) The lahars with the highest velocities originated by cata-

North Fork Toutle River, modified more than 120 km of channel, including sections of the Cowlitz and Co-

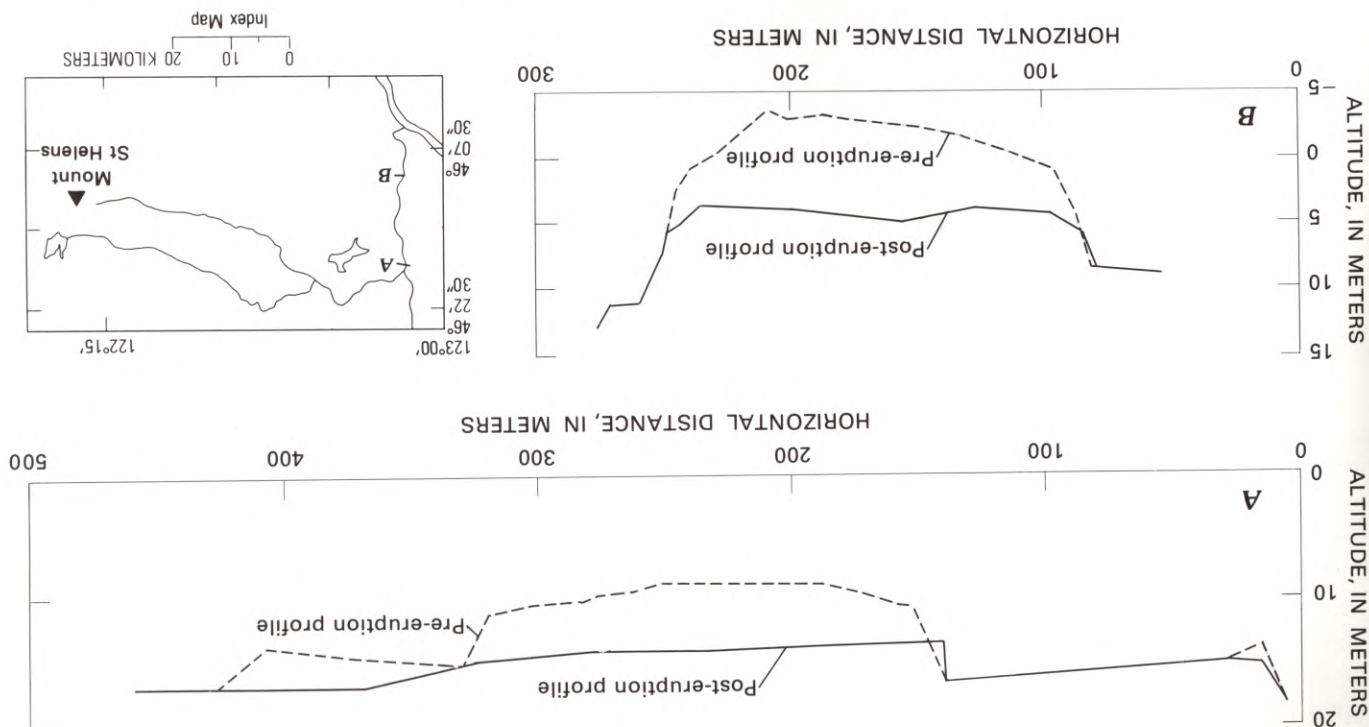
Lahars affected nearly all streams draining the cone of Mount St. Helens, but to variable extents that reflect in part the directional character of the initial eruption. Extensive lahars originated in the Toutle River system and the Muddy River-Pine Creek drain-

SUMMARY AND CONCLUSIONS

The morphologic and hydraulic changes brought about by the May 18 and 19 laharsic sedimentation along the Cowlitz River are discussed in detail by Lombard and others (this volume). Figure 282 provides examples of morphologic changes in this area. The timing and velocity of lahar movement through the lower Cowlitz River are discussed by Cummins (this volume).

and debris to flow upstream along the Cowlitz River for about 3 km. Effects of the lahars continued farther upstream, where meander bend pools formerly in ex-

Figure 282.—Preeruption and posteruption cross-sectional profiles of the Cowlitz River. A, 1.0 km below mouth of Toutle River. Note reduced channel capacity. Preeruption profile from Tudor Engineering; posteruption profile by U.S. Geological Survey, Washington District Office. B, 11.1 km upstream from confluence with Columbia River. Note reduced channel capacity. Preeruption profile from Tudor Engineering; posteruption profile by U.S. Geological Survey.



such as roads, the lateral edges of the highest lahar deposits on both the North Fork Toutle River and the lower Muddy River were marked by abrupt flow fronts at least 3 cm high. Flows of various consistencies supported cobbles and boulders at or near their surfaces. Fragile boulder-size clasts of soil and coluvium occur perfectly preserved in coarse gravel bars. These clasts and the platy structure of the thin basal layer of mudflow units suggest that vertical shear was concentrated at the base of the flow and that "plug" flow occurred at least locally. The gradual reduction in runup heights on trees with distance from the axis of maximum velocity, however, indicates a less concentrated distribution of shear in the horizontal plane.

Flow velocities ranged from less than 1.5 m/s in downstream reaches on the North Fork Toutle River to more than 40 m/s for highly mobile flows on and near the cone. Apparent discrepancies between velocities at individual points and the lower rates at which the peak stage was propagated downvalley are explained by local variations in channel configuration and slope, loss of volume through progressive deposition, and the expectable difference between rates of movement of the entire mass of a mudflow and flow near the axis of maximum velocity.

Flow characteristics of the catastrophically induced lahars, especially those in the South Fork Toutle River and Muddy River watersheds, changed strikingly downstream. Air-mobilized lithic avalanches and flows were transformed to and replaced by mudflows downvalley. In the South Fork Toutle River farther downstream, the mudflow was changed to and replaced by debris flow and normal streamflow. This contrasts with the massive lahar that originated on the North Fork Toutle River, the peak deposits of which were remarkably similar throughout the entire course of the flow to the Columbia River. Downstream changes did occur in the recessional character of this flow, particularly in the amounts and relative proportions of debris flow and normal streamflow.

The lahar deposits are generally thin compared with the depths of the initiating flows. Nonetheless, impressive amounts of fill were deposited locally, particularly by mudflows. For example, over 4 m of channel thalweg fill occurred locally on the South Fork Toutle River. Even where lahar-induced channel deposition was slight or where scour occurred in channels, overbank deposits are commonly more than 1 m thick. At some sites on the North Fork Tou-

tle River, 3–4 m of fill occurred on the flood plain. However, the postlahar channels are commonly incised through the May 18 deposits and into older alluvium or lahar deposits.

The present channels are unstable and are adjusting rapidly to changes in geomorphic and hydrologic conditions. Continued erosion will release much sediment from previously stable pre-May 18 channel and flood-plain deposits, as well as from sediment deposited on May 18 and subsequently.

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