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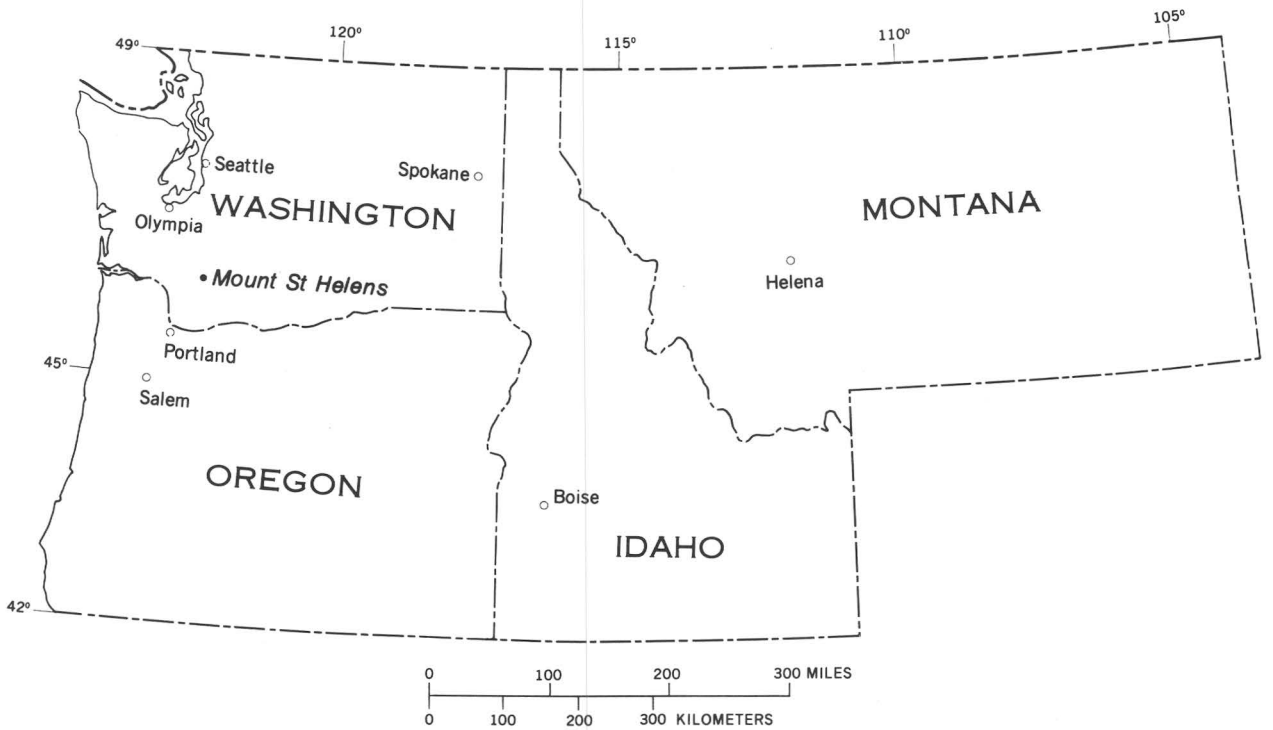
OLOGICAL SURVEY CIRCULAR 850-B

METRIC CONVERSION FACTORS

Multiply	*By*	*To obtain*
foot (ft)	0.3048	meter (m)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/sec)	.02832	Cubic meter per second (m^3/s)



COVER: North Fork Toutle River, June 30, 1980. Volcanic mud flow breccia and debris from the May 18, 1980 eruption of Mount St. Helens (in upper right) are as much as several hundred feet thick in the reach shown. Photograph by Austin Post, U.S. Geological Survey.

Mudflows Resulting from the May 18, 1980, Eruption of Mount St. Helens, Washington

By John Cummans

Hydrologic Effects of the Eruptions of Mount St. Helens, Washington, 1980

GEOLOGICAL SURVEY CIRCULAR 850-B

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FOREWORD

On May 18, 1980, after more than a month of earthquakes and eruptions, Mount St. Helens, in southwestern Washington, exploded in a volcanic eruption more violent than any in the conterminous United States during the 20th century. A lateral blast of hot gas and rock particles devastated an area of about 150 square miles on the northern side of the mountain knocking down trees to a distance of 15 miles. Several minutes later, a giant ash cloud rose to about 60,000 feet. Winds then carried the ash cloud across the United States, with heavy fallout and deposition in eastern Washington and parts of Idaho and Montana. Earlier, smaller eruptions deposited ash in western Washington and parts of Oregon and Canada.

The hydrologic effects of the May 18 eruption have been both widespread and intense. During the eruption, a massive debris avalanche moved down the north flank of the volcano depositing about 3 billion cubic yards of rock, ice, and other materials in the upper 17 miles of the North Fork Toutle River valley. The debris deposits are about 600 feet thick in the upper reaches of the valley. Following the avalanche, runoff from the melted glaciers and snow, and possible outflow from Spirit Lake, caused an extraordinary mudflow in the North Fork Toutle River. The mudflow shattered and uprooted thousands of trees, destroyed most of the local bridges, and deposited an estimated 25,000 acre-feet of sediment in the Cowlitz River channel. A considerable amount of additional sediment was conveyed through the lower Cowlitz into the Columbia River where it was deposited and formed a shoal that blocked the shipping channel. Mudflows also occurred in the South Fork Toutle River and in tributaries on the east flank of Mount St. Helens which enter Swift Reservoir.

As part of a concerted Geological Survey effort to study the volcanic event and to identify potential hazards, Survey hydrologists have mounted an intensive program to document the hydrologic effects of the eruptions. The major initial hydrologic findings are reported in this circular series. Quick, useful assessment was made possible only because the Survey has long conducted extensive water-resources investigations in the affected areas of Washington, Oregon, and Idaho. Hence, there was a well-defined basis for identification and documentation of the types and magnitudes of hydrologic changes.

The Geological Survey Circular 850, "Hydrologic Effects of the Eruptions of Mount St. Helens, Washington, 1980," consists of individually published short chapters that emphasize data collection activities, field observations, and initial comparisons of pre- and post-eruption conditions. The series will cover hydrologic events occurring on May 18 in the Toutle and Cowlitz River; physical alteration of the Toutle River system; the chemical and physical quality of precipitation, streams, and lakes affected by volcanic ash fall; ash-leaching studies; and Mount St. Helens glaciers.

H. William Menard
Director

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MUDFLOWS RESULTING FROM THE MAY 18, 1980, ERUPTION OF MOUNT ST. HELENS, WASHINGTON

By JOHN CUMMANS

ABSTRACT

On May 18, 1980, Mount St. Helens, in southwestern Washington, erupted violently, setting off a chain of devastating hydrologic event. During the eruption, a massive debris avalanche moving down the north side of Mount St. Helens was deposited in the North Fork Toutle River valley. Approximately 3 billion cubic yards of material, including rock, ash, pumice, snow, and ice was deposited directly north of the mountain in the upper 17 miles of the valley.

Following the eruption, mudflows quickly developed in the South Fork Toutle River, and in the Lewis River tributaries of Smith Creek, Muddy River, and Pine Creek. Several hours later a massive mudflow originated from the debris avalanche deposit in the North Fork Toutle River valley. This North Fork mudflow caused widespread destruction as it moved downstream through the lower Toutle and Cowlitz Rivers.

This report describes the location and chronology of the mudflows which followed the May 18 eruption. Average velocities are presented for the mudflows in the South and North Fork Toutle Rivers, and photographs illustrate the character of the debris and mud deposits.

INTRODUCTION

On March 27, 1980, Mount St. Helens, Washington erupted for the first time in more than 100 years. On May 18, following 7 weeks of earthquakes and minor eruptions, the volcano exploded violently, setting off a chain of devastating geologic and hydrologic events. The major components of the eruption included: (1) a directed blast of hot gases and ash which leveled the forest to the north for a distance of up to 15 miles, (2) a massive debris avalanche that deposited the remnants of the detached north flank of the volcano (approximately 3 billion cubic yards of rock, ash, pumice, snow, and ice) in the upper 17 miles of the North Fork Toutle River valley (Youd and Wilson, 1980), (3) a northward flow of fragmented volcanic materials that dammed the outlet of Spirit Lake, and (4) an ash column 10 miles high that traveled eastward across the United States as a giant ash cloud.

Previous geologic studies had determined that mudflows were common in past volcanic eruptions at Mount St. Helens (Crandell and Mullineaux, 1978). Thus, following the initial activity on March 27, mudflows were anticipated as part of a large eruption, although the streams most likely to be affected and the general magnitudes of flows were matters of conjecture. In preparation for potential flooding hazards, a flash flood warning system was devised by Cowlitz and Skamania county officials (see fig. 1).

Within minutes of the May 18 eruption, county personnel were ordered to previously-designated observation posts as part of the flood warning system. Simultaneously, residents along the major rivers that drain the volcano were instructed to prepare for hasty evacuation. The eruption quickly led to mudflows in the South Fork Toutle River and in the Lewis River tributaries of Smith Creek, Muddy River, and Pine Creek. Several hours later, a large mudflow came down the North Fork Toutle River after originating from the massive debris avalanche deposit.

This report describes the chronology and magnitude of mudflows on May 18 in tributaries of the Lewis River, and in the South and North Forks of the Toutle River. Particular attention is given to the chronology of events in the Toutle River system, with the North Fork mudflow given the greatest attention because of its relatively large magnitude and the consequent destruction.

Mudlfows are masses of water-saturated debris of various sizes that flow downslope as a result of gravity. Mudflows commonly resemble masses of

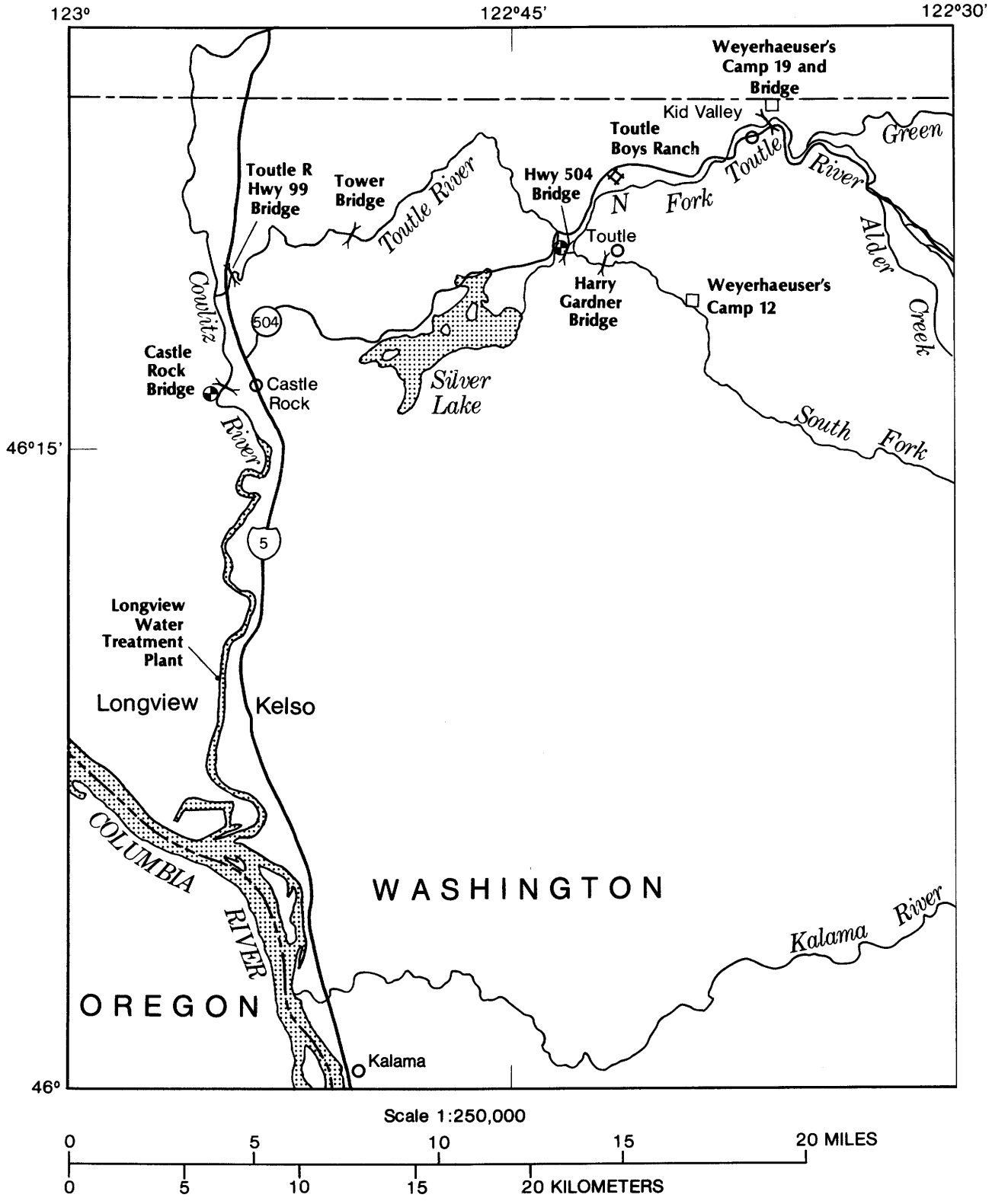
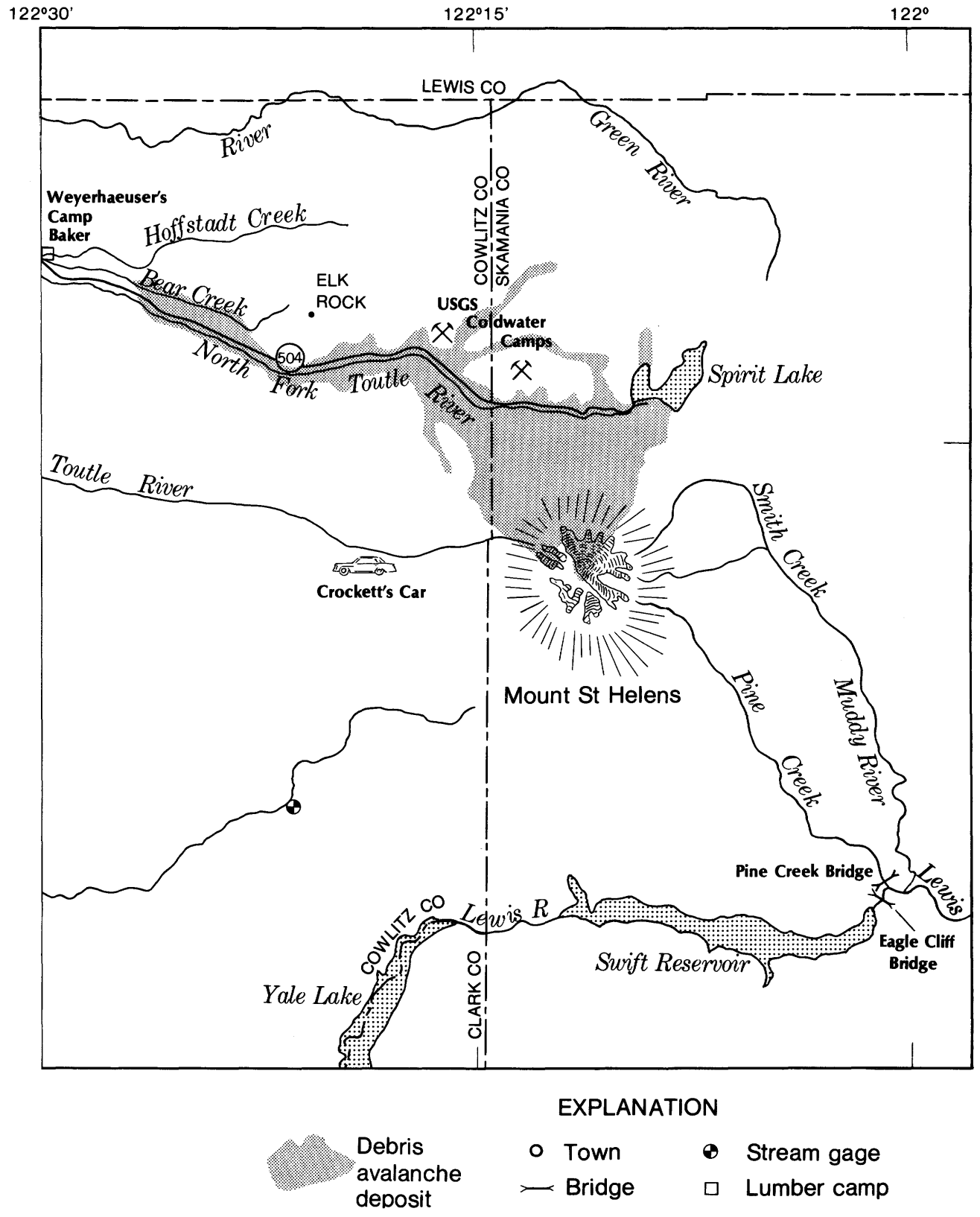


FIGURE 1. – Map of Mount St. Helens area.


122°30'
122°15'
122°
LEWIS CO
River
Green River
COWLITZ CO
SKAMANIA CO
Weyerhaeuser's
Camp
Baker
Hoffstadt Creek
Bear Creek
ELK
ROCK
USGS
Coldwater
Camps
504
North Fork Toutle River
Spirit Lake
Toutle River
Crockett's Car
Smith Creek
Mount St Helens
Pine Creek
Muddy River
Pine Creek Bridge
Lewis
Eagle Cliff
Bridge
COWLITZ CO
Lewis R
Swift Reservoir
Yale Lake
CLARK CO
EXPLANATION
Debris
avalanche
deposit
Town
Bridge
Stream gage
Lumber camp

wet concrete or mortar and, indeed, these terms were used by several observers to characterize the mudflows in the Toutle River system.

DESCRIPTION OF DRAINAGE SYSTEMS AND CHRONOLOGY OF THE MUDFLOWS

Water originating on Mount St. Helens drains into four river systems: the North Fork Toutle River, the South Fork Toutle River, the Kalama River, and several tributaries of the Lewis River (see fig. 1). Except for the Kalama River, large mudflows occurred in each of the systems following the May 18 eruption. Aerial observations in the Kalama system revealed that small mudflows did occur at high elevations in South side tributaries. However, the mudflows were comparatively so small, that all further work was conducted in the three other systems.

LEWIS RIVER

DRAINAGE SYSTEM

The sizes of drainage areas listed in the following descriptions of the Lewis River tributaries, South Fork Toutle, and North Fork Toutle are those prior to the May 18 eruption. Post-eruption drainage areas are slightly different because the drainage divides between the headwaters of the streams were altered by the blast which lowered the mountain top by about 1,300 feet. The drainage systems and the geographic and cultural locations mentioned in the text are shown in figure 1. This map is designed to aid the reader in following the location and chronology of the mudflows.

South of Mount St. Helens, the Lewis River flows in a westerly direction into Swift Reservoir (fig. 1). The Muddy River system, which includes Smith Creek, drains most of the eastern slope of Mount St. Helens before flowing into the Lewis River 1 mile upstream from the reservoir. Pine Creek heads on the southeast summit of Mount St. Helens, and flows southward into the Lewis River, entering about 1/2 mile upstream from Swift Reservoir. Together, the Muddy River system, Pine Creek, and other tributaries to Swift Reservoir drain about 10 square miles directly from the higher slopes (above 4,000 feet) of Mount St. Helens. At Swift Reservoir, the Lewis River drains a total of 480 square miles.

MUDFLOWS

Immediately following the eruption, mudflows moved rapidly down Smith Creek, Muddy River, and Pine Creek, destroying the bridge near the mouth of Pine Creek and the Eagle Cliff bridge at the head of Swift Reservoir. The mudflows scoured the stream valleys except along the lower reaches of the Muddy River where scattered trees remained. The lowermost reach of the Muddy River valley was completely choked with logs for a distance of 1 mile.

Between 9:00 a.m. and noon on May 18, the mudflows from the streams draining Mount St. Helens deposited about 11,000 acre-feet of water, mud, and debris in Swift Reservoir. Records of water level changes in the reservoir (see table 1). indicate average inflows of about 60,000 cubic feet per second between 9 and 10 a.m., 55,000 cubic feet per second between 10 and 11 a.m., and 12,000 cubic feet per second between 11 a.m. and noon. In total, the water surface of the reservoir rose 2.6 feet during this period.

Most of the incoming sediment appears to have settled near the head of the reservoir. On the morning of May 20, mud and debris extended only about 1 mile below the upstream end of the reservoir, down to an area of floating logs (fig. 2).

TOUTLE AND COWLITZ RIVERS

DRAINAGE SYSTEM

Both the North and South Forks of the Toutle River originate on the slopes of Mount St. Helens (see fig. 1). Prior to the eruption, the two streams drained a combined area of about 15 square miles from the slopes above 4000-feet elevation.

The North Fork flows in a westward direction away from Mount St. Helens. At its confluence with the South Fork, the North Fork drains 303 square miles, of which 132 square miles is drained by the Green River, a major tributary to the north.

The South Fork of the Toutle River originates on the western slopes of Mount St. Helens and drains 129 square miles above its junction with the North Fork.

The Toutle River, formed by the junction of the North and South Forks, flows in a generally westward direction into the Cowlitz River. At its mouth, the Toutle drains 512 square miles. The Cowlitz River flows south into the Columbia River, and several miles of its lower reach, including the location of the Longview Water Treatment Plant, are affected by tides in the Columbia River (fig. 1.).

TABLE 1. – Stage, storage, and inflow to Swift Reservoir during the mudflow of May 18, 1980

Time	Water-surface elevation (feet)	Estimated storage without mudflow (acre-ft)	Actual storage (acre-ft)	Accumulative runoff from event (acre-ft)	Hourly event gain (acre-ft)	Event inflow rate in preceding hour (ft^3/s)
9 a.m.	973.02	637,150	637,610	460	460	.....
10 a.m.	974.24	637,320	642,740	5,420	4,960	60,000
11 a.m.	975.37	637,530	647,480	9,950	4,530	54,800
12 noon	975.63	637,660	648,580	10,920	970	11,700
1 p.m.	975.68	637,910	648,790	10,880	.....	.....

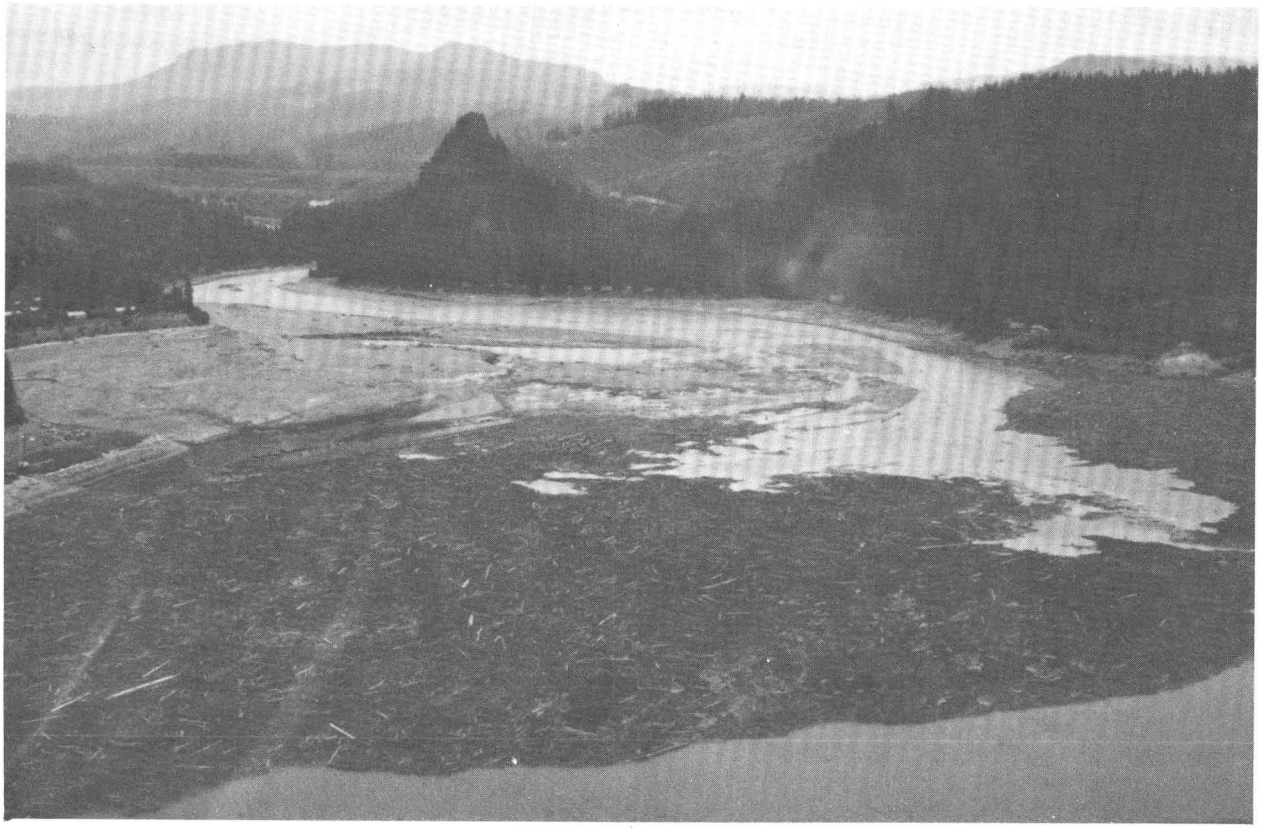


FIGURE 2. – Aerial view of east end of Swift Reservoir. The mud and debris originated in the upper reaches of Smith Creek, Muddy River, and Pine Creek. Photograph taken May 20, 1980.

MUDFLOWS

SOUTH FORK TOUTLE RIVER

The mudflow on the South Fork Toutle was first observed by David C. Crockett, KOMO TV News, Seattle, who later related his experiences to Richard B. Waitt, Jr., of the U. S. Geological Survey. Mr. Crockett reported that he was on the south side of the river about 4½ miles west of the mountain when the eruption occurred. He took several photographs and then drove rapidly down the valley. Mr. Crockett said, "Soon a huge mass of water, mud, and trees crashed through in front of me . . . snapping off trees." He stopped and was

quickly trapped by the flow. The rate of flow decreased rapidly, but it was still sufficient to carry large quantities of trees and other large debris. Mr. Crockett quickly gathered his cameras and other gear, abandoned his car, and hiked to safety. He reported crossing "warm peat, or warm, fluid, brown concrete" during his escape. These events occurred about 8:50 a.m. The approximate location of Crockett's abandoned vehicle is shown in Figure 1.

Mr. Crockett also said that a second mudflow came down the South Fork at about 2:00 p.m., which he could hear before it came into view. He reported that the river had earlier returned to its channel, but during the afternoon event, it overflowed again. The second mudflow was reportedly much smaller than the first, lasting about 20 minutes.

A photograph (fig. 3) taken May 23, five days later, shows the mudflow deposits in these upper reaches of the South Fork valley.

The first direct report on the South Fork mudflow occurred at 10:03 a.m. when a flood watch deputy radioed the Cowlitz County communications center that "a 5-foot rise of South Toutle River" was passing Weyerhaeuser's Camp 12. The camp is 42.2 river miles upstream from the mouth of the Cowlitz River. At 10:05 a.m., a second radio report indicated the flow was "knocking down trees," and at 10:07 a.m., it was reported that a "12-foot flash flood" was coming down the South Fork from Camp 12. The South Fork flow was intense, but short in duration. The mudflow generated on the South Fork Toutle River traveled 27 river miles, from the mountain to Camp 12, in 90 minutes.

FIGURE 3. – Aerial view of valley mudflow deposits in the upper reaches of the South Fork Toutle River. Photograph taken May 23, 1980.

Farther downstream, a Mr. Roald Reitan was camped along the South Fork just upstream from the town of Toutle. He was awakened by warning sirens nearby and noted that "the river was already half-full of logs." According to Reitan, over the next few minutes the river's height rose fast. At first, the water was clear with a large number of logs, but the water quickly muddied, and Reitan observed a portion of trestle (probably part of Weyerhaeuser's railroad bridge) carried along in a mass of logs. The flowing mass eventually turned to chocolate color and became thicker immediately after the trestle and logs passed, knocking down trees along the edges of flow. Reitan later stated that the mass "seemed to be moving at 30 to 35 miles an hour," and he estimated that only 3 to 5 minutes elapsed between the "half-full channel" and the overbank-flow conditions. During this time, the channel was completely filled with logs.

At 10:13 a.m., a river watch deputy radioed the Cowlitz County communications center that mud and debris were moving toward the Harry Gardner Bridge. At 10:14 a.m., the Deputy described the flow as a 12-foot wall of water containing logs, debris, and buildings.

At 10:20 a.m., the leading edge of the mudflow arrived at the South Fork's confluence with the North Fork, just upstream from the Highway 504 Bridge (locally called Coal Banks Bridge or Morgan Bridge.) A Deputy reported that the mudflow was close to the underside of the Highway 504 Bridge at 10:48 a.m., which was probably about the time of the peak-stage at that location. Both the Harry Gardner Bridge and Highway 504 Bridge survived the South Fork mudflow.

At the Toutle River gaging station at Silver Lake (located 1/4 mile below the Highway 504 Bridge), the river stage at 10:20 a.m. was 2.54 feet, a normal level. By 10:25 a.m., the river stage was rising, but the heavy mudflow quickly rendered the automatic continuous stage recorder inoperative and the actual timing of the peak was not recorded. At 2:50 p.m., Geological Survey field personnel determined that the high water mark at the gage was about 23.5 feet. This is the highest stage ever observed at the site, which has been maintained since 1909. The previous highest stage, 22.56 feet, occurred on December 2, 1977.

After the peak, the stage receded rapidly in this reach. At 11:12 a.m., sheriff's deputies reported that the river level at the Route 504 Bridge had dropped 6 feet; at 11:16 a.m., 8 feet. They also reported that the entire surface of the river there was covered with floating logs for ahout 25 minutes.

At 11:51 a.m., a log jam was reported to have just broken up on the Toutle River near Tower Bridge (26.5 river miles upstream from the mouth of the Cowlitz River), as the peak passed that area. By this time, the river had returned to "just a trickle" 10 miles upstream at the Highway 504 Bridge.

By 1:00 p.m., the mudflow had entered the Cowlitz River. At 1:30 p.m., the stage at the Castle Rock Bridge (Cowlitz River mile 17.3 and 2.7 miles below the mouth of the Toutle River) had risen to 13.15 feet, as recorded at the Geological Survey gage. Prior to the approach of the mudflow, the river was at a normal 10.0 feet stage, and it returned to 10.0 feet by 2:15 p.m. The mudflow, with its logs and debris, continued within banks down the Cowlitz River.

According to Mr. Leland F. Edtl, Longview Utilities Engineer, the leading edge of the South Fork mudflow, "with logs, trees, limbs, and bark," arrived at the intake of the Longview Water Treatment Plant (Cowlitz River mile 5.2) at 4:15 p.m. The peak probably occurred about 5 p.m. or shortly thereafter; however, Mr. Edtl observed logs in the river for 3 to 3 1/2 hours. During this period, Mr. Edtl observed no increase in water levels nor deterioration of the water quality. Water temperature was 51°F, and turbidity remained at its normal level of 4 Jackson Turbidity Units. However, between 8:00 and 8:30 p.m., the turbidity abruptly increased to 420 Jackson Turbidity Units, and the treatment-plant water intake was closed.

On May 20, U. S. Geological Survey personnel observed the South Fork Toutle River and found clear evidence of the mudflow. The flow had been confined within steep valley walls except for a 5 to 6-mile reach above the confluence with North Fork, where some overbank flow had occurred.

NORTH FORK TOUTLE RIVER

The massive debris avalanche which accompanied the May 18 eruption blocked State Highway 504 along the North Fork Toutle River with a 17-mile plug of rock, ash, ice, snow, and other debris. At Spirit Lake, at the upper end of the plug, the debris depth reached 400 feet; near Elk Rock, at the lower end, about 150 feet. The thickest debris, up to 600 feet, was deposited about 1 mile below Spirit Lake (fig. 4).

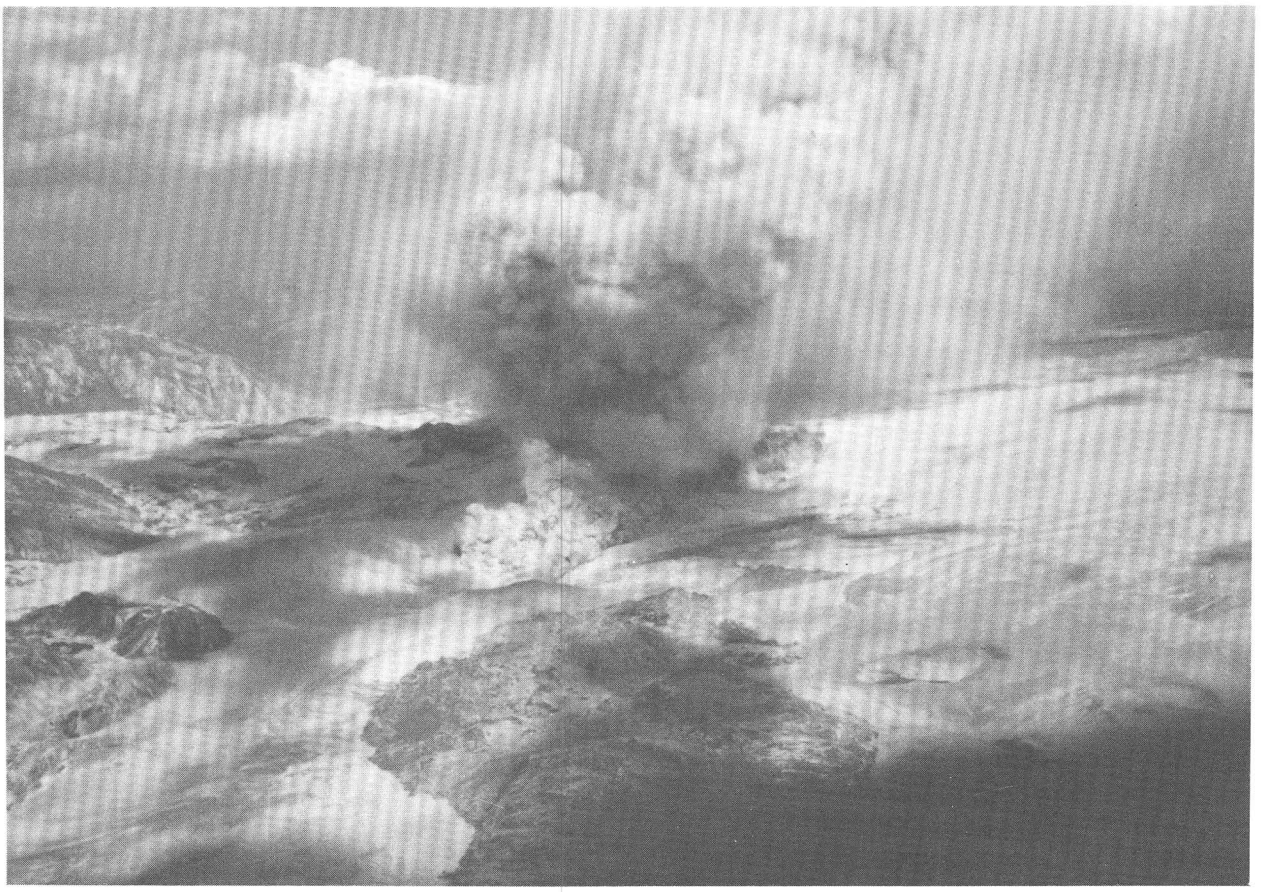


FIGURE 4. – Aerial view looking east across the thickest part of the debris avalanche deposit in the North Fork Toutle River. This location is about 1 mile downstream from Spirit Lake. Photograph taken May 23, 1980.

Large volumes of material from the debris avalanche deposit entered Spirit Lake. High-water marks later observed above the northeast arm of the lake suggest that the lake water may have been temporarily displaced as the debris came in, subsequently flowing back over the newly-deposited materials. The new lake surface is about 200 feet higher than prior to the eruption and about 200 feet lower than the surface of the massive debris deposit.

The first post-eruption observations of the upper North Fork Toutle River were made by Harry Glicken of the Geological Survey during attempted helicopter rescue missions for personnel at the Coldwater field camps (fig. 1). Between 12-noon and 1 p.m., Glicken observed small plumes of ash and steam emanating from numerous mudflows on top of the debris avalanche deposit. Below the toe of the deposit, Glicken observed downed trees, ash cover, and flowing mud; the mud was shallow, failing to innundate 2-foot boulders on the river bed.

At about the same time, a Weyerhaeuser Co. team reconnoitering the area by helicopter noted that the stage of the North Fork Toutle River was low, presenting no problems at either Camp Baker or Camp 19 (fig. 1). About 2 miles upstream from Camp Baker, the team noted blown-down timber across both Highway 504 and the main Weyerhaeuser logging road. They also saw the debris deposit, and a few miles farther upstream (probably near Elk Rock), observed the surface character of the debris which filled the valley floor.

At 1:04 p.m., while flying over Camp Baker, the team received a radio report that water and debris were moving down the North Fork. The team headed upstream to check the report and observed streams of muddy water flowing down both sides of the valley on the surface of the debris avalanche deposit. The two flows were heavy and visible for some distance as their leading edges kicked up large plumes of ash. At 1:25 p.m., the mudflows arrived near Elk Rock, about 63 miles upstream from the mouth of the Cowlitz River. Figures 5 and 6 show two areas of the debris deposit downstream

from Elk Rock; each figure clearly shows the dark remains of the mudflows on top of the lighter surface of the debris avalanche deposit.

Additional observations of the mudflows were made by Mr. Jack Schoening, a member of the Weyerhaeuser Co. team. According to Mr. Schoening, the team was over Camp Baker at 1:57 p.m. when the flows along the north side of the valley were reaching that area. A minute later, the north side flow hit the camp, moving into the equipment and shop areas. At this time, the mudflow on the south side of the valley had yet to reach Camp Baker. By 2:30 p.m., the camp was reported as destroyed. The maximum flow in the area probably occurred around 3:00 p.m., when a log jam near the camp reportedly broke loose. At 5:00 p.m., Mr. Schoening was again over the camp, and stated the devastation was worse than he observed at 2:30 p.m.

Some subsequent observations in the Camp Baker area are of interest. On May 18, Mr. Ray Pleasant, a pilot for Weyerhaeuser Co. observed the edge of the mudflow at one shop building. Several days later he noted that the mud around the building covered a wider area than before, and was about 3 feet deeper. Another Weyerhaeuser employee who noted a "little" mud near his camp equipment at about 6:00 p.m. on May 18, observed that the mud was deeper when he returned on May 19. These observations indicate that either (1) later mud flowed on top of the earlier deposits, or (2) the consistency of the mudflow was so thick that flow in the center was higher than at the edges, thus requiring time for the edges to stabilize at a final, higher depth.

At 2:40 p.m., the Cowlitz County Communications Center received a report that the mudflow was passing Alder Creek. At 3:01 p.m., the bridge

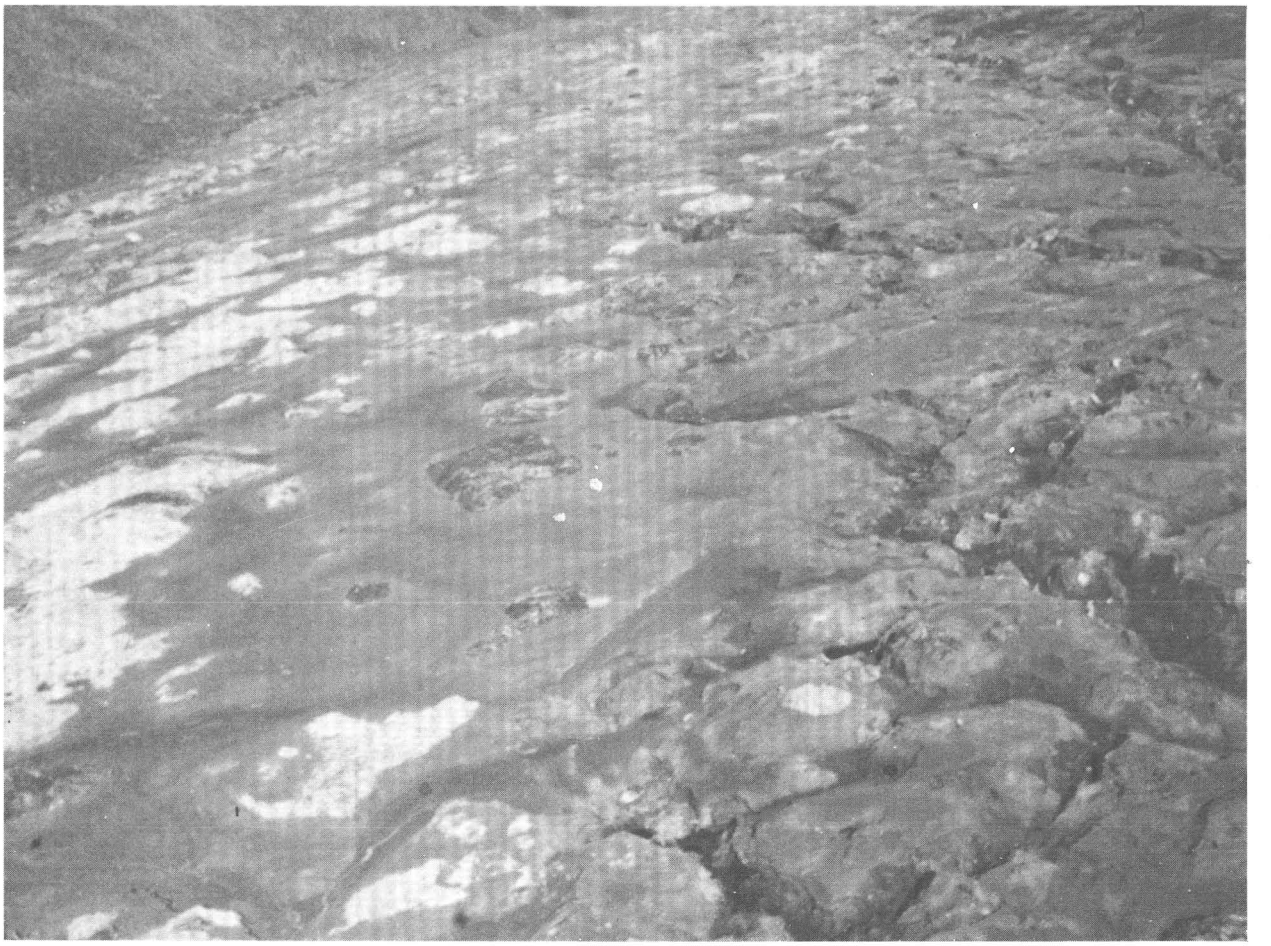


FIGURE 5. – Surface of debris avalanche deposit in the North Fork Toutle River downstream from Elk Rock. The lighter areas are the exposed surface of the debris deposit; the darker areas are brown sediment deposited by the subsequent mudflows. Photograph taken May 19, 1980.

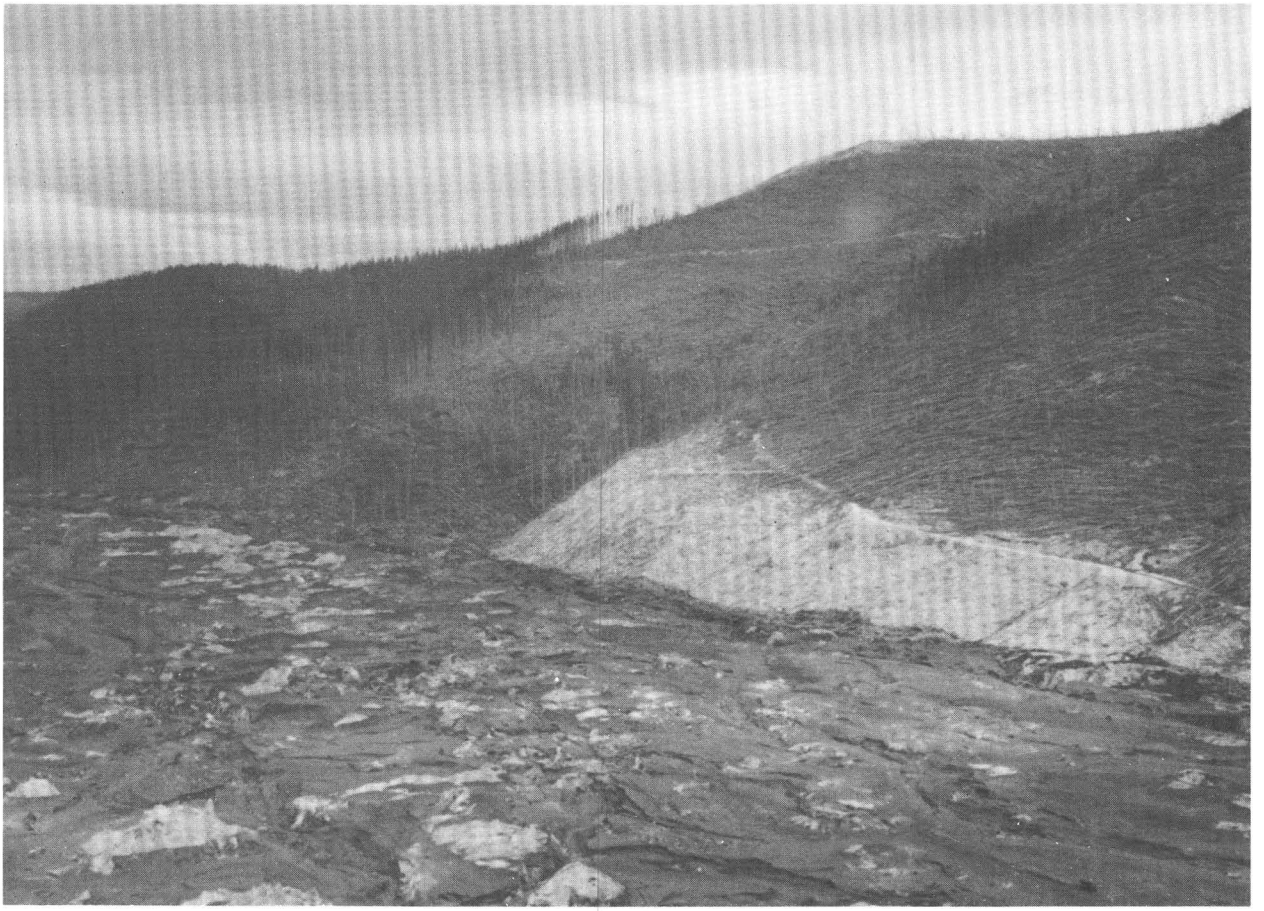


FIGURE 6. – Debris avalanche deposit along right bank of the North Fork Toutle River downstream from Elk Rock. Note edge of the blast area near center of photo where trees were blown down. Photograph taken May 19, 1980.

on Highway 504, 0.6 mile upstream from the mouth of Alder Creek, was reported as destroyed by the flow; by 3:30 p.m., the mudflow was passing the mouth of the Green River.

Mr. and Mrs. Dan Calvert, residents of Kid Valley, observed the mudflow at the Weyerhaeuser Camp 19 Bridge from about 3:00 p.m. until about 4:30 p.m., at which time they were rescued by helicopter. They stated that during this period, the flow kept rising and had the consistency of fresh mortar. At one point, they saw a fully-loaded logging truck moving downstream submerged only to the level of the lower-most tier of logs. Mr. Calvert also observed many buildings and ice chunks being carried along in the flow. The surface of the mudflow appeared to be smooth; Mr. Calvert did not recall seeing waves. Upon his return several days later, Mr. Calvert observed that the mud lines along the channel appeared to be higher than the stage at the time of his rescue.

At 4:55 p.m., Weyerhaeuser personnel observed Camp 19 by helicopter and noted that the mudflow was over the wheels of railroad cars; this level was later determined to be about the maximum height of the flow. At about 5:20 p.m., they reported the flow was continuing and that more logs had been swept from the storage area. Based on the descriptions, the peak flow at Camp 19 probably occurred at about 5 p.m.

The Cowlitz County Communications Center received a report of the mudflow reaching the Toutle Boys Ranch at about 5:45 p.m. Ray Pleasant, of Weyerhaeuser Co., observed the site shortly after 6:45 p.m., and reported that the mudflow depth appeared to have reached its maximum. As much as 3 to 4 feet of mud had been deposited in some of the buildings. The peak flow at this location probably occurred at about 6 p.m.

The North Fork mudflow was just upstream from the Highway 504 Bridge near Toutle at 5:48 p.m. After uprooting trees at Harry Gardner Park, the mudflow destroyed the Highway 504 Bridge,

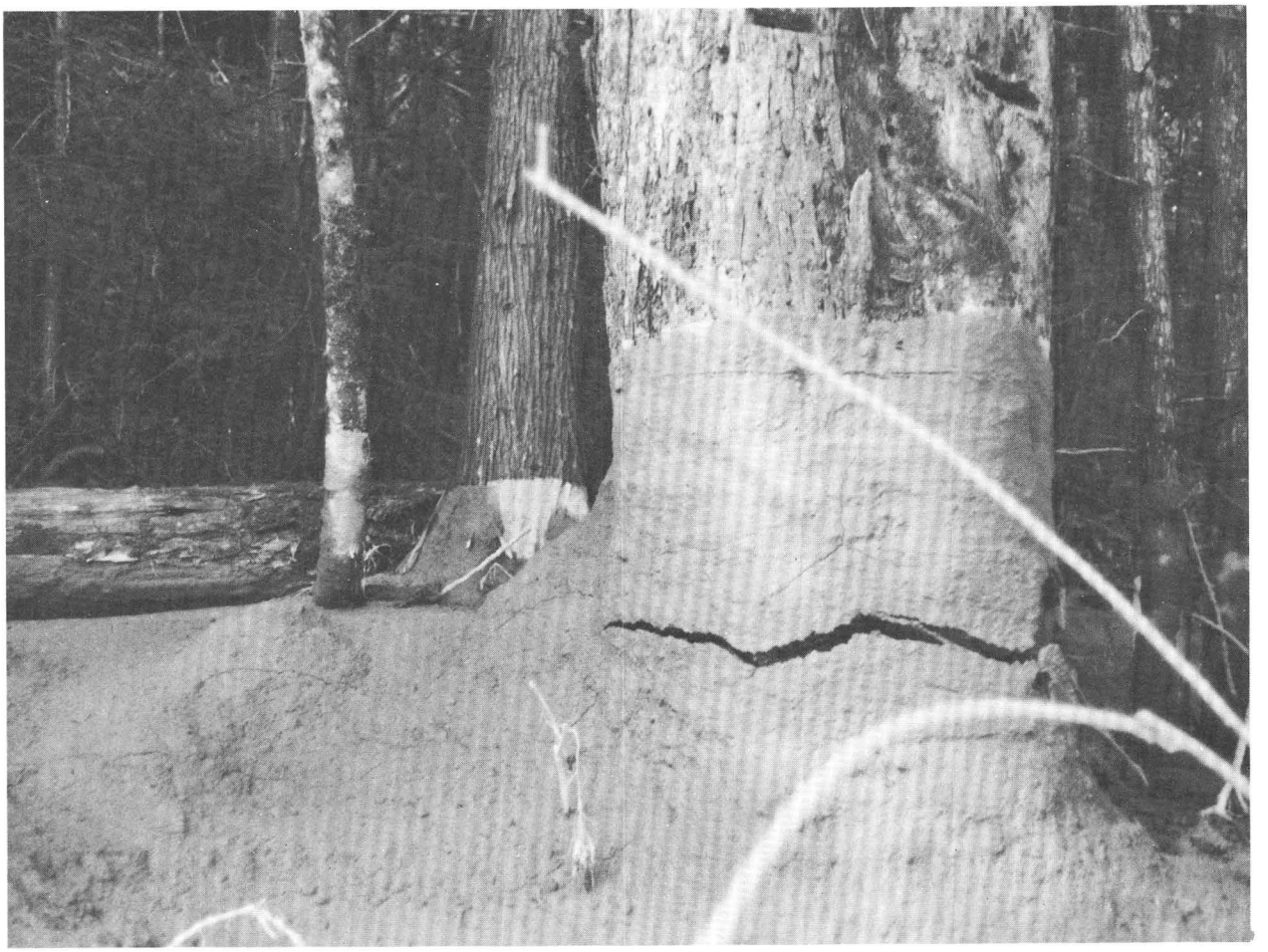


FIGURE 7.—Characteristic mudflow marks along the Toutle River just downstream from Highway 504 Bridge. The material when dry, has a coarse, abrasive texture. Photograph taken May 19, 1980.

apparently between 6:10 and 6:15 p.m. At the Geological Survey gage, 1/4 mile downstream, the automatic radio stage transmitter was functioning at 6:00 p.m., but failed to report at 6:15 p.m. The peak flow at the gage probably occurred at about 7:00 p.m.

Sheriff's deputies reported high stages at the confluence of the two forks until 8:55 p.m., when it was reported that the water level was falling as though something broke loose. On May 19, mudflow marks at the gaging site (figs. 7 and 8) just below the Route 504 Bridge were measured as 53 feet above gage datum, about 30 feet higher than for the South Fork mudflow. A surveying team then ran levels from marks at the gaging site to a narrow gorge 800 feet downstream. The measurements revealed only a slight downstream slope of the mudflow surface, indicating that ponding had occurred in this reach. The ponding was largely responsible for the extraordinary depths in this reach, and apparently was caused by a massive log jam at the entrance to the constricting gorge, which is located 0.8 mile downstream from the confluence of the North and South Forks. The blockage and ponding may have been aided by debris arriving from the secondary mudflow observed by David Crockett on the upper South Fork at 2:00 p.m. Figure 9 shows the resultant devastation just downstream from the confluence, in the area of the destroyed Highway 504 Bridge.

At 8:29 p.m., the mudflow covered the Tower Bridge, 10.3 miles downstream from the Route 504 Bridge; at 8:41 p.m., a report said the bridge had been destroyed. The peak at Tower Bridge probably occurred at about 9:15 p.m.

The mudflow arrived at the mouth of the Toutle River at about 8:30 p.m., where it was described as having a homogeneous, mortar-like consistency from bank to bank (fig. 10). At this location, the early part of the flow carried logs and buildings,

FIGURE 8.—Scoured channel and mudflow marks on trees downstream from the site of the Toutle River gage. Photograph taken May 19, 1980.

and a pickup truck was also observed. As the massive mudflow entered the Cowlitz River, the main mass moved downstream , but part moved upstream into the Cowlitz for 2½ miles.

The floodwave continued downstream and the automatic gage at Castle Rock was quickly covered with mud and rendered inoperative. However, water levels were measured periodically at this site by Geological Survey personnel. As shown in Figure 11, water levels rose to a crest of 29.3 feet at midnight. Stages only 0.1 to 0.2 foot lower were observed from 11:55 p.m. (May 18) to 12:45 a.m. (May 19).

At the Castle Rock Bridge, the temperature of mixed mudflow and Cowlitz River water was 85° F at 1:15 a.m. On May 19, at 6:30 a.m., the stage was down to 25.0 feet, but the temperature remained at 85° F. For comparison, at 9:45 a.m., the mudflow temperature in the Toutle River at the Highway 99 Bridge was 91° F.

At 3:00 a.m., on May 19, the stage at the Longview Water Treatment Plant (Cowlitz River mile 5.2) was reported to be 21 feet, which was at or near the maximum. Mr. Edtl, Longview Utilities Engineer, reported that the flood had receded 4 feet by 8:00 a.m., when the water temperature was 90° F, and turbidity was astronomically high and unmeasurable.

DISCUSSION

MUDFLOW VELOCITIES

The movement of the mudflows in the North and South Forks Toutle River is summarized in table 2. It should be noted that the computed travel velocities shown in the table are averages between successive locations. Velocities at any particular point may have varied considerably from that

FIGURE 9.—Flooded area at destroyed Highway 504 Bridge just below the confluence of the North and South Forks Toutle River. Photographs taken May 19, 1980.

shown because of local differences in channel configuration and stream-bed slope. The computed velocities are based upon the time-of-travel of the peak mudflow stage. The reported timing of the peak stages at the designated locations are believed to be accurate to within one-half hour, except for that of the Cowlitz River at Castle Rock.

Large differences occurred in the velocities of the mudflows in the North Fork and South Fork. Above the point of confluence (near Highway 504 Bridge), the weighted average velocity for the peak stage of the North Fork mudflow is about 7 feet per second, whereas that for the South Fork mudflow is about 22 feet per second. The three-fold higher velocity in the South Fork possibly resulted from a combination of steeper stream-bed slopes, smaller channel capacities, and a higher water content of the mudflow.

The South Fork mudflow moved through the Toutle river down to the Castle Rock Bridge at a greater velocity than the North Fork mudflow. Downstream from Castle Rock, under the influence of the Cowlitz River, the velocities of the two mudflows were very similar.

POST-MUDFLOW CHANNEL CHANGES

Comparison of pre- and post-eruption profiles indicate that the mudflow significantly altered the channel configuration and, hence the flow capacity of the lower Cowlitz River. Cross-sectional measurements of the Cowlitz River channels at both Kelso and Castle Rock reveal that deposits of sediment and debris raised the average elevation of the channel bottom about 15 feet at both locations. Prior to the mudflows, the maximum carrying capacity of the Cowlitz River at Castle Rock (at the flood stage of 23.0 feet) was 76,000 cubic feet per second. As of July 1980, the channel capacity was about 7,300 cubic feet per second. At that time, the river could carry less than 10 percent of its former capacity without flooding the surrounding valley.

FIGURE 10.—View of mudflow near Highway 99 Bridge on the Toutle River. The flow had a consistency of wet mortar. Photograph taken at 8:45 p.m., May 18, 1980.

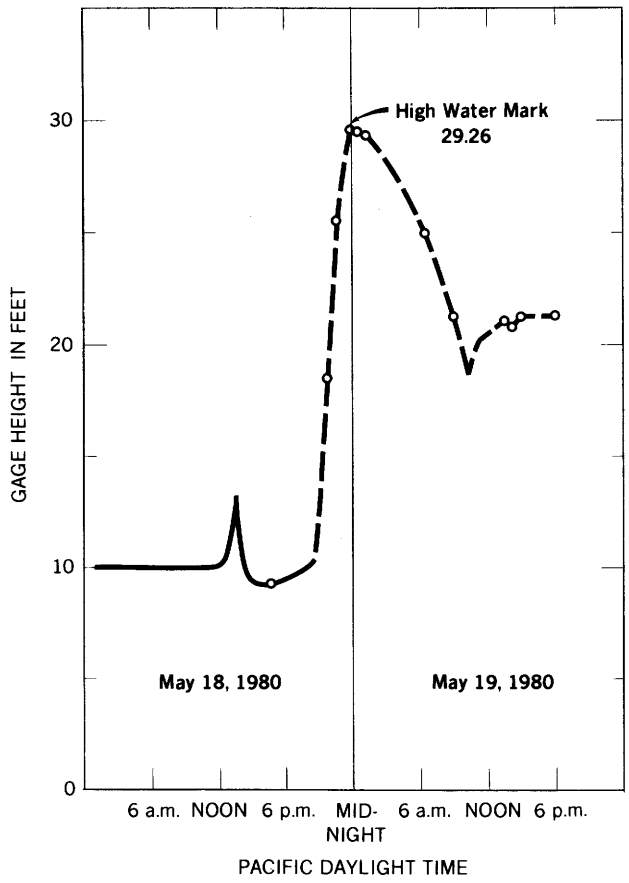


FIGURE 11.—Stage from recorder and wire weight gage readings, Cowlitz River at Castle Rock, May 18-19, 1980.

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TABLE 2. – Approximate time, location, and average velocity of the peak stages of the mudflows originating in the South and North Forks Toutle River, May 18, 1980.

Time of peak stage	Site: Location (see fig. 1)	Site: River miles upstream from mouth of Cowlitz River	Average velocity between locations (feet per second)
	South Fork Mudflow		
8:32 a.m.	Eruption at source of South Fork.	69.4	
			27.4
8:50 a.m.	David Crockett's car	63.8	
			23.5
10:10 a.m.	Weyerhaeuser Camp 12.	42.4	
			12.3
10:50 a.m.	Highway 504 Bridge	36.8	
			15.1
11:50 a.m.	Tower Bridge	26.5	
			8.1
1:30 p.m.	Castle Rock Bridge (gage)	17.3	
			5.1
5:00 p.m.	Longview Water Treatment Plant	5.2	
	North Fork Mudflow		
8:32 a.m.	Eruption (dam below Spirit Lake)	74	. . . . .
1:30 p.m.	Elk Rock area	63	
			7.8
3:00 p.m.	Weyerhaeuser Camp Baker.	55.0	
			6.9
5:00 p.m.	Weyerhaeuser Camp 19 (1900 Bridge) . .	45.6	
			7.9
6:00 p.m.	Toutle Boys Ranch	40.2	
7:00 p.m.	Toutle River gage (¼ mile below Highway 504 Bridge)	36.4	5.6
			6.5
9:15 p.m.	Tower Bridge	26.5	
			4.9
12 midnight	Castle Rock Bridge (gage)	17.3	
			4.4
4:00 a.m. (May 19)	Longview Water Treatment Plant	5.2	

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