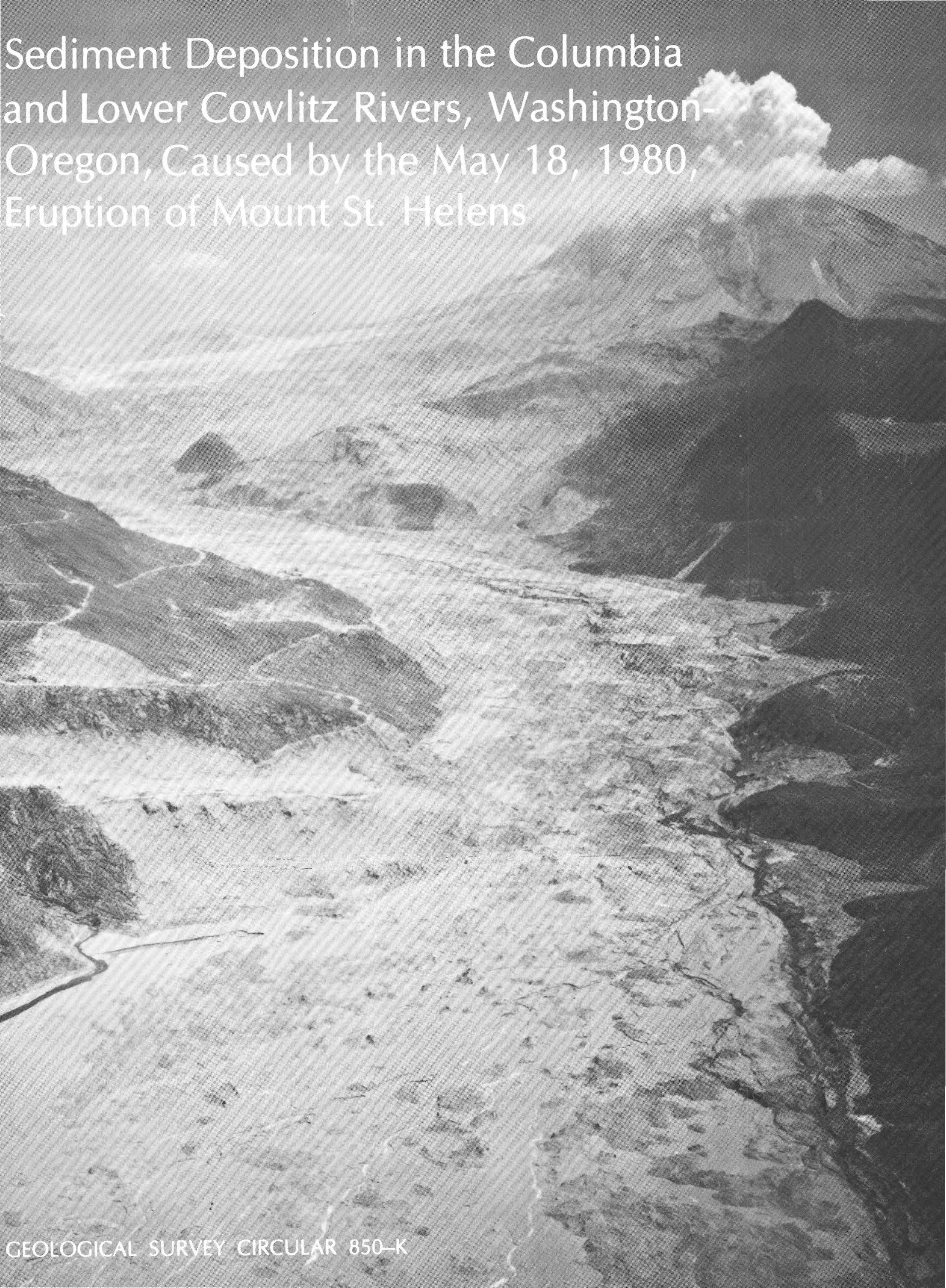
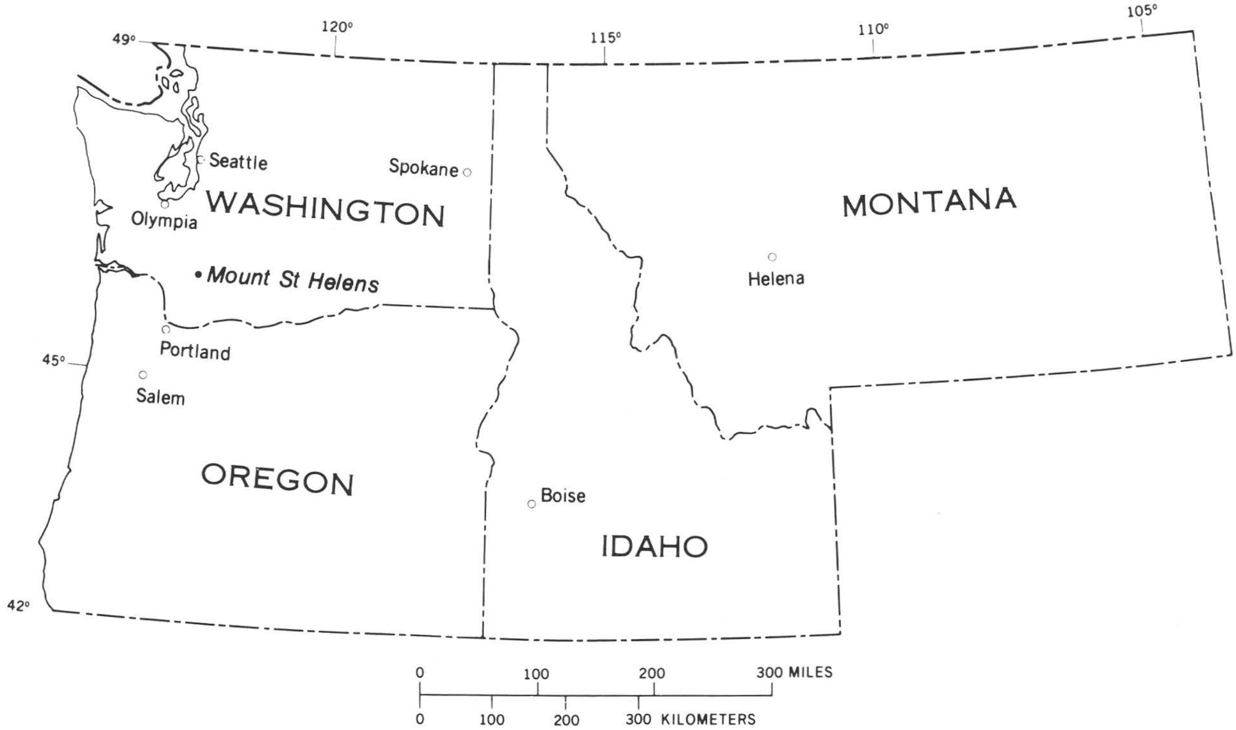
Sediment Deposition in the Columbia and Lower Cowlitz Rivers, Washington-Oregon, Caused by the May 18, 1980, Eruption of Mount St. Helens



GEOLOGICAL SURVEY CIRCULAR 850–K

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.

Sediment Deposition in the Columbia and Lower Cowlitz Rivers, Washington-Oregon, Caused by the May 18, 1980, Eruption of Mount St. Helens

By F. P. Haeni

Hydrologic effects of the eruptions of Mount St. Helens, Washington, 1980

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Dallas L. Peck, *Director*

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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 Rivers; 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.

Dallas L. Peck
Director

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ILLUSTRATIONS

Sediment Deposition in the Columbia and Lower Cowlitz Rivers, Washington–Oregon, Caused by the May 18, 1980, Eruption of Mount St. Helens

By F. P. Haeni

ABSTRACT

On May 18, 1980, Mount St. Helens violently erupted, sending billions of cubic yards of mud, ash, rock fragments, and debris down the North and South Forks of the Toutle River, the Cowlitz and Columbia Rivers, and other streams. A total of 35.6 million cubic yards of mudflow material was deposited in the lower Cowlitz (downstream from the Union Pacific Railroad bridge) and Columbia Rivers.

The arrival of this material at the Columbia River, during a period of the daily tidal cycle, when the flow was at a minimum or quite probably reversed and flowing upstream resulted in its deposition in an area 7 miles upstream and 2 miles downstream from the junction of the Cowlitz and Columbia Rivers. The thickness of the deposit was at a maximum near Coffin Rock, where a hole 140 feet deep was filled with 90 feet of sediment. Incomplete filling, compaction, and (or) erosion caused a 10-foot depression to form in the surface of the newly deposited material at this location.

On May 23, 1980, the presence of two scour channels on each side of a tonguelike deposit (delta) of very fine sand and silt indicates that the coarse-grained sediment and water surge on the morning of May 19 initially scoured the lower 0.5 mile of the Cowlitz River bed. A minimum of 0.4 million cubic yard of material was scoured from the Cowlitz River bed and subsequently redeposited in the Columbia River before the 1.3-million-cubic-yard delta was formed.

INTRODUCTION

On the morning of May 18, 1980, Mount St. Helens, southwest Washington, violently erupted, sending billions of cubic yards of rock, ash, snow, ice, and debris into the headwaters of the North and South Forks of the Toutle River. Subsequent mud and debris flows that developed from this material sent millions of cubic yards of material down the North and South Forks of the Toutle River and the Cowlitz and Columbia Rivers (fig. 1). Much of the mud and debris was deposited in the North and South Forks of the Toutle and Cowlitz River channels and flood plains and caused extensive destruction (Lombard and others, 1981).

Two major mudflows developed, one each in the headwaters of the South and North Forks of the Toutle River. The chronology of these mudflows and the resulting damage as they proceeded downstream to the Longview Water Treatment Plant is documented by Cummans (1981). When they reached the mouth of the Cowlitz River and entered the Columbia River, they were mostly confined by the river banks or levees. The extent of sediment deposition was not immediately known, but the 40-ft-deep Columbia River commercial shipping channel was only 14 ft deep on the morning of May 19, 1980.

To document the volume, areal extent, and nature of sediment deposition in the Columbia and lower Cowlitz Rivers, the U.S. Geological Survey obtained detailed bathymetric surveys by the U.S. Army Corps of Engineers and conducted seismic reflection surveys near their junction.

This report documents the sediment volumes and the nature of the scouring and deposition in the Columbia and lower Cowlitz Rivers. It is part of a series of reports published by the U.S. Geological Survey documenting the hydrologic effects of the May 18, 1980, eruption of Mount St. Helens.

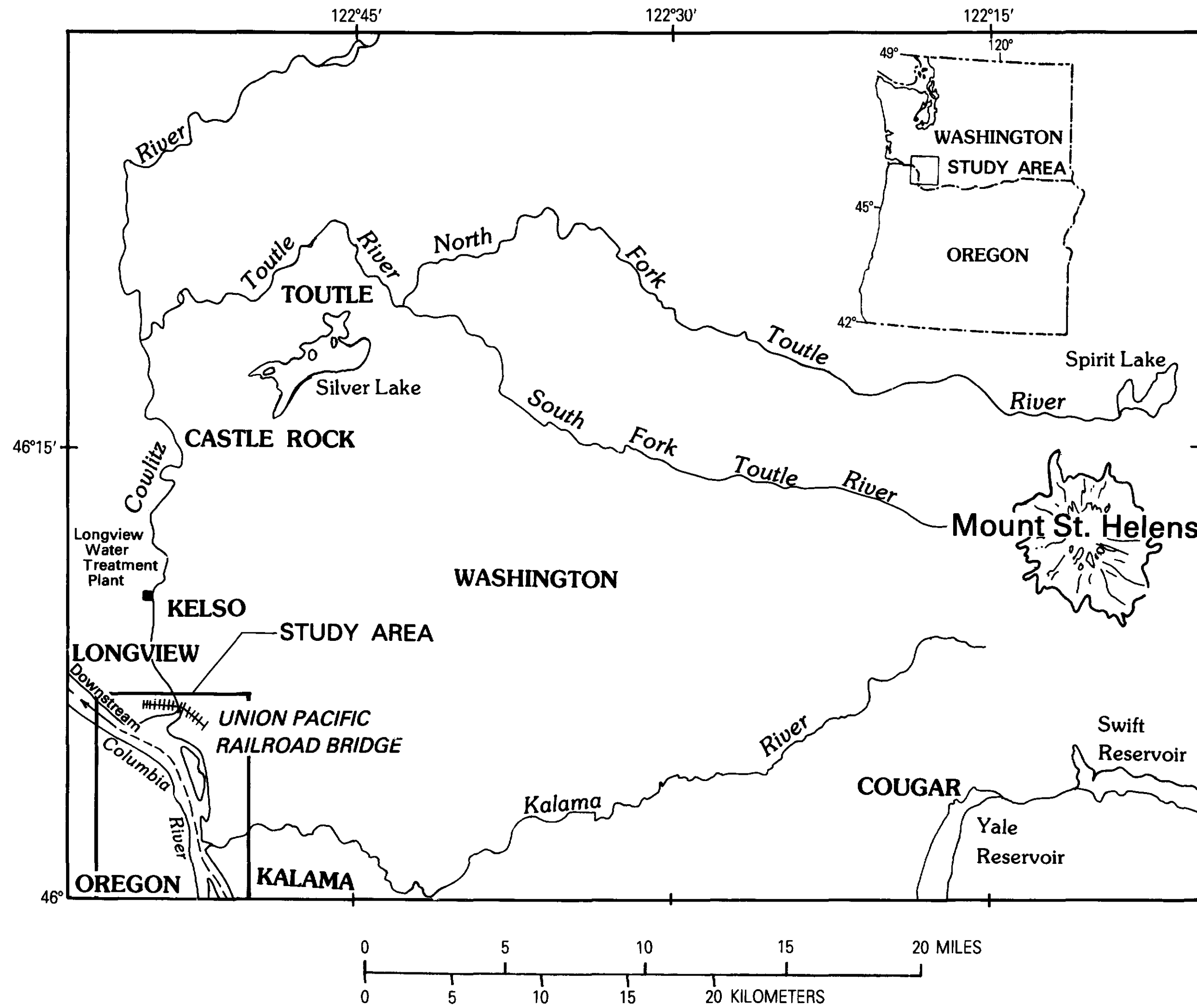


FIGURE 1.—Location of Mount St. Helens, the North Fork Toutle, the South Fork Toutle, the Cowlitz, and the Columbia Rivers, Washington–Oregon.

ACKNOWLEDGMENTS

Appreciation is expressed to the U.S. Army Corps of Engineers, Portland District, who furnished the bathymetric data used in this report. Special appreciation is extended to James R. Slack of the U.S. Geological Survey, who developed the three-dimensional computer plots.

CONFIGURATION OF THE COLUMBIA AND COWLITZ RIVER BEDS BEFORE THE MAY 18, 1980, ERUPTION OF MOUNT ST. HELENS

The U.S. Army Corps of Engineers routinely makes detailed bathymetric surveys on the Columbia and Cowlitz Rivers to use in maintaining minimum depths and widths of shipping channels. The results of these surveys are available from the Corps on orthophoto base maps at scales of 1 in equals 500 ft for the Columbia River and 1 in equals 200 ft for the Cowlitz River.

Bathymetric surveys on August 30, 1979, February 27, 1980, and March 4, 18, 20, and 25, 1980, were used to determine the shape of the Columbia and lower Cowlitz River beds before the May 18 eruption. Figure 2 shows the locations and dates of these surveys. The pre-eruption shapes of the river beds are shown in figure 3, with contours representing the depth of water, in feet, below the Columbia River datum. (A computer-generated three-dimensional perspective diagram of the same surface is shown in figure 6a and b.)

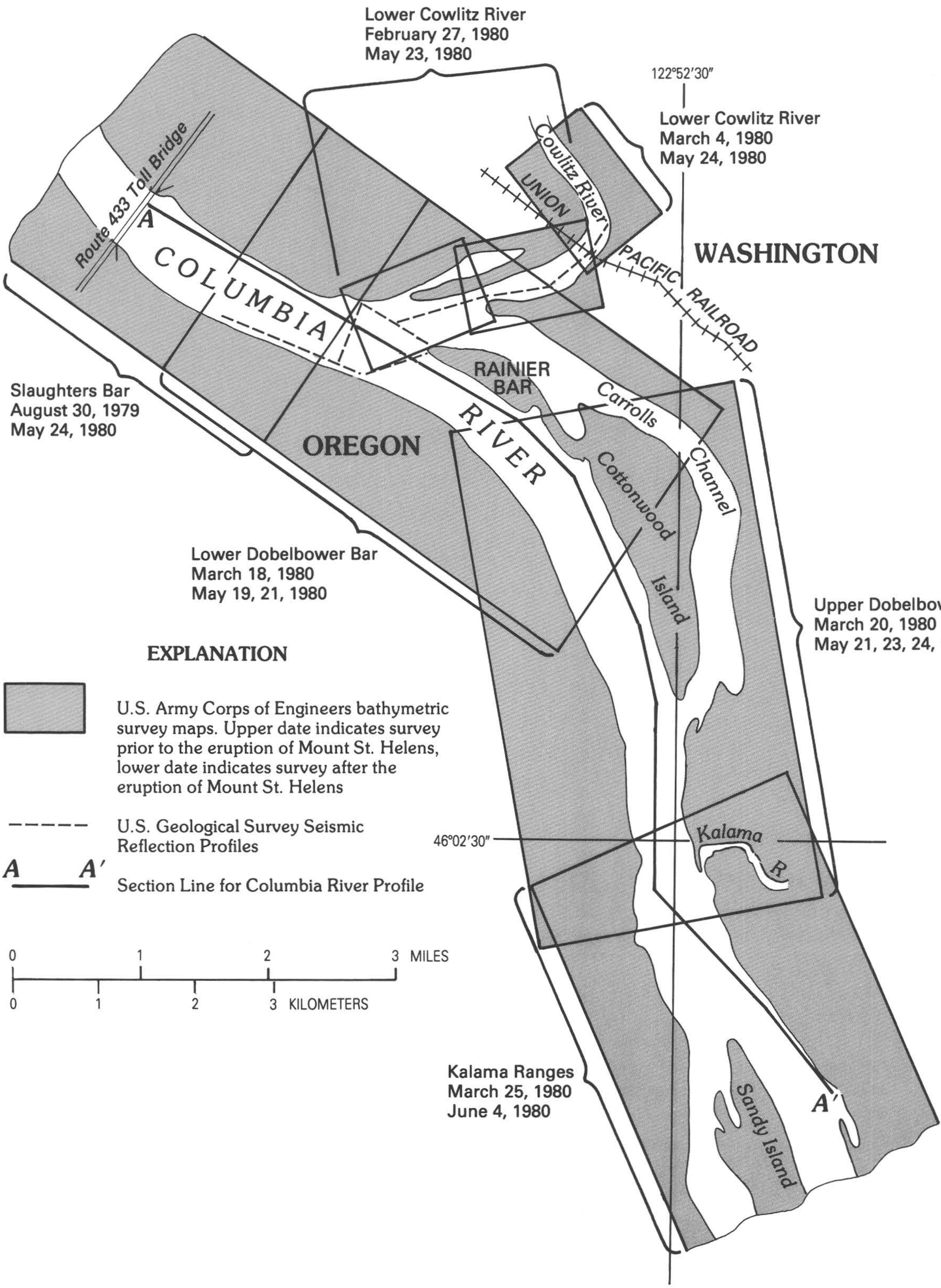
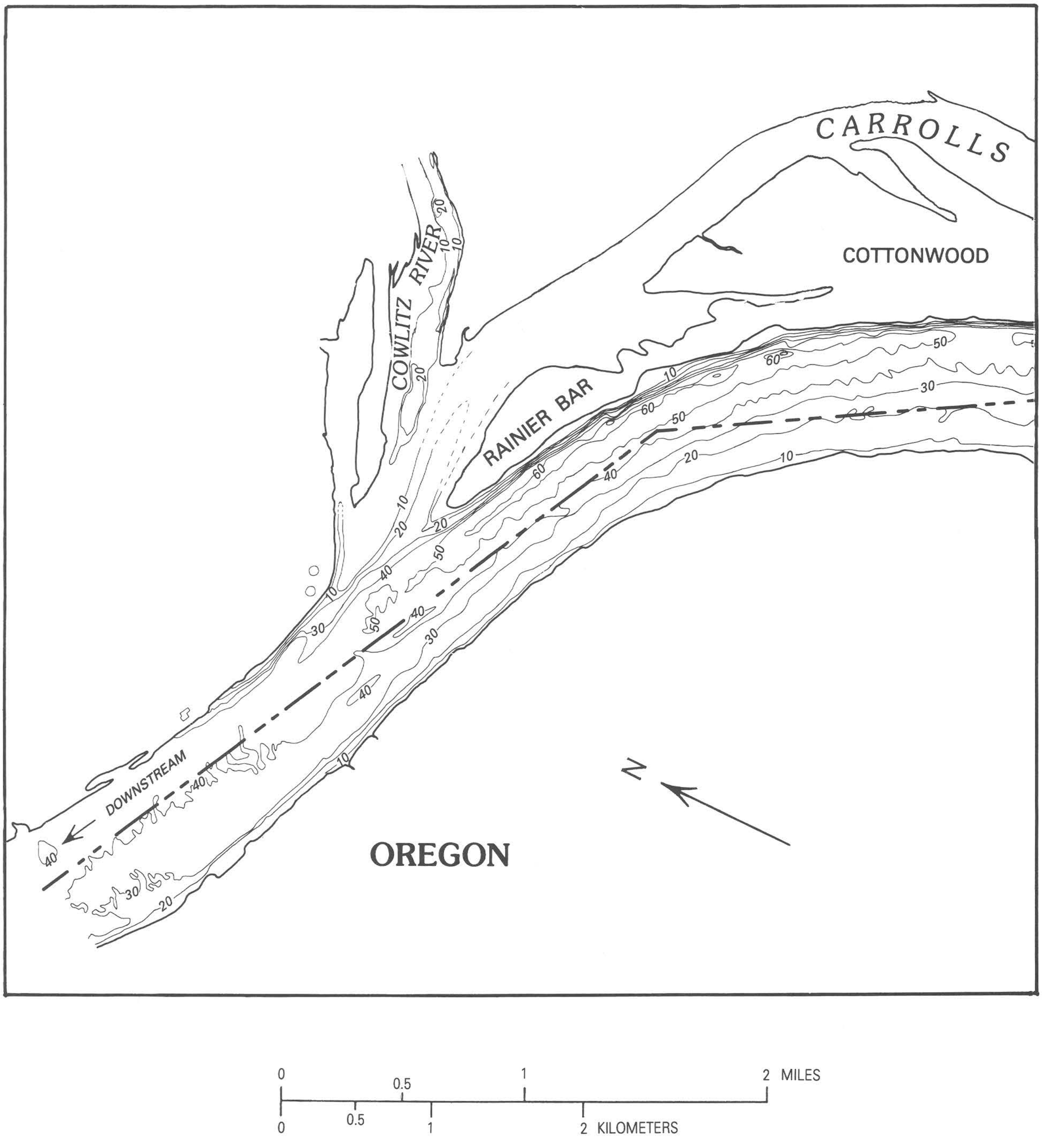


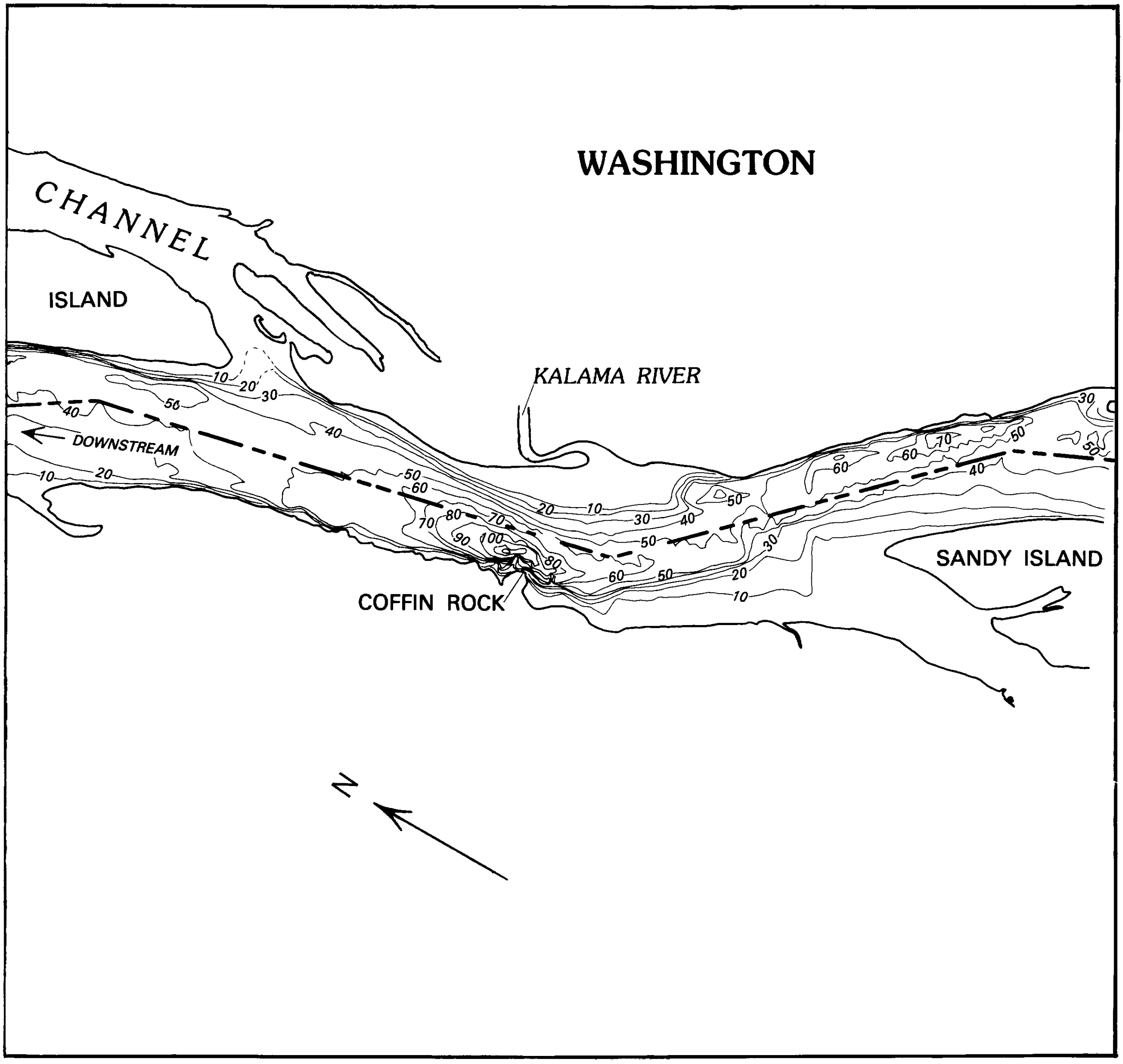
FIGURE 2.—Locations and dates of the U.S. Army Corps of Engineers bathymetric survey maps and marine seismic reflection profiles and the location of the Columbia River Profile shown in figure 7.



Datum is Columbia River Datum (0.29 ft above National Geodetic Vertical Datum at Columbia River Mile 75.3)

FIGURE 3.—Configuration of the Columbia and Cowlitz River beds near Longview, Washington, before the eruption of Mount St. Helens on May 18, 1980.

One of the most prominent features of the pre-eruption Columbia River bed was the 140-ft-deep hole near Coffin Rock. This hole may have been scoured by the increased velocity of the river as it changes direction near Coffin Rock. Similar scour holes, 70 ft deep, are present north of Sandy Island



EXPLANATION

—10— LINE OF EQUAL WATER DEPTH—indicates the depth below the Columbia River Datum. Dashed where approximately located. Interval 10 ft (3. 0 m)

Based on bathymetric data by U.S. Army Corps of Engineers surveys; August 30, 1979, February 27, 1980 and March 4, 18, 20, and 25, 1980

and south of Rainier Bar. Erosion on the outside bend of the Columbia River and deposition on the inside bend are typical of streams and rivers and generally form a characteristic asymmetrical bottom profile. The actual shape of the Columbia River bottom depends upon many factors, but, typically, the bottom is gently sloping on the inside bend and has an erosion channel on the outside bend. Straight reaches of the river generally have a symmetrical cross section.

The bed of the Cowlitz River had the same characteristics as those of the Columbia River. The Cowlitz River was much shallower, however, and, in the lower 2 mi, the maximum depths ranged from 10 to 20 ft and exceeded 20 ft in two small areas.

In addition to natural forces, dredging affects the shape of the riverbeds. A 600-ft-wide and 40-ft-deep channel is maintained on the Columbia River, and a 100-ft-wide and 8-ft-deep channel is maintained on the Cowlitz River.

The complex shape of the Columbia and the lower Cowlitz River bottoms, as shown in figures 3 and 6a and b, before the May 18 eruption was a product of many hydrologic, geologic, and manmade forces.

MUDFLOWS INTO THE COLUMBIA AND COWLITZ RIVERS ON MAY 18, 1980

The eruption of Mount St. Helens on May 18, 1980, and the subsequent mud and debris flows drastically altered the shape of both forks of the Toutle, Cowlitz, and Columbia River beds. The effects of these mudflows on the lower Toutle and Cowlitz Rivers were massive sediment deposition and destruction on the flood plains of these rivers (Lombard and others, 1981). The chronology of the mudflows is described by Cummans (1981). According to this account, two separate mudflows moved down the Toutle River system and affected the lower Cowlitz and Columbia River beds.

The first mudflow originated in the headwaters of the South Fork Toutle River and proceeded downriver. This mudflow was relatively small, and, once in the Cowlitz River, it did not overflow the banks.

In the account by Cummans (1981, p. B7), the leading edge of the first mudflow passed the Longview Water Treatment Plant (Cowlitz River, Mile 5.2, fig. 1) at 4:15 p.m. on May 18, moving 4 to 5 ft/sec. No increase in river height was reported at the treatment plant, and the leading edge was marked by trees, branches, and floating debris. Cummans estimates the peak passed the plant at about 5 p.m. or shortly thereafter, and a marked increase in turbidity was recorded at 8 p.m. If this material continued downstream at this same velocity, the leading edge of trees and debris would have reached the Columbia River at about 6:15 p.m.; the peak, at 7 p.m.; and the slug of the very turbid water, at 10 p.m. The significance of the marked increase in turbidity at the water-treatment plant is not known, but it may have been the leading edge of the sediment moving downstream. Cummans documents a witness who reported a leading edge of trees and debris ahead of the actual mudflow as it proceeded down the South Fork Toutle River.

The Columbia and lower Cowlitz Rivers, under normal conditions, are affected by tidal action and have periods of minimum downstream and possible upstream flow twice each day. The stage of the river rises and falls in response to this tidal action, and, if this stage is measured at two or more gages, the periods of upstream and downstream flow can be calculated. The stage of the river at one gage and knowledge of the flow characteristics of the river can be used in a qualitative way to determine the time of minimum downstream or upstream flow. Figure 5 shows the gage height of the Columbia River at Rainier, Oregon, for May 18 and 19, 1980. As the gage height increases, the downstream flow decreases and, for several hours near the peak gage height, flow is either downstream at a minimum or upstream. Conversely, as the gage height decreases, flow increases downstream. Each change in direction is preceded by a short period of slack water—no flow in either direction. The upstream or downstream velocity depends on (1) the rate of change of stage, (2) the volume of water or channel geometry, and (3) the magnitude of the tidal cycle.

At 7:30 p.m. on May 18, the Survey gage at Rainier, Oregon, reached its maximum for the incoming tide. Shortly thereafter, the direction of river flow changed, and the flow of the Columbia River was downstream until the next high-tide cycle early on the morning of May 19. Because the earliest the leading edge of the debris and the water of high turbidity could have arrived at this spot was 6:15 p.m. and 10 p.m., respectively, most of the material that originated in the mudflow of the South Fork Toutle River was either deposited at the junction of the two rivers or carried downstream by the Columbia River. The shape and areal extent of this deposit is not known because the part that remained at the junction of the two rivers was subsequently buried by the next mudflow and the part that went downstream seems to have been widely distributed.

The second and significantly larger mudflow originated on the North Fork Toutle River; it caused extensive damage and deposited much sediment on the flood plains of the Toutle, North Fork Toutle, and Cowlitz Rivers (Lombard, 1981). In general, the thickness of these deposits decreased downstream, and, in the lower 2 mi of the Cowlitz and in the Columbia Rivers, the sediment was almost entirely deposited within these stream channels. According to Cummans (1981, table 2, p. B16), the peak of the second mudflow was reported passing the Longview Water Treatment Plant at 4 a.m. Monday, May 19, and moving about 4 ft/sec. If it is assumed that the mudflow continued down the Cowlitz River at about the same velocity, the peak would have reached the Columbia River at 6 a.m. The river stage at Castle Rock shows that the leading edge of this mudflow was approximately 2 hr ahead of the peak stage (Cummans, 1981, fig. 11, p. B15). Therefore, the earliest that sediment started to enter the Columbia River was estimated to be 4 a.m. on May 19. From 4 a.m. to 6 a.m. on May 19, the Columbia River flowed minimally downstream and probably upstream. Consequently, the major part of the mudflow entered the Columbia River and was deposited during upstream flow (fig. 4).

The timing of these events agrees with reports from a ship's pilot on the Columbia River during this interval. The pilot noted that logs and debris floated in the water as his ship approached Longview, Washington. At 5:05 a.m., his ship was no longer making headway; he was, in fact, aground on a huge bank of mud. Another ship had successfully made the same passage just 2 hr earlier, at 3 a.m. (Zonana, 1980).

The main deposition of mudflow sediment derived from the debris avalanche and caused by the May 18, 1980, eruption was, therefore, deposited in the lower Cowlitz and Columbia Rivers between 3 a.m. and 6 a.m. on the morning of May 19, 1980, during an incoming tidal cycle (fig. 4).

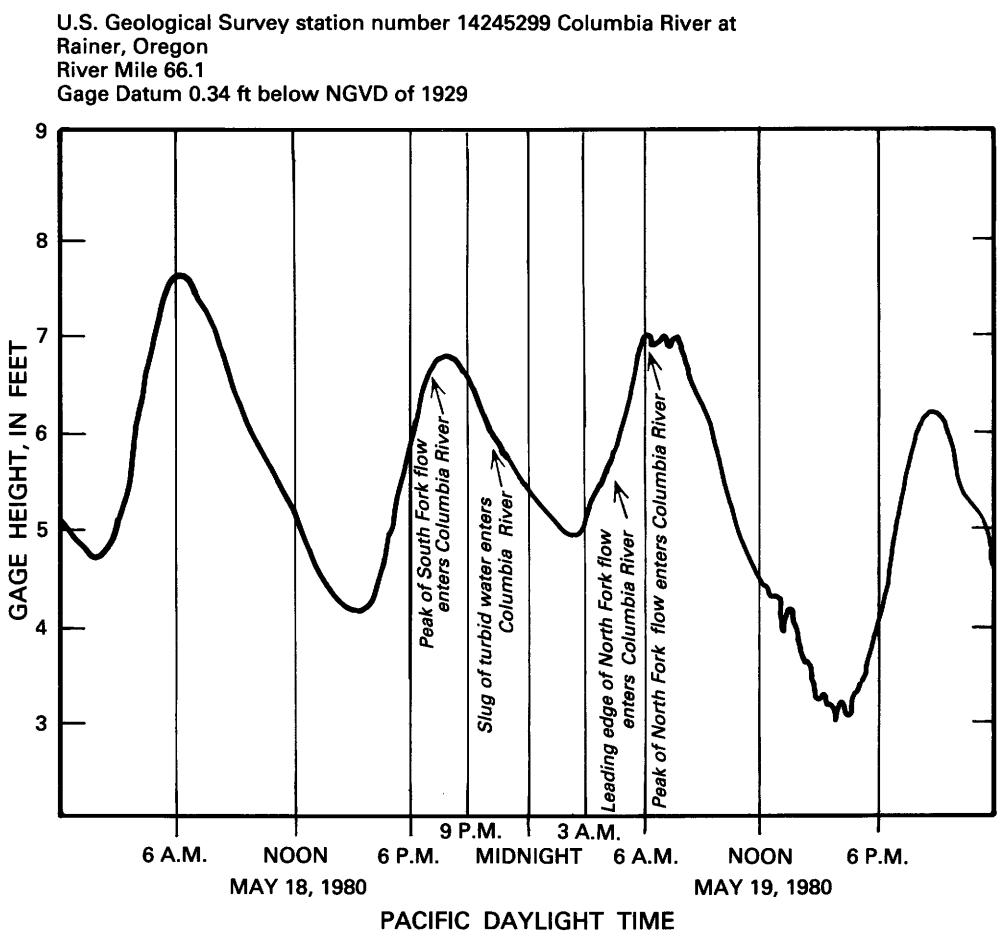
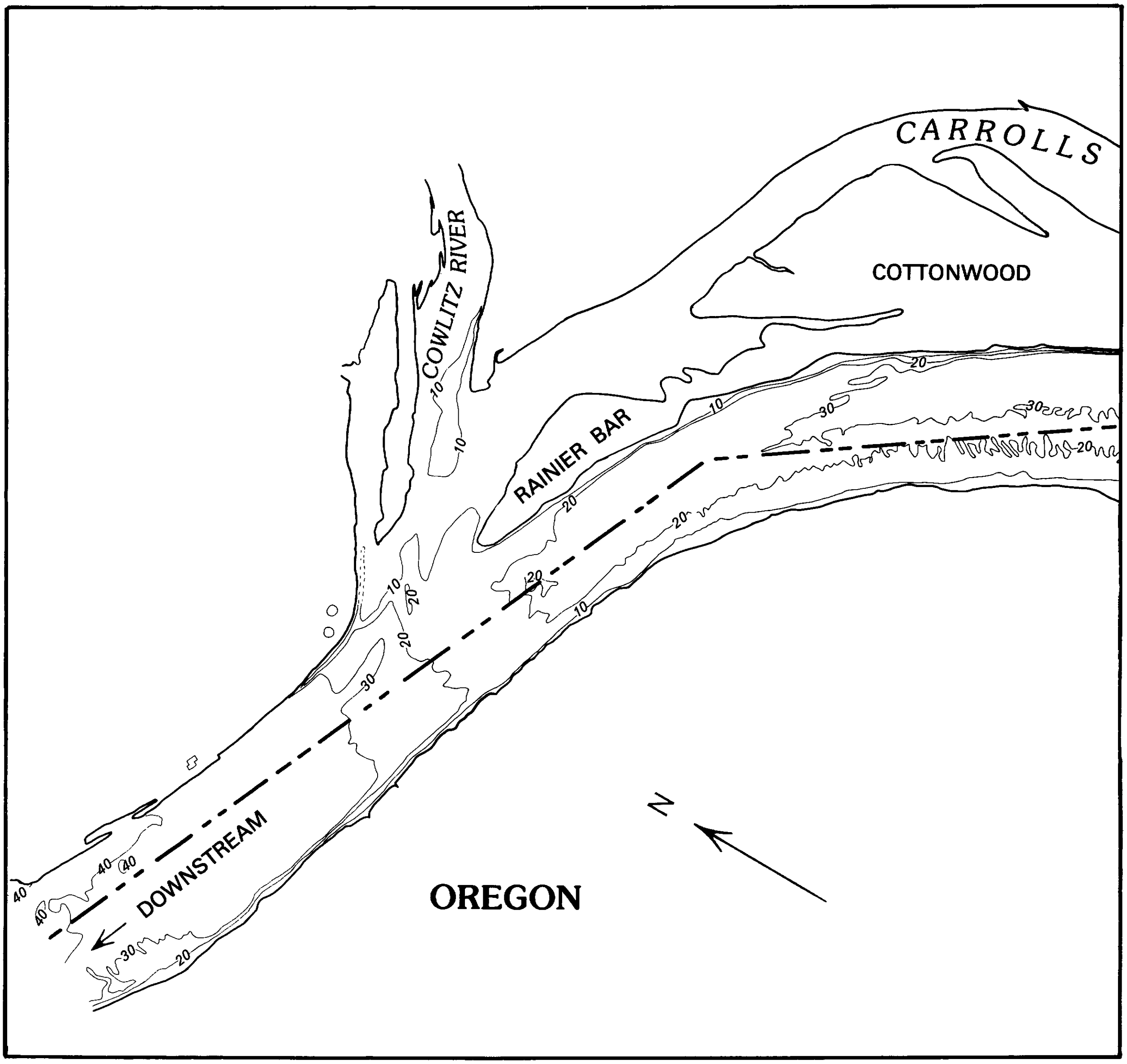


FIGURE 4.—Gage height of Columbia River at Rainier, Oregon, for May 18 and 19, 1980. (NGVD is National Geodetic Vertical Datum.)

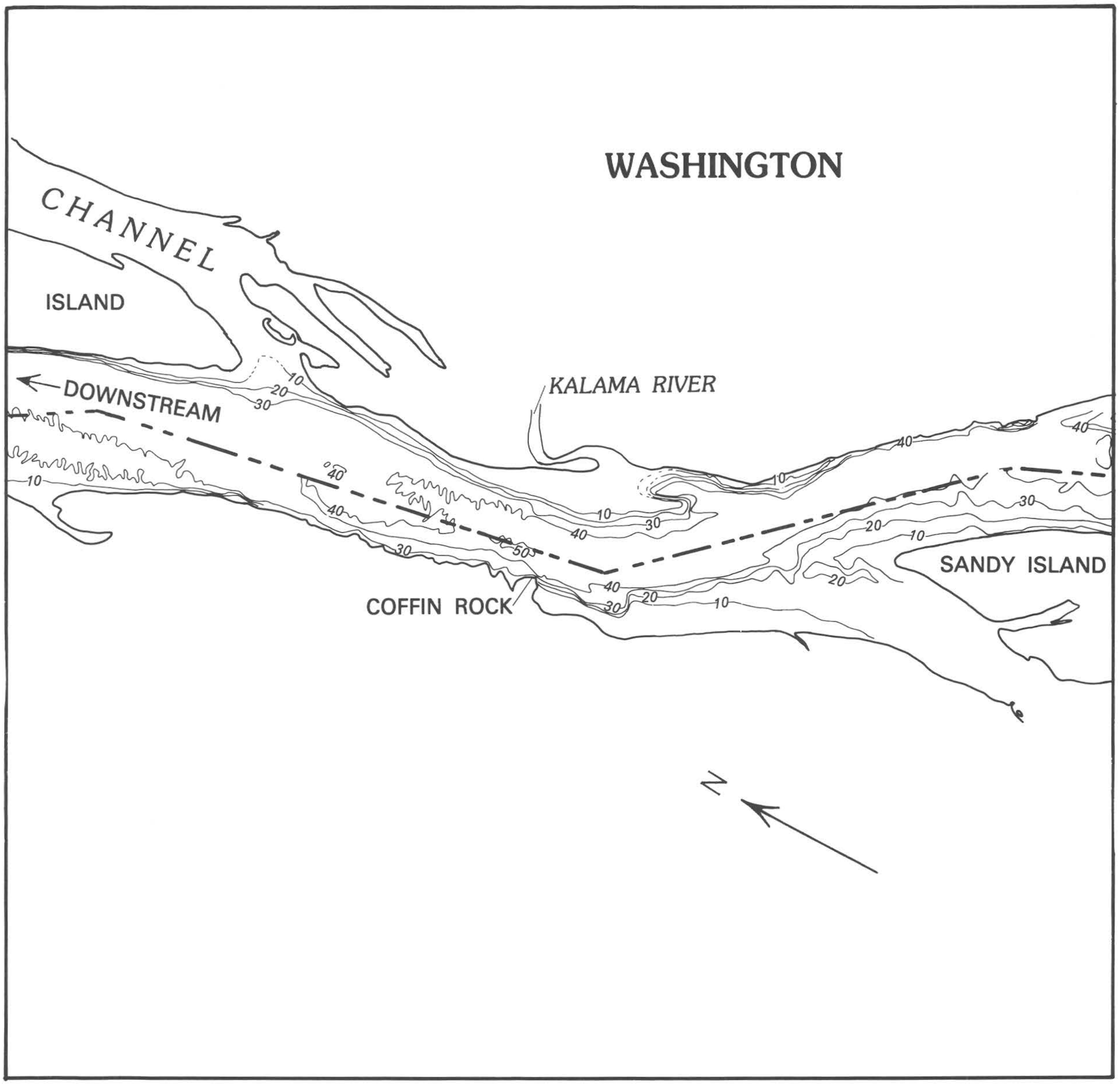


0 0.5 1 2 MILES

0 0.5 1 2 KILOMETERS

Datum is Columbia River Datum (0.29 ft above National Geodetic Vertical Datum at Columbia River Mile 75.3)

FIGURE 5.—Configuration of the Columbia and Cowlitz River beds near



EXPLANATION

—10— LINE OF EQUAL WATER DEPTH—indicates the depth below the Columbia River Datum. Dashed where approximately located. Interval 10 ft (3.0 m)

Based on bathymetric data by U.S. Army Corps of Engineers surveys; May 19, 21, 23, and 24, 1980, June 4, 1980, and supplemented by U.S. Geological Survey seismic reflection profiles; May 23, 24, and 25, 1980

Longview, Washington, after the eruption of Mount St. Helens on May 18, 1980.

FIGURE 6.—Perspective diagrams of the Columbia and Cowlitz River beds near Longview, Washington, before and after the May 18, 1980, eruption of Mount St. Helens.

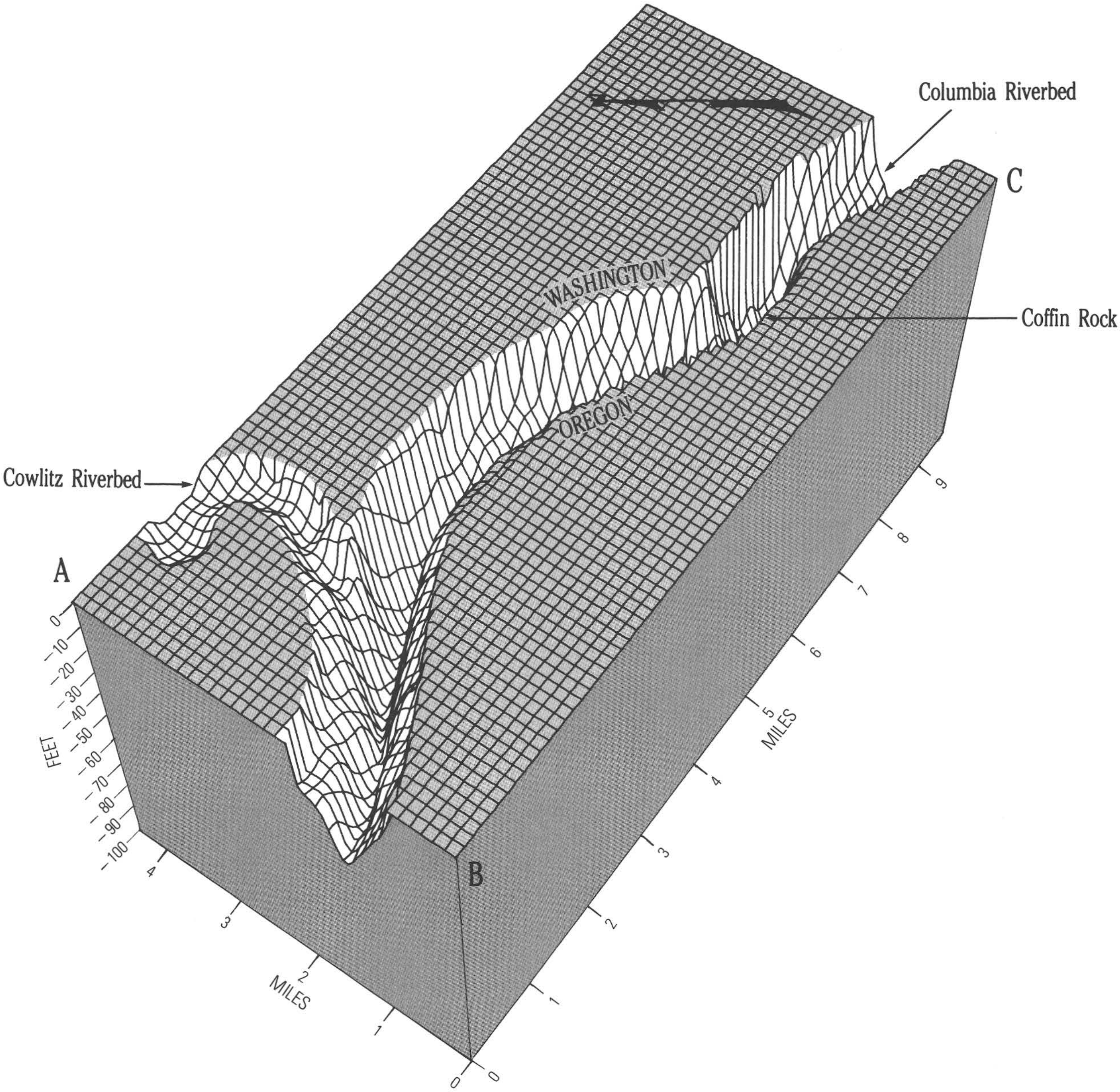


FIGURE 6A.—Aerial view of the Cowlitz and Columbia Rivers before the May 18, 1980, eruption of Mount St. Helens. View is from 45° above the surface of the Earth.

CONFIGURATION OF THE COLUMBIA AND COWLITZ RIVER BEDS AFTER THE MAY 18, 1980, ERUPTION OF MOUNT ST. HELENS

The U.S. Army Corps of Engineers, upon learning that the Columbia River was blocked to shipping, made bathymetric surveys on the Columbia and Cowlitz Rivers. The results of surveys on May 19, 21, 23, and 24 and June 4, 1980, were used in this study to determine the configuration of the river bottoms after the mudflows of May 18 and 19. These data were supplemented by marine seismic reflection surveys by the Survey from May 23 to 25. Figure 2 shows the locations of the Corps' surveys, their dates, and the locations of the marine seismic reflection lines.

The most noticeable effect of the mudflows on the Columbia River bottom was the smoothing of

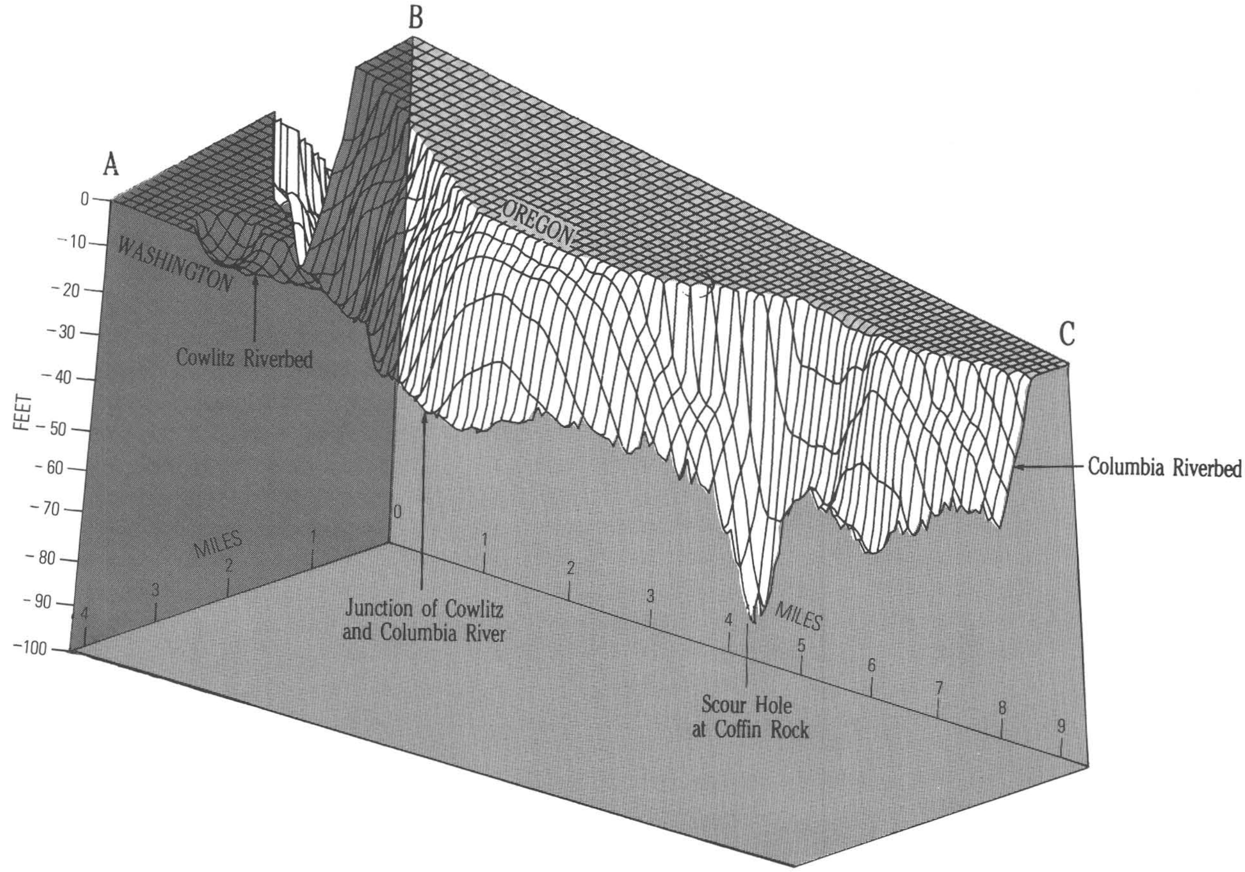


FIGURE 6*B*.—View of the Cowlitz and Columbia River beds before the May 18, 1980, eruption of Mount St. Helens. View is from 40° below the surface of the Earth.

its topography and deposition of most of the mudflow upstream from its entry point at the mouth of the Cowlitz River. All depressions in the former river bottom, including the dredged channel, the large scour hole near Coffin Rock, and the smaller holes north of Sandy Island and south of Rainier Bar were filled by the mudflow. Water was shallowest at the junction of the two rivers; the former 40-ft-deep shipping channel was only 14-ft-deep on the morning of May 19. The contours on figure 5 show the depth of water, in feet below Columbia River Datum, and depict the shape of the river bottom. A computer-generated three-dimensional perspective diagram of the same surface is shown in figures 6c and d.

A longitudinal section of the Columbia River bed, A–A′ (fig. 7), shows the configuration of the river before and after the mudflows of May 18 and 19. The location of this profile is shown in figure 2. The downstream edge of the mudflow is steep, and the upstream edge is gradual and gently sloping. Its surface is marked by a depression directly above the former 140-ft-deep scour hole. This depression is due to one or more of the following: incomplete filling of the scour hole or both compaction and erosion after the main deposition was complete.

The effect of the mudflows on the lower 2 mi of the Cowlitz River was to fill in the navigation channel with 10 to 20 ft of material and to deposit a large pile of stumps and log debris near the confluence with the Columbia River (upper right-hand corner of fig. 12). Several sections near the mouth of the Cowlitz River were deeper after the mudflow than before, indicating that the mudflows eroded bottom materials in places. Erosional and depositional events in the lower Cowlitz River (figs. 8, 11) are explained in the next section.

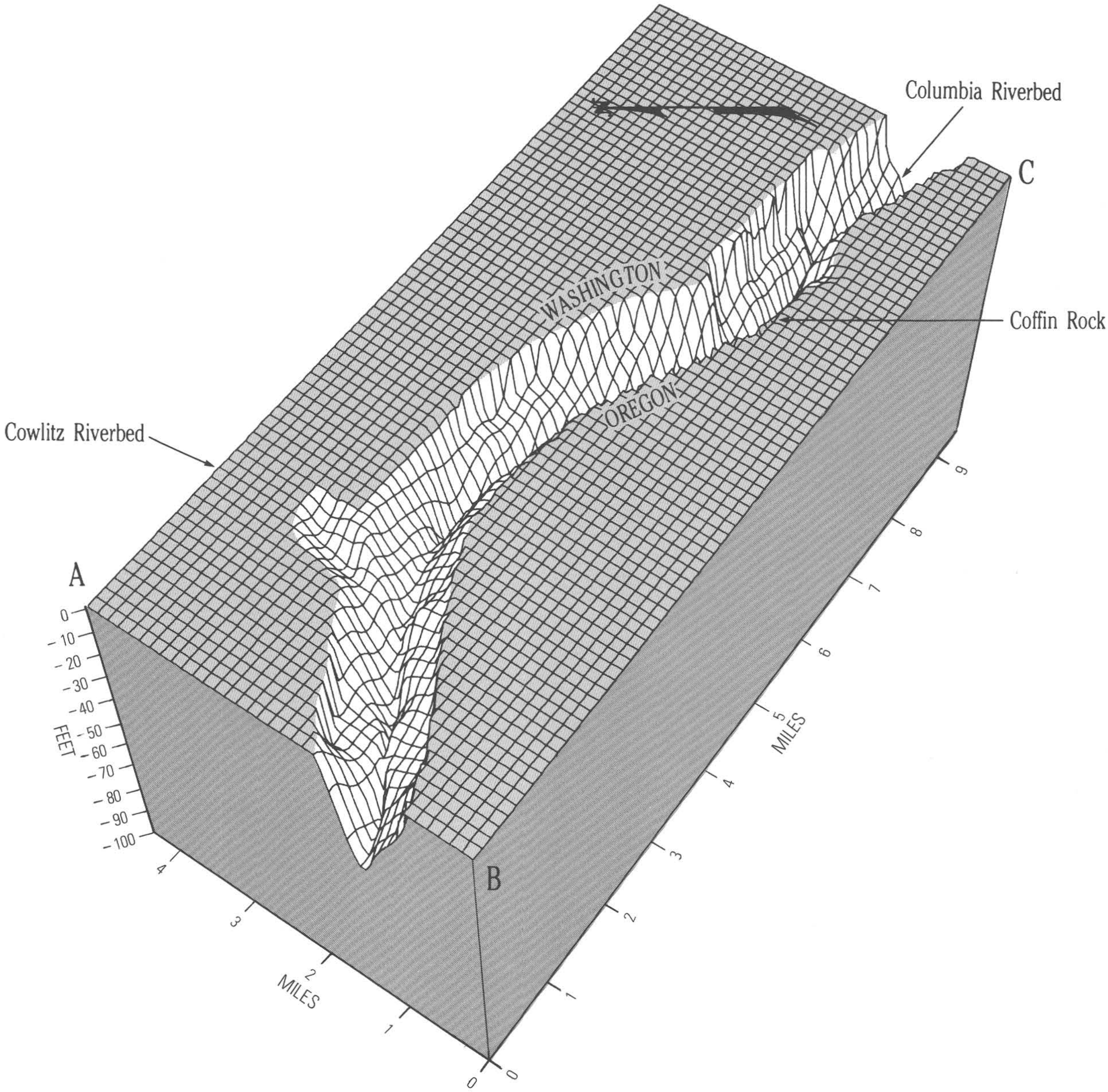


FIGURE 6C.—Aerial view of the Cowlitz and Columbia Rivers after the May 18, 1980, eruption of Mount St. Helens. View is from 45° above the surface of the Earth.

VOLUME, THICKNESS, AND TEXTURE OF THE MUDFLOW MATERIAL IN THE COLUMBIA AND COWLITZ RIVERS

The thickness of mudflow material deposited or eroded from the river bottoms is shown in figure 8. This map was prepared by comparing the pre-eruption with post-eruption bathymetric data, supplemented by marine seismic reflection profiles. A computer-generated three-dimensional perspective diagram representing the total accumulation on the bottom of these rivers is shown in figure 9.

As of June 4, 1980, the total volume deposited in the Columbia and the lower Cowlitz Rivers as a result of the May 18 eruption was 35.6 million yd^3 (fig. 8). The average thickness deposited in the Columbia near Longview, Washington, was 25 ft and reached a maximum of 90 ft. The total mudflow deposit in the Columbia near Longview as 9 mi long, reaching 7 mi upstream from its confluence with the Cowlitz.

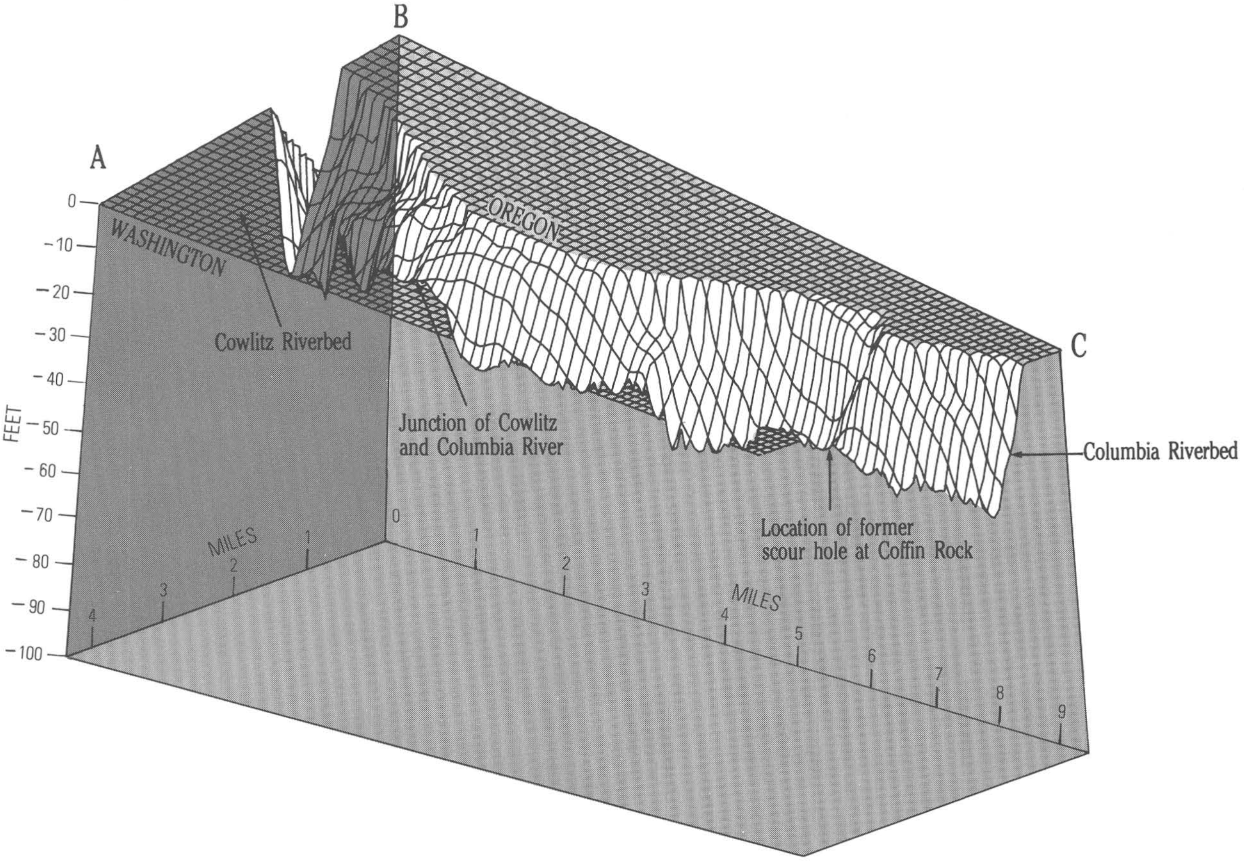


FIGURE 6*D*.—View of the Cowlitz and Columbia River beds after the May 18, 1980, eruption of Mount St. Helens. View is from 40° below the surface of the Earth.

The mudflow was thickest in the former scour hole located near Coffin Rock. This hole, 5 mi upstream from the junction of the Columbia and Cowlitz Rivers, was filled with 90 ft of material. The contours in figure 10 show the thickness of the deposited material.

A detailed thickness map of the mudflow eroded or deposited in the lower Cowlitz River is shown in figure 11. The deposited material averages 7 ft, reaches a maximum of 20 ft, and is confined mainly to the former dredged channel. The patterned area shows deeper water after the mudflows than before and, consequently, outlines areas of erosion caused by the mudflows. A minimum of 0.4 million yd^3 of material was eroded from the Cowlitz River by the mudflows, but the deposition of this eroded material is unknown. Most, however, was probably redeposited in the Columbia River near Longview, Washington, along with the greater part of the mudflow material.

The mudflow deposits in the lower Columbia and Cowlitz Rivers were sampled by the Corps of Engineers from May 24 to 31, 1980, with a clamshell dredge. Although the samples are scattered in time, distance, and depth, the data provide a general idea of the grain-sized distribution of the mudflow. The deposit in the Cowlitz River was generally fine grained, consisting of silt, very fine sand, fine sand, and small pieces of charred wood fragments and a trace of coarse angular rock fragments.

Most sediment in the Columbia River was coarser than that in the Cowlitz River and consisted of fine to coarse sand and rock fragments with some silt and wood fragments. Gravel and rock fragments as large as 2 in. in diameter were reported in many of the sediment samples. In general, the deposit was coarser grained on the bottom and finer grained on the top (Mount St. Helens debris explorations, explanation and shell bucket sample logs, U.S. Army Engineering District, Portland, Oregon, May 1980). More information on bed materials is available in a recent report by Hubbell and others (1982).

The formation of an elongated deposit (delta) in the mouth of the Cowlitz River, the grain-sized distribution of the mudflow in the Columbia and Cowlitz Rivers, and the shape and extent of the area from which material was eroded from the Cowlitz River (fig. 11) suggest the following sequence of events on May 19, 1980.

The second and significantly larger mudflow, which moved down the Cowlitz River on the morning of May 19, 1980, initially contained a significant quantity of coarse-grained sediment. When this mudflow reached the lower Cowlitz River, it scoured up to 10 ft of material from the lower 0.5 mi of the riverbed and redeposited some of this material in the Columbia River.

The combination of the deposition of material in the Columbia River, the rising tidal stage, and the widening of the Cowlitz River as it joins the Carrolls Channel, probably formed backwater conditions in the lower Cowlitz River. The backwater lowered water velocity and allowed fine-grained sediments to be deposited. The 1.3-million-yd^3 delta (fig. 11), which is composed of mostly fine-grained sediments, was formed. This sequence is supported by stratigraphic evidence throughout the Toutle-Cowlitz system which indicates that the material from the North Fork Toutle River mudflow was initially coarse grained and then became fine grained (Richard Jander, written commun., 1981).

The shape of this deposit is inferred only from data collected on May 23, 1980. Sediment movement in both the Columbia and Cowlitz Rivers is a dynamic process, and the shape and volume of accumulated material will continue to change for months and years to come. Figure 12 is an aerial photograph of the junction of the Columbia and Cowlitz Rivers taken on May 23, 1980, 5 days after the initial mudflow; it shows the large quantity of sediment and debris still moving down the Cowlitz River. The size and shape of the river channels were changing and will continue to change daily because of stream scouring, dredging, and new sediment deposition.

SUMMARY

Early on the morning of May 19, 1980, 35.6 million yd^3 of mudflow material that originated from the debris flows into the Toutle River basin during the eruption of Mount St. Helens was deposited in the Columbia and lower Cowlitz Rivers.

The texture and shape of the mudflow deposits indicate that the Cowlitz River bed, near the junction of the Columbia River, was eroded by the large mudflow on May 19 and that subsequently fine-grained sediment formed an elongated delta near the mouth of the river.

The mudflow material reaching the Columbia River was carried upstream 7 mi by tidally influenced upstream flow. The surface of the deposited material had a steep downstream slope and a gradual upstream slope. The material blocked the shipping channel and flattened the river bottom by filling in most depressions. The average thickness of this material was 25 ft, reaching a maximum of 90 ft where it filled the scour hole near Coffin Rock. Incomplete filling, compaction, and (or) erosion caused a depression to form in the surface of the material over the former deep scour hole. Mudflow material in the Columbia River consisted mostly of sand and rock fragments and small quantities of wood fragments and gravel. The material in the lower Cowlitz River was significantly finer than that in the Columbia River and consisted of silt and very fine to fine sand.

The shape and volume of the mudflow deposits documented by this report will continue to be modified by sediment erosion and deposition as well as by dredging.

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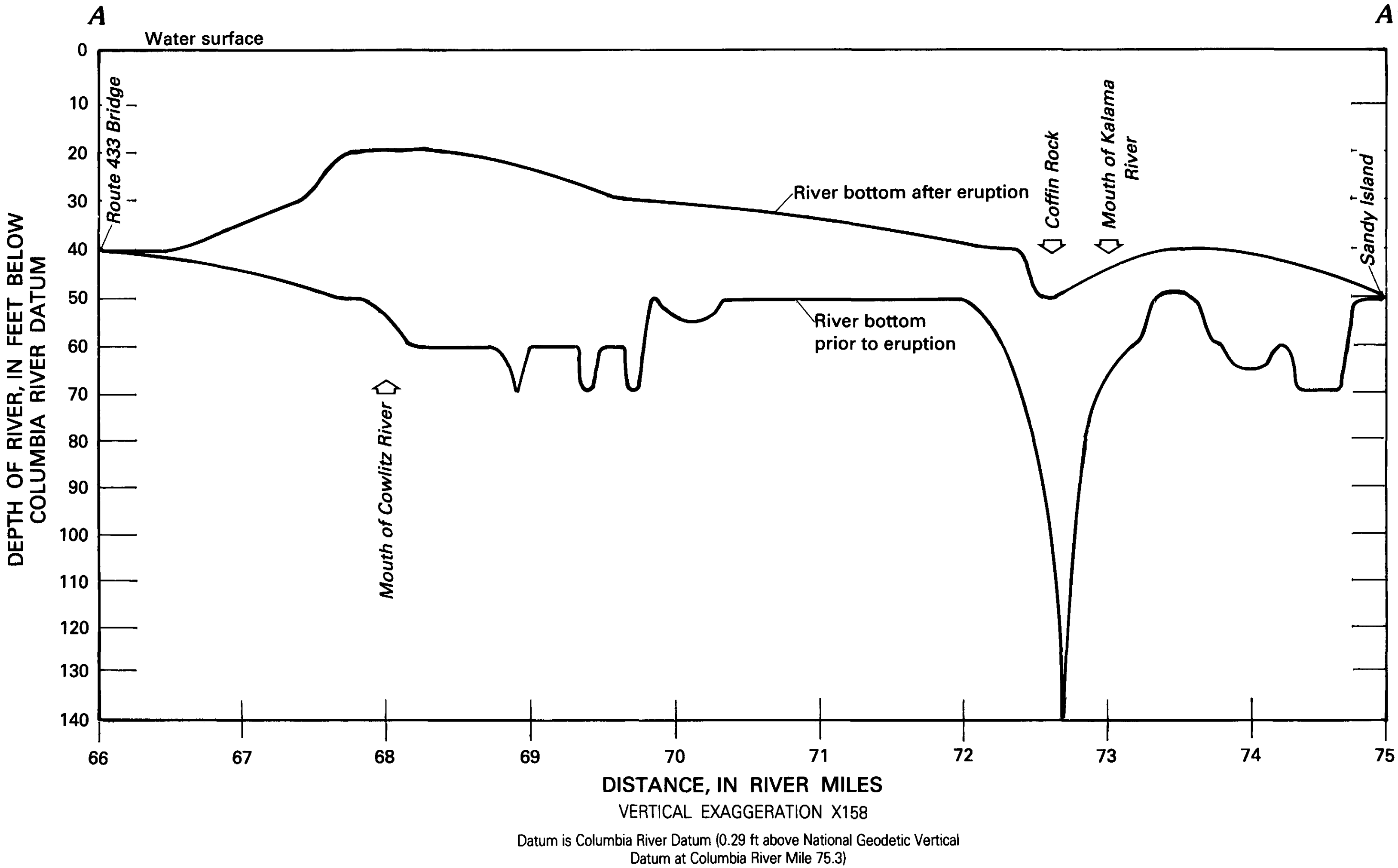


FIGURE 7.—Section of the Columbia River bed before and after the May 18, 1980, eruption of Mount St. Helens. (Profile is located along the maximum depth of the river before May 18, 1980, and is shown in figure 2.)

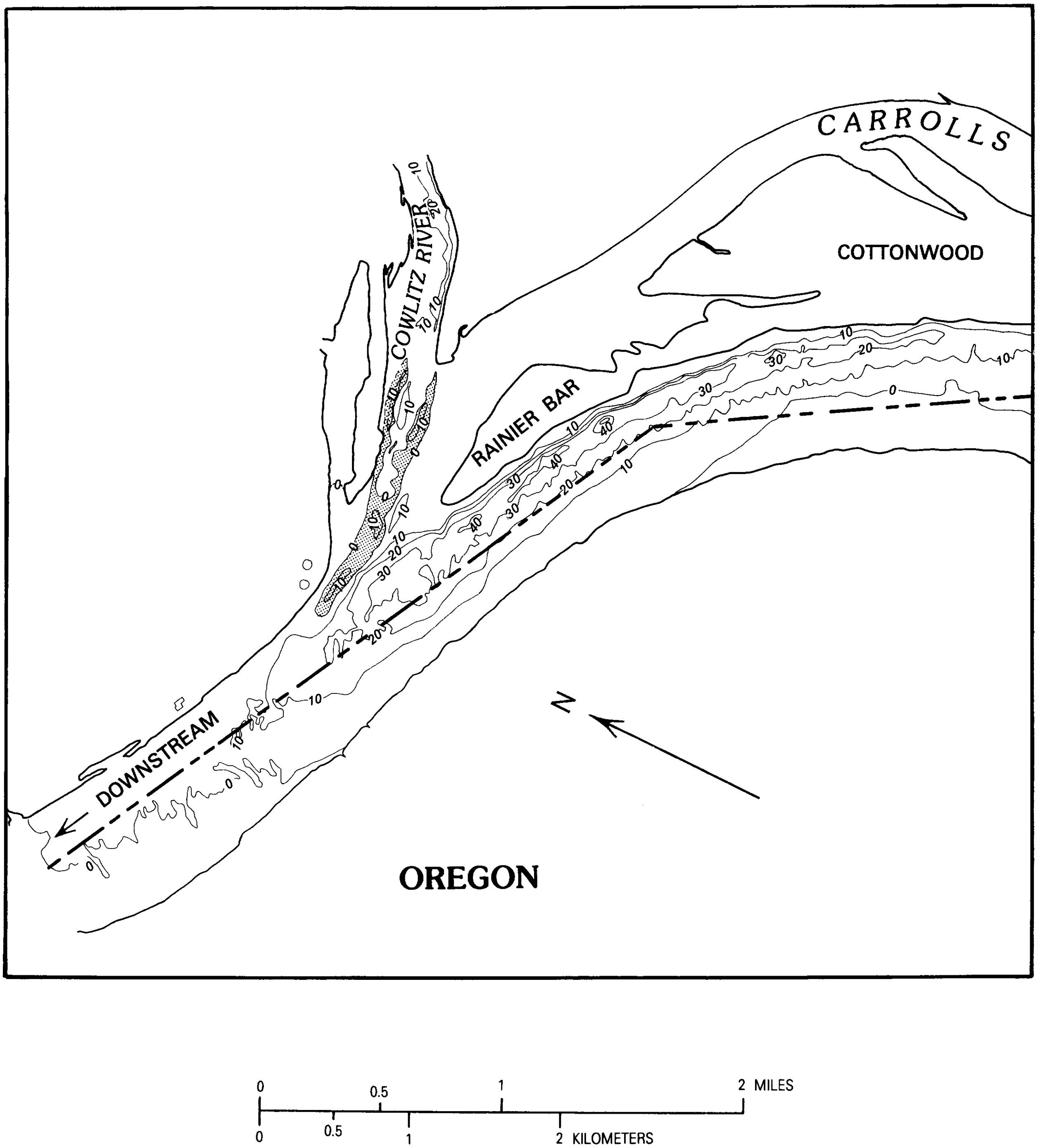
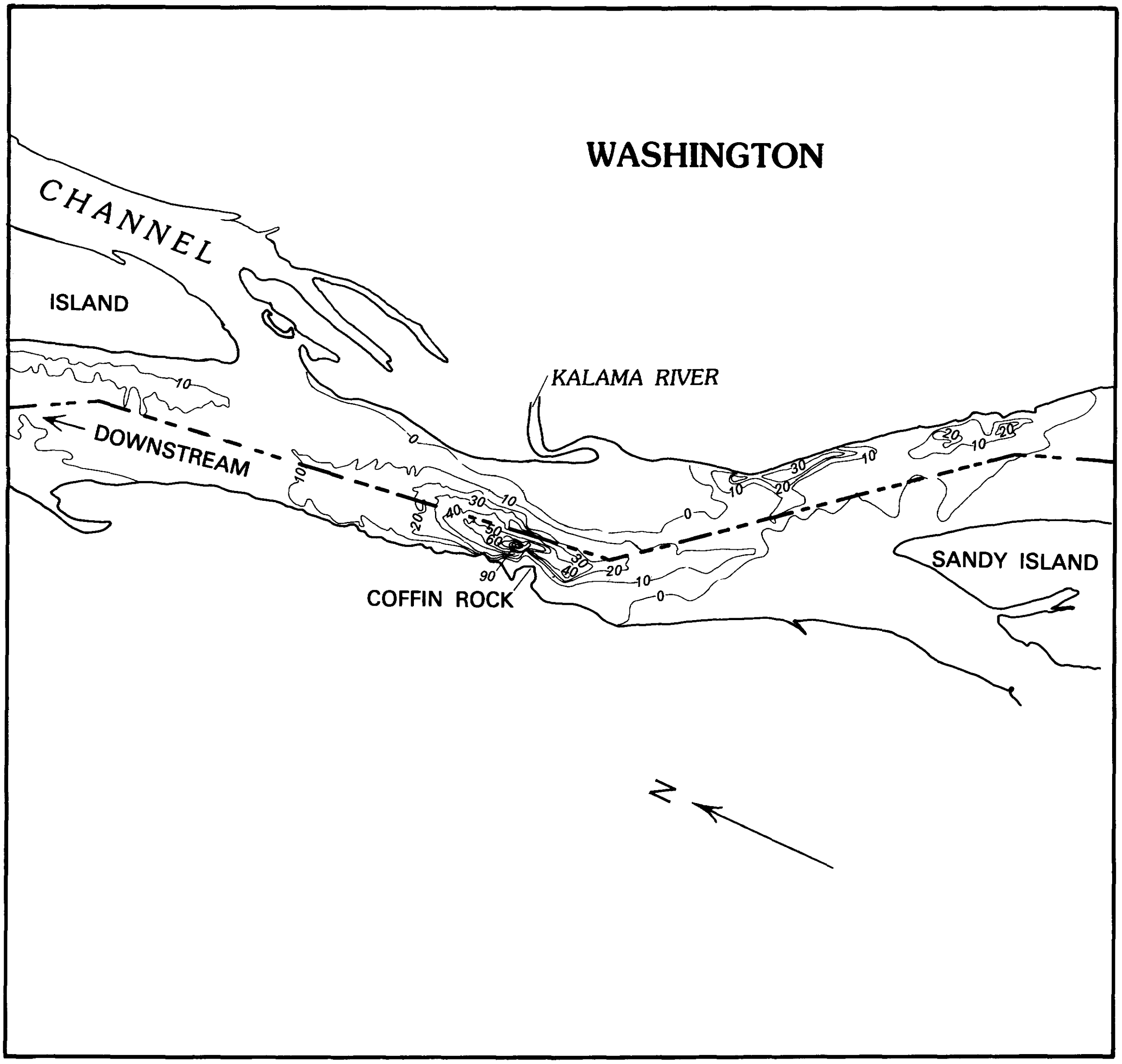


FIGURE 8.—Thickness of sediment deposited in or removed from the Columbia and lower Cowlitz Rivers



EXPLANATION

SCOUR AREA—Sediment in this area of the Cowlitz and Columbia Rivers was removed during the mud and debris flow of May 18, 1980

LINE OF EQUAL THICKNESS OF SEDIMENT DEPOSITED OR REMOVED. Dashed where approximately located. Interval 10 ft (3.0 m)

near Longview, Washington, as a result of the eruption of Mount St. Helens on May 18, 1980.

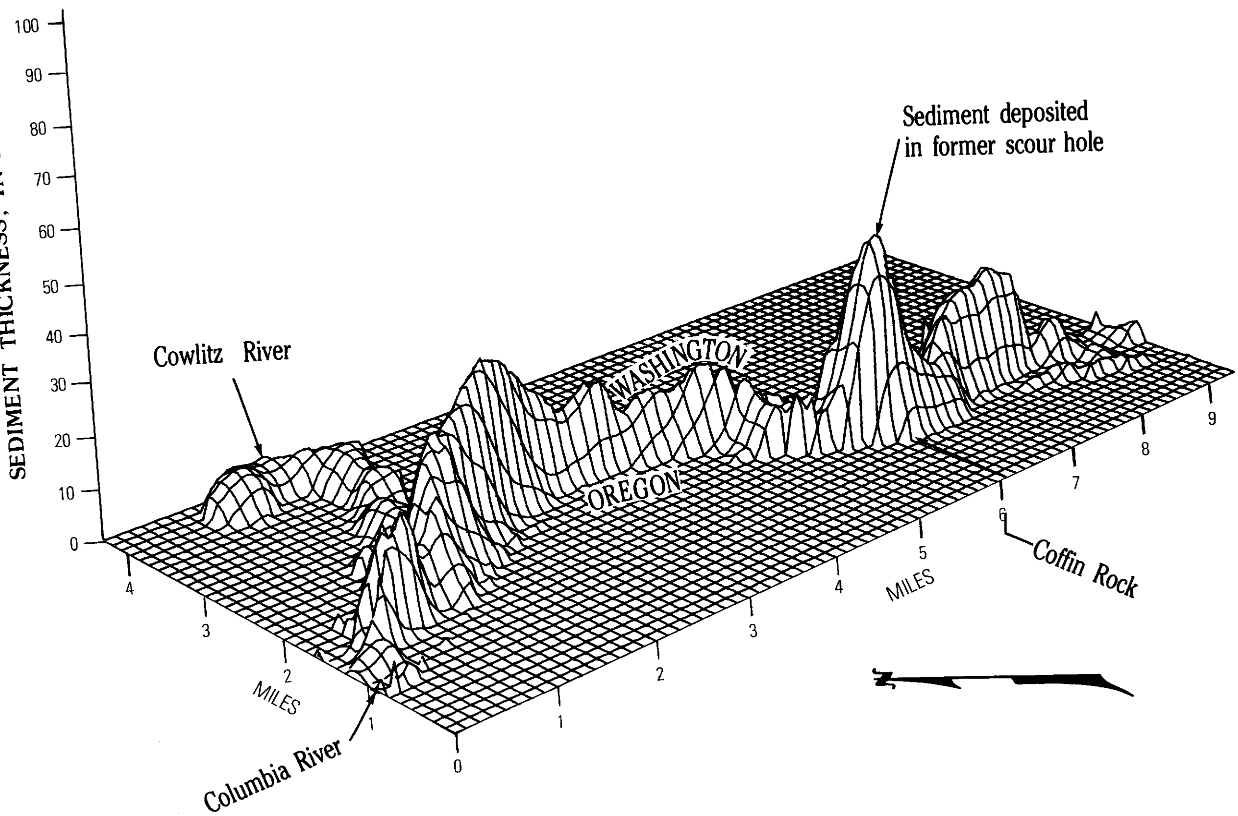
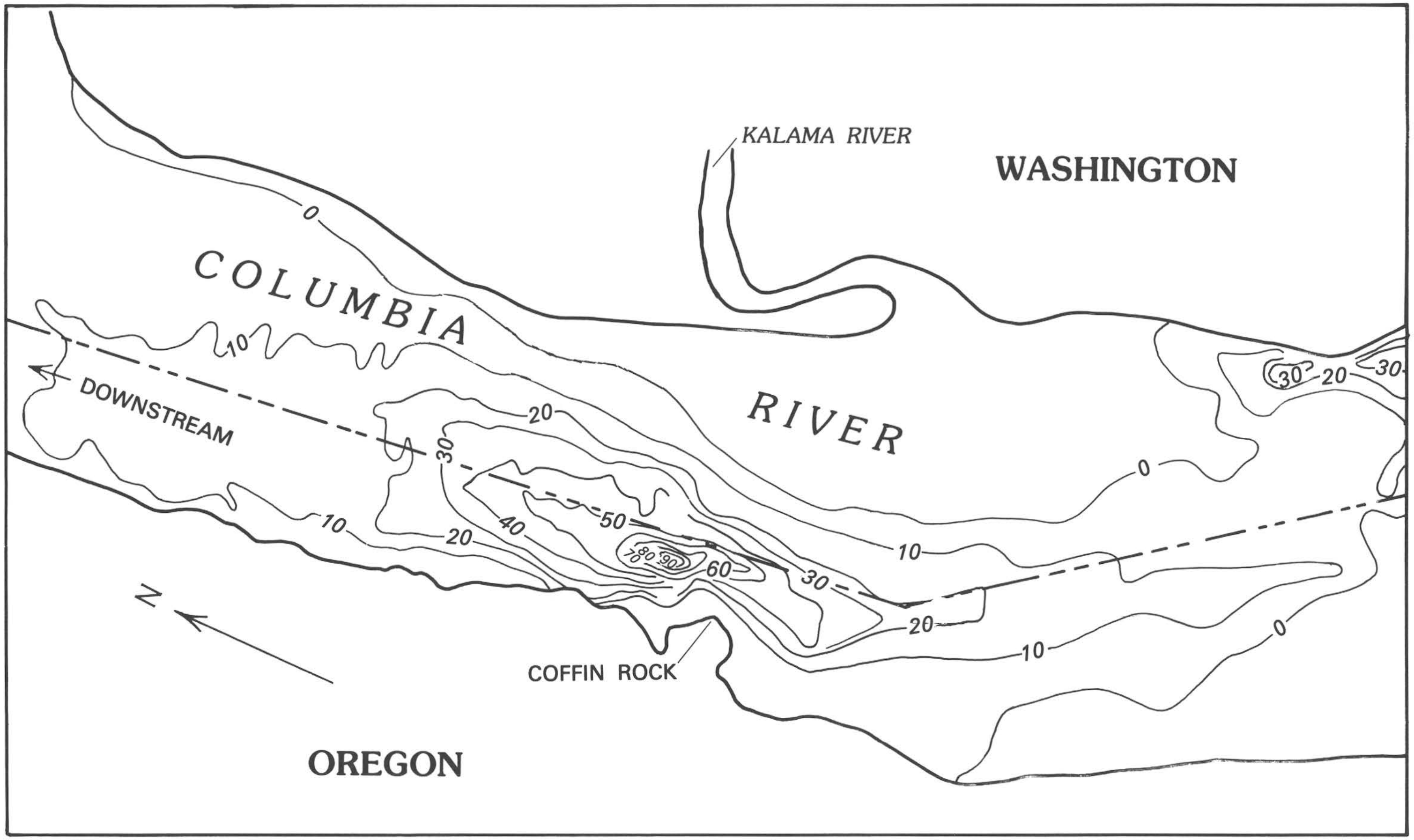


FIGURE 9.—Perspective diagram representing the accumulation of sediment on the Columbia and Cowlitz River beds after the May 18, 1980, eruption of Mount St. Helens.



EXPLANATION

—10— LINES OF EQUAL THICKNESS OF SEDIMENT DEPOSITED
Interval is 10 ft (3.0 m)

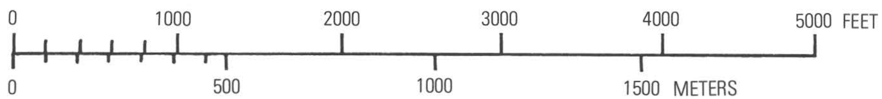
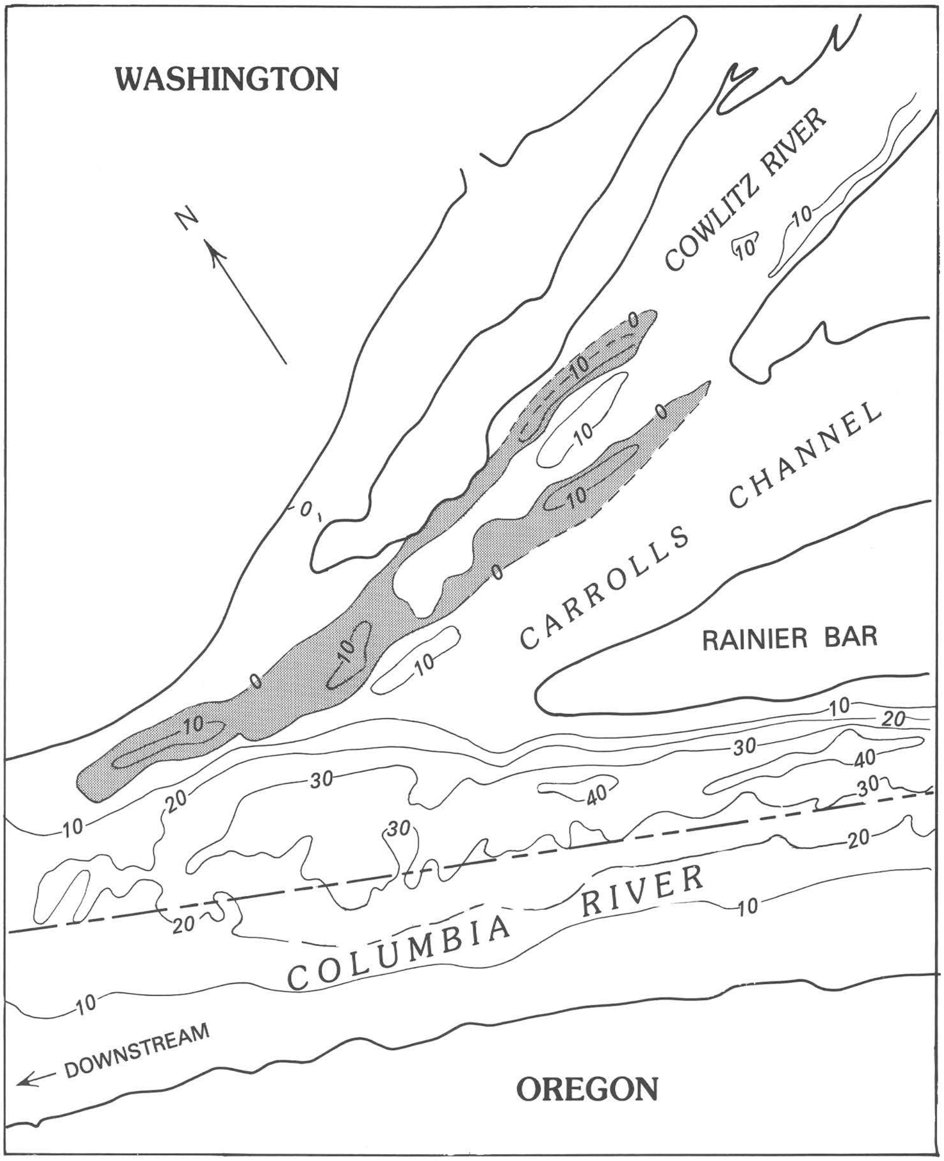


FIGURE 10.—Thickness of sediment deposition in the former scour hole near Coffin Rock.



EXPLANATION

SCOUR AREA—Sediment in this area of the Cowlitz and Columbia Rivers was removed during the mud and debris flow of May 18, 1980

—10— LINE OF EQUAL THICKNESS OF SEDIMENT DEPOSITED OR REMOVED. Dashed where approximately located. Interval 10 ft (3.0 m)

Based on bathymetric data by U.S. Army Corps of Engineers surveys; August 30, 1979; February 27, 1980; March 4, 18, 20, and 25, 1980; May 19, 21, 23, and 24, 1980; June 4, 1980, and supplemented by the U.S. Geological Survey seismic reflection profiles; May 23, 24, and 25, 1980

0 1000 2000 3000 4000 5000 FEET

0 500 1000 1500 METERS

FIGURE 11.—Thickness of sediment deposited in or removed from the lower Cowlitz River.

FIGURE 12.—Confluence of the Columbia and Cowlitz Rivers on May 23, 1980, showing suspended sediment and debris in the Cowlitz River.

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