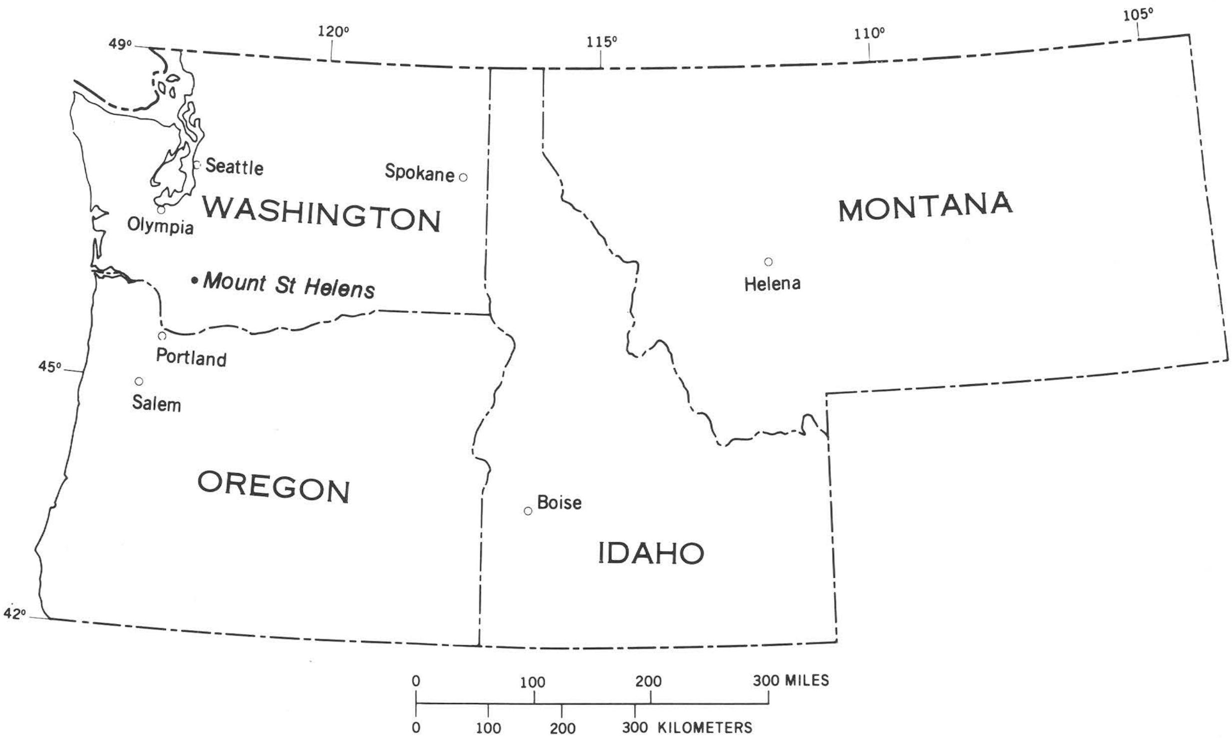
Characteristics of Columbia River Sediment Following the Eruption of Mount St. Helens on May 18, 1980

GEOLOGICAL SURVEY CIRCULAR 850–J

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.

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By David W. Hubbell, Julija M. Laenen, and Stuart W. McKenzie

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

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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 Folk 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.

Director

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CHARACTERISTICS OF COLUMBIA RIVER SEDIMENT FOLLOWING THE ERUPTION OF MOUNT ST. HELENS ON MAY 18, 1980

By David W. Hubbell, Julija M. Laenen, and Stuart W. McKenzie

ABSTRACT

The cataclysmic eruption of Mount St. Helens, in southwestern Washington, on May 18, 1980, produced devastating mudflows that delivered large quantities of debris to the lower reaches of the Cowlitz River and the Columbia River near Longview, Wash. To obtain information on the character of the "new" sediment and its disposition in the rivers, data were collected during a 9-day period in mid-August 1980. Measured suspended-sediment discharges indicate that material is being scoured from the reach of the Columbia River directly seaward from the Cowlitz River mouth at Columbia River mile (CRM) 68.0, and that some of the scoured material is redeposited between CRM 63.8 and CRM 54.0. Most material in transport is of silt and clay size. Pumice particles larger than 2.0 millimeters in diameter are randomly distributed throughout the bed material (bottom sediment). Mean size of bed material finer than 2.0 millimeters in the reach directly seaward from the Cowlitz River mouth is less than half the size of similar material directly upstream from the mouth and is somewhat finer than pre-eruption material. Specific gravity of bed material finer than 2.0 millimeters in the reach below CRM 73.5 is about 2.65, and the majority of particle-shape factors (determined indirectly) are between 0.5 and 0.8.

These values are similar to comparable values for bed materials at CRM 106.4. On the basis of this information, corrections for unusual sediment properties are not necessary in sediment-transport or dredging-earthwork computations for the Columbia River.

INTRODUCTION

On May 18, 1980, at 8:32 a.m., Mount St. Helens, in southwestern Washington, erupted in a cataclysmic explosion. Fragmented and pulverized rock, blasted from the mountain, devastated the landscape over a fan-shaped, 200 mi^2 area to the north. On the mountain, debris accumulated in the channel of the North Fork Toutle River to a thickness of 600 ft, and nearby lakes filled with lesser thicknesses of sediment. Glassy volcanic ash rose 60,000 ft into the air and drifted to the northeast. Ash deposits 10 mm (millimeters) thick occurred as far away as 400 mi. Several cubic kilometers of debris discharged from the mountain, lowering the peak by about 1,300 ft (Findley, 1981; Cummans, 1981).

Melted glacial ice, released ground water, and natural surface flow combined with the enormous quantities of debris to produce mudflows down the valleys of the North and South Forks of the Toutle River that drain to the west and in the Smith and Pine Creeks that drain to the southeast. The most extensive mudflow traveled down the North Fork Toutle River, combined with the mudflow from the South Fork, continued down the Toutle River to the Cowlitz River, and then into the Columbia River at Longview, Wash. Throughout the approximately 70-mi-long course to the Columbia (fig. 1), the mudflow flooded the river valleys and deposited vast quantities of debris in many places across the entire valley floor. At the lower end of the Cowlitz River (fig. 2), the streambed aggraded approximately 15 ft, reducing the channel capacity to roughly 15 percent of normal (Bechly, 1980).

Approximately 36 million yd^3 of sediment, mostly ranging from clay-size particles to ½-in gravel, were deposited in the Columbia River less than 24 hours after the eruption. The 600-ft-wide by 40-ft-deep navigational channel in the Columbia River was reduced to a depth of 14 ft at the mouth of the

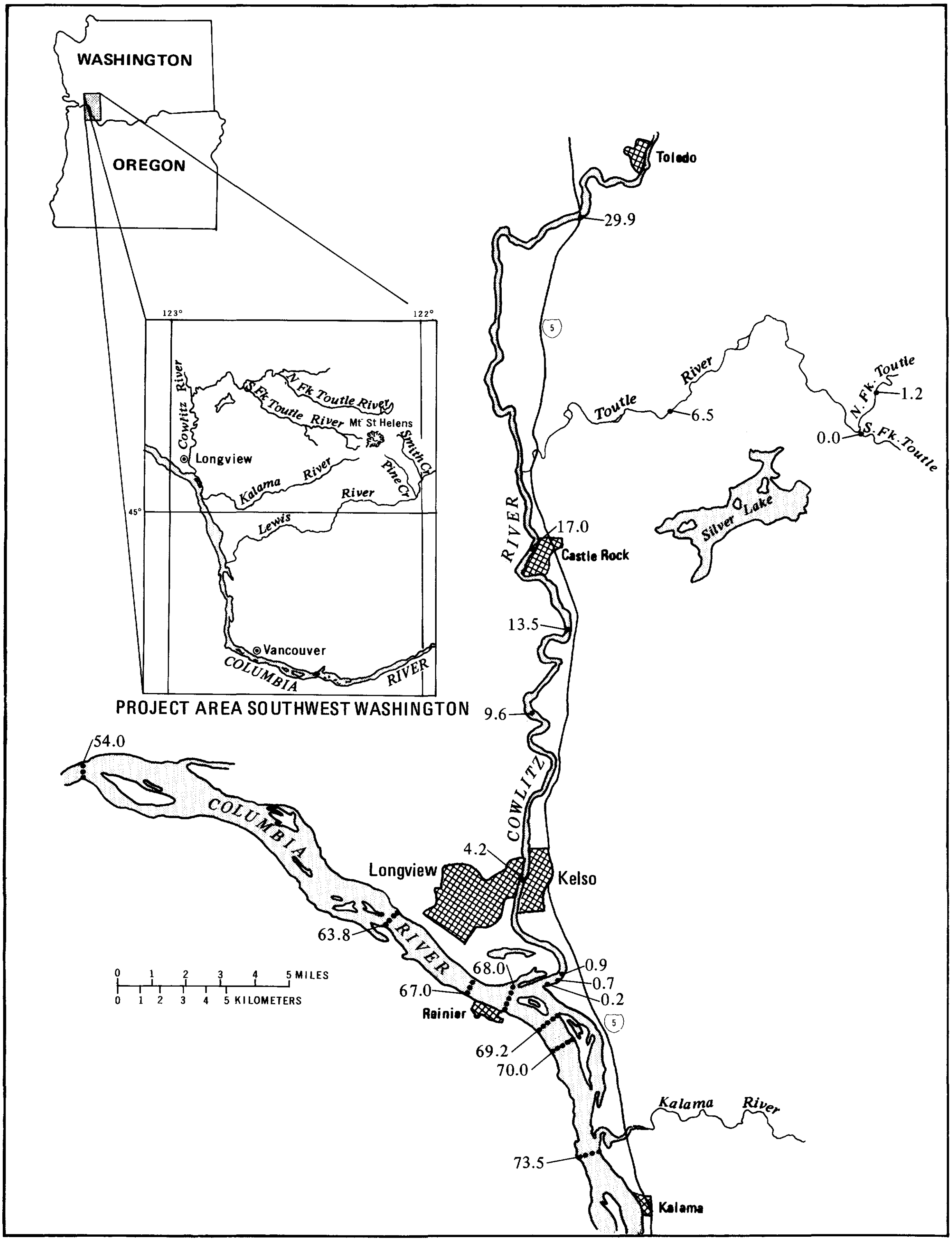

FIGURE 1.–Columbia, Cowlitz, and Toutle Rivers. Leaders indicate location of sampling sites in river miles from mouth.

FIGURE 2.—Northeast view of confluence of the Cowlitz and Columbia Rivers. The Cowlitz River enters from the upper left. Seaward flow in the Columbia River is from right to left.

Cowlitz River, and new deposits were readily measured in a reach 7 mi landward and 2 mi seaward from the confluence (Bechly, 1980; Haeni, 1981).

In addition to the immediate devastation along the Cowlitz River and disruption of navigation in the Columbia River caused by flooding and sediment deposition, serious long-term problems now exist in the lower reaches of the Cowlitz River and in the Columbia river and its estuary from drastic alteration of the sedimentation regimen. Because of (1) increased erosion from extensive areas in the Toutle and Green River drainage basins covered by ash or by unconsolidated and (or) unvegetated surface material, (2) increased bank erosion along the channels, and (3) progressive streambed degradation, sediment loads may be substantially greater than they were in the past. The increased loads present the potential for increased deposition in the lower Cowlitz and Columbia Rivers. Hence, channel maintenance to reduce flood hazards and sustain navigation very likely will require increased dredging. Additional major mudflows would substantially compound this problem.

Deleterious consequences in the Columbia River estuary are less obvious, but potentially serious. Mass-balance computations based on radioactivity indicate that prior to the eruption, approximately 30 percent of the sediment finer than 0.062 mm (clays and silts) delivered to the estuary became permanently deposited there (Hubbell and Glenn, 1973). Also, current and bottom-sediment transport patterns suggest that little, if any, sand or coarser sediment leaves the estuary, except possibly during extreme upland-flow or storm events (Hubbell and others, 1971). Continual deposition of unusually large quantities of sediment in the estuary for some time in the future not only will increase the normal dredging burden, but also may have important physical, ecological, and esthetic consequences from significant changes in water clarity and in depositional patterns in nondredged areas.

Because of the variety of potential problems associated with changes in the sedimentation regimen, the magnitude of anticipated changes must be forecast as accurately as possible. Engineering calculations of the competence of the rivers to entrain and transport sediment and of the effectiveness of control measures to perform their design functions, as well as other types of calculations, can be made accurately only if up-to-date information is available on the character of the sediment and its disposition in the rivers. To provide such information, the Oregon District of the Water Resources Division, U.S. Geological Survey, cooperated with the U.S. Army Corps of Engineers, Portland District, in a study of the physical characteristics of sediment deposited in the lower Cowlitz and Columbia Rivers as a result of the Mount St. Helens eruption. The primary intent of the investigation was to ascertain to what extent, if any, the "new" sediment differed from normal Columbia River sediments. In addition, the spatial distribution of suspended sediment in the Columbia River was observed at several locations to ascertain any trends that might exist.

This report presents hydrologic data collected for the investigation and discusses the findings. The information pertains mainly to the particle-size distribution, shape factor, and specific gravity of bottom sediments, although some information is given on the disposition of suspended sediment; the results are based on limited data that were collected over a very short span of time.

ACKNOWLEDGMENTS

Field measurements and samplings for this investigation were made by Oregon District personnel, U.S. Geological Survey. Oregon District personnel also determined the concentration and particle-size distribution of suspended-sediment samples from all locations, except one on the Cowlitz River. Washington District personnel furnished sediment-discharge data for Cowlitz River mile 17.0 and water discharges for the Cowlitz and Toutle Rivers. Particle-size analyses of bed material by sieving were made by the Materials Laboratory, U.S. Army Corps of Engineers, North Pacific Division. Oregon District personnel analyzed the particle size of bed material by the visual-accumulation-tube method, and they determined specific gravities. The writers gratefully acknowledge the contributions of all involved groups and individuals, who worked under a demanding time schedule.

DATA COLLECTION

SUSPENDED SEDIMENT

From August 11 to August 20, 1980, suspended sediment was sampled intermittently at locations in the Columbia River in the vicinity of Longview, Wash. The purpose of sampling was to determine the particle-size distribution, concentration, discharge, and spatial distribution of suspended sediment at locations upstream and downstream from the mouth of the Cowlitz River, after a moderate period of restabilization. In addition, some suspended-sediment samples were obtained in the Cowlitz River and in the two forks and main stem of the Toutle River, to define suspended-sediment discharges during the investigative period.

Depth-integrated suspended-sediment samples were collected on several occasions from cross sections at Columbia River miles (CRM) 73.5, 63.8, and 54.0, and at Cowlitz River mile 0.2; one cross-section measurement also was made at Cowlitz River mile 4.2. Except for the measurements made on August 19 and 20, 1980, all sampling in the Columbia was done at five verticals in the cross section by the equal-discharge-increments (EDI) method (Office of Water Data Coordination, 1978) using a U.S. D–77 sampler modified to operate isokinetically as a collapsible-bag sampler (Stevens and others, 1980). Near-equal-volume samples of about 2 L (liters) of water-sediment mixture were obtained at each vertical and were composited for analysis. On August 19 and 20, samples also were collected at five verticals by the EDI method, but a U.S. P–61 suspended-sediment sampler, rather than a D–77 collapsible-bag sampler, was used. Sampling at each vertical was by one-way integration over the full depth. To provide representative samples, individual samples (bottles) were obtained from depth segments not exceeding 30 ft, until the entire depth was sampled. In this process, the

TABLE 1.—*Suspended-sediment discharge measurement data for locations along the Columbia, Cowlitz, and Toutle Rivers*

[Due to rounding procedures, the sum of sediment discharges greater than and less than 62 μm may not equal the total measured suspended-sediment discharge]

River mile	Date (1980)	Time (P.d.t., 2400 hours)	Daily mean discharge (ft³/s)	Concentration (mg/L)			Measured suspended sediment discharge (t/d)		
				< 62 μm	> 62 μm	Total	< 62 μm	> 62 μm	Total
Columbia River									
73.5	Aug. 12	0900	139,000	11	2	13	4,130	750	4,880
73.5	do	1025	139,000	8	4	[1]12	3,000	1,500	4,500
73.5	Aug. 14	1400	140,000	20	3	23	7,560	1,130	8,690
73.5	Aug. 18	1200	124,000	9	1	10	3,010	330	3,350
73.5	do	1205	124,000	12	3	[1]15	4,000	1,000	5,000
73.5	Aug. 20	1330	149,000	12	2	14	4,830	800	5,630
73.5	do	1330	149,000	13	3	[1]16	5,200	1,200	6,400
63.8	Aug. 13	1430	142,000	70	12	82	26,800	4,600	31,400
63.8	do	1535	142,000	59	1	[1]60	22,600	400	23,000
63.8	Aug. 14	1000	143,000	48	7	55	18,500	2,700	21,200
63.8	Aug. 18	1530	127,000	86	7	93	29,500	2,400	31,900
63.8	Aug. 20	1030	152,000	29	13	[1]42	11,900	5,300	17,200
63.8	do	1030	152,000	34	2	36	14,000	820	14,800
54.0	Aug. 13	1130	142,000	60	5	65	23,000	1,920	24,900
54.0	do	1150	142,000	55	15	[1]70	21,100	5,700	26,800
54.0	Aug. 18	1030	130,000	29	1	[1]30	10,200	400	10,500
54.0	do	1030	130,000	42	1	43	14,700	350	15,100
54.0	do	1328	130,000	46	4	[1]50	16,100	1,400	17,600
54.0	do	1330	130,000	55	2	57	19,300	700	20,000
Cowlitz River									
.2	Aug. 12	1300	3,000	609	0	609	4,930	0	4,930
.2	Aug. 18	1345	2,500	601	0	601	4,060	0	4,060
.2	Aug. 20	1140	2,700	1,070	0	1,070	7,800	0	7,800
4.2	Aug. 11	1000	3,000	400	600	1,000	3,240	4,860	8,100
17.0	Aug. 11	1230	2,960	-----	-----	1,140	-----	-----	9,110
17.0	Aug. 12	0705	2,960	-----	-----	[2]1,100	-----	-----	8,790
17.0	Aug. 13	0705	2,970	-----	-----	[2]1,600	-----	-----	12,800
17.0	Aug. 14	0710	2,940	-----	-----	[2]1,400	-----	-----	11,100
17.0	Aug. 18	0705	2,540	-----	-----	[2]1,400	-----	-----	9,600
17.0	Aug. 19	0705	2,520	-----	-----	[2]1,400	-----	-----	9,500
17.0	Aug. 20	0705	2,680	-----	-----	[2]1,500	-----	-----	10,900
Toutle River									
6.5	Aug. 11	----	264	3,650	2,650	6,300	2,600	1,890	4,490
North Fork Toutle River									
1.2	Aug. 11	----	160	190	930	1,120	80	400	480
South Fork Toutle River									
.0	Aug. 11	----	104	8,350	3,250	11,600	2,340	910	3,260
.0	Aug. 13	----	103	-----	-----	12,700	-----	-----	3,530

[1] Estimated from point-integrated samples listed in table 3.

[2] Estimated from single vertical concentration furnished by the Washington District, U.S. Geological Survey, Water Resources Division.

sampler was traversed vertically at a selected constant rate that provided a volume of water-sediment mixture from the entire vertical, which was about equal to the volume from each of the other verticals; the near-equal volumes from each vertical were composited for analysis.

Depth-integrated suspended-sediment samples from the Cowlitz River were collected at seven verticals spaced according to the equal-width-increments (EWI) method (Office of Water Data Coordination, 1978) using a U.S. P-61 sampler; the quart-size samples were composited for analysis. Toutle River samples were obtained by wading and using a U.S. DH-48 depth-integrating hand sampler. Because of streambed instability, some measurement sections on the Cowlitz and Toutle Rivers could not be waded and sampled across their full widths. Despite this difficulty, the sampling was considered to be in accordance with the EWI method at all sections, and samples were

TABLE 2. – *Particle-size distribution of depth-integrated suspended-sediment samples from the Columbia, Cowlitz, and Toutle Rivers*

[Method of analysis: S, sieve; VA, visual-accumulation tube; P, pipette]

Date (1980)	Time (P.d.t., 2400 hours)	Daily mean discharge (ft^3/s)	Sediment concentration (mg/L)	Percent finer than indicated size, in micrometers													Method of analysis
				2	4	8	16	31	62	88	125	175	250	350	500	1,000	
Columbia River mile 73.5																	
Aug. 12	0900	139,000	13	--	--	--	--	--	86	--	--	--	--	--	--	--	S
Aug. 14	1400	140,000	23	--	--	--	--	--	86	--	--	--	--	--	--	--	S
Aug. 18	1200	124,000	10	--	--	--	--	--	88	--	--	--	--	--	--	--	S
Aug. 20	1330	149,000	14	--	--	--	--	--	87	--	--	--	--	--	--	--	S
Columbia River mile 63.8																	
Aug. 13	1430	142,000	82	--	--	--	--	--	85	--	--	--	--	--	--	--	S
Aug. 14	1000	143,000	55	--	--	--	--	--	88	--	--	--	--	--			S
Aug. 18	1530	127,000	93	--	--	--	--	--	93	--	--	--	--	--	--	--	S
Aug. 20	1030	152,000	36	--	--	--	--	--	94	--	--	--	--	--	--	--	S
Columbia River mile 54.0																	
Aug. 13	1130	142,000	65	--	--	--	--	--	92	--	--	--	--	--	--	--	S
Aug. 18	1030	130,000	43	--	--	--	--	--	98	--	--	--	--	--	--	--	S
	1330	130,000	57	--	--	--	--	--	96	--	--	--	--	--	--	--	S
Cowlitz River mile 0.2																	
Aug. 12	1300	3,000	609	21	30	64	87	95	100	--	--	--	--	--	--	--	P
Aug. 18	1345	2,500	601	28	40	66	87	96	100	--	--	--	--	--	--	--	P
Aug. 20	1140	2,700	1,070	32	46	71	86	92	100	--	--	--	--	--	--	--	P
Cowlitz River mile 4.2																	
Aug. 11	1000	3,000	1,000	9	15	20	24	27	40	41	44	50	70	86	94	100	VA, P
Toutle River mile 6.5																	
Aug. 11	----	264	6,300	5	11	16	27	40	58	67	75	80	83	87	92	100	VA, P
North Fork Toutle River mile 1.2																	
Aug. 11	----	160	1,120	2	2	4	7	11	17	21	31	41	55	69	79	97	VA, P
South Fork Toutle River mile 0.0																	
Aug. 11	----	104	11,600	5	10	17	31	48	72	82	89	93	96	98	99	100	VA, P

composited for a single analysis at each section and time.

Suspended-sediment discharge-measurement data for the various cross sections and times of sampling are listed in table 1. Sediment in low-concentration samples was divided by sieving into portions finer than 62 μm (micrometers) and equal-to or coarser-than 62 μm, to permit the discharge of silt plus clay to be determined separately from the discharge of sand. Complete size analyses were made of samples from the Cowlitz and Toutle Rivers that contained an adequate amount of sediment. Particle-size distributions defined by the analyses are given in table 2.

Point-integrated suspended-sediment samples were obtained in the Columbia River at CRM 73.5 and 54.0 at three different times, and at CRM 63.8 on two occasions. For each measurement, duplicate quart samples were collected with a U.S. P-61 sampler, generally from five points in the depth, at a single vertical in midstream. Because of relatively low concentrations, only percentages, by weight, of sediment finer than 62 μm (by sieving) could be accurately defined. These values, with other pertinent information, are shown in table 3.

BED MATERIAL

Samples of bed material (bottom sediment) were collected at six cross sections in the Columbia River and at nine locations along the Cowlitz and Toutle Rivers. Except for samples collected from the Interstate Highway 5 bridge at Vancouver, Wash. (CRM 106.4), on September 17, 1980, all Columbia River sampling was done on August 12 and 13, 1980. Sampling on the Cowlitz and Toutle Rivers was done on August 11, 1980. The primary purposes for examining bed material in the Columbia River were to determine the particle-size distribution of bottom sediments in the reach

TABLE 3.—*Particle-size distribution of point-integrated suspended-sediment samples from the Columbia River*

Date (1980)	Time (P.d.t., 2400 hours)	Daily mean discharge (ft^3/s)	Total depth (ft)	Height above bed (ft)	Sediment concentration (mg/L)	Percent < 62 μm
		River mile 73.5				
Aug. 12	1015	139,000	65	1	14	70
	1020	139,000	65	15	14	63
	1025	139,000	65	25	12	81
	1030	139,000	65	47	11	81
	1035	139,000	65	60	13	61
Aug. 18	1203	124,000	40	1	10	81
	1205	124,000	40	4	25	87
	1207	124,000	40	12	--	--
	1209	124,000	40	24	16	76
	1210	124,000	40	35	9	78
Aug. 20	1330	149,000	45	1	54	32
	1330	149,000	45	5	27	82
	1330	149,000	45	15	16	78
	1330	149,000	45	28	12	87
	1330	149,000	45	40	12	78
		River mile 63.8				
Aug. 13	1525	142,000	36	1	70	92
	1535	142,000	36	4	66	88
	1545	142,000	36	11	75	88
Aug. 20	1025	152,000	45	1	57	71
	1027	152,000	45	5	58	61
	1029	152,000	45	10	42	67
	1030	152,000	45	29	41	72
	1032	152,000	45	40	40	76
		River mile 54.0				
Aug. 13	1140	142,000	60	1	64	82
	1145	142,000	60	5	91	76
	1150	142,000	60	20	74	78
	1152	142,000	60	42	59	75
	1155	142,000	60	55	79	78
Aug. 18	1023	130,000	57	1	53	96
	1026	130,000	57	4	36	96
	1028	130,000	57	19	39	94
	1030	130,000	57	40	28	95
	1032	130,000	57	52	20	93
Aug. 18	1328	130,000	61	1	72	92
	1328	130,000	61	6	57	92
	1328	130,000	61	21	55	94
	1328	130,000	61	43	44	96
	1328	130,000	61	56	41	94

where sediment derived from the Mount St. Helens eruption was initially deposited and to learn if the shapes of particles that presently (August 12–20, 1980) make up the bed material in this reach are substantially different from the shapes of normal Columbia River sediments as characterized by bed material at Vancouver. Cowlitz and Toutle River samples were obtained and analyzed to define the size distributions and shapes of bed-material particles that could be transported to the Columbia.

Samples from the Columbia River were collected at CRM 106.4, 73.5, 70.0, 69.2, 67.0, and 63.8 with a U.S. BM–54 sampler. Five or more samples, generally spaced an equidistance apart across the full width, were obtained from each cross section. A midstream sample from river mile 0.9 on the Cowlitz River also was collected with the U.S. BM–54 sampler. At the other locations on the Cowlitz and Toutle Rivers, samples were collected with scoop-type samplers; because of physical conditions, sampling was limited to the parts of the cross sections that were accessible by wading. Although the sampling on the Cowlitz and Toutle Rivers probably was not completely representative of the entire cross section, samples generally were satisfactory for the purposes of the study.

Many of the bed-material samples collected from the Columbia River near the mouth of the Cowlitz River (CRM 68.0) had unusual characteristics. On the basis of sieve separations, roughly 21 percent, by weight, of sample material collected from the north (Washington side) two-thirds of the channel at CRM 73.5, 70.0, and 69.2 consisted of particles coarser than 2.0 mm (2,000 μm), whereas only about 7 percent of the material from the south one-third of the channel was of that size. A typical sample having particles coarser than 2.0 mm consisted of well-sorted material between 0.125 and 2.0 mm and various heterogeneously sized larger particles. Samples having a high percentage of particles coarser than 2.0 mm invariably had several very large pumice particles up to about 25 mm in diameter. At CRM 73.5, virtually all particles coarser than 2.0 mm were visually observed to be pumice. At CRM 70.0 and 69.2, roughly one-fourth of the coarser material was pumice; the remainder was fairly angular rock fragments. During sampling at several of the cross sections, pumice was observed to be floating on or near the surface.

Material collected from the lower Cowlitz River contained fine, clay-size particles. Unlike clay, however, the fine material exhibited little or no cohesion. Typically, in the lower Cowlitz, exposed sandbars were capped with a ½-in layer of this fine material (fig. 3).

To facilitate determinations of the shape factor and specific gravity of bed-material particles and to permit more representative comparisons of the particle-size distributions of pre- and post-eruption bed material, detailed size analyses were made only of the material finer, by sieving, than 2.0 mm. Elimination of the coarse material effectively excluded most of the pumice and all the large particles (erratics) from the analyses. In addition to practical reasons, this procedure seemed warranted, because the distribution of visually discernible pumice and other large particles is random and local; and the present (August 1980)

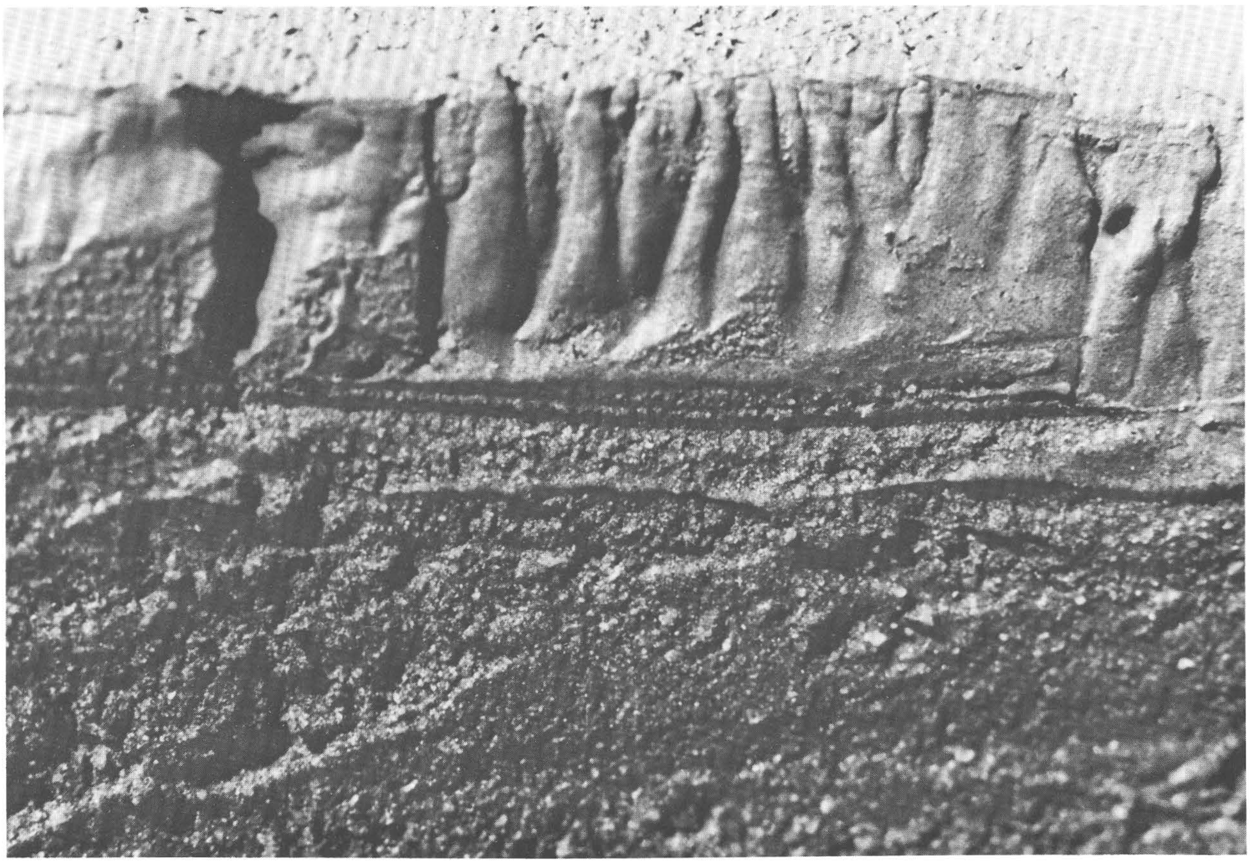

FIGURE 3.—Section of typical exposed sandbar in the lower Cowlitz River. Fine-grained surface layer is about 0.5 in thick.

disposition of pumice is a temporary condition due to its extreme mobility and susceptibility to fracturing.

Particle-size distributions of all bed-material samples are given in table 4. *The size distributions are expressed in terms of 100 percent finer than 2.0 mm even though physically larger particles may have been present in the sample.* The percentage, P, of the total sample represented by the tabulated size distribution is listed in the third column of table 4. To convert the listed percent finer values to represent the whole original sample, multiply each value by the fraction, P/100.

The portion of each sample finer than 2.0 mm was analyzed by two different methods–the visual-accumulation tube (VA) method (Guy, 1969) and sieving (S). VA analysis expresses the size distribution in terms of fall diameters; the distribution indicates the percentage of particles, by weight, that have fall diameters less than the indicated diameter (size). The fall diameter of a particle is defined as the diameter of a sphere that has a specific gravity of 2.65 and the same standard fall velocity as the particle. The standard fall velocity of a particle is the average rate of fall that the particle would finally attain, if falling alone in quiescent distilled water of infinite extent, at a temperature of 24°C (degrees Celsius) (Inter-Agency Committee on Water Resources, 1957). The fall diameter of a particle depends on the size, three-dimensional shape, and density of the particle. Sieve analysis expresses the size distribution in terms of a linear dimension; the distribution indicates the percentage of particles, by weight, that can be oriented so they will pass through a square opening having a side dimension equal to the indicated diameter size. The sieve diameter of a particle depends only on the size and cross-sectional shape of the particle. Because sizing is based on different criteria, particle-size distributions defined by the two methods generally are different. The purpose for the dual analyses is discussed in the section on shape factor and specific gravity of post-eruption bed material. For a few samples, sizes finer than 62 μm were determined by the pipette method (Guy, 1969). This method also gives sizes in terms of fall diameters.

TABLE 4.–*Particle-size distribution of surficial bed material finer than 2 mm from the Columbia, Cowlitz, and Toutle Rivers*

[Method of analysis: VA, visual-accumulation tube; P, pipette; S, sieve]

Date (1980)	Lateral position[1]	Percent of total sample	Percent finer than indicated size, in micrometers																			Method of analysis
			2	4	8	16	31	62	74	88	125	149	175	250	297	350	500	590	1000	1190	2000	
Columbia River mile 106.4																						
Sept. 17 --	10	99	--	--	--	--	--	1	--	1	1	--	8	27	--	64	87	--	98	--	100	VA
			--	--	--	--	--	--	0	--	--	6	--	--	32	--	--	91	--	98	100	S
	30	100	--	--	--	--	--	--	--	--	0	--	1	20	--	64	81	--	99	--	100	VA
			--	--	--	--	--	--	--	--	--	0	--	--	19	--	--	82	--	97	100	S
	50	100	--	--	--	--	--	--	--	--	--	--	0	3	--	28	56	--	98	--	100	VA
			--	--	--	--	--	--	--	--	--	0	--	--	9	--	--	62	--	94	100	S
	70	100	--	--	--	--	--	--	--	--	0	--	2	11	--	33	68	--	99	--	100	VA
			--	--	--	--	--	--	0	--	--	2	--	--	18	--	--	71	--	98	100	S
	90	100	--	--	--	--	--	--	--	--	0	--	2	12	--	34	54	--	98	--	100	VA
			--	--	--	--	--	--	0	--	--	3	--	--	30	--	--	60	--	85	100	S
Columbia River mile 73.5																						
Aug. 12 --	5	100	--	--	--	--	--	--	--	--	0	--	2	56	--	95	99	--	100	--	--	VA
			--	--	--	--	--	--	--	--	0	1	--	--	52	--	--	100	--	--	--	S
	20	85	--	--	--	--	--	26	--	35	54	--	71	86	--	97	100	--	--	--	--	VA
			--	--	--	--	--	9	18	--	--	62	--	--	91	--	--	95	--	99	100	S
	30–35	100	--	--	--	--	--	0	--	1	2	--	22	77	--	96	99	--	100	--	--	VA
			--	--	--	--	--	--	0	--	--	4	--	--	56	--	--	99	--	100	--	S
	40	100	4	6	14	29	53	56	--	56	57	--	61	82	--	97	99	--	100	--	--	VA, P
			--	--	--	--	--	44	44	--	--	46	--	--	86	--	--	99	--	100	--	S
	45	99	--	--	--	--	--	--	--	--	--	--	0	2	--	18	60	--	100	--	--	VA
			--	--	--	--	--	--	--	0	--	1	--	--	26	--	--	63	--	98	100	S
	50	100	--	--	--	--	--	--	--	--	0	--	5	53	--	94	97	--	98	--	100	VA
			--	--	--	--	--	--	0	--	--	2	--	--	60	--	--	100	--	--	--	S
	70	87	--	--	--	--	--	--	--	--	0	--	2	21	--	59	77	--	99	--	100	VA
			--	--	--	--	--	--	0	--	--	1	--	--	42	--	--	83	--	99	100	S
	85	59	--	--	--	--	--	1	--	1	1	--	1	22	--	68	94	--	100	--	--	VA
			--	--	--	--	--	1	1	--	--	2	--	--	23	--	--	54	--	80	100	S
	95	78	--	--	--	--	--	1	--	1	1	--	6	38	--	71	85	--	97	--	100	VA
			--	--	--	--	--	--	0	--	--	5	--	--	60	--	--	86	--	98	100	S

TABLE 4.—*Particle-size distribution of surficial bed material finer than 2 mm from the Columbia, Cowlitz, and Toutle Rivers*—Continued

[Method of analysis: VA, visual-accumulation tube; P, pipette; S, sieve]

Date (1980)	Lateral position[1]	Percent of total sample	Percent finer than indicated size, in micrometers																			Method of analysis
			2	4	8	16	31	62	74	88	125	149	175	250	297	350	500	590	1000	1190	2000	
Columbia River mile 70.0																						
Aug. 12	5	92	--	--	--	--	--	1	--	1	1	--	5	24	--	69	85	--	95	--	100	VA
			--	--	--	--	--	--	0	--	--	2	--	--	28	--	--	83	--	96	100	S
	10	94	--	--	--	--	--	--	--	--	0	--	1	8	--	30	56	--	94	--	100	VA
			--	--	--	--	--	--	0	--	--	1	--	--	9	--	--	62	--	95	100	S
	20	95	--	--	--	--	--	--	--	--	--	--	0	1	--	14	44	--	96	--	100	VA
			--	--	--	--	--	--	0	--	--	1	--	--	10	--	--	54	--	91	100	S
	35	64	--	--	--	--	--	--	--	--	0	--	2	16	--	31	45	--	92	--	100	VA
			--	--	--	--	--	0	1	--	--	4	--	--	34	--	--	58	--	84	100	S
	50	83	--	--	--	--	--	--	--	--	0	--	2	9	--	24	43	--	88	--	100	VA
			--	--	--	--	--	--	0	--	--	2	--	--	18	--	--	51	--	81	100	S
	75	59	--	--	--	--	--	--	--	--	--	--	0	4	--	20	33	--	84	--	100	VA
			--	--	--	--	--	1	1	--	--	1	--	--	8	--	--	37	--	70	100	S
Columbia River mile 69.2																						
Aug. 12	5	98	--	--	--	--	--	--	--	--	--	--	0	7	--	37	69	--	97	--	100	VA
			--	--	--	--	--	--	0	--	--	1	--	--	14	--	--	76	--	97	100	S
	15	82	--	--	--	--	--	--	--	--	--	--	0	2	--	12	29	--	54	--	100	VA
			--	--	--	--	--	--	0	--	--	1	--	--	15	--	--	59	--	87	100	S
	25	90	--	--	--	--	--	1	--	1	1	--	2	5	--	21	41	--	92	--	100	VA
			--	--	--	--	--	1	1	--	--	3	--	--	17	--	--	65	--	92	100	S
	45	50	--	--	--	--	--	--	--	--	0	--	3	9	--	19	34	--	91	--	100	VA
			--	--	--	--	--	--	0	--	--	2	--	--	14	--	--	37	--	74	100	S
	55	96	--	--	--	--	--	--	--	--	0	--	1	2	--	8	25	--	93	--	100	VA
			--	--	--	--	--	--	0	--	--	1	--	--	4	--	--	29	--	87	100	S
	65	63	--	--	--	--	--	--	--	--	0	--	3	10	--	22	42	--	88	--	100	VA
			--	--	--	--	--	--	0	--	--	1	--	--	12	--	--	40	--	74	100	S
	75	77	--	--	--	--	--	--	--	--	0	--	1	13	--	45	63	--	94	--	100	VA
			--	--	--	--	--	--	0	--	--	1	--	--	17	--	--	63	--	86	100	S
	95	72	--	--	--	--	--	--	--	--	--	--	0	3	--	14	32	--	93	--	100	VA
			--	--	--	--	--	--	0	--	--	1	--	--	7	--	--	35	--	78	100	S
	95	91	--	--	--	--	--	--	--	--	--	--	--	0	--	4	16	--	93	--	100	VA
			--	--	--	--	--	--	--	--	--	0	--	--	3	--	--	30	--	80	100	S
Columbia River mile 67.0																						
Aug. 12	5	100	3	3	6	11	19	50	--	72	88	--	97	98	--	98	98	--	99	--	100	VA, P
			--	--	--	--	--	36	44	--	--	99	--	--	99	--	--	100	--	--	--	S
	10	97	--	--	--	--	--	--	--	0	1	--	8	22	--	52	77	--	98	--	100	VA
			--	--	--	--	--	0	1	--	--	4	--	--	20	--	--	66	--	93	100	S
	20	99	--	--	--	--	--	--	--	0	1	--	9	47	--	74	91	--	97	--	100	VA
			--	--	--	--	--	--	0	--	--	6	--	--	70	--	--	93	--	99	100	S
	30–50	100	--	--	--	--	--	--	--	0	1	--	13	52	--	90	98	--	100	--	--	VA
			--	--	--	--	--	--	0	--	--	10	--	--	82	--	--	100	--	--	--	S
	60–80	100	--	--	--	--	--	--	--	0	1	--	8	52	--	94	98	--	100	--	--	VA
			--	--	--	--	--	--	0	--	--	3	--	--	50	--	--	100	--	--	--	S
	90	95	--	--	--	--	--	1	--	1	3	--	13	58	--	91	98	--	99	--	100	VA
			--	--	--	--	--	1	2	--	--	14	--	--	92	--	--	98	--	99	100	S
	95	100	--	--	--	--	--	77	--	92	96	--	96	98	--	100	--	--	--	--	--	VA
			--	--	--	--	--	91	95	--	--	99	--	--	100	--	--	--	--	--	--	S
	95	93	--	--	--	--	--	10	--	16	24	--	46	87	--	97	99	--	100	--	--	VA
			--	--	--	--	--	9	13	--	--	34	--	--	91	--	--	98	--	99	100	S
	95	100	4	4	8	20	43	79	--	88	95	--	98	99	--	100	--	--	--	--	--	VA, P
			--	--	--	--	--	77	84	--	--	95	--	--	100	--	--	--	--	--	--	S
Columbia River mile 63.8																						
Aug. 13	10	--	--	--	--	--	--	4	--	20	70	--	92	96	--	--	--	--	100	--	--	VA
			--	--	--	--	--	6	11	--	--	86	--	--	99	--	--	100	--	--	--	S
	20	96	--	--	--	--	--	--	--	0	8	--	24	37	--	53	69	--	94	--	100	VA
			--	--	--	--	--	7	7	--	--	21	--	--	44	--	--	74	--	97	100	S
	30	100	--	--	--	--	--	--	--	0	4	--	15	42	--	80	92	--	99	--	100	VA
			--	--	--	--	--	0	1	--	--	12	--	--	58	--	--	94	--	100	--	S
	40	100	--	--	--	--	--	1	--	2	11	--	20	25	--	43	81	--	99	--	100	VA
			--	--	--	--	--	2	3	--	--	19	--	--	31	--	--	72	--	98	100	S
	50	98	3	5	8	11	14	16	--	19	37	--	57	62	--	74	91	--	100	--	--	VA, P
	60	58	1	1	2	3	4	5	--	9	30	--	48	54	--	65	76	--	95	--	100	VA, P
	80	98	--	--	--	--	--	--	--	0	4	--	14	18	--	33	56	--	82	--	100	VA
			--	--	--	--	--	--	0	--	--	5	--	--	17	--	--	70	--	96	100	S
	90	100	5	6	16	52	77	97	--	99	100	--	--	--	--	--	--	--	--	--	--	VA, P
			--	--	--	--	--	94	97	--	--	99	--	--	100	--	--	--	--	--	--	S

TABLE 4.—*Particle-size distribution of surficial bed material finer than 2 mm from the Columbia, Cowlitz, and Toutle Rivers*—Continued

[Method of analysis: VA, visual-accumulation tube; P, pipette; S, sieve]

Date (1980)	Lateral position[1]	Percent of total sample	Percent finer than indicated size, in micrometers																			Method of analysis
			2	4	8	16	31	62	74	88	125	149	175	250	297	350	500	590	1000	1190	2000	
Cowlitz River mile 0.7																						
Aug. 12 --	5	100	6	8	8	18	89	100	--	--	--	--	--	--	--	--	--	--	--	--	--	P
			--	--	--	--	--	99	99	--	--	100	--	--	--	--	--	--	--	--	--	S
	50	100	6	9	23	63	97	100	--	--	--	--	--	--	--	--	--	--	--	--	--	P
			--	--	--	--	--	99	99	--	--	99	--	--	100	--	--	--	--	--	--	S
	90	--	--	--	--	--	--	99	99	--	--	100	--	--	--	--	--	--	--	--	--	S
Cowlitz River mile 0.9																						
Aug. 11 --	50	100	1	2	4	14	31	65	--	87	97	--	99	100	--	--	--	--	--	--	--	VA, P
			--	--	--	--	--	39	53	--	--	97	--	--	100	--	--	--	--	--	--	S
Cowlitz River mile 4.2																						
Aug. 11 --	15	99	--	--	--	--	--	9	--	16	37	--	57	92	--	98	99	--	100	--	--	VA
			--	--	--	--	--	8	11	--	--	42	--	--	96	--	--	99	--	100	--	S
	20	89	0	1	2	3	4	5	--	5	6	--	9	27	--	49	62	--	95	--	100	VA, P
			--	--	--	--	--	15	16	--	--	23	--	--	46	--	--	78	--	94	100	S
	60	92	--	--	--	--	--	1	--	1	2	--	5	14	--	29	49	--	97	--	100	VA
			--	--	--	--	--	1	1	--	--	7	--	--	26	--	--	56	--	89	100	S
Cowlitz River mile 9.6																						
Aug. 11 --	30	99	--	--	--	--	--	2	--	4	19	--	51	74	--	90	97	--	100	--	--	VA
			--	--	--	--	--	8	41	--	--	41	--	--	83	--	--	96	--	100	--	S
	70	99	--	0	2	3	6	16	--	18	35	--	70	89	--	96	98	--	100	--	--	VA, P
			--	--	--	--	--	4	5	--	--	24	--	--	88	--	--	98	--	99	100	S
Cowlitz River mile 13.5																						
Aug. 11 --	99	97	--	--	--	0	1	4	--	6	14	--	48	78	--	82	87	--	96	--	100	VA, P
	99	98	--	--	0	1	2	3	--	3	10	--	46	88	--	95	97	--	99	--	100	VA, P
			--	--	--	--	--	1	1	--	--	15	--	--	90	--	--	97	--	99	100	S
Cowlitz River mile 29.9																						
Aug. 11 --	1	95	--	--	--	--	--	2	--	2	8	--	18	48	--	90	100	--	--	--	--	VA
			--	--	--	--	--	2	3	--	--	16	--	--	65	--	--	100	--	--	--	S
Toutle River mile 6.5																						
Aug. 11 --	33	83	--	--	--	--	--	--	--	--	0	--	6	21	--	57	72	--	94	--	100	VA
			--	--	--	--	--	0	1	--	--	4	--	--	27	--	--	62	--	88	100	S
	67	96	--	--	--	--	--	--	--	0	1	--	3	18	--	40	70	--	95	--	100	VA
			--	--	--	--	--	1	1	--	--	6	--	--	34	--	--	64	--	89	100	S
North Fork Toutle River mile 1.2																						
Aug. 11 --	16	95	--	--	--	--	--	--	--	--	--	--	0	2	--	11	28	--	94	--	100	VA
			--	--	--	--	--	1	1	--	--	2	--	--	8	--	--	36	--	84	100	S
	50	78	--	--	--	--	--	--	--	--	--	--	0	1	--	11	32	--	88	--	100	VA
			--	--	--	--	--	1	1	--	--	2	--	--	12	--	--	51	--	81	100	S
South Fork Toutle River mile 0.0																						
Aug. 11 --	1	63	3	6	12	16	22	30	--	35	41	--	48	56	--	66	75	--	98	--	100	VA, P
			--	--	--	--	--	2	7	--	--	23	--	--	45	--	--	69	--	89	100	S
	5	80	--	--	0	1	2	8	--	15	28	--	38	50	--	58	63	--	96	--	100	VA, P
			--	--	--	--	--	5	8	--	--	23	--	--	47	--	--	67	--	90	100	S
	5	98	--	--	--	--	--	2	--	7	13	--	20	45	--	75	90	--	95	--	100	VA
			--	--	--	--	--	1	3	--	--	15	--	--	58	--	--	92	--	98	100	S

[1] Relative distance from left bank (looking downstream), expressed as percentage of full width.

DATA ANALYSIS

LONGITUDINAL DISTRIBUTION OF SUSPENDED-SEDIMENT TRANSPORT RATES

Suspended-sediment discharge data presented in table 1 have been arranged in table 5 to facilitate comparisons of suspended-sediment discharges of material coarser and finer than 62 μm at various locations in the reach between CRM 73.5 and 54.0. Although the data are sparse and partly estimated, several general conclusions can be made about the disposition of suspended sediment in the Columbia River. All suspended-sediment data suggest that, during the data-collection period, sediment was scoured from the streambed immediately downstream from the mouth of the Cowlitz River (CRM 68.0). It is not possible to determine from the data how far downstream the degradation occurred; however, a significant amount of sediment was scoured from the reach between CRM 68.0 and 63.8, as evidenced by the consistently higher suspended-sediment discharges, on all days, at CRM 63.8 than at CRM 68.0 (table 5). Conversely, the general decrease in suspended-sediment discharges from CRM 63.8 downstream to CRM 54.0 during the same period suggests that suspended matter was being deposited in that reach (table 5). Because the decrease in suspended-sediment discharge between CRM 63.8 and 54.0 is roughly half the increase between CRM 68.0 and 63.8, apparently the Columbia is capable of transporting the suspended sediment presently being discharged by the Cowlitz River, but it cannot sustain the seaward transport of the additional burden of the total amount of sediment scoured upstream from CRM 63.8. Although the Columbia River is capable of transporting all the suspended sediment now being supplied by the Cowlitz River, this might not be true if suspended-sediment inflow from the Cowlitz became significantly higher.

The general absence of suspended sand at Cowlitz River mile 0.2 suggests that the quantity of bedload discharged into the Columbia River from the Cowlitz during the data-collection period was relatively small. Also, because hydraulic conditions are not greatly different, it seems unlikely that bedload discharges in the Columbia River upstream from CRM 68.0 would be substantially larger than those at CRM 54.0. For these reasons, the scour and fill sequence suggested by the suspended-sediment discharge data probably can be considered indicative of actual net degradation and aggradation.

VERTICAL DISTRIBUTION OF SUSPENDED SEDIMENT

Point-integrated suspended-sediment samples were collected at CRM 73.5, 63.8, and 54.0 (table 3) to provide information on whether the vertical distribution of suspended sediment downstream from the mouth of the Cowlitz River is unusual in any way because of the presence of deposited eruption-derived debris. The data were analyzed within the framework of conventional suspended-sediment theory.

Under conditions of moderately steady flow, the vertical distribution of suspended sediment in a narrow size range can be approximately characterized by

$$\frac{c_y}{c_a} = \left(\frac{d-y}{y} \quad \frac{a}{d-a} \right)^z \tag{1}$$

where

c_y and c_a are the concentrations of suspended sediment in the size range at heights of y and a, respectively, above the streambed;

d is the total depth of flow at the vertical; and

Z is an exponent that theoretically equals $V_s/k\, u_*$

in which

V_s is the fall velocity of particles in the size range;

k is the von Karman coefficient for turbulent exchange; and

u_* is the shear velocity.

For any height, a, with a given distribution and total depth, c_a and $\left(\frac{a}{d-a}\right)^Z$ are constants,

and equation 1 can be written as

$$c_y = K \left(\frac{d-y}{y} \right)^Z. \tag{2}$$

The exponent Z in equation 2 can be determined for measure distributions by plotting values of c_y, defined from point-integrated samples collected at various heights, y, above the bed, against corresponding values of $(d-y)/y$ on logarithmic-coordinate graph paper; Z is the slope of the straight line defined by the points. Low values of Z result when the concentration of the size range is nearly uniform (constant) throughout the depth, and high values occur when the concentration is much higher near the bottom than it is near the surface.

Data listed in table 3 for material finer than 62 μm and coarser than 62 μm were used to compute values of Z (table 6). Because of generally low concentrations and tide effects, comparisons among data for different days and different locations are inconclusive. However, by comparing concentrations at CRM 73.5 at all levels throughout the depth with those at CRM 63.8 and 54.0 (table 3), it

TABLE 5.—*Longitudinal distribution of suspended-sediment discharges between Columbia River miles 73.5 and 54.0 during the period August 13–20, 1980*

[CRM, Columbia River mile]

Discharges at specific river miles	Location or reach	Discharge of sediment finer than 62 μm (tons per day)				Discharge of sediment coarser than 62 μm (tons per day)				Total discharge (tons per day)			
		8–13	8–14	8–18	8–20	8–13	8–14	8–18	8–20	8–13	8–14	8–18	8–20
CRM	73.5	[1]5,600	7,560	3,500	5,000	[1]1,100	1,130	700	1,000	[1]6,700	8,690	4,200	6,000
Cowlitz RM	0.2	[2]11,500	[3]10,000	4,100	7,800	[2]1,300	[3]1,100	0	0	[2]12,800	[3]11,100	4,060	7,800
[4]CRM	68.0	[4]17,100	[4]17,600	[4]7,600	[4]12,800	[4]2,400	[4]2,200	[4]700	[4]1,000	[4]19,500	[4]19,800	[4]8,300	[4]13,800
CRM	63.8	24,700	18,500	29,500	13,000	2,500	2,700	2,400	3,100	27,200	21,200	31,900	16,000
CRM	54.0	22,100	-----	15,100	-----	3,800	----	700	----	25,900	----	15,800	----
Increase or (decrease) through the reach													
CRM	68.0–63.8	7,600	940	21,900	200	100	500	1,700	2,100	7,700	1,400	23,600	2,200
CRM	63.8–54.0	(2,600)	-----	(14,400)	-----	1,300	----	(1,700)	----	(1,300)	-----	(16,100)	-----

[1] Estimated from measured discharges on 8–12 and 8–14.
[2] Estimated from discharge at Cowlitz River mile 17.0 on 8–13 and available particle-size distributions at river mile 0.2.
[3] Estimated from discharge at Cowlitz River mile 17.0 on 8–14 and available particle-size distributions at river mile 0.2.
[4] Sum of discharges at CRM 73.5 and Cowlitz River mile 0.2.

is evident that suspended-sediment concentrations downstream from the Cowlitz River are consistently higher than those upstream, even at times in the tidal cycle when flow conditions are much less dynamic downstream than they are upstream. The somewhat lower Z values, which occurred when shear velocities were low because of low velocities, suggest that the sizes of material in suspension at CRM 63.8 and 54.0 are not substantially different from those at CRM 73.5.

LONGITUDINAL DISTRIBUTION OF BED MATERIAL

Particle size statistics that characterize the size distribution of bed material finer than 2.0 mm (see table 4) are presented in table 7. In the table, particle sizes at specific percentiles and percentile ranges are expressed in millimeters; distribution statistics are given in phi notation. By definition,

$$\phi = -\log_2 D \quad \text{(Krumbein, 1934)} \quad (3)$$

or, more precisely,

$$\phi = -\log_2 \left(\frac{D}{1.0\ \text{mm}} \right) \quad \text{(McManus, 1963)} \quad (4)$$

where

ϕ is particle diameter, in phi notation, and
D is particle diameter, in millimeters.

Equation 4 relates phi and millimeter values, within the range from 0.062 to 4.00 mm, as follows:

Phi	4	3	2	1	0	−1	−2
Millimeters	0.062	0.125	0.250	0.500	1.00	2.00	4.00

Use of phi notation facilitates comparison of particle-size distributions, because statistics are expressed in relative terms; that is, particles one phi unit apart are different in size by a factor of 2, regardless of whether the particles are large or small. Similarly, multiples of the deviation measure (comparable to standard deviation) express the number of times particles at a particular point in the size distribution are greater or smaller than the mean particle size. Distribution statistics, based on Inman's (1952) formulas, are as follows:

$$\text{Mean } (M\phi) = \tfrac{1}{2}(\phi_{16} + \phi_{84}) \quad (5)$$

$$\text{Median } (Md\phi) = \phi_{50} \quad (6)$$

$$\text{Sort or deviation measure } (\sigma_\phi = \tfrac{1}{2}(\sigma_{16} - \Phi_{84}) \quad (7)$$

$$\text{Skewness} - \text{Alpha 1 } (\alpha_1) = \frac{(M_\phi - Md_\phi)}{\sigma_\phi} \quad (8)$$

$$-\text{Alpha 2 } (\alpha_2) = \frac{\tfrac{1}{2}(\phi_5 + \phi_{95}) - Md_\phi}{\sigma_\phi} \quad (9)$$

where

ϕ_p is the phi value of the particle size for which p, percent of the analyzed material by weight, is finer.

Values of these statistics for all bed-material samples are listed in the farthest right columns of table 7.

Average M_ϕ and σ_ϕ values for each measurement cross section along the Columbia River have been used to examine how the particle-size distribution of present (August 12–20, 1980) surficial bed material differs from that in the river, prior to the Mount St. Helens' eruption. Data collected in 1962–63 (Haushild and others, 1966) and 1965

TABLE 6.—*Vertical distributions of suspended sediment at Columbia River cross sections as characterized by measured Z values*

[CRM, Columbia River mile]

Cross section (CRM)	Date (1980)	Time (P.d.t., 2400 hours)	Daily mean discharge (ft³/s)	Z value < 62 μm	Z value > 62 μm	Flow condition
73.5	Aug. 12	1025	139,000	0.03	0.13	Strength of flow during strong ebb.
73.5	Aug. 18	1205	124,000	.10	.12	About 1 h before strength of flow on fairly weak ebb.
73.5	Aug. 20	1330	149,000	.11	.24	Beginning of ebb flow on a weak ebb.
63.8	Aug. 13	1535	142,000	.01	−.16	Beginning of floodflow.
63.8	Aug. 20	1030	152,000	.04	.15	End of weak floodflow.
54.0	Aug. 13	1150	142,000	.03	.07	About 1½ h after strength of flow on strong ebb.
54.0	Aug. 18	1030	130,000	.12	.04	About 1 h before strength of flow on fairly weak ebb.
54.0	do	1328	130,000	.07	.19	Do.

(Hubbell and Glenn, 1973) are plotted in figure 4 to represent pre-eruption conditions. None of the pre-eruption samples from CRM 64 and fewer than 15 percent of the samples from CRM 59 or CRM 54 contained particles coarser than 2.0 mm; hence, the data essentially are comparable with the data in table 7. Arbitrary lines, based on the pre-eruption data, are drawn to delimit the range in which M_ϕ values would be expected to occur along the length of the Columbia between river miles 106.4 and 14.0. Post-eruption data from table 7 also are plotted in figure 4.

Computed average M_ϕ values of material presently in the river at measurement cross sections close to the Cowlitz River mouth generally lie outside the expected range (fig. 4) for pre-eruption conditions. Upstream, at CRM 70.0 and 69.2, the material appears to be significantly coarser (about 0.8 phi unit) than the pre-eruption bed material. Immediately downstream from the confluence, there is an abrupt change in the mean particle size. M_ϕ increases, roughly, from 1.0 to 2.3, which indicates that the mean size of present bed material downstream from the confluence is less than half the mean size of material upstream from the confluence (0.20 mm compared to 0.50 mm). Material downstream from the confluence is roughly 0.5 phi unit finer than pre-eruption material in that reach.

Whereas material in the navigational channel generally is coarser than that on the marginal slopes and adjacent flats, the reduction in mean size at CRM 63.8 from pre-eruption material is fairly consistent over the entire width (see Hubbell and Glenn, 1973, p. L53). The increase in fine material downstream from the confluence probably is due to the continual influx of significant amounts of fines from the Cowlitz River, as well as the presence of remnant material from the mudflow. The slight downstream decrease in size between CRM 67.0 and 63.8 suggests that fine material being entrained immediately downstream from CRM 68.0 (see table 5) may be depositing in the vicinity of CRM 63.8 and downstream from that point.

Average σ_ϕ values at all cross sections except CRM 63.8 show that the relative range of particle sizes finer than 2.0 mm included in the present bed material is virtually the same as it was in the past, even though M_ϕ values are different. At CRM 63.8, the material in the north half of the channel is composed of an unusually wide range of particle sizes.

SPECIFIC GRAVITY AND SHAPE FACTOR OF POST-ERUPTION BED MATERIAL

Because of the large quantities of debris that were created through violent explosion and pyroclastic activity, the potential existed for much of the sediment delivered by the Cowlitz River to the Columbia to be substantially more angular and of a different specific gravity than normal Columbia River sediments. To ascertain differences between the "old" and "new" bed material, specific gravities were measured in the laboratory, and particle-shape factors were estimated from empirical relations between fall and sieve diameters.

SPECIFIC GRAVITY

Specific gravities of selected samples were determined by the standard pycnometer procedure (American Society for Testing and Materials, 1969). In this procedure, specific gravity (sp gr), is computed from

$$\text{sp gr} = \frac{W_s}{W_w - (W_m - W_s)} \qquad (10)$$

TABLE 7.—*Particle-size statistics of surficial bed material finer than 2 mm from the Columbia, Cowlitz, and Toutle Rivers*

Date (1980)	Lateral position[1]	Geometric-mean size of particles in different percentile ranges, expressed in terms of sieve (S) and fall (F) diameters, in millimeters: 10–20 S	10–20 F	45–55 S	45–55 F	80–90 S	80–90 F	Shape factor of particles in indicated percentile ranges: 10–20	45–55	80–90	Fall diameter at indicated percentile, in millimeters: 35	50	65	Inman values, in phi units: Mean	Sort	Alpha 1	Alpha 2
		Columbia River mile 106.4															
Sept. 17	10	0.202	0.205	0.342	0.311	0.513	0.497	0.64	0.52	0.76	0.271	0.311	0.358	1.66	0.58	-0.04	-0.26
	30	.268	.237	.403	.319	.657	.544	.35	.30	.61	.285	.319	.360	1.48	.57	-.29	-.50
	50	.322	.311	.505	.466	.903	.697	.62	.67	.63	.388	.466	.544	1.11	.55	.00	-.08
	70	.264	.269	.442	.418	.745	.624	.69	.67	.66	.361	.418	.484	1.28	.57	.04	.09
	90	.223	.264	.456	.465	1.160	.703	>1.00	.83	.46	.360	.467	.553	1.21	.67	.17	.20
		Columbia River mile 73.5															
Aug. 12	5	.214	.207	.284	.244	.373	.309	.52	.30	.35	.230	.244	.264	1.99	.27	-.17	-.30
	20	.069	.055	.127	.116	.245	.242	----	----	.61	.088	.116	.155	3.12	1.04	.01	-.06
	30–35	.194	.163	.274	.211	.379	.279	<.30	<.30	<.30	.193	.211	.231	2.23	.36	-.05	-.14
	40	----	.008	.133	.035	.286	.262	----	----	.47	.019	.029	.187	4.40	2.45	-.30	-.04
	45	.251	.338	.452	.464	.777	.619	>1.00	.84	.62	.414	.464	.518	1.13	.41	.04	.08
	50	.201	.199	.267	.246	.365	.315	.57	.46	.43	.228	.246	.269	2.00	.31	-.07	-.30
	70	.221	.233	.325	.328	.613	.576	.78	.72	.77	.288	.328	.393	1.46	.62	-.25	-.37
	85	.248	.234	.526	.310	1.286	.427	.49	<.30	<.30	.279	.310	.345	1.66	.41	-.06	-.20
	95	.187	.203	.264	.283	.569	.516	.90	.86	.68	.245	.283	.330	1.66	.62	-.27	-.66
		Columbia River mile 70.0															
Aug. 12	5	.237	.219	.373	.306	.652	.540	.43	.33	.61	.274	.307	.342	1.60	.56	-.20	-.82
	10	.321	.286	.503	.463	.892	.784	.45	.67	.78	.380	.463	.561	1.08	.69	-.05	-.12
	20	.317	.357	.544	.528	1.039	.778	>1.00	.79	.65	.458	.528	.608	.93	.53	.00	-.06
	35	.213	.252	.457	.529	1.192	.856	>1.00	>1.00	.65	.392	.529	.630	1.13	.87	.24	.17
	50	.271	.291	.567	.547	1.260	.939	.87	.79	.69	.436	.547	.667	.93	.80	.07	.12
	75	.355	.325	.771	.618	1.376	1.016	.55	.62	.71	.513	.618	.745	.79	.79	.12	.13
		Columbia River mile 69.2															
Aug. 12	5	.286	.283	.438	.406	.738	664	.65	.64	.76	.348	.406	.477	1.21	.58	-.15	-.32
	15	.287	.380	.510	.890	1.110	1.271	>1.00	>1.00	>1.00	.597	.899	1.073	.52	.84	.43	.53
	25	.263	.318	.472	.551	.968	.864	>1.00	>1.00	.82	.455	.551	.648	.93	.68	.10	.08
	45	.298	.308	.740	.589	1.347	.896	.76	.60	.61	.505	.589	.685	.91	.72	.20	.38
	55	.433	.416	.741	.621	1.186	.875	.69	.66	.67	.549	.622	.704	.72	.50	.07	.19
	65	.318	.290	.711	.553	1.347	.940	.49	.55	.66	.447	.554	.672	.93	.80	.09	.20
	75	.275	.257	.484	.389	1.127	.756	.50	.43	.56	.323	.389	.515	1.20	.74	-.23	-.39
	95	.370	.362	.739	.591	1.316	.863	.68	.61	.59	.515	.591	.678	.84	.59	.13	.17
	95	.437	.478	.775	.661	1.299	.890	1.00	.69	.63	.593	.661	.736	.60	.41	.00	.14
		Columbia River mile 67.0															
Aug. 12	5	----	0.021	0.075	0.062	0.106	0.116	----	----	1.00	0.046	0.063	0.079	4.25	1.10	0.22	0.88
	10	.247	.213	.458	.347	.906	.593	.30	.30	.44	.294	.346	.418	1.49	.69	-.06	-.09
	20	.178	.191	.245	.261	.422	.435	.84	.83	.84	.230	.259	.312	1.80	.56	-.26	-.72
	30–50	.165	.180	.222	.246	.304	.332	1.00	1.00	1.00	.220	.246	.275	2.03	.42	.02	-.08
	60–80	.202	.192	.285	.247	.382	.316	.46	.33	.36	.225	.247	.270	2.02	.34	.01	.00
	90	.148	.177	.202	.237	.263	.325	>1.00	>1.00	>1.00	.215	.237	.264	2.05	.40	-.07	-.03
	95	----	----	----	----	----	.074	----	----	----	----	----	----	4.14	.34	-.19	-.89
	95	.080	.082	.179	.181	.262	.249	----	.62	.53	.150	.182	.203	2.78	.73	.44	.66
	95	----	.012	----	.035	.082	.079	----	----	----	.025	.035	.046	5.01	1.27	.14	.41
		Columbia River mile 63.8															
Aug. 13	10	.075	.081	.107	.109	.155	.154	----	.54	.54	.100	.109	.121	3.16	.43	-.08	-.34
	20	.116	.148	.331	.331	.751	.724	>1.00	.70	.86	.238	.332	.456	1.62	1.09	.02	-.08
	30	.161	.173	.262	.267	.446	.405	.85	.69	.61	.232	.267	.304	1.92	.56	.02	-.13
	40	.138	.147	.396	.375	.736	.548	.80	.65	.50	.306	.375	.425	1.81	.89	.44	.49
	50	----	.034	----	.157	----	.435	----	----	----	.121	.157	.271	2.65	1.41	-.02	1.22
	60	----	.099	----	.208	----	.650	----	----	----	.138	.198	.353	1.99	1.30	-.27	-.26
	80	.250	.205	.449	.458	.801	1.032	<.30	.83	>1.00	.365	.458	.618	1.11	1.15	-.02	.12
	90	----	.007	----	.015	----	.038	----	----	----	.012	.015	.022	5.89	1.12	-.15	.45
		Cowlitz River mile 0.7															
Aug. 12	5	----	.012	----	.021	----	.029	----	----	----	.190	.021	.024	5.64	.53	.12	2.40
	50	----	.005	----	.012	----	.021	----	----	----	.010	.013	.016	6.50	.93	.20	.80
		Cowlitz River mile 0.9															
Aug. 11	50	----	.016	.070	.046	.108	.086	----	----	----	.034	.046	.063	4.72	1.14	.25	.49
		Cowlitz River mile 4.2															
Aug. 11	15	.082	.080	.165	.157	.233	.277	----	.41	.56	.122	.157	.188	2.84	.67	.24	.49
	20	----	.202	.310	.371	.773	.739	----	>1.00	.85	.286	.363	.521	1.37	.89	-.10	.60
	60	.211	.254	.506	.497	1.083	.742	>1.00	.79	.57	.395	.505	.580	1.19	.73	.28	.44

TABLE 7.—*Particle-size statistics of surficial bed material finer than 2 mm from the Columbia, Cowlitz, and Toutle Rivers*—Continued

Date (1980)	Lateral position[1]	Geometric-mean size of particles in different percentile ranges, expressed in terms of sieve (S) and fall (F) diameters, in millimeters: 10–20 S	10–20 F	45–55 S	45–55 F	80–90 S	80–90 F	Shape factor of particles in indicated percentile ranges: 10–20	45–55	80–90	Fall diameter at indicated percentile, in millimeters: 35	50	65	Inman values, in phi units: Mean	Sort	Alpha 1	Alpha 2
Cowlitz River mile 9.6																	
Aug. 11	30	0.065	0.116	0.173	0.177	0.320	0.314	----	0.65	0.65	0.151	0.175	0.216	2.40	0.67	−0.18	−0.29
	70	.114	.064	.194	.145	.284	.232	----	<.30	.30	.125	.145	.168	3.09	.92	.32	.70
Cowlitz River mile 13.5																	
Aug. 11	99	.146	.121	.203	.181	.269	.419	<.30	.30	>1.00	.158	.181	.212	2.13	.83	−.41	−.63
Cowlitz River mile 29.9																	
Aug. 11	1	.141	.158	.242	.252	.356	.334	1.00	.75	.60	.219	.253	.280	2.10	.49	.23	.62
Toutle River mile 6.5																	
Aug. 11	33	.224	.222	.460	.332	1.074	.704	.60	.30	.50	.290	.332	.422	1.35	.78	−.31	−.46
	67	.203	.239	.415	.396	1.056	.697	>1.00	.67	.51	.330	.396	.470	1.31	.73	−.04	−.21
North Fork Toutle River mile 1.2																	
Aug. 11	16 & 84	.364	.388	.704	.604	1.220	.852	.88	.67	.63	.533	.604	.684	.79	.53	.12	.21
	50	.306	.383	.574	.609	1.272	.953	>1.00	1.00	.70	.518	.609	.716	.73	.62	.02	−.02
South Fork Toutle River mile 0.0																	
Aug. 11	1	.110	.013	.327	.191	1.018	.607	----	<.30	.37	.088	.193	.341	3.40	2.63	.38	.72
	5	.107	.138	.321	.264	.995	.441	>1.00	.30	< .30	.221	.264	.312	2.00	.77	.10	−.13
	5	.145	.085	.261	.259	.479	.714	----	.63	>1.00	.160	.250	.513	1.99	1.47	−.01	.15

[1] Relative distance from left bank (looking downstreams), expressed as percentage of full width.

where

W_s is dry weight of sediment introduced into the pycnometer,

W_w is weight of distilled water at temperature, T, required to fill the pycnometer,

W_m is weight of the water-sediment mixture at temperature, T, in the filled pycnometer.

Material coarser (by sieving) than 2.0 mm was excluded from the specific gravity determinations as it had been from the particle-size analyses. The purpose of rejecting this material was to eliminate large lightweight pumice particles and other erratics. Visual observation of the samples revealed that pumice particles coarser than 2.0 mm occurred in random quantities, and that many samples contained no pumice particles of that size.

Results of the specific-gravity determinations are given in table 8. With the exception of several samples that visibly contained fine pumice (see "Remarks" in table 8), measured specific gravities of bed material from the Columbia River at and below CRM 73.5 averaged 2.63 and had a standard deviation of 0.07. Similar specific gravities were measured for the bed material in the Cowlitz and Toutle Rivers. Interestingly, the two suspended-sediment samples that were analyzed had lower specific gravities of about 2.57 (table 8). On the basis of these determinations, it seems that the specific gravity of Columbia River bed material finer than 2.0 mm has not changed significantly, and a nominal value of 2.65 can be used to characterize the bottom sediments in the Columbia, lower Cowlitz, and lower Toutle Rivers.

The validity of computing shape factors in this manner is contingent on the accuracy of figure 5 and the extent to which the following conditions are satisfied:

1. The specific gravity of individual particles equals 2.65.
2. The "ordered" position of each particle relative to every other particle is exactly the same whether ordering is based on standard fall velocity, which establishes the fall diameter, or on controlling cross-sectional area, which establishes the sieve diameter. That is, the particle having the lowest standard fall velocity (smallest fall diameter) also has the smallest controlling cross-sectional area (smallest sieve diameter), the particle with the second smallest fall diameter has the second smallest sieve diameter, and so forth.

When condition 2 is satisfied, the same particles are in the same relative weight ranges, regardless of the method of analysis. Because of this equivalency within any selected relative weight range, representative fall and sieve diameters for any range can be used with the relations in figure 5

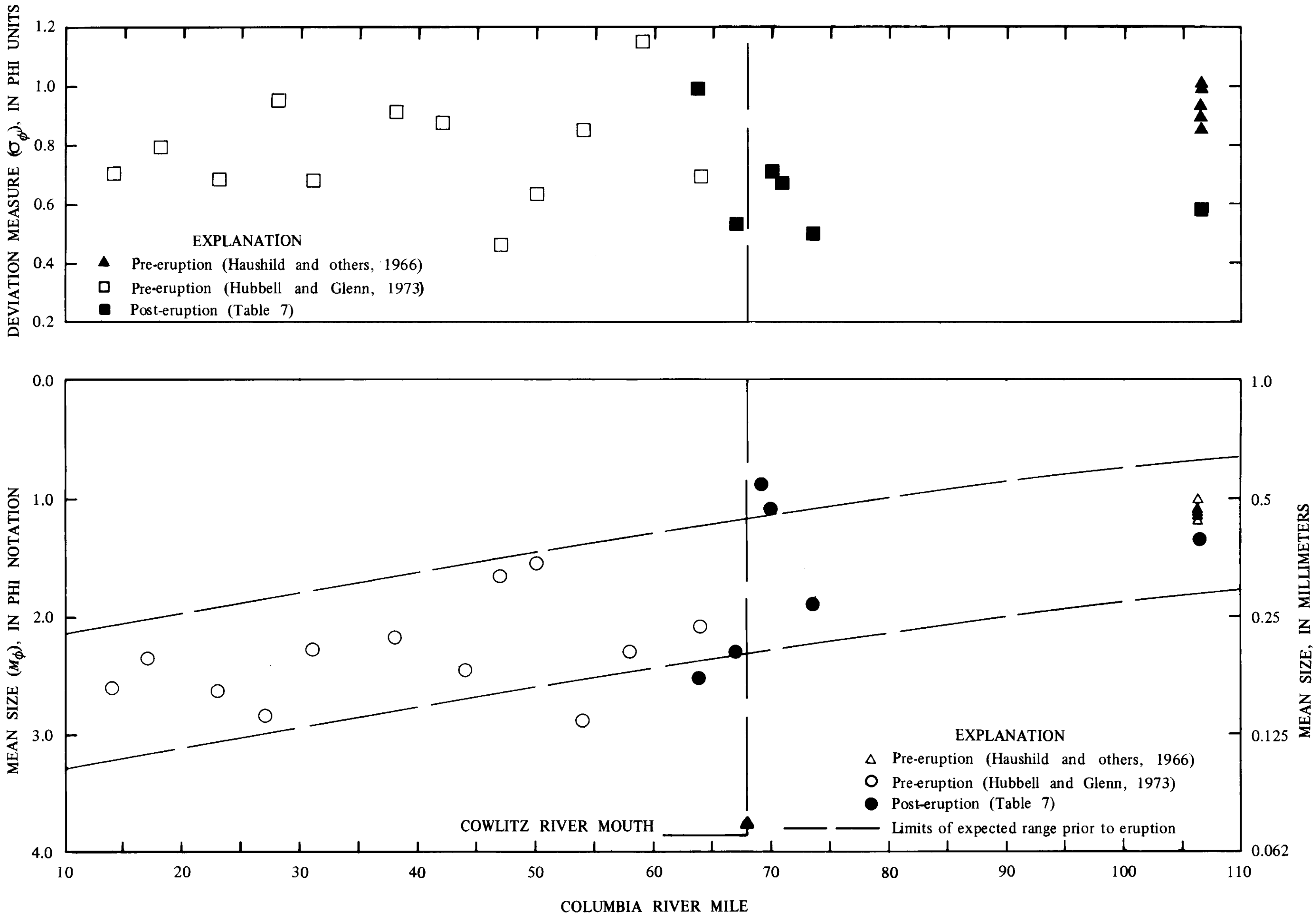

FIGURE 4.—Variation of bed-material particle-size statistics between Columbia River miles 106.4 and 14.0 for pre- and post-eruption periods.

TABLE 8.—*Specific gravity of Columbia, Cowlitz, and Toutle River sediments*

[Type of material: BM, bed material; SS, suspended sediment]

River	River mile	Lateral position[1]	Type of material	Specific gravity	Remarks
Columbia	106.4	10	BM	2.58	
	106.4	30	BM	2.68	
	106.4	50	BM	2.64	
	73.5	30	BM	2.61	
	73.5	40	BM	1.62	Fine pumice present.
	73.5	50	BM	2.70	
	70.0	40	BM	1.58	Fine pumice present.
	69.2	25	BM	2.64	
	69.2	55	BM	2.63	
	69.2	65	BM	2.10	Fine pumice present.
	69.2	75	BM	2.55	
	67.0	20	BM	2.65	
	67.0	50	BM	2.69	
	67.0	60	BM	2.67	
	67.0	90	BM	2.66	
	63.8	40	BM	2.58	
	63.8	50	BM	2.73	
	63.8	60	BM	2.48	
Cowlitz	.9	50	BM	2.69	
	4.2	20	BM	2.66	
	9.6	30	BM	2.68	
	9.6	40	BM	2.63	
	13.5	99	BM	2.72	
	13.5	99	BM	2.66	
	29.9	1	BM	2.63	
Toutle	6.5	[2]20	BM	2.68	
	6.5	33	BM	2.64	
	6.5	67	BM	2.55	
	6.5	[2]90	BM	2.58	
N. Fork Toutle	1.2	16	BM	2.64	
	1.2	50	BM	2.58	
	1.2	--	SS	2.59	
S. Fork Toutle	0.0	1	BM	2.73	
	0.0	99	BM	2.76	
	0.0	--	SS	2.55	

[1] Relative distance from left bank (looking downstream), expressed as percentage of full width.

[2] No particle-size analysis.

to estimate a shape factor, provided condition 1 also is satisfied. In reality, of course, neither of these conditions is completely satisfied. However, if the actual conditions are not too different from those that existed for the sediment used to define figure 5, estimated shape factors should be fairly reliable. It is obvious that the governing conditions were not met in all samples, because some computed shape factors were unrealistically low (less than 0.3) or impossibly high (greater than 1.0).

PARTICLE-SHAPE FACTORS

Shape factors were estimated for all samples of bed material collected from both the unaltered part (CRM 106.4) and the affected part (downstream from CRM 73.5) of the Columbia River. Estimations were made using the fall-diameter distribution for each sample, as defined by VA analysis; the sieve-diameter distribution for the same sample, as defined by sieve analysis; and the empirically defined relationships graphed in figure 5. In these relationships, the shape factor, S.F., of a particle is defined as:

$$\text{S.F.} = c/\sqrt{ab} \tag{11}$$

where

a is length of the longest axis,
b is length of the intermediate axis, and
c is length of the shortest of the three mutually perpendicular axes of the particle.

For the analysis, geometric-mean fall diameters and sieve diameters of particles in the 10–20, 45–55, and 80–90 percentile ranges (by weight) were determined from the size distributions defined by VA analysis and sieving; computed geometric-mean sizes for each sample are listed in table 7. Fall and sieve diameters for each percentile range were used, in turn, to estimate corresponding shape factors from figure 5. No shape factor was determined for a percentile range, if either the fall or sieve diameter (or both) was less than 0.1 mm because of the insensitivity of the relationships for small particles. Estimated shape factors are listed in the center columns of table 7. Approximately 60 percent of the shape factors are between 0.5 and 0.8.

In addition to verifying that condition 1 was generally satisfied (specific gravities were close to 2.65), an effort was made, by an independent method, to confirm that condition 2 also was reasonably well satisfied. Four different samples, two from the Columbia River and one each from the Cowlitz and Toutle Rivers, that had been retained as size-range separates following routine sieve analysis of the sample, were reanalyzed by VA analysis. For each analyzed size range, a geometric-mean sieve diameter was determined from the upper and lower sieve sizes of the range, and a geometric-mean fall diameter was deter-

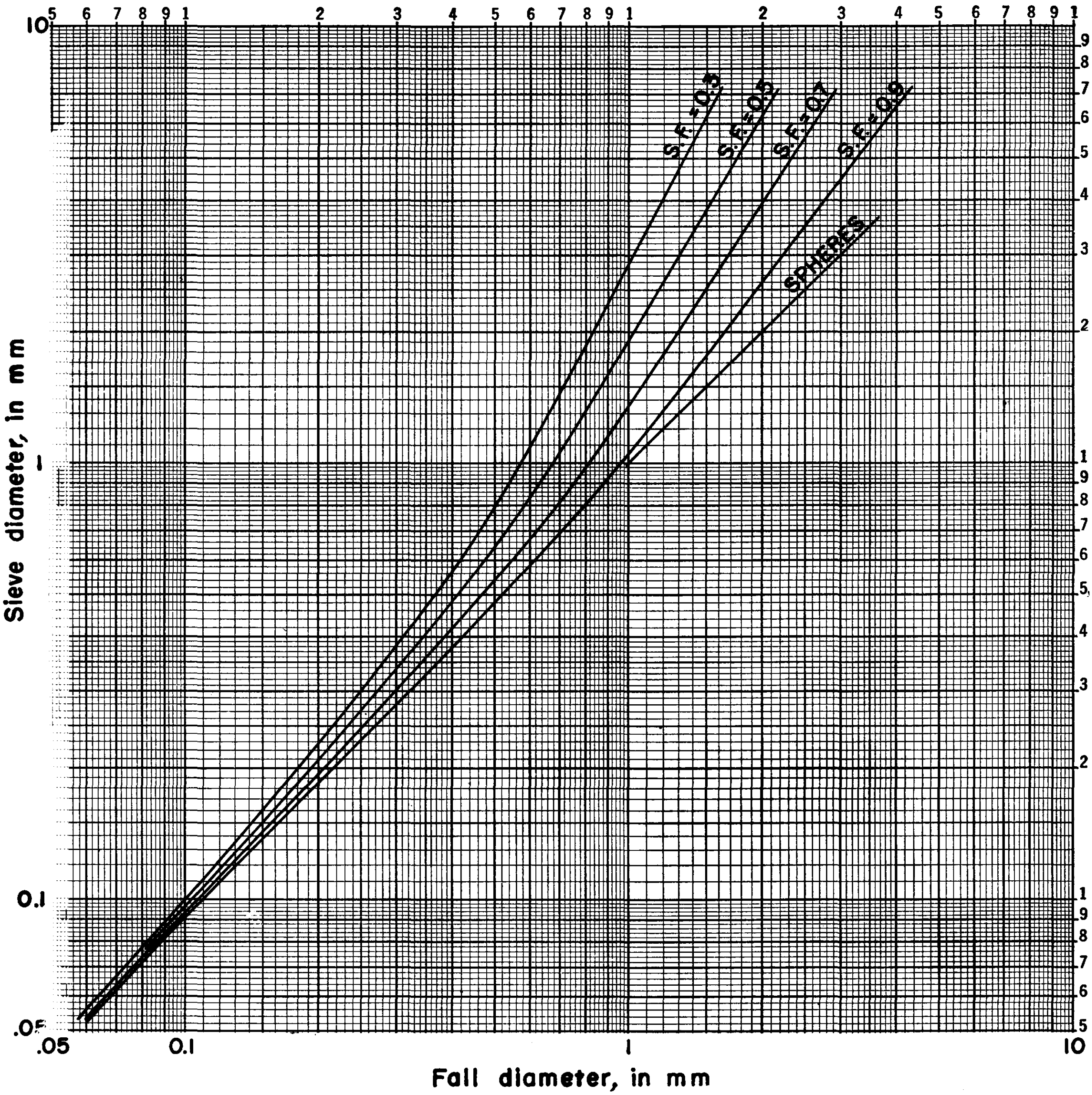

FIGURE 5.–Relations between sieve and fall diameters of naturally worn quartz (sp gr = 2.65) particles for different shape factors

mined from the largest and smallest fall diameters defined from the VA analysis. The two geometric-mean diameters for each defined size range were used to obtain a shape factor from figure 5. These shape factors, in turn, were compared with shape factors given in table 7 for the same sample. Because particle sizes represented in the individual size separates did not necessarily coincide closely with sizes represented by the percentile ranges listed in table 7, only nine computed shape factors were truly comparable to values in the table. The purpose of the comparisons was to determine if shape factors computed from the entire sample (S.F. –1 values), under the assumption that condition 2 was satisfied, agreed with shape factors computed from size separate data (S.F. –2 values) for which condition 2 was known to exist.

Statistical analysis of seven possible comparisons from the Columbia and Cowlitz River samples indicates a correlation coefficient of 0.71

between S.F. −1 and S.F. −2 values and a standard error of estimate of S.F. −1 values of 0.18. When two possible comparisons from the Toutle River sample are included, the correlation coefficient decreases to 0.53. On the basis of this test and the assumption that higher correlations would have been achieved with more observations and exactly comparable shape factors, it seems reasonable that most shape factors determined for the Columbia and lower Cowlitz Rivers that lie in the interval, 0.3–1.0, will be within about ±0.2 of the actual shape factor defined by figure 5.

Shape factors listed in table 7 have been combined to summarize the shape-factor data at each cross section. In this process, shape factors less than 0.3 and greater than 1.0 were rejected on the basis that one or both conditions which were required to relate fall and sieve diameters to the shape factor probably had not been satisfied. Shape factors within the range 0.3 to 1.0 were assumed to be valid, although subject to error. The mean and standard deviation of individual shape factors for each cross section and percentile range are given in table 9 with the number of values, N, in each statistic. Because differences between fall and sieve diameters due to particle shape become more pronounced as size increases (fig. 5), shape factors for the 80–90 percentile range probably are the most reliable.

Uniformity in mean values between sections and the fairly large standard deviation for each section suggest that there is substantially more variability in shape factors (or specific gravities) within each cross section than between cross sections, including the cross section at CRM 104.6. Hence, for such considerations as one-dimensional sediment-transport computations and dredging or earthwork determinations involving bulk density, it appears that no corrections are needed to account for unusual particle shapes or substantially different specific gravities of the sediment in the reach from CRM 106.4 to CRM 63.8, except possibly for sediment in the vicinity of CRM 67.0, where variability of the data is too large to allow any reliable conclusion.

TABLE 9.—*Summary statistics of bed-material shape factors at Columbia River cross sections*

[SD, standard deviation; N, number]

Columbia River mile	Percentile range 10–20 Mean	SD	N	45–55 Mean	SD	N	80–90 Mean	SD	N
106.4	0.58	0.15	4	0.60	0.20	5	0.62	0.11	5
73.5	.65	.18	5	.64	.25	5	.56	.15	7
70.3	.58	.20	4	.64	.19	5	.68	.06	6
69.2	.68	.17	7	.60	.09	7	.66	.09	8
67.0	.65	.33	4	.62	.31	5	.70	.29	6
63.8	--	--	2	.68	.10	5	.63	.16	4

CONCLUSIONS

Lesser suspended-sediment discharges at CRM 68.0 than at CRM 63.8 during the data-collection period (August 11–20, 1980) indicate that the bed of the Columbia River immediately downstream from the mouth of the Cowlitz River (CRM 68.0) was degrading; greater discharges at CRM 63.8, than at CRM 54.0, suggest that some of the scoured material is redeposited downstream from CRM 63.8.

Suspended-sediment concentrations are greater throughout the total depth at locations downstream from CRM 68.0 than they are upstream from that point, even during times in the tidal cycle when the flow is relatively quiescent, which suggests that most of the suspended sediment is very fine.

Lightweight pumice particles larger than 2.00 mm are distributed randomly throughout the bed material in the Columbia River near the mouth of the Cowlitz River. Most of the pumice has a physical size larger than 2.0 mm. Samples having a high percentage of particles coarser than 2.0 mm invariably had several very large pumice particles. The present (August 1980) areal distribution and size gradation of pumice probably is temporarily due to its extreme mobility and its susceptibility to fracturing.

On the basis of particle-size analyses by the VA method of sieved material finer than 2.0 mm, the mean size of the bed material immediately upstream from the Cowlitz River mouth seems to be significantly coarser than it was before the eruption. Downstream from the mouth, the mean size decreases abruptly across the full width of the Columbia River. At CRM 67.0, the mean size was less than half of what it was at CRM 70.0 and 69.2 and somewhat less than the mean size of pre-eruption bed material. At CRM 63.8, the mean was even finer than at CRM 67.0. Progressive downstream decrease in the size of the bed material further suggests that material entrained immediately below the mouth of the Cowlitz may begin redepositing several miles downstream. In the bed material of the Columbia River, the relative spread of particle sizes finer than 2.0 mm about the mean, as indicated by Sort values (phi notation), is essentially the same as it was prior to the eruption.

Specific-gravity determinations of bed material finer than 2.0 mm that was sampled at and downstream from CRM 73.5 averaged 2.63 and had a standard deviation of 0.07. From these determinations, it seems that the specific gravity has not changed significantly from pre-eruption conditions and that 2.65 can be taken as a nominal specific-gravity value.

Shape factors determined by an indirect means indicate that variations in the shape of bed-material particles are much greater within a cross section than among different cross sections throughout the reach of the Columbia River from mile 106.4 to mile 63.8. Similarities in shape factors of material from CRM 106.4 and from cross sections downstream of CRM 73.5 imply that there are no large differences between the shape of pre- and post-eruption surficial bed material. The majority of shape factors are between 0.5 and 0.8.

Reasonable uniformity in the specific gravity of bed material finer than 2.0 mm and in mean shape factors from one cross section to another suggests that, for one-dimensional sediment transport computations and gross dredging or earthwork estimates involving bulk density, no corrections need to be made for unusual bed-material properties.

Sediment-transport and channel conditions observed during the 9-day, mid-August, 1980, data-collection period of this investigation can be expected to change as the Columbia, Cowlitz, and Toutle River systems, aided by man's dredging and river maintenance activities, tend toward a new quasi-equilibrium (sedimentation regime). Additional data, similar to the data in this report, collected periodically could be used to assess the rate of change.

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