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The Evolving Landscape of the Columbia River Gorge

Lewis and Clark and Cataclysms on the Columbia

TRAVELERS RETRACING LEWIS AND CLARK'S JOURNEY to the Pacific over the past two hundred years have witnessed tremendous change to the Columbia River Gorge and its primary feature, the Columbia River. Dams, reservoirs, timber harvest, altered fisheries, transportation infrastructure, and growth and shrinkage of communities have transformed the river and valley.[1] This radically different geography of human use and habitation is commonly contrasted with the sometimes romantic view of a prior time provided both by early nineteenth-century chroniclers and present-day critics of the modern condition — an ecotopia of plentiful and perpetual resources sustaining a stable culture from time immemorial. Reality is more complicated. Certainly the human-caused changes to the Columbia River and the gorge since Lewis and Clark have been profound; but the geologic history of immense floods, landslides, and volcanic eruptions that occurred before their journey had equally, if not more, acute effects on landscapes and societies of the gorge. In many ways, the Lewis and Clark Expedition can be viewed as a hinge point for the Columbia River, the changes engineered to the river and its valley in the two hundred years since their visit mirrored by tremendous changes geologically engendered in the thousands of years before.

In their landscape and hydrographic descriptions, Lewis and Clark recorded effects of several different "cataclysms on the Columbia," a

Carleton Watkins, photographer, OHS neg., OrHi 21646

The Columbia River is confined to a gap about sixty yards wide at the entrance to the Long Narrows, shown here in 1882.

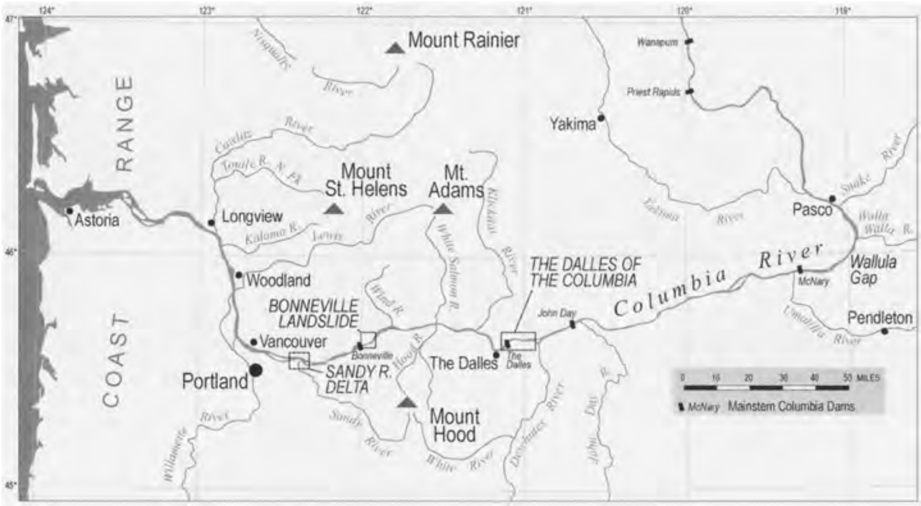
phrase John Allen used for the title of his 1986 book on the ice-age Missoula floods.[2] Geologic cataclysms affecting the Columbia River Gorge, however, include more than the gigantic floods of fifteen to seventeen thousand years ago. Others involve more human timescales. In addition to shooting through the narrows at The Dalles of the Columbia, perhaps a remnant of the great ice-age floods, Lewis and Clark drifted past a submerged forest and portaged Cascade Rapids, the result of a huge landslide only three hundred and fifty years before their exploration. At the downstream end of the gorge, Lewis and Clark walked on rich bottomlands partly formed by Mount Hood volcanism fewer than twenty-five years earlier. This essay aims to weave Lewis and Clark's first maps and observations of these three areas into a narrative of modern geologic thinking about landscape formation, particularly for the Columbia River Gorge.

"Other objects worthy of notice will be the soil & face of the country . . ."

WHILE NOT TRAINED AS GEOLOGISTS, Lewis and Clark, true to Jefferson's instructions, were careful observers of the landscape.[3] They provided volumes of rich observations and findings that established both geographic knowledge and methodological precedent for future explorations and surveys of the West. In the spring of 1804, however, when Lewis and Clark headed west, geology was hardly an established science. The first widely distributed scientific treatment of earth history had been published in 1802, John Playfair's *Illustrations of the Huttonian Theory of the Earth.* This treatise advanced the emerging British idea that the earth's features were formed by slow, continuous processes, not by radical upheavals such as biblical floods. This concept of uniformantarianism and the effectiveness of slow gradual erosion by rivers were advanced more fully by Charles Lyell in his 1830–1833 *Principles of Geology.*[4]

Many surveys of the Columbia River region after Lewis and Clark would include geologists: James D. Dana of the U.S. Exploring Expedition of 1838–1842; John S. Newberry of the Pacific Railroad Surveys of 1854–1855; Samuel F. Emmons of the King Survey of 1867–1873. In 1879, Clarence King's survey of the fortieth parallel and three other western geological and topographical surveys merged into the U.S. Geological Survey (USGS), with King as director. Within the newly formed USGS were Emmons, John Wesley Powell, Clarence E. Dutton, and protégés of Newberry such as G.K. Gilbert.[5] Building on observations and measurements from all over the West, these geologists and many others established a basic understanding of the geologic history of western North America by the early twentieth century. This included evidence of extensive continental and alpine glaciation, growth and shrinkage of huge ice-age lakes, and episodes of volcanism, mountain building, and canyon cutting.[6]

More than just documenting the geologic history of the West, these geologists and geographers also developed key concepts of landscape formation. Some of these principles, which still steer landform analysis, are traceable back to Dana's and Newberry's reports on the Columbia River region. This was especially the case for the Columbia River Gorge, where the landscape reflects an ever-changing and wildly swinging balance between the power of the Columbia River, concentrating runoff from 240,000 square miles, and the rock and debris that the river must cut through in maintaining its way to the Pacific through the Cascade Range.



U.S. Geological Survey

This map shows areas discussed in this article in relation to modern landmarks.

Lewis and Clark reached the Columbia River at the Snake River confluence on October 16, 1805.[7] They proceeded quickly downstream, reaching the site of Clark's proclamation "in *View* of the *Ocian*" only twenty-two days later, on November 7. Departing Fort Clatsop on March 23, 1806, they lingered a bit more on their return, following the Columbia valley upriver as far as the Walla Walla River confluence. There they diverged east from the Columbia on April 30. Their time in the Columbia River Gorge — the Columbia River valley through the Cascade Range between the Deschutes and Sandy rivers — totaled thirty-seven days, from October 21 to November 3, 1805, outbound and from March 31 to April 22, 1806, on their return. Most — and most valuable — of their observations in the gorge were ethnographic and botanic, but they also described the spectacular and formidable landscape: Celilo Falls, The Dalles of the Columbia, a submerged forest, Cascade Rapids, waterfalls misting the gorge walls, and the sand-laden Hood and Sandy rivers. Lewis and Clark were alternately amazed and dismayed by the changes in climate, physiography, and flora and fauna they encountered.

"I heard a great roreing"
"The Dalles Type of River Channel"

THE NOISY FALLS AND RAPIDS at "The Dalles of the Columbia" audibly impressed William Clark as the expedition approached the Cascade Range

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in late October 1805.[8] In this reach of river, prior to its inundation behind The Dalles Dam in 1957, the Columbia descended eighty feet in twelve miles as it flowed over the twenty-foot-high Celilo Falls and then through a series of constrictions and expansions before emerging, presumably quieter, as a "butifull jentle Stream of about half a mile wide" near present-day The Dalles. These falls and constrictions were not just noisy; they also impeded upstream fish passage and human navigation, factors that had already made The Dalles area one of the premier cultural centers in the Pacific Northwest, famously described by Clark as "the Great Mart of all this Country." Lewis and Clark's immediate concerns were navigation and relations with the Natives, but later this area of "rugid black rock" and others like it in the Columbia River Basin became the intellectual battleground of a great debate in twentieth-century geology — the Spokane Flood controversy.[9]

The outstanding physical and cultural characteristics of The Dalles inspired William Clark, Patrick Gass, and Meriwether Lewis (during the return trip) to devote several journal pages to describing and mapping this reach of river. They measured river fall, flood heights, lengths of portages, numbers of Indian dwellings, and stacks of drying fish. Clark's descriptions of the black rocks, perpendicular cliffs flanking the valley bottom, and

William Clark's map shows the reach between Celilo Falls (labeled Great Falls) and the expedition's camp at Fort Rock, near present-day The Dalles.

windblown sand collected in hollows make his resulting maps, such as the one of Celilo Falls, the first geologic maps made in the Pacific Northwest.[10]

Their hydrologic observations, too, are vivid, sharpened by a wild ride through the chutes. Before entering the fifty-yard-wide Short Narrows, Clark wrote: "... I deturmined to pass through this place notwithstanding the horrid appearance of this agitated gut Swelling, boiling & whorling in every direction (which from the top of the rock did not appear as bad as when I was in it[)]."[11] Before even seeing the entrance to the Short Narrows, Clark anticipated the constriction and resulting backwater from three miles upstream at Celilo Falls:

> ... that from Some obstruction below, the cause of which we have not yet learned, the water in high fluds (which are in the Spring) rise <nearly> below these falls nearly to a leavel with the water above the falls; the marks of which can be plainly trac'd around the falls. at that Stage of the water the Salmon must pass up which abounds in Such great numbers above.[12]

This observation neatly links the geology, hydrology, and ecology by which The Dalles of the Columbia merits its spotlight in regional history.

"The Dalles is one of the most remarkable places upon the Columbia"

LATER EXPLORERS, SURVEYORS, ENGINEERS, AND SCIENTISTS who passed through the Columbia River Gorge were motivated first by establishing U.S. ownership, then by the practical issue of navigation, and finally by the river's vast hydropower. Explorers, missionaries, and fur traders during the three decades after Lewis and Clark — such as Wilson Hunt, David Thompson, Peter Skeen Ogden, Nathaniel Wyeth, and Samuel Parker — reiterated Clark's observations of flow through multiple rock-bound channels, in particular noting the branching channels, the strong currents, and the intense whirlpools and boils. Government surveys during the 1840s and 1850s provided more hydrologic and geologic observations. A contingent of the U.S. Exploring Expedition under the command of the U.S. Navy's Charles Wilkes explored the Columbia River in the summer of 1841. This group, led by expedition artist Joseph Drayton and in the company of Ogden, described The Dalles while ascending the river in flood in early July. Wilkes summarized:

> The Dalles is one of the most remarkable places upon the Columbia. The river is here compressed into a narrow channel, three hundred feet wide, and half a mile

long; the walls are perpendicular, flat on the top, and composed of basalt.... The tremendous roar arising from the rushing of the river through this outlet, with the many whirlpools and eddies which it causes, may be more readily imagined than described.[13]

The Wilkes Expedition included geologist James Dwight Dana, who did not actually visit The Dalles but who recognized from Drayton's observations and samples that the basaltic rocks forming The Dalles of the Columbia were part of the regionally extensive lavas that covered the Columbia plains of eastern Washington and flanked the lower Snake and Columbia rivers.[14]

About two years later, in November 1843 (and in much lower water), John Charles Frémont's exploring party descended the Columbia, passing quickly by "the roar of the *Falls of the Columbia*" and then to the Long Narrows, where

the whole volume of the river at this place passed between the walls of a chasm, which has the appearance of having been rent through the basaltic strata which form the valley-rock of the region. At the narrowest place we found the breadth, by measurement, 58 yards, and the average height of the walls above the water 25 feet; forming a trough between the rocks.... The rock, for a considerable distance from the river, was worn over a large portion of its surface into circular holes and well-like cavities, by the abrasion of the river, which, at the season of high waters, is spread out over the adjoining bottoms.[15]

In early September 1855, Henry Abbot of the U.S. Corps of Topographical Engineers explored railroad routes between California and the Columbia River. Like Frémont, he described the Long Narrows at low water:

the river rushes through a chasm only about 200 feet wide, with vertical basaltic sides rising from 20 to 30 feet above the water.... There are many fine specimens of columnar basalt in this vicinity, and the banks rise in low basaltic terraces, which, on the northern side opposite the town [The Dalles], are very rough and broken.[16]

Accompanying Abbot was a young geologist, John Strong Newberry, whose career, like Dana's, would culminate in steering the study of U.S. geology in government and academia. Newberry reported: "The Dalles of the Columbia are formed by one of those beds of trap [basalt], through which the stream cuts in deep and narrow channels...."[17]

These observations from government exploratory parties were the first after William Clark's to provide geologic context for The Dalles of the Columbia. Newberry's descriptions of the basaltic rocks, the ragged rocky surfaces, and the inferences of fluvial-erosion are among the first

Carleton Watkins, photographer, OHS neg., OrHi 21648

An 1882 photograph by Carlton Watkins, looking west, shows the upstream entrance to the Long Narrows and the flanking "scabland." The Dalles–Celilo Portage Railroad runs through the foreground.

such writings in the Pacific Northwest. Dana and especially Newberry leveraged observations along the Columbia River and elsewhere in the Pacific Northwest into broad and still-held conclusions regarding processes and regional landscape evolution. The erosion required to form The Dalles seemed consistent with evidence elsewhere in the region of the great erosional capacity of large rivers. Newberry argued that this allowed the Columbia River to maintain a near sea-level route through a rising Cascade Range and thus anticipated by twenty years the concept of an "antecedent river," promoted by John Wesley Powell in his description of the Colorado River and the formation of the Grand Canyon.[18]

The press for navigational improvements and hydropower structures resulted in the first detailed surveys of The Dalles by the U.S. Engineers in October 1874, followed by additional surveys during the next few decades. These maps quantitatively show the rugged above-water topography and the marked widening and narrowing of the river, and they provide the

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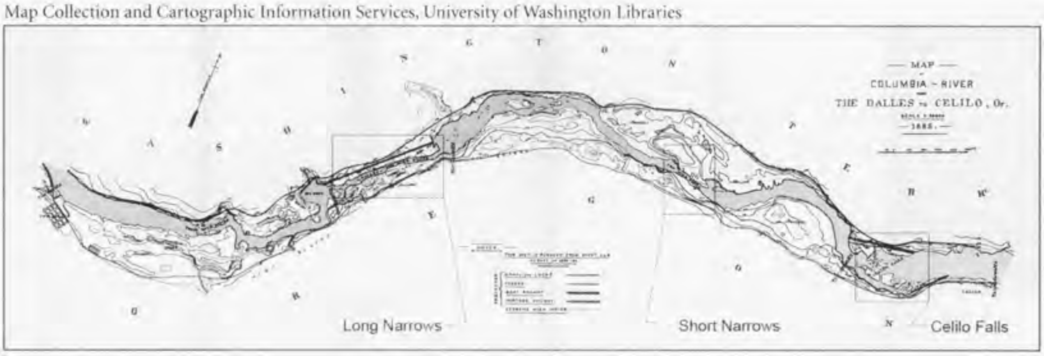


A map made in 1888 by the U.S. Army Corps of Engineers shows the Columbia River between Celilo Falls and the city of The Dalles (annotations added for this article). This reach of river, confined to bedrock slots and holes, was known as "The Dalles of the Columbia."

first measurements of the great depths of the channels; some rock-bound holes in Long Narrows sounded at 170 feet below the low-water surface, more than 100 feet below sea level.[19]

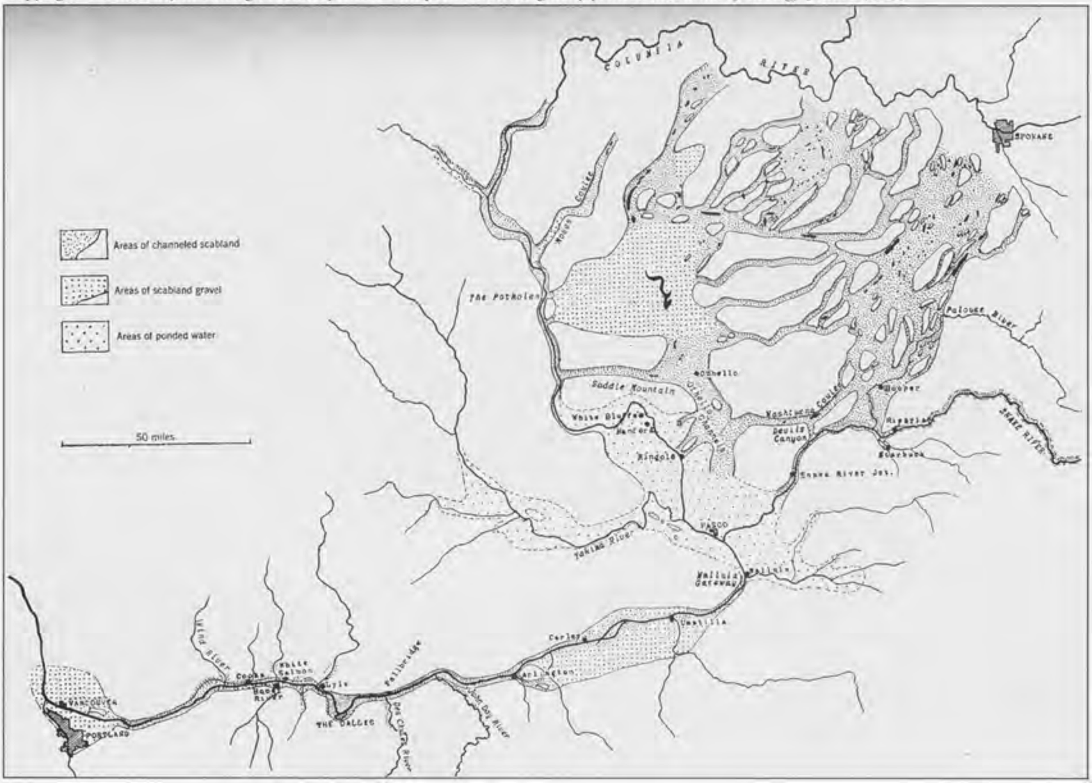
"All other hypotheses meet fatal objections"

THE 1874 TOPOGRAPHIC MAPPING by the U.S. Engineers and early twentieth-century U.S. Geological Survey topographic quadrangles showed the bizarre landscape of The Dalles and other places along the Columbia River. These were the maps that inspired J Harlan Bretz to hypothesize that a cataclysmic ice-age flood had carved what he called the "Channeled Scabland" of eastern Washington and the Columbia River Gorge.[20] Bretz's first experience in the gorge was in the summer of 1915, when he assisted geologist Ira Williams in describing the geology along the new highway linking Portland and The Dalles. In 1922, as a new faculty member in the geology department at the University of Chicago, Bretz returned to the Columbia River Basin with students to explore the landscape shown by the maps.[21] Like earlier explorers at The Dalles, he found flat, barren basalt flows with rugged and rocky surfaces, in some places gouged by huge holes and deep vertical slots. These features were episodically flooded by the raging Columbia during peak snowmelt; but in many other places in eastern Washington, such as Grand Coulee, similar landscapes were waterless. As he mapped the fluted, channeled, and potholed surfaces, he saw that they formed long anastomosing tracts of scabland separated by islands of softly rounded hills of windblown sand and silt cultivated by dryland wheat farmers.

In more than a dozen geological reports published between 1923 and 1932, Bretz built a case that these scablands had been eroded by a truly cataclysmic flood from a then-unknown source. He deduced that the flood had spilled out of the Columbia and Spokane river valleys in northern and eastern Washington, cutting rocky coulees hundreds of feet deep and miles wide southwest across eastern Washington, before regathering in Pasco Basin and following the Columbia valley westward through the gorge. Bretz asserted that the eroded scabland topography and nearby deposits of sand and gravel resulted from river channel processes, but at a valley scale. The streamlined mounds of gravel hundreds of feet high that flanked the coulees were not terraces left by rivers in earlier ages but immense flood bars deposited almost instantaneously in reaches of slacker current. The basalt benches resulted from plucking and erosion at the bottom of deep and fast currents that covered entire valley bottoms to depths of hundreds of feet. Finding that "all other hypotheses meet fatal objections," Bretz wrote: "These remarkable records of running water on the Columbia Plateau and in the valleys of the Snake and Columbia Rivers cannot be interpreted in terms of ordinary river action and ordinary valley development.... Enormous volume, existing for a very short time, alone will account for their existence."[22] In short, Bretz concluded that this landscape was formed in days, not eons.

"We are all now catastrophists"

Named the "Spokane flood" by Bretz in 1925 — but now more commonly called the Missoula Floods for their more recently discovered source in ice-dammed Lake Missoula — the "outrageous hypothesis" spurred three decades of sometimes acrimonious debate.[23] The issue was not just the genesis of peculiar scabland landscapes in the Pacific Northwest. It dove at the heart of accepted geological thinking. In the early 1900s, European and North American geology was less than a century past overcoming the doctrine that landscapes were formed from the Noachian flood. By the 1870s, science had embraced wholesale Charles Lyell's uniformitarianism — that landscapes form from slow, gradual, everyday processes operating over millions and millions of years. Bretz's cataclysmic flood explanation was a heretical return to catastrophism, "flaunting catastrophe too vividly in the face of the uniformity that had lent scientific dignity to interpretation of the history of the earth."[24] Although the first geologists in the region, Dana and Newberry, had



J Harlan Bretz's sketch map, which appeared in his article "The Spokane Flood beyond the Channel Scablands" in 1925, shows the region affected by the Spokane Flood.

recognized that extraordinary events had helped shape the landscape of the Pacific Northwest, some key figures in U.S. geology entered the fray, eager to show that the Channeled Scabland could be explained by "leisurely streams with normal discharge."[25]

The Columbia River Gorge was an important venue for this debate. Papers by Bretz in 1925 and 1928 described features in the gorge revealing erosion and deposition by floodwaters a thousand feet deep. Bretz calculated the flow rate to have been 70 million cubic feet per second, more than fifty times the largest historic Columbia River flood of 1894. Ira Allison of Oregon State College and Edwin T. Hodge of the University of Oregon were quick to form alternative explanations for flood features in the gorge, separately calling on complicated sequences of ice jams and gradual river downcutting to produce Bretz's flood features.[26] Thus, they provided a interpretation that "does not require a short-lived catastrophic flood but explains the scablands, the gravel deposits, diversion channels. . . . as the effects of a moderate flow of water, now here and now there, over an extended period of time. It thus removes the flood from the 'impossible' category."[27]

The Dalles of the Columbia in particular provided evidence for Bretz's case for the Spokane Flood. In a 1924 paper, "The Dalles Type of River Channel," Bretz linked the actual processes of basalt erosion to the resulting forms of the channeled scabland, especially focusing on the role that plucking by swirling river currents played in forming the large eroded holes, both in the present channel and on the flanking rocky surfaces.[28] He also related flat-topped knobs, straight and vertically bound rock channels, circular holes, and rough, hackly rock surfaces — classic scabland — to the plucking and impact abrasion of the extensively fractured but horizontally bedded basalt flows. Bretz linked the intense and swirling currents seen by Lewis and Clark to the erosional features at The Dalles and, by analogy, to scabland topography elsewhere, providing strong support that the waterless tracts of channeled and potholed basalts originated at the bottom of deep, swift, turbulent currents. The dry scabland tracts branching across eastern Washington could only be explained by flows that were vastly larger than any Columbia River flood viewed by early white explorers.

Despite Bretz's careful field observations and sound reasoning, much of the scientific community denied a cataclysmic origin for the channeled scabland. Not until a last field campaign in 1952 — specifically conducted to answer critics — coupled with aerial photographs and a new generation of less dogmatic geologists did Bretz's "outrageous hypothesis" become accepted. Bretz may have had his final satisfaction in 1965, when an international field expedition of geologists saw the channeled scabland at the end of a trip and telegrammed him with a message: "We are now all catastrophists."[29]

In 1957, one hundred and fifty years after Lewis and Clark's final portage eastward around Celilo Falls and only a year after Bretz silenced many critics of the Spokane Flood with the publication of his 1952 field study, the closing gates of The Dalles Dam stilled the "great roreing" of The Dalles of the Columbia. Nevertheless, echoes from the story of the ice-age flood still reverberate. Students of science in many fields learn about J Harlan Bretz and the Spokane Flood as a modern example of observation and careful reasoning triumphing over dogmatic paradigms. Geologists, geographers, and planetary scientists continue to draw from features of the Missoula Floods to understand the landscapes of other hugely flooded terrains in North America and Asia. As I write this, nearly 199 years after Lewis and Clark's portage over the "rugid black rock," the forefront of U.S. exploration is the probing by NASA's rovers, *Spirit* and *Opportunity*, which are crawling over now-waterless but perhaps similarly flooded and channeled terrains on Mars.[30] Back in October 1805, however, Lewis and Clark paddled downstream in their wooden canoes to landscapes transformed by even more recent cataclysms than the ice-age floods.

"the grand Schute"
"The Submerged Forest of the Columbia"

AFTER DESCENDING THE FINAL RAPIDS OF THE DALLES and onto a calmer Columbia River on October 25, 1805, the Corps of Discovery camped at "Fort Rock" near present-day The Dalles. On October 28, in adverse winds, rain, and little current, they pushed on into the heart of the Columbia River Gorge. Clark noted the change in topography, including the "high Mounts. on each side" and "Several places where the rocks projected into the river & have the appearance of haveing Separated from the mountains and fallen promiscuisly into the river," as well as several waterfalls on the south valley walls.[31]

In the reach between the Little White Salmon and Wind rivers, Clark described the "remarkable circumstance" of what became known as the "submerged forest of the Columbia" when he noted "a number of Stumps at Some distance in the Water."[32] Lewis's journal on their return trip in 1806 offers more description:

> throughout the whole course of this river from the [Cascade] rapids as high as the Chilluckkitequaws [Native American settlement near The Dalles], we find the trunks of many large pine trees s[t]anding erect as they grew at present in 30 feet water; they are much doated and none of them vegetating; at the lowest tide of the river many of these trees are in ten feet water.[33]

Continuing downstream, Lewis and Clark reached the "Commencement of the grand Schute," later known as Cascade Rapids, forty miles from Fort Rock. At low water, the Columbia River descended thirty-seven feet over a distance of eight miles, with twenty-one feet of fall accomplished in the first half mile at the main rapids.[34] As Clark described it:

> This Great Shute or falls is about ½ a mile with the water of this great river Compressed within the Space of 150 paces in which there is great numbers of both large and Small rocks, water passing with great velocity forming [foaming?] & boiling in a most horriable manner.[35]

G.K. Gilbert, photographer, U.S. Geological Survey

A view south across the Columbia River from near Stevenson, Washington, taken in 1899 shows snags of the "drowned forest" emerging from the lake-like portion of the river upstream from Cascade Rapids.

"many times may the trough of this masterful river have been partially or entirely clogged . . ."

LIKE THE DALLES, both the rapids and the submerged trees upstream were noted by early pioneers, explorers, and geographers, including Rev. Samuel Parker, Frémont, Drayton of the Wilkes Expedition, and Abbot and Newberry from the U.S. Corps of Topographical Engineers.[36] Cascade Rapids was later mapped and measured because of its importance to navigation, and the submerged forest attracted attention by its oddity. It was even noted in Lyell's 1833 edition of *Principles of Geology*.[37] Unlike The Dalles, the formation of Cascade Rapids and the submerged forest involved cataclysms of only a few hundred years ago, not several thousand. Also, the events at Cascade Rapids had direct and substantial effects on the ecology and human use of the lower Columbia.

Lewis and Clark interpreted the processes that may have formed the submerged forest and rapids. Before arriving at the rapids, Clark noted: "this part of the river resembles a pond partly dreaned leaving many Stumps bare both in & out of the water...." He continued: "... stumps of pine trees ... gives every appearance of the rivers damed up below from Some cause which I am not at this time acquainted with...."[38] Upon reaching Cascade Rapids on October 31, 1805, he saw how the rocks formed the rapids and completed the scenario:

those obstructions together with the high Stones which are continually brakeing loose from the mountain on the Stard [north] Side and roleing down into the Shute aded to those which brake loose from those Islands above and lodge in the Shute, must be the Cause of the rivers daming up to Such a distance above ...[39]

Lewis expanded on this on during their return:

certain it is that those large pine trees never grew in that position, nor can I account for this phenomenon except it be that the passage of the river through the narrow pass at the rapids has been obstructed by the rocks which have fallen from the hills into that channel within the last 20 years; the appearance of the hills at that place justify this opinion, they appear constantly to be falling in, and the apparent state of the decayed trees would seem to fix the era of their decline about the time mentioned.[40]

These interpretations, which resemble present thinking, were the first of many advanced by explorers, geographers, and geologists over the next hundred years. Reverend Parker described navigating through the "forest" of submerged trees in 1835, looking for evidence that the trees themselves had slid down from the adjacent valley slopes or that there was a downstream dam. Finding no evidence of either, he concluded: "It is plainly evident that here has been a subsidence of a tract of land, more than twenty miles in length, and about a mile in width."[41] Daniel Lee and Joseph Frost, also missionaries, disagreed with Parker and explained, much like Lewis and Clark did:

The supposition that a *subsidence* has occurred here appears groundless. Admit a dam at the Cascades, and these appearances perplex no more, their origin seems natural. At the Cascades there are indications that the stream has left its former bed, in which its course was westward, and abruptly turning to the south, rushes and plunges down in that direction nearly a mile.[42]

In late June 1841, Drayton of the Wilkes Expedition, traveled up the river at very high flow and, as Wilkes described it:

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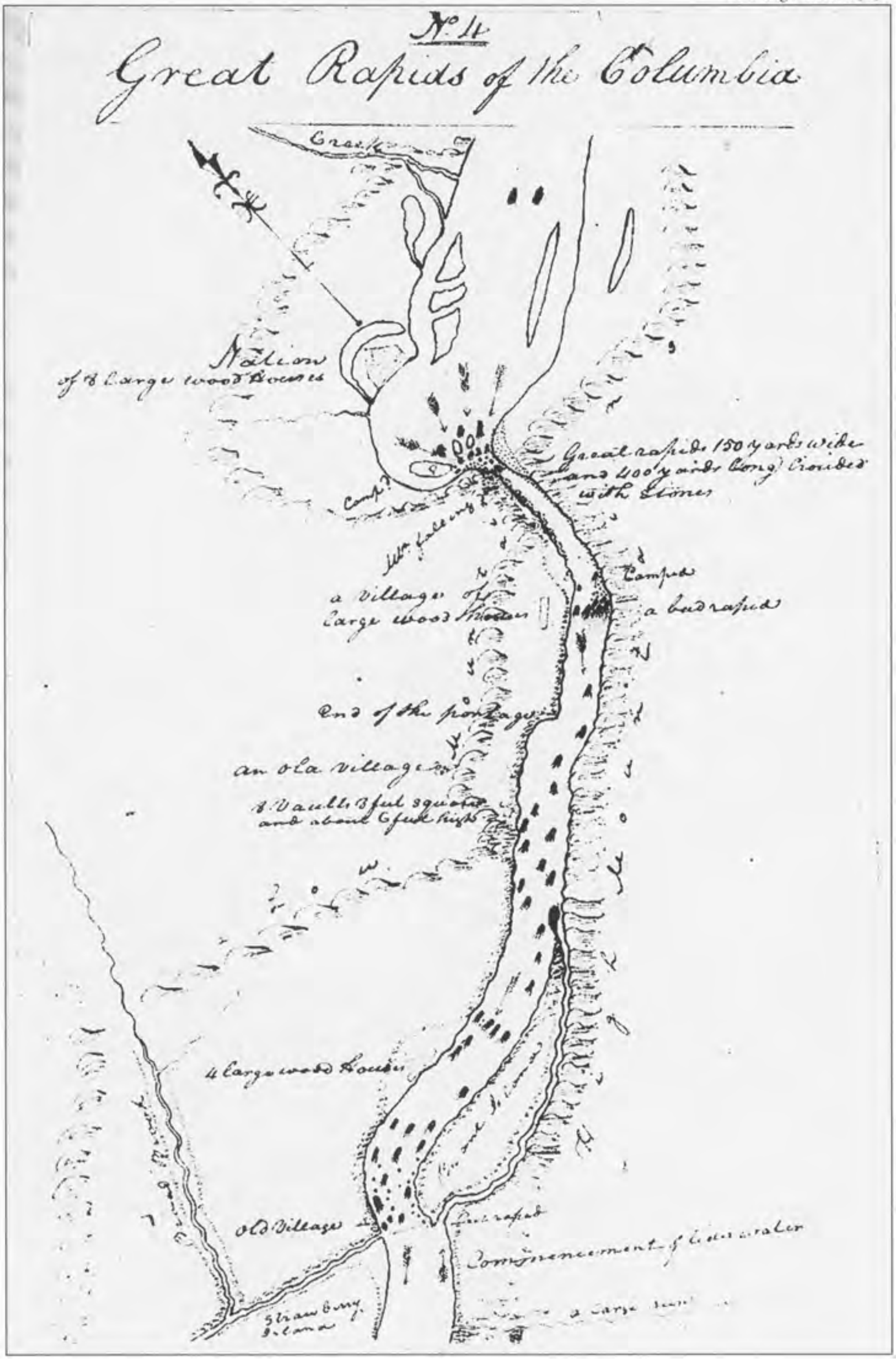

William Clark sketched this map of Cascade Rapids and described the area in the journals on October 31, 1805. The expedition members passed the rapids again on their return trip.

He is of opinion that the point on which the pine forest stands, has been undermined by the great currents during the freshets; and that it has sunk bodily down until the trees were entirely submerged.[43]

Two years later, in November 1843, Frémont's expedition navigated the river at low flow and on November 17 recorded:

These collections of dead trees are called on the Columbia the *submerged forest*, and are supposed to have been created by the effects of some convulsion which formed the cascades, and which by damming up the river, placed these trees under water and destroyed them. But I venture to presume that the cascades are older than the trees; and as these submerged forests occur at five or six places along the river, I had an opportunity to satisfy myself that they have been formed by immense land-slides from the mountains, which here closely shut in the river, and which brought down with them into the river the pines of the mountain.[44]

The first professional geologist to comment on the Cascade Rapids and the submerged forest was Newberry, attached to Abbot's 1854-1855 Pacific Railroad Survey. Reporting from observations on September 17 and 18, 1855, he wrote:

...the river is bordered on either side by the erect, but partially decayed, stumps of trees, which project in considerable numbers above the surface of the water. This has been termed the sunken forest, and has been generally attributed to slides from the sides of the mountains, which have carried down into the bed of the stream the standing trees. This phenomenon is, however, dependent on a different cause. As I have mentioned, the vicinity of the falls has been the scene of recent volcanic action. A consequence of this action has been the precipitation of a portion of the wall bordering the stream into its bed. This impediment acting as a dam, has raised the level of the water above the Cascades, giving to the stream its lake-like appearance, and submerging a portion of the trees which lined its banks. Of these trees, killed by the water, the stumps of many are still standing, and by their degree of preservation attest the modern date of the catastrophe.[45]

Subsequent geologists advocated even more scenarios. In 1870, Samuel F. Emmons, a geologist with Clarence King's Geological Exploration of the Fortieth Parallel, proposed that the river in its downcutting through the Cascade Range encountered an opening in an underlying layer of erodible rock and "thus for a certain distance the whole Columbia would run underground," only later to "gradually wear away the supports of the overhanging sheet of basalt" until the natural bridge collapsed, leaving "the river dammed up to the present level." In 1887, Clarence Dutton, a geologist with the newly consolidated U.S. Geological Survey, proposed that broad crustal upwarping near Cascade Rapids caused upstream im-

U.S. Army Corps of Engineers

This aerial view westward (downstream) from an elevation of about two thousand feet, taken in 1929, shows the main drop of Cascade Rapids where the Columbia River has been diverted southward around the toe of the Bonneville landslide. At the left is Cascade Locks, completed in 1896, which facilitated steamship travel upriver of the rapids. The Bridge of the Gods, completed in 1926, took advantage of the natural constriction of the Columbia between the eroded toe of the Bonneville landslide and the southern valley margin. The bridge still stands at its present location but was raised about forty feet during construction of Bonneville Dam to accommodate ship traffic on the pool that now drowns Cascade Rapids.

poundment. In 1899, G.K. Gilbert, a renowned early USGS geologist, first speculated that the large land mass diverting the river south at Cascade Rapids was perhaps a moraine left by large glaciers flowing through the gorge during the last ice age; a month later, he stated that a landslide was responsible for the blockage. USGS geologist Joseph Silas Diller hedged his bets, suggesting in 1916 that uplift, faulting, or landsliding were all plausible explanations.[46]

In 1916, Ira A. Williams (assisted by Bretz) sealed the case with detailed descriptions of the topography and stratigraphy of the area surrounding Cascade Rapids, proclaiming in his geologic guidebook for the newly opened Columbia River Highway:

> It is no far-drawn speculation that at times large bodies of rock would suddenly slump from these cliffs into the river. Particularly would this be expected from the Table [M]ountain side where so favorable and unsubstantial a combination of strata still exists. We are not at all certain but that many times may the trough of this masterful river have been partially or entirely clogged and its current checked if not actually ponded by gigantic landslides. . . . What more natural then, than that the latest of these cataclysmic slides of which the channel is not yet wholly cleared, may have swung the river far aside and formed temporarily so much of a barrier as to completely dam the river, and even to permit passage across of the native inhabitants.[47]

This report was the first published statement of current thinking: an immense landslide slid from the northern gorge walls and blocked the Columbia River, forcing the river to cut a new course to the south, circling five miles around the toe of the landslide. The large rocks forming Cascade Rapids are debris within the landslide that are too large for the Columbia River to remove. The submerged forest upstream was the former valley bottom forest. The Douglas fir, western red cedar, and white oak were once rooted above the level of annual floods but then were submerged by the lake-like river kept forty feet high by the remaining impediment of Cascade Rapids.

"The Indians say these falls are not ancient"

THE CASCADE, OR BONNEVILLE, LANDSLIDE was well-studied over the next two decades as a consequence of dam-siting analyses leading to the 1934–1938 construction of Bonneville Dam.[48] The most systematic analysis of the submerged forest was spurred by the impending additional submergence in the pool behind the dam. Donald B. Lawrence, a Portland resident working on a doctorate in botany at Johns Hopkins University, counted, mapped, and photographed the drowned forest during low water in 1934 and 1935.[49] He tabulated more than eighteen hundred trees singly and in groups in the twenty-five miles above Cascade Rapids. Lawrence determined that the lowest of the submerged snags were rooted at only 33.5 feet above sea level, similar to maximum flood stages downstream of Cascade Rapids. This showed that no such rapids (or any significant river gradient) could have existed when the trees were growing.[50]

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On August 30, 1934, Donald B. Lawrence posed at the site of the submerged forest near Wyeth, Oregon, where several snags protruded from the beach and water at low water.

One of Lawrence's objectives was to determine the age of the landslide and the Cascade Rapids. The well-preserved drowned snags hinted of recentness, and Lewis and Clark suggested that the trees were killed only about twenty years before their visit. Lawrence used dendrochronology to find out. By counting and measuring widths of annual rings from sawn sections of the drowned trees and finding overlapping periods of years by ring-width patterns in nearby live trees, he might cross-date the death of the snags that presumably drowned within months after the landslide dammed the river. With this approach, Lawrence did document that four of the six submerged trees died the same year, but he found no overlap between the drowned trees and the three live trees that he analyzed and so could not determine the precise year. He could only conclude that the submerged trees must have drowned sometime before the germination of the oldest measured live tree in about 1735. Lawrence later searched the landslide debris itself and found from ring counts that the oldest growing tree germinated in 1562, presumably some time after the tumultuous event. In 1958, two decades after the closure of Bonneville Dam, Lawrence submitted two retained samples of the submerged forest to the then-new technique of radiocarbon dating. These gave age estimates of about seven hundred years ago, leading Lawrence to conclude that the landslide and resulting tree submergence had occurred in about 1250. More recent work, including more accurate radiocarbon dating of some of Lawrence's original samples, tentatively indicates that the trees died in about 1450.[51]

The Native American legends describing the Bridge of the Gods, supposedly a natural bridge or blockage across the Columbia River, were either ignored or romanticized into fanciful tales of debacles and debauchery by early observers. But Thomas Condon, a missionary and later Oregon's first state geologist, sifted through oral histories of Cascade Rapids and The Dalles. Coupling these accounts with his own observations and inferences, Condon in 1869 recognized some of the possible ecological and cultural consequences of the events forming Cascade Rapids and the submerged forest.[52] Foremost was the creation of a new barrier to human navigation and fish passage: "The Indians say these falls are not ancient, and that their fathers voyaged [from the sea] without obstruction in their canoes as far as The Dalles."[53] The later portage required at Cascade Rapids surely affected the movement of people and goods across the Cascade Range, helping to make the area a natural toll gate and trading center.[54] The numerous Native American settlements recorded by Lewis and Clark near Cascade Rapids reflect the abundant fishing and commerce there. Most or all of these sites and others abandoned nearby have been shown by archaeological studies to postdate the Bonneville landslide.[55]

The Bonneville landslide and Cascade Rapids must have affected the migration of that icon of the Pacific Northwest, salmon. At first, the landslide blocked the Columbia River — and passage — completely. Then, after being overtopped by the impounded river, upstream migration was surely slowed by long, steep rapids. An outstanding question is: "For how long did the Bonneville landslide completely block the Columbia River?" Surrounding topography suggests a temporary dam as high as 240 to 300 feet, matching the cumulative height of today's dams at Bonneville, The Dalles, and John Day and perhaps backing up water as far upstream as Wallula Gap. For modern flow rates of the Columbia River, this natural dam would overtop in only three to eight months, after which the river eventually incised a new channel through and around it. If erosion of a new channel through the blockage — reducing the total river fall around and through the landslide from perhaps more than two hundred feet at first to about thirty-seven feet at the time of Lewis and Clark — took more than a few years, then upriver salmon pasage would have been either stopped or significantly diminished in the years or decades after the landslide.

More indirectly but perhaps more significant in the long term, the formation of Cascade Rapids may also have enabled fish passage upstream at The Dalles of the Columbia. The Columbia River had not eroded through the landslide dam completely but left the thirty-seven-foot drop (at low flow) of Cascade Rapids through bouldery debris. By elevating the upstream river surface, Cascade Rapids may have acted as a natural fish ladder, facilitating passage over the chutes and falls of The Dalles. Condon suggested so:

> The five miles of rapids we now call the Cascades have a total fall of thirty-seven feet. If thirty feet of this were, by any cause, now transferred fifty miles above to the other fall at the Tumwater [Celilo Falls, with a low flow drop of about twenty feet], the result would certainly be a barrier to all further progress upward of the salmon of the Columbia.[56]

Essentially, Condon proposed that Columbia Basin salmon runs upstream of Celilo postdate the landslide, now known to have been in about 1450, implying that the historically huge salmon runs of the upper basin developed in just a few hundred years. This conclusion remains speculative, but aspects may have merit. While recent archaeological research documents at least some early Native American consumption of salmon at upstream sites, some accounts of Native American oral histories suggest little or no upstream fish passage prior to the formation of Cascade Rapids.[57] The pre-rapids passage conditions through The Dalles are not well understood. Condon's premise that total river fall at Cascade Rapids was concentrated at Celilo Falls prior to the landslide is unlikely. Then-steeper descents through the intervening rapids of the Short and Long

Narrows probably accommodated some of the additional thirty-seven feet of fall. Yet, the total drop at low water (and probably high flow) through the total length of The Dalles, including Celilo Falls, would have been about one hundred and twenty feet instead of the post-Cascade Rapids drop of about eighty feet. This higher gradient surely hindered passage, perhaps eliminating upstream salmon migration during periods of low flow because of taller falls at the Narrows or Celilo.

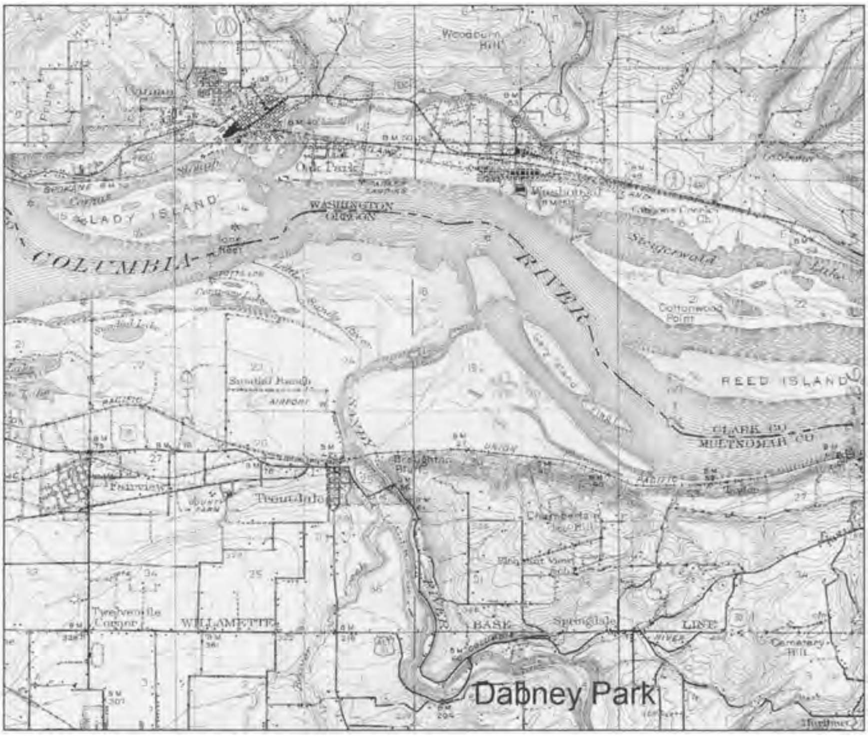
Like The Dalles of the Columbia, Cascade Rapids and the submerged forest now lie beneath a reservoir. The submerged forest, whose roots are even more deeply drowned than before, fell like much of the bottomland forests of the Columbia valley — by the saw. To reduce navigation hazards in Bonneville Reservoir, the U.S. Army Corps of Engineers cut down most of what remained of the "remarkable circumstance" of "Stumps at Some distance in the Water" that Clark reported on October 30, 1805.[58]

A "Conocal form Covered with Snow" and the "The quick Sand river"

THE CASCADE RANGE near the Columbia River Gorge is built up of volcanic rocks erupted over the last 40 million years. Crowning the range are volcanoes such as Mount Hood and Mount St. Helens, which have risen in the last million years or so and were repeatedly active in the centuries before Lewis and Clark. Clark's maps show the general extent of the Cascade Range, which he called the "Western Mountains," but it is not evident that Lewis and Clark knew that the snow-clad peaks were volcanoes.[59] Yet, by describing the terrain as they emerged from the Columbia River Gorge, they inadvertently documented effects of a Mount Hood eruption of two decades before. Thus, their maps and descriptions have geological value beyond historical anecdote by providing timely observations of the effects of Cascade Range eruptions on the Columbia River.

On November 2, 1805, Lewis and Clark's expedition completed its portage around the "Grande Schute" and floated "on down a Smooth gentle Stream" of the lower Columbia River as it exits its gorge through the Cascade Range. Here, Clark noted, "the river widens to near a mile, and the bottoms are more extensive and thickly timbered, as also the high mountains on each Side." On the morning of November 3, after camping on the Oregon side, probably near present-day Corbett Station, Clark walked three miles downstream along wide, sandy beaches flanking the Oregon shore. He "halted at the mouth of a large river on the Lard [south] Side, This river throws out emence quanty of <quick> Sand and is verry

U.S. Geological Survey



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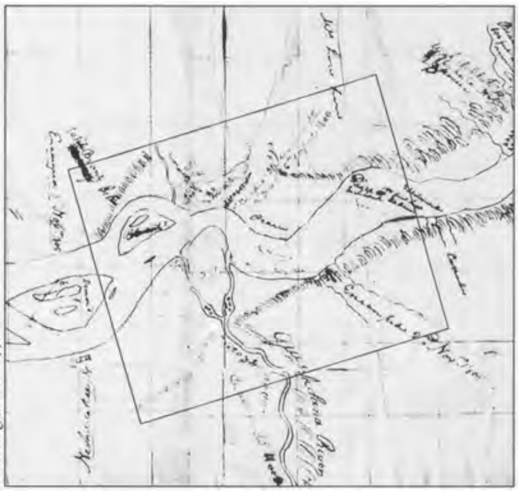

Part of a 1942 USGS topographic quadrangle map (Camas, Washington, above) shows the boxed area on a detail of Clark's 1805–1806 map (left) of the confluence of the Columbia and the "quick Sand River" (Sandy River).

Shallow . . . much resembling the river Plat[te]."[60] In his second entry for the day, he repeated that he:

arrived at the enterance of a river which appeared to Scatter over a Sand bar, the bottom of which I could See quite across and did not appear to be 4 Inches deep in any part; I attempted to wade this Stream and to my astonishment found the bottom a quick Sand, and impassable.... Capt Lewis and my Self walked up this river about 1½ miles to examine this river which found to be a verry Considerable Stream Dischargeing its waters through 2 Chanels which forms an Island of about 3 miles in length on the river and 1½ miles wide, composed of Corse Sand which is thrown out of this quick Sand river Compressing the waters of the Columbia and throwing the whole Current of its waters against its Northern banks, within a Chanel of ½ a mile wide.[61]

In the three miles Clark traversed from their camp to the upper (eastern) channel of what is now known as the Sandy River, the Lewis and Clark Expedition probably passed the uppermost landing point of the party of Lt. W.R. Broughton, commander of the H.M.S. *Chatham,* who was part of Capt. George Vancouver's British expedition that was surveying the Pacific coast.[62] On October 30, 1792, thirteen years before Lewis and Clark were in the gorge, Broughton's party landed on "Possession Point," a

high sandy point of the River, from whence we had a beautiful view of a very remarkable high mountain, whose summit, and a considerable extent below it, was covered with Snow, and presented a very grand view, this Captn Broughton named Mount Hood, the breadth of the River here was between a quarter and half a mile, and depth of the water 6 fathoms.[63]

This point of land is now referred to as the Sandy River Delta, a low plain of about six square miles jutting northward from where the Sandy River emerges from its canyon at Troutdale. The two channels of Lewis and Clark's maps and descriptions correspond to the two distributary branches of twentieth-century maps. While Broughton's chart shows only a single channel that evidently joined the Columbia about a mile downstream of Lewis and Clark's westernmost channel, both exploring parties agree on the narrowness of the Columbia River off the northern apex of the delta — a quarter to a half mile wide — in contrast to the two-and-a-half-mile width estimated by Lewis and Clark at their November 2 campsite upstream. The present-day width is nearly a mile at the same place where Lewis and Clark's map shows the Columbia being its most narrow.[64]

Lewis and Clark were attentive to the "quick Sand" River upon their return trip, for it was the only watercourse they had seen to drain the immense area between the Cascade Range and the Coast Range south of the Columbia River. While camped across the Columbia from the east branch of the Sandy River from March 31 to April 6, 1806, they learned from visiting Native Americans that another river — the Mult-no-mâh, now called the Willamette — entered downstream, its mouth hidden from the explorers by islands. They were also told that "quick Sand river was Short only headed in Mt. Hood which is in view . . . and is distant from this place about 40 miles." On April 1, three men led by Sergeant Prior were dispatched up the Sandy River. They reported: ". . . the bead [bed] of this river is formed entirely of quick Sand; its banks are low and at present overflown. the water is turbed and current rapid."[65]

As later geological studies show, the prominent Sandy River Delta, the constricted and north-pushed Columbia River, and the sand-laden Sandy River observed by Lewis and Clark owe their existence to the recent eruptive history of Mount Hood. Much of the delta is formed of sand and lahars — mudflows or debris flows shed from slopes of volcanoes — deposited during and just after Mount Hood eruptions of about the year 500.[66] Those deposits displaced the river two miles northward and onto the old volcanic rocks of Ione Reef and Missoula Flood mega-boulders of Ough Reef. But the Sandy River's coarse sandbed and extensive sandbars, which Lewis and Clark recorded in 1805-1806, and Broughton's 1792 "sand bank," which crosses the Columbia River near the mouth of the Sandy River (called by him the Baring River), were deposited by far younger eruptions. An eruptive episode at Mount Hood, termed the "Old Maid" eruption, probably started in the winter of 1781-1782, only eleven years before Broughton and twenty-four years prior to Lewis and Clark. Clark's map of the Sandy River Delta shows areas of active sand deposition and corresponds closely to modern maps of Old Maid deposits.[67] This indicates that twenty-four years after the beginning of the eruption, the Sandy River channel was still aggrading the huge volume of sediment dumped into its headwaters. Sergeant Prior's April 1 six-mile ascent of the Sandy River to where the river "appeared to bend to the East" must have ended near present-day Dabney State Park, where the exploring party would have walked on a sandy channel bed nearly fifty feet above the present cobble-gravel channel.[68]

At various places on the journey, Lewis and Clark saw all five high Cascade Range volcanoes visible from the Columbia: Mount Rainier, Mount Adams, Mount St. Helens, Mount Hood, and Mount Jefferson. First seen was Mount Hood shortly after reaching the Columbia River on their westward trip, its "Conocal form Covered with Snow." Last viewed was Mount Jefferson, which they named for their sponsor on March 30, 1806.[69] All of these volcanoes have likely affected the Columbia River several times during the last several hundred thousand years, but Mount Hood and Mount St. Helens have repeatedly sent lahars and eruption-related sediment to the Columbia River in the past twenty-five hundred years. These eruptions and the resulting downstream sedimentation built extensive valley bottoms, not just the Sandy River Delta but also where the Lewis and Cowlitz rivers join the Columbia near present-day Woodland and Longview, Washington. A substantial volume of sediment probably entered the Columbia River via the Lewis, Kalama, and Cowlitz rivers after the Mount St. Helens eruptions of 1480-1482, just a few decades after the Bonneville landslide.[70] The May 18, 1980, eruption of Mount St. Helens, which transformed "the most noble looking object of its kind in nature" into its present cratered form, sent a lahar down the Toutle and then the Cowlitz River all the way to the Columbia, depositing 50 million cubic yards of sediment in the Cowlitz River channel and filling the Columbia River with another 45 million cubic yards.[71] Without the extensive dredging and sediment control structures emplaced by the U.S. Army Corps of Engineers in the early 1980s, it is likely that the mouth of the Cowlitz River would now, twenty-four years after the 1980 eruption of St. Helens, look much like the "verry Shallow" and "turbed" Quick Sand River viewed by Lewis and Clark in 1805, two dozen years after the 1781 start of the Old Maid eruption on Mount Hood.

LEWIS AND CLARK'S EXPLORATION of an overland route to the Pacific more than marks a historical turning point for the Columbia River. Their records of the physical landscape and those by the explorers, geographers, and geologists who came after them underlie current understanding of the special geologic situation of the Columbia River Gorge, one that is largely a product of geologic cataclysms. Instead of a landscape of slow geologic processes involving unfathomable "millions and millions of years," as is typically droned out in visitor-center narrations throughout the West, the floods, landslides, and volcanic eruptions shaping the Columbia River Gorge involved tremendous forces over time periods ranging from days to decades. Unraveling the cataclysmic origin of the Columbia River landscape has altered geologic thinking and prompted understanding of other mysterious landscapes throughout the world and even on other planets.

Lewis and Clark did not set out to change geologic paradigms. Their orders were to describe local conditions, and they noted the effects of the various cataclysms of the Columbia because of their influence on human activities. The Dalles and Cascade Rapids hindered navigation, promoting human development that took advantage of resulting trading and natural

Courtesy Terry Toedtemeier

Carleton Watkins's The Rapids, Upper Cascades, Columbia River, Oregon, *taken in 1883, gives a sense of the power of the water as it passed over the rocks in this area.*

resource opportunities; at first, fisheries and portaging services but later bridges, locks, and dams. Sediment shed during eruptions has built out extensive bottomlands along the Columbia, many hosting Native American settlements before Lewis and Clark and now the site of airports, river ports, highways, towns, and crops. The recent ages of some of the geologic events that formed these features show quite emphatically that the pre-1805 landscape — including the land, people, and ecosystems — was not static but one of drastic and dramatic change. It is almost certain that the productive fishery and numerous Native American villages at Cascade Rapids did not exist before about 1450, and it is possible that the immense salmon runs of the upper Columbia River Basin may postdate this time. The large volcanic eruptions of Mount Hood in about 500 and again in the 1780s, as well as the large Mount St. Helens eruptions of about 1480, almost certainly had large effects on the Columbia River and the ecosystems and occupants that depended on it.

Many of these geologic cataclysms mirror modern alterations to the Columbia River within the Columbia River Gorge. Modern dams are analogous to the blockage by the Bonneville landslide in about 1450. Large sediment pulses into the river from volcanic eruptions are analogous to, but far larger than, sedimentation caused by land-use practices. The huge Missoula Floods of the last ice age reshaped and locally dredged the Columbia River channel beyond the deepest dreams of the U.S. Army Corps of Engineers. Yet, the tremendous natural resources sustaining the Native American populations at the time of Lewis and Clark attest to the resilience of the Columbia ecosystem in the face of such huge disturbances, even ones of just a few decades or centuries before. For some, the recovery by the Columbia River to past geologic cataclysms could give hope that the "very romantic sceens" beheld by Lewis and Clark only two hundred years ago — a wild and noisy Columbia River boiling and swirling through falls and chutes, the tremendous fisheries in the main stem and tributaries, thick forests carpeting the river bottoms and canyon walls, and the crowded flocks of waterfowl gathering in the annually flooded bottomlands — will once again be seen, perhaps within the next two hundred years.[72]

Notes

My work on the geology of the Columbia River Gorge has been in collaboration with Richard Waitt, Tom Pierson, Alex Bourdeau, Patrick Pringle, and Nathan Reynolds. Reviews by Waitt, Pierson, Bourdeau, Miriam Garcia, John Williams, and Gordon Grant improved this manuscript.

1. For recent summaries emphasizing changes to the Columbia River, see Richard White, *The Organic Machine: The Remaking of the Columbia River* (New York: Hill and Wang, 1995); and William Dietrich, *Northwest Passage: The Great Columbia River* (New York: Simon and Schuster, 1995).

2. J.E. Allen et al., *Cataclysms on the Columbia* (Portland, Ore.: Timber Press, 1986).

3. Subhead quote from President Thomas Jefferson's instructions to Capt. Meriwether Lewis, June 20, 1803, in Donald Jackson, ed., *Letters of the Lewis and Clark Expedition*, 2 vols., 2nd ed. (Urbana: University of Illinois Press, 1978), 1:61–6. For a full description of Lewis and Clark's landscape observations, see John A. Moody et al., *Lewis and Clark's Observations and Measurements of Geomorphology and Hydrology, and Changes with Time*, U.S. Geological Survey Circular 1246 (Reston, Va.: GPO, 2003).

4. John Playfair, *Illustrations of the Huttonian Theory of the Earth* (Edinburgh: William Creech, 1802); Charles Lyell, *The Principles of Geology* (1830–1933; reprint, New York: Johnson Reprint, 1969). For a history of the science of landform development, see Keith J. Tinkler, *A Short History of Geomorphology* (Totowa, N.J.: Barnes and Noble, 1985).

5. See Mary C. Rabbitt, *Minerals, Lands, Geology for the Common Defense and General Welfare*, 3 vols. (Washington, D.C.: GPO, 1979–1986). See also Richard A. Bartlett, *Great Surveys of the American West* (Norman: University of Oklahoma Press, 1962); and William H. Goetzmann, *Exploration and Empire: The Explorer and the Scientist in the Winning of the American West* (New York: Alfred A. Knopf, 1966).

6. Richard B. Waitt, "Quaternary Research in the Northwest 1805–1979 by Early Government Surveys and the U.S. Geological Survey, and Prospects for the Future," in *Frontiers of Geological Exploration of Western North America*, ed. Alan E. Leviton et al. (San Francisco: American Association for the Advancement of Science, Pacific Division, 1982), 167–207.

7. Lewis and Clark chronology, observations, and quotes are from Gary E. Moulton, ed., *The Definitive Journals of Lewis and Clark*, vols. 2–8 (Lincoln: University of Nebraska Press, 2002).

8. See Lewis A. McArthur and Lewis L. McArthur, *Oregon Geographic Names*, 7th ed. (Portland: Oregon Historical Society Press, 2003), 945–6. See also Clark, October 24, 1805, in Moulton, ed., *Journals*, 5:331.

9. Clark, October 24, 25, 1805, April 16, 1806, in Moulton, ed., *Journals*, 5:333.

10. Ibid., 322, 324.

11. Clark, October 24, 1805, in ibid., 333.

12. Ibid., 331.

13. Charles Wilkes, *Narrative of the United States Exploring Expedition, during the Years 1838, 1839, 1840, 1841, 1842* (Philadelphia: C. Sherman, 1844), 4:411.

14. James D. Dana, *United States Exploring Expedition, during the Years 1838, 1839, 1840, 1841, 1842, Under the Command of Charles Wilkes, U.S.N., Geology* (New York: Putnam, 1849), 10:645–8.

15. Samuel M. Smucker, *The Life of Col. John Charles Frémont, and his Narrative of Explorations and Adventures, in Kansas, Nebraska, Oregon and California* (New York: Miller, Orton and Mulligan, 1856), 321–2.

16. Henry L. Abbot, *Explorations for a Railroad Route, from the Sacramento Valley to the Columbia River made by Lieut. R.S. Williamson, Corps of Topographical Engineers*, vol. 6, pt. 1 of *Reports of Explorations and Surveys, to Ascertain the Most Practicable and Economical Route for a Railroad from the Mississippi River to the Pacific Ocean* (Washington, D.C.: A.O.P. Nicholson, 1857), 88.

17. J.S. Newberry, *Geological Report, Routes in California and Oregon Explored by Lieut. R.S. Williamson, Corps of Topographical Engineers*, vol. 6, pt. 2, no. 1, of *Reports of Explorations and Surveys*, 54.

18. Ibid., 53–5. John Wesley Powell, in *Exploration of the Colorado River of the West and Its Tributaries, 1869–1872* (Washington, D.C.: GPO, 1875), 152–3, defines an "antecedent" river as one that maintains its course through a rising geologic structure, as the Columbia River has through the Cascade Range. A "consequent" river's course is imposed on it by adjacent structures, such as the Willamette River, which is confined between the crests of the Cascade and Coast ranges.

19. N. Michler, 1 inch to 600 feet scale map, The Dalles to Celilo, U.S. Engineers, September 1874, copy at Reference Library, Oregon Historical Society, Portland [hereafter OHS Reference Library]. See J H. Bretz, "The Dalles Type of River Channel," *Journal of Geology* 32 (1924): 139–49, for calculation of closed depressions. Measurements are based on L.F. Harza and V.H. Reineking, *The Columbia River Power Project near The Dalles, Oregon*, Bulletin no. 3 (Salem, Ore.: Office of the State Engineer, 1913).

20. Bretz's first published paper outlining evidence of huge floods was "Glacial Drainage on the Columbia Plateau," *Bulletin of the Geological Society of America* 34 (1923): 573–608. The term "channeled scabland" was first defined in J H. Bretz, "The Channeled Scablands of the Columbia Plateau," *Journal of Geology* 31 (1923): 617–18, and was drawn from the local terms "scabland" and "scabrock," describing "areas where denudation has removed or prevented the accumulation of a mantle of soil, and the underlying rock is exposed or covered largely with its own coarse, angular debris."

21. I.A. Williams, "The Columbia River Gorge: Its Geologic History Interpreted from the Columbia River Highway," *The Mineral Resources of Oregon* (Oregon Bureau of Mines and Geology) 2 (November 1916): 18. See also V.R. Baker, "The Spokane Flood Controversy," in *The Channeled Scabland*, ed. V.R. Baker and D. Numamedal (Washington, D.C.: National Aeronautics and Space Administration, 1978), 3–14. A popular account appears in Allen et al., *Cataclysms on the Columbia*.

22. Bretz, "Channeled Scablands," 621; J H. Bretz, "The Spokane Flood beyond the Channeled Scablands," *Journal of Geology* 33 (1925): 259. See also Baker, "Spokane Flood Controversy," 3–14.

23. See Bretz, "Spokane Flood," 98; Bretz, "The Lake Missoula Floods and the Channeled Scabland," *Journal of Geology* 77 (1969): 509; Bretz, "Bars of the Channeled Scabland," *Bulletin of the Geological Society of America* 39 (1928): 701.

24. E.C. Olson, introduction to Bretz, "Lake Missoula Floods," 503.

25. R.F. Flint, "Origin of the Cheney-Palouse Scabland Tract," *Bulletin of the Geological Society of America* 49 (1938): 472.

26. E.T. Hodge "Geology of the Lower Columbia River," *Bulletin of the Geological Society of America* 49 (1938): 898–911.

27. I.S. Allison, "New Version of the Spokane Flood," *Bulletin of the Geological Society of America* 46 (1933): 677.

28. Bretz, "Dalles Type of River Channel," 139–49.

29. Bretz, "Channeled Scabland," 957–1049; Bretz, "Lake Missoula Floods," 541.

30. Bretz et al., "Channeled Scabland," 957–1049. See also V.R. Baker, *The Channels of Mars* (Austin: University of Texas Press, 1982); and D.M. Burr et al., "Recent Aqueous Floods from the Cerberus Fossae, Mars," *Geophysical Research Letters* 29 (2002).

31. Clark, October 30, 1805, in Moulton, ed., *Journals*, 5:355–6.

32. Ibid., 354–5.

33. Lewis, April 14, 1806, in Moulton, ed., *Journals*, 7:118.

34. Clark, October 30, 1805, in Moulton, ed., *Journals*, 5:355. Information on the water surface

profile is in an October 1874 survey conducted by Maj. N. Michler of the U.S. Engineers. This map as well as a reduced plan and profile show a "low water" drop of 37.3 feet between the upper and lower landings. At the time of the survey, when the water was 4.5 feet above extreme low water, the total drop was 36.7 feet, with 21.1 feet of the descent in the uppermost half mile of the rapids. Copies of the maps are in the collection of the OHS Research Library.

35. Clark, October 31, 1805, in Moulton, ed., *Journals*, 5:363.

36. Summaries of early accounts of the submerged forest are given in J.N. Barry, "The Drowned Forest of the Columbia Gorge," *Washington Historical Quarterly* 26 (1935): 119–22; and more completely in D.B. Lawrence, "The Submerged Forest of the Columbia River Gorge," *Geographical Review* 26 (1936): 583–5.

37. Charles Lyell, *The Principles of Geology* (1833; reprint, New York: Johnson Reprint, 1969), 190.

38. Clark, October 30, 1805, in Moulton, ed., *Journals*, 5:354–6.

39. Clark, October 31, 1805, in ibid., 363.

40. Lewis, April 14, 1806, in Moulton, ed., *Journals*, 7:118.

41. S. Parker, *Journal of an Exploring Tour Beyond the Rocky Mountains Under the Direction of the A.B.C.F.M. in the Years 1835, 36 and 37*, 3rd ed. (Ithaca, N.Y.: Mack, Andrus and Woodruff, 1842), 141.

42. D. Lee and J.H. Frost, *Ten Years in Oregon* (New York: J. Collard, 1844), 200.

43. Wilkes, *United States Exploring Expedition*, 4:407.

44. Smucker, *Life of Col. John Charles Frémont*, 335.

45. Newberry, *Geological Report*, 56.

46. Emmons, "Submerged Trees," 156–7; Dutton, "Submerged Trees," 82–4; J.S. Diller et al., *Guidebook of the Western United States, part D, The Shasta Route and Coast Line*, USGS Bulletin 614 (Washington, D.C.: GPO, 1916), 27. Emmons's paper is the only one to suggest an actual rock bridge over the Columbia River, and it may have inspired F.H. Balch's *The Bridge of the Gods, a Romance of Indian Oregon* (Chicago: A.C. McClurg, 1890). On Gilbert's speculation that the blockage was a glacial moraine, see field note entry for August 12, 1899, in his Notebook 3479, RG 57, Records of the USGS, National Archives, Washington, D.C., 87; documentation of a landslide origin is in his field notes for September 4–12, 1899, Notebook 3480, in ibid., 15–33.

47. Williams, "Columbia River Gorge," 92–3.

48. An irony perhaps is that the Bonneville landslide created one of the few suitable dam sites along the lower Columbia River. Reports detailing the geologic conditions of the Bonneville Dam site include R.L. Schuster and P.T. Pringle, "Engineering History and Impacts of the Bonneville Landslide, Columbia River Gorge, Washington–Oregon, USA," in *Landslides: Proceedings of the First European Conference on Landslides*, ed. J. Rybar et al. (Exton, Penn.: A.A. Balkema, 2002), 689–99; and J.W. Sager, "Bonneville Dam," in *Engineering Geology in Washington*, ed. R. Glaster, Washington Division of Geology and Earth Resources Bulletin 78:1 (1989): 337–46. Early dam-site studies were conducted by E.T. Hodge. See Hodge, *Report of Dam Sites on Lower Columbia River* (Portland, Ore.: Pacific Division, Corps of Engineers, U.S. Army, 1932).

49. *Oregonian*, August 8, 1935.

50. Lawrence, "Submerged Forest," 581–92.

51. Ibid., 590–1; D.B. Lawrence and E.G. Lawrence, "Bridge of the Gods Legend, Its Origin, History and Dating," *Mazama* 40:13 (December 1958): 40–1. Four recent radiocarbon dates (unpublished results, Jim O'Connor and others, USGS, Portland, Ore.) from two of Lawrence's original samples of the "submerged forest" (in the collection of the World Forestry Center, Portland, Ore.) indicate tree death was between 1415 and 1455. Additional attempts at cross-dating are underway by Patrick Pringle of the Washington State Department of Natural Resources.

52. E.T. Drake, "Pioneer Geologist Thomas Condon of Oregon: Scientist, Teacher, Preacher," in Leviton et al., eds., *Frontiers of Geological Exploration*, 77; Thomas Condon, "Geological Notes from Oregon," *Overland Monthly* 3:4 (1969): 355–60, reprinted in Condon, *The Two Islands and What Came of Them* (Portland, Ore.: J.K. Gill, 1902), 177–82.

53. D. Lee and J.H. Frost, *Ten Years in Oregon* (New York: J. Collard, 1844), 200.

54. Stephen Dow Beckham, "This Place Is Romantic and Wild: An Historical Overview of the Cascades Area, Fort Cascades, and the Cascades Townsite, Washington Territory," *Heritage Research Reports*, no. 27, to Portland District, U.S. Army Corps of Engineers, 1984.

55. S.D. Beckham et al., "Prehistory of the Columbia River Gorge National Scenic Area, Oregon and Washington," *Heritage Research Reports*, no. 75, U.S. Department of Agriculture Forest Service, Columbia River Gorge National Scenic Area, 1988. For information on Native American oral histories of the Bridge of the Gods, see Lawrence and Lawrence, "Bridge of

the Gods," 33; E.E. Clark, "The Bridge of the Gods in Fact and Fancy," *Oregon Historical Quarterly* 53 (March 1952): 29–38.

56. Condon, "Geological Notes," 180.

57. J.C. Chatters et al., "A Paleoscience Approach to Estimating the Effects of Climatic Warming on the Salmonid Fisheries of the Columbia River Basin," in *Climate Change and Northern Fish Populations*, ed. R.J. Beamish (Ottawa: Canadian Special Publications in Fisheries and Aquatic Sciences 121, 1995), 489–96. See Lee and Frost, *Ten Years in Oregon*, 197; Condon, "Geological Notes from Oregon," 177; and Lawrence and Lawrence, "Bridge of the Gods Legend," 41.

58. Lawrence and Lawrence, "Bridge of the Gods Legend," 41.

59. Clark, March 31, 1806, in Moulton, ed., *Journals*, 7:41.The first clear description of the Cascade Range as a volcanic chain was by Dana of the 1841 Wilkes Expedition in *United States Exploring Expedition*, 10:625–6, 640. See also E.L. Orr et al., *Geology of Oregon*, 4th ed. (Dubuque, Iowa: Kendall/Hunt, 1992), 141–66.

60. Clark, November 2, 3, 1805, in Moulton, ed., *Journals*, 6:8–9, 11. There is some uncertainty regarding their campsite location for the night of November 2. Moulton (6:10) suggested a location near the present site of Latourell, but a location fitting better with Clark's map and descriptions, especially the estimate of three miles to the Sandy River confluence, would be two miles farther west, near present-day Corbett Station, perhaps at Tunnel Point or Onion Rock.

61. Clark, November 3, 1805, in Moulton, ed., *Journals*, 6:12.

62. A copy of Broughton's chart is at the OHS Research Library. Vancouver's narrative of Broughton's observations near the Sandy River confluence were published in T.C. Elliot, "The Log of the H.M.S. *Chatham*," *Oregon Historical Quarterly* 18 (June 1917): 73–82. Another log of Broughton's expedition, presumably written by Edward Bell, a clerk on the *Chatham*, was published in J.N. Barry, "Columbia River Exploration, 1792," pts. 1 and 2, *Oregon Historical Quarterly* 33 (March 1932): 31–42; 33 (June 1932): 143–55.

63. Entry in Bell's journal for October 27, 1792, in Barry, "Columbia River Exploration, 1792," 33:145.

64. Gary E. Moulton, ed. *Atlas of the Lewis and Clark Expedition*, vol. 1 of Moulton, ed., *Journals* (Lincoln: University of Nebraska Press, 1983), map 79.

65. Clark, March 31, April 1, 1806, in Moulton, ed., *Journals*, 7:41, 51.

66. The eruptive history of Mount Hood is described in D.R. Crandell, *Recent Eruptive History of Mount Hood, Oregon, and Potential Hazards from Future Eruptions*, USGS Bulletin 1492 (Reston, Va.: GPO, 1980); and K.A. Cameron and P.T. Pringle, "A Detailed Chronology of the Most Recent Major Eruptive Period at Mount Hood, Oregon," *Bulletin of the Geological Society of America* 99 (1987): 845–51.

67. Elliot, "Log of the H.M.S. *Chatham*," 81; P.T. Pringle et al., "A Circa A.D. 1781 Eruption and Lahars at Mount Hood, Oregon: Evidence from Tree-Ring Dating and from Observations of Lewis and Clark in 1805–6," *Geological Society of America Abstracts with Programs* 34:6 (2002): 511; Moulton, ed., *Atlas*, map 79. Ongoing studies of the Sandy River Delta area are being conducted by Elizabeth Rapp, Portland State University, and Jim O'Connor and Thomas Pierson of the USGS.

68. Lewis, April 1, 1806, in Moulton, ed., *Journals*, 7:49; unpublished data courtesy of Thomas Pierson, U.S. Geological Survey, Vancouver, Wash..

69. Clark, October 18, 1805, March 30, 1806, in Moulton, ed., *Journals*, 5:298, 7:36.

70. See D.R. Mullineaux and D.R. Crandell, "The Eruptive History of Mount St. Helens," in *The 1980 Eruptions of Mount St. Helens, Washington*, USGS Professional Paper 1250, ed. P.W. Lipman and D. R. Mullineaux, USGS Bulletin 1492 (Washington, D.C.: GPO, 1981), 3–16.

71. Lewis, March 30, 1806, in Moulton, ed., *Journals*, 7:33; R.L. Schuster, "Effects of the Eruptions on Civil Works and Operations in the Pacific Northwest," in Litman and Mullineaus, eds., *1980 Eruptions of Mount St. Helens*, 708–9.

72. Lewis, April 14, 1806, in Moulton, ed., *Journals*, 7:118.