ROADSIDE GEOLOGY OF
MOUNT ST. HELENS
NATIONAL VOLCANIC MONUMENT
AND VICINITY

by Patrick T. Pringle
Shaded relief map of the Mount St. Helens area showing areas affected by 1980 eruption processes. The image was created from 30 m digital elevation data.
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by Patrick T. Pringle

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(360) 891-5206
www.mshinstitute.org

Front Cover. Mount St. Helens from the north shore of Spirit Lake, about 7 mi
(11 km) north-northeast of the crater. Photo taken in 1982 by Lyn Topinka, U.S.
Geological Survey.

Back Cover. Mount St. Helens from the Longview "Y" Camp, circa 1937. Courtesy
of the Washington State Historical Society; original photo by Claude Palmer of
Photo Art Studios, Inc., Portland, Oregon.

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Dick Janda at the lahar source area on the debris avalanche on May 24, 1980. Photo by Barry Voight, Pennsylvania State University.

DEDICATION

To Richard “Dick” Janda (1939–1992). Dick's understanding of volcanic processes and hazards at Mount St. Helens was surpassed only by his spirited efforts to communicate his insights to public officials and the general public. He remains a great inspiration to friends and colleagues.

PREFACE

This guidebook is largely a compilation of research by many investigators who for decades have been examining the geologic history, structure, and processes of the Mount St. Helens area. I will acknowledge some of the principal sources of information below because I have included few references in the text in order to make it read more smoothly.

Much of the eruptive history of Mount St. Helens has been taken from the reports of U.S. Geological Survey (USGS) geologists Dwight Crandell, Donal Mullineaux, and Jack Hyde (deceased); Cliff Hopson (Univ. of Calif. at Santa Barbara) also contributed many details. Post-1980 erosion exposed previously unstudied deposits. Examination of those rocks, combined with new understanding and technological advances, has resulted in refinement of the eruptive history. USGS geologists Kevin Scott and Jon Major expanded the history of lahars in the Toutle–Cowlitz and Lewis River drainages. Brian Hausback (Calif. State Univ. at Sacramento) and Don Swanson (USGS) discovered ancient debris-avalanche deposits exposed in gullies cut after 1980, and Chris Newhall (USGS) identified similar deposits south of the volcano. The interdisciplinary collaborations of Rick Hoblitt, John Pallister, Dwight Crandell, and Donal Mullineaux (all USGS) with dendrochronologist
David Yamaguchi and botanist Donald Lawrence (Univ. of Minn., deceased) have resulted in a much improved and amazingly detailed history of the two eruptive periods that preceded the modern eruption. The history of Tertiary rocks in the area has been updated by new or recently published mapping by Russ Evarts, Roger Ashley, and Don Swanson (all USGS), Paul Hammond (Portland State Univ.), and Tim Walsh, Bill Phillips, Josh Logan, Hank Schasse, and Mike Korosec (all Wash. Dept. of Natural Resources, Divn. of Geology and Earth Resources).

Interpretations of the eruptive events and eruptive processes of May 18, 1980, and later eruptions have been compiled from USGS Professional Paper 1250 and other reports too numerous to mention. Tom Pierson, Kevin Scott, Dick Janda, and Ken Cameron (all USGS), as well as Lee Fairchild and Mark Wigmosta (both Univ. of Wash.), are among those who studied lahar processes in detail. For discussions of the blast density flow, I borrowed heavily from the publications of Richard Fisher (Univ. of Calif. at Santa Barbara), Tim Druitt (Univ. of Wales), and USGS geologists Rick Hoblitt, Richard Waitt, Dan Miller, Susan Kieffer, Steve Brantley, and Harry Glicken (deceased), and others whose investigations have provided many new insights about this unprecedented event at the volcano. Glicken's ideas, as well as those of Barry Voight (Penn. State Univ.) and Dick Janda, were the basis for much of my discussion of the debris avalanche. He described the geology of the debris-avalanche deposit in great detail in his Ph.D. dissertation and in several papers. Elliott Endo and Craig Weaver (both USGS), Steve Malone (Univ. of Wash.), and others have greatly improved the understanding of the seismicity and subsurface structure of the volcano. Don Swanson, Tom Casadevall, Christina Heliker, Bill Chadwick, Dan Dzurisin, John Ewert, Tom Murray, Robin Holcomb, Don Peterson, Jim Moore, Norm MacCloud, and Gene Iwatsuba (all USGS), Mac Rutherford (Brown Univ.), Katharine Cashman (Univ. of Ore.), Steven Carey and Haraldur Sigurdsson (Univ. of R.I.), Bill Criswell (Univ. of N.Mex.), Cathie Hickson (Geological Survey of Canada), and many others have added to our understanding of eruptive processes at Mount St. Helens since 1980. Tom Dunne and Brian Collins (both Univ. of Wash.), Dick Janda, Dave Meyer, and Holly Martinson (all USGS), Fred Swanson (U.S. Forest Service), Hugh Mills (Tenn. Tech. Univ.), and others have written extensively about post-eruption erosion and deposition. Ed Wolfe and Mike Clynne (USGS) continue to investigate and map the pre-eruption history of Mount St. Helens.

Finally, I thank the following reviewers for their critical, thoughtful, and inspiring comments on the text: Don Swanson, Richard Waitt, Russ Evarts, Steve Brantley, Peter Frenzen, Ken and Ellen Cameron, Kitty Reed, Bill Phillips, Eric Schuster, and Tim Walsh. Jari Roloff edited the text, designed and laid out the pages, and had numerous helpful review suggestions. Former State Geologist Ray Lasmanis supported this project from its earliest stages. Nancy Eberle designed the front and back covers and collaborated on the design and illustrations. Keith Ikerd prepared overlays for the photographs. Keith Ronnholm, Barry Voight, Rick Hoblitt, Charlie Larson, Lyn Topinka, Jon Major, the Washington State Historical Society, and Photo Art Studios, Inc., kindly allowed me to use their photographs. Dave Wieprecht and Dave Hirst (USGS) provided agency photos. My wife Leslie contributed valuable field assistance and moral support during this project. All figures and photographs are by the author unless otherwise noted.

I am grateful to the staff of the U.S. Forest Service at Mount St. Helens National Volcanic Monument for assistance and partial funding for this project through a challenge cost-share agreement.

Pat Pringle
May 2002
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INTRODUCTION

Welcome to the Mount St. Helens National Volcanic Monument, which was established by Congress in 1982 and is managed by the U.S. Forest Service. The monument was created to protect the unique environment formed by the 1980 eruptions of Mount St. Helens.

This road guide describes and interprets geologic features at diverse sites in the monument and surrounding area. It complements other published natural history and geologic guidebooks and can be used in conjunction with maps of the Mount St. Helens National Volcanic Monument available at the Mount St. Helens Visitor Center at Silver Lake on State Route (SR) 504 and at information stations along roads leading to the monument.

This booklet examines five aspects of Mount St. Helens geology: (1) pre-Mount St. Helens rocks and their history, (2) glacial history and glacial deposits of the area, (3) pre-1980 history and activity of Mount St. Helens volcano, (4) post-1980 eruptions and deposits, and (5) ongoing processes of erosion and landscape modification.

HOW TO USE THIS GUIDE

The text consists of four parts: Part I is an introduction to the geologic history of the Mount St. Helens area and a summary of the 1980–1986 eruptions; Part II is a road guide to the geology of Mount St. Helens and vicinity; Part III explains geologic processes and terminology; and Part IV contains a list of references cited, plus selected references for further reading, followed by a glossary.

The road guide provides general descriptions of the rocks and geologic history of specific areas, as well as more detailed explanations of features at roadside stopping points. It follows several major routes (Fig. 1) to the volcano: (A) the western approach along the Toutle River valley on the new Spirit Lake Memorial Highway, SR 504; (B) the southern approach along the lower Lewis River valley and the south flanks of the mountain via SR 503 and Forest Road (FR) 83; (C) the eastern approach, which includes stops along FRs 90, 25, and 99; (D) FR 99 to Windy Ridge; (E) the northern approach along the Cowlitz River valley via U.S. Highway 12, SR 131, FR 25, and FR 99; (F) the alternate northern approach via FR 26; and (G) the alternate southern loop on FR 81.

Units of measure: Measurements throughout the text are given in standard English units (feet, miles) followed by metric units (meters, kilometers) in parentheses (Table 1).

Units of geologic time: Geologists use some compact abbreviations to express geologic time. For example, Ma stands for mega-annum or million years. Points in
Figure 1. Location map of the Mount St. Helens area showing the national monument, major rivers, and various routes of the road guide. Symbols shown here are those used on maps throughout this guide.
Table 1. Metric equivalents for English units. To get the number of metric units, multiply the number of English units by the metric equivalent.

<table>
<thead>
<tr>
<th>English unit</th>
<th>Metric equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 inch</td>
<td>2.540 centimeters</td>
</tr>
<tr>
<td>1 foot</td>
<td>0.305 meter</td>
</tr>
<tr>
<td>1 yard</td>
<td>0.914 meter</td>
</tr>
<tr>
<td>1 yard$^3$</td>
<td>0.765 meter$^3$</td>
</tr>
<tr>
<td>1 mile</td>
<td>1.609 kilometers</td>
</tr>
<tr>
<td>1 mile$^2$</td>
<td>2.590 kilometers$^2$</td>
</tr>
<tr>
<td>1 mile$^3$</td>
<td>4.168 kilometers$^3$</td>
</tr>
<tr>
<td>1 ton, short</td>
<td>0.907 tonne</td>
</tr>
</tbody>
</table>

Geologic time, such as the upper and lower age limits of the Oligocene Epoch, are written as 22.7 Ma and 36.6 Ma, meaning 22,700,000 years and 36,600,000 years. Or a bed deposited in the Pliocene might have an age of 3.4 Ma. Time spans, however, are indicated by the abbreviation m.y., again meaning million years. The Oligocene Epoch lasted about 14 m.y. For ages expressed in thousands of years, the abbreviation ka, for kilo-annum, is used. Thus, a certain glacial deposit has an age of 140 ka, indicating 140,000 years. Time intervals are simply expressed as thousands of years; there is no handy abbreviation like m.y. You will see these conventions used throughout this book. Table 2 is a quick reference for these and other abbreviations used in the text.

Radiocarbon dates: Age estimates for geologic units less than about 40,000 years old that have been derived by radiocarbon ($^{14}$C) dating methods are given as "yr B.P.", meaning "radiocarbon years before present" where the "present" is A.D. 1950. Radiocarbon years can differ slightly from calendar years because of variations in the carbon isotope content of atmospheric carbon dioxide through time. Tree ring data have been used to recalibrate these ages back to about 11,000 years ago. However, for the sake of simplicity, raw radiocarbon ages are used in this guide. However, tree-ring dates for Mount St. Helens deposits laid down since A.D. 1480 are given in calendar years.

Glossary: A glossary of geologic terms is provided at the end of Part IV. Glossary entries are italicized the first time they appear in each section.

A few words about safety: If you are driving alone and using this guidebook, please do not try to read it and drive at the same time. Instead, pull off the road into a designated turnout or parking area, then find the information you need. Better yet, share the field trip with a friend or friends, and let them do the navigating and reading while you drive. Rubbernecking to look at geologic features can

Table 2. Abbreviations used in text

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.D.</td>
<td>anno Domini (year of [our] Lord)</td>
</tr>
<tr>
<td>cm</td>
<td>centimeter(s)</td>
</tr>
<tr>
<td>ft</td>
<td>foot, feet</td>
</tr>
<tr>
<td>FR</td>
<td>Forest Road</td>
</tr>
<tr>
<td>Gl.</td>
<td>glacier</td>
</tr>
<tr>
<td>hr</td>
<td>hour(s)</td>
</tr>
<tr>
<td>I-</td>
<td>Interstate Highway</td>
</tr>
<tr>
<td>in.</td>
<td>inch(es)</td>
</tr>
<tr>
<td>ka</td>
<td>kilo-annum or thousand years</td>
</tr>
<tr>
<td>km</td>
<td>kilometer(s)</td>
</tr>
<tr>
<td>m</td>
<td>meter(s)</td>
</tr>
<tr>
<td>mm</td>
<td>millimeter(s)</td>
</tr>
<tr>
<td>Ma</td>
<td>mega-annum or million years</td>
</tr>
<tr>
<td>mi</td>
<td>mile(s)</td>
</tr>
<tr>
<td>m.y.</td>
<td>million years (time span)</td>
</tr>
<tr>
<td>s</td>
<td>second(s)</td>
</tr>
<tr>
<td>SR</td>
<td>State Route</td>
</tr>
<tr>
<td>US</td>
<td>U.S. Highway</td>
</tr>
<tr>
<td>yr B.P.</td>
<td>radiocarbon years before present</td>
</tr>
</tbody>
</table>
Figure 2. Small phreatic eruption at Mount St. Helens on May 11, 1980. Dashed line shows the approximate outline of the bulge. The graben, a down-dropped block, formed as the bulge was pushed outward by the rising magma. View is to the south and shows the Dogs Head, Sugar Bowl, and Goat Rocks dacite domes. Photo by Robert Krimmel, U.S. Geological Survey.

be dangerous on the narrow, winding roads that lead to and traverse the national monument.

Note: Gas stations are sparse in this area, so it advisable to plan ahead.

Etiquette for visitors in the Mount St. Helens National Volcanic Monument: The monument is a natural laboratory. Scientists (both professional and amateur) are studying geologic deposits, ongoing volcanic processes, and recovery of the landscape and its inhabitants. Please respect this landscape and any scientific plots, equipment, or experiments you may come across in your explorations. Please stay on designated trails and refrain from taking pumice, ash, rock, or plant
Figure 3. View to the north-northwest of the Plinian eruption column of Mount St. Helens during the early afternoon of May 18, 1980. Note the trace of the pyroclastic surge and lahar on Muddy fan downslope from Shoestring Glacier (lower right). Photo by Robert Krimmel, U.S. Geological Survey.

samples from inside the boundaries of the national monument. And always pack your litter out!

SUMMARY OF RECENT ERUPTIVE ACTIVITY AND HAZARDS

Mount St. Helens awakened with earthquakes on March 20, 1980, after 123 years of dormancy. The volcano produced a phreatic or steam eruption on March 27. After two more months of activity, including numerous earthquakes and relatively mild steam eruptions (Fig. 2), Mount St. Helens erupted cataclysmically on May 18, 1980, at 8:32 A.M. This large eruption was characterized by a huge landslide (débris avalanche), an explosive lateral blast, numerous pyroclastic flows, devastating volcanic debris flows and mudflows (called lahars) that flowed down river valleys originating on the volcano, and a tremendous tephra plume that injected ash into
Figure 4. Generalized diagram showing the devastation caused by the climactic eruption of Mount St. Helens on May 18, 1980. The singe zone is at the periphery of the area affected by the blast. Other symbols used are identified in Figure 1. Modified from Lipman and Mullineaux (1981).
the stratosphere for more than 9 hours (Figs. 3 and 4). The 1979 summit elevation of Mount St. Helens was 9,677 ft (2,951 m). It was reduced to 8,365 ft (2,551 m) and 0.6 mi$^3$ (2.5 km$^3$) of material was removed by the May 18 eruption. (For a discussion of volcanic processes, see p. 103 and Table 9.)

The May 18 event ranks as one of the most significant natural disasters in the United States this century. Some aspects of this eruption, like its tremendous lateral blast, were unprecedented in scale at Mount St. Helens and had never been witnessed or documented elsewhere from such close range. The debris avalanche was the largest landslide in recorded history. Intensive study of these volcanic events and their deposits and close observation of the volcano during its recent eruptive activity have led to far-reaching advances in volcanology (the science of volcanic studies) and to increased international cooperation in the study of volcanic hazards and the development of volcano monitoring technology (see p. 33).

Five additional explosive eruptions followed during the summer and fall of 1980. Each of these events produced plumes of ash that reached altitudes of 4 to 8 mi (6–13 km) and numerous pyroclastic flows. For all except the October eruption, small domes grew following the explosive event and then were blown away by subsequent eruptions.

Between late 1980 and 1986, 17 distinct eruptive episodes (Fig. 5) constructed a 876-ft (267 m) -tall lava dome. This dome is a large mound of viscous lava that cooled as it piled up over the vent area in the center of the gaping 1-mi (1.6 km) -wide crater created on May 18, 1980. Each of these dome-growth episodes produced between 3 million and 10 million yd$^3$ (2 million and 8 million m$^3$) of lava. On several occasions, small explosions accompanied the build-up of pressure preceding the eruption.

Typically, thousands of volcanic earthquakes precede the eruption of lava at Mount St. Helens by a few weeks or months. These earthquakes are caused as the viscous magma forces its way through brittle rocks to the surface. When the mag-
Figure 6. Lava Dome as seen from the south, showing the lobe of lava extruded on October 21 and 22, 1986. The thin lines in the snow on the west crater floor are thrust and tear faults that developed before this extrusion. Thrust faults are parallel to the perimeter of the dome, and tear faults are radial to it. Rubbly remnants of other lobes are visible on the dome surface. Also shown are the graben formed during the May 1985 eruption and The Spillover, where the 1980 debris avalanche spilled over Johnston Ridge. Note the east-dipping beds of Tertiary rocks north of the volcano. Photo by Lyn Topinka, U.S. Geological Survey.

ma finally pushes into the dome and leaks to the surface as lava, it adds to the dome’s height and width. The most recent dome growth episode occurred in October of 1986 (Fig. 6).

Since 1986, the volcano has been quiet except for occasional explosions and ash plumes reaching altitudes as high as 3.5 mi (5.6 km) above sea level. These explosions have thrown rocks more than 1,000 yd (1 km) from the dome, formed small pyroclastic flows in the crater, and have generated small lahars that flowed more than 10 mi (16 km) from the volcano down its north flank. Although they
have generated widespread public interest, these recent explosions have been confined to the crater and nearby areas.

Inside the crater, rockfalls are common, and these remain significant hazards to researchers who enter the crater between October and May. In winter, snow avalanches off the Lava Dome and from the crater walls have been large enough to flow out of the crater.

Geologists have found evidence suggesting that the reservoir of magma that fed the 1980 to 1986 eruptions is much larger than the volume of material erupted during that time. Therefore, there is plenty of magma remaining to supply future eruptions. The top of the magma chamber is about 4 mi (7 km) below the surface (Fig. 7). The magma in the narrow conduit beneath the Lava Dome has probably cooled and become solid, so future additions to the dome will likely be preceded by explosive activity as the volcano clears its throat and the magma forces its way through this crystallized plug to the surface.

Scientists expect major volcanic eruptions at Mount St. Helens to be preceded by days, weeks, or months of earthquake activity. During a major eruptive event, hazards would include tephra falls, explosive ejections of rocks, pyroclastic flows and surges, lava flows, lahars, and floods and would definitely extend outside the crater. Figure 8 is a preliminary hazards map showing the areas most likely to be affected. However, small explosions can occur in the crater without warning and might not be associated with an impending eruption. (A more detailed discussion of volcanic hazards is found on p. 35.)

The U.S. Geological Survey (USGS) maintains a network of monitoring devices and keeps the Forest Service and other public agencies informed about conditions at the volcano, including any significant changes in its activity. In the meantime, the biggest hazard to visitors in the Mount St. Helens National Volcanic Monument is the routine danger of traffic mishaps.

PHYSIOGRAPHY OF THE SOUTHERN WASHINGTON CASCADES

Mount St. Helens is a young addition to the landscape. The volcano sits on a glaciated and eroded mostly volcanic terrain composed of faulted, gently folded Tertiary bedrock. (The Tertiary Period lasted from about 65 Ma to 1.6 Ma.)

Resistant granitic rocks and the recrystallized (hornfelsed) rocks bordering them compose the high peaks north of the volcano. These mountains were the source areas of large glaciers that occupied several river valleys in this part of Washington during glacial episodes that preceded the birth of Mount St. Helens a little more than 40,000 years ago. Most older peaks in the monument reach elevations between 4,000 and 6,000 ft (1,200 and 1,800 m), and valley bottoms are at 1,000 to 3,000 ft (300–900 m).

Three river systems drain the volcano. Swift and Pine Creeks, along with the Smith Creek–Muddy River system, drain into the west-flowing Lewis River south of Mount St. Helens (see Fig. 1). The North and South Fork Toutle Rivers, which drain the north and west sides of the mountain, join to form the Toutle River, a tributary to the Cowlitz River. The Kalama River drains the southwest flank of Mount St. Helens and flows into the Columbia River north of Kalama. The Lewis River, which drains the south and east flanks, joins the Columbia slightly south of Woodland, WA, and the Cowlitz flows into the Columbia at Longview. All these valleys have been affected by eruptions from Mount St. Helens over its more-than-
**Figure 7.** Simplified geologic cross section of Mount St. Helens and the east-tilted Tertiary rocks that underlie it, as seen from the north. Several types of intrusive features are also shown. Older dacite consists of domes erupted during the Pine Creek eruptive period, about 3,000 to 2,500 yr B.P. (See p. 27.) The magmatic plumbing system of the volcano as inferred from seismic data is also shown. Definitions of geologic terms used in this figure can be found in the glossary at the end of the book. Modified from Evarts and others (1987) and Pallister and others (1992).
Figure 8. This preliminary volcanic hazards map, redrawn from one prepared by the U.S. Geological Survey (U.S. Forest Service, 1992), shows hazard zones close to the volcano that could be at great risk in the event of a major eruption. These areas would be evacuated and closed to the public. Such eruptive activity is typically preceded by a systematic increase in seismic activity that would give adequate warning. Symbols used are identified in Figure 1.

40,000-year history, and volcanic debris reaches thicknesses of hundreds of yards or meters in the upper reaches of these valleys.

Most of the modern Mount St. Helens edifice was formed within the last 3,000 years (Fig. 7). Younger deposits sit on top of older dacite that Jean Verhoogen (1937, p. 19) called "old Mount St. Helens". (A detailed summary of the volcano's history can be found on p. 24.)
PART I: HISTORY OF THE MOUNT ST. HELENS AREA

EARLY ACCOUNTS AND EXPLORATION OF THE AREA

"I was suddenly awakened by my mother, who called out to me that the world was falling to pieces. I then heard a great noise of thunder overhead and all the people crying in terror. Something was falling very thick, which we first took to be snow but proved to be ashes, which fell to a depth of six inches."

from an interview of Cornelius or Bighead (chief of the Spokane Tribe, whose Indian name was Silimxnotylmilakabok)
taken from an account of the 1800 eruption by Charles Pickering (Wilkes, 1845)

"The clearness of the atmosphere enabled us to see the high round snowy mountain....I have distinguished by the name Mount St. Helens, in honor of his Britannic Majesty's ambassador at the Court of Madrid [Alleyne Fitzherbert, the Lord of St. Helens]."

Master George Vancouver, October 20, 1792 (Vancouver, 1929)

"It is emensely high and covered with snow." "...a kind of cone in the form of a Sugar lofe...the most noble looking object of its kind in nature."

Lt. William Clark, Nov. 4, 1805, and March 30, 1806, near Vancouver, WA (Thwaites, 1959)

American Indians, Explorers, and Pioneers

Native cultures in the Pacific Northwest, such as the Salish and Klickitat Indians, called Mount St. Helens Loo-Wit Lat-kla or Louwala-Clough (fire mountain or smoking mountain). In their legends, a female spirit (Mount St. Helens) tried to make peace between two sons (Mounts Adams and Hood) of the Great Spirit who fought over her, throwing fiery rocks at each other and causing earthquakes. The warring of the sons destroyed the Bridge of the Gods that once crossed the Columbia River. These legends are undoubtedly referring to volcanic eruptions and earthquakes that both frightened and awed the area’s early inhabitants.

The first documented observation of Mount St. Helens by Europeans was by George Vancouver on May 19, 1792, as he was charting the inlets of Puget Sound at Point Lawton, near present-day Seattle. Vancouver did not name the mountain until October 20, 1792, when it came into view as his ship passed the mouth of the Columbia River.
Figure 9. An eruption from the Goat Rocks dome on the north flank of Mount St. Helens painted by Canadian artist Paul Kane in 1847. The view is to the east, apparently from the Columbia or Cowlitz River. Photo courtesy of the Royal Ontario Museum.

A few years later, Mount St. Helens experienced a major eruption. Explorers, traders, missionaires, and ethnologists heard reports of the event from various peoples, including the Sanpoil Indians of eastern Washington and a Spokane chief who told of the effects of ash fallout. Later studies determined that the eruption occurred in 1800.

The Lewis and Clark expedition sighted the mountain from the Columbia River in 1805 and 1806 but reported no eruptive events or evidence of recent volcanism. However, their graphic descriptions of the quicksand and channel conditions at the mouth of the Sandy River near Portland, Oregon, suggest that Mount Hood had erupted within a couple decades prior to their arrival.

Meredith Gairdner, a physician at Fort Vancouver, wrote of darkness and haze during possible eruptive activity at Mount St. Helens in 1831 and 1835. He reported seeing what he called lava flows, although it is more likely he would have seen mudflows or perhaps small pyroclastic flows of incandescent rocks.

On November 22, 1842, Reverend Josiah Parrish, while in Champoeg, OR, (about 80 mi or 130 km south-southwest of the volcano), witnessed Mount St. Helens in eruption. Ash fallout from this event evidently reached The Dalles, OR (48 mi or 80 km southeast of the volcano). Missionaries at The Dalles corroborated Parrish’s account. Captain J. C. Fremont recounts the report of a clergyman named Brewer, who gave him a sample of the ash a year later (Wilkes, 1845):

"On the 23rd day of the preceding November, St. Helens had scattered its ashes, like a light fall of snow, over the Dalles of the Columbia."
Other accounts of the same ashfall note that it was "like fine sand", its color "appeared like ashes", and the odor was "that of sulphur" (Majors, 1980).

Contemporary sketches and paintings by Paul Kane (Fig. 9) suggest the mountain was probably erupting at a point halfway down the north slope before or during 1847. The vent was apparently the Goat Rocks dome (Fig. 2), which was removed by the 1980 eruption. On the basis of these and other observations, scientists think eruptive activity may have continued intermittently until 1857.

Small eruptions were reported in 1898, 1903, and 1921, but these events were not independently confirmed, nor have their deposits been identified. Judging by the nature of the post-May 18, 1980, activity at Mount St. Helens, it is likely that these events were steam emissions, small explosions, or large rockfalls.

**Mining**

The first technical investigations of the geology near and at Mount St. Helens resulted from an interest in metallic minerals. Mining claims for copper, gold, and silver were staked in the St. Helens mining district north of the volcano as early as 1892. During trips to the area, hunters and fishermen had discovered sulfide minerals such as pyrite, chalcopyrite, arsenopyrite, galena, sphalerite, and other vein
These zones of hydrothermal alteration contained vein minerals, such as the sulfides pyrite and chalcopyrite. The Sweden tunnel was about 2,200 ft long.

alteration minerals, including specular hematite, magnetite, and tourmaline. These minerals occur in a porphyry copper deposit associated with the Spirit Lake pluton. (See p. 19 for more information about the Spirit Lake pluton and the age of the mineral deposits associated with it.)

Mining fever broke out about 1900, and hundreds of claims were staked in the Spirit Lake area as prospectors sought high-grade vein deposits. About 14 tons of copper ore from the Sweden mine (Fig. 10) were hauled to a Tacoma smelter in 1905 and used to cast the bronze statue of Sacajawea for the Lewis and Clark Exposition held in Portland, Oregon, which commemorated the 100th anniversary of their expedition. The challenge of transporting this ore is suggested in a 1910 report by Professor F. L. Barker of Eugene University (now the University of Oregon):

"The Sweden is reached by Northern Pacific Railroad to Castle Rock, Wash., thence by excellent mountain wagon road forty eight miles to Spirit Lake, then by boat across the lake two and one half miles to the landing of the Sweden...or the trip around the lake may be made by land about four miles."

Other mines in the area included the Margaret (Earl) group. Although thousands of prospect pits and more than 11,000 ft (3,355 m) of underground
workings were dug, the veins proved difficult to work and contained only modest amounts of gold and silver. By 1929, most of the mines had been abandoned, although exploratory work continued sporadically until the eruption of 1980.

Geologic Studies of Mount St. Helens

"The water of the...[North Fork] Toutle rises on the side of the cone of Mount St. Helens and is filled with a fine gray sediment which makes this fork look like a stream of milk."

Zapfe (1912)

The first technical geologic description of the area near Mount St. Helens was published by Carl Zapfe in 1912. He provided an overview of the geology of the St. Helens mining district and brief descriptions of Mount St. Helens ("an extinct volcano") and local glacial features such as cirques and striations on rock surfaces.

In 1937, Jean Verhoogen completed the first detailed geologic study of Mount St. Helens. He compiled a history of the volcano and recognized its youth and wide variety of lava types. About that same time, botanist Donald B. Lawrence began a series of investigations here and at neighboring Mounts Adams and Hood. During his 1939 field work, he noticed anomalous tree ring patterns in areas where Mount St. Helens tephra deposits were particularly thick. He reasoned that "the fall of these rough abrasive particles through the tree crowns must have resulted in great mechanical injury to the needles, twigs, and branches" (Lawrence, 1938, p. 53). He further noted that the eruption must be recorded by "a series of very narrow rings starting about the year 1802 or '03" (Lawrence, 1939, p. 51). He used similar logic to estimate the time of eruption for the Floating Island lava flow. David Yamaguchi of the University of Washington later reinterpreted the timing of both events and the eruption of the Goat Rocks dome by using cross-dating techniques. (See p. 29 and 97.)

In 1946, Ward Carithers of the Washington Division of Mines and Geology (now the Division of Geology and Earth Resources) described two pumice deposits from Mount St. Helens in his report on the pumice and pumicite occurrences of Washington. This report was prepared because of commercial interest in pumice for making abrasives.

Detailed work on the eruptive history of Mount St. Helens began in the late 1950s. Dwight R. Crandell and Donal R. Mullineaux of the USGS discovered that the volcano was relatively young, perhaps only slightly more than 40,000 years old. They divided its history into four stages of activity, each of which was punctuated by intermittent eruptive periods. The volcano was apparently dormant for thousands of years between these stages. They described Mount St. Helens as the youngest and most active volcano in the Cascade Range, and although the mountain had been quiet since about 1857, they warned of the likelihood and hazards of future eruptions, on the basis of the frequency and style of past eruptions. Remarkably, the mountain erupted in 1980, only 2 years after the publication of their report (Crandell and Mullineaux, 1978). The history of the volcano (based on their work and the research of others) is described in more detail starting on page 24.

The intensive research conducted at Mount St. Helens since the 1980 eruption is summarized in "What have scientists learned from Mount St. Helens?" (p. 33) and the following section (p. 37).
GEOLOGIC HISTORY OF THE MOUNT ST. HELENS AREA

Pre-Mount St. Helens Rocks: 40 Million Years of Volcanic Activity

A generalized geologic history (Fig. 11) of the Mount St. Helens area can be interpreted as follows:

55 Ma to 43 Ma (middle Eocene time)

Basalt rocks (known as the Siletzia and Crescent terranes) that were originally part of the oceanic plate were wedged against and became part of the North American plate during this interval, in a process geologists call accretion (see p. 97 and Fig. 59).

Before the formation of the Cascades, rivers draining a granitic highland to the east and northeast flowed westward across a landscape of low relief and emptied into the sea. The rivers deposited sediments in two large marine basins, now preserved as the sedimentary rocks of the Cowlitz Formation and the Puget Group. The shoreline was near the route of Interstate Highway 5 (I-5) or slightly to the west. Throughout western Washington, coal deposits formed in a coastal lowland during this time. Sedimentary deposits covered the accreted oceanic basalt during the latter half of this interval. A chain of volcanoes (volcanic arc) was located several hundred miles (kilometers) to the east (Idaho and eastern Washington) at this time—it later migrated west.

42 Ma to about 37 Ma (late Eocene time)

The earliest Cascade Range volcanoes probably erupted in an environment like that of present day Fuego Volcano in the Pacific coastal plain of western Guatemala. Throughout most of western Washington, these volcanoes produced fairly high-silica eruptive products, including some rhyolites and much fragmental material. (See p. 96 and 106). However, west of the present location of Mount St. Helens, shield volcanoes erupted basaltic lavas that became interbedded with the alluvium of the river system. Later, andesite lavas were erupted, including minor amounts of fragmental volcanic debris. A small group of peaks called the Rockies, about 10 mi (16 km) northwest of Morton and almost due north of Mount St. Helens, are an erosional remnant of this volcanic system; the deposits are called the Northcraft Formation.

37 Ma to about 17 Ma (late Eocene, Oligocene, and earliest Miocene time)

At the start of this interval, a large pulse of volcanism apparently interrupted the streamflow and blocked off sediment carried from eastern sources. The new volcanic arc, slightly farther east than the Northcraft volcanoes, extended from near the Canada–United States boundary southward into California. These early Cascade Range volcanoes produced lava at a rapid rate. In southwest Washington, the Hatchet Mountain and Goble volcanic rocks were erupted during this time, as was an overlying volcanic sequence that is exposed near Spirit Lake. Some of these rocks are similar in age to the voluminous Ohanapecosh Formation volcanic rocks near Mount Rainier. Ultimately this pile of lava and volcanic debris attained a thickness of nearly 6 mi (10 km) at the present latitude of Mount St. Helens.
Figure 11. Simplified version of the geologic time scale (not to scale) showing major geologic events in the southwest Washington Cascades. U, upper; M, middle, L, lower; m.y., million years. The time scale is developed from those of Salvador (1985) and Aguirre and Pasini (1985). See Tables 3 and 4, p. 25 and 28, for more detailed information on the geologic history of Mount St. Helens.
Known volcanic centers in the immediate area were at or near Spud and Bismarck Mountains; other centers may have been buried or eroded away. During this time, the silica content of the lavas near Mount St. Helens gradually increased; basalt and basaltic andesite gave way to andesite and dacite (see Table 6, p. 94). The corresponding increase in the viscosity of the lava caused more explosive eruptions. Therefore, production of fragmental volcanic deposits increased and lava flows decreased. The deposits and erosional remnants of these volcanoes or their "plumbing systems" are visible throughout the area and are noted in the road guide.

The Spirit Lake pluton intruded surrounding rocks and possibly fed a volcanic system near the end of this interval. Other intrusions in the region have been dated at 22 Ma to 18 Ma. Gentle folding of the Cascades probably began after 21 Ma and before 18 Ma (Evarts and others, 1987).

17 Ma to about 12 Ma (middle Miocene)

During this period, volcanism apparently slowed down in the Cascades. However, because the area was being tectonically lifted, much evidence of the volcanoes of this age and their deposits has been eroded away. This prevents us from getting a representative glimpse of Cascade Range volcanic activity during this time. Miocene intrusive features such as dikes and sills, many of which may have fueled volcanic eruptions, are fairly common.

Between 17.5 Ma and 6 Ma, huge volumes of lava called flood basalt (Columbia River Basalt Group) erupted from feeder dikes (vents) in eastern Washington, eastern Oregon, and Idaho (Figs. 11 and 12). A few of the flows evidently traveled hundreds of miles west along part of the course of ancestral Columbia River to reach the coast over a period of several weeks or months. Because the Columbia River basalt flows were so extensive, they can be used as an indicator of the amount of uplift and folding of rocks that has occurred since then. For example, after their eruption about 16.5 Ma, rocks of the Grande Ronde Basalt in the Cascades
north of Mount Adams were uplifted at least 0.6 mi (1 km) in comparison with rocks of the same basalt flow in eastern Washington. Grande Ronde Basalt, one of several formations of the Columbia River Basalt Group, is exposed in a quarry that is visible from I-5, high on the valley wall east of the Lewis River, about 0.6 mi (1 km) south of Woodland (see Leg B, p. 61).

12 Ma to about 10 Ma (late Miocene)
Numerous dikes and sills were intruded north and east of Mount St. Helens during this time. Volcanic products that correlate with the intrusions have not been identified, however. Gentle uplift and folding of the rocks continued.

5 Ma to Holocene (Pliocene through Pleistocene)
Volcanism in the Cascades picked up again at about 5 Ma. However, not much evidence for it is found near Mount St. Helens. The first eruptions in the Indian Heaven volcanic field to the southeast were produced slightly before 0.73 Ma, although some older basalt in that area has been dated at 3.7 Ma, 3.0 Ma, and 1.7 Ma. Goat Rocks volcano, 39 mi (65 km) to the northeast, was active between about 3.2 Ma and 1.0 Ma. Ages of 3.0 Ma, 1.0 Ma, and 0.74 Ma have been obtained for Goat Mountain plug dome, southwest of Mount St. Helens. Marble Mountain shield volcano was erupted sometime prior to 160 ka (see Fig. 44).

During the Pleistocene, glaciers covered much of the area near Mount St. Helens (Fig. 13). At least two and probably as many as four major episodes of alpine glaciation are recorded in the southern Washington Cascades, although the number of major glacial advances during the Pleistocene was probably more than ten. Eruptions and growth of Mount St. Helens started about 40 ka.

Huge outburst floods from glacial Lake Missoula repeatedly coursed down the Columbia River between 15,300 and 12,700 yr B.P. In the Portland basin near where the Trojan nuclear plant is now, these floods were hydraulically dammed and formed a temporary lake 400 ft deep. They also left slackwater deposits along the lower reaches of the Cowlitz and Lewis Rivers. More than 80 individual outburst floods have been documented east of the Cascades. Tephra deposits of Swift Creek-age (about 13,000 yr B.P.) from Mount St. Helens that are interbedded with the flood deposits in eastern Washington have helped date the flood events.

Glacial Deposits and Glaciation in the Mount St. Helens Area: Dramatic Alterations of the Landscape
During the Pleistocene, glaciers repeatedly spread over much of the Cascade Range and down onto parts of the adjoining lowlands. These alpine glaciers originated in the highlands near Mounts Rainier, Adams, and St. Helens. They evidently coalesced when these glaciers were at their maximum extent and created an ice cap over much of the crest of the Cascades. During each glacial episode, the glaciers radically modified the terrain by stripping off tens of yards or meters of rock, carving cirques and large U-shaped valleys, depositing glacial debris, and, when they melted, scouring the landscape with huge quantities of sediment-laden meltwater.

Rocks in till show that the alpine glaciers that predate Mount St. Helens had their source in the granitic highlands north of Spirit Lake. Abundant glacial deposits, including till, outwash, and moraines, record the glacial advances (see p. 108).
Hayden Creek glaciation (about 140 ka)

Much erosion can be attributed to the extensive Hayden Creek alpine glaciation. During this episode (and probably earlier ones), ice caps almost completely covered higher areas. The presence and configuration of U-shaped valleys show that these ice caps fed large valley glaciers that moved down the Clearwater, Smith–Muddy–Lewis, Toutle, and Green River drainages. A valley glacier of Hayden Creek age extended down the Cowlitz River for 63 mi (105 km) from Mount Rainier. The glacier in the Lewis River valley extended to within about 5 mi (8 km) of the location of I-5. This glacier dammed tributary valleys like those of Siouxon and Canyon Creeks (west and south of Yale Lake) to form meltwater lakes. Deposits in Cow, Maratta, and Hoffstadt Creeks (tributaries to North Fork Toutle River) indicate there were proglacial lakes in these valleys as well. Tens of feet of varves, or layered clays and silts, were deposited in these lakes (Fig. 14). These very fine lake sediments are generally unstable when saturated, and their location and extent greatly affects road building and other activities in the area.

Evans Creek glaciers (22,000 to 11,000 yr B.P.)

Evans Creek, the most recent alpine glaciation, was a substage of the latest major regional glaciation. It lasted from about 22,000 to 11,000 yr B.P. in the Mount St.
Helens area. During this period, icecaps were limited. A valley glacier from an icecap at Mount Rainier extended down the Cowlitz River 38 mi (64 km) and valley glaciers from near Mount St. Helens extended west for about 19 mi (31 km) down the North Fork Toutle valley and about 10 mi (16 km) to the south (Crandell, 1987).

The floors of cirques, small bowl-shaped glacial valleys, carved during Evans Creek time are found as low as 2,700 ft (824 m) elevation near Mount St. Helens. Some of the cirques are now occupied by lakes known as tarns; St. Helens, Grizzly, Venus, Shovel, Fawn, and Meta Lakes are good examples (see Fig. 64).

**Neoglacials Advances**

Two minor advances of the glaciers have been recorded within the last 10,000 years; we call these the neoglacials advances. The first of these episodes peaked between 2,800 and 2,600 yr B.P. The second episode, often called the “Little Ice Age”, has been documented both by historic accounts and by tree-ring analysis of trees growing on, or adjacent to, moraines. The Little Ice Age lasted from about A.D. 1250 until the mid-1800s and reached a peak in the 15th and 16th centuries. Judging by moraines left by these advances, the glaciers at Mount St. Helens were larger and somewhat longer than they were before the mountain erupted in 1980. Neoglacials ice extended nearly a kilometer farther down the mountain. Even these more robust glaciers of the neoglacials advances, however, were puny versions of the huge and extensive Pleistocene glaciers.

The May 18, 1980, eruption removed all of Loowit and Leschi Glaciers and parts of Shoestring, Forsyth, Wishbone, Ape, Toutle, Swift, and Nelson Glaciers—in all, more than 70 percent of the pre-eruption ice volume (Fig. 15). Erosion and melting by the blast and later pyroclastic flows (both of which were hot, turbulent mixtures of gas and rocks) stripped much of the ice and snow pack from the mountain in the early moments of the eruption. Only two unnamed glaciers on the south side suffered no net volume loss during the eruption.

The Shoestring and Forsyth Glaciers lost about 75 and 90 percent of their volumes respectively when their zones of snow accumulation were removed by the eruption. Post-eruption changes in the Shoestring Glacier have been carefully documented to see how rapidly and how much the glacier has shrunk because of this loss. (See “The Shoestring Glacier Story”, p. 70.)

The presence of crevasses and flow features in a snow-and-rock field now growing against the south crater wall indicates that a new glacier is forming inside

**Figure 14.** Annual layers of accumulated sediment (varves) deposited about 140 ka in a glacial lake of Hayden Creek age in Canyon Creek valley south of Mount St. Helens.
Figure 15. Glaciers of Mount St. Helens before and after the May 18, 1980, eruption. In A, the dashed line shows the outline of the bulge that developed on the volcano's north flank prior to the eruption. In B, the heavy solid line outlines the post-May 18 crater. The eruption removed more than 70 percent of the snow and ice volume from the volcano. A new glacier has grown between the south crater wall and the dome (see Update, p. 123. Unnamed glaciers are numbered 1 and 2. Redrawn from Brugman and Post (1981).
the crater. This glacier probably contains a large amount of rock debris because rock constantly falls from the crater wall and the Lava Dome (Fig. 16).

Lavas, Deposits, and Geologic History of Mount St. Helens: A Youthful Volcano with a Tumultuous Disposition

Mount St. Helens has erupted intermittently for at least the last 40,000 years. Four major stages of activity during that time have been outlined by USGS geologist Dwight Crandell (1987). Dormant intervals (periods during which little or no tephra was produced) separated the eruptive stages (Table 3). Eruptive periods lasting a few years to possibly centuries make up each eruptive stage, although only those eruptive periods that have occurred within the most recent (Spirit Lake) eruptive stage are named. The timing of the eruptive events has been established by a thorough study of the tephra and lahar deposits around the volcano.

Different tephra layers are identified by the heavy-mineral content of pumice fragments and are distinguished in the field by these heavy minerals which include crystals of pyroxene, amphibole, and biotite. Because tephra layers represent events that lasted very short times and are widespread, they provide excellent stratigraphic markers and have been used to establish relative ages for events far removed from the volcano. Layers produced since A.D. 1480 have been more precisely dated by tree-ring methods.

Ape Canyon Eruptive Stage (about 50 ka to 36,000 yr B.P.)

The deposits of this stage provide the first confirmed record of modern Mount St. Helens. These early deposits indicate that Mount St. Helens began its history with an explosive fury similar to, but even larger than, that

![Figure 16. Wide-angle photo of the west crater wall taken from the west top of the Lava Dome. Note the dikes that intruded a dome of Pine Creek age exposed in the crater wall. The distance from the crater floor to the crater rim is about 2,000 ft (600 m).](image)
shown in recent centuries. Products included large volumes of *pumice*-rich dacite fallout tephra (known as tephra set C), as well as pyroclastic flows and lahars.

USGS geologist Donal Mullineaux has found six distinct tephra layers from this stage and has observed that the presence of biotite crystals (*phenocrysts*) in clasts of the Ape Canyon stage is unique among the Mount St. Helens tephra deposits. Poorly developed soil layers between individual tephra units suggest that the Ape Canyon eruptive stage could have consisted of as many as four distinct eruptive episodes and that these episodes were spread over a period of perhaps 5,000 years. One study, which used a method called *thermoluminescence dating*, suggests that one of the set C tephra layers may be as old as 50 ka (Berger and

Table 3. Eruptive history of Mount St. Helens. Left columns show eruptive stages and dormant intervals; right columns show the eruptive periods and dormant intervals of the Spirit Lake eruptive stage. Only major tephra units are shown. Ash from possible earlier eruptions (100 ka–50 ka) has recently been discovered in eastern Washington (Busacca and others, 1992). Data in table from Mullineaux (1986) and Crandell (1987); redrawn from Hopson and Melson (1990).

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<th>Tephra set or layer</th>
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<td>10,000</td>
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<td>40,000</td>
<td>Ape Canyon</td>
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<td>500</td>
<td>Goat Rocks</td>
<td>Goat Rocks dome</td>
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<td>pre-1980 summit dome</td>
<td>Sugar Bowl dome; East dome</td>
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<tr>
<td>1500</td>
<td>Sugar Bowl</td>
<td>unnamed</td>
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<td>2000</td>
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<td>2500</td>
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<td>domes constructed during this time crop out in the crater and on the north side in canyons set Y</td>
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<td>3500</td>
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<td>Yn tephra layer deposited by large Plinian eruption</td>
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Busacca, 1991). Researchers have found two still older tephra layers that are chemically similar to C tephra and thus may record even earlier eruptions from Mount St. Helens between 100 ka and 50 ka (Busacca and others, 1992). The Ape Canyon eruptive stage probably ended by about 36,000 yr B.P. It was followed by a lengthy dormant interval of at least 15,000 years.

**Cougar Eruptive Stage (about 20,000 to 18,000 yr B.P.)**

This eruptive stage began about 20,000 yr B.P. and continued for about 2,000 years. Identified deposits include a sequence of lahars, a debris avalanche south of the volcano, pyroclastic flows, and dacite tephras (sets M and K). (See Stop B-1, p. 63.) The lahars and pyroclastic flows are found mostly on the southeast, south, and west sides of the mountain. The only andesite lava flow of this stage is on the southeast flank. (Legs B and G of the road guide take you to these deposits.)

Erupted material filled the Lewis River valley with more than 375 ft (115 m) of debris. Some of this debris undoubtedly extended the length of the Lewis River to the Columbia, although much of it has been covered by later deposits. One of the lahar deposits contains abundant rounded cobbles and pebbles and large chunks of what appears to be a debris-avalanche deposit similar to that produced by the May 1980 eruption. This lahar might have been generated by the breakout of an ancient lake dammed by a debris-avalanche deposit of this age.

A lack of volcanic deposits from Mount St. Helens between about 18,000 and 13,000 yr B.P. suggests that the mountain was dormant during this interval.

**Swift Creek Eruptive Stage (13,000 to 10,000 yr B.P.)**

This eruptive stage was characterized by the eruption of large volumes of tephra (sets S and J) and pumiceous pyroclastic flows. After the eruption of tephra set S, numerous *lithic pyroclastic flows* were produced. These probably originated at a summit lava dome or domes. Thick sequences of lahars filled the valleys of Pine Creek, Swift Creek, the lower Lewis River, and the South Fork Toutle River. The summit of the volcano was probably flanked by thick fans of fragmental debris on the west, south, and east sides.

A dormant interval of more than 5,000 years preceded the beginning of the Spirit Lake eruptive stage.

**Spirit Lake Eruptive Stage (3,900 yr B.P. to present)**

This stage consists of seven eruptive periods that include the most recent eruption and all other eruptive activity of the past 3,900 *radiocarbon* years (4,500 calendar years). These periods, in decreasing order of age, are the Smith Creek, Pine Creek, Castle Creek, Sugar Bowl, Kalama, Goat Rocks, and modern eruptive periods. The first two periods are characterized by volcanic activity similar to that of the earlier Ape Canyon, Cougar, and Swift Creek eruptive stages mentioned in the preceding paragraphs. However, the third period, the Castle Creek eruptive period, marked a change in the eruptive style of Mount St. Helens. In this period, more viscous silicic lavas, such as dacite, alternate with more *mafic* lavas including basalt and andesite. Details of the modern eruptive period are covered in a separate section (p. 29).

**Smith Creek Eruptive Period (3,900 to about 3,300 yr B.P.)** About 3,900 yr B.P., explosive eruptions of the Smith Creek eruptive period ended the more-than-5,000-year hiatus in volcanic activity at Mount St. Helens. Later, shortly after 3,510
yr B.P., a massive eruption produced a widespread layer of tephra known as the Yn tephra. The volume of this tephra suggests that this is the largest eruption yet discovered from Mount St. Helens. The Yn eruption produced about 1 m$^3$ (4 km$^3$) (solid rock equivalent) of pumice, ash, and rock, more than 13 times the amount produced in 1980 (Carey and others, 1989). The area covered by this deposit stretches nearly 540 mi (900 km) north-northeast into Canada. Geologists who have reconstructed the eruption based on its magnitude, chemistry, and the extent of its deposits have concluded that it must have been very similar to the tremendous eruption at Mount Vesuvius in Italy in A.D. 79. That famous eruption buried the towns of Pompeii and Herculaneum. The descriptions of its vertical column of ash by the Roman historian Pliny led to the term Plinian column. The May 18, 1980, eruption also produced a Plinian column (see Fig. 3).

At least four additional major tephra layers were produced during the Smith Creek eruptive period. The presence of lithic pyroclastic flows suggests that lava domes were being formed during this time as well. Almost all the Y tephras (as tephras from this period are known) can be distinguished from other Quaternary tephras from Cascade Range volcanoes by the presence of crystals of an amphibole mineral called cumingtonite.

Pyroclastic flows and lahars of the Smith Creek eruptive period traveled mainly down the east and north sides of the volcano. Deposits of Smith Creek lahars have been found as far as 30 mi (50 km) down the Toutle River. An ancestral Spirit Lake may have been born at this time when a debris avalanche or erupted material dammed the upper North Fork Toutle River.

Pine Creek Eruptive Period (about 2,900 to 2,500 yr B.P.) Intermittent eruptions occurred during this interval. A thick fan composed of lithic pyroclastic flows was constructed on the southeast side of the mountain. Some of these flows may have been produced by the domes whose remnants can now be seen in the crater walls exposed by the 1980 eruption. (See Fig. 16.) Tephra set P was produced during this time, but it does not have great volume or extent.

Silver Lake was formed about 2,500 yr B.P. when Outlet Creek was dammed by a series of enormous lahars generated by repeated breakouts of lakes upstream in the Toutle River drainage (Scott, 1988). Recently, geologists have discovered deposits of two ancient debris avalanches in the canyons of Step and Loowit creeks, which drain the crater of Mount St. Helens (Hausback and Swanson, 1990). These ancient debris avalanches may have created the dams that were breached.

Recognition of these enormous ancient lake-breakout lahars alerted scientists to the possibility of similar events being generated by an outburst flood from Spirit Lake. This concern led to the construction of facilities that could drain the lake—first a pipeline in 1982 and, later, the tunnel that presently drains lake water to South Coldwater Creek and the North Fork Toutle River.

Castle Creek Eruptive Period (about 2,200 to 1,600 yr B.P.) After an approximately 300-year dormant interval, the Castle Creek eruptive period began. This period marks a major change in the eruptive activity at Mount St. Helens. The volcano’s lava composition began to alternate between higher and lower proportions of silica. Basalt, andesite, and dacite were produced during this period. The Cave Basalt, which formed Ape Cave, was produced about 1,900 yr B.P., as was the
### Table 4. Mount St. Helens eruptive products of the past 500 years. PFs, pyroclastic flows. Precise ages for the events have been derived by tree-ring studies (Yamaguchi, 1983; Yamaguchi and others, 1990; Yamaguchi and Lawrence, 1993)

<table>
<thead>
<tr>
<th>Eruptive period</th>
<th>Tephra</th>
<th>Volume (km²)</th>
<th>Type of activity</th>
<th>Date</th>
<th>Silica (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980 to ?</td>
<td>...</td>
<td>...</td>
<td>dome; PFs</td>
<td>1980 to 1986</td>
<td>61-63</td>
</tr>
<tr>
<td>18 May</td>
<td>0.34</td>
<td>blast; PFs</td>
<td></td>
<td>1980</td>
<td>64-62</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>dormant for 123 years</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goat Rocks</td>
<td>...</td>
<td>Goat Rocks</td>
<td>dome; PFs</td>
<td>1842 to 1857</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>...</td>
<td>Floating Island</td>
<td>lava flow</td>
<td>1800</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>T</td>
<td>explosive eruption</td>
<td></td>
<td>1800</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>dormant for several decades</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kalamas</td>
<td>...</td>
<td>dome; PFs</td>
<td></td>
<td>mid-1600s to late 1700s</td>
<td>61-64</td>
</tr>
<tr>
<td></td>
<td>...</td>
<td>lava (Worm Flows); PFs</td>
<td></td>
<td>≈1505 to mid 1500s</td>
<td>57-58</td>
</tr>
<tr>
<td></td>
<td>...</td>
<td>minor tephra</td>
<td>pre-1505</td>
<td></td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>explosive andesitic eruption</td>
<td>≈1500</td>
<td></td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>...</td>
<td>PFs; dome</td>
<td>1490s</td>
<td></td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>We</td>
<td>explosive dacitic eruption</td>
<td>1482</td>
<td></td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>Wn</td>
<td>explosive dacitic eruption</td>
<td>1480</td>
<td></td>
<td>68-65</td>
</tr>
</tbody>
</table>

basalt of Lava Canyon. The Dogs Head dacite dome (northwest flank of the mountain) was probably erupted during this time.

Geologists are not sure why Mount St. Helens began these unusual fluctuations in the composition of its lavas. The fluctuations may reflect the progressive tapping of deeper and deeper parts of a stratified magma chamber. The magma chamber may have developed this layering over many thousands of years as denser mafic lavas accumulated at the bottom of the chamber and magma containing more silica migrated to the top. By the end of the Castle Creek eruptive period, the volcano had become nearly as high as it was before the 1980 eruption.

**Sugar Bowl Eruptive Period (age range uncertain)** Events of this period produced the Sugar Bowl dome and possibly East Dome. Lahars, pyroclastic flows, and a small, northwest-directed lateral explosion were produced as well. The explosion deposit extends about 18 mi (30 km) from the volcano, but the maximum width of the deposit is only about 7 mi (12 km). A $^{14}$C age estimated for the explosion is 1,150 yr B.P. No dates are available to bracket the beginning and end of the Sugar Bowl eruptive period, however.

**Kalama Eruptive Period (A.D. 1480 to late 1700s)** Tree-ring dating has clarified the timing of the Kalama eruptive events (Yamaguchi and others, 1990). (See also
p. 97.) The eruption in 1480, which produced the Wn tephra, began the Kalama eruptive period. The Wn layer has about six times the volume of the tephra produced in 1980 (Table 4). Even the smaller We tephra eruption of 1482 was about 20 percent larger than the 1980 eruption. These eruptions were followed by pyroclastic flows and formation of a lava dome during the 1490s and, in about 1500, by an explosive andesitic eruption that produced the X tephra.

Minor amounts of andesite tephra were deposited after the X tephra, and andesite lava and pyroclastic flows during the early to mid 1500s produced the sinuous Worm Flows on the south and southeast flanks of the cone (Fig 3). From the mid 1600s to late 1700s, the silica content of lavas increased while construction of the volcano’s summit dome produced dacite pyroclastic flows. The volcano was dormant for only a few decades before the Goat Rocks eruptive period.

**Goat Rocks Eruptive Period (A.D. 1800 to 1857)** The Goat Rocks eruptive period commenced in 1800 with the eruption of the T tephra. Recent tree-ring studies indicate that the Floating Island lava flow (a high-silica andesite flow, now mantled by 1980 eruptive products) was extruded within a few months of this tephra eruption. Silica content of the magma increased again from 1842 to about 1857, while the Goat Rocks dacite dome was constructed. (See Fig. 9.) A dormant period of 123 years then preceded the most recent eruptive sequence.

**Modern Eruptive Period (A.D. 1980 to ?)** Geologists have noted that, as in the Kalama and Goat Rocks eruptive periods, the post-May 1980 eruptive products show a decrease in silica content and followed by an increase. They suggest that the 1980–1986 activity resembles the pattern of the Goat Rocks eruption and speculate that, if it follows the Goat Rocks cycle, we will have continued intermittent lava extrusion, possibly over the next 30 years or so (until early in the next century), and then a dormant period before yet another explosive eruption. Considering the explosive eruptions that have occurred at Mount St. Helens over the past 500 years, Crandell estimated a 10 percent probability per decade of similar eruptions in the future.

**THE MODERN ERUPTIVE PERIOD, 1980–PRESENT**

**Pre-May 18 Warning Signs**

The earthquakes that signaled movement of molten magma under the volcano (and a possible eruption) began on March 20, 1980, and on March 27, a phreatic eruption created a small summit crater. Although earthquakes, swelling, and disruption of the mountain and its glaciers continued, the phreatic activity occurred only intermittently over the next 7 weeks. Repeated surveys, initiated in mid April and continued during the next few weeks, showed that a large bulge had formed on the north flank of the mountain in response to the intrusion of magma. The bulge moved outward at an average rate of about 5 ft (1.5 m) per day—until May 18, when Mount St. Helens became the first Cascade Range volcano to erupt juvenile material since Mount Lassen’s 1914 to 1921 activity.

**The Catastrophic Eruption of May 18, 1980**

On May 18, at 08:32 PDT, the catastrophic eruption began, apparently triggered by a magnitude 5.1 earthquake. The bulge collapsed in a series of three huge slide blocks (Figs. 17 and 18). This debris avalanche, the largest landslide in recorded
Figure 17. Initial moments of the May 18, 1980, eruption, as seen from Bear Meadow, 7 mi (11 km) northeast of the mountain. The top photo, taken about 14 seconds after the start of the eruption, shows the high-velocity cloud of the blast penetrating the second slide block of the debris avalanche and overtaking the first slide block. (Compare this photo with C in Fig. 18.) The bottom photo, taken with a telephoto lens about 7 seconds later, shows the expanding blast cloud continuing to blow through and engulf the debris avalanche as the crater expands. Note the projectiles indicated by the streaks near the right edge of the cloud. (Compare this photo with D in Fig. 18.) Photos by Keith Ronnholm, Remote Measurement Systems, Inc.
**Figure 18.** Diagram showing the intrusion of new magma into Mount St. Helens. The intrusion led to the formation of the bulge and disruption of the north flank of the mountain prior to the cataclysmic eruption of May 18. The failure of the individual slide blocks is discussed in the text. A, the configuration of the mountain before the 1980 eruptive events compared with the profile of the bulge on May 18; B, the volcano on May 18 just before the eruption; C, D, and E show the movement of the debris avalanche and the onset of the blast and vertical eruption column within the first minute after the collapse as confining pressure on the cryptodome is released. Compare C and D with Figure 17. Redrawn from Lipman and Mullineaux (1981).

history (0.6 mi$^3$ or 2.5 km$^3$ of material), traveled northward through Spirit Lake and swept over the top of Johnston Ridge (1,150 ft or 350 m high) into the Coldwater Creek drainage. (See p. 102 for more information about debris avalanches and other mass movement.) It also raced from the volcano westward 15 mi (25 km) down the North Fork Toutle River, reaching speeds greater than 60 mi/hr (27 m/s). Keith and Dorothy Stoffel, two geologists who saw the avalanche from an airplane, described it as "rippling and churning". The sudden removal of this immense volume of material from the mountain instantly reduced the pressure holding back the hydrothermal and magmatic system and released the laterally directed blast. This blast, a pyroclastic density current composed of large rocks, smaller particles, and gas, moved out across the landscape at more than 650 mi/hr (300 m/s), stripping off the soil layer in areas close to the volcano and leveling most vegetation within 12 mi (18 km) in a 180° arc north of the volcano. About 230 mi$^2$ or 600 km$^2$ were severely damaged by the blast. (See
p. 105 for more information about pyroclastic density currents.)

Major lahars, started mainly where snow and ice were melted by the blast, traveled down the South Fork Toutle and Muddy Rivers, carrying boulders, logs, trucks, and even bridges with them. Smaller lahars flowed down channels on all sides of the mountain, some traveling only a few kilometers beyond its base. (See p. 107 for more information on lahars.)

The water-saturated debris-avalanche deposit in the North Fork Toutle River valley began to lose water almost immediately after it stopped moving. This water, together with the silt and clay it carried, gave birth to the largest and most destructive lahar of May 18 later in the day. Flowing at velocities of up to 27 mi/hr (12 m/s), this lahar reached the Columbia River just after midnight. There it dropped more than 45 million yd$^3$ (35 million m$^3$) of sediment, reducing the average channel depth from 39 ft (12 m) to about 12 ft (3.5 m). This plug of sediment blocked the shipping channel to ocean-going vessels for 13 days and disrupted shipping traffic for 3 months, costing ports millions of dollars. (See Fig. 4 for a map of the devastation caused by this eruption.)

An eruption of ash rose to more than 12 mi (20 km) within 10 minutes of the explosion and formed an enormous mushroom cloud 45 mi (75 km) across. Later, an eruption column jetted vertically for more than 9 hours. Fallout from the eruption, including particles ranging in size from boulders to ash (sand-sized), exceeded 0.2 mi$^3$ (1 km$^3$) and spread across Washington and Idaho and into Montana (Fig. 19). The ash disrupted human activities, especially transportation, and damaged civil works such as sewage- and water-treatment facilities. Within 2 weeks, airborne ash had drifted around the globe.

Starting about noon, pyroclastic flows accompanied the vertical column of ash. Some of the larger pyroclastic flows formed when material "boiled over" the rim of the crater; others were formed by the gravitational collapse of material from the vertical eruption column. The flows left a thick accumulation of ash, pumice, and rocks on the debris avalanche-deposit north of the volcano. These flow deposits are made up of numerous overlapping ash sheets and lobes of pumice. The Pumice Plain, north of Mount St. Helens, is composed of these deposits, which in some places are as much as 100 ft (30 m) thick. (See p. 105 for a discussion of pyroclastic density currents and pyroclastic flows.)

Fifty-seven people died as a result of the eruption, most from ash asphyxiation. The debris avalanche filled the upper North Fork Toutle River valley to depths of more than 600 ft (180 m) locally. More than 200 mi (320 km) of roads, 15 mi (24 km) of railways, at least 43 bridges (many of them wooden logging-road
bridges), and about 200 homes were destroyed or severely damaged. Mount St. Helens was reduced in volume by about 0.6 mi$^3$ (2.5 km$^3$), a volume that would fill a football field to a height of more than 600 mi (960 km). The mountain lost more than 1,300 ft (396 m) off its summit.

**Post-May 18 Volcanic Events**

Five smaller explosive eruptions occurred later during 1980, each accompanied by pyroclastic flows and tephra. Small dacite lava domes, mounds of blocky gray lava, grew during and after three of these episodes and were blown apart by the July 22, August 7, and October 16, 1980, eruptions. From December 1980 until October 1986, 17 episodes of dome growth constructed the composite Lava Dome to a current height of 876 ft or 267 m (Fig. 6 and cover photo). The domes grew by a combination of inflation, as the lava pushed into the dome from below, and deposition of new lava as lava lobes protruded out onto the surface of the dome.

Minor explosions accompanied several of these episodes, and lahars that flowed at least 10 mi (15 km) from the crater were generated on two occasions (March 19, 1982, and May 14, 1984). Other, very minor explosions have occurred independent of eruptive activity, some with no warning. Some of these events occurred soon after storms, indicating that they are probably caused by geyser-like explosions resulting when water percolates down into the dome and contacts hot rock. The most recent dome-growth event (October 1986) increased the volume of the dome to 96 million yd$^3$ (74 million m$^3$), more than 40 times the volume of the Seattle Kingdome indoor stadium. Although this figure seems impressive, it amounts to only about 3 percent of what the mountain lost in the May 18 eruption.

**WHAT HAVE SCIENTISTS LEARNED FROM MOUNT ST. HELENS?**

Mount St. Helens is now the world’s most closely studied composite volcano. As a result, our understanding of volcanic processes and deposits has greatly improved, as has public interest in volcanoes and volcanology. Volcano-monitoring techniques have been refined to the point that we can now confidently predict major eruptive events at Mount St. Helens. This has led to the application of similar monitoring techniques at other volcanoes around the world.

**Volcano Monitoring: Listening for Signs of Restlessness**

What is volcano monitoring? Just as an increased pulse rate or sudden change in weight are clues to our own health, so changes in a volcano’s physical condition can presage a change in its eruptive status in the near future. In the early 1980s, monitoring efforts at the U.S. Geological Survey’s Cascades Volcano Observatory in Vancouver, Wash., focused on earthquakes and on measuring movement along thrust faults and radial cracks in the crater floor with a carpenter’s steel tape (Fig. 20). Increasing displacement rates on cracks and thrust faults indicated rising, swelling magma, and analysis of the rate of these changes allowed scientists to predict dome-building onsets (Swanson and others, 1983).

Monitoring the Lava Dome with surveying equipment such as electronic distance-measuring devices and theodolites began in 1981 and made possible more reliable prediction of eruptions. Geologists observed that rates of movement on dome features systematically increased before the extrusion of lava, reaching rates as high as 174 ft/day (53 m/day) or more than 0.5 in./s (1.3 cm/s)! When the
swelling rates increased beyond a given threshold, a "window" of time was predicted during which the eruption could be expected (Fig. 21).

Strainmeters and electronic tiltmeters placed on the Lava Dome now send data on dome growth to the Cascades Volcano Observatory and the University of Washington via radio telemetry. These instruments can take measurements continuously or at regular intervals even during bad weather and (or) at night and supplement field surveys by geologists.

The combined use of these prediction techniques was effective in all but one instance during the 1980–1986 dome-growth episodes. Only the explosion that occurred in May 1984 (and was followed by lava extrusion) was not predicted.

Thanks to a new computer-assisted monitoring system devised at the Cascades Volcano Observatory, most data can now be plotted automatically against other available monitoring information on a common time base (Fig. 21). For example, volcanic gas discharge, earthquake energy, surveyed deformation mea-
measurements, tilt, and ground temperature changes can be plotted simultaneously. Changes in seismic activity and atmospheric conditions, as well as instrument difficulties, can leave distinct patterns in the data record. This system has been useful in predicting the three latest dome-building episodes at Mount St. Helens, and it was successfully used during recent eruptions at Mount Spurr and Redoubt volcanoes in Alaska and at Mount Pinatubo in the Philippines.

Seismic monitoring remains the most effective tool for predicting volcanic activity. Seismologists at the University of Washington have made substantial progress in interpreting the wide variety of earthquakes that have occurred at Mount St. Helens. They have classified these earthquake characteristics in order to determine the type of volcanic activity and its location. This experience has helped scientists discriminate the recorded signals of and locate events such as debris flows at Mount St. Helens, as well as at Mounts Rainier, Adams, and Hood.

**Volcanic Hazards Analysis: Forecasting and Planning for Future Activity**

Volcanic hazards are destructive volcanic processes that have a high probability of occurring. (See also p. 106.) Risk, the magnitude of the potential loss, involves not only the geologic hazard, but also people, property, and livestock and their vulnerability to the hazard. As the population increases near a volcano, there is more at risk for a given hazard. Geologists, therefore, study natural hazards like earthquakes and volcanoes to define the nature, extent, and frequency of past volcanic processes so that risks can be minimized. It is almost always cheaper to plan for and (or) avoid disasters than it is to suffer them and rebuild afterward.

The main technique for evaluating hazards at a volcano is to study the history of its deposits, paying close attention to the frequency and nature of past eruptions and the extent of the resulting deposits. Eyewitness observations of Mount St. Helens eruptions and prompt investigation of the deposits have provided scien-

**Figure 21.** Increases in rates of precursory activity with time for the eruptive episode of March 19, 1982. Measurements showed simultaneous increases in several kinds of activity in the weeks preceding March 19. By relating the timing and rates of increase, scientists were able to predict the start of the eruption within smaller and smaller time intervals (predictive windows 1, 2, and 3). A predictive window is a period during which an eruptive event is thought to be most likely to occur.
tists with new insights about volcanic processes. As a result, geologists have
developed new criteria for recognizing the deposits of debris avalanches and pyro-
clastic density currents, enabling them to reinterpret deposits at other volcanoes
around the world. Hummocky deposits similar to those of the Mount St. Helens
debris avalanche have been identified at Mount Shasta and at numerous volca-
noes worldwide. Geologists now realize that this type of gigantic avalanche oc-
curs more frequently than previously recognized and that events thought to be
unprecedented in the geologic record, like the enormous 1980 blast at Mount St.
Helens, have occurred before and must be considered in a volcanic hazards study.

Investigations at Mount St. Helens have also led to advances in understand-
ing lahars and lahar-related flows and their deposits. On one occasion, geologists
were able to witness a lahar generated by an explosion on the dome, sample the
flow at a downstream locality as it passed, observe the lahar’s impact on the
stream channel during the event, and then study the deposits of the lahar as they
became exposed by stream action over the next year. During this and other events,
they observed the distinctive features and progressive textural changes of lahar
and lahar-related deposits that could help them determine how a particular depo-
sit had formed. This information has resulted in an improved classification
scheme for lahar deposits. For example, the recognition of sandy lahar-runout de-
posits not previously correlated with lahars has resulted in more accurate recon-
structions of the behavior, volume, stage height, and extent of these ancient sedi-
ment flows. The sedimentary characteristics of lahar deposits have important im-
plications for the design of structures and civil works in river valleys surrounding
volcanoes.

Secondary Effects of Eruptions

The secondary effects of the 1980 Mount St. Helens eruption serve as a reminder
that hazards can linger long after the initial eruptive activity has ceased. At Mount
St. Helens, dramatic post-eruption erosion and sedimentation and the ongoing
potential of floods from lakes impounded by the debris avalanche have presented
costly problems. Nearly $1 billion was spent during the first 10 years after the
eruption to mitigate the flood hazards.

During the first 3 years after 1980, an estimated 8 million tons of tephra were
washed off hillslopes into the Toutle River system. While hillslope erosion eased
somewhat after 1983, erosion of the debris avalanche and the subsequent widen-
ing and incision of this drainage system by the development of a stream network
resulted in a huge sediment discharge to downstream areas. (See p. 43.) The post-
eruption Toutle River became one of the most sediment-laden rivers in the world.
Downstream water quality and aquatic habitat severely deteriorated, and in-
creased downstream flooding due to sediment-filled river channels jeopardized
homes and roads built near the river.

Numerous natural dams were created by the debris avalanche in the North
Fork Toutle River drainage. On at least five occasions during 1980 to 1982, the col-
lapse of one of these dams released a small lake or pond adjacent to the debris av-
lanche and caused minor floods. (See Elk Rock Viewpoint, p. 49.) However, public
concern focused on Spirit, Coldwater, and Castle Lakes, the three largest lakes im-
pounded by the debris avalanche. Studies by geologists in the 1980s indicated that
enormous floods had resulted from the breakouts of similar lakes in pre-historic
times. The levels of Coldwater and Castle Creek were stabilized in 1981 by trench outlets. Pumping of Spirit Lake via a floating barge and outlet pipe began in November of 1982. A permanent outlet tunnel at Spirit Lake, completed by the U.S. Army Corps of Engineers in 1985, allows the lake to be lowered an additional 30 to 40 ft (9 to 12 m) for safety reasons.

**Preparedness and Mitigation: Public Awareness of Volcanic Hazard**

The 1980 events at Mount St. Helens have changed not only the way volcanic hazards are studied, but also public awareness of those hazards. The three most important aspects of volcanic hazards mitigation are: (1) communication of volcano-monitoring and volcanic-hazards information by geoscientists to the public, the media, and responsible agencies; (2) emergency preparedness by responsible agencies and officials; and (3) community and regional planning and land-use designations. All three aspects are interrelated. Successful mitigation depends on the timely communication of understandable scientific information about the current state of the volcano, as well as the nature, extent, implications, and likelihood of the variety of volcanic processes possible at that volcano.

Communication of scientific information about the status of a volcano (Table 5) has improved mainly because geologists have observed Mount St. Helens so closely. Public demand for prompt and comprehensible technical information and the experience of working with an accessible volcano, such as Mount St. Helens, have helped scientists refine the communication process. Geologists now use three types of public statements when describing volcanic activity:

- **Factual statements** provide information but do not anticipate future events.
- **Forecasts** are comparatively imprecise statements about the nature of expected activity (typically based on the past history and potential of a volcano and on geologic mapping).
- **Predictions** are relatively precise statements about the time, place, nature, and size of impending activity (usually based on measurements at the volcano).

Public statements about Mount St. Helens and other volcanoes from Alaska to the Philippines have been accepted by the media and the public because they define and translate scientific information and clarify public expectations and understanding of volcanic events and hazards. They also improve credibility and trust and can foster serious planning efforts (Swanson and others, 1985).

**WHAT IS THE FUTURE OF MOUNT ST. HELENS?**

Reconstructing the history of a volcano provides many clues to the kind of future activity we can expect, but history cannot be used to predict the exact timing and nature of a volcano’s short-term activities. With new information and instrumentation, however, scientists have had great success predicting the behavior of Mount St. Helens days or weeks in advance.

As we have learned, the May 18, 1980, eruption was only one of five explosive eruptions in the last 500 years. Eruptive activity, including pyroclastic flows, lava flows, and lahars, usually continues for decades or centuries. If the volcano follows a pattern similar to that suggested by the geologic record, we can expect more activity in the near future, including more explosive eruptions. The Lava Dome may continue to grow and fill the existing crater...or it may stop growing if
### Table 5. Types of volcanic hazards statements. The examples shown are taken from statements issued jointly by the U.S. Geological Survey (Cascades Volcano Observatory) and the University of Washington Geophysics Program. Similar hazard levels and types of statements would be used worldwide, based on United Nations standards

<table>
<thead>
<tr>
<th>Hazard level</th>
<th>Type of statement</th>
<th>Purpose of statement, with example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (green)</td>
<td>Information</td>
<td>Describes unusual events, typically short-lived, such as steam bursts, small avalanches or mudflows, rockfalls, thunder storms, or smoke plumes from fires. Can be the first statement issued when background conditions change and may be issued as a commentary to clarify a situation.</td>
</tr>
<tr>
<td>2 (yellow)</td>
<td>Extended Outlook Advisory</td>
<td>&quot;A period of sustained seismic activity on March 22 apparently was associated with a large snow and rock avalanche from the south crater wall.&quot;</td>
</tr>
<tr>
<td>3 (orange)</td>
<td>Volcano Advisory</td>
<td>Expresses concern about volcanic unrest or hydrologic conditions but does not imply an imminent hazard. Used when the USGS can firml suggest changes that could lead to an eruption or hazardous hydrologic event.</td>
</tr>
<tr>
<td>4 (red)</td>
<td>Volcano Alert</td>
<td>Thursday, October 16, 1986, 6:00 P.M. PDT — &quot;Seismicity within the crater and deformation rates on parts of the dome are increasing slowly at Mount St. Helens. These changes are similar to those that preceded earlier episodes of rapid dome growth. If current trends continue, another episode is likely to begin within the next 3 weeks. As in previous episodes of dome growth, small explosions are possible but hazards will likely be confined to the crater.&quot;</td>
</tr>
</tbody>
</table>

the volcano becomes dormant for an extended interval. As long as the volcano’s magma chamber and dome core remain hot, small unanticipated steam explosions may occur.

In the meantime, the best way to get familiar with the volcano is to examine its effects and its deposits. They will give you a better understanding of the history, nature, and processes of this natural laboratory. The road guide in Part II will introduce you to many of the features used to decipher Mount St. Helens’ past and to predict its future.
RECENT GEOMORPHIC EVOLUTION OF THE LANDSCAPE

Some of the biggest changes at the mountain since 1993 have been caused by erosion. On February 6–11, 1996, severe rainstorms caused major flooding and landslides throughout the Pacific Northwest. The sustained rainfall from a very warm, humid tropical air mass fell on a heavy snowpack and caused a “rain-on-snow” flood. The Spirit Lake instrument site recorded about 31 in. and the June Lake station recorded 36.5 in. of precipitation (including snow moisture) between February 5 and 10 of that year. Numerous landslides destroyed about $15 million of forest roads near Mount St. Helens, including areas along FR 26 (now open only as far north as Quartz Creek). Many of the landslides visible in the Clearwater valley were triggered by this storm.

On September 16, 1997, a heavy rainstorm eroded the crater floor and triggered a debris avalanche as much as 80 ft deep at Loowit Falls. A small debris flow and flood from this event reached Spirit Lake. The crater floor will no doubt continue to be sculpted by headward erosion during events such as this.

In the crater, a new glacier, perhaps composed of roughly equal parts ice and rock, is growing between the south crater walls and the Lava Dome. The top surface of this new glacier appears as north-sloping mass of snow that is slowly beginning to surround and overwhelm the Lava Dome. Growth of this glacier suggests that future eruptions will almost certainly be characterized by episodes of steam emissions or explosions and by interactions of hot rock debris with snow and ice.
Figure 22. Sketch map for Leg A along SR 504, showing numbered road stops (referred to in text), geologic units, features, and structures, and May 18, 1980, Mount St. Helens deposits and generalized areas of devastation by the blast. E, approximate western and southern limits of glaciers of Evans Creek age (22,000–11,000 yr B.P.); ER, Elk Rock Viewpoint (monument entry); H, approximate western limit of glaciers of Hayden Creek age (140 ka); NF, North Fork Viewpoint. Road symbols are identified in Figure 1.
North Fork Toutle River valley. This erosion choked rivers with sediment that was transported both in a state of suspension (suspended load) and as moving bed material (bed load). (See p. 43.)

Alternating episodes of erosion and deposition create alluvial terraces. These form where a stream cuts into sediments previously deposited in its valley. The complex array of terraces visible in the upper reaches of the North Fork Toutle valley attests to that river’s struggle to re-establish equilibrium following the influx of sediments after eruptions.

Mass Movement

The movement of geologic materials under the influence of gravity is called mass movement or mass wasting. Slump, creep, lahars (volcanic debris flows and mudflows), debris slides, rockfalls, debris avalanches, and combinations of flow types are all forms of mass movement that have been particularly active in the Mount St. Helens area because of the effects of the May 18, 1980, eruption (Table 8).

Falls. Falls travel most of the distance through the air. Movement is extremely rapid and includes free fall and movement by tumbling and rolling of fragments of bedrock or soil. Rockfalls are common in Mount St. Helens crater.

Slides. Slides move by shear displacement as a unit along one or more zones of weakness, often because of the higher pore pressure of fluids with those zones. Movement along the surface may be rotational, as in a slump, or translational along a more or less planar surface. Scars from debris slides (shallow soil slips) commonly appear on steep slopes that have been stripped of vegetation. Numerous studies have shown that live tree roots contribute to holding the soil together and help tie the upper soil horizon to the subsoil. The 1980 tephra deposits increased runoff and surface erosion on hillslopes. This runoff and surface erosion, when combined with the decrease in tree-root tensile strength caused by

<table>
<thead>
<tr>
<th>TYPE OF MOVEMENT</th>
<th>TYPE OF MATERIAL</th>
<th>RATE OF MOVEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ROCK</td>
<td>SOIL</td>
</tr>
<tr>
<td>Falls</td>
<td>rock falls</td>
<td>collapse</td>
</tr>
<tr>
<td>Slides</td>
<td>slump blocks</td>
<td>slump blocks</td>
</tr>
<tr>
<td>(varied water</td>
<td>wedge failures</td>
<td>rotational slides</td>
</tr>
<tr>
<td>content)</td>
<td>translational slides</td>
<td>shallow slips</td>
</tr>
<tr>
<td>Flows</td>
<td>rock creep</td>
<td>soil creep</td>
</tr>
</tbody>
</table>

**UNCONSOLIDATED MATERIALS**

|                  | Saturated    | Dry to mostly dry|                  |
|------------------|--------------|------------------|                  |
|                  | plastic flows| debris avalanche  | slow to rapid    |
|                  | mudflows     |                  |                  |
|                  | debris flows |                  |                  |
| Complex          | combinations (earthflows) |              |                  |
the stripping of vegetation and soil by the blast, has contributed to many shallow landslides in the devastated area.

**Slumps.** A slump is a type of slide where the movement is rotational, producing a rupture that is concave upward. Slumps and slump earthflows (Fig. 61) are common in the thick deposits of the 1980 debris avalanche and pyroclastic flows. Rapid incision into these deposits by streams has resulted in steep valley walls that are unstable. Clay-rich, hydrothermally altered zones within the debris avalanche deposit are especially vulnerable to plastic flow when saturated. If enough water is present, the material can "liquefy" and flow as a mudflow. During one such mudflow, which was triggered by a rainstorm in January 1990, a saturated mass of the 1980 debris-avalanche deposit flowed from the area of the Pumice Plain down along the North Fork Toutle River to its confluence with Coldwater Creek (6 mi or 10 km). When slumps and slump earthflows occur, they typically leave behind a steep scarp that is itself vulnerable to further slumping. Slumps also commonly occur in areas underlain by till and (or) glacial lake deposits (p. 21), both of which are vulnerable to plastic flow when they are saturated. Slumping commonly occurs in conjunction with the plastic flow of sediments underneath the slumping unit.

**Flows.** Flows move as if they were viscous fluids. Properties of flows vary according to their sediment concentration, amount and nature of clay minerals, and energy. Creep is a flow that moves at an almost imperceptible rate.

**Complex movements.** Complex movements are combinations of two or more of the five principal types of movements shown in Table 8, such as the slump earthflow.

**VOLCANOES AND VOLCANIC PROCESSES**

A volcano is a vent in the surface of the Earth (or other planet) through which magma (molten rock, called lava when it reaches the surface) and associated gases erupt. Volcano is also the term used to describe the structure produced by the material ejected through the vent. Tephra is a general term for ejected fragmental material of any size, whereas ash is defined as ejected volcanic debris that is less than 2 mm in diameter (sand size or smaller).
There are at least five types of volcanoes near Mount St. Helens. The first, typified by Mount St. Helens, is a composite volcano (also known as a stratovolcano). Composite cones are commonly associated with subduction zones. Mount St. Helens is situated on the Circum-Pacific Rim ("Ring of Fire") where subducting ocean floor sinks beneath the edges of continents and is remelted at depth (Fig. 59). Some composite volcanoes are also found in the Mediterranean–Himalayan Belt where collisions between continental plates are occurring.

Composite volcanoes can have their own individual eruptive personalities; however, they are typically characterized by the following traits:

- Their lava has an intermediate viscosity, which causes it to pile up and form steep slopes around the vent and to form domes. The lava contains about 55 to 65 percent silica, which defines it as andesite and dacite. (See Table 6, p. 94.)
- They have a moderate to high potential for violent explosions compared to volcanoes with lavas that contain less silica. (The higher the silica content of the magma, the higher the viscosity and the potential for explosive eruptions.)
- They consist of interbedded pyroclastic debris and lava flows. The ratio is generally about 50:50, but, for example, at Mount Rainier and Mount Baker the ratio is about 10:90.
- Lava flows tend to be thick: 65 to 330 ft (20–100 m).
- They generate lahars (volcanic debris flows) and debris avalanches because of the large amount of fragmental material and their steep slopes. Lahars are caused mainly by the interaction of pyroclastic debris with snow and ice, by collapse of weakened parts of the volcano, and by erosion of fragmental debris.

Glacier Peak and Mounts Adams, St. Helens, Rainier, and Baker are Washington's modern composite volcanoes. Other types of volcanoes found in the region are calderas, shield volcanoes, cinder cones, and maar volcanoes. The nearest postglacial shield volcanoes and cinder cones can be found at the Indian Heaven volcanic field about 18 mi (30 km) southeast of Mount St. Helens. These features are generally formed by eruptions of fluid basaltic lava. The nearest maar volcano is at Battleground Lake, about 30 mi (50 km) south-southwest of Mount St. Helens. Maars are formed by explosion of shallow superheated ground water in contact with magma: in a sense, they are larger versions of the phreatic explosion pits. Calderas are large, roughly circular volcanic depressions whose diameter is many times larger than the volcanic vent itself. They are typically formed by eruptions in which such a large part of the magma chamber is emptied that the volcano collapses on itself. Crater Lake, in Oregon, is the nearest postglacial caldera. Nearby relics of ancient calderas are the Fife Peaks caldera east of Mount Rainier (not recognized as a caldera until 1991) and a possible caldera associated with the Spirit Lake pluton. Yellowstone (Wyoming) and Newberry (Oregon) calderas are the other Quaternary calderas in the Northwest.

**Lava Flows and Domes**

Viscous lava tends to pile up and form domes because it does not flow very readily. Lava that has a lower viscosity, such as Hawaiian basaltic lava, can flow for many miles. The main hazard from the more fluid lava flows is damage or total destruction by burying or burning everything in their path—and they can cover...
Table 9. Types and characteristics of volcanic mass movements. Modified from Eisebacher and Clague (1984)

<table>
<thead>
<tr>
<th>Type of movement</th>
<th>Temp. (°C)</th>
<th>Water content</th>
<th>Gas content</th>
<th>Clay content</th>
<th>Solid constituents</th>
<th>Relation to eruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>pyroclastic density current</td>
<td>&gt;100</td>
<td>low</td>
<td>high</td>
<td>low</td>
<td>pyroclastics</td>
<td>during</td>
</tr>
<tr>
<td></td>
<td>&lt;850</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lahars</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hot debris flow (noncohesive)</td>
<td>30-100</td>
<td>high</td>
<td>low</td>
<td>low</td>
<td>pyroclastics; crystalline volcanic rocks</td>
<td>during</td>
</tr>
<tr>
<td>cold debris flow (noncohesive)</td>
<td>&lt;30</td>
<td>high</td>
<td>low</td>
<td>low</td>
<td>pyroclastics, crystalline volcanic rocks</td>
<td>during or unrelated</td>
</tr>
<tr>
<td>cold mudflow (cohesive)</td>
<td>&lt;30</td>
<td>high</td>
<td>low</td>
<td>high</td>
<td>crystalline volcanic rocks; clay from hydrothermal alteration</td>
<td>during or unrelated</td>
</tr>
<tr>
<td>rock avalanche</td>
<td>&lt;30</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>crystalline volcanic rocks</td>
<td>during or unrelated</td>
</tr>
<tr>
<td>debris avalanche</td>
<td>&lt;30</td>
<td>low</td>
<td>low</td>
<td>low to high</td>
<td>pyroclastics</td>
<td>during or unrelated</td>
</tr>
<tr>
<td>rockfall</td>
<td>&lt;30</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>crystalline volcanic rocks</td>
<td>during or unrelated</td>
</tr>
</tbody>
</table>

1 The solid constituents of mudflows (cohesive lahars) are mainly dust (clay and silt size), ash, and lapilli; in contrast, debris flows (noncohesive lahars) consist of both fine and coarse pyroclastic material or a mixture of such material and fragments of lava flows, domes, plugs, dikes, or sills.

very large areas. Lava flows of higher viscosity, such as the andesitic Worm Flows at Mount St. Helens, generally do not flow great distances from the volcano. Dome collapses, however, can produce hazardous pyroclastic flows and surges when the lava is still fairly hot, because of the greater tendency of their more viscous lava to fragment and turbulently interact with snow and ice.

Pyroclastic Density Currents: Flows, Surges, and Blasts

The word pyroclastic literally means “broken by fire”. The general name for several different kinds of pyroclastic phenomena is pyroclastic density currents (Table 9). These include pyroclastic flows, surges (hot and cold), and explosive blasts (Tilling, 1989).

As the silica content of a volcano’s products increases, so does the viscosity. The higher viscosity (greater resistance to flow) of magmas having a high silica content makes it more difficult for the gases driving the eruption to escape. To relieve gas pressure and move, the magma tends to blow apart to form pyroclastic flows instead of flowing cohesively as a lava flow. Typically, pyroclastic density currents have two components: a ground-hugging, basal portion (pyroclastic
flow) and a turbulent pyroclastic surge of finer particles that rides above the flow (Fig. 62).

**Pyroclastic Flows**

Pyroclastic flows are masses of hot (about 570°–1470°F or 300°–850°C), fairly dry pyroclastic debris (large rock fragments) and gases that move rapidly along the ground at velocities ranging from 8 to 140 mi/hr (3.5–60 m/s) (Fisher and Schmincke, 1984). Direct hazards of pyroclastic flows are incineration, asphyxiation, impact, and burial. Pyroclastic flows can also generate lahars and floods by quickly melting snow and ice. At some volcanoes, these flows have dammed tributary valleys to form lakes or have started fires. Pyroclastic flows are strongly controlled by topography and are usually restricted to valley floors. Most pyroclastic flows from composite volcanoes travel less than 15 mi (25 km) from the vent.

**Pyroclastic Surges**

Pyroclastic surges are hot, turbulent clouds of finer particles that ride above, and develop from, a pyroclastic flow. Surges are driven by gases and heat escaping a flow. They have a lower concentration of particles than flows and can affect larger areas. Pyroclastic surges can travel many tens of miles or kilometers from the
volcano and are not necessarily confined to the valleys. Hot pyroclastic surges can generate secondary pyroclastic flows like the one down the valley of South Coldwater Creek during the 1980 eruption. (See p. 59.) Surges are responsible for many catastrophes, including 30,000 deaths at Mount Pelée in Martinique, West Indies (1902), and 2,000 at El Chichón in Mexico (1982).

**Blasts (Blast Density Flows)**

Blasts or blast density flows are very powerful laterally directed explosions such as those at Mount St. Helens in 1980 and at Bezymianny, Kamchatka, in 1956. As demonstrated at Mount St. Helens, this type of explosion can affect a large area (216 mi² or 600 km²). Debris carried by the blast (the “stone wind”) can flatten trees and plane off nearly everything in its path.

**Lahars: Volcanic Debris Flows and Mudflows**

Lahars are debris flows or mudflows, rapidly flowing mixtures of rock debris and water that originate on the slopes of a volcano. They can be cold or carry hot pyroclastic material. Lahars are one of the greatest hazards at composite volcanoes because they can travel great distances from the volcano, placing people living in valleys draining the volcano at risk.

Composite volcanoes have all the necessary ingredients for lahars. Their average silica composition (andesite–dacite range) yields a moderately explosive magma of relatively high viscosity that produces a significant amount of fragmental debris. The resulting steep-sided volcanic pile is extremely vulnerable to slope failures and collapse, especially where rocks have been weakened by hydrothermal activity. In hydrothermal action, a combination of heat and acids and salts in solution alters volcanic deposits to clay minerals. Clay minerals act as a lubricant and lower the stability of the volcano’s slopes. Volcanoes at which hydrothermal alteration occurs are typically those with large amounts of snowpack and glacial ice, a source of water ready to be melted during an eruption.

The driving force in a lahar is gravity. In a normal river flood, the water is carrying individual rock particles along. In a lahar, the particles are so concentrated that they flow downslope en masse carrying the water. Lahars are restricted to stream valleys, although some lahars that have very large volumes can pass over topographic barriers under rare circumstances.

**Noncohesive Lahars**

Lahars with a low clay content (less than 4 percent) typically begin as a flood surge that incorporates enough sediment to become a debris flow. They can transform downstream to more diluted flow types such as lahur-runout flows and floods. These flows are sometimes called noncohesive lahars. The South Fork Toutle and Muddy River lahars of 1980 (Fig. 63) were formed when hot pyroclastic material melted snow and ice. The causes of noncohesive lahars can include:

- Interaction of a pyroclastic density current with snow and ice
- Severe rainstorms and (or) rapid snowmelt that causes erosion of tephra (or other fragmental debris) or landslides from the slopes of a volcano
- Flood caused by failure of a landslide-dammed lake on a volcano’s flank
- Glacial outburst flood (jökulhlaup) on a volcano’s flank
Cohesive Lahars

Lahars rich in clay-sized particles (more than 4 percent) are sometimes called mudflows or cohesive lahars. **Cohesive lahars** can originate when an entire sector or sizeable mass of a volcano collapses or slides away. This might be triggered by regional or **volcanic earthquakes**, steam explosions, or by means other than eruptions. Cohesive lahars can have huge volumes and flow great distances without undergoing significant dilution. The Electron and Osceola Mudflows at Mount Rainier and the Middle Fork Nooksack flow at Mount Baker are examples of fairly clay-rich lahars. The Osceola Mudflow had a volume of at least 0.6 m$^3$ (3 km$^3$) and flowed more than 60 mi (100 km) from Mount Rainier. An ancient cohesive lahar from Mount Hood crossed the Columbia River. The 1980 North Fork Toutle mudflow was a cohesive lahar. (See p. 30.)

**GLACIERS AND GLACIAL DEPOSITS**

A glacier is a large mass of ice that moves slowly downslope and spreads (where not constrained) under the force of its own weight. Glaciers are formed by the compaction and recrystallization of snow (Fig. 64). When an ice mass develops enough depth and weight, it deforms (becomes plastic) and can begin to move. Two signs of glacier movement are **crevasses** and **rock flour**. A crevasse is a deep fissure or crack in the ice caused by the glacier’s movement over an uneven surface.
The turbid, white meltwater from a glacier contains finely crushed or ground rock particles (rock flour) in suspension.

Glaciers have radically modified the Cascades landscape. Figure 64 shows the structural and depositional features of an alpine glacier. Piles of debris called moraines form at the terminal and lateral edges of the ice when a glacier has occupied the same location for some time. Terminal moraines that cross stream valleys are particularly vulnerable to erosion. Moraines are eroded away like any other sedimentary deposit; commonly only fragments of the moraine are preserved along the edges of valleys.

Till is a glacial deposit formed under, in, or on a glacier. Stratified drift includes bedded deposits consisting of layers of glacial material deposited as outwash from a melting glacier or deposited in quiet water adjacent to a glacier. The effects of glacial erosion on rock include smoothing, gouging, and glacial striations. Striking examples of glacial erosion are exposed along the Harmony Trail (Fig. 49).
GEOLOGIC STRUCTURES IN THE MOUNT ST. HELENS AREA

About 18 million years ago, localized compression of the Earth's crust began to fold and fault the rocks of the Cascades. That process may still be going on today.

Folds

Folds are curves or bends in the rock strata. Folds that arch upward in the middle are called anticlines and those that are bowed downward, synclines (Fig. 65). While driving through the Mount St. Helens National Monument and adjacent areas, you will pass along or across the axes of several broad anticlines and synclines. West of Mount St. Helens these structures trend northwest, whereas east of the volcano they trend nearly north. The Lakeview Peak anticline, west of Mount St. Helens, plunges downward at both its northwest and southeast ends, giving the anticline a sort of whaleback look. This configuration suggests a minor component of crustal compression has, at some time, been parallel with the fold as well as perpendicular to it.

Faults

Faults are fractures in rock along which movement has occurred (Fig. 66). They are the result of brittle failure of rock. No major faults are visible in outcrop within the monument. However, offsets along small faults can be seen in several roadside outcrops and in the back country. (See mile 25.0, p. 45.) Generally, these have displacements of only a few meters at most. Smoothly polished and grooved surfaces called slickensides are visible in some zones of faulting.

Normal fault. A normal fault is a steeply dipping fault in which the hanging wall has moved downward relative to the footwall. The dip of the fault plane is usually between 45° and 90°.

Reverse fault. A reverse fault is a steeply dipping fault in which the hanging wall appears to have moved upward relative to the footwall. The dip is usually greater than 90°.

Thrust fault. A thrust fault is a low-angle fault (less than 45°),

**Figure 65.** Sketch showing the features of synclines and anticlines and the map symbols for each.
typically caused by horizontal compression, in which the hanging wall has moved upward relative to the footwall. Small thrust faults in the crater floor were used in the early 1980s to monitor the deformation that preceded extrusion of lava from the dome. (See Fig. 20 and discussion on p. 33.) Slickensides on lava dome rocks indicate that similar brittle failure takes place within, or immediately under the dome.

**Strike-slip fault.** A *strike-slip fault* is a fault in which displacement occurred parallel to the strike of the fault plane, that is, sideways instead of up and down.

**Fault Zones**

The Chelatchie Prairie fault zone is an east-northeast-trending *normal fault* system a few kilometers south of, and generally parallel to the Lewis River. Tumtum Mountain is situated on this fault zone. Rocks north of faults in the zone have dropped downward with respect to the rocks on the south side. Geologists have not noted any recent activity on this fault zone.

The *St. Helens zone* is a north-northwest-trending zone of active seismicity that extends for about 80 mi (130 km) and passes through Mount St. Helens. (See the various road-guide maps.) This seismic zone is apparently a series of strike-slip faults that are related to the collision between the North American plate and the Juan de Fuca plate. The St. Helens zone and nearby faults create a zone of weakness in the crust that probably controls the location of the vent that feeds Mount St. Helens as well as the vents of the Marble Mountain–Trout Creek Hill volcanic zone to the south.

A strong (*magnitude* 5.1) earthquake occurred along the St. Helens zone in 1981. The epicenter was near Elk Lake, about 10 mi (15 km) north-northwest of the Mount St. Helens crater. Seismologists have estimated that this fault zone could generate an earthquake as large as magnitude 6.2 to 6.8—depending on the length of the fault segment that ruptured.
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FIELD GUIDES AND FURTHER READING


GLOSSARY

**ablation** – the loss of snow and ice from a glacier due to melting, erosion, evaporation, or sublimation.

**accretion** – that process by which one terrane, a fault bounded body of rock of regional size, is attached to another having a different history. Typically accretion occurs during tectonic collision.

**accretionary lapilli** – a mass of cemented ash 1-10 mm in size.

**alluvium** – a general term for stream deposits.

**amphibole** – a group of dark, rock-forming ferromagnesian silicate minerals; for example, hornblende.

**andesite** – a fine-grained extrusive igneous rock generally containing abundant plagioclase, lesser amounts of hornblende and biotite, little or no quartz; or 54 to 62 percent silica.

**anticline** – a convex-upward fold having stratigraphically older rocks in its core.

**ash** – see volcanic ash.

**ash cloud** – an eruption cloud of volcanic gas and fine particles.

**basalt** – a fine-grained volcanic rock, typically dark, that contains 45 to 54 percent silica.

**bed load** – sediment, such as cobbles, pebbles, and granules, that is transported along the bed of a river but is not in suspension.

**biotite** – “black mica”; a common mafic mineral.

**blast** – the enormous volcanic explosion and pyroclastic density current on May 18, 1980.


creep – slow downhill movement of surficial materials (such as soil).
crevasse – a deep fissure in the surface of a glacier.
cross dating – a method of matching tree rings that uses the known patterns or characteristics of tree rings in an area to precisely date wood or trees such as those buried in volcanic deposits or injured by volcanic activity.
cryptodome – the near-surface intrusion of magma that produced the pre-May 18, 1980, bulge in the north flank of Mount St. Helens.
dacite – a fine-grained extrusive igneous rock typically having 62 to 69 percent silica.
debris avalanche – a granular flow of unsorted rock debris that typically moves at high velocity.
debris flow – a moving mass of debris, typically saturated.
debris slide – a shallow mass movement of the soil layer or other geologic material.
dendrochronology – the scientific study of tree rings.
devastated area – the area of downed and singed vegetation created by the volcanic events at Mount St. Helens on May 18, 1980.
dike – a tabular intrusive rock body that forms where magma cuts across the bedding planes of other rock bodies.
diorite – a coarse-grained intrusive igneous rock having roughly the same chemical composition as andesite (54 to 62 percent silica).
discharge – the rate of stream flow at a given time in units of volume per unit of time (ft³/s or m³/s).
dome – see volcanic dome.
drift – a general term for any glacial deposit.
dehthflow – a type of mass movement that typically takes place along well-defined failure planes and may involve more than one failure process, such as slumping and plastic flow.
faceted spur – the end of a ridge that has been ground down by the action of ice or water.
fault – a fracture along which a rock mass has been displaced.
feldspar – a common rock-forming mineral group consisting of silicates of aluminum, sodium, potassium, and calcium.
ferramagnesian minerals – silicate minerals such as olivine, pyroxenes, and amphiboles, that contain considerable amounts of iron and magnesium.
firm – a material that is transitional between snow and glacier ice.
fission-track dating – a method of determining the age of a rock based on the number of tracks recording emission of subatomic particles during radioactive deterioration.
flood basalt – plateau basalt; the lava produced by enormous fissure eruptions, such as the Columbia River basalt flows.
flow breccia – a deposit of angular rock fragments, some of which are welded together, that is produced in association with a lava flow.
fold – a bend in a rock stratum or layer.
fumarole – a volcanic vent that emits gases.
gabbro – a coarse-grained intrusive igneous rock consisting mainly of calcium-bearing plagioclase and pyroxene minerals and having roughly the same chemical composition as basalt (45 to 54 percent silica).
glacier – a mass of ice, mainly recrystallized snow, that is heavy enough to move under its own weight.
granite – a coarse-grained intrusive igneous rock composed of potassium feldspar, plagioclase, quartz, and some mafic minerals; more than 69 percent silica.
granodiorite – a coarse-grained intrusive rock, similar to a granite, in which plagioclase minerals are more common than potassium feldspar; 62 to 69 percent silica.
groundmass – the fine-grained matrix of a porphyritic igneous rock.
half-life – the time required for half of the atoms in a sample of a radioactive isotope to decay.
heavy mineral – slang for ferromagnesian or mafic minerals.
hornblende – a mafic mineral of the amphibole group.
hornfels – a fine-grained metamorphic rock formed by recrystallization.
hydrothermal activity – the migration of hot, typically mineral-rich fluids produced by magma or by reactions of magma with adjacent rocks and (or) ground water.
hydrothermal alteration – the alteration of rocks or minerals owing to contact with hydrothermal waters.
igneous rock – a rock formed by the cooling of magma.
intrusive rock – an igneous rock that solidifies under the surface of the Earth.
isotope – one of two or more forms of an element having different atomic weights.
joint – a fracture in a rock along which movement has not occurred.
juvenile material – volcanic rocks derived directly from magma that has reached the surface.
K-Ar dating – see Potassium-Argon dating.
lahar – general term for a volcanic debris flow, a moving mixture of pyroclastic material and water that originates at a volcano.

lahar runout – the muddy flood caused by dilution of a lahar as it mixes with streamwater. The deposits are typically very sandy and have fewer large rocks than lahar deposits.

lapilli – volcanic particles in the range of 2 to 64 mm.

lateral blast – see blast.

lateral moraine – an accumulation of till along the sides of a glacier where it meets the valley wall.

lava – magma that reaches the Earth’s surface.

levee – an area of deposits marginal to a flow that roughly records the maximum height of the flow.

lithic pyroclastic flow – a pyroclastic flow that contains a significant percentage of previously formed rock fragments mixed in with the juvenile rocks.

lithification – the process by which sediment is converted into solid rock.

mafic rock – a rock that contains more than 50 percent ferromagnesian minerals.

magma – molten rock; can contain liquids, gases, and crystals.

magnatism – the formation and movement of magma.

magnitude – a scale for measuring the energy released by an earthquake.

mass movement – the movement of geologic materials downslope under the influence of gravity.

mass wasting – see mass movement.

metamorphic rock – a rock whose composition and (or) texture has changed because of heat and (or) pressure.

mineral – a naturally formed solid chemical substance having a fixed crystal structure and range of chemical compositions.

moraine – a landform composed of till or drift.

mudline – the maximum level of inundation by a lahar or flood based on the height of mudmarks on trees or rocks. See Fig. 63.

normal fault – a steeply dipping fault in which the hanging wall has moved downward relative to the footwall. See Fig. 66.

outburst floods – jökulhlaups; sudden releases of water stored in or adjacent to a glacier or in a glacial lake.

outcrop – an exposure of rock or a deposit.

outwash – stratified deposits produced by glacial meltwater.

pahoehoe – [pā.hoy’.hoy] a Hawaiian term for basaltic lava flows having a smooth or ropy surface.

phenocryst – a large individual crystal in a porphyritic igneous rock.

phreatic explosion or eruption – an explosive mixture of steam and fine rock debris produced when water contacts hot rock.

plastic flow – change in shape of a solid that takes place without rupture.

Plinian column – a strong, turbulent, and sustained vertical eruption column.

pluton – the cooled body of a large intrusive igneous rock mass.

porphyritic – a texture of igneous rock in which coarse mineral crystals are scattered among finer grains and (or) glass.

porphyry copper deposit – a type of hydrothermal mineral deposit associated with plutons that contains associated copper minerals.

potassium-argon dating – the radiometric determination of the age of a rock sample based on the ratio of argon-40 to potassium-40.

proglacial – immediately in front of or just beyond the limits of the glacier.

pumice – solidified rock froth; a porous volcanic rock that floats.

pyroclastic density current – a general name for any of the mixtures of volcanic gas and particles (including surges and flows) that move downslope on the flanks of a volcano under the influence of gravity. See Table 9.

pyroclastic flow – a mass of hot, dry, pyroclastic debris and gases that move rapidly along the ground surface. They can be caused by an eruption or collapse of a dome.

pyroclastic surge – a turbulent, mixture of gases and particles that flows above the ground surface at high velocities. It can develop from a pyroclastic flow and is highly mobile.

pyroxene – a group of mafic silicate minerals.

Quaternary – the geologic period lasting from about 1.7 Ma to the present. It consists of the Pleistocene Epoch (ending about 10 ka) and the Holocene (10 ka to present).

radiocarbon dating – the calculation of the age of geologic material by any of the methods based on nuclear decay of natural radioactive elements in carbonaceous material.

radiocarbon years – years before 1950 (by convention) based on the proportion of the 14C isotope to normal carbon atoms. Typically radiocarbon years differ from “calendar years” because of variations of the carbon isotope content of atmospheric carbon dioxide through time. A calibration to adjust these ages on the
basis of tree rings (for about the last 8,000 years) has been devised; however, for simplicity, only the raw radiocarbon ages are presented in this guidebook. For the most part, these ages do not differ radically from actual calendar years. Tree-ring dates for Mount St. Helens deposits laid down since A.D. 1480, however, are given in calendar years.

**radiometric age** – see radiometric dating.

**radiometric dating** – a method of estimating the age of a rock or mineral by measuring the proportion of radioactive elements to their decay products in a rock sample.

**raveling** – erosion involving the movement of individual rocks and grains down a slope.

**rock flour** – fine rock particles produced by glacial pulverization.

**rootless explosion crater** – small, shallow craters produced by phreatic explosions.

**St. Helens zone** – a linear zone of earthquake activity that extends from north of Mount St. Helens through the volcano almost to the Columbia River.

**scoria** – an igneous rock containing abundant cavities (vesicles) but which does not float.

**shield volcano** – a large, broad volcano having fairly shallow slopes formed by the eruption of highly fluid basalt lava.

**sill** – a tabular intrusive rock body that forms where magma is injected between two layers of rock.

**singe zone** – the zone at the periphery of the devastated area in which trees were scorched or damaged but not blown down.

**slickensides** – striated or polished surface of a rock produced by abrasion along a fault.

**slips** – debris slides.

**slosh line** – see trimline.

**slump** – a type of mass wasting in which blocks of material fail with a backward rotational motion.

**snag** – the trunk of a dead tree.

**stratigraphy** – the study of strata, its succession and composition, fossils and other characteristics.

**stratification** – a scratch or groove on a rock produced by the passage of a glacier or other geologic agent.

**strike** – the bearing or azimuth along which a fault or fold or other planar feature is oriented.

**strike-slip fault** – a fault in which displacement has been parallel to the strike of the fault. See Fig. 66.

**suspended load** – fine sediment carried in suspension by a river.

**syncline** – a fold that is concave upward, like a trough.

**talus** – rock debris, typically coarse, that accumulates at the base of a cliff or slope.

**tarn** – a small mountain lake that occupies a cirque.

**tephra** – a general term for all sizes of rock and lava that are ejected into the air during an eruption.

**terrace** – a long, narrow, nearly flat surface that forms a step-like bench in a slope.

**terrane** – a large block of the Earth’s crust, bounded by faults, that can be distinguished from other blocks by its geologic character.

**Tertiary** – the geologic period lasting from about 67 Ma to 1.7 Ma.

**thrust fault** – low-angle fault (less than 45°) in which the hanging wall has moved upward relative to the footwall; typically caused by horizontal compression.

**till** – an unsorted glacial deposit produced directly under, within, or on top of a glacier.

**transform fault** – strike-slip faults that separate major geologic plates or plate segments.

**trimline** – boundary between the area affected by scour or scrape and undisturbed terrain that denotes the maximum height of runup or inundation by an avalanche, debris flow, flood, wave, or glacier.

**tuff** – a fine-grained rock composed mostly of volcanic ash.

**valley glacier** – a glacier that heads at a cirque or cirques and then flows into, and is confined by, a valley; an alpine glacier.

**viscosity** – resistance to internal flow.

**volcanic arc** – a curved belt of volcanoes and volcanic rocks associated with a subduction zone.

**volcanic ash** – fine-grained pyroclastic particles (less than 2 mm in diameter).

**volcanic dome** – a steep-sided bulbous mass of lava, such as the Lava Dome, that is commonly formed by eruptions of highly viscous dacite or rhyolite lava.

**volcanic earthquakes** – the sudden release of strain energy under or in a volcano as magma or volcanic gas pushes its way to the surface.

**volcanoclastics** – a general name for all fragmental material produced by a volcano.

**vug** – a cavity in a vein or rock. Some vugs are lined with crystals.
UPDATE 1993–2001

Since the second printing of this book (1993), the Spirit Lake Highway (SR 504) has been completed to the new Johnston Ridge Observatory (JRO). Along SR 504 several other new facilities are available for visitors and new hiking trails have opened, such as the Hummocks Trail and Winds of Change Trail. These trails allow the visitor to observe the deposits and effects of the 1980 eruption and to witness the ecosystem recovery and post-disturbance landscape adjustments.

This update describes or lists: post-1993 road changes and new trails, volcanic and geomorphic activity at the volcano since 1993, a growing glacier in the crater, results of selected new geological research at the mountain, as well as citations and books that may help visitors, new references and further reading, selected internet resources.

Road Changes and New Trails

SR 504 now extends 8 mi (13 km) past Coldwater Creek to the top of Johnston Ridge and the spectacular Johnston Ridge Observatory (JRO). JRO hosts interpretive programs and exhibits and an unparalleled view of Mount St. Helens, the effects of the 1980 and subsequent eruptions, and ecosystem recovery (Fig. 34, p. 57). Along the new Hummocks Trail (p. 52), visitors can hike among the gigantic chunks of the debris avalanche, the world’s largest historic landslide deposit. Those who revisit the Hummocks Trail periodically will see geomorphic changes, such as slumping and erosion of the debris avalanche, and channel changes of the North Fork Toutle River. The hummocks and the ponds among them are also of interest because of the nature of the vegetation and ecosystem recovery taking place there.

Volcanic and Geomorphic Activity Since 1993

Mild background seismic activity has continued since 1993, with noteworthy episodes of increased activity in the spring and summer of 1998 and the fall of 2001. The level of earthquake activity at Mount St. Helens had been gradually increasing in early 1998 and accelerated during May, June, and early July 1998. Rates of activity increased from an average of about 60 well-located events per month in January 1998 to 318 in June and 445 in July. Most of these earthquakes were very small, with only three events exceeding magnitude 2. The largest earthquake was on 1 May, at magnitude 2.2. These earthquakes occurred in two clusters directly beneath the lava dome in the crater. One cluster was at 1.2 to 3.1 mi (2–5 km) depth and the other 4.4 to 5.6 mi (7–9 km) below the dome. Airborne surveys of volcanic gases have revealed the discharge of magmatic carbon dioxide at a rate of about 2000 tons/day. Under high pressure deep within Earth’s crust, carbon dioxide is dissolved in magma.

The 1998 seismic activity seems to be similar to that which occurred in 1995, although the activity of May 1998 was more energetic. The 1995 activity lasted for several months, had a maximum earthquake rate of 95 events per month, and resulted in no volcanic activity. Earthquakes returned to background levels by August 1998. A similar increase in earthquake activity in the St. Helens system occurred from 1989 to 1991. However, at that time there were also a number of very
shallow earthquakes accompanied by a series of sudden steam explosions. These explosions ejected rocks and ash from cracks in the dome. Rocks were thrown as far as 0.6 mi (1 km) from the dome, ash clouds reached altitudes of 3.7 mi (6 km), and a dusting of ash was deposited locally downwind. By the end of 1998, earthquake activity had subsided to background levels of less than five events per day, but future earthquake episodes could lead to steam emissions or another eruption of the volcano.

**A Growing Glacier in the Crater**

In the 1993 edition of this book, I mentioned that a small glacier was growing in the crater south of the Lava Dome (Fig. 15). That body of rock, ice, and snow has continued to grow throughout the 1990s and is now more than 500 ft (~150 m) thick (Fig. 67) and has a volume greater than 100 million yds$^3$ (76 million m$^3$) (Hill, 2001; Schilling and others, 2002). Mills and Keating (1992) suggested that rock debris made up a significant fraction of the material accumulating on the crater floor. U.S. Geological Survey scientists estimate that rock may account for about one-third of the volume of the new glacier. The new glacier is a source of perennial water that will contribute to the ground water in the volcano and also be available for incorporation into future lahars.
Selected Additional References, Field Guides, and Further Reading


Selected Internet Resources (as of April 2002)

- Cascade Volcano Observatory

- DNR Division of Geology and Earth Resources

- Mount St. Helens National Volcanic Monument
  - http://www.fs.fed.us/gpnf/mshnvm/

- Mount St. Helens Institute
  - http://www.mshinstitute.org/

- Mount St. Helens seismicity
  - http://spike.geophys.washington.edu/SEIS/PNSN/HELENS/
Washington Division of Geology and Earth Resources
Information Circular 88
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