Road Guide to Volcanic Deposits of Mount St. Helens and Vicinity, Washington

U.S. GEOLOGICAL SURVEY BULLETIN 1859

AVAILABILITY OF BOOKS AND MAPS OF THE U.S. GEOLOGICAL SURVEY

Instructions on ordering publications of the U.S. Geological Survey, along with prices of the last offerings, are given in the current-year issues of the monthly catalog "New Publications of the U.S. Geological Survey." Prices of available U.S. Geological Survey publications released prior to the current year are listed in the most recent annual "Price and Availability List." Publications that are listed in various U.S. Geological Survey catalogs (**see back inside cover**) but not listed in the most recent annual "Price and Availability List" are no longer available.

Prices of reports released to the open files are given in the listing "U.S. Geological Survey Open-File Reports," updated monthly, which is for sale in microfiche from the U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225. Reports released through the NTIS may be obtained by writing to the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161; please include NTIS report number with inquiry.

Order U.S. Geological Survey publications **by mail** or **over the counter** from the offices given below.

BY MAIL

Books

Professional Papers, Bulletins, Water-Supply Papers, Techniques of Water-Resources Investigations, Circulars, publications of general interest (such as leaflets, pamphlets, booklets), single copies of Earthquakes & Volcanoes, Preliminary Determination of Epicenters, and some miscellaneous reports, including some of the foregoing series that have gone out of print at the Superintendent of Documents, are obtainable by mail from

U.S. Geological Survey, Books and Open-File Reports
Federal Center, Box 25425
Denver, CO 80225

Subscriptions to periodicals (Earthquakes & Volcanoes and Preliminary Determination of Epicenters) can be obtained ONLY from the

Superintendent of Documents
Government Printing Office
Washington, D.C. 20402

(Check or money order must be payable to Superintendent of Documents.)

Maps

For maps, address mail orders to

U.S. Geological Survey, Map Distribution
Federal Center, Box 25286
Denver, CO 80225

Residents of Alaska may order maps from

Alaska Distribution Section, U.S. Geological Survey,
New Federal Building - Box 12
101 Twelfth Ave., Fairbanks, AK 99701

OVER THE COUNTER

Books

Books of the U.S. Geological Survey are available over the counter at the following Geological Survey Public Inquiries Offices, all of which are authorized agents of the Superintendent of Documents:

- **WASHINGTON, D.C.**--Main Interior Bldg., 2600 corridor, 18th and C Sts., NW.
- **DENVER, Colorado**--Federal Bldg., Rm. 169, 1961 Stout St.
- **LOS ANGELES, California**--Federal Bldg., Rm. 7638, 300 N. Los Angeles St.
- **MENLO PARK, California**--Bldg. 3 (Stop 533), Rm. 3128, 345 Middlefield Rd.
- **RESTON, Virginia**--503 National Center, Rm. 1C402, 12201 Sunrise Valley Dr.
- **SALT LAKE CITY, Utah**--Federal Bldg., Rm. 8105, 125 South State St.
- **SAN FRANCISCO, California**--Customhouse, Rm. 504, 555 Battery St.
- **SPOKANE, Washington**--U.S. Courthouse, Rm. 678, West 920 Riverside Ave..
- **ANCHORAGE, Alaska**--Rm. 101, 4230 University Dr.
- **ANCHORAGE, Alaska**--Federal Bldg, Rm. E-146, 701 C St.

Maps

Maps may be purchased over the counter at the U.S. Geological Survey offices where books are sold (all addresses in above list) and at the following Geological Survey offices:

- **ROLLA, Missouri**--1400 Independence Rd.
- **DENVER, Colorado**--Map Distribution, Bldg. 810, Federal Center
- **FAIRBANKS, Alaska**--New Federal Bldg., 101 Twelfth Ave.

Road Guide to Volcanic Deposits of Mount St. Helens and Vicinity, Washington

By MICHAEL P. DOUKAS

U.S. GEOLOGICAL SURVEY BULLETIN 1859

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE : 1990

For sale by the
Books and Open-File Reports Section,
U.S. Geological Survey, Federal Center,
Box 25425, Denver, CO 80225

Library of Congress Cataloging-in-Publication Data

Doukas, Michael P.
Road guide to volcanic deposits of Mount St. Helens and vicinity, Washington / by Michael P. Doukas.
p. cm.—(U.S. Geological Survey bulletin ; 1859)
Includes bibliographical references.
Supt. of Docs. no.: I 19.3:1859
1. Volcanic ash, tuff, etc.—Washington (State)—Saint Helens, Mount, Region—Guide-books. 2. Saint Helens, Mount, Region (Wash.)—Description and travel—Guide-books. I. Title. II. Series.
QE75.B9 no. 1859 557.3 s—dc20 89-600384
[QE461] [552.20979755] CIP

CONTENTS

FIGURES

TABLES

FIELD-TRIP STOPS

Leg I

Road Guide to Volcanic Deposits of Mount St. Helens and Vicinity, Washington

By Michael P. Doukas

Abstract

Mount St. Helens, the most recently active and most intensively studied Cascades volcano, is in southwestern Washington. The volcano is a superb outdoor laboratory for studying volcanic processes, deposits of observed events, and deposits whose origins are inferred by classic geologic techniques, including analogy to recent deposits. During the past 4,500 years, Mount St. Helens has been more active and more explosive than any other volcano in the conterminous United States.

Mount St. Helens became active in mid-March 1980, and eruptive activity began on March 27. Since the climactic eruption of May 18, 1980, the volcano has continued to be active at least until 1988. The 1980 activity of Mount St. Helens is summarized in U.S. Geological Survey Professional Papers 1249 and 1250.

This road guide is a tour of Mount St. Helens volcano and vicinity, with emphasis on the effects and deposits of the 1980 eruption. The road log starts from the U.S. Geological Survey's David A. Johnston Cascades Volcano Observatory, Vancouver, Wash. The guide is organized around two primary routes. Leg I is on paved and gravel roads from Vancouver to areas east of Mount St. Helens, including Windy Ridge Overlook near Spirit Lake. This is possibly the most scenic route described in the guide, including a transect of the devastated zone of May 18, 1980, Spirit Lake, and numerous vistas of the volcano. Leg II leads to areas west of the volcano from Vancouver via U.S. Interstate Highway 5, then on a paved and gravel road along the Toutle River. Highlights include the spectacular effects of mudflows and a view of the huge debris-avalanche deposit that was formed on May 18, 1980.

INTRODUCTION

Mount St. Helens, the most recently active and most intensively studied Cascade volcano, is in southwestern Washington (fig. 1). The volcano is a superb outdoor laboratory for studying volcanic processes, deposits of observed events, and deposits whose origins are inferred by classic geologic techniques, including analogy to recent deposits (fig. 1). Most of the visible cone has been formed within the past 1,000 yr, capping an older volcanic center active more than 40,000 to 2,500 yr B.P. (Hoblitt and others, 1980; Mullineaux and Crandell, 1981; Hopson, 1971). Before 2,500 yr B.P., the repeated emplacement of dacite domes was accompanied by eruption of pyroclastic materials of similar composition (table 1). Since then, more mafic magma has also been erupted (fig. 2). Lava flows from Mount St. Helens are found 10 mi (16 km) away from the volcano, pyroclastic-flow deposits 12 mi (19 km) and lahar (mudflow) deposits 35 mi (56 km) away (fig. 3). Air-fall tephra from Mount St. Helens has been widespread; the Y tephra, for example, is found more than 600 mi (965 km) away in Alberta, Canada.

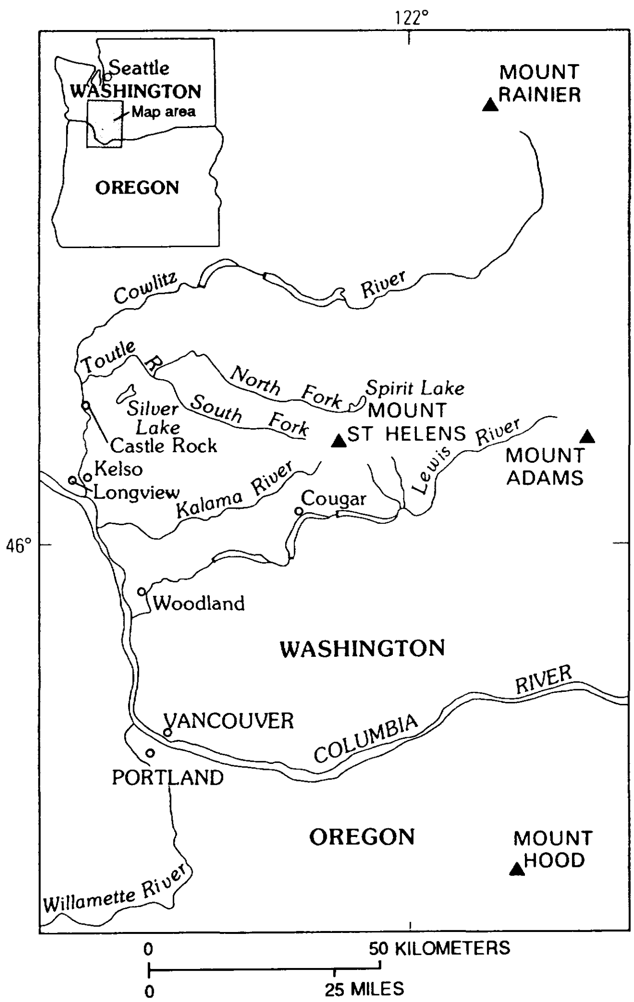


Figure 1. Southwestern Washington and northwestern Oregon, showing location of Mount St. Helens relative to nearby Mounts Rainier, Adams, and Hood volcanoes.

Manuscript approved for publication, June 7, 1988.

Table 1. Summary of pre-1980 volcanic history of Mount St. Helens

[Eruptive stages and periods are separated by dormant intervals for which no unequivocal volcanic products have been recognized. Years before 1980 are based on tree-ring dates (Yamaguchi, 1983), ^{14}C ages, and (or) historical records. A.D. dates during the Goat Rocks and Kalama eruptive periods from Yamaguchi (1983, 1985). All tephras consist of multiple layers not subdivided further here; only the thickest layers of W, B, and Y tephras are distinguished. Locations are of outcrops that illustrate the various deposits during each eruptive period. Do., ditto. After Crandell and others (1981), Mullineaux and Crandell (1981), and Crandell (1988)]

Eruptive stages and periods	Eruptive products	Location (leg and stop)
Spirit Lake eruptive stage:		
Modern eruptive period (1980-88).	Avalanche	(See table 2).
	Lateral blast	
	Lahar	
	Pyroclastic flows	
	Tephra	
	Domes (dacitic)	
Goat Rocks eruptive period (150-100 yr B.P.)	Dome (dacitic)	(Destroyed May 18, 1980).
	Lava flows (andesitic)	North flank of volcano.
(A.D. 1800)	T tephra (dacitic)	I-15, I-16, I-17, I-30.
Kalama eruptive period (500-338 yr B.P.)	Pyroclastic flows (dacitic, andesitic)	Ic-22, I-23.
(A.D. 1647?)	Summit dome (dacitic)	(Destroyed May 1980).
	Lahars from summit	Muddy River fan, Ib-5.
	Lava flows (andesitic)	Southeast flank.
	X tephra (andesitic)	I-4, I-6, I-16, I-17.
(A.D. 1482)	We tephra (dacitic)	I-4, I-6.
(A.D. 1480)	Wn tephra (dacitic)	I-16, I-17, I-20, I-30.
Sugar Bowl eruptive period (1,200 yr B.P.).	Dome (dacitic)	Northeast flank of volcano.
	Pyroclastic flows (dacitic)	Do.
	Deposits of lateral blast (dacitic)	I-17, I-20.
Castle Creek eruptive period (2,500-1,600 yr B.P.).	Bu tephra (basaltic)	I-4, I-16, I-17.
	Bi tephra (dacitic)	Do.
	Bo tephra (andesitic)	Do.
	Bh tephra (andesitic)	Do.
	Lava flows (basaltic)	I-2, I-4, I-20.
	Pyroclastic flows (dacitic, andesitic)	
Pine Creek eruptive period (3,000-2,500 yr B.P.).	P tephra (dacitic)	I-4, I-16, I-17.
	Pyroclastic flows (dacitic)	Canyon of Pine Creek.
	Domes (dacitic)	Crater.
	Lahars	I-9, II-4.
Smith Creek eruptive period (4,000-3,300 yr B.P.).	Ye tephra (dacitic)	I-4.
	Pyroclastic flows (dacitic)	
	Yn tephra (dacitic)	I-16, I-17.
Swift Creek eruptive stage (13,700-9,200 yr B.P.).	J tephra (dacitic)	I-4, Ic-23.
	Pyroclastic flows (dacitic)	West Fork Swift Creek.
	Lahars	Ic-26.
	Domes (dacitic)	
	S tephra (dacitic)	I-4.
Fraser Glaciation (ended approx 13,000 yr B.P.).		
Cougar eruptive stage (20,400-19,200 yr B.P.).	K tephra (dacitic)	I-1.
	Pyroclastic flows (dacitic)	I-7, I-25.
	Domes (dacitic)	
	Avalanche	Ic-27.
	Lava flows (andesitic)	West Fork Swift Creek.
	M tephra (dacitic)	I-1.
Ape Canyon eruptive stage (approx 40,000?-35,000 yr B.P.).	C tephra (dacitic)	I-6.
	Pyroclastic flows (dacitic)	Do.
	Lahars	I, Lewis River.

In comparison with its several-hundred-thousand-year-old neighbors, Mounts Rainier and Adams, Mount St. Helens is a young volcano. During the past 4,500 yr, Mount St. Helens has been more frequently and explosively active than any other volcano in the conterminous United States (Crandell and Mullineaux, 1978). Many dated deposits (Mullineaux and Crandell, 1962; Greeley and Hyde, 1972; Crandell and Mullineaux, 1973; Hyde, 1975; Crandell and others, 1981; Mullineaux, 1986) show the high frequency of eruptions. Before the current activity began, Crandell and others (1975) and Crandell and Mullineaux (1978) had suggested that the volcano could erupt soon, possibly before the end of the 20th century.

THE ERUPTION OF 1980–86

The 1980 activity of Mount St. Helens is summarized in U.S. Geological Survey (USGS) Professional Papers 1249 (Foxworthy and Hill, 1982) and 1250 (Lipman and Mullineaux, 1981). The activity began on March 15 with an increasing number of earthquakes beneath the volcano. The first phreatic eruption occurred on March 27, coincident with a high level of seismic activity. A summit crater formed and continued to enlarge for 2 months as phreatic activity continued. Tephra erupted during this time was composed of pulverized old rock, not new magma; however, viscous magma was intruding high into the cone, forming a cryptodome whose surface manifestation was the famous "bulge" on the north flank. This bulge grew outward at a maximum rate of 8.2 ft/d (2.5 m/d) with no acceleration or other significant change until the climactic eruption.

The eruption at 8:32 a.m. p.d.t. May 18 was apparently triggered by a magnitude 5.1 earthquake that caused the unstable north flank to fail as three great retrogressive landslide blocks. The landslides developed into a complex debris avalanche that sped down the valley

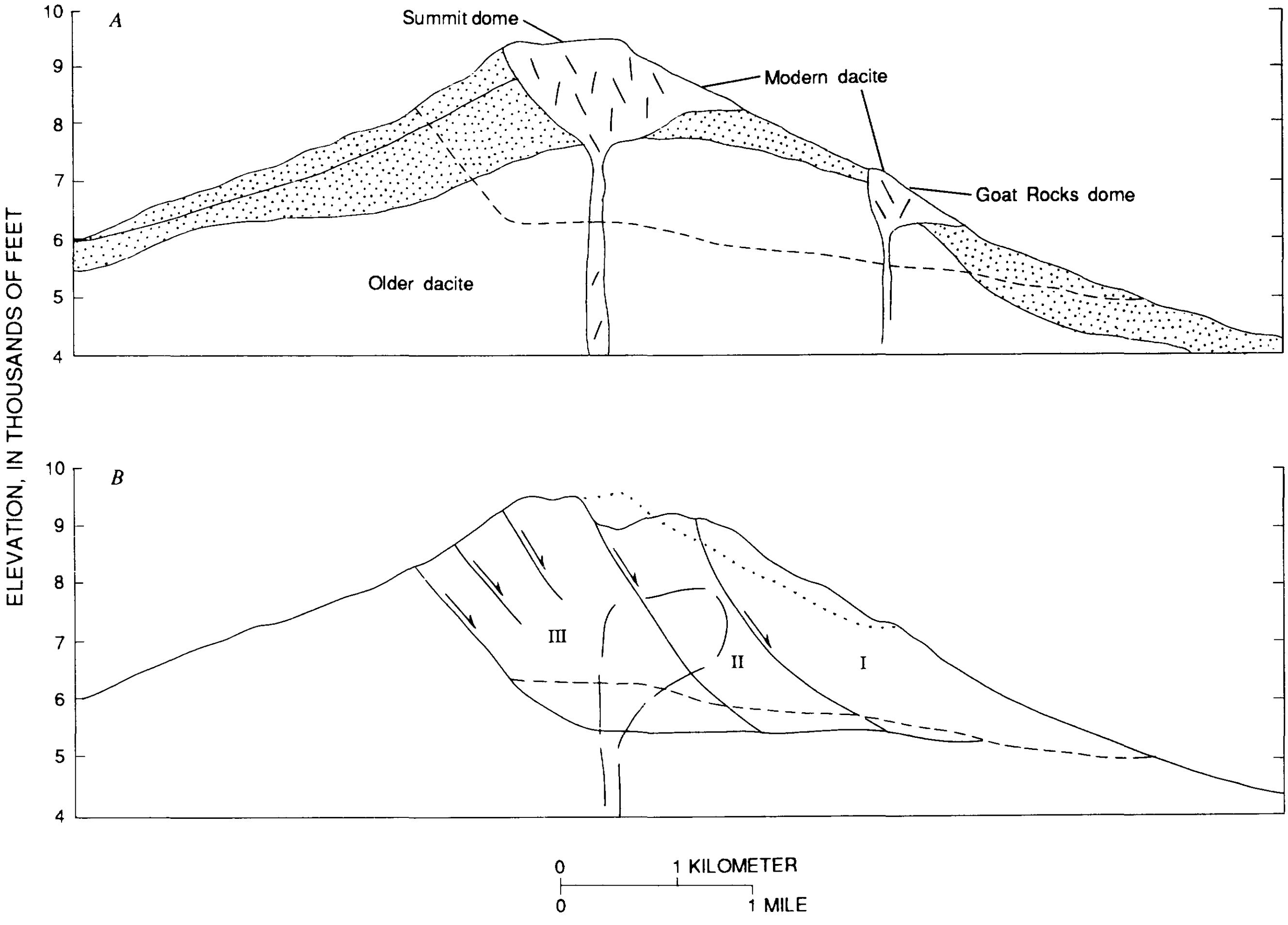


Figure 2. Generalized north-south geologic cross sections through Mount St. Helens. *A*, Young summit dome (dacite) and surface flows (stippled areas) overlie older (more than 2,500 yr) dacitic pyroclastic flows, lavas flows, and domes. Geology generalized from C.A. Hopson (written commun., 1983) and Glicken (1986). Dashed line, approximate outline of 1980 crater floor. *B*, Preeruptive summit dome. Roman numerals denote main-slide blocks of avalanche; arrows indicate direction of failure. Dotted line, pre-1980 surface; long-dashed line, presumed outline of intruding magma in 1980; short-dashed line, approximate outline of 1980 crater floor.

of the North Fork Toutle River, reaching its termination 16 mi west of the volcano in about 10 minutes. Unloading of the volcano by these landslides relieved pressure on the cryptodome and its associated hydrothermal system; the depressurized gases violently expanded and generated a northward-directed lateral explosion or blast. A pyroclastic surge (Moore and Sisson, 1981) or flow (Walker and McBroome, 1983) developed from the blast and fanned outward from the volcano, felling trees and killing most wildlife in a 212-mi^2 (550 km^2) area. Two columns convectively rose from the devastated zone and joined to reach a maximum height of 16 mi (25 km) by 9:00 a.m.

The landslides and blast removed the upper 1,312 ft (400 m) of the cone and left a crater 2,050 ft (625 m) deep, 1.7 mi (2.7 km) long, and 1.3 mi (2.0 km) wide. About 30 min after the blast, debris falling from the unstable crater wall and lesser vesiculating dacitic magma from the roots of the cryptodome were explosively ejected in an eruption column that ranged from 9 to 10 mi (14–16 km) in height throughout the morning. Dark-gray ash, consisting largely of lithic debris from this column, fell more than 930 mi (1,500 km) away. The eruption column lightened in color and became more energetic at about noon, possibly as a fresh supply of gas-rich magma reached the surface; pumiceous pyroclastic flows spilled northward from the crater and covered part of the debris avalanche, forming the Pumice Plain. Light-gray magmatic ash from this 9 to 12 mi (14–19 km) column fell on earlier, dark-gray lithic ash in eastern Washington and northern Idaho. The eruptive activity declined and ended that night.

Many mudflows formed on May 18, mostly by melting of snow and glacial ice. The largest mudflow, down the North Fork Toutle River, formed as the debris avalanche dewatered (Janda and others, 1981; Voight and others, 1981, 1983). This flow destroyed or heavily damaged 200 homes and deposited more than 95 million yd^3 (72 million m^3) of sediment in the Cowlitz and Columbia Rivers, where clogged shipping channels required costly dredging (Schuster, 1981).

Five explosive eruptions between May 25 and October 18, 1980 (table 2), generated pyroclastic flows and tephra falls, and three eruptions ended with emplace

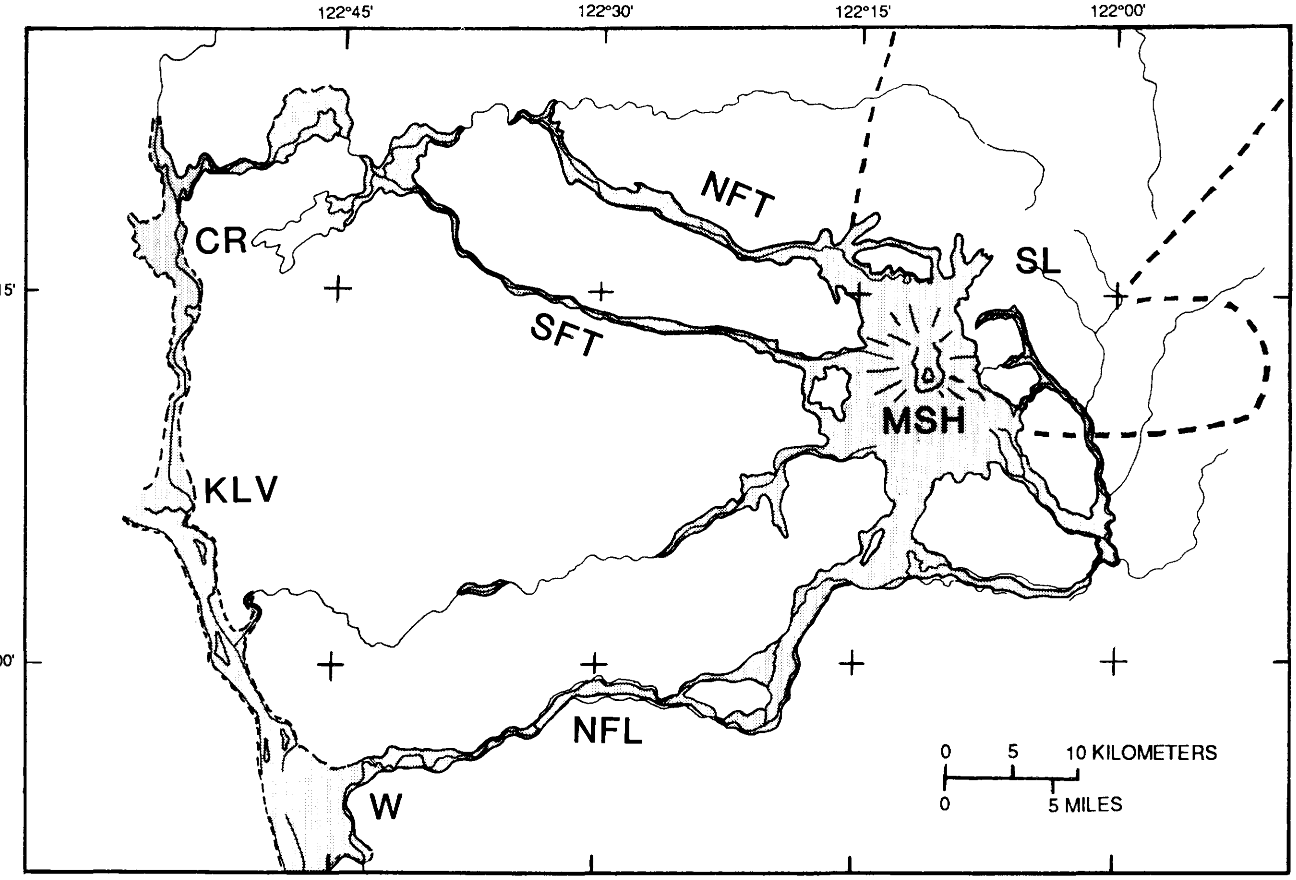


Figure 3. Southwestern Washington, showing general distribution of volcanic deposits derived from Mount St. Helens. Shaded areas, lava flows, pyroclastic flows, lahars, and avalanches from Mount St. Helens; contact dashed were approximately located. Heavy-dashed line, 20-cm isopach (equal-thickness contour) of major ash falls younger than 2,500 yr (T, Wn, We, Yn, Ye tephras of Crandell and Mullineaux, 1978). CR, Castle Rock; KLV, Kelso-Longview; MSH, Mount St. Helens; NFL, North Fork Lewis River; NFT, North Fork Toutle River; SFT, South Fork Toutle River; SL, Spirit Lake; W, Woodland.

Table 2. Eruptive activity at Mount St. Helens during 1980–86

[Dome growth occurred both by endogenous and exogenous processes. Tephra and pyroclastic-flow pumice erupted during 1980-83 contain Fe-Mg phenocryst-assemblage hypersthene-hornblende-augite (Kuntz and others, 1981; Cashman and Taggart, 1983); augite is reported at less than 0.5 volume percent. Locations are of outcrops that illustrate the various types of eruptive processes during each period. Do., ditto]

Date	Dominant activity	Other products	Location (leg and stop)
1980 Mar. 27	Explosive	Lithic ash	Minor amounts around volcano.
Apr.	do	do	Do.
May 18	do	Avalanche	I-22, II-11, II-13.
		Lateral blast	I-11, I-12, I-13, I-14, I-15, I-17, I-20.
		Blast deposit[1]	II-12, II-13.
		Lahar	I-3, I-4, I-5, I-6, I-8.
		Pyroclastic flow	I-20, I-22.
		May 18 tephra	I-11, I-12, I-17.
May 25	do	Pyroclastic flow; May 25 tephra.	I-22; minor air-fall lobe northwest of volcano.
June 12	Explosive, dome growth.	Pyroclastic flow; June 12 tephra.	I-22; minor air-fall lobe southwest of volcano.
July 22	Explosive	Pyroclastic flow; July 22 tephra.	I-11, I-22; air-fall lobe northeast of volcano.
Aug. 7	Explosive, dome growth.	Pyroclastic flow; August 7 tephra.	Minor air-fall lobe north of volcano.
Oct. 17	do	Pyroclastic flow; October 17 tephra.	Minor air-fall lobe southwest of volcano.
Dec. 28	Dome growth, minor explosive.	-----	Crater.
1981 Feb. 5	Dome growth		Do.
Apr. 22	do		Do.
June 19	do		Do.
Sept. 6	do		Do.
Oct. 31	do		Do.
1982 Mar. 19	Minor explosive	Lahar	I-21.
Mar. 21	Dome growth	Ice and ash avalanche.	Do.
		March 19 tephra	Minor air-fall lobe southeast of volcano.
Apr. 4, 5	Minor explosive		Crater.
May 14	Dome growth		Do.
Aug. 18	do		Do.
1983 Feb. 2, 3	Minor explosive	Lahar	North flank.
Feb.-Dec.	Dome growth (continuous).	-----	Crater.
1984 Jan.	Dome growth (end of continuous).	-----	Do.
Feb. 10	Dome growth		Do.
Mar. 29	do		Do.
May 14, 26	Minor explosive	Lahar	North flank.
June 17	Dome growth		Crater.
Sept. 12	do		Do.
1985 May 30	do		Do.
1986 May 9	do	Rockfall	Do.
Oct. 21	do		Do.

[1]The term "blast deposit" is here used to designate a deposit resulting from any process initiated by the lateral explosion. Precise transport and deposition mechanisms are controversial (Walker and McBroome, 1983; Hoblitt and Miller, 1984; Waitt, 1984a; Walker and Morgan, 1984).

ment of a small dacitic lava dome. From October 18 until at least June 1985, a composite dome grew in the new crater in an episodic but predictable way (table 2; Swanson and others, 1983 and in press).

Natural events continue to affect Mount St. Helens. Eruptions periodically add dacitic lava to the dome within the crater and deposit minor amounts of ash downwind from the volcano. Streams erode and rework the debris-avalanche and mudflow deposits in the valleys and slopes surrounding the volcano.

Man has also affected the landscape around Mount St. Helens. Construction of a sediment-retention dam has altered the appearance of the avalanche deposit. Spillways have been constructed at three lakes impounded by the avalanche, and in 1982–84 the level of Spirit Lake was controlled by a major pumping operation. Salvage of downed timber has removed much evidence of the lateral blast in many areas. The natural state is being preserved insofar as possible within the newly created Mount St. Helens National Volcanic Monument.

This road guide to Mount St. Helens volcano, emphasizes the effects and deposits of the 1980 eruption. The road log starts from the USGS, David A. Johnston Cascades Volcano Observatory, 5400 MacArthur Boulevard, Vancouver, Wash.; travelers can also join the route at other locations (fig. 4). This road guide is intended

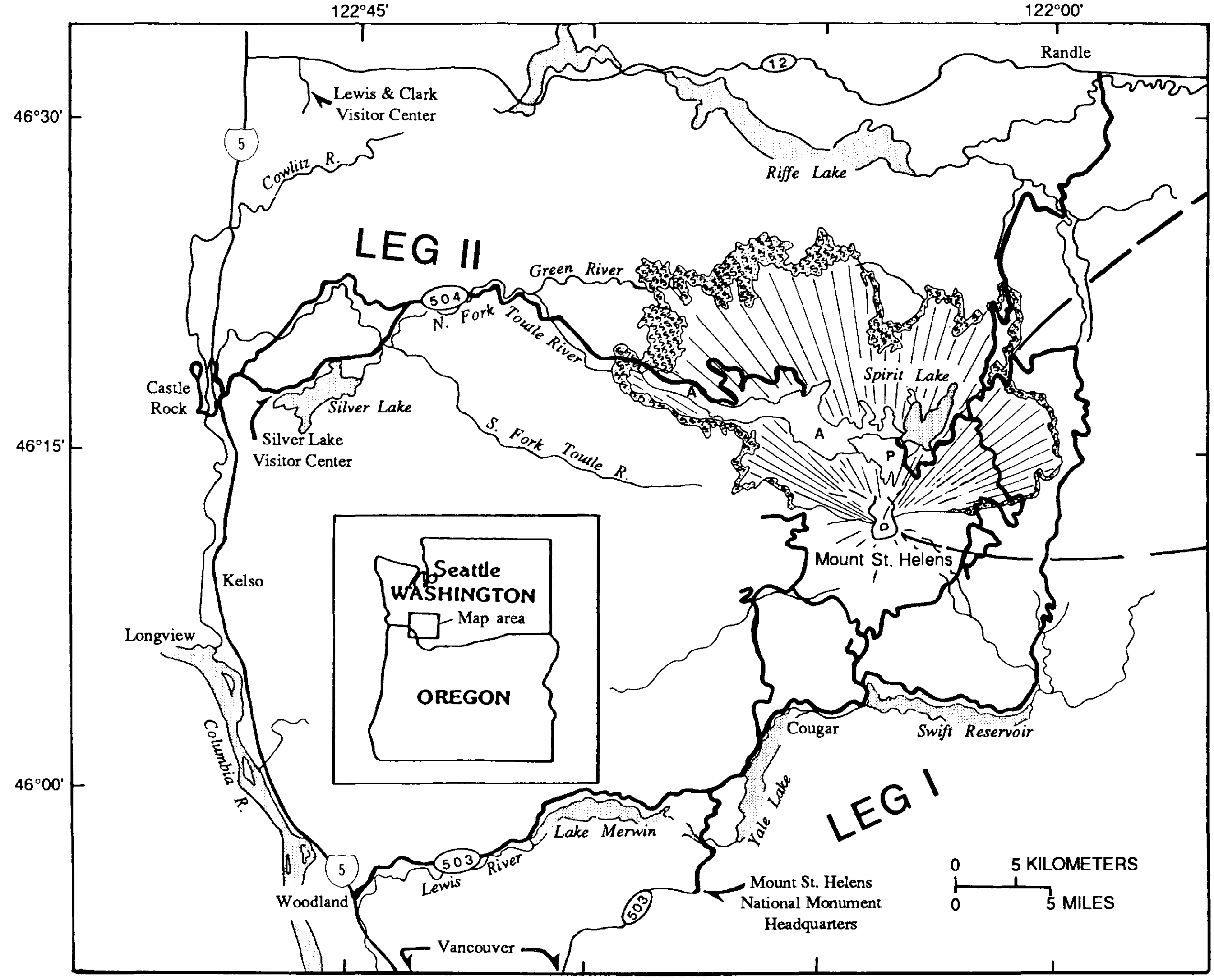


Figure 4. Southwestern Washington, showing field-trip routes to Mount St. Helens. Leg I consists of routes to areas south, east and northeast of the volcano. Leg II leads to areas west of the volcano. Radiating lines, inner devastated zone where virtually every large tree was uprooted or broken off, branches stripped, and the trunk abraded and left aligned in the direction of local blast motion. Patterned areas, sear zone at fringe of devastated zone where vegetation was left standing but killed by heat. A, avalanche; P, pyroclastic flows. Long-dashed line, area of 1980 tephra fall.

mainly for use by individuals with a background in geology, although parts of it may be useful to the layman. The guide is organized around two primary routes. Leg I (fig. 4) leads on paved and gravel roads from Vancouver to the Windy Ridge overlook near Spirit Lake via Cougar (legs I, Ib). This is possibly the most scenic route described in the guide, yielding a transect of the devastated zone of May 18, 1980, Spirit Lake, and numerous vistas of the volcano. The trip requires at least a full day from Vancouver. Be advised that gas, food, and other services are available only in Cougar, at the Eagle Cliff store (east end of the Swift Reservoir), and in Randle.

Leg II (fig. 4) leads to the volcano from Vancouver via U.S. Interstate Highway 5, then on a paved and gravel road along the Toutle River. Highlights include the spectacular effects of mudflows and a view of the huge debris-avalanche deposit that was formed on May 18, 1980. This trip also requires a full day from Vancouver; it is not now possible to connect legs I and II north of the volcano to make a convenient loop. For those who wish to see other geologic features not on the main routes, several side trips are described to points of special interest (legs Ia, Ib, Ic, Id). Because visitors may have various amounts of time and varied interests while visiting Mount St. Helens, tables have been provided so that the visitor may decide what stops to make (tables 1, 2). Each table contains a list cross-referencing the periods of volcanic activity at Mount St. Helens with outcrops that illustrate the various types of processes and products from that period; outcrops are located by leg and stop number. Included within the road log are mileages between points of interest. Parts of leg I from the Swift Reservoir and leg Id from Randle have mileages that can be read either north or southbound.

Access to some of these sites requires a four-wheel-drive vehicle; a few areas also require special permits. We recommend that you discuss your itinerary with U.S. Forest Service (USFS) or USGS personnel who are familiar with current conditions.

Weather and road conditions can change access to the volcano, so check with the Gifford Pinchot National Forest (Vancouver, Wash.) or Mount St. Helens National Volcanic Monument Headquarters (Amboy, Wash.). The traveling times between the Cascades Volcano Observatory and localities near the volcano are listed in table 3.

The most valuable references for this road guide are USGS Professional Paper 1250, "The 1980 Eruptions of Mount St. Helens, Washington," and the USFS-USGS-Washington Department of Natural Resources 1:100,000-scale map "Mount St. Helens and Vicinity." Other useful material is listed in the section below entitled "References."

Table 3. Traveltimes from the Cascades Volcano Observatory to points near Mount St. Helens

[CVO, Cascades Volcano Observatory; USFS, U.S. Forest Service]

Route	Distance (mi)	Time (h)
Vancouver (CVO) to Woodland via U.S. Interstate Highway 5.	22.1	1/2
Vancouver (CVO) to Castle Rock via U.S. Interstate Highway 5.	50	1+
Vancouver (CVO) to Randle via U.S. Interstate Highway 5 and U.S. Highway 12.	118.8	2
Vancouver (CVO) to Cougar via Washington Highway 503 and USFS Road 90.	50.3	1+
Cougar to Windy Ridge parking lot via USFS Roads 90, 25, and 100.	54	2+

ROAD GUIDE

CAUTION: SOME OF THE ROADS IN THIS GUIDE ARE SUITABLE ONLY FOR FOUR-WHEEL-DRIVE VEHICLES AND ARE IMPASSABLE IN THE WINTER AND SPRING. CHECK WITH LOCAL AUTHORITIES BEFORE ATTEMPTING ROADS OFF THE MAIN HIGHWAYS.

Leg I. Vancouver to Spirit Lake

Vancouver to the Swift Reservoir

Cumulative mileage	(mileage between points)	
0.0	0.0	Leave Cascades Volcano Observatory. Travel west on Mill Plain Blvd. to junction with U.S. Interstate Highway 5. Head north on U.S. Interstate Highway 5. Surface is underlain by gravel and sand of the great Pleistocene glacial Lake Missoula floods.
15.6	(15.6)	Pass Ridgefield exit to Washington Highway 501. View of Mount St. Helens to the northeast.
19.8	(4.2)	Cross the East Fork Lewis River. Outcrops in roadcut on east side of road are lava flows of the upper Eocene or lower Oligocene Goble Volcanics Series of Lowry and Baldwin (1946), interbedded with sandstone and siltstone of the Cowlitz Formation (in part equivalent to the Hatchet Mountain Formation (Roberts, 1958), consisting of porphyritic andesite, olivine basalt, basalt, and breccia, with interbedded sedimentary rocks).

21.5	(1.7)	Cross the North Fork Lewis River.
22.1	(0.6)	Take exit 21 to Woodland; head east along Washington Highway 503 along north side of the Lewis River.
23.4	(1.3)	Concrete retaining walls for flood protection.
29.8	(6.4)	Lewis River fish hatchery.
31.8	(2.0)	Outcrops of interbedded Tertiary lava flows and breccia of the Hatchet Mountain(?)Formation (Roberts, 1958), equivalent of the Goble Volcanic Series of Lowry and Baldwin (1946).
32.5	(0.7)	Junction with road to the Merwin Dam and Lelooska Indian exhibit.
33.5	(1.0)	Outcrops of Tertiary lava flows and other volcanic rocks along road for several miles. Entering area of figure 5.
37.8	(4.3)	Junction with Wilkinson Road.
42.1	(4.3)	Red-baked sedimentary deposits beneath lava flow.
44.5	(2.4)	Valley glaciers occupied the Lewis River valley during the local Amboy glaciation (Mundorff, 1984). Here, glaciers reached a thickness of 1,950 ft (600 m). The Amboy drift deposited from these glaciers was found to be overlain by the C tephra from Mount St. Helens (35,000–40,000 yr old). Mundorff (1984) suggested that the Amboy drift is correlative with the Hayden Creek drift (^{14}C dating showed wood found in Canyon Creek east of Lake Merwin to be older than 60,000 yr) and represents a geologic event of early Wisconsin age.
45.2	(0.7)	Junction of Lewis River Road and Washington Highway 503.

SIDE TRIP Ia. Yale Dam and Volcanic Monument headquarters

Cumulative mileage	(mileage between points)	
0.0	(0.0)	Road to headquarters of Mount St. Helens National Volcanic Monument. Head south on Washington Highway 503.

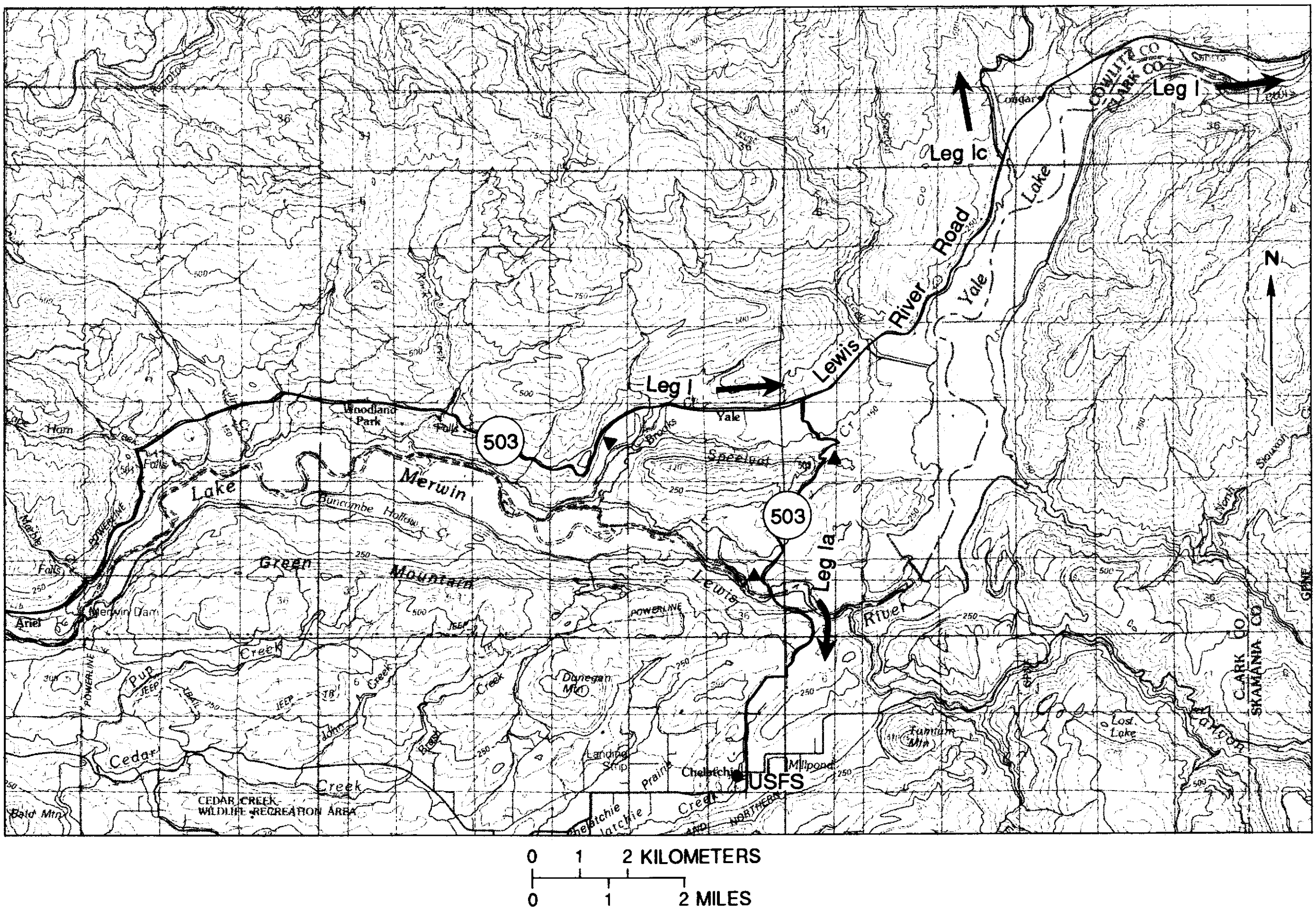


Figure 5. Field-trip route along the Lewis River near Lake Merwin and Yale Lake, showing part of leg I and starting point of legs Ia and Ic. Triangles, viewpoints; circled numbers, U.S. Forest Service roads; USFS, U.S. Forest Service station.

1.4 (1.4) VIEWPOINT. Speelyai viewpoint, 17 mi (27 km) SW. of Mount St. Helens. Southwest flank of Mount St. Helens is visible from here.

2.9 (1.5) Yale Dam turnoff. About 300 ft (100 m) beyond the intersection are laharic overbank deposits of the Swift Creek eruptive stage (13,000–8,000 yr B.P.) overlying brown silt (loess?). Near the base of the brown silt is a bed of air-fall lapilli, probably part of the M tephra (early Cougar eruptive stage, 20,000–18,000 yr B.P.). Two fine-grained lahars exposed in a small borrow pit several hundred yards farther down the road are separated by about 0.4 in. (1 cm) of S tephra (early Swift Creek eruptive stage, 13,000 yr B.P.).

3.4 (0.5) Bridge over east end of the Merwin Reservoir.

5.7 (2.3) Chelatchie, USFS Mount St. Helens Volcanic Monument headquarters. Check in here if you have a gate key to pick up, passes to sign, and so on.

END OF SIDE TRIP Ia

Return north on Washington Highway 503; rejoin leg I.

Cumulative mileage	(mileage between points)	
0.0	(0.0)	Turn right and head east on Lewis River road to the town of Cougar. Terrace surface and valley fill contain deposits of the Cougar eruptive stage.
1.3	(1.3)	Cross Speelyai Creek. Terrace surface is underlain by lahars of the Cougar eruptive stage.
2.5	(1.2)	Yale Reservoir to the right.
3.1	(0.6)	Across lake to the east are deposits of the Cougar eruptive stage.
3.3	(0.2)	Visitor-information station to Mount St. Helens National Volcanic Monument.
4.4	(1.1)	Junction with USFS Road 81 and side trip to Merrill Lake (leg Ic).
4.7	(0.3)	Bridge over Dog Creek. Entering area of figure 6.
5.1	(0.4)	Road to borrow pit and outcrop of lahar of the Swift Creek eruptive stage. Deposits predating the S tephra (ca. 13,000 yr B.P.)
5.4	(0.3)	Enter the town of Cougar, where gas and food are available (may be last gas for 160-mi [260 km] round trip). Travel east from Cougar on Lewis River road, which becomes USFS Road 90.
7.3	(1.9)	Ahead, the surface unit is the Cave Basalt, formed during the Castle Creek eruptive period (2,200–1,700 yr B.P.), a high-alumina basalt, uncon formably overlying deposits of the Cougar eruptive stage.
7.8	(0.5)	Hydroelectric-power house on right. Rip-rap of hydroelectric-power canal on left is composed of Cave Basalt.
8.2	(0.4)	On both sides of the road are tumuli, a feature common in tube-fed pahoehoe basalt flows. During Castle Creek time, the Cave Basalt flowed down a broad fan from the south flank of Mount St. Helens and poured over the cliff north of the road, covering the floor of the Lewis River valley.
9.5	(1.3)	In north bank and bed of the Lewis River ahead on the right is a lahar of the Ape Canyon eruptive stage (40,000–35,000 yr B.P.) that contains wood dated at 36,000±2,100 yr (Crandell and others, 1981). The wood here is slightly charred or uncharred, but the presence of larger biotite-bearing dacite clasts showing consistent paleomagnetic vectors suggests that the clasts were hot upon emplacement (C.G. Newhall, oral commun., 1983). To visit this spot, you should pull off the road before it rises up to cross the hydroelectric-power canal.
9.9	(0.4)	Power canal bridge; Swift Dam up valley. Outcrops of deposits of the Cougar eruptive stage on north side of road.
10.8	(0.9)	North side of road. Lower 30 ft (9 m) consists of lahar and stream deposits of the Cougar eruptive stage, above which is exposed reddish-pink outcrops of a debris-avalanche deposit (coarse flowage deposit of Hyde, 1975) and pyroclastic flows of the Cougar eruptive stage.
11.6	(0.8)	STOP 1 AND VIEWPOINT. Swift Reservoir overlook.

The road between the power canal bridge and the Swift Reservoir overlook climbs through a dissected fan of deposits of the Cougar eruptive stage that blocked the Lewis River valley here and extended as far downstream

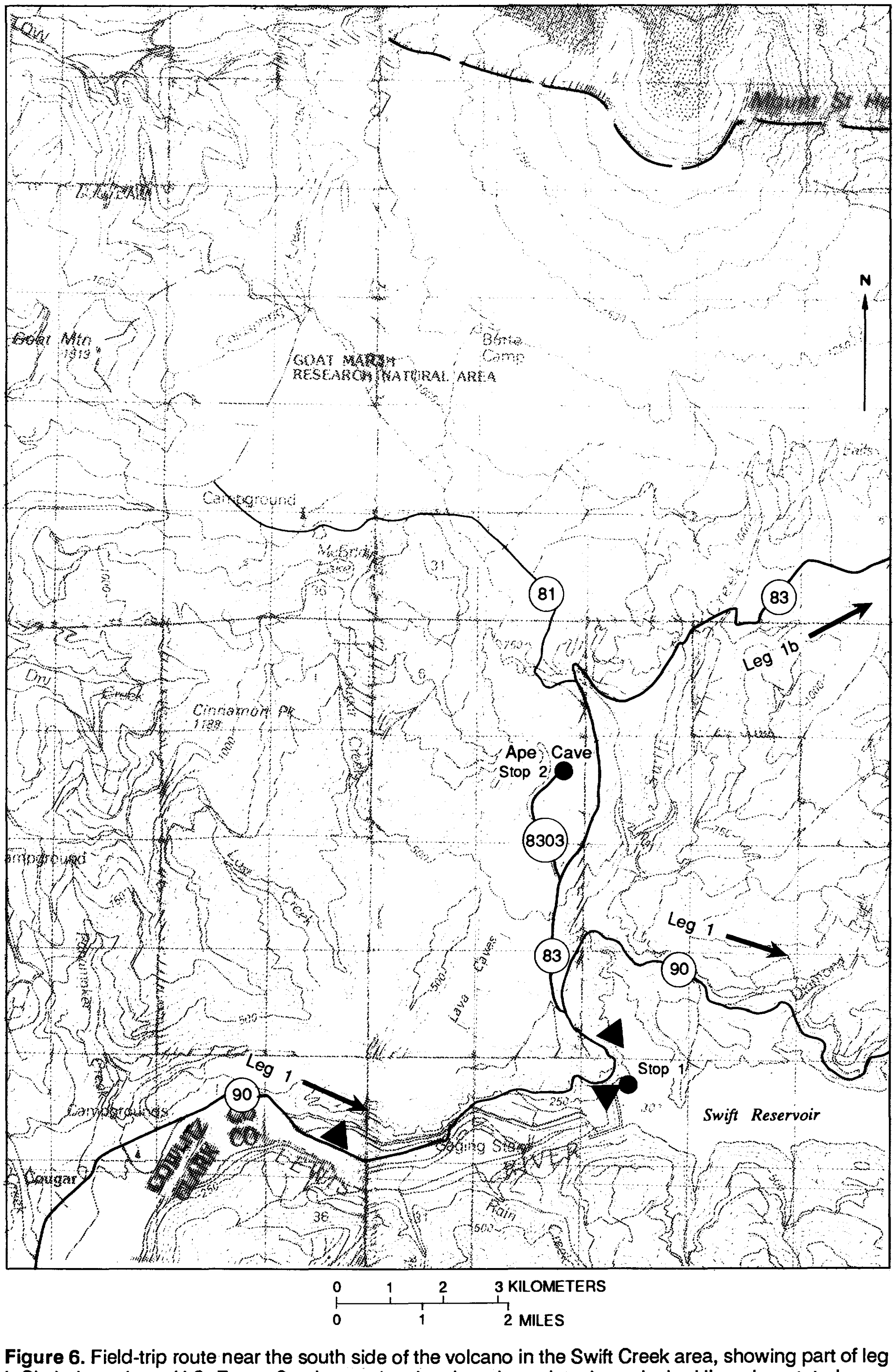


Figure 6. Field-trip route near the south side of the volcano in the Swift Creek area, showing part of leg I. Circled numbers, U.S. Forest Service roads; triangles, viewpoints; long-dashed line, devastated-zone boundary.

as the Merwin Reservoir (side trip Ia). You are standing on the upper surface of a fan that once extended across the Lewis River valley (fig. 7). Southwest of the overlook, across the Lewis River valley at this altitude, is a remnant of the fan surface. In a borrow pit in this remnant are stratified sand and gravel, lahar deposits, pyroclastic-flow material, and tephra of the Cougar eruptive stage (Crandell, 1987). An 18,560-yr age was obtained on charcoal from a 6-ft (2 m)-thick pyroclastic-flow deposit overlying M tephra and a 20,350-yr age was obtained on charcoal from a pumiceous pyroclastic-flow deposit underlying M tephra (Crandell and others, 1981). During an earlier part of the Cougar eruptive stage, an avalanche similar to that of 1980 may have occurred on the south flank of Mount St. Helens (Hyde, 1975; Newhall, 1982). These deposits can be seen as reddish-pink outcrops on the north side of the road as you travel up the hill. The deposits once had a volume of at least 0.4 mi^3 (1 km^3), and extended at least 9 mi (15 km) from the volcano (Newhall, 1982). A lake apparently formed behind the avalanche. Breaching of the blockage by the lake generated a large lahar. This and a similar 2,800-yr-old deposit of the Pine Creek eruptive period (seen on leg II, stop 5) may represent the type of phenomena that could result if the large lakes dammed by the 1980 eruptions of Mount St. Helens were to breach their barriers.

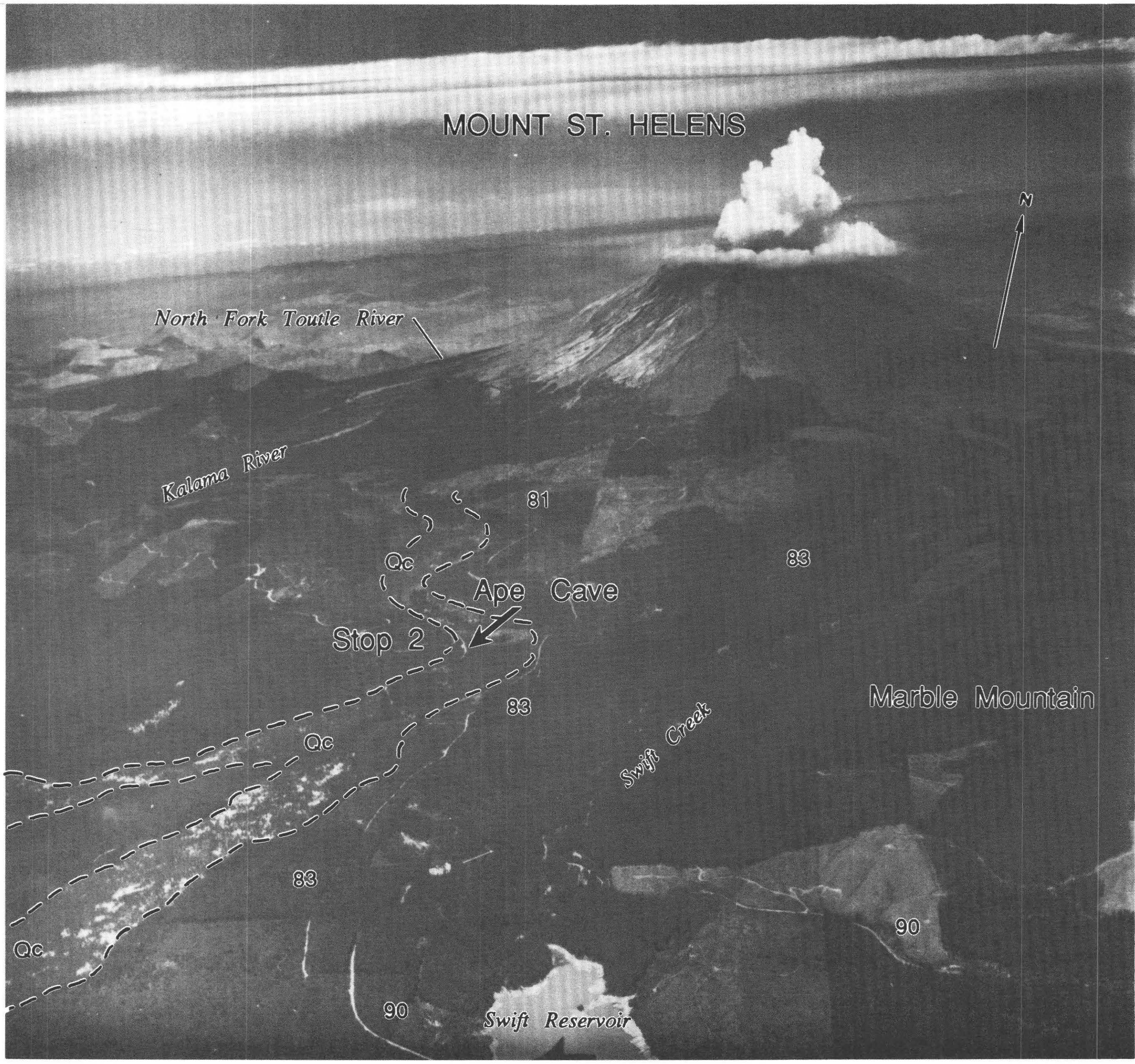


Figure 7. South side of Mount St. Helens. Qc, Cave Basalt (Holocene); dashed lines indicate approximate boundaries. Numbers, U.S. Forest Service roads. Photograph by Austin Post, taken June 30, 1980.

GO TO PAGE 20 FOR CONTINUATION OF SWIFT RESERVOIR ROUTE LEG I.

SIDE TRIP Ib. Swift Reservoir to Ape Cave lava tube, Pine Creek-Muddy River fan, and Smith Creek-Muddy River

Cumulative mileage	(mileage between points)	
0.0	(0.0)	STOP 1 AND VIEWPOINT. Swift Reservoir dam overlook. Continue on USFS Road 90.
0.9	(0.9)	Junction of USFS Roads 83 and 90. Leg I continues to right (route to Spirit Lake). Turn left onto USFS Road 83 for side trip Ib to the Ape Cave lava tube and east slopes of Mount St. Helens.
2.6	(1.7)	Junction of USFS Roads 83 and 8303. Turn left to Ape Cave.
2.8	(0.2)	Lava Cast picnic grounds. Exposed in basalt 300 ft (100 m) south of the parking lot are molds of trees that were inundated by the Cave Basalt flow.
3.8	(1.0)	STOP 2. Parking lot of lower entrance to Ape Cave.

Warm clothing and flashlight or lantern are needed if you plan to explore the cave. Ape Cave is one of numerous lava tubes formed in the Cave Basalt (fig. 8). The basalt consists of pahoehoe flows that originated on the southwest flank of Mount St. Helens and flowed down the surface of older pyroclastic-flow deposits. Charcoal samples from two localities under the lava tubes yielded ^{14}C ages of 1,860±250 and 1,925±95 yr (Greeley and Hyde, 1972).

Return to junction of USFS Roads 83 and 8303 to continue leg Ib.

Cumulative mileage	(mileage between points)	
0.0	(0.0)	Turn left on USFS Road 83 and head north. Road follows the surface of pyroclastic-flow deposits and lahars of the Cougar eruptive stage.

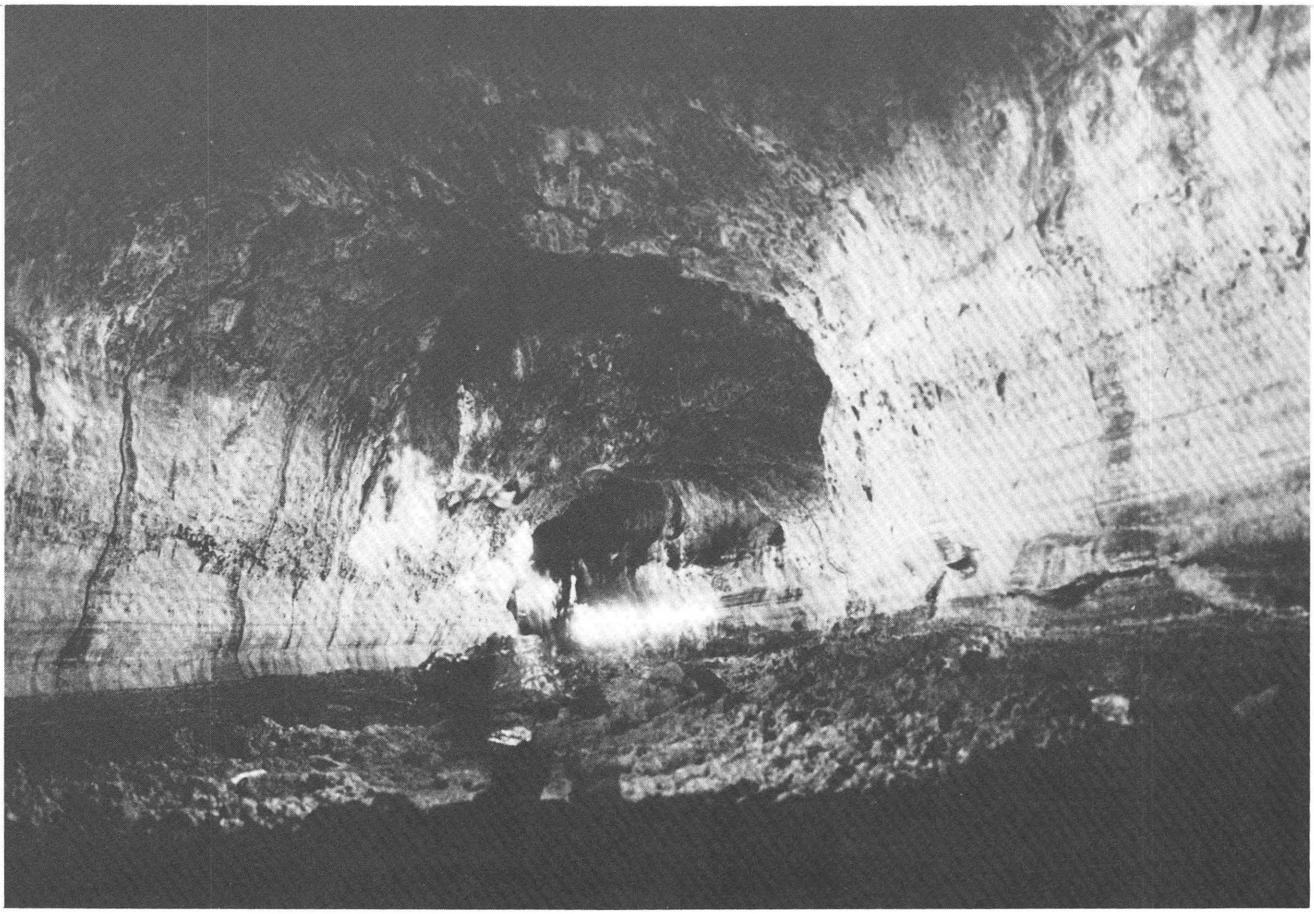


Figure 8. Interior of Ape Cave lava tube within the Cave Basalt; tube here is approximately 30 ft (9 m) wide. Photograph by Ken Cameron.

1.3 (1.3) Junction of USFS Roads 83 and 81. Road to left (USFS Road 81) leads to Red Rock Pass, Merrill Lake, the Kalama River basin, and leg Ic.

Bear right and continue on USFS Road 83. For the next half-mile (0.8 km) are exposed deposits of the Swift Creek and Cougar eruptive stages. Pyroclastic flows and lahars of the Swift Creek eruptive stage are interbedded with S tephra (13,000–18,000 yr old) and overlie till of the Fraser glaciation. This till consists predominantly of rock debris derived from the volcano (Hyde, 1975).

1.8 (0.5) Cross the West Fork Swift Creek. The oldest and longest andesite flow from Mount St. Helens is exposed for the next half-mile (0.8 km) along the southwest-facing slope. The flow is overlain here by a pumiceous pyroclastic-flow deposit of the Cougar eruptive stage. These deposits are, in turn, overlain in the roadcut by pyroclastic-flow deposits and lahars of the Swift Creek eruptive stage.

The best drinking water on the mountain is from a spring on the north side of road, a short distance east of the creek crossing.

3.8 (2.0) Cross the East Fork Swift Creek. Exposed in the creek bed is a basalt flow of the Castle Creek eruptive period overlain by lahar deposits of the same age.

4.2 (0.4) Junction of USFS Roads 83 and 8312. Bear left (for road to Marble Mountain, turn right on USFS Road 8312).

4.8 (0.6) Outcrops of the Ohanapecosh Formation on left, north of road.

5.7 (0.9) Junction of USFS Roads 83 and N825; bear right. Entering area of figure 9.

6.2 (0.5) Junction of USFS Road 83 and unmarked road; bear left.

6.8 (0.6) Tephra deposits, ranging in age back to the Swift Creek eruptive stage (table 1), are exposed in outcrop just past unnamed creek. These deposits include dark scoria

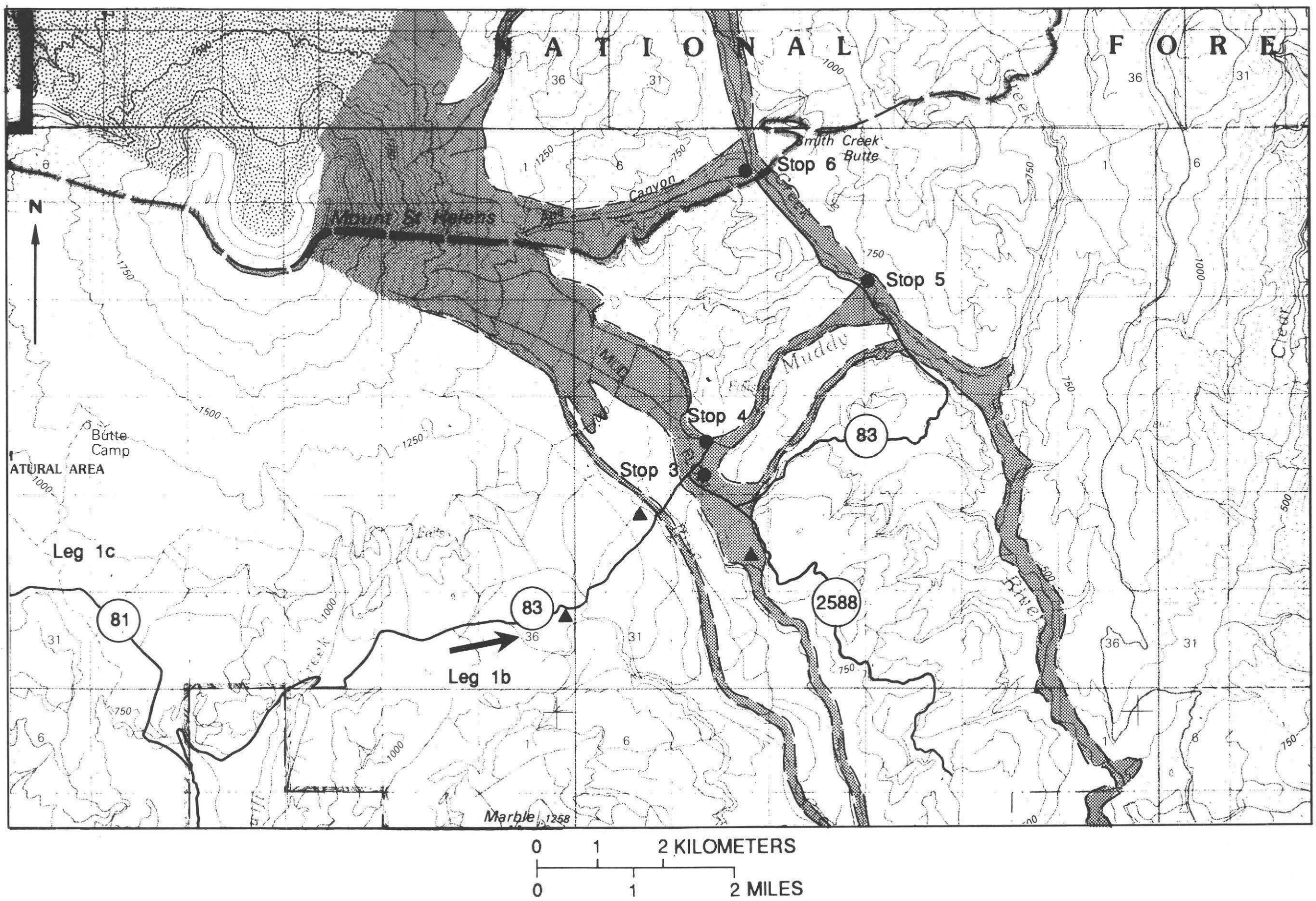


Figure 9. Field-trip route near southeast side of the volcano in the Pine Creek, Muddy River, and Smith Creek areas, showing part of leg Ib. Triangles, viewpoints; circled numbers, U.S. Forest Service roads; long-dashed line, devastated-zone boundary; short-dashed lines and shading, areas covered by pyroclastic flows and lahars on east side of volcano; stippling, areas covered by pyroclastic flows and avalanche on north side of volcano.

of the X tephra and white pumice lapilli of the We tephra from the Kalama eruptive period, basaltic and dacitic ash of the B tephra from the Castle Creek eruptive period, the P tephra from the Pine Creek eruptive period, yellow pumice of the Ye tephra from the Smith Creek eruptive stage, and orange pumice of the J tephra from the Swift Creek eruptive stage.

7.1 (0.3) Road crosses over a spur composed of Ohanapecosh Formation that underlies Marble Mountain volcanic rocks south of road; enter the Pine Creek-Muddy River fan complex.

Information concerning events that occurred at the following stops in the Lewis River-Pine Creek-Muddy River-Smith Creek drainage basin (fig. 10) on May 18, 1980, was reported by Janda and others (1981).

8.2 (1.1) VIEWPOINT. Cross Pine Creek. A previous bridge survived the May 18, 1980, eruption but was destroyed the following winter by high water.

8.6 (0.4) Leave forested area that was little affected by mudflows and enter onto mudflow-swept fan surface.

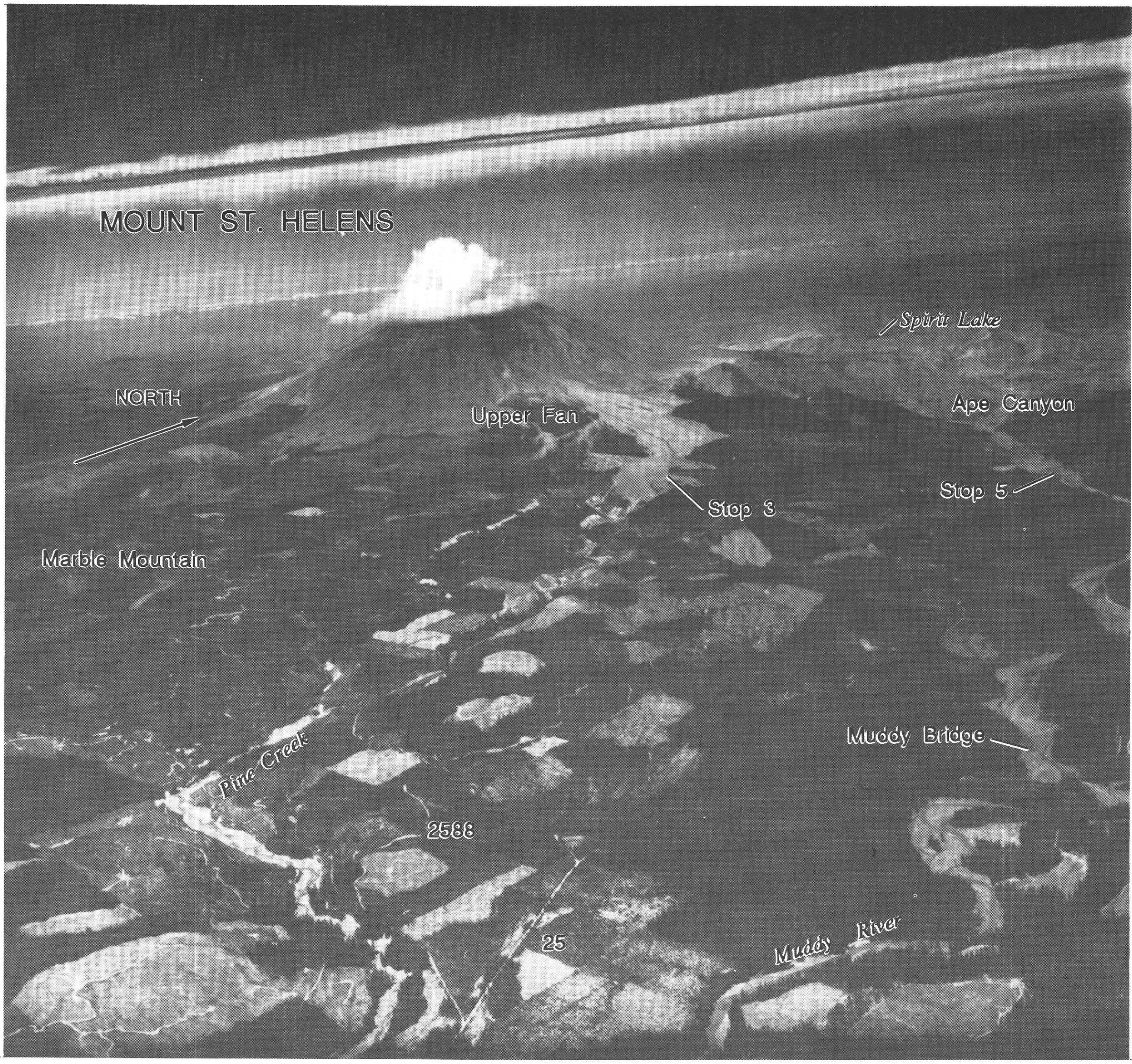


Figure 10. Southeast side of Mount St. Helens. Numbers, U.S. Forest Service roads. Photograph by Austin Post, taken June 30, 1980.

8.7 (0.1) STOP 3. USFS "Lahar Viewpoint."

A short walk to the east brings you to a small hill and the viewpoint. This area was swept by a lahar within 15 minutes after the onset of the May 18 eruption (fig. 11). At this point, the speed of the lahar was estimated at about 44 mi/h (20 m/s). Conspicuous notch in east rim of Mount St. Helens is truncated valley cut by the Shoestring Glacier. This glacier formerly was fed by an ice and snow field at the summit of Mount St. Helens. The eruption of May 18 decapitated the glacier and removed approximately three-quarters of its original volume (Brugman and Meier, 1981).

Depending on road conditions and vehicle restrictions, you may have to walk to the next stop. Travel on road that leads to northeast from the parking area.

9.2 (0.5) STOP 4. Outstanding outcrops of pyroclastic-flow and air-fall deposits, and the lahar-impact area.

Here is one of a few exposed sections that show an extensive stratigraphic record of Mount St. Helens eruptive history (figs. 12, 13). S tephra underlies an erosional surface (early Swift Creek eruptive stage). Two conspicuous orange layers of J tephra (late Swift Creek eruptive stage) are overlain by Y tephra (Smith Creek eruptive stage), which is interbedded with pyroclastic-surge deposits. Overlying the deposits of the Smith Creek eruptive period is P tephra (a mixture of reworked tephra and possible surge deposits of the Pine Creek eruptive period); B tephra (basaltic and basaltic andesite scoria and dacite of the Castle Creek eruptive period, older than the Cave Basalt); W tephra (layer We, white pumice lapilli and ash of the Kalama eruptive period, erupted A.D. 1482); X tephra (andesitic ash of the Kalama eruptive period, in part contemporaneous with andesitic flows on the south flank of the mountain); and 1980 lahar deposits and 1982 tephra deposits.

Head downstream from the tephra exposure, cross the road washout, and walk up USFS Road 83 into the stand of trees. A lahar on the morning of May 18, 1980 (approx 8:45 a.m. P.d.t.), traveled over the small ridge on the northeast banks of the Muddy River and moved through here. Examples of battering as the flow traveled through the trees are evident: The bark has been removed from the lower trunks of trees, laharic debris remains trapped on the upslope side of standing trees, and cobble-size rocks can be found embedded in tree trunks. Large boulders carried by the flow were left behind. Bayonet trees (sharpened by the abrasive action of the flow) point downstream.

Downstream from the washed-out USFS Road 83 are outcrops of columnar-jointed basalt from the Castle Creek eruptive period.

END OF SIDE TRIP Ib

Return to parking lot and head south down the Pine Creek fan (fig. 11). This part of the guide describes the route down into the Muddy River-Smith Creek drainage along USFS Road 83. The trip will return to the junction of USFS Roads 2588 and 83, continue southeast, and connect with leg I.

0.5 (0.5) Junction of USFS Roads 83 and 2588 on surface of the Pine Creek-Muddy River fan. Note relation between lahar-swept surface and unaffected areas. This area was clear cut before the 1980 eruption, and the lahar that passed here battered cut stumps. Just east of the road, the position of the edge of the lahar can be detected by the presence of unbattered stumps.

Continue straight on USFS Road 2588 to the Muddy River, Pine Creek, Lewis River, and USFS Roads 25 and 90, or turn left on USFS Road 83.

0.7 (0.2) You are now at top of grade leading to the Muddy River. In the next ¾ mi (1.2 km), note effects of the May 18, 1980, mudflow that spilled into the Hoo Hoo Creek drainage from the Pine Creek-Muddy River fan. X through B tephras crop out for the next 3 mi.

Entering area of figure 14.

4.7 (4.0) Tephra layers of the Cougar eruptive stage are exposed on the south bank of Hoo Hoo Creek just west of USFS Road 83.

5.1 (0.4) Bridge over the Muddy River at south edge of lower Muddy River fan. Here is a view upstream of part of the dissected fan. The bulk of the Muddy River fan consists of dacite debris from the summit dome of Mount St. Helens dating from the Kalama eruptive period (370 yr B.P.).

On the east bank of the Muddy River in a borrow pit is an almost complete set of representative air-fall tephras from Mount St. Helens, as defined by Mullineaux (1986; see table 1). ^{14}C ages of 37,600±1,300 and 36,000±2,500 yr (Crandell and others, 1981) were obtained on charcoal from two horizons within the C tephra exposed in the slope above the quarry. Locate temporary footbridge or wade the river to visit the locality.

5.2 (0.1) Enter onto lower Muddy River fan surface, swept by lahars on the morning of May 18, 1980.

5.5 (0.3) STOP 5. North end of fan (fig. 15). Erosion by Smith Creek has exposed materials of the Kalama eruptive period, which make up the bulk of the fan, and May 18 deposits at the top. The 1980

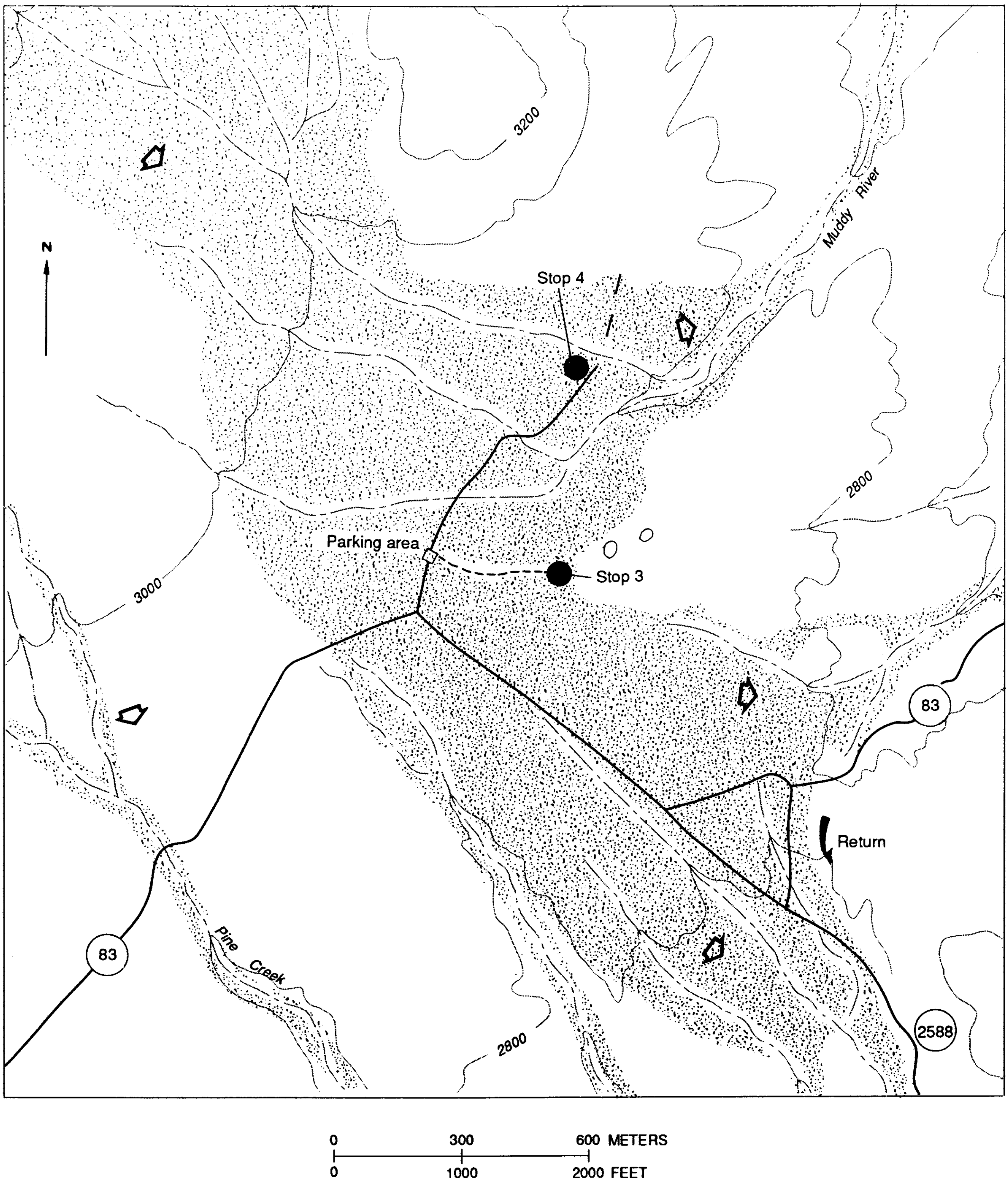


Figure 11. Generalized geologic map of upper Muddy River-Pine Creek fan, showing extent of lahar that swept this area (shading). Arrows indicate direction of lahar's path. Circled numbers, U.S. Forest Service roads; short-long-dashed lines, streamcourses; short-dashed line, path to stop 3. Contour interval, 200 ft.

materials, which are about 3 ft (1 m) thick here, overlie preeruption roots and woody debris.

On the morning of May 18, two floods converged on this locality; one from the Muddy River probably reached here about 8:40 a.m. P.d.t. (traveling at 65 to 105 ft/s [20–32 m/s] over a distance of 6 mi [10 km]). The Smith Creek flood, combined with the lahar that came down Ape Canyon, appears to have become impounded for a short time before continuing downstream to the Swift Reservoir.

A stand of trees that probably date from the period during emplacement of the old summit dome has been exhumed on the east bank of Smith Creek upstream from the main part of the lower Muddy River fan.

Continue upvalley on USFS Road 83. (THIS ROAD IS CLOSED TO PUBLIC ACCESS, AND A VEHICLE PERMIT IS REQUIRED; CHECK WITH THE USFS.) Entering area of figure 16.

7.2 (1.7) STOP 6. Smith Creek bridge site and the Beavertail landslide.

An outcrop containing C tephra and pyroclastic flows of the Ape Canyon eruptive stage can be reached by walking upstream on the west bank or climbing uphill and heading north, depending on how much water is in creek; outcrop is highest, light-colored cutbank south of the mouth of Ape Canyon. A ^{14}C age of older than 42,000 yr (Crandell and others, 1981) was obtained on charcoal from a pumiceous pyroclastic-flow deposit exposed in an old roadcut (now a high bank) about 650 ft (200 m) south of the mouth of Ape Canyon. In this roadcut are three pyroclastic flows, with pumice of the C tephra lying between the top two.

The lahar that coursed down Ape Canyon on the morning of May 18 flowed 260 ft (80 m) up the east valley wall of Smith Creek onto the toe of the Beavertail landslide; this runup distance requires a flow velocity exceeding 85 mi/h (135 km/h). Ape Canyon marks the south edge of the blast zone; vegetation on the south side of the canyon was little affected, whereas trees to the north were singed or downed by the hot lateral blast. The 1980 tephra deposited here consists of the A1 layer from the blast, air-fall pumice from the morning of May 18, and lapilli from the July 22, 1980, eruption (white-and-gray pumice and dark lithic material).

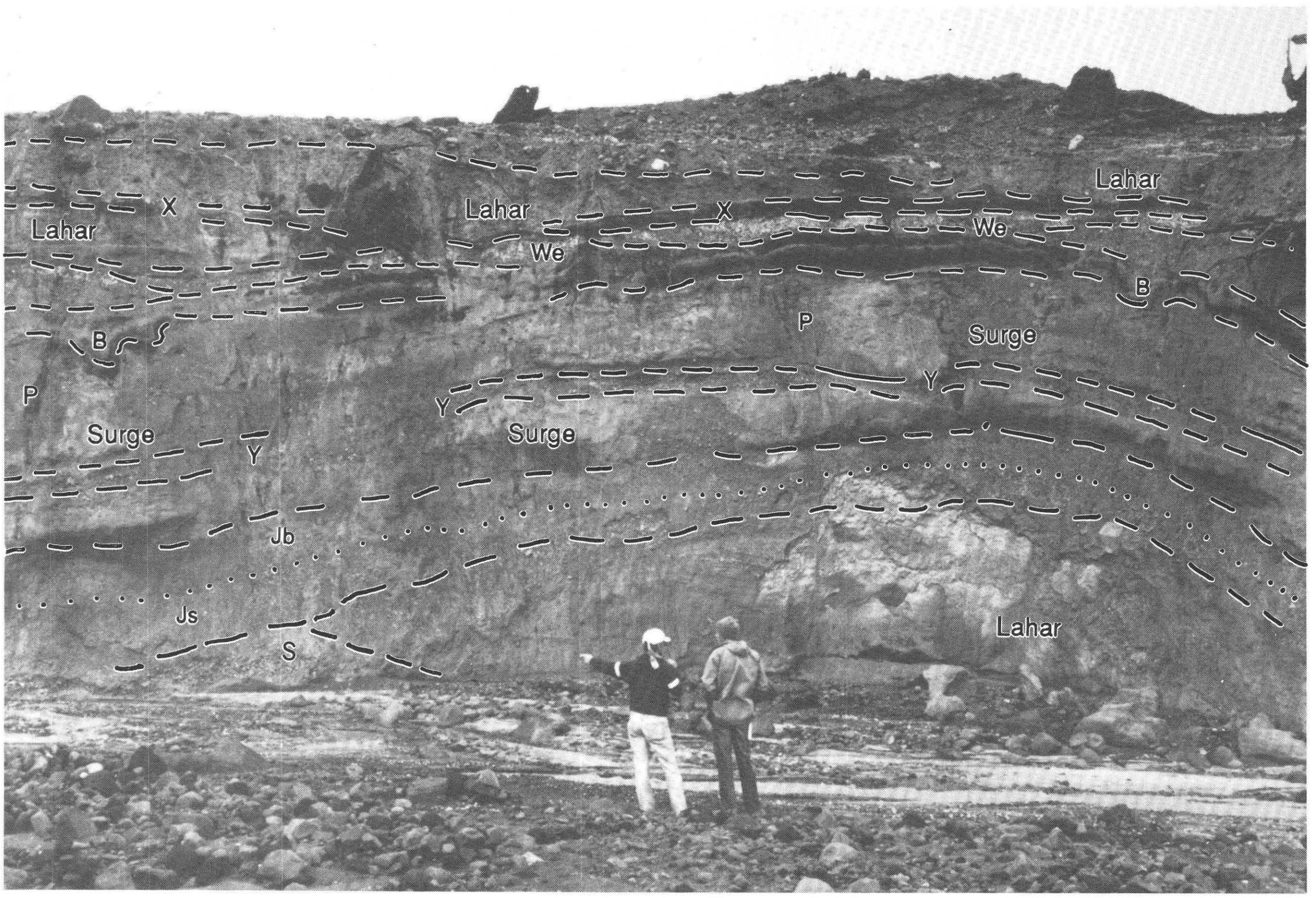


Figure 12. Outcrop at stop 4. Letters denote air-fall-tephra layers (see fig. 13; table 1).

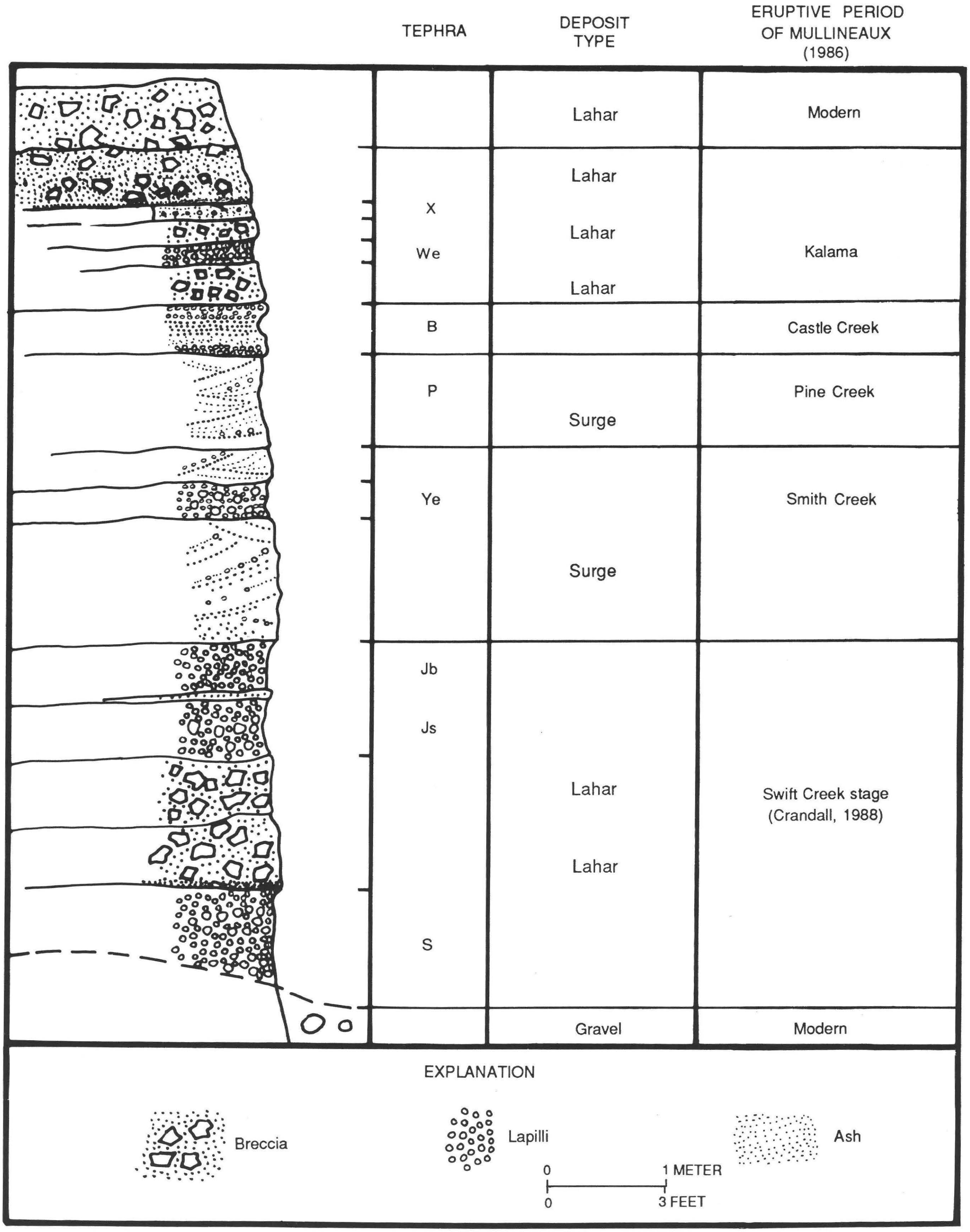


Figure 13. Generalized stratigraphic section of outcrop at stop 4. Layers include deposits from lahars and surges (ash clouds), alternating with pyroclastic-flow deposits, air-fall tephra, and lava flows that traveled down the Muddy River-Pine Creek fan. One lava flow of Castle Creek age lies buried beneath the active stream channel. Deposit type indicates presumed style of deposition of flowage material.

Return to Pine Creek-Muddy River fan surface and junction of USFS Roads 83 and 2588, and turn left.

14.5 (0.5) VIEWPOINT. Overlook of Pine Creek-Muddy River fan and Mount St. Helens. View of lahar-swept Pine Creek-Muddy River fan surface. On the morning of May 18, 1980, the lahar moved down the fan and then poured into deeper canyons of the Pine Creek drainage (fig. 11).

21.2 (6.7) Junction of USFS Roads 25 and 2588 with leg I. Turn right to return to Cougar; turn left to go to Spirit Lake and Randle.

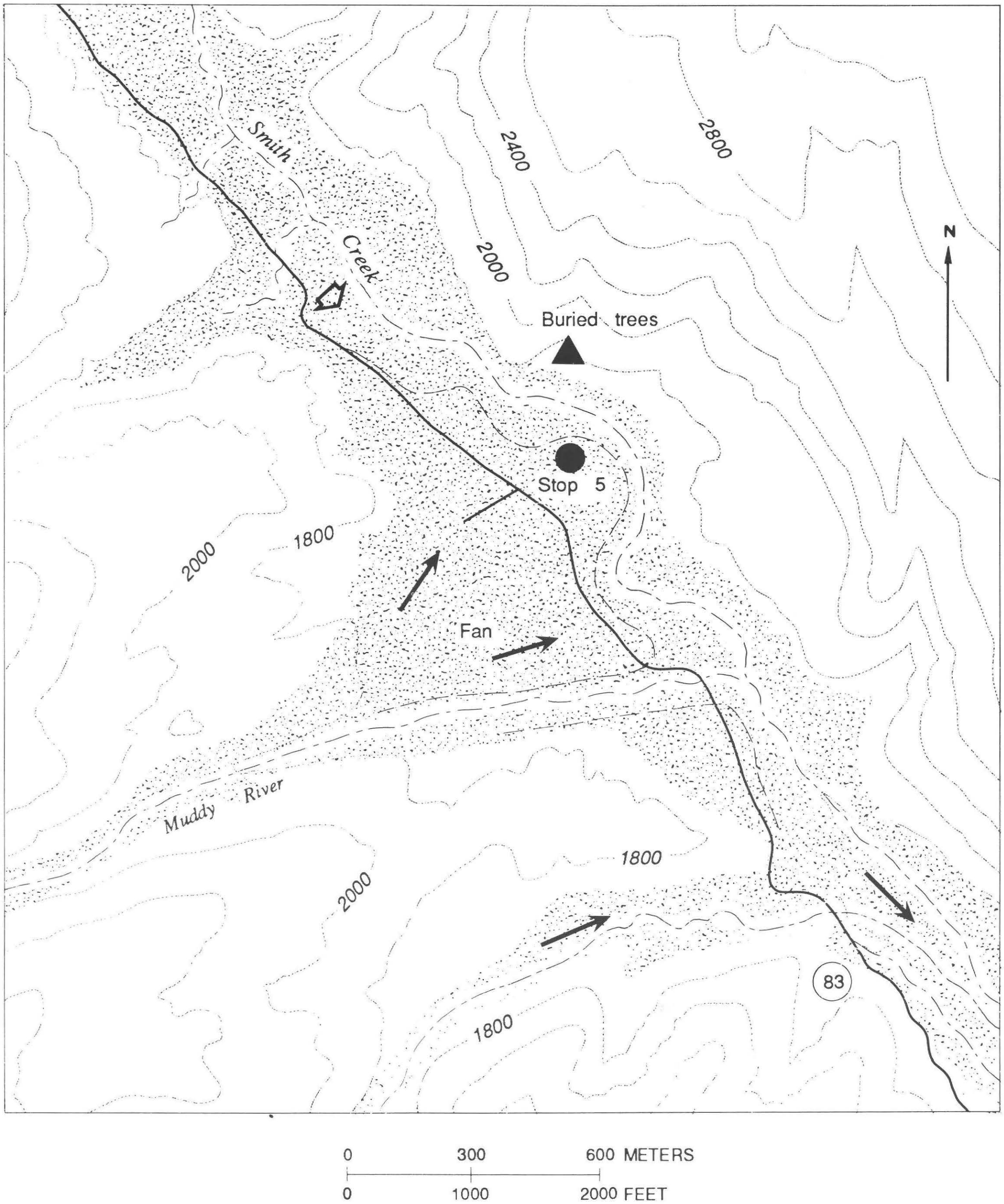


Figure 14. Generalized geologic map of area near confluence of Smith Creek and Muddy River, showing extent of lahar generated on May 18, 1980 (shading). Solid arrows, direction of Muddy River lahar's path; open arrow, direction of Smith Creek lahar's path. Circled number, U.S. Forest Service road; short-long-dashed lines, streamcourses; dashed line, edge of channel cut into fan deposits. Contour interval, 200 feet.

Swift Reservoir to Spirit Lake

Swift Reservoir dam overlook to Elk Pass and road to Spirit Lake via USFS Road 25. (Route can be followed by reading southbound along USFS Road 25 from USFS Road 99 junction or northbound from the Swift Reservoir dam overlook.)

North-bound	South-bound	
0.0 (0.0)	40.1 (0.9)	Swift Reservoir dam overlook, heading north on USFS Road 90 (leg I, fig. 17).
0.9 (0.9)	39.2 (0.6)	Junction of USFS Roads 83 and 90. Stay on USFS Road 90.
1.5 (0.6)	38.6 (0.3)	STOP 7. Park on right side of road. Pyroclastic-flow deposits of the Cougar eruptive stage are exposed on north side of road. BEWARE OF TRAFFIC. Note large breadcrust bombs within finer grained matrix of a pyroclastic flow, 64 ft (20 m) thick.
1.8 (0.3)	38.3 (3.0)	Bridge over Swift Creek.
2.1 (0.3)	38.0 (1.1)	USFS Road 7900 to Marble Mountain, a Pleistocene shield volcano.
3.2 (1.1)	36.9 (1.1)	Porphyritic basalt from Marble Mountain.
4.3 (1.1)	35.8 (0.7)	Andesite flow from Marble Mountain.
5.0 (0.7)	35.1 (0.3)	On left side of road, lava flow from Marble Mountain overlies sedimentary rocks of the Ohanapecosh Formation (Oligocene). Good example of a baked contact.
5.3 (0.3)	34.8 (0.7)	Turnout to examine baked contact. WATCH OUT FOR LOGGING TRUCKS!
6.0 (0.7)	34.1 (2.5)	Cross Diamond Creek.
8.5 (2.5)	31.6 (1.4)	Cross Marble Creek.
9.9 (1.4)	30.2 (1.1)	Partially welded rhyodacitic tuff of Oligocene or early Miocene age.
11.0 (1.1)	29.1 (1.6)	Well-bedded volcaniclastic rocks of the Ohanapecosh Formation

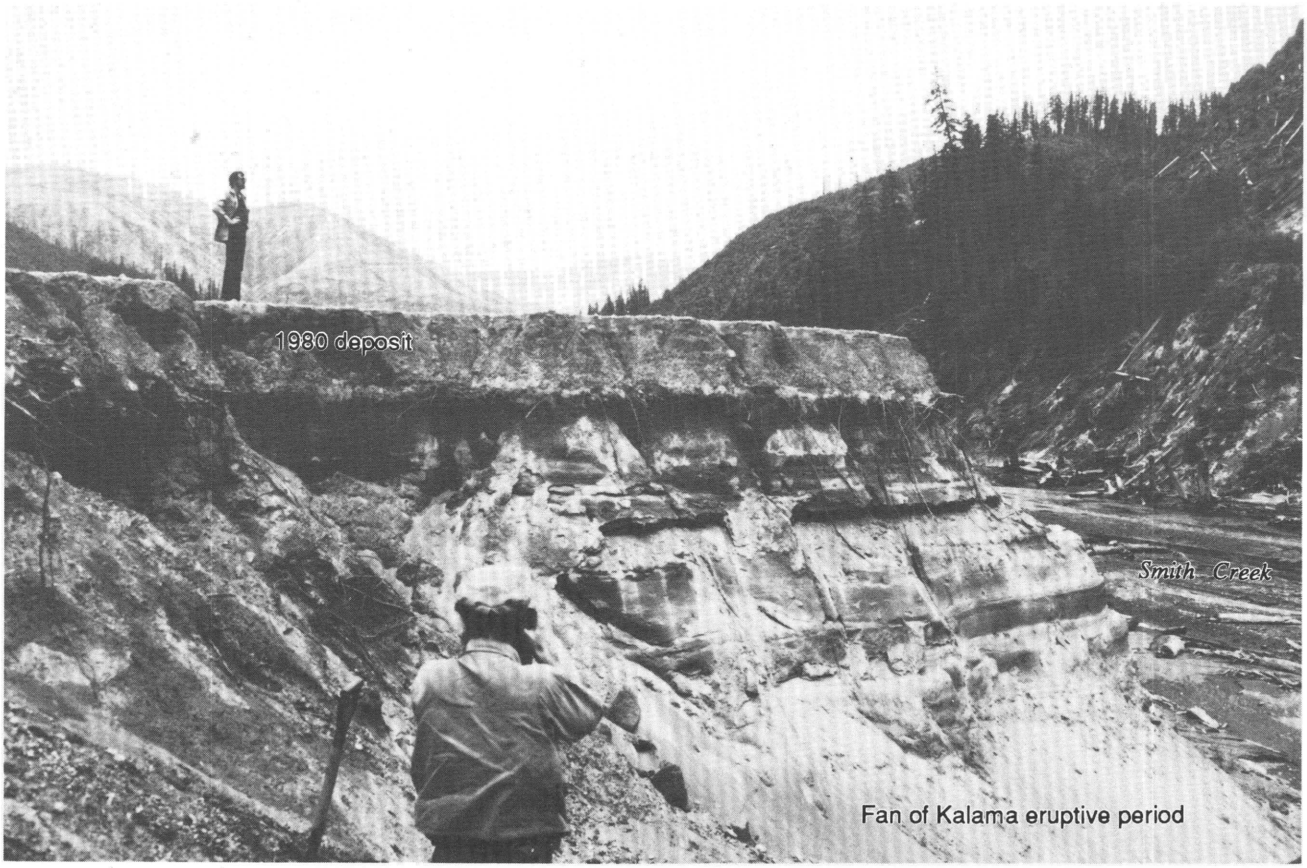


Figure 15. Exposed section of fan at confluence of Smith Creek and Muddy River at stop 5. Section consists of summit-dome material of the Kalama eruptive period of Mullineaux (1986) overlain by 5 ft (1.5 m) of May 1980 deposit.

		are exposed in a large clearcut area.
12.6 (1.6)	7.5 (2.0)	Camp Creek inlet overlook. On north side of road is till deposited by glaciers that descended the Lewis River valley.
14.6 (2.0)	25.5 (0.7)	OPTIONAL SIDE TRIP. Turn right at Forest Camp sign. Here, at east end of the Swift Reservoir, is an alluvial fan formed by debris from the Mount St. Helens eruption of May 18, 1980.

Return to USFS Road 90; turn right.

15.3 (0.7)	24.8 (0.2)	INFORMATION STOP. USFS Information center; preeruption Mount St. Helens District Ranger Station.

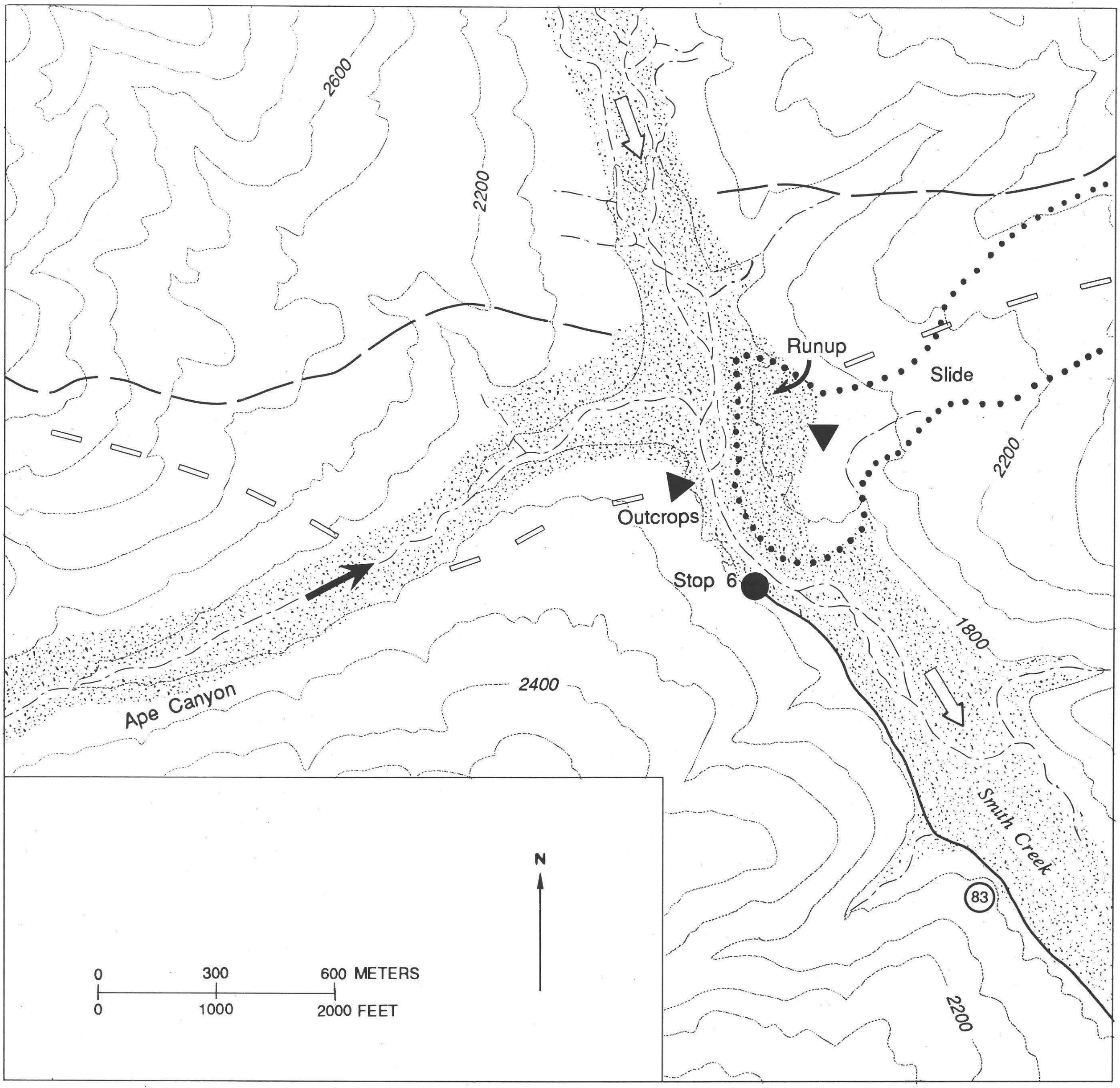


Figure 16. Generalized geologic map of area near confluence of Smith Creek and Ape Canyon showing extent of lahars generated on May 18, 1980 (shading). Solid arrow, direction of Ape Canyon lahar's path; open arrow, direction of Smith Creek lahar's path; circled number, U.S. Forest Service road; triangles, viewpoints; solid-dashed line, boundary of tree blowdown; open-dashed line, boundary of singe zone; dotted line, boundary of Beavertail landslide. Contour interval, 200 ft.

15.5 (0.2)	24.6 (0.7)	Junction of USFS Roads 25 and 90; continue straight on USFS Road 25.
16.2 (0.7)	23.9 (0.1)	STOP 8. The Pine Creek bridge crosses Pine Creek just upstream of its confluence with the Lewis River.

Pine Creek drains an area of about 24 mi^2 (62 km^2) and heads on the south flank of Mount St. Helens. Voluminous lahars associated with the 1980 eruption flowed down the creek. It took approximately 28 minutes for the flow, averaging 34 ft/s (10 m/s) in velocity, to traverse the 14.8 mi (24 km) from the cone. Lahars 32 ft (10 m) deep flowed past the bridge (Janda and others, 1981, p. 465); mudlines are still visible on trees upstream. A boulder estimated to weigh about 60 tons was found resting on the road surface, only the bottom meter buried in lahar deposits. The boulder has been moved a few meters to permit work on the road and bridge. At the bridge, more bank erosion occurred from storm runoff in late 1980–83 than from the May 18, 1980, lahars.

16.3 (0.1)	23.8 (1.8)	STOP 9. Turn right into borrow pit on east side of road. Good exposures of lahars and associated fluvial materials of the Pine Creek eruptive period (Crandell and Mullineaux, 1973).
18.1 (1.8)	22.0 (1.3)	Junction of USFS Roads 25 and 2588. If you were to turn left, in 7.3 mi (12 km) you would join up with leg I at the upper part of the Muddy River fan. Continue straight.
19.4 (1.3)	20.7 (0.4)	Junction of USFS Roads 25 and 2586. Continue straight.
19.8 (0.4)	20.3 (1.2)	STOP 10. Muddy River bridge and viewpoint.

Shifting channels and fluvial processes have reworked much of the lahar deposits from May 18, 1980, but areas up stream and downstream from the bridge still show effects of the lahars: mudlines on trees, large boulders, and downstream-pointing "bayonet" trees. As on Pine Creek, subsequent storms have deeply eroded and broadened channels in the lahar deposits.

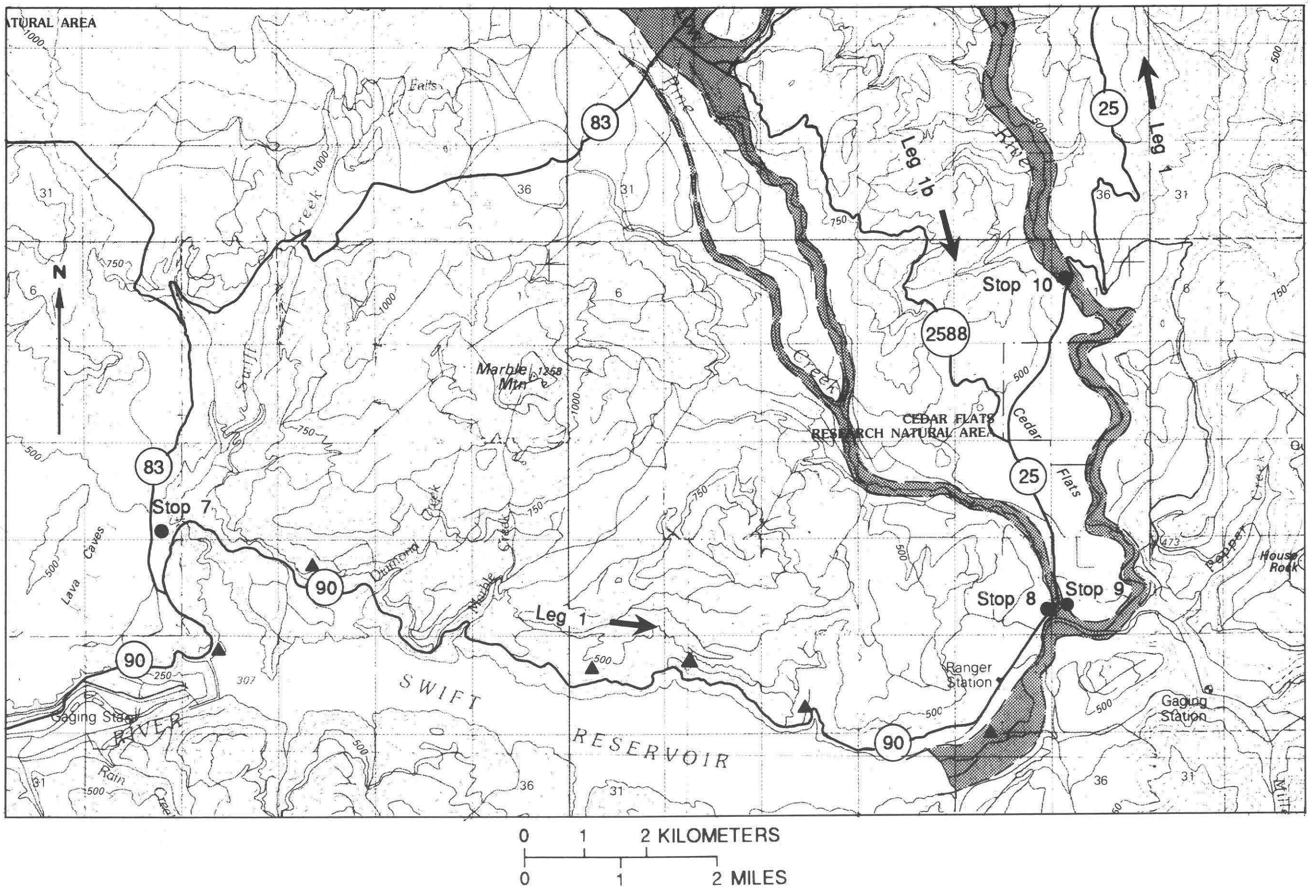


Figure 17. Field-trip route along the Swift Reservoir to confluence of the Lewis River, Muddy River, and Pine Creek, showing part of leg I. Triangles, viewpoints; circled numbers, U.S. Forest Service roads; dashed lines and shading, extent of lahar inundation.

Continue on USFS Road 25. For the next 20 mi (32 km) are many good exposures of tephra, in order of increasing age: 1980, X, We, B, P, Ye, J, and S.

21.0 (1.2)	19.1 (3.7)	Junction of USFS Roads 25 and 93.

Bear left on USFS Road 25. You are approaching the south edge of the tephra deposit from the July 22, 1980, eruption and 20-cm isopachs of the We (ca. A.D. 1482) and Ye (ca. 4,000–3,300 yr B.P.) tephras (fig. 18).

24.7 (3.7)	15.4 (0.5)	Now crossing the south edge of the tephra deposit from the plinian eruption column of May 18, 1980. Most of this deposit has been removed by erosion or covered by vegetation, but farther north the deposit thickens. Along USFS Road 25, the deposit is about 22 mi (35 km) wide.
25.2 (0.5)	14.9 (4.2)	Junction of USFS Roads 25 and 2573. Continue on USFS Road 25. A view of this road in July 1980 before it was cleared of airfall tephra is shown in figure 19.
29.4 (4.2)	10.7 (0.2)	VIEWPOINT. (No turnout here; be careful of traffic.) Overlook into the Clearwater Creek drainage.

To the north is part of the zone devastated by the May 18, 1980, blast. On the east wall of Clearwater Creek valley is the east edge of the devastated zone, about 10 mi (16 km) from the summit. Most of the fallen or damaged timber has been salvaged.

29.6 (0.2)	10.5 (0.4)	Junction of USFS Roads 25 and 2565.
30.0 (0.4)	10.1 (6.2)	On the south side of road is a Quaternary basalt flow erupted from a vent at the top of the ridge to the south (Hammond, 1980).
36.2 (6.2)	3.9 (1.7)	STOP 11. Elk Pass. You are now at the approximate axis of the May 18, 1980, tephra fall, here about 6 in. (15 cm) thick. The stratigraphy of the deposit is visible in and around a borrow pit just to the west (fig. 20).
40.1 (3.9)	0.0 (4.6)	Junction of USFS Roads 25 and 99. Turn left onto USFS Road 99 to Spirit Lake.

North-bound	South-bound	
West-bound	East-bound	
0.0 (0.0)	9.0 (4.6)	Junction of USFS Roads 25 and 99. Eastbound traffic: Turn right for Cougar and left for Randle.
4.6 (4.6)	4.4 (2.1)	STOP 12. Bear Meadows. Here, Gary Rosenquist and Keith Ronholm each took a remarkable set of photographs of the early stages of the eruption on the morning of May 18, 1980 (Lipman and Mullineaux, 1981, fig. 38).

Eyewitness reports (Rosenbaum and Waitt, 1981) stated: One observer watching the mountain through binoculars saw the north side of the volcano start to get "fuzzy, like there was dust being thrown down the side." Several seconds later, the north face began to slide. The lower part of the north side seemed to slide away more quickly than the upper. The first dark-colored cloud appeared near the middle of the north slope in an area vacated by the slide, and a light-colored cloud formed near the summit. A short time later, a very black cloud emerged from the summit area. The upper part of the north flank moved downward, and the flank eruption seemed to explode through the moving material. The flank eruption grew rapidly, especially to the north.

The "bulge was moving—the whole north side was sliding down." The first cloud appeared to form at the bottom of a cirque-like wall from which the bulge had moved. Within about 20 seconds the landslide was out of view behind a ridge. At this time, there were two distinct clouds which seemed to be emanating from separate vents: an extremely dark one rising vertically from the summit, and a lighter one from the north flank.

The dark cloud grew vertically from the summit. The lighter cloud, which seemed to come from the area vacated by the landslide, grew more or less spherically, except that a large "arm" shot out to the north in the direction of the avalanche. The spherical cloud seemed to approach from the mountain—not as part of the northward arm—and reached the ridge closest to the mountain 25–30 seconds after the start of the landslide. When the cloud hit the ridge, it rose and boiled upward.

Shortly after the vertical eruption began, a large horizontal blast occurred. Just before the top of the mountain became obscured, the south side of the summit crumbled into the hole formed by the landslide. As the cloud grew, what appeared to be a shock wave similar to that associated with a nuclear explosion moved ahead of the cloud. About 1½ minutes after the blast, a noise like a clap of thunder accompanied some sort of pressure change. The initial noise was followed by a continuous rumbling "like a freight train."

A rumbling noise began within 7–8 seconds of the start of the landslide. One member of the group sensed a pressure decrease at about the same time. A "shock wave," which looked like heat waves, formed ahead of the blast cloud. The witness had driven 2 or 3 miles to the northeast. Seven or eight minutes after the eruption's start, rocks began falling from the part of the cloud that had passed overhead. He collected two "golfball size" rocks (determined later to be dacite) from the fall. The rock fall continued for roughly 30 seconds and was then replaced by material that splattered on the windshield. As he drove, this material was replaced by "mud drops," which would flatten, not splatter. The maximum diameter of a mudball observed after flattening was about ¾ in.

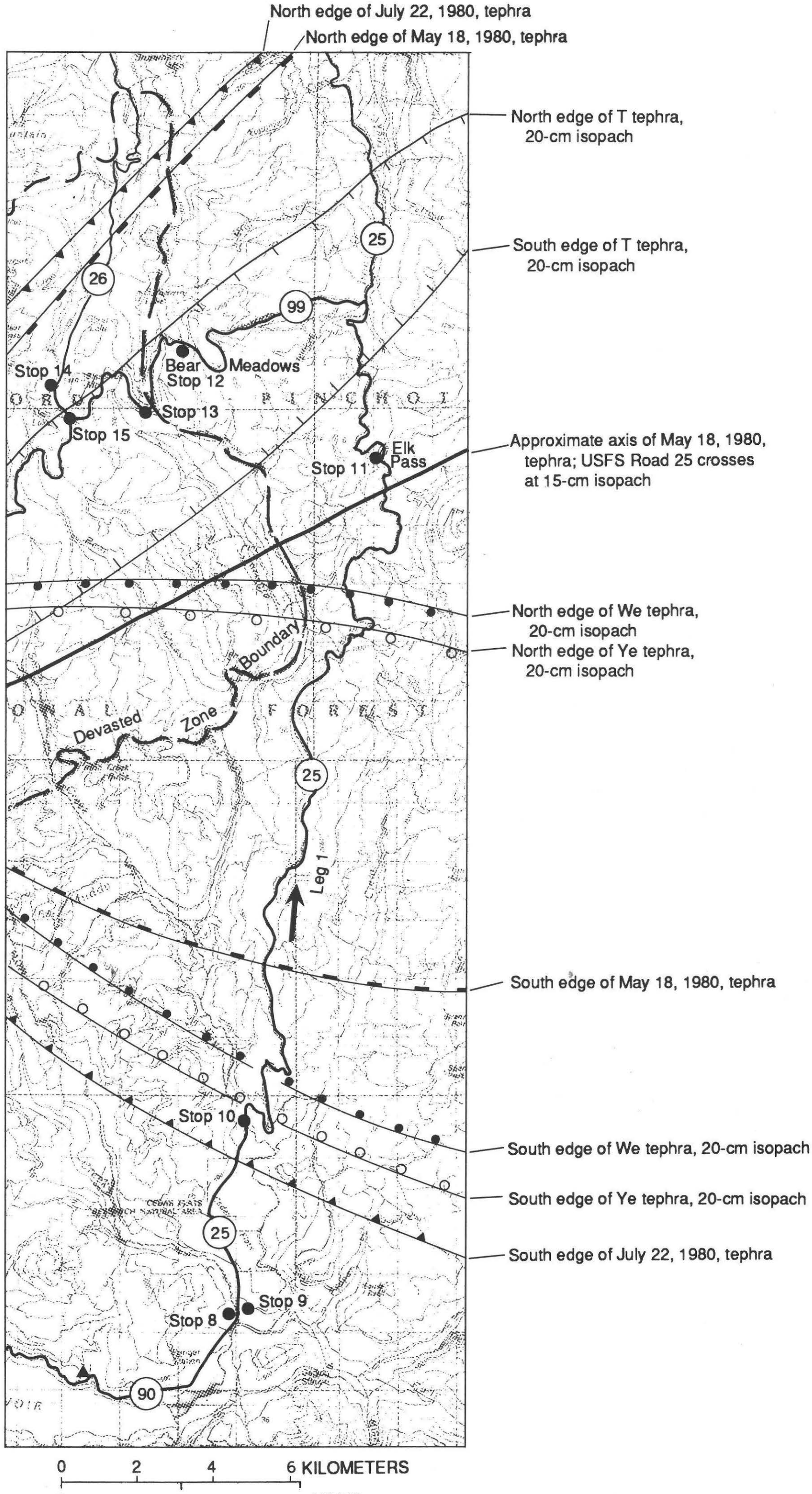


Figure 18. Field-trip route near devastated-zone boundary (dashed line), showing limits and isopachs of plumes of the We, Ye, May 18, 1980, and July 22, 1980, tephras crossed by leg I. Mount St. Helens is 4.5 mi (7.2 km) from the west edge of the area. Data for We and Ye tephras from Crandell and Mullineaux (1978); data for May 18, 1980, from Waitt and Dzurisin (1981); data for July 22, 1980, from Wood and others (in press). Triangle, viewpoint; circled numbers, U.S. Forest Service roads.

Gradually, the mud fall abated, and the ash fall became heavier. The ash was finer than sand. For a short time he encountered a second fall of mud drops, similar to but heavier than the first. This was quickly replaced by intense ash fall. Soon the ash fall became so intense that he could no longer see to drive. The ash fall eventually abated very gradually.

Continue east on USFS Road 99.

6.7 (2.1)	2.3 (2.3)	STOP 13. Northeast edge of sear zone and headwaters of Clearwater Creek. A good place to contrast unaffected forest with the blast-devastated landscape (try to find the 1980 blast deposit here).

Westbound, entering area of figure 21.

Eastbound, leaving map in figure 21.

9.0 (2.3)	0.0 (0.0)	Junction of USFS Roads 26 and 99. Westbound, turn right to go to the Norway Pass trailhead.

This is the start of the eastbound (read up) exit from the devastated zone. Westbound traffic only from here down.

9.5	(0.5)	STOP 14. Norway Pass trailhead. Spectacular view in upper Green River of timber blowdown. In this area, timber will not be salvaged but left untouched.

You may continue north on USFS Road 26 (leg Id) toward Randle (see fig. 31) or return to Meta Lake (stop 15).

10.0	(0.5)	STOP 15 AND VIEWPOINT. Junction of USFS Roads 26 and 99.

A car damaged by the blast belonged to a family killed at their small mine, on the ridge 1½ miles (2.4 km) to the west. Thick tephra layers are exposed along USFS road 99 from here to the Windy Ridge parking lot (figs. 22, 23).

Another good exposure is ahead at the Independence trailhead. The 1980 air-fall tephra and 1980 blast deposit overlie forest duff, T tephra (dacite pumice), Z tephra (pink dacite ash from old summit dome, ca. A.D. 1600), X tephra (thin, andesite ash), and Wn tephra (dacite pumice). A blast deposit from Sugar Bowl dome on the northeast flank of the volcano is patchy and difficult to define here but thickens toward the volcano. B tephra (andesite and basalt ash, with one thin dacite layer)

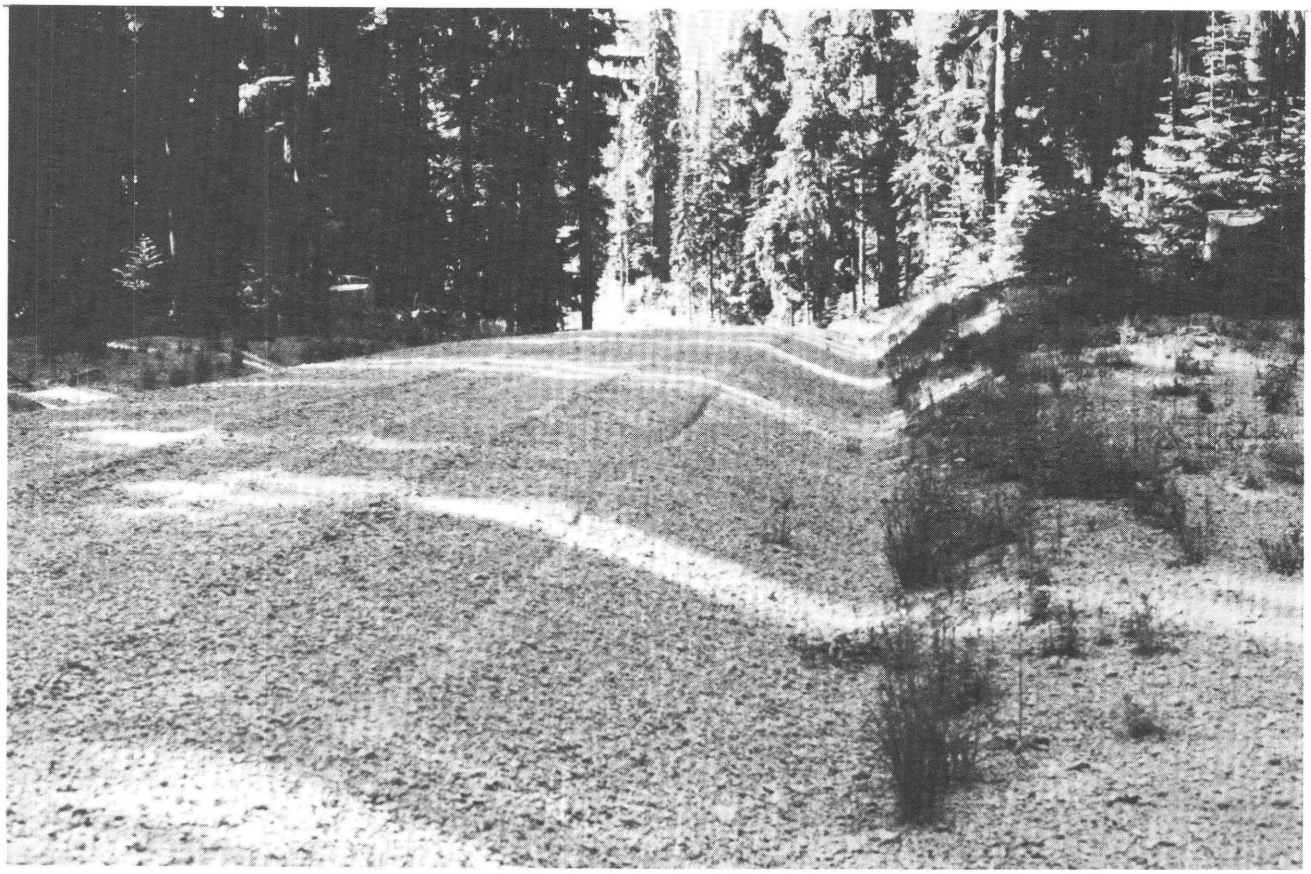


Figure 19. Air-fall tephra covers part of U.S. Forest Service Road 25 in July 1980.

overlies P tephra (dacite ash layers), which, in turn, overlies Yn tephra (yellow-brown dacite pumice) and layers of the J tephra (table 1).

10.2 (0.2) STOP 15. Trail to Meta Lake.

This site within the blast zone is about 8.5 mi (14 km) from the volcano; to the northeast, the blast swept out to a distance of 13 mi (21 km). A short trail leads from the road to Meta Lake, an interesting path through downed timber, to a lake that was only moderately disturbed by the blast. Small trees on the shore and fish in the lake survived because they were under the snowpack. One blown-down tree near the start of the trail shows tightly clustered rings for a few years after A.D. 1800 (the year when pumice of the T tephra was erupted from Mount St. Helens).

11.8 (1.6) STOP 16. Snack stand. Junction of USFS Roads 94 and 99, 8 mi (13 km) from the summit of Mount St. Helens. Headwaters of Bean Creek to the south have exposures of the Ohanapecosh(?) Formation (conspicuous outcrops of greenish-brown tuff) and the andesite of Smith Creek Butte (Hammond, 1980).

13.3 (1.5) STOP 17. Independence Pass trail parking lot: ¼-mi (0.4 km) hike through downed timber.

In the parking turnaround here is an excellent exposure of the Windy Ridge tephra sequence. At the end of the trail is an excellent view of Mount St. Helens and Spirit Lake. In good weather you can see part of the growing lava dome within the crater (1986 height, 918 ft [280 m]). Along this trail is a cut tree trunk that shows tightly clustered growth rings corresponding to the years A.D. 1801–5 (effects of eruption of pumice of the T tephra in A.D. 1800; Yamaguchi, 1983). Along the trail the blast deposit can be recognized by its gray color. It contains gravel- to sand-size rock fragments from the edifice of Mount St. Helens, pieces of slightly vesicular gray dacite from the cryptodome, and fragments of shredded wood. The hike is an opportunity to explore the diverse effects of the blast on both large and small trees. Small trees buried under the winter snow remained untouched. Very few large trees were transported or reoriented after they fell. Standing trunks on and behind

Figure 20. Section along axis of May 18, 1980, tephra deposit. Below the knife is several inches (centimeters) of material deposited by the lateral blast; above the knife is more than 6 in (15 cm) of ash and lapilli deposited during the morning of May 18, 1980 (see fig. 22). Overlying these layers are coarse lapilli from the July 22, 1980, eruption.

the ridge to the north indicated that the flow was diffuse enough to loft over them but still snapped off their crowns.

14.7 (1.4) STOP 18. Harmony Basin viewpoint.

The first gap in the ridge to the west (fig. 21) provides a view of the north end of Spirit Lake and the Harmony Falls basin. Here, you can see evidence that the avalanche displaced water from the Spirit Lake basin: Logs are sparse in a zone extending far above lake level, and the few logs in this zone commonly point downslope, in contrast to those higher up that were felled by the blast and point uniformly away from Mount St. Helens. Many of the logs washed from the slope are now floating in the lake. In 1980, the surface of the lake was almost entirely covered by a matte of floating logs and debris.

Waitt (1984) inferred the following sequence of events:

1. The surge rushed northeastward, leveling the forest and depositing layer A1 (fig. 23). Patterns of downed timber indicate that topography partly channeled movement. Most of the Spirit Lake basin was swept by a northeast-moving density current, whereas the head of the Harmony Falls basin was engulfed by a current rushing northward out of Smith Creek and over the divide.
2. The first landslide, moving more than 160 mi/h (250 km/h), entered Spirit Lake. It created a catastrophic wave that surged up the Harmony Falls basin and rinsed the slopes clean of timber and layer A1 to a level marked by the sharp trimline on the north side of the valley.
3. Losing momentum, this water descended to the basin floor and poured back into the lake, carrying most of the logs with it but leaving some grounded in "rafts."
4. The gradually waning pyroclastic current continued, depositing layer A2.
5. Layer A3 (blast fallout) and later air falls accumulated.

15.1 (0.4) VIEWPOINT. Cedar Creek viewpoint, 2d gap.

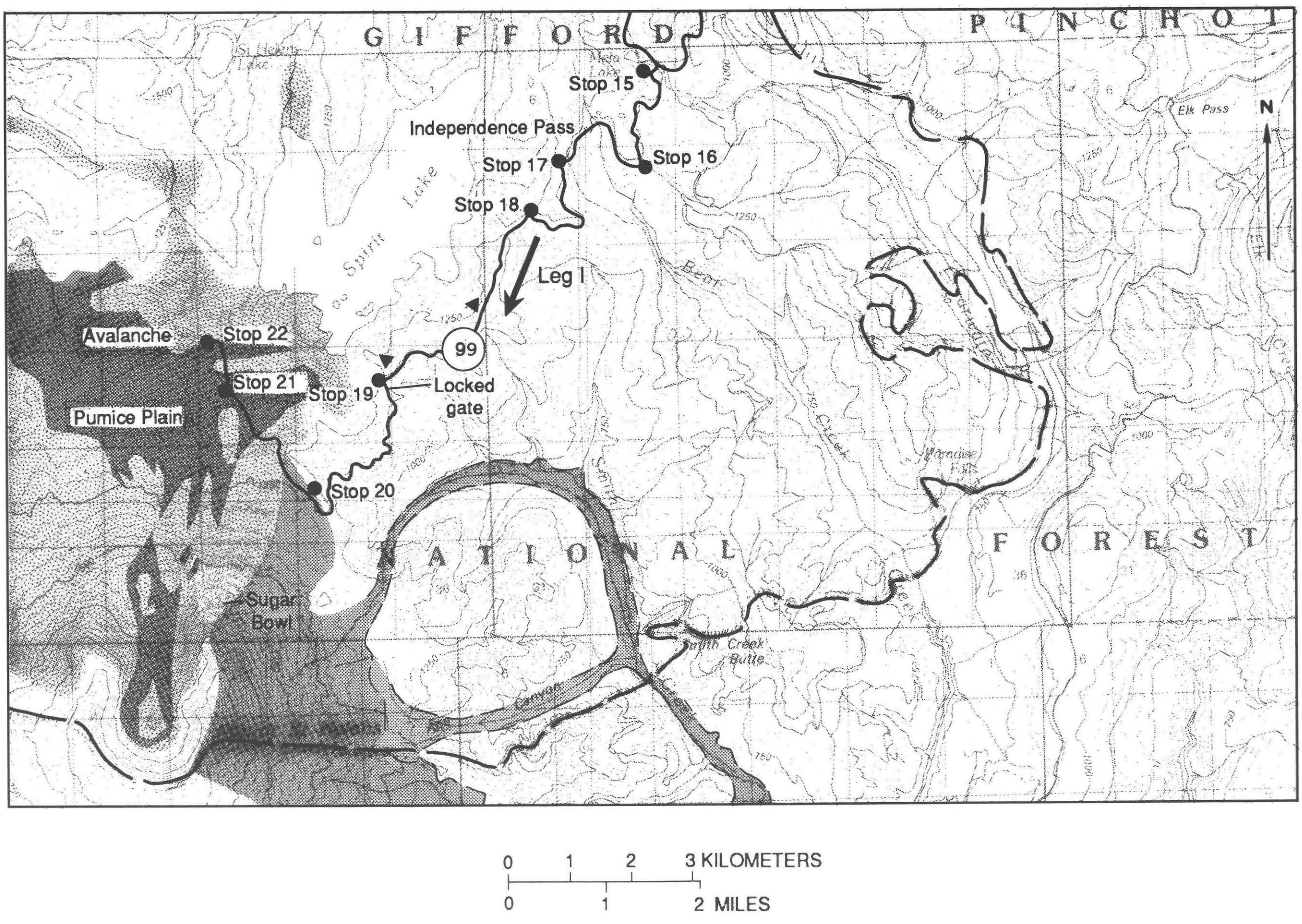


Figure 21. Field-trip route near northeast side of Mount St. Helens, showing part of leg I. Triangles, viewpoints; circled number, U.S. Forest Service road; short-dashed lines and shading, limits of lahar inundation; stippling, areas covered by pyroclastic flows and avalanche on north side of volcano; long-dashed line, devastated-zone boundary.

15.9 (0.8) VIEWPOINT. A panorama of Spirit Lake.

16.5 (0.6) VIEWPOINT. Good view and exposed tephra stratigraphy.

16.8 (0.3) VIEWPOINT. Into headwaters of Smith Creek and the northeast slopes of Mount St. Helens.

17.6 (0.8) STOP 19. Windy Ridge parking lot is at end of the public road, about 4 mi (6.5 km) from the summit.

The blast deposit here is about 3 ft (1 m) thick, veneered by 1980 air-fall deposits. The best viewpoint is reached by a short climb to the top of the hill just north of the parking lot (figs. 24–26). All of Spirit Lake, including the floating logs, the swash zone from the water wave generated by the avalanche, and much of the crater, is visible. The debris-avalanche deposit dams Spirit Lake and forms the hummocky topography in the distance. On the south end of Harrys Ridge, (the first ridge west of Spirit Lake) all trees and soil were removed down to bedrock by the avalanche and blast. Light-gray pyroclastic-flow and ash-cloud deposits, mainly from May 18 but also from June 12 and July 22, 1980, cover and lap against the debris avalanche south of Spirit Lake. Many of these deposits have been stripped or buried by lahars generated by rapid snowmelt during explosions in the lava dome. Several fumaroles apparently rooted in the pyroclastic flows still steam in 1986, visible best on humid days. Much of the northern part of the crater is visible from here, but in October 1986 only the very top of the dome, 918 ft (280 m) high, 2,600 ft (800 m) wide, and located in the southern part of the crater, shows over the shoulder of Sugar Bowl dome. The water level in Spirit lake is maintained by a gravity-fed tunnel cut through Harrys Ridge to South Coldwater Creek, which drains into the North Fork Toutle River. The portal is visible about halfway along the west shore of the lake. The spillway prevents overtopping and possible catastrophic erosion of the unstable debris-avalanche blockage. Between November 1982 and April 1985, U.S. Army Corps of Engineers contractors maintained lake level by using barge-mounted pumps that withdrew water and sent it down a channel on the pumice plain. The progressive shorelines of Spirit Lake are mapped in figure 26. The altitude of the lake before the eruption was 3,198 ft (975 m); in fall 1980, it was 3,408 ft (1,039 m), and the level controlled by pumping was 3,463 ft (1,056 m), a total increase since May 17, 1980, of 265 ft (80 m). Current lake level is 3,438 ft (1,048 m). A tiny shed high on Harrys Ridge houses surveying and radio equipment used by USGS volcanologists to monitor volcanic activity;

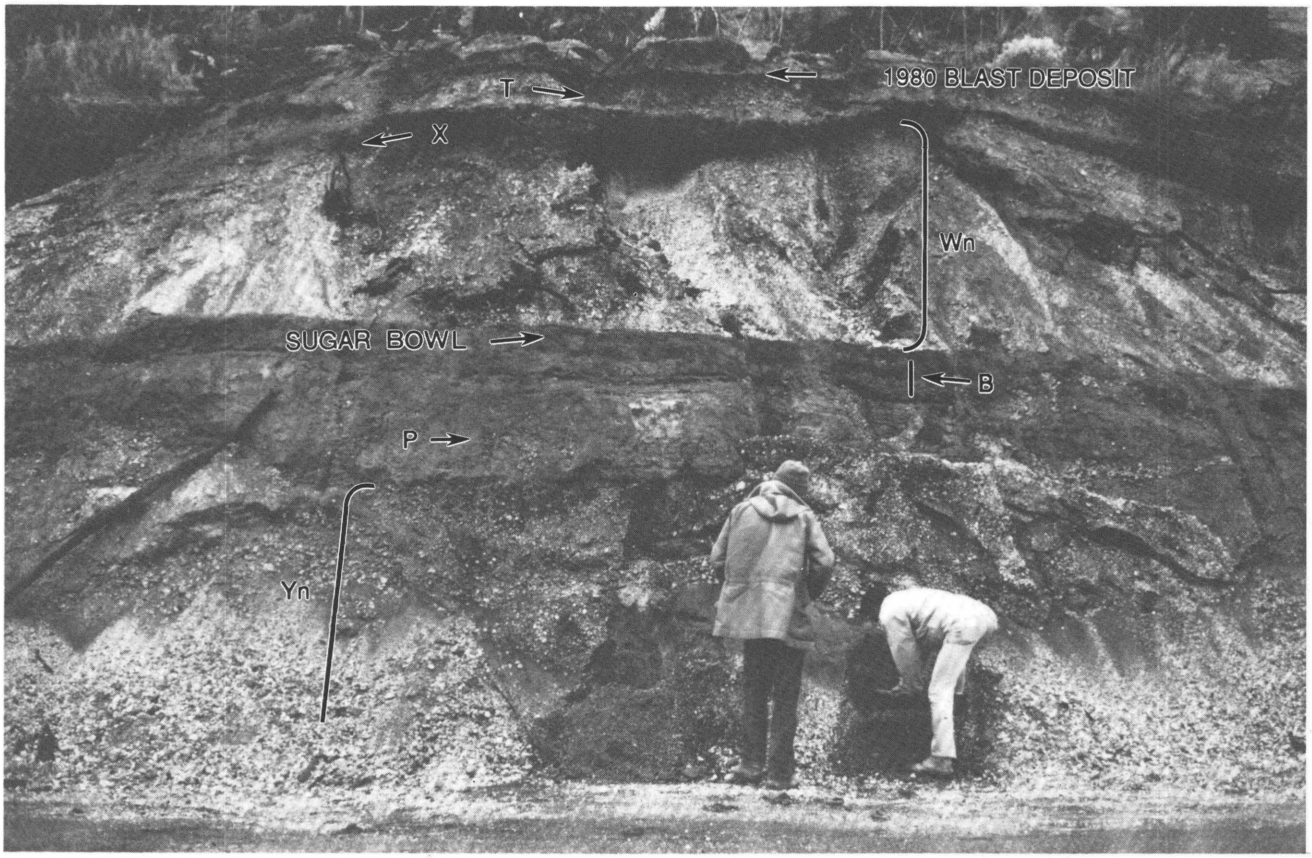
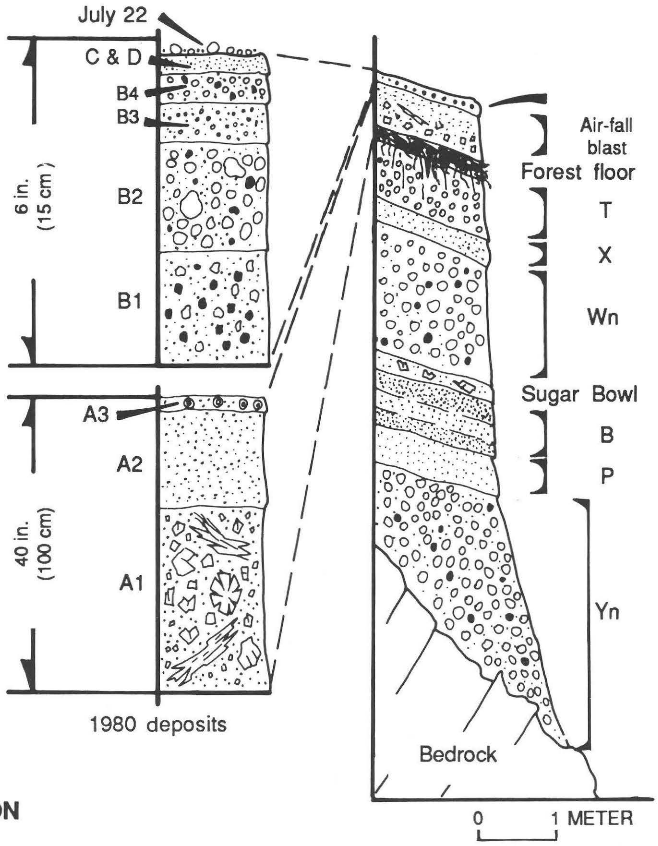


Figure 22. Volcanic deposits exposed in roadcut along U.S. Forest Service Road 99 (see fig. 23).



EXPLANATION

July 22, 1980

Scattered ash and lapilli

Plinian air fall of May 18, 1980

D Fine ash from waning eruption column — Silty, medium to fine sand, about 2 cm thick

C Fine ash from ash cloud produced by pyroclastic flows

B4 Upper pumice-rich layer

B3 Upper lithic-rich layer — Finer grained than B2

B2 Lower pumice-rich layer — Pumice/lithic-pebble gravel

B1 Basal lithic-rich layer — Pumice/lithic-granule gravel

Blast deposit of May 18, 1980

A3 Sand-silt facies — Massive, dark-olive-gray sandy silt less than 2 cm thick; contains pisolites

A2 Sand facies — Normally graded, fine to coarse sand

A1 Basal gravel facies — Contains light-gray to gray, vesicular, juvenile dacite clasts; lithic granules, and macerated-wood fragments; poorly sorted, weakly stratified to nonstratified gravel of angular clasts

Tephra sets along Windy Ridge

Eruptive period 1 of Mullineaux (1986)	Approximate age (yr)
T (A.D. 1800) tephra, Goat Rocks.	180-123
X tephra, Wn (A.D. 1482) tephra, Kalama.	500-350
Sugar Bowl tephra, Sugar Bowl.	1,150
B tephra, Castle Creek.	2,200-1,700
P tephra, Pine Creek.	3,000-2,500
Yn tephra, Smith Creek.	4,000-3,300

Figure 23. Schematic stratigraphic column of pyroclastic deposits from Mount St. Helens along U.S. Forest Service Roads 94 and 99 in devastated zone. Deposits include mainly tephra consisting of pumice lapilli; two layers not consisting of typical air-fall material are the Sugar Bowl and 1980 blast deposits, which consist of slightly vesicular to nonvesicular lithic fragments in a poorly sorted matrix. Description of air-fall and blast deposits of 1980 from Waitt and Dzurisin (1981) and Waitt (1984).

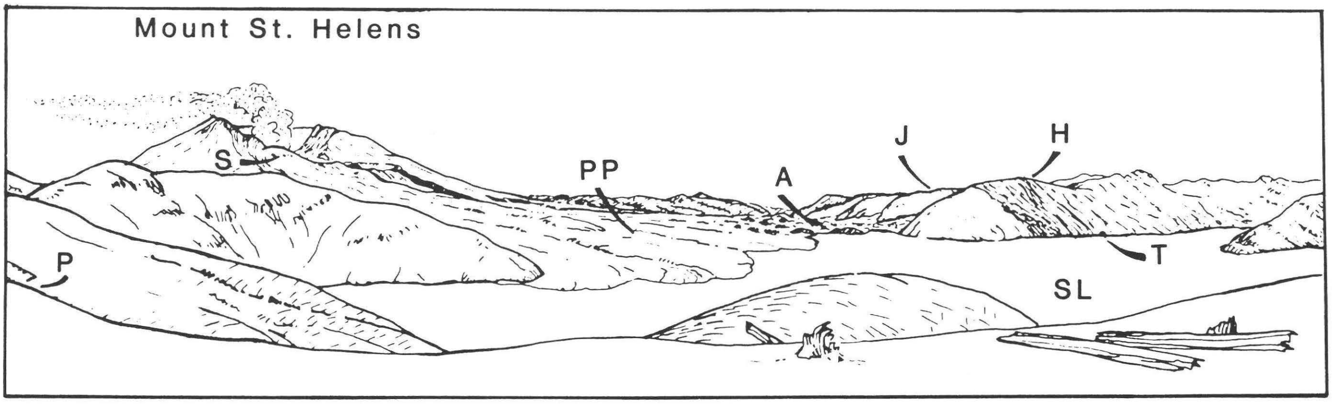


Figure 24. Windy Ridge overlook, about 4.6 mi (7.8 km) from crater. View westward, down valley of North Fork Toutle River, with Spirit Lake (SL) in foreground. Volcanic gas and steam continuously rise from dome; during humid weather, water vapor condenses to form visible plumes from dome and from fumaroles in pyroclastic flows of the Pumice Plain (PP). A, debris avalanche (Spirit Lake blockage); H, Harrys Ridge; J, Johnston Ridge; P, Windy Ridge parking lot; S, Sugar Bowl dome; T, Spirit Lake outlet tunnel. Drawing by Bobbie Myers.

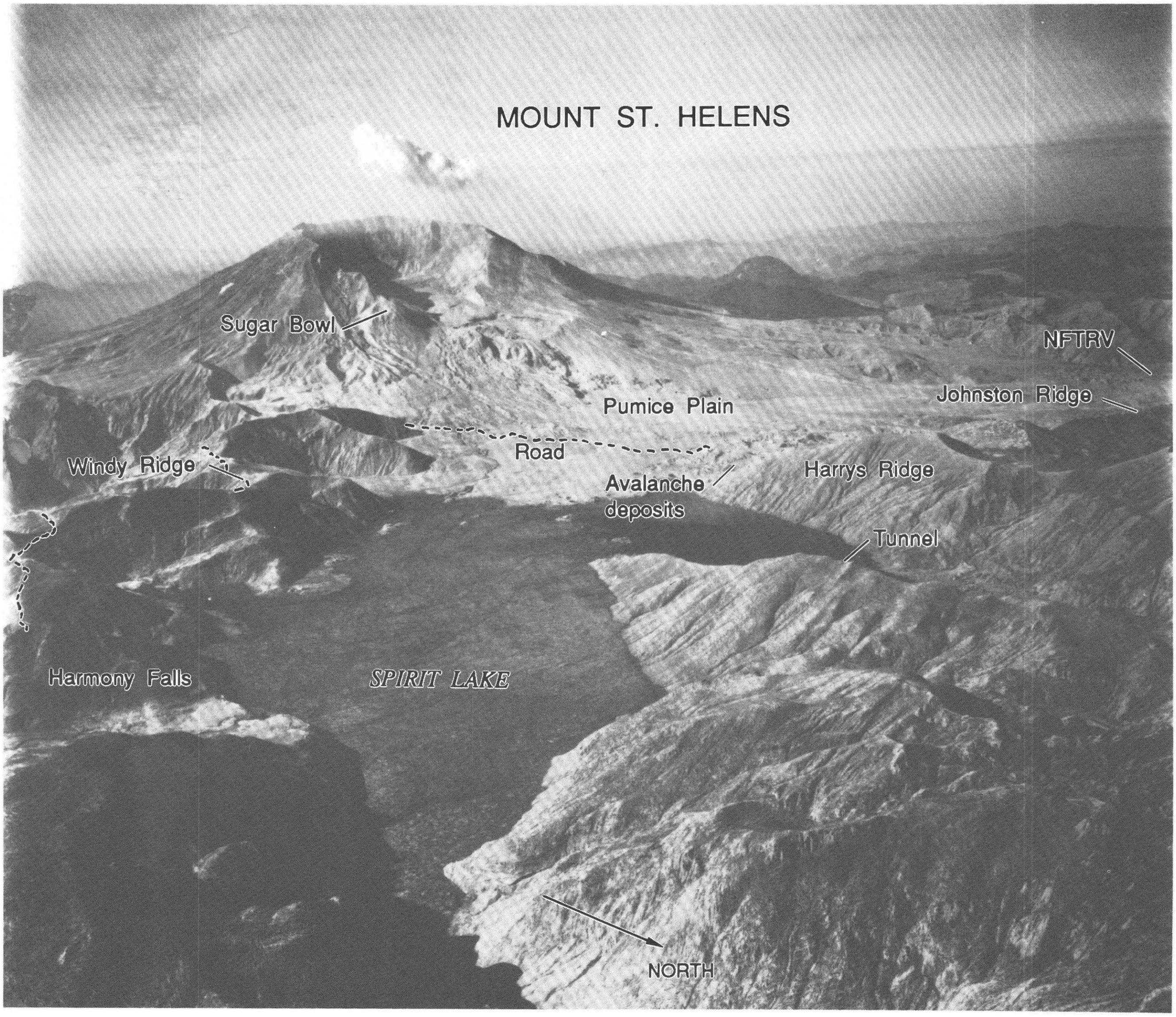


Figure 25. Northeast side of Mount St. Helens. NFTRV, North Fork Toutle River valley. Dashed line, U.S. Forest Service Road 99. Photograph by Bob Krimmel, taken September 10, 1980.

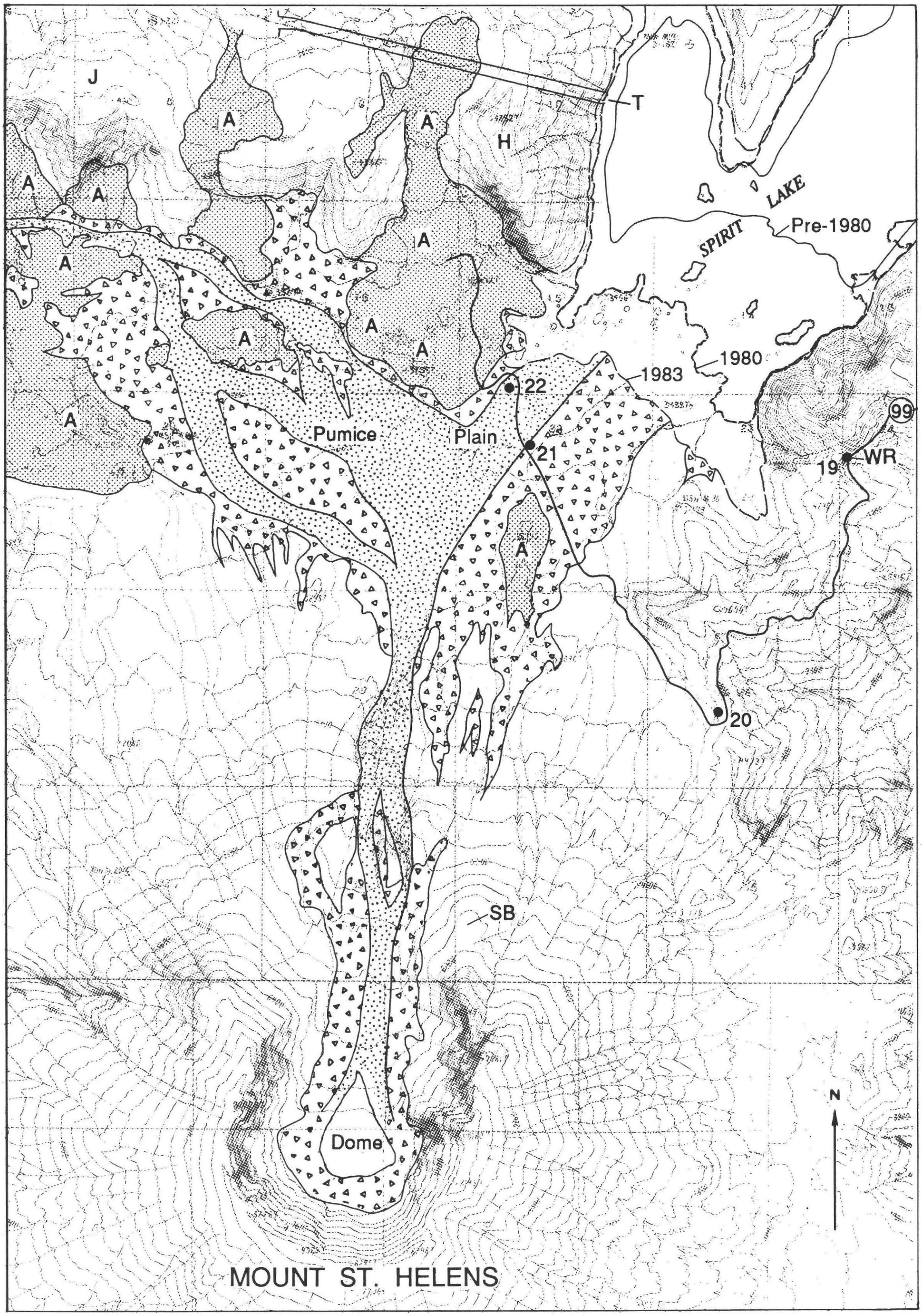


Figure 26. Generalized geologic map of area north of Mount St. Helens near Spirit Lake and Windy Ridge, showing 1980–82 deposits and progressive shorelines of Spirit Lake, pre-1980, 1980, and 1983; irregular closed outlines in lake are debris-avalanche islands. A, debris avalanche; H, Harrys Ridge; J, Johnston Ridge; SB, Sugar Bowl dome; T, Spirit Lake Tunnel; WR, Windy Ridge overlook; triangles, 1980 pumiceous pyroclastic flow (Rowley and others, 1981); stippling, path and deposits of March 19, 1982, lahar (Waitt and others, 1983); numbered dots, field-trip stops; circled number, U.S. Forest Service road.

most current monitoring is conducted within the crater and on the dome. The USGS notifies the USFS and other Government agencies when monitoring indicates significant changes in activity. All decisions regarding access and land use in Mount St. Helens National Monument are made by the USFS.

ENTRY BEYOND THE WINDY RIDGE PARKING LOT TOWARD SPIRIT LAKE REQUIRES SPECIAL USFS PERMITS, A GATE KEY, RADIOS, AND SO ON. ARRANGEMENTS FOR ENTRY MUST BE MADE WITH THE USFS. THE ROAD TO SPIRIT LAKE IS NOT MAINTAINED.

Cumulative mileage	(mileage between points)	
0.0	(0.0)	From Windy Ridge parking lot, enter restricted zone through locked gate at south end of parking lot.
1.8	(1.8)	Saddle View to west overlooks junction of road to Spirit Lake with old road to preeruption Timberline parking lot and northeast slope of Mount St. Helens.

Deposits of the Pine Creek eruptive period through 1980 are exposed east of the crest of this saddle. The Sugar Bowl blast deposit, tephra of the Kalama eruptive period, and 1980 deposits are exposed in cuts along the east side of the road beyond the saddle. During the formation of Sugar Bowl, a dome of porphyritic dacite, a directed blast carried rock fragments laterally northeastward more than 15 mi (24 km). Here, the Sugar Bowl deposit is characterized by distinct dark-gray ash, lapilli, and breadcrusted bombs.

2.1 (0.3) STOP 20. First creek crossing near junction with Timberline Road. Stop off on right side of road.

This drainage was swept by a blast dacite-bearing pyroclastic flow on the morning of May 18. The surface of the flow is littered with vesicular as well as dense, glassy, breadcrust blast dacite. Explore northeastward along the gully. At the base of the south-facing ridge, streamcuts expose deposits ranging in age from 2,200 yr B.P. to A.D. 1980 (fig. 27).

2.5 (0.4) Outcrops of basalt flows of the Castle Creek eruptive period south of the road.

3.8 (1.3) STOP 21. Road crosses outer edge of deposits of the March 19, 1982, snow avalanche and lahar (Waitt and others, 1983) (fig. 26). During summer 1986, a revegetation study plot was located here.

4.0 (0.2) STOP 22. Here, the 1982 lahar deeply scoured the pyroclastic flows of May 18, 1980. Walking south upchannel will bring you to exposures of 1982 lahar deposits in the bed of the channel and of 1980 pyroclastic-flow deposits in the high banks.

4.3 (0.3) STOP 22. Parking area. Road rises up onto hummocky surface of avalanche deposit. Stop here and explore the Spirit Lake blockage (figs. 28, 29).

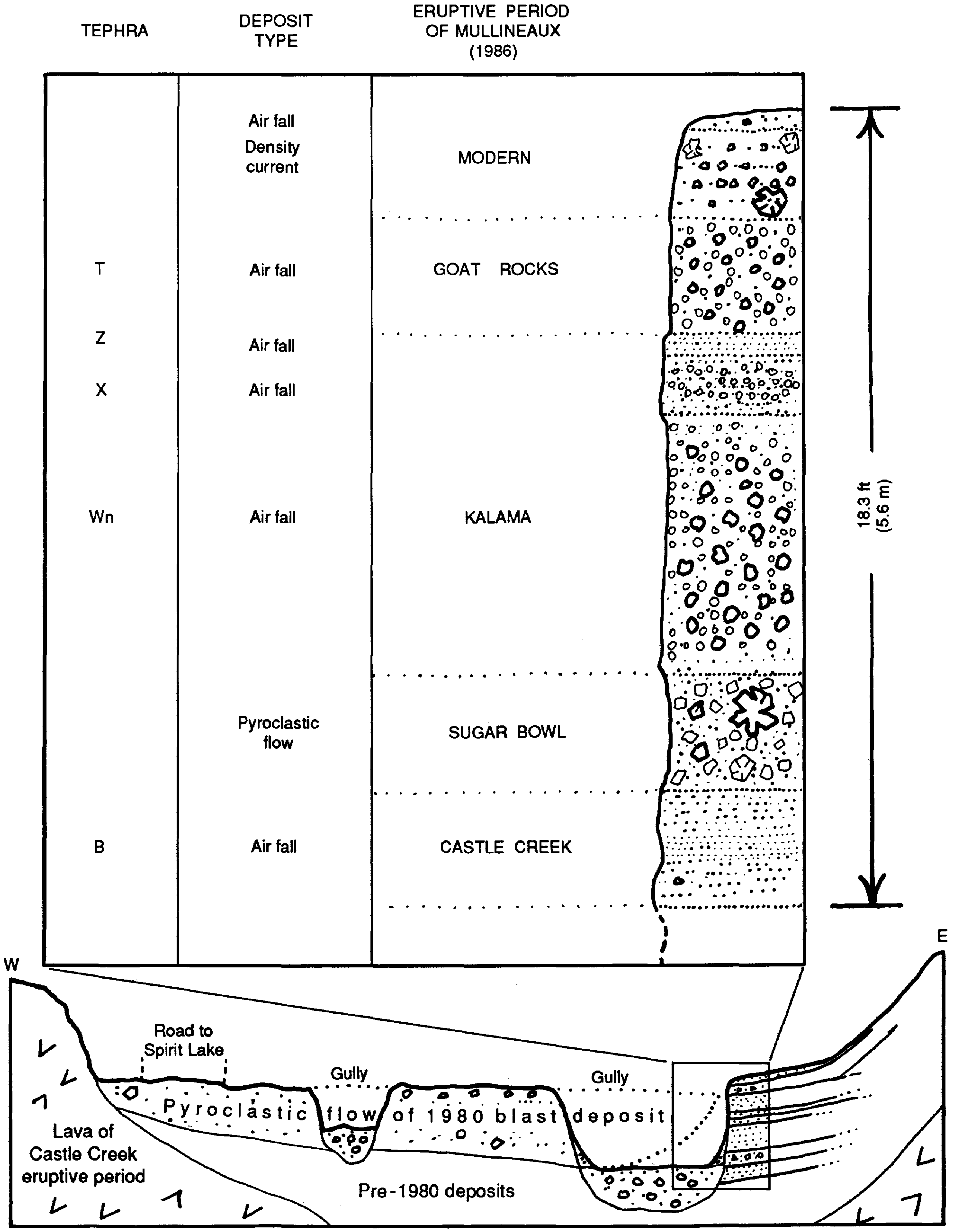
Six major events occurred on the morning of May 18, 1980: (1) a magnitude 5.1 earthquake, (2) a huge rockfall/debris avalanche, (3) a lateral explosion (the blast), (4) a heavy ash fall, (5) pyroclastic flows, and (6) lahars (mudflows). Near the shores of Spirit Lake can be seen examples of all these phenomena except the earthquake itself.

The deposits exposed in the outcrop shown in figure 29 tell a story about the events that morning. Here, the blast deposit overlies a fractured block of red basalt in the avalanche. Explosions within the chaotic mixture of hot debris deposited ash in draping layers over the outcrops. Illutriate from pyroclastic flows drifted over the pile of rubble and laid down a blanket of fine ash. Pyroclastic flows on May 18, 1980, reached this area, smoothing the rough topography of the avalanche deposit east of stop 22. By midday, tephra from the main plinian eruption mixed with the locally produced phreatic ash, further masking the underlying deposits. By the afternoon of May 18, this area was a drab-gray landscape.

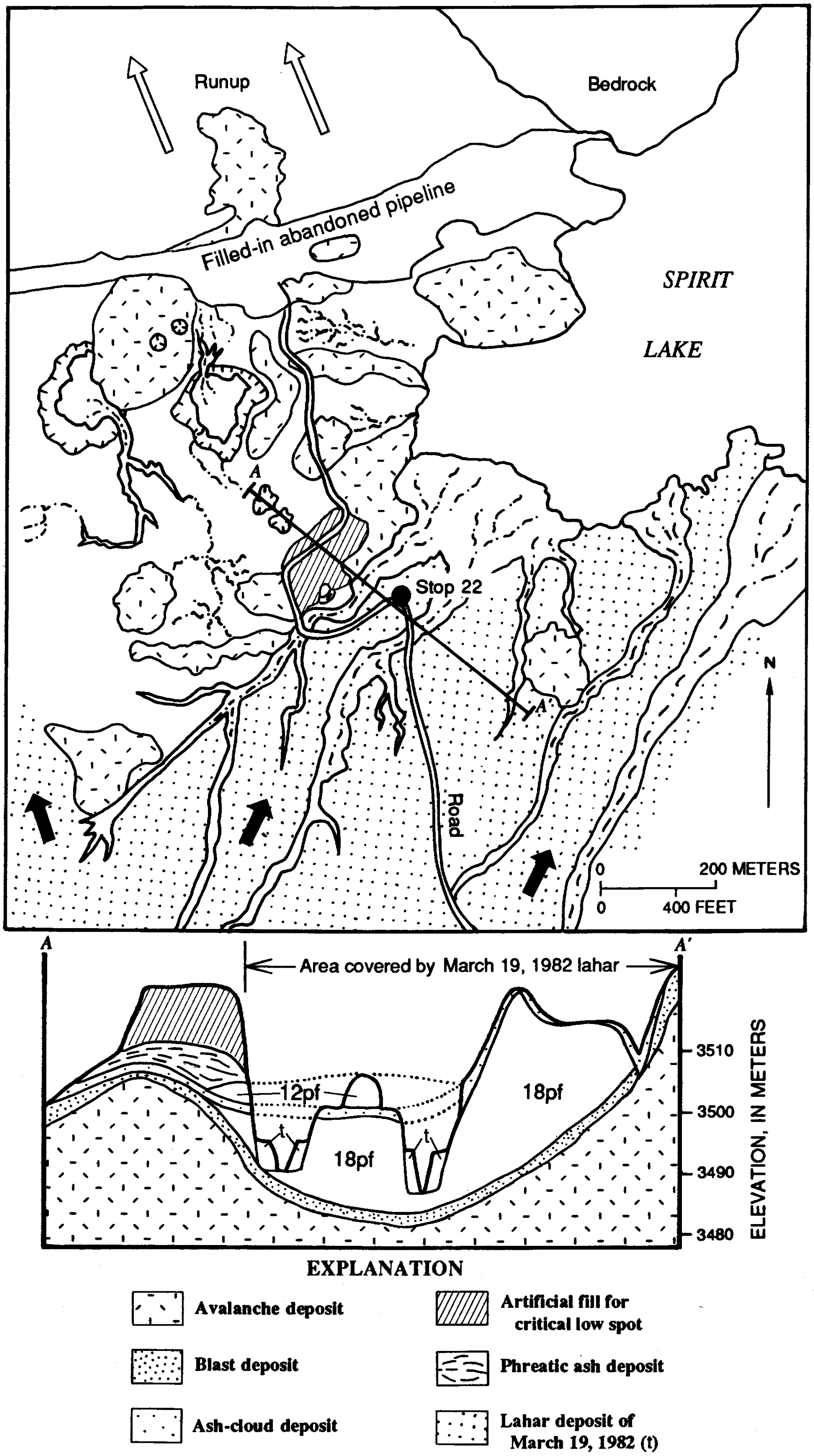
Pyroclastic flows from the June 12, 1980, eruption reached here; they are distinguishable by a pink coating

Figure 27. Schematic west-east geologic section at Timberline Road at stop 20, showing position of pyroclastic flow (dotted where missing or eroded) containing abundant clasts of blast dacite. Heavy line, present land surface; gullies filled with reworked pyroclastic material. Prismatic jointing indicates that clasts were hot during transport. In inset, 1980 tephra overlies blast deposit (modern). Pyroclastic flow is from the Sugar Bowl eruptive period. B, tephra layers from the Castle Creek eruptive period; Wn, tephra set from A.D. 1482 eruption of the Kalama eruptive period; X, andesitic ash layer of the Kalama eruptive period; Z, late ash of the Kalama eruptive period; T, tephra set from A.D. 1800 eruption of the Goat Rocks eruptive period.

of ash on the surface of pumice blocks. Tephra from the fifth eruption on August 7, 1980, was also deposited here. The last major natural impact was a lahar on March 19, 1982. A slurry of rock, water, and ice generated by an eruption in the crater swept down the north flank of the volcano and entered Spirit Lake.



As Spirit Lake began to fill with water during the following years, a potential disaster was in the making. Steps taken by the U.S. Army Corps of Engineers to prevent breaching of Spirit Lake included pumping of lake water over the avalanche blockage and filling in of critical low spots (figs. 28, 29) in the avalanche.



SIDE TRIP Ic. Kalama River valley and the South Fork Toutle River (fig. 30)

Cumulative mileage	(mileage between points)	
0.0	(0.0)	Turn left (north) from Lewis River Road toward Merrill Lake (USFS Road 81).
2.1	(2.1)	Outcrops of Tertiary intrusive rocks.
3.6	(1.5)	Junction of Weyerhaeuser Roads 7200 and 7600.
4.8	(1.2)	Junction with road to Merrill Lake and Washington Natural Resources campground. Continue straight ahead.
6.0	(1.2)	Entering upper Kalama River valley. Outcrops are of the Cave Basalt (formed during the Castle Creek eruptive period, 2,200–1,700 yr B.P.); tumuli dot the surface of lava flows.
6.9	(0.9)	Junction of Weyerhaeuser Roads 7200, 7500 and 7600. Continue straight ahead on USFS Road 81.
7.4	(0.5)	Entering Gifford Pinchot National Forest.
8.2	(0.8)	STOP 23. Turn right into quarry.

Outcrops of lithic pyroclastic flows of the Kalama eruptive period overlie the Cave Basalt. Charcoal from the lowermost pyroclastic-flow deposit yielded a radiocarbon age of 610±200 yr (Crandell and others, 1981). Paleomagnetic study of this unit indicates that it was emplaced over a range of temperatures (Hoblitt and Kellogg, 1979; R.P. Hoblitt, oral commun., 1985). Charcoal from the uppermost pumiceous pyroclastic-flow deposit yielded a radiocarbon age of 290±70 yr. The deposit, which contains abundant hypersthene-hornblende pumice similar to that in the W tephra, probably originated during explosive eruptions of the W tephra.

Across the road from the quarry, the Kalama River has eroded through the pyroclastic flows and exposed the Cave Basalt.

8.7	(0.5)	Junction of USFS Roads 81 and 8117. You are driving up the Kalama River valley on a surface underlain by lithic pyroclastic flows erupted during the Kalama eruptive period.
11.1	(2.5)	Junction of USFS Roads 81 and 8122; continue straight ahead on USFS Road 81.
11.7	(0.6)	Junction of USFS Roads 81 and 8123; continue straight ahead on USFS Road 8123.
12.3	(0.6)	STOP 24. Junction of USFS Roads 70 and 8123. Park and walk west (5 min). A quarry exposes pyroclastic-flow deposits of the early Kalama eruptive period from Mount St. Helens (table 1). The flows overlie an ash-cloud deposit, oxidized J tephra, colluvium, till, and bedrock.

Return to USFS Road 8123 and continue northeast.

13.4	(1.1)	Junction of USFS Roads 8123 and 8123170. USFS Road 8123 was inundated by lahars on May 18, 1980, and washed out the following winter.

Continue along USFS Road 8123170. Good water is available just past the intersection at Coldspring Creek. Along the road for the next mile (1.6 km) are outcrops of a pyroclastic flow of the Kalama eruptive period that topped the ridge to the north and flowed down into Clear Creek. Genetically associated ash-cloud deposits overlie the pyroclastic-flow deposit.

14.4	(1.0)	Junction of USFS Roads 4192 and 8123170; bear right.
15.0	(0.6)	Along the road are deposits of pre-1980 eruptions, most of which are probably ash-cloud deposits of the Kalama eruptive period; no coarse pumice layers are evident.
15.8	(0.8)	Junction of USFS Road 8123170 and Weyerhaeuser Road 4100. Turn left.
16.0	(0.2)	STOP 25. Overlook into headwaters of the South Fork Toutle River, which was swept by two lahars on May 18, 1980.

Less than 10 minutes after the start of the eruption (Rosenbaum and Waitt, 1981): "* * * a huge mass of

◄

Figure 28. Generalized geologic map and cross section of eastern part of Toutle River blockage near stop 22. North half of area is covered by veneer of ash-cloud deposits. t, terraced lahar deposits of March 19, 1982; 12pf, June 12, 1980, pyroclastic-flow deposit; 18pf, May 18, 1980, pyroclastic-flow deposit. Dot-dashed lines, latest streamcourses. Solid arrows indicate directions of pyroclastic flow; open arrows indicate direction of avalanche runup over Johnston Ridge (see fig. 29). Heavy line in cross section denotes present land surface.

water, mud, and trees crashed down a small tributary within the South Fork Toutle valley. It snapped off trees and 'exploded' when it hit lows, bursting as much as 60 ft when it hit obstacles * * *." The river returned to and stayed within its deep channel until about 2:00 p.m. P.d.t., when there occurred a second smaller flood deep enough to spill out of the channel.

In the 6 years since the eruption, the surface of the riverbed has been reworked, so that little, if any, of the 1980 surface remains. Across the river valley to the north is timber that was seared and downed by the laterally directed blast. In the roadcut on the south side of the road is till of the Fraser glaciation overlying lithic pyroclastic-flow deposits containing blocks with prismatic jointing. These pyroclastic-flow deposits are of the Cougar eruptive stage.

16.5 (0.5) Junction of Weyerhaeuser Roads 4100 and 4195; bear left, staying on Weyerhaeuser Road 4100.

17.0 (0.5) First 0.2 mi (0.3 km) is on a poorly maintained gravel road along which are excellent outcrops of prismatically jointed blocks in pyroclastic-flow deposits of the Cougar eruptive stage.

17.4 (0.4) Weyerhaeuser Road 4100 leaves the hill and enters onto the flood plain of the South Fork Toutle River, heading west.

18.1 (0.7) Junction of Weyerhaeuser Roads 4100 and 5700; bear right on Weyerhaeuser Road 4100.

18.2 (0.1) Junction of Weyerhaeuser Roads 4100 and 5710; turn left on Weyerhaeuser Road 5710.

18.4 (0.2) Cross bridge: bear right, leaving Weyerhaeuser Road 5710, and head west.

19.0 (0.6) Turn left, road continues 500 ft (150 m).

19.1 (0.1) STOP 26. Bear left to borrow pit. Here are good exposures of lahars of the Swift Creek eruptive stage. Charcoal from sand at the top of the lahars has a ^{14}C age of

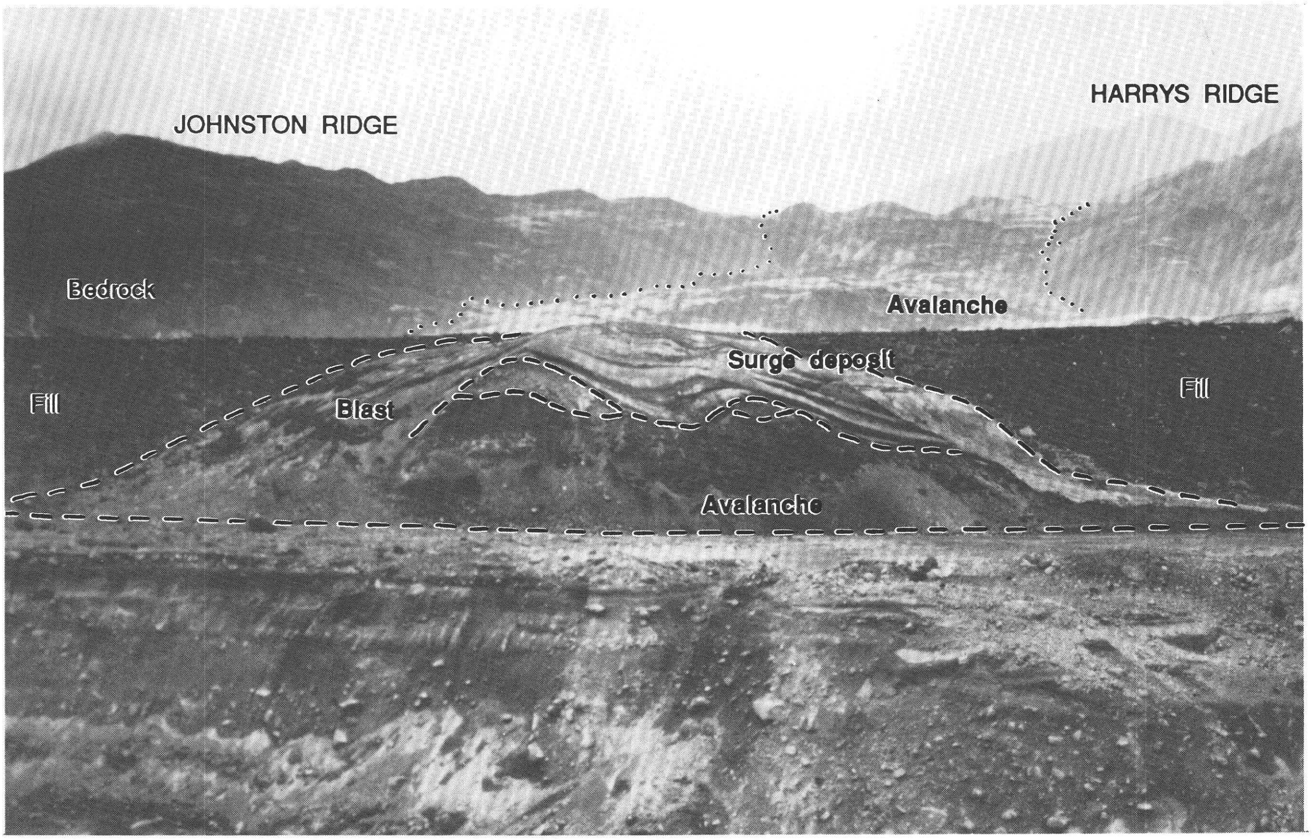


Figure 29. North Fork Toutle River blockage at stop 22. Here, red fractured rock of avalanche deposit underlies blast deposit and pumiceous surge deposit from secondary phreatic explosions on the Pumice Plain. In foreground are pumiceous pyroclastic-flow deposits of June 12, 1980; in surrounding middle ground is artificial fill at one of the critical points in the Spirit Lake blockage; in background are light-colored ash-cloud deposits overlying the avalanche runup, where the avalanche crossed over Johnston Ridge into South Coldwater Creek drainage basin. Dashed and dotted lines indicate approximate boundaries. View northward.

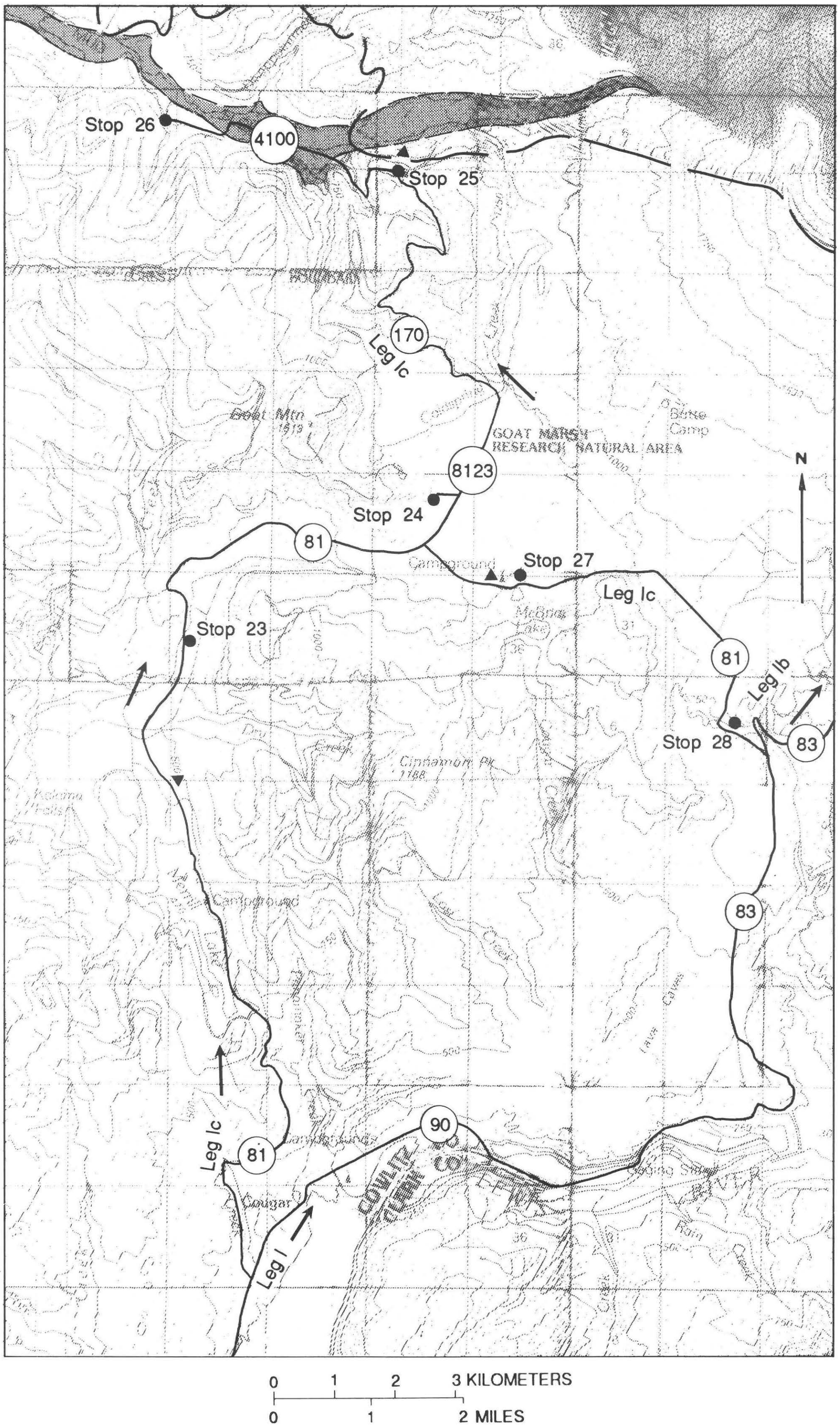


Figure 30. Field-trip route near southwest side of volcano in the Kalama and South Fork Toutle River areas, showing leg Ic. Triangles, viewpoints; circled numbers, U.S. Forest Service and Weyerhaeuser roads; long-dashed line, devastated-zone boundary; short-dashed lines and shading, limits of lahar inundation; stippling, area covered by pyroclastic flows and avalanche on north side of volcano.

12,270±90 yr (Crandell and others, 1981).

Just south of here is the former location of the KOMO TV car where David Crockett was trapped by lahars on May 18, 1980. Lahars carried away the bridge south of here and covered the road behind him.

20.0	(0.9)	Return to junction of Weyerhaeuser Roads 4100 and 5710 at bridge.
20.1	(0.1)	Turn right on Weyerhaeuser Road 4100.
20.8	(0.7)	Junction of Weyerhaeuser Roads 4100 and 5700; bear left on Weyerhaeuser Road 4100.
21.2	(0.4)	Weyerhaeuser Road 4100 leaves the flood plain and climbs the hill.

Return to junction of USFS Roads 81 and 8123 in the Kalama River valley and turn left.

27.9	(0.0)	A pyroclastic flow containing dacitic clasts is exposed for the next 330 ft (100 m).

For the next half-mile (0.8 km) the surface is littered with breadcrust bombs. The deposit consists of a loose, reddish-gray, unsorted and unstratified mixture of sand and angular andesite fragments. The deposit was formed by a pyroclastic flow during the Kalama eruptive period. Hoblitt (1979) reported that these deposits were emplaced at temperatures above 550° C.

28.3	(0.4)	Junction of USFS Roads 81 and 81610. Here, the Kalama Springs campground was inundated by a mudflow on May 18, 1980. Burial of the root burl of these trees was deep enough to kill them.
28.4	(0.1)	The Kalama River and McBride Lake. McBride Lake was probably created by impoundment from pyroclastic flows of the Kalama eruptive period.
28.5	(0.1)	STOP 27. Outcrops of pyroclastic flows and avalanche deposits, probably of the Cougar eruptive stage (Hyde, 1975; Newhall, 1982).
28.9	(0.4)	The Cave Basalt, underlain by an andesite flow of the Castle Creek eruptive period (C.A. Hopson, written commun., 1984).
29.0	(0.1)	Andesite of the Kalama Springs area and Red Rock Pass.
30.2	(1.2)	Junction of USFS Roads 81 and 8100830.
32.1	(1.9)	STOP 28. Deposits north of the road are described by Hyde (1975; stop 1) as parts of the Swift Creek assemblage. These outcrops consist of till of the Fraser glaciation overlain by pyroclastic-flow deposits and S tephra from the Swift Creek eruptive stage.
32.7	(0.6)	Junction of USFS Roads 81 and 83. Turn left to join up with leg Ib (fig. 6) to the Muddy River fan; turn right to Ape Cave and the town of Cougar.

END OF SIDE TRIP Ic

SIDE TRIP Id. Randle to Meta Lake

Route can be followed by reading southbound from Randle or northbound from Meta Lake and the junction of USFS Roads 26 and 99. Stop numbers run north to south.

North-bound	South-bound	
25.5 (0.9)	0.0 (0.0)	From Randle, head south. Here you are about 25 mi (40 km) from Mount St. Helens; burnt branches and ash fell here on May 18, 1980.
24.6 (1.2)	0.9 (0.9)	Bear right on Woods Creek Road.
23.4 (6.6)	2.1 (1.2)	Bear right onto Spear Road and the entrance to Gifford Pinchot National Forest; stay on paved road. Entering north end of area of figure 31.
16.8 (3.6)	8.7 (6.6)	Cross the Cispus River. Junction of USFS Roads 25 and 26; bear right onto USFS Road 26. About 1 mi (1.6 km) south on USFS Road 25 is the northern portal to the monument.
13.2 (4.5)	12.3 (3.6)	Strawberry Mountain trail.
8.7 (1.0)	16.8 (4.5)	Junction of USFS Roads 26 and 2608; bear left on USFS Road 26.
7.7 (0.2)	7.8 (1.0)	Outcrop of the T, Wn, and Yn tephras in roadcut. Now crossing the north edge of tephra deposit from the plinian eruption of May 18, 1980. Most of the deposit has been removed by erosion or covered by vegetation, but farther south the deposit thickens.
7.5 (0.5)	8.0 (3.2)	STOP 29. Quartz Creek. Stop just within sear zone that borders the blast zone of May 18, 1980. This locality is 14 mi (23 km) from the summit.

Continue on USFS Road 26.

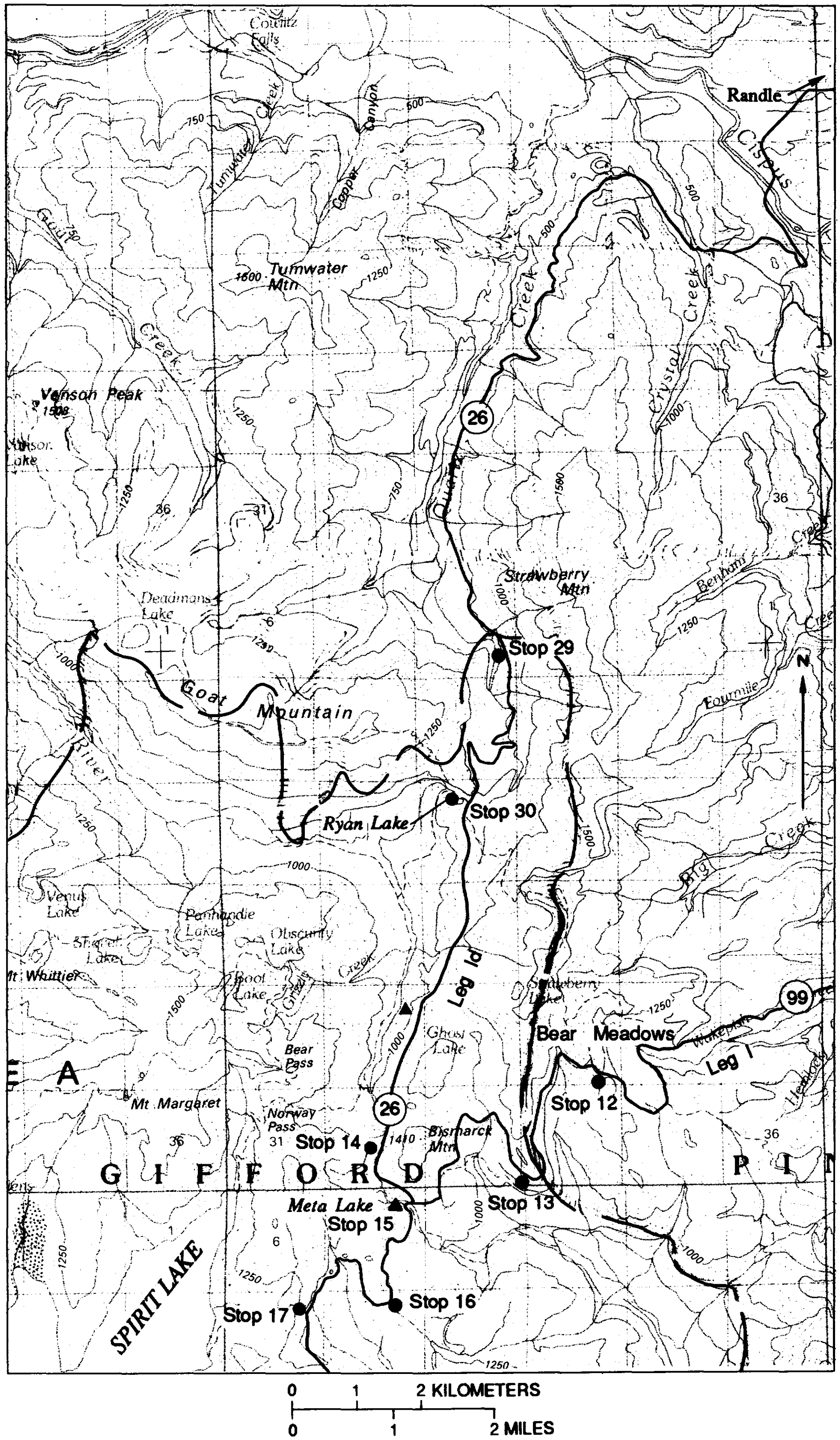


Figure 31. Field-trip route near northeast side of volcano in the Green River and Quartz Creek areas, showing leg Id and part of leg I. Triangles, viewpoints; circled numbers, U.S. Forest Service roads; dashed line, devastated-zone boundary; stippling, area of debris avalanche.

4.3 (0.5)	21.2 (3.2)	STOP 30. Junction of USFS Roads 26 and 2612. Hike 150 ft (50 m) to Ryan Lake and exposures of tephra stratigraphy (see fig. 22). One person died here from asphyxiation caused by the ingestion of fine ash.

Witnesses approximately 6 mi (9.6 km) west of here reported noises like three rifle shots in the distance and then an apparent pressure change that seemed to force them to the ground. A black cloud shot overhead 10 to 15 seconds after the noises. "Golfball size" and smaller pieces of rock dropped from this cloud (some of which were collected and are a glassy dacite). The cloud moved some distance north and then pulled back to the south (so that blue sky appeared overhead) in a span of about 5 seconds, although it did not completely disappear from sight. Then, the cloud reapproached with a "roaring noise." As it passed overhead, a cedar tree began to fall, and within seconds "there were no trees left." Seconds later, it was totally dark, and ash was falling so heavily that visibility, with a flashlight, was no more than a foot. Although thousands of trees fell, the witnesses did not hear them, nor did they feel a blast or wind at that time: "Whatever happened, it happened over our heads." The first material to fall "was cold and was like mud," and may have contained some ice. The particles seemed to be somewhat larger than sand size and appeared to fall vertically. A minute or two after the trees blew down, it became uncomfortably hot, as if a forest fire was nearby. The heat did not last long (excerpted from Rosenbaum and Waitt, 1981).

3.7 (2.8)	21.7 (0.5)	VIEWPOINT. To the west lies the Green River. You have crossed the drainage divide between Quartz Creek, which flows north into the Cispus and Cowlitz Rivers, and the Green River, which flows west into the Toutle and Cowlitz Rivers.

For the next 3 mi (4.8 km) are excellent views of downed timber. This area had a mature old-growth forest of Douglas-fir (and other species); some trees were more than 500 yr old.

0.9 (0.3)	24.5 (2.8)	STOP 14 (of leg I). Norway Pass trailhead. Spectacular view in upper Green River of timber blowdown. The blowdown here will not be salvaged but left untouched and allowed to decay naturally.
0.6 (0.6)	24.8 (0.3)	Meta Lake on south side of road. Good examples of downed timber and pre-1980 air-fall tephra exposed on north side of road.
0.0 (0.0)	25.4 (0.6)	Junction of USFS Roads 26 and 99 and leg I. Continue right to Spirit Lake, or left to Randle or Cougar.

END OF SIDE TRIP Id

END OF LEG I

Leg II. Vancouver to Coldwater Lake via the North Fork Toutle River (see fig. 4).

Events that occurred on May 18, 1980, in the Toutle River drainage basin were discussed by Janda and others (1981).

CAUTION: SOME OF THE ROADS IN THIS GUIDE ARE SUITABLE ONLY FOR FOUR-WHEEL-DRIVE VEHICLES AND ARE IMPASSABLE IN THE WINTER AND SPRING. BE SURE TO CHECK WITH LOCAL AUTHORITIES BEFORE ATTEMPTING ROADS OFF THE MAIN HIGHWAY. TRAVEL EAST OF GREEN RIVER SEDIMENT RETENTION DAM (STOP 7) MAY BE CLOSED TO PUBLIC ACCESS AND A VEHICLE PERMIT REQUIRED TO TRAVEL ON. CHECK WITH THE USFS.

Cumulative mileage	(mileage between points)	
0.0	(0.0)	Leave Cascades Volcano Observatory. Travel west on Mill Plain Boulevard to junction with U.S. Interstate Highway 5. Drive north on U.S. Interstate Highway 5. Surface is underlain by gravel and sand of the great Pleistocene Missoula floods.
15.6	(15.6)	Junction with Ridgefield exit. View northeastward of Mount St. Helens.
19.8	(4.2)	Cross the East Fork Lewis River. Outcrops in roadcut on east side of road are lava flows of the upper Eocene or lower Oligocene Goble Volcanic Series of Lowry and Baldwin (1946) interbedded with the Eocene Cowlitz Formation (in part equivalent to the Hatchet Mountain Formation), composed of porphyritic andesite, olivine basalt, basalt, and breccia, with interbedded sedimentary rocks.
21.5	(1.7)	Cross the Lewis River.
22.5	(1.0)	Junction with Woodland exit. Continue north on U.S. Interstate Highway 5.

33.5	(11.0)	Cross the Kalama River.

The Trojan Nuclear Power Plant is located directly west of here on the west bank of the Columbia River, 5 mi (8 km) upstream from the mouth of the Cowlitz River. Soundings by the U.S. Corps of Engineers on May 24, 1980, showed that the river channel in front of the plant, which originally had a depth of 120 ft (36 m), had partially filled to a maximum depth of 40 ft (12 m). This deposition of material was confined to the deeper parts of the river channel and did not affect the plant's water-intake structure, which is at a depth of 10 ft (3 m) (Schuster, 1981).

38.5	(4.7)	Junction with Longview exit. Continue north on U.S. Interstate Highway 5.
41.2	(3.0)	Passing Kelso exit.

During the May 18, 1980, eruption and subsequent flooding, high flow was recorded at Kelso at 4:00 a.m. P.d.t. May 19, nearly 19½ hours after the eruption began; peak water temperature was 90 °F (32 °C). A smaller peak was recorded here at 5:00 p.m. May 18, with a high-water temperature of 51 °F (10.5 °C) from a flood that traveled down the South Fork Toutle River. West of the freeway, what was once a golf course has now become a repository for dredge spoils and the site of a shopping mall.

Entering area of figure 32; continue north on U.S. Interstate Highway 5.

47.9	(6.7)	West of U.S. Interstate Highway 5 are areas inundated by lahars from the May 18, 1980, eruption and spoil piles of debris dredged from the Cowlitz River.
51.6	(3.7)	Leave freeway at Castle Rock, exit 49.

Cumulative mileage	(mileage between points)	
0.0	(0.0)	Turn left and cross freeway, heading west.
0.3	(0.3)	Dredging operations on right.
0.8	(0.5)	Turn right onto A street.
1.3	(0.5)	VIEWPOINT. Cross Castle Rock bridge over the Cowlitz River.

During the May 18, 1980, eruption and subsequent flooding, the effects of the South Fork Toutle River lahar were scarcely noticed here. At 1:30 p.m. P.d.t. the stage had risen to 13.15 ft (4 m), but by 2:15 p.m. it had returned to the preflood condition of 10 ft (3 m). The high flow from the North Fork Toutle River lahar was recorded at the Castle Rock bridge at midnight, nearly 15½ hours after the 8:32 a.m. eruption. High-water temperature here was 85 °F (29 °C). To your left as you leave the bridge is the Cowlitz County Fairgrounds. From 3 to 5 ft (0.9–1.5 m) of sediment was deposited over the entire fairgrounds by the flood on May 18–19, 1980 (Lombard and others, 1981).

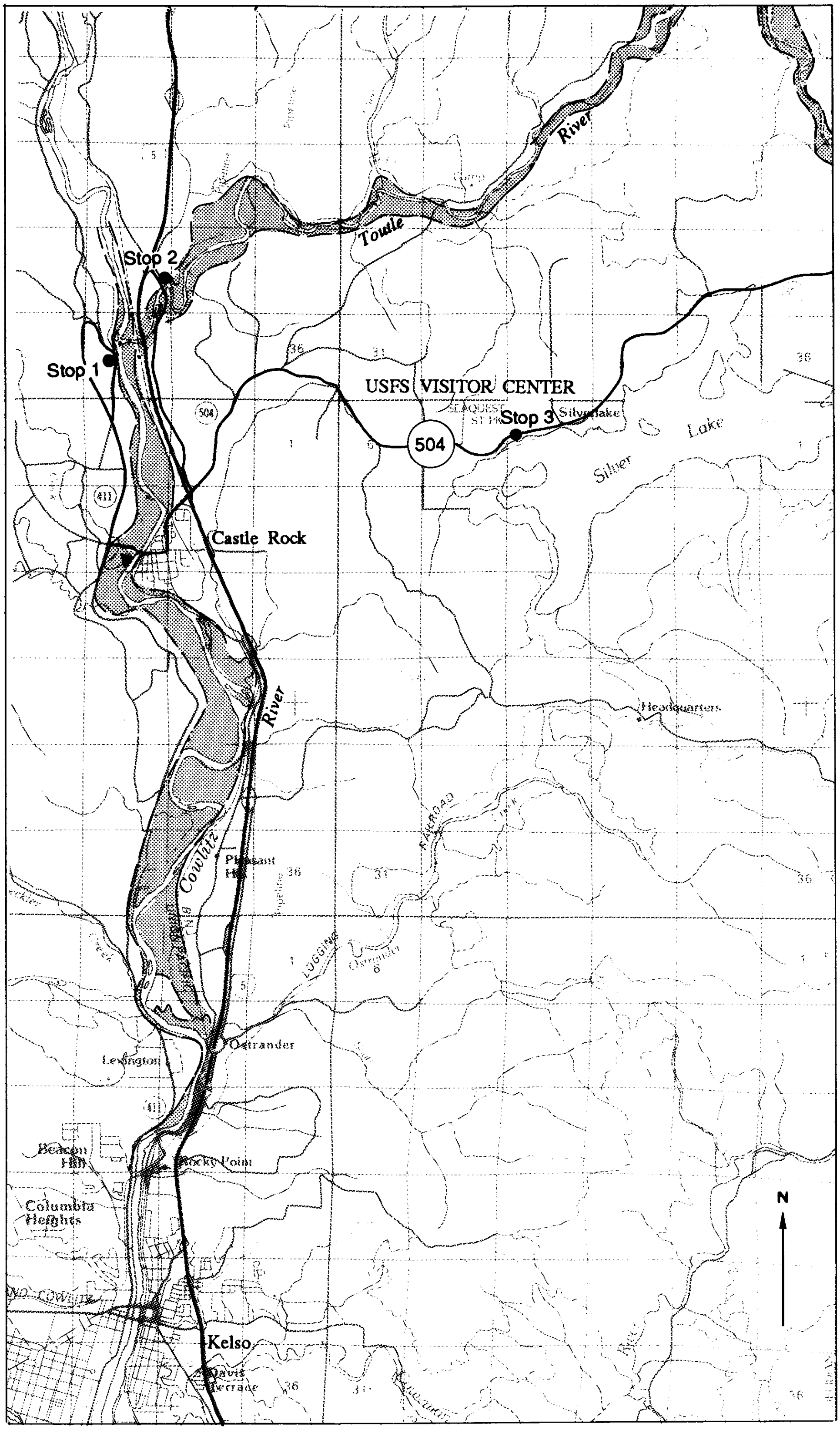
1.6	(0.3)	Right turn at next intersection onto Washington Highway 411.
2.0	(0.4)	Lahar deposits of the Cougar eruptive period in upper terrace and of the Pine Creek eruptive period in lower terrace surface.
3.0	(1.0)	Bear right onto Chapman Road.
3.7	(0.7)	STOP 1 AND VIEWPOINT. View eastward to U.S. Interstate Highway 5 bridge and confluence of the Cowlitz and Toutle Rivers.

Here, the lahar from the South Fork Toutle entered the Cowlitz River at 1:00 p.m. P.d.t. on May 18, 1980. The lahar from the North Fork Toutle River arrived at the mouth of the Toutle River at about 8:30 p.m., where it was described as having a homogeneous, mortarlike consistency from bank to bank. The early part of the lahar past this point was seen to carry logs, buildings, and a pickup truck. As the lahar entered the Cowlitz River, the main mass moved downstream, but part moved upstream for 2.5 mi (4 km) (Cummans, 1981). Logs from the flow were deposited onto the Burlington Northern Railroad bridge, and U.S. Interstate Highway 5 was closed to traffic.

Return to U.S. Interstate Highway 5 overpass. Travel east on Washington Highway 504 from overpass, past on ramp to next left.

Cumulative mileage	(mileage between points)	
0.0	(0.0)	Turn left onto Old Pacific Highway.
2.5	(2.5)	STOP 2. Washington Highway 99 bridge across the Toutle River. Bridge survived the May 18, 1980, lahar.

Here, the front of the mudflow from the South Fork Toutle River passed by at about 1:00 p.m. P.d.t. on May 18; the mudflow from the North Fork Toutle River arrived at about 8:30 p.m. High-mudflow marks may still be visible on nearby trees. Houses rafted on the lahar



0 1 2 KILOMETERS
0 1 2 MILES

Figure 32. Field-trip route on the Cowlitz and Toutle Rivers in the Kelso-Castle Rock-Silver Lake area, showing part of leg II. Triangle, viewpoint; circled number, U.S. Forest Service road; dashed lines and shading, limits of lahar inundation.

surface crashed into the bridge superstructure. Water temperature here was 91 °F (33 °C) at 9:45 a.m. May 19. Peak floods probably arrived here around 10:00 p.m. May 18, 14 hours after the 8:32 a.m. eruption.

Return to Washington Highway 504.

Cumulative mileage	(mileage between points)	
0.0	(0.0)	Turn left onto Washington Highway 504 and travel east.
1.9	(1.9)	Junction with Tower Road; continue straight.
2.5	(0.6)	Outcrops of the upper Eocene or lower Oligocene Goble Volcanic Series of Lowry and Baldwin (1946) (equivalent to the Hatchet Mountain Formation).
5.4	(2.9)	STOP 3. Seaquest State Park and Mount St. Helens National Volcanic Monument Visitor Center.

A stop at the visitor center is highly recommended. Silver Lake was formed when a tributary valley of the North Fork Toutle River was dammed by prehistoric lahars from Mount St. Helens that moved down the Toutle River drainage. Entering area of figure 33.

8.9	(3.5)	Junction with a campground turnoff.
10.5	(1.6)	Junction of Washington Highway 504 and South Fork Toutle River Road.

Take road that bears right, past store, to South Fork Toutle River Road.

10.8	(0.3)	Cross over Outlet Creek draining Silver Lake. Exposed in streambank are outcrops of lahars of the Pine Creek eruptive period (part of the Silver Lake lahar assemblage of Crandell and Mullineaux, 1962). Wood fragments from sand beneath this sequence of lahars

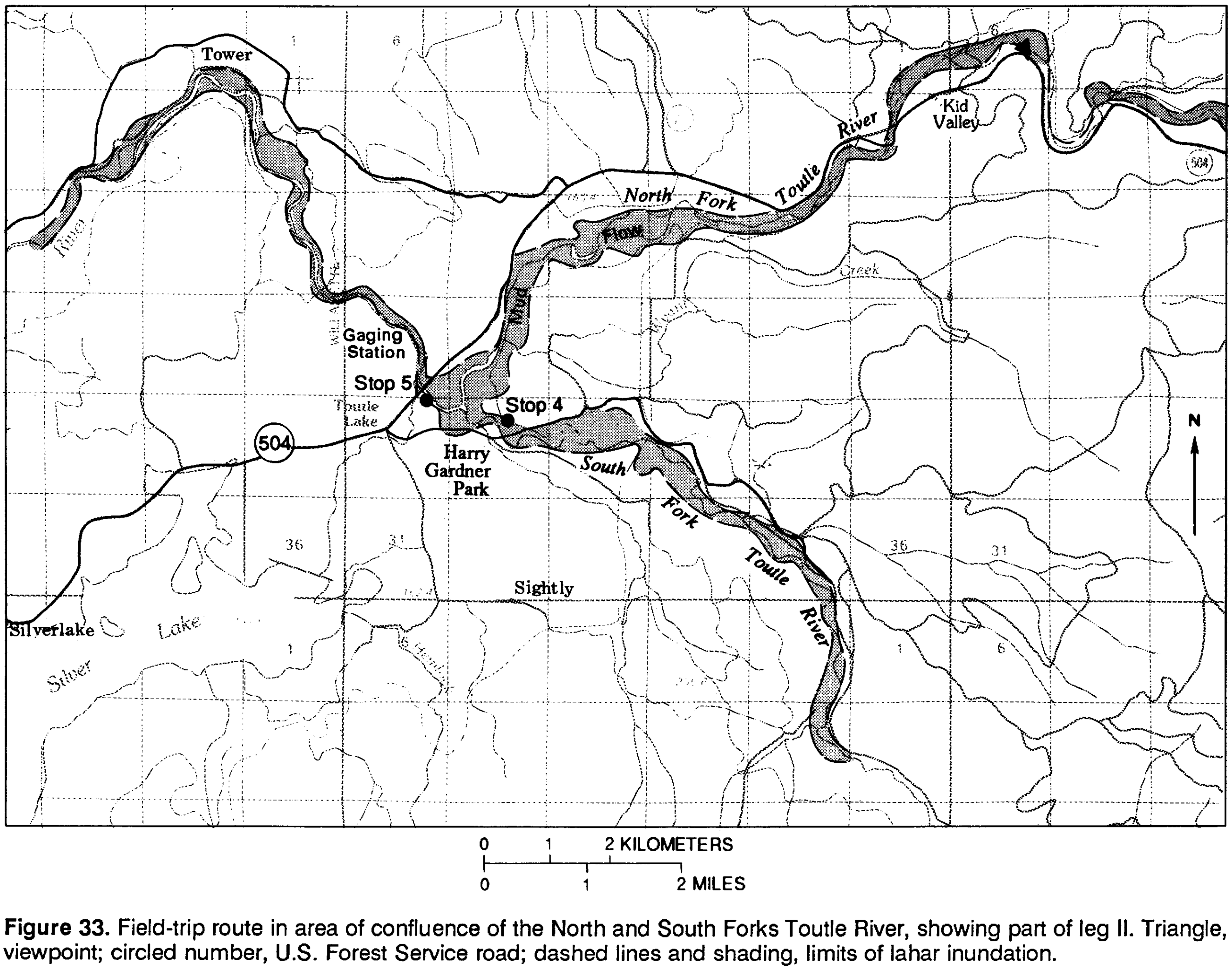


Figure 33. Field-trip route in area of confluence of the North and South Forks Toutle River, showing part of leg II. Triangle, viewpoint; circled number, U.S. Forest Service road; dashed lines and shading, limits of lahar inundation.

give a radiocarbon age of about 2,810 yr. Alluvium and a lahar deposit beneath the sand contain pumice derived from the Y tephra of the Smith Creek eruptive period (4,000–3,300 yr B.P.) (Crandell and others, 1981).

11.7 (0.9) Enter area inundated by May 18, 1980, lahars from the South Fork and North Fork Toutle Rivers.

13.0 (1.3) STOP 4. Cross South Fork Toutle River bridge and pull off on north side of road. Walk about 600 ft (182 m) north, to high bank.

Here, the outcrops, more than 20 ft (7 m) high, consist of lahars of the Pine Creek eruptive period (fig. 34). One lahar here contains unusually well rounded clasts and monolithic megaclasts of silt-size material. This lahar has been interpreted as a breakout lahar, formed by sudden breaching of an ancient Spirit Lake (K.M. Scott, oral commun., 1985). A lahar would have been able to carry the fragile megaclasts of silt, whereas a stream would have destroyed the clasts.

To the right of the high cliff are deposits from the May 18, 1980, mudflows that overlie asphalt paving of the Harry Gardner Park parking lot. The lower, lithic-rich layer represents the first and largest lahar that came down the South Fork Toutle River, arriving here at 10:13 a.m. P.d.t. on May 18. The upper, pumice-rich layer

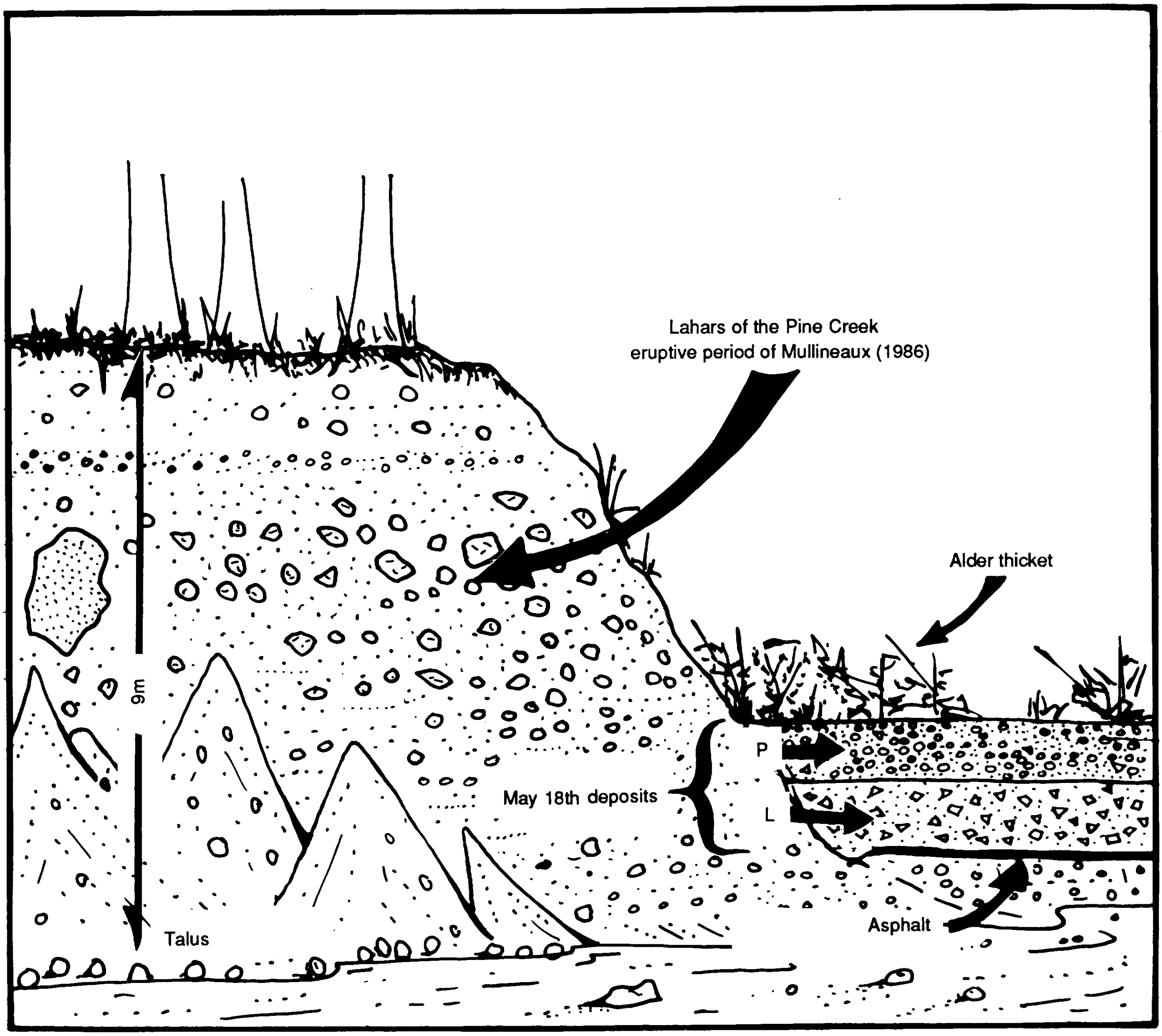


Figure 34. Schematic stratigraphic section in Harry Gardner Park at stop 4. L, lithic-rich layer; P, pumice-rich layer.

represents deposits from a second lahar in the South Fork Toutle River. This pumice-rich lahar reached here in the evening of May 18 and was dammed by thick deposits of the lahar from the North Fork; the pumice came from the plinian eruption that began around noon. David Crockett, 6 mi (9.6 km) west of the volcano, reported a second mudflow originating in the South Fork Toutle River around 2:00 p.m. May 18 (Rosenbaum and Waitt, 1981).

Return to junction of Washington Highway 504 and South Fork Toutle River Road.

Cumulative mileage	(mileage between points)	
0.0	(0.0)	Turn right onto Washington Highway 504 and proceed east.
0.6	(0.6)	STOP 5. Pull off just before bridge across the Toutle River. View from here, with bridge at 12 o'clock.

Downstream (at 10 o'clock) is the location of the gaging station where mudflow marks were as high as 53 ft (16 m) above the gage datum, about 39 ft (12 m) higher than the South Fork Toutle River lahar. About 0.8 mi (1.3 km) downstream is a constriction in the Toutle River valley, probably the cause of blockage and subsequent ponding of the North Fork Toutle River. Peak flow probably occurred at 7:00 p.m. P.d.t. May 18. Just downstream of Washington Highway 504 is Outlet Creek, which drains Silver Lake. Upstream (1:00 o'clock), to the left, is the North Fork Toutle River, and to the right (2:30 o'clock) is the South Fork Toutle River. In the far distance (2:30 o'clock) is Mount St. Helens, and in the middle ground is Harry Gardner Park (2:30 o'clock). Upstream in the high west bank are lahars and fluvial deposits of the Pine Creek eruptive period overlying deposits of the Smith Creek, Swift Creek, and Ape Canyon eruptive periods. Both bridges, here and about 1 mi (1.6 km) SE. over the South Fork Toutle River, survived the South Fork Toutle River lahar. Later, at 6:10 p.m., the North Fork Toutle River lahar destroyed the Washington Highway 504 bridge.

Cross over Washington Highway 503 bridge and continue east on Washington Highway 504.

3.9	(3.3)	Junction with Tower Road; continue straight.
4.9	(1.0)	Junction with Washington Highway 505; continue straight ahead on Washington Highway 504.

For the next 12 mi (19 km), many sections of the road cross river terraces inundated by May 18 lahars. Inundated areas are readily identifiable by the thick growths of young alder.

9.2	(4.3)	Maple Flats turnout. Observations between 3:00 to 4:30 p.m. P.d.t. on May 18, 1980, indicate that the lahar kept rising and had the consistency of fresh mortar. Peak flow here occurred shortly before 5:00 p.m. May 18. Near here, the Goble Volcanic Series has been dated at 32.2 to 35.9 m.y. (Oligocene).
10.5	(1.3)	Entering area of figure 35. Travel along new roadbed. Lahars of the Pine Creek eruptive period are exposed in cutbank across river.

A new sediment-retention dam will be constructed near the mouth of the Green River to prevent sediment from being washed down the North Fork Toutle River. Farther travel up the North Fork depends on road conditions and degree of completion of dam. Check with the USFS for new routing of road.

13.6	(3.1)	Alder Creek. Exposed on south side of road are deposits of the Pine Creek and Smith Creek eruptive period. The May 18, 1980, flow on the North Fork Toutle River arrived here at about 2:40 p.m. P.d.t.
13.9	(0.3)	Buried bridge on left. This bridge was carried 0.25 mi (0.4 km) downstream by the lahar of May 18, 1980.
14.2	(0.25)	Cross the North Fork Toutle River. Here is the original position of the bridge, destroyed at 3:01 p.m. P.d.t. May 18, 1980.
16.4	(2.2)	Camp Baker, a sorting yard for the Weyerhaeuser Corp., was swept by lahars starting at 1:57 p.m. P.d.t. May 18, 1980. Many of the damaged buildings and equipment have been removed by salvage operations.
16.5	(0.1)	STOP 6. Bridge just east of the Camp Baker sorting yard, over Hoffstadt Creek. East streambank shows lithic lahar deposits of May 18, 1980, similar to the deposit at Harry Gardner Park, underlain by road asphalt and deposits of the Pine Creek eruptive period and at least one later eruptive period.
18.0	(1.5)	Turn off for N–1 Visitor Site.

Farther travel up the North Fork Toutle River depends on road conditions.

18.5 (0.5) STOP 7. Site of abandoned U.S. Army Corps of Engineers sediment-retention structure N–1.

This rock-fill dam was designed and constructed as a temporary sediment-control measure in July-September 1980; it was originally more than 6,100 ft (1,860 m) long and 43 ft (13 m) high. In two stilling basins, sediment was deposited and water allowed to continue downstream. During its effective life-time the structure was breached three times (February, March, and December 1982). The structure gave planners 2 years to develop a more permanent sediment-management strategy (Meyer, 1986b).

STRUCTURE N–1 MARKS THE RESTRICTED-ZONE BOUNDARY IN 1986. ENTRY REQUIRES SPECIAL PERMITS, RADIOS, GATE KEY, AND SO ON. ARRANGEMENTS FOR ENTRY MUST BE MADE WITH THE USFS.

20.0 (1.5) Approximate location of toe of 1980 debris avalanche. Original log-laden toe was removed during construction of structure N–1. The mounds and hummocks you see upstream are parts of the avalanche. Grass and clover were planted in an attempt to stabilize the surface here.

Junction of Weyerhaeuser Roads 3100 and 3500; continue on Weyerhaeuser Road 3500 (to right).

21.7 (1.7) Bridge over Bear Creek. Note exposures of dissected hummocks.

22.4 (0.7) Junction of Weyerhaeuser Roads 3300 and 3500; continue on Weyerhaeuser Road 3300.

22.9 (0.5) STOP 8. Park at bottom of hill and hike about 0.5 mi (0.8 km) up the North Fork Toutle River on the avalanche. At this locality are excellent examples of avalanche topography (hummocks, entrapped lakes, mudflows), erosion, deposi-

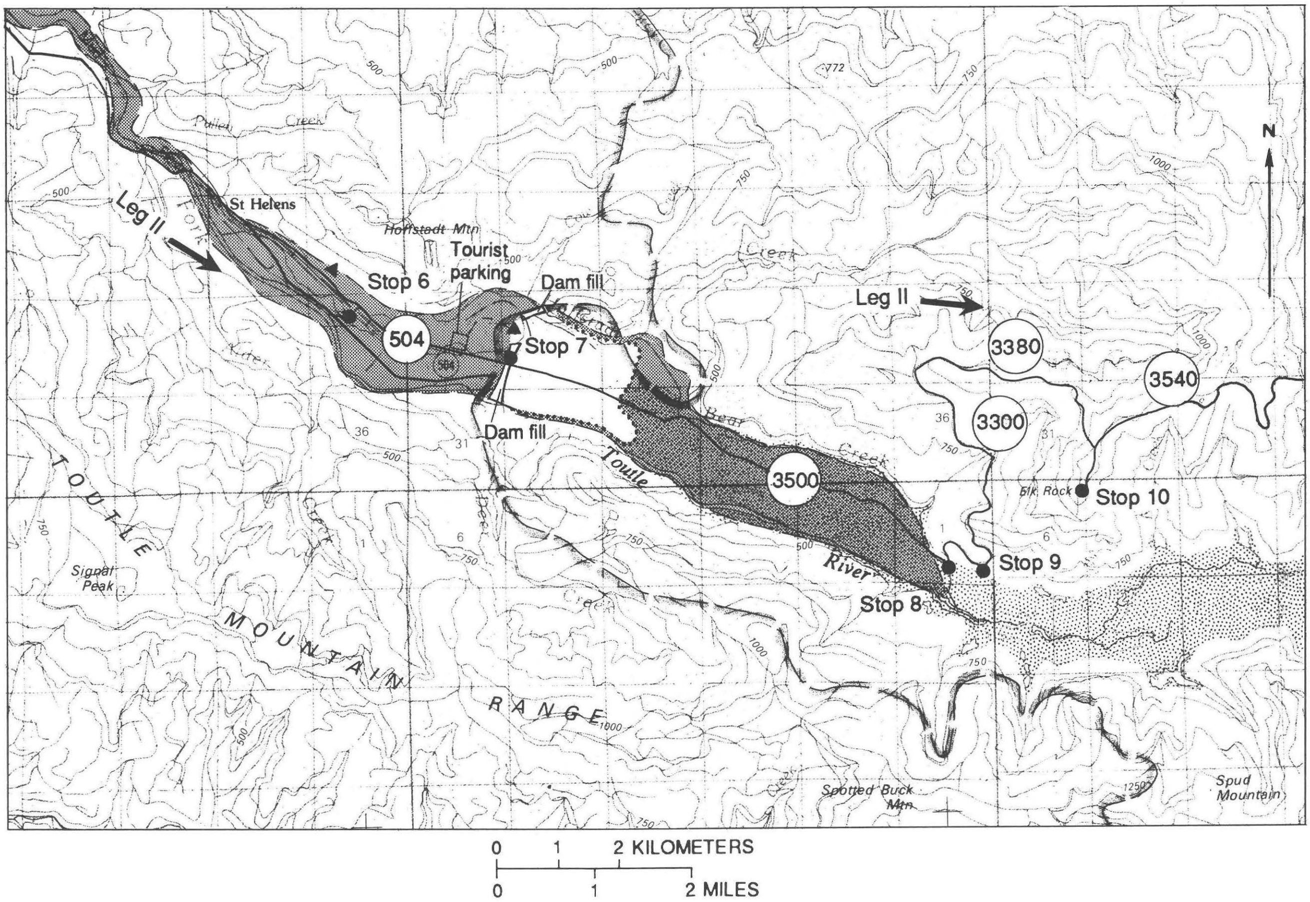


Figure 35. Field-trip route on the North Fork Toutle River in the Pullen-Alder Creek-Elk Rock areas, showing part of leg II. Triangles, viewpoints; circled numbers, Weyerhaeuser roads; short-dashed lines and shading, limits of lahar inundation; long-dashed line, devastated-zone boundary; stippling, area of debris avalanche; dotted line, settlement pond of sediment-retention structure N–1.

tion, and revegetation (manmade or natural).

23.1 (0.2) STOP 9. View of the North Fork Toutle River debris avalanche.

Note the contrast between replanted avalanche surface (west of Elk Rock) and undisturbed avalanche, avalanche levees, lakes, and hummocks below and east of Elk Rock. Note also deposits and effects of the March 19, 1982, lahar, as well as fluvial deposits and downed timber that has not been salvaged. Reworked blast deposit is locally present in this area. Tephra from the May 25, 1980, eruption deposited here has been almost completely removed by erosion.

Continue on Weyerhaeuser Road 3300. Pay careful attention to the road numbers—it's easy to get lost in the maze of roads here.

24.6 (1.5) Junction with Weyerhaeuser Road 3310 to the Cowlitz County riverwatch station. This outpost was used by Cowlitz County as a backup to the USGS warning system in the event of an outbreak from Spirit Lake. A lahar traveling downstream from here would take 4 to 6 hours to reach the Cowlitz River and Castle Rock.

26.6 (2.0) Junction of Weyerhaeuser Roads 3300, 3380, and 3381; turn right onto Weyerhaeuser Road 3381 (follow signs leading to Weyerhaeuser Road 3540).

28.0 (1.4) Junction of Weyerhaeuser Roads 3340, 3344, and 3381; bear left on Weyerhaeuser 3340 (follow signs leading to Weyerhaeuser 3540).

28.3 (0.3) Junction with Weyerhaeuser Roads 3340 and 3346; turn right onto Weyerhaeuser 3346 road (follow signs leading to Weyerhaeuser 3540).

28.9 (0.6) Junction with Weyerhaeuser Road 3540; turn right onto Weyerhaeuser Road 3540.

Entering area of figure 36.

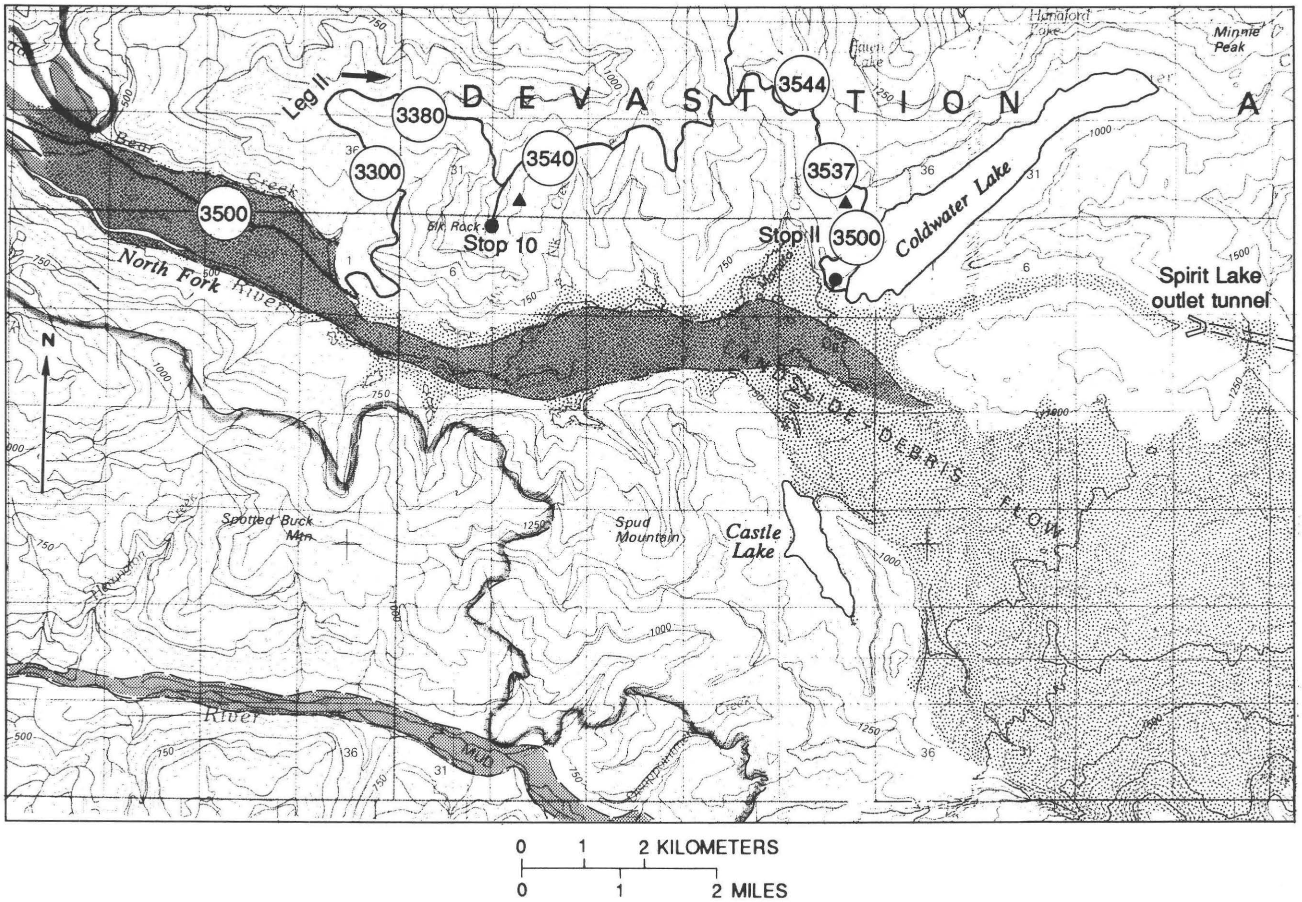


Figure 36. Field-trip route on the North Fork Toutle River in the Elk Rock-Coldwater Lake area, showing part of leg II. Triangles, viewpoints; circled numbers, Weyerhaeuser roads; short-dashed lines and shading, limits of lahar inundation; long-dashed line, devastated-zone boundary; stippling, area of debris avalanche.

29.5 (0.6) STOP 10. Right turn to a dead end on the east slope of Elk Rock.

Here is an excellent view of Mount St. Helens, the debris avalanche, and the spillway draining Coldwater Lake (fig. 37). The crater of Mount St. Helens is 10 mi (16 km) away. The blast deposit was thin here (5 in. [13 cm]), and is being eroded further.

Return to Weyerhaeuser Road 3540; continue to right.

30.9 (1.4) Bear left on Weyerhaeuser Road 3540.

32.4 (1.5) Junction of Weyerhaeuser Roads 3540 and 3545. Road to north (Weyerhaeuser Road 3545) leads to Morton and the Green River drainage basin. Turn right for the Coldwater Lake blockage on Weyerhaeuser Road 3540 (main construction road to South Coldwater Creek).

Entering area of figure 38.

36.4 (4.0) STOP 11. Coldwater Lake blockage.

Figure 37. Mount St. Helens from the Elk Rock area. A, area of debris avalanche; J, Johnston Ridge; SL, Spirit Lake. Dashed line, Weyerhaeuser Road 3540. View southeastward; photograph by Bob Krimmel, taken June 16, 1982.

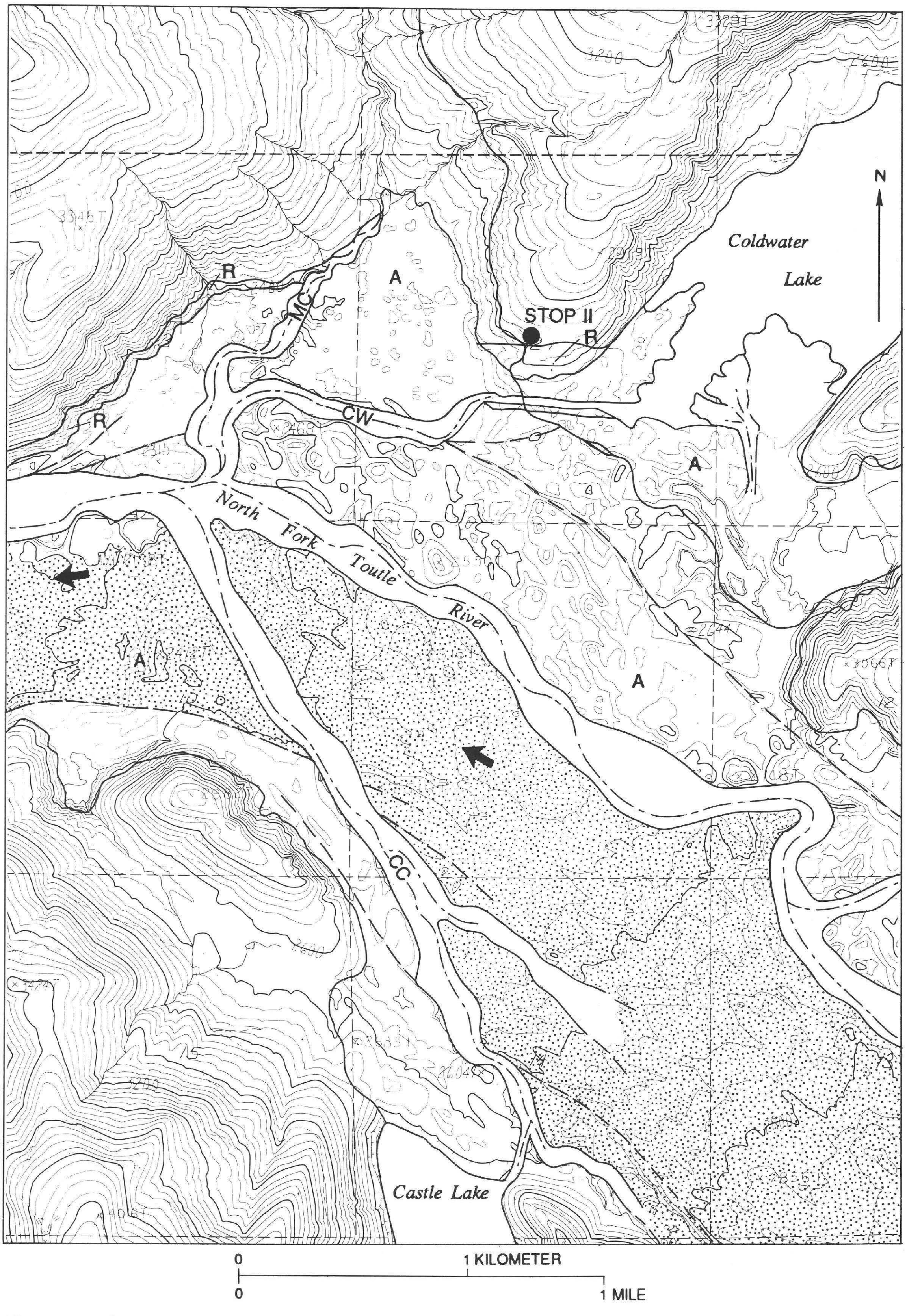


Figure 38. Simplified geologic map of Coldwater Lake blockage near stop 11. A, area of rockfall-debris avalanche that filled the North Fork Toutle River valley; CC, Castle Creek; CW, Coldwater Creek; MC, Marada Creek; R, runup of debris avalanche on valley walls; long-short-dashed lines, streamcourses; dashed lines, location of avalanche scarps; stippling, source area of May 18, 1980, North Fork Toutle River lahars. Arrows indicate direction of lahar flow.

The view from the Coldwater exit affords an excellent view of the debris-avalanche deposit and its diverse parts. The following description comes from reports by Glicken (1986) and Meyer (1986a, b).

The eruption on May 18, 1980, was initiated by a magnitude 5.1 earthquake, which triggered a large landslide off the volcano; the landslide was quickly hidden by the advancing cloud of steam and hot rocks of the lateral "blast." Beneath this maelstrom came the 2.7-km^3 (0.7 mi^3)-volume debris avalanche.

The failure of the avalanche took place as huge slices or slide blocks (Glicken, 1986). Slide block I consisted of the north face of Mount St. Helens, mostly young rocks less than 2,500 years old (dacite, andesite, and basalt). The block remained relatively intact, depositing material on and adjacent to Johnston Ridge as it passed over the ridge; part of it went into Spirit Lake, and part of it flowed downvalley to form the material on the margins of the debris-avalanche deposit. Slide block I unroofed the magma chamber (cryptodome) that had been growing inside the mountain for 6 weeks. The explosions that resulted from depressurization of the cryptodome burst through slide block II and created a pyroclastic density current (the "blast") that devastated 212 mi^2 (550 km^2) of the surrounding landscape.

Most of the volume of slide block II, as well as all of slide block III, made a 90° turn to the west at Harrys Ridge and Johnston Ridge and became a flowing-debris avalanche. Slide block II contained fragments of ancestral dacite from the core of the volcano; slide block III contained fragments of ancestral dacite and "blast" dacite of the cryptodome.

The debris avalanche moved in part as a flow of blocks that traveled 10 mi (16 km). Much of slide block III moved as an explosively motivated flow that traveled over the debris-avalanche blocks of slide block II and moved 17.6 mi (28 km) from the crater. The avalanche reached its present length in 3 to 10 minutes.

Water contained within and under the avalanche and from melted ice was squeezed up through the debris and coalesced into a lahar that moved down the valley of the North Fork Toutle River.

The debris-avalanche deposit is characterized by extremely irregular topography. Hummocks of many shapes and sizes are interspersed with irregular and circular depressions, creating a surface with as much as 246 ft (75 m) of relief. Surface expression on the debris-avalanche deposits results from (1) lateral spreading during primary deposition; (2) differential compaction of the deposit after deposition; (3) phreatic explosions resulting from hot debris coming in contact with water (ice melt or preexisting streams); (4) postlahar bank failures; and (5) melting of buried ice.

One of the most striking features of the post-1980 geomorphology of the North Fork Toutle River debris-avalanche deposit is the development of major stream channels. Here, near the Coldwater Creek blockage area, the channels are those of Coldwater Creek and the upper North Fork Toutle River (figs. 38, 39).

Coldwater Creek, downstream from Coldwater Lake, formed during the controlled release of Coldwater Lake July 1981. In May 1985, outflow from Spirit Lake was diverted into the South Fork Coldwater Creek through a tunnel under Harrys Ridge. In response to the additional flow, the channel widened 65 ft (20 m) and incised about 13 ft (4 m).

The upper North Fork Toutle River developed along a 2–mi (3 km)-long, aligned group of closed depressions. Individual depressions had 20 to 100 ft (6–30 m) of local relief. Some lahars formed in this area on May 18, 1980, but the throughflowing channel was created by the November 7, 1980, breaching of Carbonate Lake, a temporary lake on the debris avalanche. Subsequent channel modification has resulted from (1) breakout of small lakes on the surface of the debris-avalanche deposit; (2) storm flow; (3) lahars, primarily those of March 19, 1982, and May 14, 1984; and (4) pumping from Spirit Lake during 1982–84.

Across the outlet channel to the south are hummocks that consist of semicoherent blocks of volcanic rock (fig. 39). The closer ones, within the deposits of slide block I, are chiefly composed of andesite and basalt. Beyond the sharp escarpment, which marks a marginal avalanche levee, are deposits mainly of block II, composed of dacite from ancestral domes within the volcano. The marginal levees can be found throughout the middle part of the debris-avalanche deposit; they formed along valley walls or across the mouths of tributary valleys, as the debris-avalanche flowed downvalley. Coldwater, Castle, and Jackson Lakes and numerous unnamed ponds were impounded by this facies of the debris-avalanche deposit (Voight and others, 1981). To the south, east of Castle Lake, the surface of the debris-avalanche deposit is mantled with blast deposit, creating a relatively flat surface (fig. 38). Along the north margin of the flat, landslide scarps mark the left bank of the North Fork Toutle River. This bank is highly unstable because of a high water table and ground-water outflow. Brown "bathtub rings" from the May 18, 1980, lahar are present throughout most low-lying areas of the Coldwater Creek blockage. The lahar was formed on the surface of the debris-avalanche deposit by slumping and flowing of water-saturated debris, and by dewatering of the deposit through numerous springs (Meyer, 1986a).

END OF LEG II

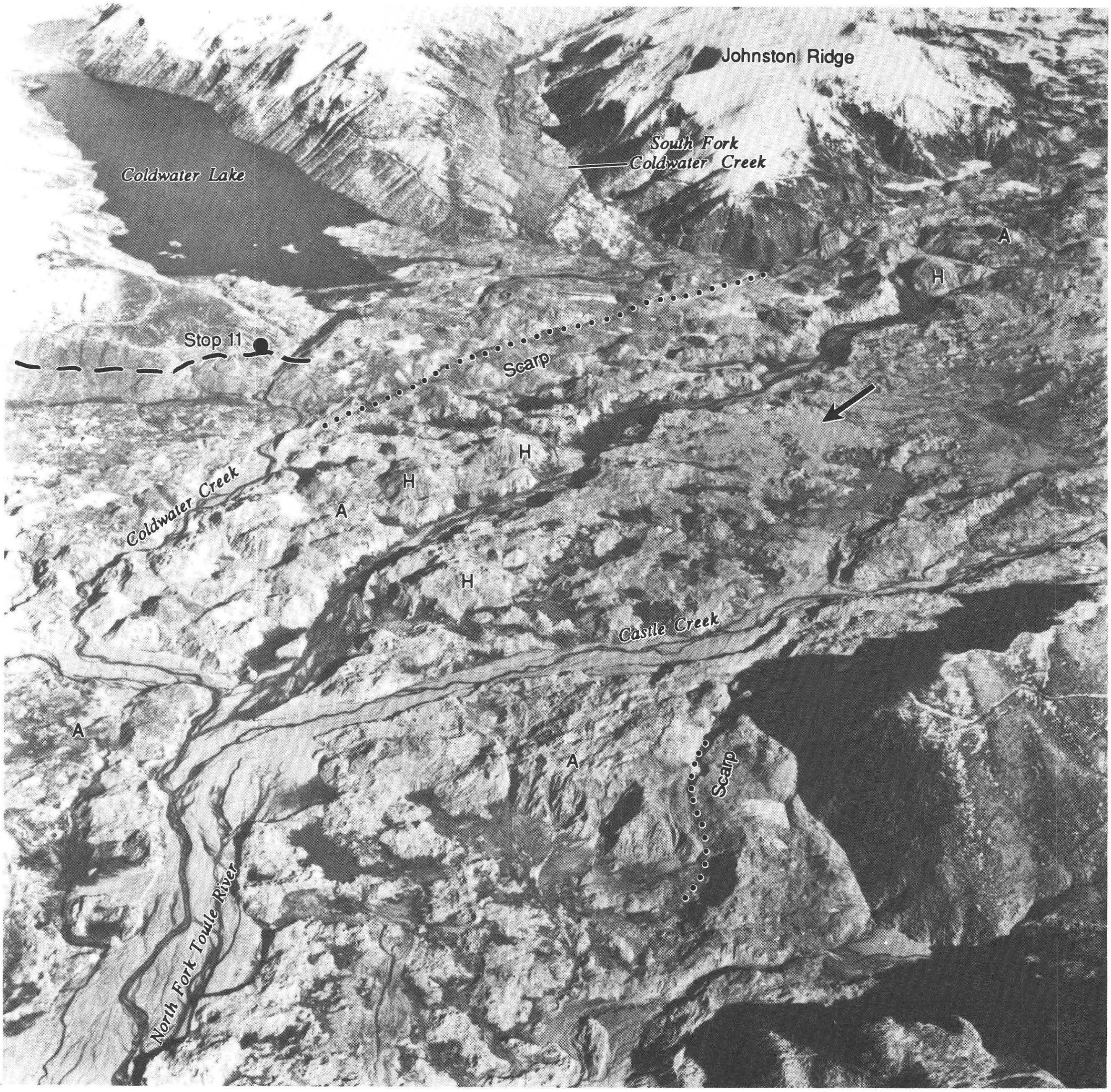


Figure 39. Coldwater Creek-Castle Creek area, showing rockslide/debris avalanche (A) near Coldwater Lake. Manmade outlet channel cuts diagonally across bedrock spur south of stop 11, draining Coldwater Lake into Coldwater Creek. Scarps (dotted lines) designate avalanche levees; arrow indicates direction of debris flow. Dashed line, field-trip route. H, hummocks. View northeastward.

REFERENCES CITED

Armstrong, J.E., Crandell, D.R., Easterbrook, D.J., and Noble, J.B., 1965, Late Pleistocene stratigraphy and chronology in southwestern British Columbia and northwestern Washington: Geological Society of America Bulletin, v. 76, no. 3, p. 321–330.

Brugman, M.M., and Meier, M.F., 1981, Response of glaciers to the eruptions of Mount St. Helens, *in* Lipman, P.W., and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 743–754.

Cashman, K.V., and Taggart, J.E., 1983, Petrologic monitoring of 1981 and 1982 eruptive products from Mount St. Helens: Science, v. 221, no. 4618, p. 1385–1387.

Crandell, D.R., 1988, Deposits of pre-1980 pyroclastic flows and lahars from Mount St. Helens Volcano, Washington: U.S. Geological Survey Professional Paper 1444, 91 p.

Crandell, D.R., and Mullineaux, D.R., 1973, Pine Creek volcanic assemblage at Mount St. Helens, Washington: U.S. Geological Survey Bulletin 1383–A, p. A1–A23.

——— 1978, Potential hazards from future eruptions of Mount St. Helens Volcano, Washington: U.S. Geological Survey Bulletin 1383–C, p. C1–C26.

Crandell, D.R., Mullineaux, D.R., and Rubin, Meyer, 1975, Mount St. Helens Volcano: Recent and future behavior: Science, v. 187, no. 4175, p. 438–441.

Crandell, D.R., Mullineaux, D.R., Rubin, Meyer, Spiker, Elliot, and Kelley, M.L., 1981, Radiocarbon dates from volcanic deposits at Mount St. Helens, Washington: U.S. Geological Survey Open-File Report 81–844, 15 p.

Cummans, John, 1981a, Mudflows resulting from the May 18, 1980, eruption of Mount St. Helens, Washington: U.S. Geological Survey Circular 850–B, p. B1–B16.

——— 1981b, Chronology of mudflows in the South Fork and North Fork Toutle River following the May 18 eruption, *in* Lipman, P.W., and Mullineaux, D.R., eds., The 1980 Eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 479-486.

Doukas, M.P., and Swanson, D.A., 1987, Mount St. Helens, with emphasis on 1980–85 eruptive activity as viewed from Windy Ridge, *in* Hill, M.L., ed., Decade of North American Geology Project centennial field guide 1: Boulder, Colo., Geological Society of America, Cordilleran Section, p. 333–338.

Fiske, R.S., Hopson, C.A., and Waters, A.C., 1963, Geology of Mount Rainier National Park, Washington: U.S. Geological Survey Professional Paper 444, 93 p.

Foxworthy, B.L., and Hill, Mary, 1982, Volcanic eruptions of 1980 at Mount St. Helens—the first 100 days: U.S. Geological Survey Professional Paper 1249, 125 p.

Glicken, Harry, 1986, Rockslide-debris avalanche of May 18, 1980, Mount St. Helens Volcano: Santa Barbara, University of California, Ph.D. thesis, 303 p.

Greeley, Ronald, and Hyde, J.H., 1972, Lava tubes of the Cave Basalt, Mount St. Helens, Washington: Geological Society of America Bulletin, v. 83, no. 8, p. 2397–2418.

Hammond, P.E., 1980, Reconnaissance geologic map of the southern Washington Cascade Range: Portland, Oreg., Portland State University, Department of Earth Sciences, scale: 1:125,000.

Hildreth, Wes, and Fierstein, Judy, 1983, Mount Adams and its 30 "parasites" [abs.]: Geological Society of America Abstracts with Programs, v. 15, no. 5, p. 331.

Hoblitt, R.P., Crandell, D.R., and Mullineaux, D.R., 1980, Mount St. Helens eruptive behavior during the past 1,500 yr: Geology, v. 8, no. 11, p. 555–559.

Hoblitt, R.P. and Kellogg, K.S., 1979, Emplacement temperatures of unsorted and unstratified deposits of volcanic rock debris as determined by paleomagnetic techniques: Geological Society of America Bulletin, v. 90, pt. 1, no. 7, p. 633–642.

Hopson, C.A., 1971, Eruptive sequence at Mount St. Helens, Washington: Geological Society of America Abstracts with Programs, v. 3, p. 138.

——— 1983, Stratigraphy of Mount St. Helens 1980 crater walls [abs.]: Eos (American Geophysical Union Transactions), v. 65, no. 45, p. 1144.

Hyde, J.H., 1975, Upper Pleistocene pyroclastic-flow deposits and lahars from Mount St. Helens, Washington: U.S. Geological Survey Bulletin 1383–B, p. B1–B20.

Hyde, J.H., Greeley, R., 1973, Geological field trip guide, Mount St. Helens lava tubes, Washington, *in* Beaulieu, J.D., compiler, 1973, Geologic field trips in northern Oregon and southern Washington: Oregon Department of Geology and Mineral Industries Bulletin 77, p. 183–206.

Janda, R.J., Scott, K.M., Nolan, K.M., and Martinson, H.A., 1981, Lahar movement, effects, and deposits, *in* Lipman, P.W., and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 461–478.

Kuntz, M.A, Rowley, P.D., Macleod, N.S., Reynolds, R.L., Mcbroome, L.A., Kaplan, A.M., and Lidke, D.J., 1981, Petrography and particle-size distribution of pyroclastic-flow, ash-cloud, and surge deposits, *in* Lipman, P.W., and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 525-539.

Lipman, P.W., and Mullineaux, D.R., eds., 1981, The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, 844 p.

Lombard, R.E., Miles, M.B., Nelson, L.M., Kresch, D.L., and Carpenter, P.J., 1981, Channel conditions in the lower Toutle and Cowlitz Rivers resulting from the mudflows of May 18, 1980: U.S. Geological Survey Circular 850–C, p. C1–C16.

Lowry, W.D., and Baldwin, E.M., 1946, Late Cenozoic geology of the lower Columbia River Valley, Oregon and Washington: Geological Society of America Bulletin, v. 63, no. 1, p. 1–24.

Meyer, D.F., 1986a, Channel formation and modification under various water and sediment discharges, South Fork Coldwater Creek, Washington, *in* Iverson, R.M., and Martinson, H.A., eds., Mount St. Helens; American Geomorphological Field Group, Field Trip Guidebook and Abstracts, 178 p.

——— 1986b, Surficial processes and deposits at the Coldwater Drainage, *in* Iverson, R.M. and Martinson, H.A., eds., Mount St. Helens: American Geomorphological Field

Group field trip guidebook and abstracts, 178 p.
Moore, J.G., and Sisson, T.W., 1981, deposits and effects of the May 18 pyroclastic surge, *in* Lipman, P.W. and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 421–438.
Mullineaux, D.R., 1986, Summary of pre-1980 tephra-fall deposits erupted from Mount St. Helens, Washington State, USA: Bulletin Volcanologique, v. 48, no. 1, p. 17–26.
Mullineaux, D.R., and Crandell, D.R., 1962, Recent lahars from Mount St. Helens, Washington: Geological Society of America Bulletin, v. 73, no. 7, p. 855–869.
——— 1981, The eruptive history of Mount St. Helens, Washington, *in* Lipman, P.W., and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 3–15.
Mullineaux, D.R., Hyde, J.H., and Rubin, Meyer, 1975, Widespread late-glacial and post-glacial tephra deposits from Mount St. Helens volcano, Washington: U.S. Geological Survey Journal of Research, v. 3, no. 3, p. 329–335.
Mundorff, M.J., 1964, Geology and ground-water conditions of Clark County, Washington, with a description of a major alluvial aquifer along the Columbia River: U.S. Geological Survey Water-Supply Paper 1600, 268 p.
——— 1984, Glaciation in the lower Lewis River basin, southwestern Cascade Range, Washington: Northwest Science, v. 58, no. 4, p. 269–281.
Newhall, C.G., 1982, A prehistoric debris avalanche from Mount St. Helens [abs.]: Eos (American Geophysical Union Transactions), v. 63, no. 45, p. 1141.
Roberts, A.E., 1958, Geology and coal resources of the Toledo-Castle Rock district, Cowlitz and Lewis Counties, Washington: U.S. Geological Survey Bulletin 1062, 71 p.
Rosenbaum, J.G., and Waitt, R.B., Jr., 1981, Summary of eyewitness accounts of the May 18 eruption, *in* Lipman, P.W., and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 53–67.
Rowley, P.D., Kuntz, M.A., and Macleod, N.S., 1981, Pyroclastic-flow deposits, *in* Lipman, P.W., and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 489–512.
Schuster, R.L., 1981, Effects of the eruptions on civil works and operations in the Pacific Northwest, *in* Lipman, P.W., and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 701–718.
Swanson, D.A., Casadevall, T.J., Dzurisin, Daniel, Malone, S.D., Newhall, C.G., and Weaver, C.S., 1983, Predicting eruptions at Mount St. Helens, June 1980 through December 1982: Science, v. 221, no. 4618, p. 1369–1376.
Swanson, D.A., Dzurisin, Daniel, Holcomb, R.T., Iwatsubo, E.Y., Chadwick, W.W., Jr., Casadevall, T.J., Ewert, J.W., and Heliker, C.C., in press, Growth of the lava dome at Mount St. Helens, Washington (USA), 1981–83, *in* Fink, Jonathan, ed., The growth of silicic domes: Geological Society of America Special Paper.
Voight, Barry, Glicken, Harry, Janda, R.J., and Douglass, P.M., 1981, Catastrophic rockslide avalanche of May 18, *in* Lipman, P.W., and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 347–377.
Voight, Barry, Janda, R.J., Glicken, Harry, and Douglass, P.M., 1983, Nature and mechanics of the Mount St Helens rockslide-avalanche of 18 May 1980: Geotechnique, v. 33, no. 3, p. 243-273.
Waitt, R.B., 1984, Deposits and effects of devastating lithic pyroclastic density current from Mount St. Helens on 18 May 1980—field guide for northeast radial: U.S. Geological Survey Open-File Report 84–839, 10 p.
Waitt, R.B., and Dzurisin, Daniel, 1981, Proximal air-fall deposits from May 18 eruption—stratigraphy and field sedimentology, *in* Lipman, P.W., and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 601–616.
Waitt, R.B., Pierson, T.C., MacLeod, N.S., Janda, R.J., Voight, Barry, and Holcomb, R.T., 1983, Eruption-triggered avalanche, flood, and lahar at Mount St. Helens—effects of winter snowpack: Science, v. 221, no. 4618, p. 1394–1397.
Walker, G.P.L., and McBroome, L.A., 1983, Mount St. Helens 1980 and Mount Pelée 1902—flow or surge?: Geology, v. 11, no. 10, p. 571–574.
Wilkinson, W.D., Lowry, W.D., and Baldwin, E.M., 1946, Geology of the St. Helens quadrangle, Oregon: Oregon Department of Geology and Mineral Industries Bulletin 31, 39 p.
Wood, S.H., Doukas, M.P., Shipley, S., Waitt, R.B., Vallance, J., Eggers, A., and Sarna-Wojcicki, A.M., in press, The July 22, 1980, eruption of Mount St. Helens: Characteristics of the eruption and airfall tephra, *in* U.S. Geological Survey Professional Paper 1251.
Yamaguchi, D.K., 1983, New tree-ring dates for recent eruptions of Mount St. Helens: Quaternary Research, v. 20, no. 2, p. 246–250.

SELECTED SERIES OF U.S. GEOLOGICAL SURVEY PUBLICATIONS

Periodicals

Earthquakes & Volcanoes (issued bimonthly).
Preliminary Determination of Epicenters (issued monthly).

Technical Books and Reports

Professional Papers are mainly comprehensive scientific reports of wide and lasting interest and importance to professional scientists and engineers. Included are reports on the results of resource studies and of topographic, hydrologic, and geologic investigations. They also include collections of related papers addressing different aspects of a single scientific topic.

Bulletins contain significant data and interpretations that are of lasting scientific interest but are generally more limited in scope or geographic coverage than Professional Papers. They include the results of resource studies and of geologic and topographic investigations; as well as collections of short papers related to a specific topic.

Water-Supply Papers are comprehensive reports that present significant interpretive results of hydrologic investigations of wide interest to professional geologists, hydrologists, and engineers. The series covers investigations in all phases of hydrology, including hydrogeology, availability of water, quality of water, and use of water.

Circulars present administrative information or important scientific information of wide popular interest in a format designed for distribution at no cost to the public. Information is usually of short-term interest.

Water-Resources Investigations Reports are papers of an interpretive nature made available to the public outside the formal USGS publications series. Copies are reproduced on request unlike formal USGS publications, and they are also available for public inspection at depositories indicated in USGS catalogs.

Open-File Reports include unpublished manuscript reports, maps, and other material that are made available for public consultation at depositories. They are a nonpermanent form of publication that may be cited in other publications as sources of information.

Maps

Geologic Quadrangle Maps are multicolor geologic maps on topographic bases in 7 1/2- or 15-minute quadrangle formats (scales mainly 1:24,000 or 1:62,500) showing bedrock, surficial, or engineering geology. Maps generally include brief texts; some maps include structure and columnar sections only.

Geophysical Investigations Maps are on topographic or planimetric bases at various scales; they show results of surveys using geophysical techniques, such as gravity, magnetic, seismic, or radioactivity, which reflect subsurface structures that are of economic or geologic significance. Many maps include correlations with the geology.

Miscellaneous Investigations Series Maps are on planimetric or topographic bases of regular and irregular areas at various scales; they present a wide variety of format and subject matter. The series also includes 7 1/2-minute quadrangle photogeologic maps on planimetric bases which show geology as interpreted from aerial photographs. Series also includes maps of Mars and the Moon.

Coal Investigations Maps are geologic maps on topographic or planimetric bases at various scales showing bedrock or surficial geology, stratigraphy, and structural relations in certain coal-resource areas.

Oil and Gas Investigations Charts show stratigraphic information for certain oil and gas fields and other areas having petroleum potential.

Miscellaneous Field Studies Maps are multicolor or black-and-white maps on topographic or planimetric bases on quadrangle or irregular areas at various scales. Pre-1971 maps show bedrock geology in relation to specific mining or mineral-deposit problems; post-1971 maps are primarily black-and-white maps on various subjects such as environmental studies or wilderness mineral investigations.

Hydrologic Investigations Atlases are multicolored or black-and-white maps on topographic or planimetric bases presenting a wide range of geohydrologic data of both regular and irregular areas; principal scale is 1:24,000 and regional studies are at 1:250,000 scale or smaller.

Catalogs

Permanent catalogs, as well as some others, giving comprehensive listings of U.S. Geological Survey publications are available under the conditions indicated below from the U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225. (See latest Price and Availability List.)

"Publications of the Geological Survey, 1879-1961" may be purchased by mail and over the counter in paperback book form and as a set of microfiche.

"Publications of the Geological Survey, 1962-1970" may be purchased by mail and over the counter in paperback book form and as a set of microfiche.

"Publications of the U.S. Geological Survey, 1971-1981" may be purchased by mail and over the counter in paperback book form (two volumes, publications listing and index) and as a set of microfiche.

Supplements for 1982, 1983, 1984, 1985, 1986, and for subsequent years since the last permanent catalog may be purchased by mail and over the counter in paperback book form.

State catalogs, "List of U.S. Geological Survey Geologic and Water-Supply Reports and Maps For (State)," may be purchased by mail and over the counter in paperback booklet form only.

"Price and Availability List of U.S. Geological Survey Publications," issued annually, is available free of charge in paperback booklet form only.

Selected copies of a monthly catalog "New Publications of the U.S. Geological Survey" available free of charge by mail or may be obtained over the counter in paperback booklet form only. Those wishing a free subscription to the monthly catalog "New Publications of the U.S. Geological Survey" should write to the U.S. Geological Survey, 582 National Center, Reston, VA 22092.

Note.--Prices of Government publications listed in older catalogs, announcements, and publications may be incorrect. Therefore, the prices charged may differ from the prices in catalogs, announcements, and publications.