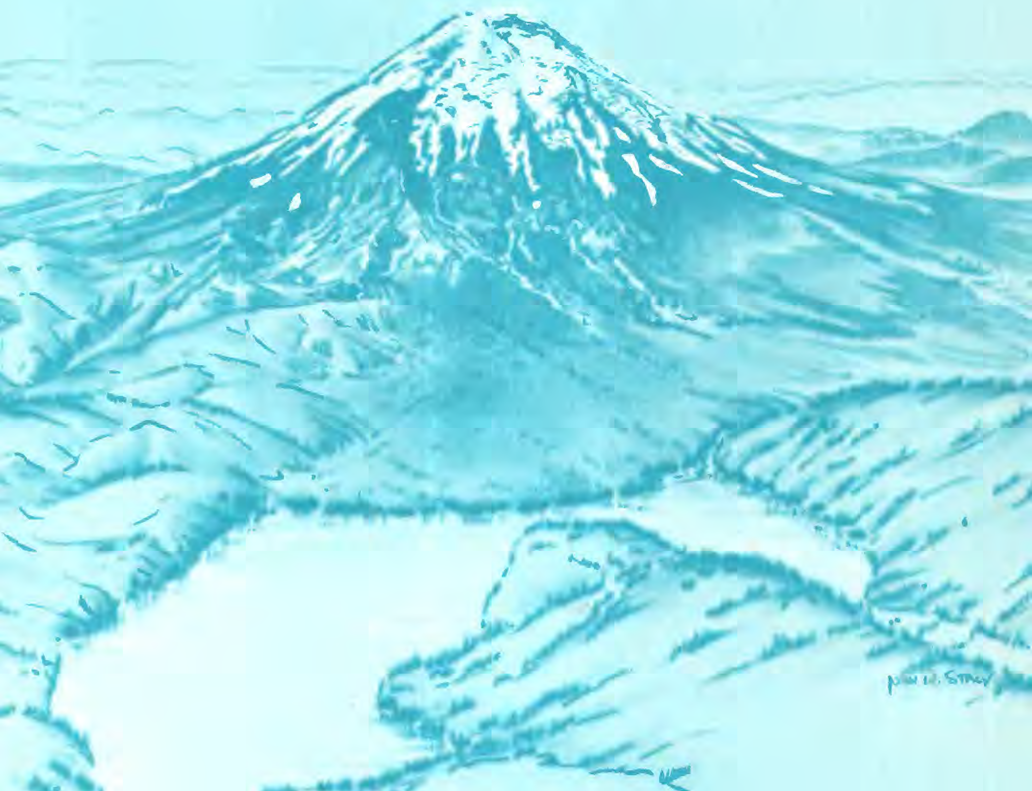
UPPER PLEISTOCENE PYROCLASTIC-FLOW DEPOSITS AND LAHARS SOUTH OF MOUNT ST. HELENS VOLCANO, WASHINGTON



GEOLOGICAL SURVEY BULLETIN 1383-B

Upper Pleistocene Pyroclastic-Flow Deposits and Lahars South of Mount St. Helens Volcano, Washington

By JACK H. HYDE

GEOLOGY OF MOUNT ST. HELENS VOLCANO, WASHINGTON

GEOLOGICAL SURVEY BULLETIN 1383-B

A study of a valley-fill assemblage of pyroclastic-flow deposits, lahars, and alluvium of late Pleistocene age south of Mount St. Helens volcano

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1975

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

Library of Congress Cataloging in Publication Data
Hyde, Jack H.
Upper Pleistocene pyroclastic-flow deposits and lahars south of Mount St. Helens volcano, Washington.
(Geology of Mount St. Helens volcano, Washington)
(Geological Survey Bulletin 1383-B)
Bibliography: p.
Supt. of Docs. no.: I 19.3:1383-B
1. Volcanic ash, tuff, etc.—Washington (State)—Saint Helens, Mount. 2. Lahars—Washington (State)—Saint Helens, Mount. 3. Geology Stratigraphic—Pleistocene. 4. Geology—Washington (State)—Saint Helens, Mount.
I. Title. II. Series. III. Series: United States Geological Survey Bulletin 1383-B.
QE75.B9 no. 1383-B [QE461] 557.3'08s [551.2'1] 75-619236

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington, D. C. 20402
Stock Number 024-001-02729-1

CONTENTS

ILLUSTRATIONS

TABLES

COMMON MEASURES AND THEIR METRIC EQUIVALENTS

Common Measure	Equivalent
Inch	2.54 centimetres (cm).
Foot	0.3048 metre (m).
Mile	1.6093 kilometres (km).

UPPER PLEISTOCENE PYROCLASTIC-FLOW DEPOSITS AND LAHARS SOUTH OF MOUNT ST. HELENS VOLCANO, WASHINGTON

By JACK H. HYDE

ABSTRACT

The Swift Creek volcanic assemblage consists chiefly of deposits of pyroclastic flows, lahars, and alluvium which are interbedded with tephra. These deposits and the glacial drift of late Pleistocene age associated with them provide the best available record of geologic events at Mount St. Helens during the period between about 36,000 to 12,000 years ago. The assemblage was formed during intermittent episodes of andesitic and dacitic volcanism and includes some of the oldest known volcanic deposits from Mount St. Helens. The Swift Creek assemblage forms a valley fill that extends 14 km down the Swift Creek valley and into the Lewis River valley, where it is as much as 200 m thick. Pyroclastic flows reached the mouth of Swift Creek and lahars extended at least 24 km farther. Glaciers which originated on the volcano during the Fraser Glaciation were apparently small and did not extend very far down valleys. The small size of glaciers, together with the nonvesicular andesitic and dacitic rock debris in the volcanic assemblage, suggests that the old Mount St. Helens eruptive center consisted mostly of low domes or a succession of domes rather than a large, high volcano. The large volume of rock debris transported into the Lewis River valley during eruptions caused the river to aggrade; downcutting occurred when the influx of material from the volcano decreased.

INTRODUCTION

Mount St. Helens is a volcano of late Quaternary age situated near the west margin of the Cascade Range in southwest Washington, 70 km northeast of Portland, Oreg. (fig. 1). The present cone consists of lava flows of olivine basalt and pyroxene andesite which surround a summit plug of dacite. Valley fills adjacent to the volcano include pyroclastic-flow deposits, lahars, and alluvium, which are locally interbedded with tephra and glacial drift. These deposits provide the best available record of geological history at an eruptive center which predated the present cone. This eruptive center, which is called old Mount St. Helens, was characterized by repeated eruptions of hornblende-hypersthene dacite and andesite (Verhoogen, 1937; Hopson, 1971).

The purpose of this report is to describe the stratigraphic sequence of pyroclastic-flow deposits, lahars, tephra, and alluvium in the Swift Creek

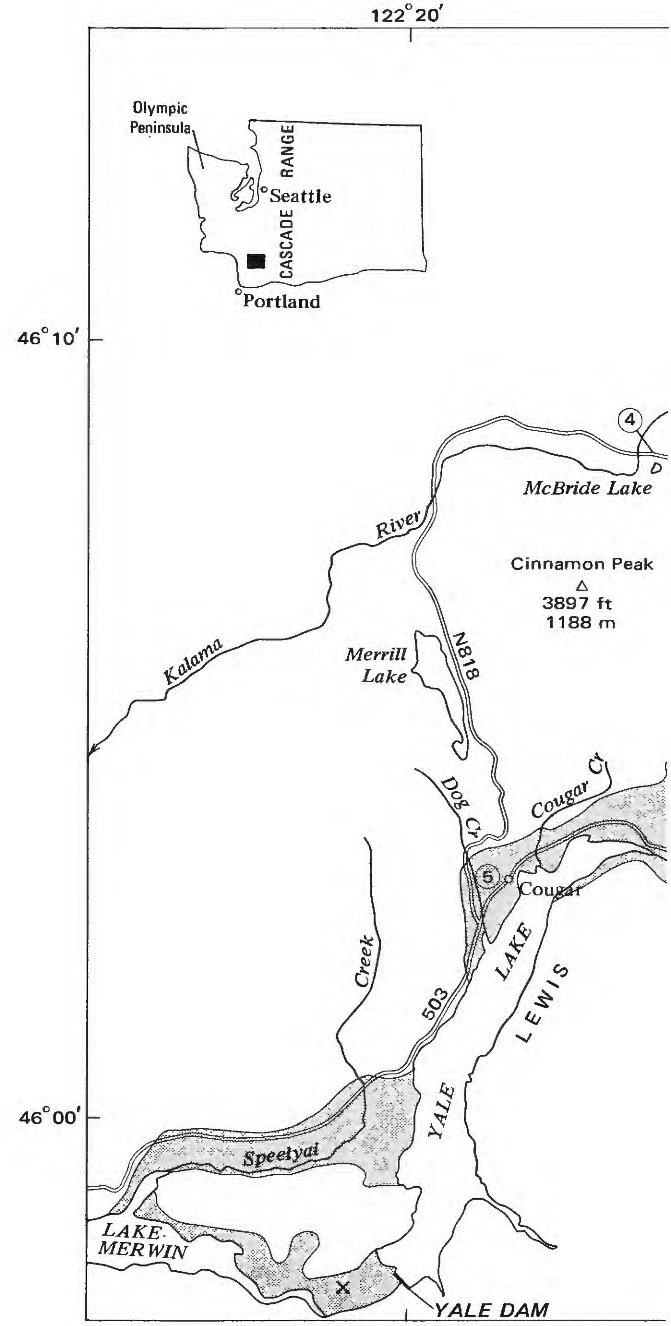
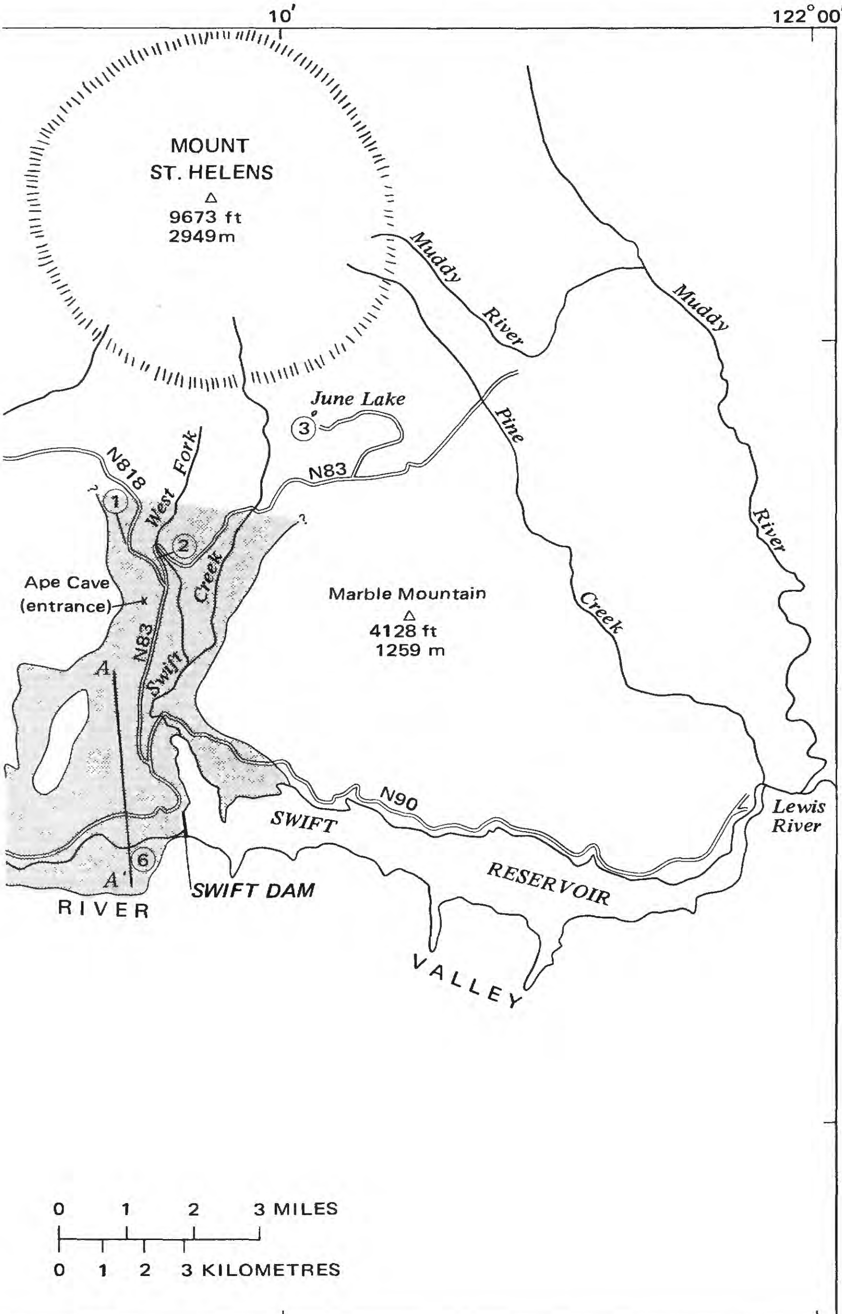


FIGURE 1.—Inferred original extent of Swift Creek assemblage deposits near the base of Mount St. Helens. Numbers in circles



(pattern) upvalley from Lake Merwin. The assemblage is covered by younger volcanic show localities mentioned in text. Line *A–A′* is location of profile shown in figure 4.

and Lewis River valleys south of Mount St. Helens and the relation of these materials to drift of the last major glaciation, to determine the eruptive and glacial history represented by the deposits, and to discuss the effect of these deposits on the Lewis River valley. The Swift Creek assemblage, which is the informal term used for the group of unconsolidated deposits in the Swift Creek and Lewis River valleys, provides the best known record of the eruptive history of old Mount St. Helens prior to about 12,000 years ago. Correlative deposits were formed in some other valleys heading at Mount St. Helens, but nowhere is there as extensive a record as in the Swift Creek and Lewis River valleys. The Pine Creek valley, southeast of the volcano, contains a similar depositional record of events between about 12,000 and 2,500 years ago (Crandell and Mullineaux, 1973), and deposits in the Kalama River valley southwest of the volcano provide details of eruptions within the last 2,500 years (Hyde, 1970).

Mount St. Helens is drained by the Kalama River on the southwest and by tributaries of the Lewis River on the south that include Swift Creek and Pine Creek (fig. 1). Swift Creek drains most of the south side of the volcano and joins the Lewis River about 8 km east of the community of Cougar. The Lewis River heads about 55 km east of Mount St. Helens and joins the Columbia River at Woodland, about 55 km southwest of the volcano. Downstream from the mouth of Pine Creek, the Lewis River is impounded by three dams for the purpose of hydroelectric-power generation; the resulting lakes are Swift Reservoir, Yale Lake, and Lake Merwin.

TERMINOLOGY

The term "tephra" refers to fragmental volcanic debris originating from a volcanic vent and transported through the air (Thorarinsson, 1954). Tephra may consist of (1) new magma represented by pumice or scoria, (2) dense glassy rock fragments, or (3) crystals, or may consist of a mixture of all three. Some tephra may also contain fragments derived from preexisting solid rock. In this report nonvesicular tephra is referred to by the adjective lithic. Most tephra at Mount St. Helens was erupted into the air and was deposited as a result of vertical or near-vertical fallout.

The term "ash-cloud deposit" is used in this report for material deposited from clouds of airborne ash associated with pyroclastic flows (Crandell and Mullineaux, 1973). These deposits consist mostly of lithic ash but pumice is not uncommon. The deposits range in thickness from a few centimetres to a metre and may decrease in grain size and thickness away from the vent and in directions away from the axis of the valley down which a pyroclastic flow traveled. Most such deposits form a single massive bed, but planar parallel bedding is common and "foreset" bedding was noted at a few localities. Ash-cloud deposits genetically related to pyroclastic flows resemble airfall tephra layers but may be distinguished from them by a more restricted areal distribution, by rapid lateral changes in thickness and grain size, and by an abundance of lithic fragments (Crandell and Mullineaux, 1973).

Many of the unconsolidated volcanic deposits in the Swift Creek assemblage resulted from the mass flowage of volcanic rock debris. Some deposits were formed by hot, dry pyroclastic flows and others by lahars, both of which are discussed below. The precise origin of some mass-flowage deposits cannot be determined, and these will be referred to as flowage deposits; this term is also used collectively for sequences which include deposits of both modes of origin.

A lahar is a rapid flow of rock debris mobilized by water and derived from a volcano (Bemmelen, 1949; Mullineaux and Crandell, 1962; Crandell, 1971). The term also is used to designate the resulting deposit. The rock debris may be either hot or cold.

Pyroclastic flows are hot, dry flows of volcanic rock debris. They owe their mobility to gravity as well as to the explosive force of the eruption, to gas-emitting particles, to air trapped and heated within the mass, or to some combination of these factors. The resulting deposits may consist of dense rock fragments, pumice fragments, or mixtures of both. Pyroclastic flows range from gas-rich, highly mobile flows of pumice to less mobile avalanches of lithic blocks and ash. Pumiceous pyroclastic flows generally originate from the rapid eruption of very large volumes of pumice; pyroclastic flows of predominantly lithic material commonly are caused by the sliding of accumulations of hot rock debris on the side of the volcano, or by the partial collapse of a volcanic dome or spine.

The deposits of pyroclastic flows generally can be differentiated, by evidence that they once were hot, from colluvium, landslide deposits, and alluvium. The presence of heat when a deposit was formed can be demonstrated if the constituent rock fragments possess a preferred orientation of a natural remanent magnetism (NRM), because the rock fragments must have come to rest while their ferromagnetic minerals were still above their Curie or blocking temperature (Aramaki and Akimoto, 1957; Chadwick, 1971: Crandell, 1971). A red to reddish-gray color in the upper few metres of a flowage deposit has also been used as evidence that the deposit was hot when emplaced and was therefore probably of pyroclastic-flow origin (Smith, 1960; Williams, 1960). The deposits of lahars generally show a rude vertical size gradation from coarse at the base to fine near the top (Mullineaux and Crandell, 1962; Crandell, 1971). Deposits formed by lahars which were carrying hot rock fragments may show some characteristics of both lahars and pyroclastic flows.

TEPHRA

The Swift Creek assemblage can be subdivided and correlated by means of three principal groups, or sets, of tephra deposits. The tephra forming these sets were erupted before, during, and after the assemblage was formed. Each set consists of several layers having the same suite of Fe-Mg phenocrysts; overlying and underlying tephra sets contain different heavy-mineral suites (Mullineaux and others, 1972; 1975).

The oldest tephra set, unnamed, is distinguished by the presence of biotite crystals which generally can be seen with a hand lens. In the area south and southwest of the volcano, the set includes a lower bed 15–30 cm thick and an upper pair of beds which typically are separated by a layer of silt a few centimetres thick; this pair of beds is referred to here as "the couplet." A radiocarbon date of 37,600±1,000 years has been obtained on a sample of charcoal (table 1) from the upper part of the lowest layer of the set east of Mount St. Helens (D. R. Mullineaux, unpub. data, 1973). Dates of about 20,000 and 18,500 years, that have been determined on samples from a locality south of the volcano, bracket the couplet (table 1).

TABLE 1.—*Selected radiocarbon dates of volcanic deposits derived from Mount St. Helens*
[All dates were determined by Meyer Rubin in the radiocarbon laboratory of the U.S. Geol. Survey]

Date (years before present)	Laboratory No.	Kind of sample and stratigraphic position
8,300±350	W-2587	Charcoal from within upper part of tephra set J.
11,800±300	W-2655	Wood from lahar below tephra set J.
11,880±350	W-2441	Charcoal from ash beneath tephra set J.
13,130±350	W-2983	Charcoal from pyroclastic flow below upper bed of tephra set S.
18,560±550	W-2413	Charcoal from pyroclastic-flow deposit beneath tephra set S.
20,350±500	W-2540	Charcoal from pyroclastic flow below upper bed of tephra set S.
36,000±2,000	W-2653	Wood from lahar.
37,600±1,000	W-2661	Charcoal from upper part of lowest layer of the unnamed tephra set.

Tephra set S includes several beds of pumice which contain abundant cummingtonite and hornblende. The age of the set is not yet precisely known. It is younger than 18,500 years, and a radiocarbon date of about 13,100 years has been obtained on charcoal taken from a pyroclastic-flow deposit that underlies one or more of the upper beds of the set. Other radiocarbon dates indicate that the entire set is more than 12,000 years old. Set S is the oldest tephra found on top of glacial drift formed during the last major glaciation of the area, and has been found interbedded with pyroclastic-flow deposits and lahars which postdate that glaciation.

Tephra set J consists of several beds of coarse pumice in which the only Fe-Mg phenocrysts are hornblende and hypersthene. A brown oxidized zone is commonly present in the upper part of the tephra. The age of the set is between 12,000 and 8,000 years.

GLACIER EXTENTS DURING SWIFT CREEK TIME

Much of the Swift Creek assemblage accumulated during the last major glacial episode (Fraser Glaciation) in western Washington which occurred between about 25,000 and 10,000 years ago (Armstrong and others, 1965), and glacial drift is interbedded with deposits of volcanic origin in some areas.

A glacier originating on the south flank of the old Mount St. Helens volcano moved down the valley of Swift Creek. The cirque in which this glacier originated is apparently carved into the rocks of old Mount St. Helens (C. A. Hopson, oral commun., 1972) and is now mostly obscured by young lava flows and flowage deposits, but part of its headwall is still visible at an altitude of 1,200–1,500 m, about 4 km directly south of the summit of the volcano. End moraines formed by this glacier are crossed by U.S. Forest Service road N818 about 0.5 km north of its junction with road N83 (loc. 1, fig. 1). There, about 8 m of drift is exposed beneath 2–3 m of tephra and pyroclastic-flow deposits (fig. 2). These moraines evidently do not mark the greatest downvalley extent of the glacier, because till having weathering features similar to those of the moraines is exposed about 1.5 km farther south, near the entrance to Ape Cave. Till is also exposed in the west valley wall of Swift Creek at locality 2 (fig. 1), where it seems to be part of an end moraine that was subsequently buried by several flowage deposits. The oldest flowage deposit is coarse and displays crude internal stratification, and may be either alluvium or a mudflow of glacial origin. Above it is a succession of pyroclastic-flow deposits (p. B15).

Glacial drift and moraines in the upper part of the Swift Creek valley were formed by a glacier originating on the southeast flank of Mount St. Helens in the area north of June Lake. Faceted spurs and lateral moraines containing over 60 percent andesite and dacite fragments are present on both sides of a valley south of June Lake, but farther south, near the base of Marble Mountain, the drift is covered with young flowage deposits. Glacial drift is not exposed in deep cuts farther downstream, and the glacier probably terminated near the base of Marble Mountain.

The glacial drift that is interbedded with the Swift Creek assemblage at Mount St. Helens probably was deposited during the Evans Creek Stade of the Fraser Glaciation. This correlation is based on a comparison of such relative weathering features as depth of oxidation and thickness of weathered rinds on stones in glacial drift in this area with those described in other areas of western Washington (Crandell, 1969, p. 18). The Evans Creek Stade was originally thought to have occurred between about 25,000 and 15,000 years ago (Armstrong and others, 1965). Subsequent work has suggested that alpine glaciers in southwestern British Columbia began to advance after 20,000 years ago (Halstead, 1968), and alpine glaciers on the west side of the Olympic Peninsula evidently reached their maximum extents before about 18,800 years ago (Heusser, 1974).

Glaciers of Fraser age also developed in cirques at altitudes above 1,100 m in the mountains adjacent to Mount St. Helens, but most were less than 10 km in length. Small glaciers existed along the ridge at the head of Cougar Creek northeast of Cinnamon Peak, where till and end moraines are present in several cirques. Small glaciers also extended down the north and west sides of Cinnamon Peak and terminated in the Kalama River valley about 2 km north of Merrill Lake.

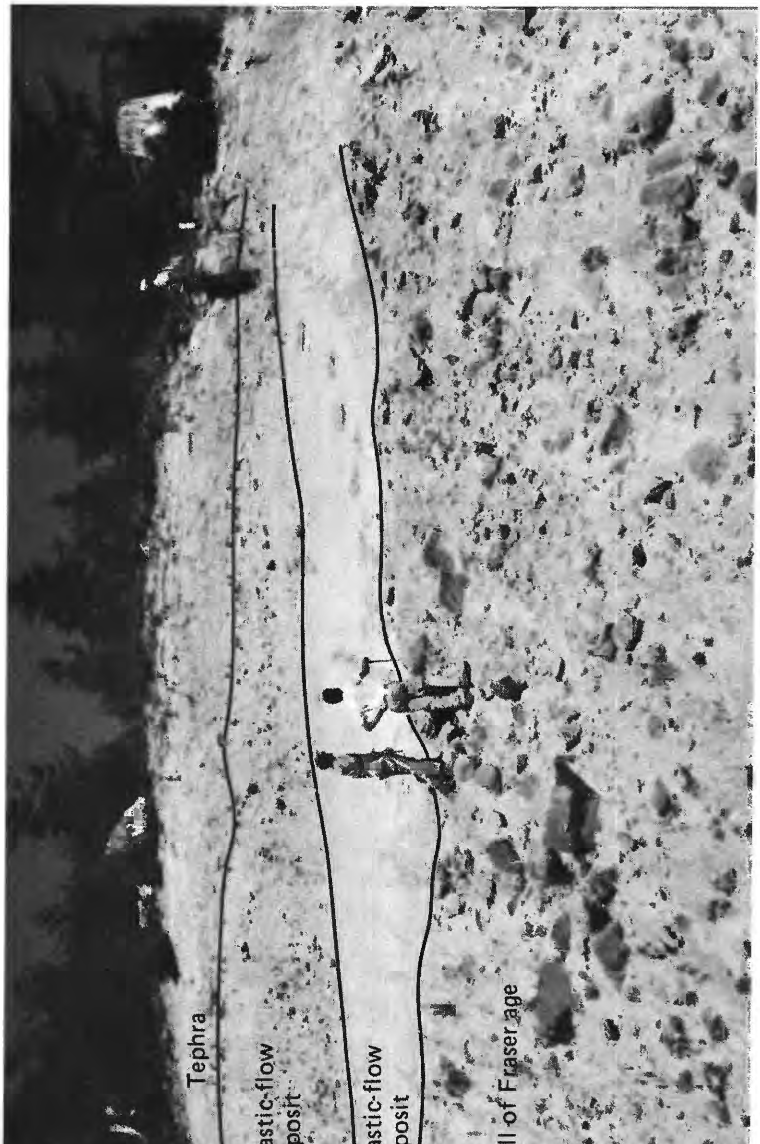


FIGURE 2.—Till of Fraser age veneered with pyroclastic-flow deposits and tephra. Roadcut exposure at locality 1 (fig. 1).

Exposures of glacial drift in the vicinity of Mount St. Helens and in the Lewis River valley west of the volcano show that the area was glaciated at least three times prior to the Fraser Glaciation and prior to the formation of the Swift Creek assemblage. These earlier alpine glaciers extended at least 50 km farther down the Lewis River valley than did the glacier of Fraser age. During these earlier glaciations all the area at, and adjacent to, the present site of Mount St. Helens, except perhaps the highest peaks, may have been covered by glaciers.

DESCRIPTION OF THE SWIFT CREEK ASSEMBLAGE

The Swift Creek volcanic assemblage was formed prior to the eruption of tephra set J, and includes some of the earliest products of the old Mount St. Helens eruptive center. The assemblage consists of a succession of pyroclastic-flow deposits, lahars, and alluvium, and is divided into two parts; one part is older than glacial drift of Fraser age, and the other is younger.

OLDER PART OF THE SWIFT CREEK ASSEMBLAGE

Before and during the early part of the Fraser Glaciation, a broad fan of pyroclastic-flow deposits and lahars resulting from volcanism at the old Mount St. Helens eruptive center spread southward and southwestward and formed fills in preexisting valleys that drained the south side of the volcano. These deposits have been covered with younger volcanic deposits and glacial drift in the area between the base of the volcano and the Lewis River valley. They can be seen, however, in a streamcut near June Lake (loc. 3, fig. 1), beneath till of Fraser age. There, the volcanic deposits include three lahars from 0.3 to more than 2 m thick, the upper two of which are separated by sand and fine gravel. A reddish-gray oxidized zone in the upper two lahars suggests that they were hot when they were deposited.

The older part of the Swift Creek assemblage is also exposed in a roadcut near McBride Lake (loc. 4, fig. 1). There, till of Fraser age is underlain by a pumiceous pyroclastic-flow deposit 0.7 m thick which is separated by a thin bed of sand from a lithic pyroclastic-flow deposit as much as 3 m thick. Lenticular sand and gravel as much as 2.7 m thick underlie this deposit, and the basal unit of the exposed sequence is a flowage deposit more than 8 m thick. The flowage deposit is unsorted and unstratified, and consists of angular fragments of andesite and dacite in a compact silty sand matrix. Rock fragments in the flowage deposit have random directions of NRM.

The fill deposits in the old Swift Creek valley extend southward and form high terraces on both sides of the Lewis River valley near Swift Dam (figs. 1, 3). The deposits originally must have formed a fan in the Lewis River valley, whose surface extended not only southward across the valley as well as downstream, but also sloped eastward, upstream. On the north

FIGURE 3.—Aerial view eastward up the Lewis River valley. The long southward-sloping surface left and above Swift Dam is formed by the top of the Swift Creek assemblage.

side of the valley, the top of the fill is at an altitude of about 370 m, and on the south side of the valley, 1.5 km downstream from the dam, its top is about 70 m lower because of a 55 m/km southward slope of the fill surface (fig. 4). The deposits just east of the mouth of Swift Creek slope eastward. The Lewis River was temporarily ponded by this fan, but a fill terrace upstream from the fan and graded to it has not been found.

The nature of the valley-fill deposits near Swift Dam is illustrated by streambed outcrops, roadcuts, and borrow-pit exposures. The lowest deposit exposed is a lahar which crops out in the bed of the Lewis River between Swift Dam and the upstream end of Yale Lake; it contains wood fragments which have a radiocarbon age of about 36,000 years (table 1).

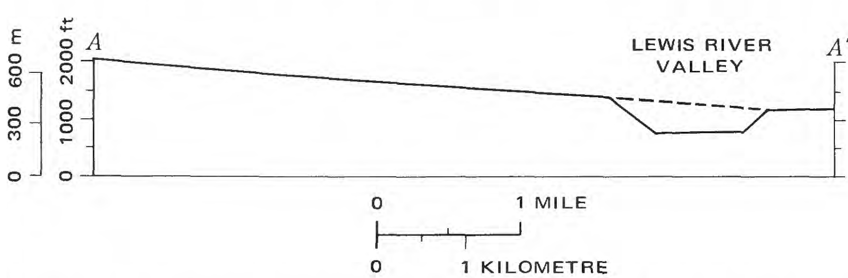


FIGURE 4.—Profile showing the relationship between the surface of the Swift Creek assemblage and the Lewis River valley. Vertical exaggeration about ×2.

The deposit is partly oxidized and slightly cemented by secondary iron oxides. The lahar contains fragments of nonvesicular andesite and dacite as large as 25 cm in diameter as well as fragments of pumice which has a biotite-cummingtonite-hornblende heavy-mineral suite. Wood fragments are abundant, and some are as large as 30 cm in diameter. The wood is not carbonized, and the deposit shows no evidence of having been hot when it was emplaced. The base of the lahar is not exposed, and it may be considerably below the streambed. Holes drilled beneath the valley floor near the centerline of Swift Dam encountered angular rock fragments, pumice, and wood down to an altitude of about 141 m, which is about 49 m below the present river level (Chief Engineer, Pacific Power and Light Co., unpub. data, 1967). It is not known whether the drill holes penetrated a single lahar nearly 50 m thick or a series of thinner but texturally similar lahars. However, the presence of these deposits beneath the flood plain suggests that when Mount St. Helens first came into existence the Lewis River was flowing on a profile at least 50 m lower than at present. The drill holes show the base of the valley fill to be at an altitude of about 126 m (fig. 5).

Other parts of the valley fill crop out in roadcuts and in borrow pits (fig. 5). On the north side of the Lewis River valley, the lowest deposit exposed is a crudely bedded boulder gravel more than 23 m thick whose base is concealed. The boulders are as large as 2 m in diameter and are chiefly dacite and andesite derived from old Mount St. Helens. They are subangular and subround and are enclosed in a silty sand matrix. This deposit probably is chiefly of fluvial origin, but parts of it may have been formed by lahars. Overlying the gravel is a series of pyroclastic-flow deposits and lahars. The lowest unit of this series is an unstratified and unsorted coarse flowage deposit of dacite and andesite fragments 10–20 cm in diameter in a compact matrix of silty sand. The deposit is 20 m thick. Inconclusive results were obtained from remanent-magnetism determinations on rock fragments from this deposit, and it is not known whether it was formed by a pyroclastic flow or by a lahar. It is overlain by a pyroclastic-flow deposit which consists almost entirely of blocks of gray pumice as large as 2 m in diameter and which is 23 m thick. Deposits of fluvial sand and gravel, lahars, and another pyroclastic flow, having a combined thickness of about 13 m, form the upper part of the fill on the north side of the valley.

The coarse flowage deposit of unknown origin and the overlying pyroclastic-flow deposits and lahars are also exposed along a logging road and in a borrow pit (loc. 6, fig. 1; measured section, p. B13) on the south side of the Lewis River, 1.5 km west of Swift Dam. There, a pyroclastic-flow deposit of blocks of dark-gray pumice, which overlies the coarse flowage deposit, is 12 m thick and contains charcoal that has a radiocarbon age of 20,350±500 years (table 1; fig. 6). The pyroclastic-flow

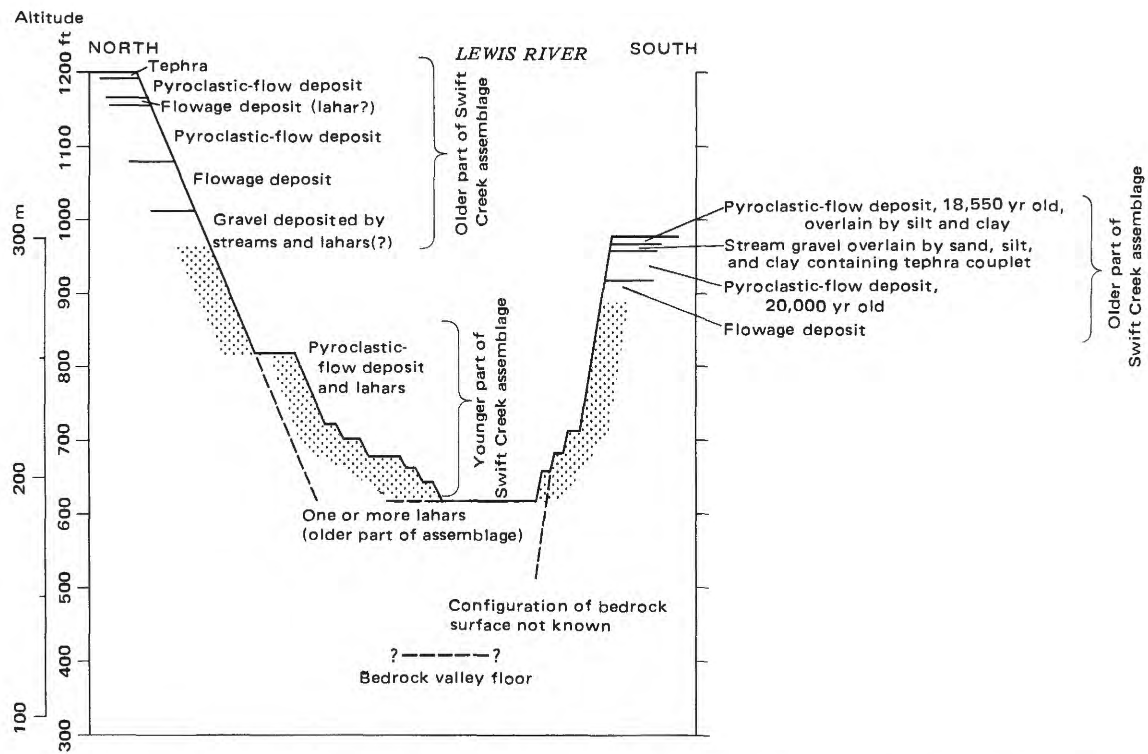


FIGURE 5.—Stratigraphic sequence of deposits exposed near the mouth of Swift Creek. Younger part of the Swift Creek assemblage lies below 248 m (820 ft) altitude. Areas of no exposure are shown by stipple pattern. Deposits on south side of valley are exposed in a borrow pit (loc. 6, fig. 1), Horizontal scale is diagrammatic.

deposit is overlain by fluvial sand and gravel 1–2 m thick which contains rock types derived from the drainage basin of either the upper Lewis River or Swift Creek, as well as rocks from old Mount St. Helens. On top of the gravel is a thick deposit of clayey silt and sand about 2 m thick, in the middle of which is the tephra couplet (p. B6). A second pyroclastic-flow deposit of light-gray pumice blocks, 2 m thick, overlies the fine sediments and contains charcoal which has a radiocarbon age of 18,560±550 years (table 1). The deposits of clayey silt and sand, which lie between the two pyroclastic-flow deposits, are unstratified and probably are of eolian origin. They may consist of sediment that was blown from the Lewis River flood plain, as well as of fine-grained tephra. The clayey silt and sand deposits both below and above the couplet seem to be weathered. However, in view of the time interval of less than 2,000 years during which they were formed, their clayey texture may be wholly original and probably does not represent weathering of individual mineral grains to clay.

Measured section

[Locality 6 (fig. 1), south side of Lewis River valley, borrow pit beside a private logging road near Rain Creek, SE¼ sec. 29, T. 7 N., R. 5 E. Color notations are those of the Munsell system (Munsell Color Co., 1954)]

	Thickness in metres
10. Sandy silt, brown (10*YR* 4/4); nonsticky and nonplastic to slightly sticky and slightly plastic, structureless	1
9. Proclastic-flow deposit, medium-gray; pumiceous silty sand matrix; rock fragments mostly gray pumice as large as 1 m; charcoal at base (radiocarbon sample W-2413: 18,560±550 yr); thickness variable, average	2
8. Tephra(?); layers of silt and sand, brown to gray, some sand-size white pumice..	.15
7. Clayey silt and sand, dark-brown (10*YR* 3/3), grades downward to brown (10*YR* 4/4) and yellowish-brown (10*YR* 5/6)	1
6. Tephra couplet; two layers of yellow pumice and lithic fragments 5 cm thick separated by 10 cm of silty sand	.2
5. Clayey silt and sand, mottled brown, reddish-brown, and gray; sticky, plastic..	1
4. Stratified sand and pebble-to-boulder gravel, light-yellowish-brown to gray; rock fragments of basalt, dacite, andesite, and Tertiary bedrock; some boulders as large as 1 m	1–2
3. Pyroclastic-flow deposit, medium- to dark-gray; pumiceous silty sand matrix; rock fragments mostly gray pumice as large as 1.3 m; abundant charcoal (radiocarbon sample W-2540: 20,350±500 yr)	12
2. Sand, gray; discontinuous; as much as	.06
1. Flowage deposit, gray; silty sand matrix, compact; rock fragments mostly dacite and andesite, angular, 10–20 cm in diameter; unstratified	>2

Remnants of the older part of the Swift Creek assemblage are preserved along the sides of the Lewis River valley near Cougar and in an abandoned segment of the valley which is now occupied by Speelyai Creek (fig. 1). The top of the fill at Cougar is at an altitude of about 230 m and is about 85 m above the valley floor now drowned by Yale Lake. Only the uppermost part of the fill deposits is exposed there. It consists of a

FIGURE 6.—Borrow-pit exposure of pyroclastic-flow deposits separated by fluvial sand and gravel and tephra in the older part of the Swift Creek assemblage at locality 6. Note shovel (center of photograph) for scale.

coarse fluvial gravel made up mostly of cobbles and boulders of dark-gray pumice. This pumice probably was derived from one of the two pyroclastic-flow deposits exposed on the south side of the Lewis River valley near Swift Dam (measured section, units 3 and 9, p. B13).

Only coarse fluvial gravel, interbedded with tephra, is exposed above lake level at the upvalley end of the Speelyai Creek fill. The tephra couplet occurs near the top of this sequence and is overlain by coarse gravel which locally fills a channel cut into the tephra couplet and into the underlying fluvial deposits. Both gravel deposits are made up of rocks derived from Mount St. Helens. Fragments of dark-gray pumice were not identified within these gravel deposits, but a few boulders of the pumice were noted in a beach gravel at the base of a cliff cut by waves into the deposits. At the downvalley end of the Speelyai Creek fill, the top of the fill is at an altitude of about 130 m, and it lies 90 m above the valley floor drowned by Yale Lake. The basal part of the fill exposed there consists of a lahar more than 10 m thick; it is overlain by another lahar whose thickness is 10 m. The upper 70 m of the fill deposits consists of interbedded fluvial gravel and lahars.

Remnants of the older part of the Swift Creek assemblage can also be found along the present channel of the Lewis River between Yale Dam and the head of Lake Merwin. The upper surface of the fill in that area is at an altitude of a little less than 135 m.

YOUNGER PART OF THE SWIFT CREEK ASSEMBLAGE

The formation of the older and younger parts of the Swift Creek assemblage was separated by a time interval of unknown duration, during which alpine glaciers advanced and then retreated in the higher parts of the area. Recession of the glaciers was followed by an additional interval which is represented by a weathered zone in the uppermost 24–30 cm of till. After this weathering interval, volcanism at the old Mount St. Helens eruptive center again caused pyroclastic flows and lahars to move down valleys cut into the older fill. Pyroclastic-flow deposits formed at that time are best exposed in roadcuts along the west wall of the Swift Creek valley at locality 2 (fig. 1). There, two pumiceous pyroclastic-flow deposits overlie a flowage deposit of unknown origin which rests directly on till of Fraser age. Rock fragments in the lowest pyroclastic-flow deposit consist of 73 percent pumice and 27 percent nonvesicular andesite and dacite, but 23 percent of the fragments in the overlying deposit are pumice. The pyroclastic flows that formed these deposits probably originated in eruptions of gas-rich magma. Tephra set S separates these two deposits form a third pyroclastic-flow deposit in which pumice is absent. The deposit contains angular, radially jointed rock fragments 10–20 cm in diameter and is only about 1 m thick. In an old borrow pit on the ridge above the locality 2 road exposures, this same deposit is 7 m thick and contains blocks as large as 2 m in diameter. Rock fragments in the third pyroclastic-flow deposit have a preferred orientation of NRM. The abundance of nonvesicular rock fragments in this deposit suggests that the pyroclastic flow was caused by the disruption of part of a growing dome at the eruptive center.

Ash-cloud deposits, which were formed during the accumulation of the younger part of the Swift Creek assemblage, are interbedded with the tephra sequence on the west and south sides of the Swift Creek valley. West of Ape Cave they are as thick as 2 m at a height of 200 m above the valley floor. On the north side of Marble Mountain, they are 2 m thick about 100 m above the valley floor. The deposits typically are nonstratified fine- to coarse-grained lithic ash with scattered pumice fragments. The ash-cloud deposits probably formed from clouds of ash rising above hot pyroclastic flows moving down the Swift Creek valley.

The younger part of the Swift Creek assemblage in the Lewis River valley is represented by a few pyroclastic-flow deposits and by lahars and fluvial deposits derived from old Mount St. Helens. Remnants of two pyroclastic-flow deposits are exposed on the east valley wall near the mouth of Swift Creek. The lower deposit consists of an unsorted and unstratified silty sand containing rock fragments of dacite and andesite as large as 60 cm. Above it is a pyroclastic-flow deposit from which charcoal has yielded a radiocarbon date of 13,130±350 years (table 1). The two deposits are overlain by upper beds of tephra set S (D. R. Mullineaux, unpub. data, 1973) and rest upon units of the older part of the Swift Creek assemblage.

The best exposure of the younger part of the Swift Creek assemblage farther down the Lewis River valley is in a borrow pit at locality 5 (fig. 1), at the outskirts of the community of Cougar, where three lahars are exposed. The lowest lahar, which is more than 8 m thick, is separated from the other two by a lenticular deposit, less than a metre thick, of oxidized silt and stratified sand and gravel (fig. 7). The upper two lahars are each a little more than a metre thick. All the lahars consist chiefly of sand and granule gravel; the few pebbles and cobbles in them are andesite and dacite derived from old Mount St. Helens. The lowest lahar contains masses of stratified sand and gravel as large as 1×2m across that may have been transported in a frozen condition which prevented disaggregation during movement. A time interval during which the lowest lahar was exposed to subaerial weathering is suggested by oxidation in the silt which overlies it.

The top of the deposits at the pit near Cougar is at an altitude of about 200 m and is about 20 m lower than the top of the older part of the Swift Creek assemblage nearby.

Four lahars are exposed in the walls of the valley of Dog Creek, about 1 km west of Cougar but closer to the center of the valley than the borrow-pit exposure. The lahars are each 1 to 2 m thick and are texturally similar to those at the borrow pit. Fluvial sand and gravel derived from the Lewis

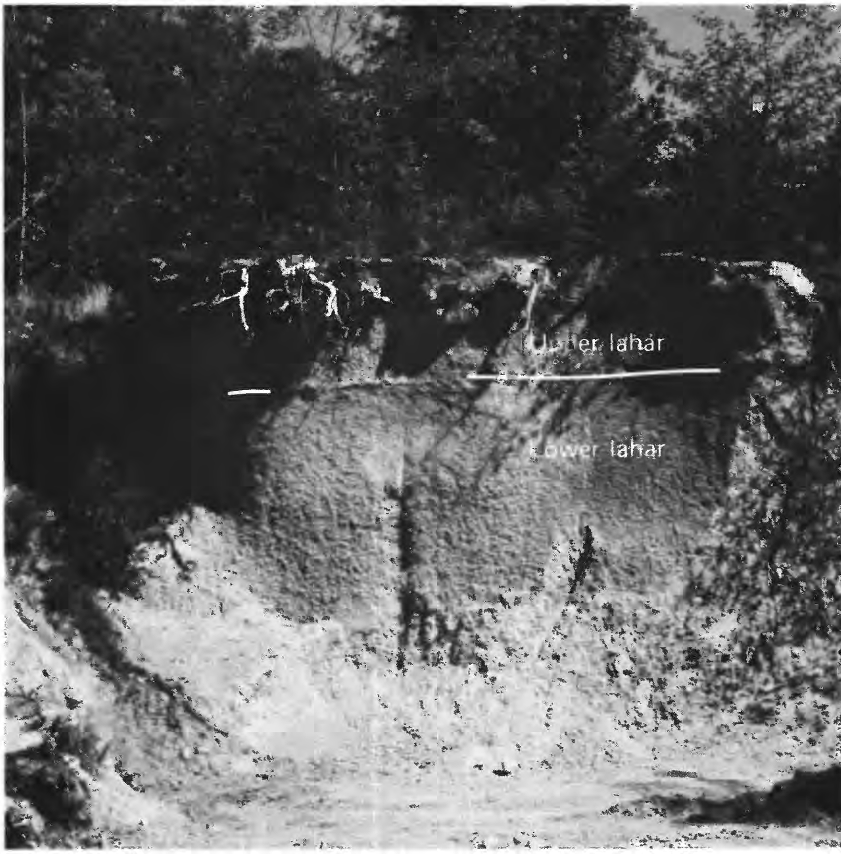


FIGURE 7.—Borrow-pit exposure at locality 5 of two lahars of the younger part of the Swift Creek assemblage. The lahars are separated by a lenticular deposit of oxidized silt, sand, and gravel. The lower lahar is about 3 m thick in this outcrop and shows a textural gradation toward the top.

River drainage basin is interbedded with lahars in the lower part of the outcrop, and locally derived gravel deposited by Dog Creek is interbedded with the lahars in the upper part of the outcrop.

Farther down the Lewis River valley, fine-grained lahars with a minimum total thickness of 15 m are exposed in cuts along State Highway 503, 3 km west of Yale Dam. A discontinuous layer of tephra, not more than 1 cm thick, is preserved between two of the lahars here, as well as between the lahars that crop out along a road near the mouth of Speelyai Creek. The heavy-mineral suite of this tephra is similar to that of tephra set S.

The younger part of the Swift Creek assemblage forms a flat west-sloping surface at an altitude of 120–135 m immediately west of Yale Dam. The surface is directly underlain by lahars which have a combined thickness of several metres. In gravel-pit exposures 1.3 km west of Yale

Dam, the lahars overlie a thick deposit of oxidized silt which caps the older part of the Swift Creek assemblage.

The Lewis River near Yale Dam probably first occupied its present course when a pre-Fraser alpine glacier blocked the former main valley, forced the river to the south, and eroded the new channel below the level of the former channel. The abandoned segment of the old valley, now occupied by Speelyai Creek, subsequently was aggraded by deposits formed by lahars and floods.

CHARACTER OF VOLCANIC ERUPTIONS

The stratigraphic succession and physical character of volcanic deposits in the Lewis River and Swift Creek valleys show that the old Mount St. Helens eruptive center was characterized by explosive dacitic and andesitic volcanism from its beginning until the time tephra set J was erupted (table 2). Other studies (Hyde, 1970; Hopson, 1971; Mullineaux and others, 1972; Crandell and Mullineaux, 1973) have shown that no significant change in eruptive patterns occurred after Swift Creek time, except for the intermittent eruption of more mafic lava flows and tephra during the last 2,500 years.

TABLE 2.—*Sequence of events at Mount St. Helens and in the adjacent region prior to 12,000 years ago, as indicated by deposits in the area south of the volcano*

Event	Approximate age, or limiting dates (years ago)	
Eruption of tephra set J	<12,000,	>8,000
Eruption of tephra set S and formation of hot pyroclastic flows and lahars (younger part of the Swift Creek assemblage)	<18,000(?),	>12,000
Advance and retreat of alpine glaciers	<20,000(?),	>18,000(?)
Eruption of tephra (unnamed set), formation of hot pyroclastic flows, lahars, and coarse fluvial deposits (older part of the Swift Creek assemblage)	<40,000(?),	18,000
Advance and retreat of alpine glaciers	<40,000(?)	

The lithic and pumiceous pyroclastic-flow deposits of the Swift Creek assemblage probably were caused by repeated intrusion of viscous magma at shallow depth. The pumiceous pyroclastic-flow deposits probably were formed by eruptions of volatile-rich magma. These eruptions alternated with those of volatile-poor magma which formed domes and spines whose disintegration and collapse resulted in hot pyroclastic flows of nonvesicular rock debris. The preferred orientation of NRM in rock fragments shows that many pyroclastic-flow deposits were emplaced above temperatures of at least 300° C, and perhaps more than 500° C, but below their welding temperature.

The distribution of volcanic deposits shows that an eruptive center was located in the approximate position of the modern cone throughout the time the Swift Creek assemblage accumulated, but little is known of its exact position, size, or shape. The distribution of cirques and glacial deposits suggests that the volcano was not large during Fraser time, and the nature of the volcanic rock debris derived from it suggests that the old center consisted of one or more low andesite and dacite domes. Crandell and Mullineaux (1973) have suggested a similar character for old Mount St. Helens between about 12,000 and 2,500 years ago.

EFFECT OF VOLCANISM ON THE LEWIS RIVER VALLEY

The main effect of volcanism on the Lewis River valley during Swift Creek time seems to have been the formation of a large fill of unconsolidated volcanic deposits which was continuously or intermittently trenched by the Lewis River. The volume and texture of material contributed to the Lewis River temporarily exceeded the ability of the river to transport all the rock debris downstream on the existing gradients, and thus the river was temporarily ponded. Periods of subsequent downcutting occurred when the influx of rock debris from the volcano decreased.

Before volcanism began at the old Mount St. Helens eruptive center the Lewis River was probably flowing on or close to bedrock near the mouth of Swift Creek and for a considerable distance downstream. Bedrock was encountered at a depth of 65 m below the valley floor at Swift Dam, and rock is exposed today at river level immediately downstream from Yale Dam and about 20 km farther downvalley, below Merwin Dam.

The character of volcanic eruptions suggests that most of the deposits in the Swift Creek assemblage accumulated in a very small fraction of the total time represented by the oldest and youngest units in the fill. Some deposits may represent events which occurred over a period of days or months, but many were formed as a result of a single volcanic event, such as a pyroclastic flow or lahar, whose total duration was perhaps only a matter of minutes. Thus, because of the short-lived nature of the events which resulted in the Swift Creek assemblage, it seems unlikely that deposits transported down Swift Creek into the Lewis River valley had more than a temporary effect on the profile of the river upstream. This conclusion is supported by the apparent absence of a fill which would have formed in the Lewis River valley upstream from the mouth of Swift Creek if the profile of the river had been more than temporarily changed. The Lewis River must have entrenched the fill at and downstream from Swift Creek in the intervals between volcanic events, and probably removed only a small part of the fill before it became reestablished on a gradient not unlike the one it had before the event.

The lahars and alluvium of the older part of the Swift Creek assemblage aggraded the abandoned segment of the Lewis River valley near Speelyai Creek, as well as the main part of the present valley. Lahars of the younger part of the Swift Creek assemblage were mostly confined to the trench cut by the Lewis River into the older part of the assemblage.

REFERENCES CITED

Aramaki, Shigeo, and Akimoto, Syun-iti, 1957, Temperature estimation of pyroclastic deposits by natural remanent magnetism: Am. Jour. Sci., v. 255, no. 9, p. 619–627.

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: Geol. Soc. America Bull., v. 76, no. 3, p. 321-330.

Bemmelen, R. W. van, 1949, The geology of Indonesia; v. IA, General geology of Indonesia and adjacent archipelagoes: The Hague, Govt. Printing Office, 732 p.

Chadwick, R. A., 1971, Paleomagnetic criteria for volcanic breccia emplacement: Geol. Soc. America Bull., v. 82, no. 8, p. 2285-2293.

Crandell, D. R., 1969, Surficial geology of Mount Rainier National Park, Washington: U.S. Geol. Survey Bull. 1288, 41 p. [1970].

———1971, Postglacial lahars from Mount Rainier volcano, Washington: U.S. Geol. Survey Prof. Paper 677, 75 p.

Crandell, D. R., and Mullineaux, D. R., 1973, Pine Creek volcanic assemblage at Mount St. Helens, Washington: U.S. Geol. Survey Bull. 1383-A, 23 p.

Halstead, E. C., 1968, The Cowichan ice tongue, Vancouver Island: Canadian Jour. Earth Sci., v. 5, no. 6, p. 1409-1415.

Heusser, C. J., 1974, Quaternary vegetation, climate, and glaciation of the Hoh River valley, Washington: Geol. Soc. America Bull., v. 85, no. 10, p. 1547–1560.

Hopson, C. A., 1971, Eruptive sequence at Mount St. Helens, Washington: Geol. Soc. America Abs. with Programs, v. 3, no. 2, p. 138.

Hyde, J. H., 1970, Geologic setting of Merrill Lake and evaluation of volcanic hazards in the Kalama River Valley near Mount St. Helens, Washington: U.S. Geol. Survey open-file report, 17 p.

Mullineaux, D. R., and Crandell, D. R., 1962, Recent lahars from Mount St. Helens, Washington: Geol. Soc. America Bull., v. 73, no. 7, p. 855–869.

Mullineaux, D. R., Hyde, J. H., and Rubin, Meyer, 1972, Preliminary assessment of upper Pleistocene and Holocene pumiceous tephra from Mount St. Helens, southern Washington: Geol. Soc. America Abs. with Programs, v. 4, no. 3, p. 204–205.

———1975, Widespread late glacial and postglacial tephra deposits from Mount St. Helens volcano, Washington: U.S. Geol. Survey Jour. Research, v. 3, no. 3, p. 329–335.

Munsell Color Co., 1954, Munsell soil color charts: Baltimore, Md.

Smith, R. L., 1960, Ash flows: Geol. Soc. America Bull., v. 71, no. 6, p. 795–841.

Thorarinsson, Sigurdur, 1954, The eruption of Hekla 1947–1948, v. 2, pt. 3, The tephra-fall from Hekla on March 29, 1947: Vísindafélag Íslendinga Rit, 68 p.

Verhoogen, Jean, 1937, Mount St. Helens, a recent Cascade volcano: California Univ. Dept. Geol. Sci. Bull., v. 24, no. 9, p. 263-302.

Williams, Howel, 1960, Volcanic history of the Guatemalan Highlands: California Univ. Pubs. Geol. Sci., v. 38, no. 1, p. 1-87.

☆U.S. GOVERNMENT PRINTING OFFICE: 1975—677-340/27

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849