Bull Volcanol (1993) 55:264-272

Bulletin of Volcanology

Tree-ring evidence for 1842–1843 eruptive activity at the Goat Rocks dome, Mount St. Helens, Washington

David K Yamaguchi[1], **Donald B Lawrence**[2]

[1] Mountain Research Station and Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, Boulder, CO 80309, USA
[2] Department of Plant Biology, University of Minnesota, St. Paul, MN 55108, USA

Received: April 24, 1992/Accepted: November 11, 1992

Abstract. Until the 18 May 1980 eruption of Mount St. Helens, a debris fan and adjacent forest downslope from the dacitic Goat Rocks dome, on the north flank of the volcano, contained evidence that the dome was active in 1842 or 1843. The fan was destroyed by the debris avalanche of 18 May. Before 1980, the oldest tree cored on the debris fan showed that the fan predated 1855 by a few years. The young age of this tree suggests that the dome was active several decades after extrusion of the nearby andesitic "floating island" lava flow, dated to 1800. An anomalous series of narrow rings that starts with the 1843 ring is present in cores from two older trees adjacent to the fan. These ring-width patterns imply that these trees were damaged in late 1842 or early 1843 by flowage material from the dome; the trees were probably singed by an ash-cloud surge that originated on the dome as a hot-rock avalanche. Several lines of evidence suggest that the anomalous ring patterns record tree injury by surge, rather than by lahars or nonvolcanic causes (climate or insects). First, comparable ring patterns formed in all sampled trees that survived the 18 May surge, but formed in only a few sampled trees abraded or partially buried by 18 May lahars. Second, a 13-cm fine-ash layer, consistent with either tephra fall or surge emplacement, was present on the 1840s forest floor; yet the lack of similar tree-ring responses to 1980 tephra fall shows that such minor tephra fall could not have caused the ring patterns. Third, identical 1843 narrow-ring patterns are absent in control trees further from the volcano. The ring patterns of the trees adjacent to the Goat Rocks fan provide the first field evidence that the dome was active in late 1842 or early 1843. Thus, the new tree-ring dates confirm stratigraphic evidence for the youth of the activity of the Goat Rocks dome. They also link historical accounts of mid nineteenth century volcanism at Mount St. Helens with continuing dome extrusion. The dates additionally corroborate and revise the dacite-andesite-dacite petrologic cycle interpretation of Mount St. Helens' Goat Rocks eruptive period (1800–1857). They constrain the cycle to no more than 43 years. Lastly, the dates support the notion that the vent that erupted the 1800 dacitic T tephra was different from the one that produced the Goat Rocks dome. We infer that the magma that formed the "floating-island" lava flow plugged the T tephra vent. This forced residual magma from the compositionally zoned magma chamber into an alternate conduit. The second conduit produced the unnamed 1842 lithic tephra and the Goat Rocks dome.

Key words: Mount St. Helens – historical eruptions – Goat Rocks dome – dome growth – hot rock avalanche – ash-cloud surge – tree-ring daring

"To the northwest and southeast can be seen two mountains [Mount Rainier and Mount St. Helens, Fig. 1], the height of which I am still ignorant, however, they exceed 4000 feet [1220 m]. They are covered with snow, even in the greatest heat of summer.

One of them [Mount St. Helens], that to the southeast, is conical in shape and faces my dwelling. The 5th of December last [1842], at three o'clock in the afternoon, one of the sides opened and there was an eruption of smoke such as all our oldest *voyageurs* [French-Canadian fur trappers] here have never seen. These eruptions of smoke took place during several days at delayed intervals, after which eruptions of fire broke forth. They take place almost continually, but with an intensity which varies greatly in a short time ...

... It is especially in the evening that all this is better observed and offers the spectator a magnificent view.

At the foot of this mountain is a little river whose waters empty into the Cawlitz [*sic*]. Since this volcano has broken forth, almost all the fish that are edible have died ..."

JBZ Bolduc, missionary at
the Mission of St. Francis
on the lower Cowlitz River

Correspondence to: DK Yamaguchi

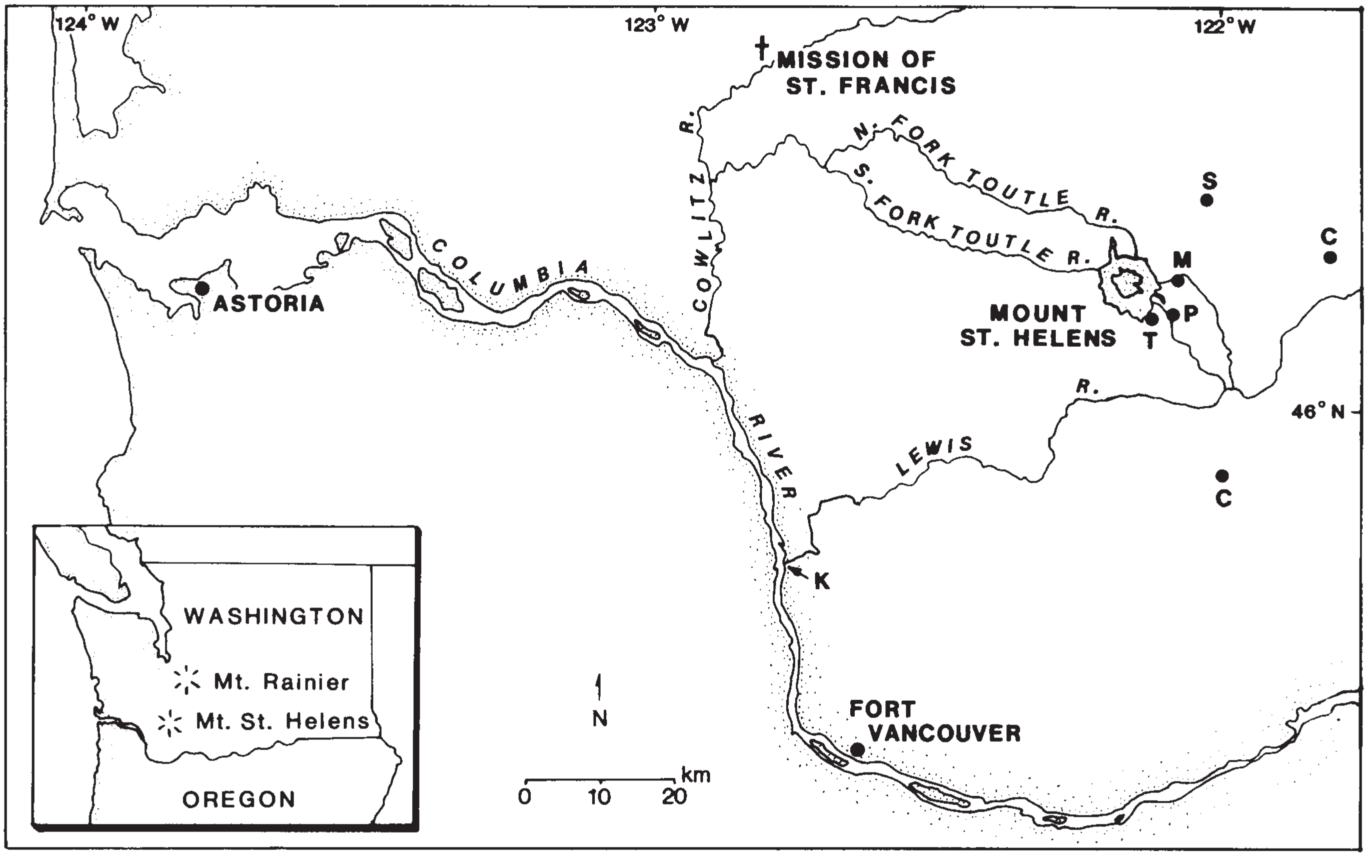

Fig. 1. Index map. *K* shows Paul Kane's vantage of a March 1847 eruption (Table 2). *Circles* show modern-analog or control tree-sampling sites not shown in Fig. 2. *S*, 1980 ash-cloud surge; *P*, *M*, Pine Creek and Muddy River 1980 lahars; *T*, fine 1980 tephra fall; *C*, control sites

"I left home with my family on the 11th of December [1842], and crossed over to Astoria and spent the night ... Here I left my family, and set out with my canoe for Vancouver, and on the following day [13 December 1842] as we were ascending the [Columbia River], having Mount St. Helen in full view, we discovered a vast column of smoke ascending from the north-west side of the mount near its top ..."

JH Frost, missionary
(both quotes from Majors 1980)

Introduction

In recent years, all major events of Mount St. Helens' Goat Rocks eruptive period (1800–1857; Pallister et al. 1987) save one – the emplacement of the dacite Goat Rocks dome on the volcano's north flank (Fig. 2) – have been assigned calendar dates (Table 1). Accurate dating of this event is important to increasing understanding of Mount St. Helens' behavior during the eruptive cycle that preceded its 1980–1986 activity. From new tree-ring evidence, we assign a date of late 1842 or early 1843 to a probable Goat Rocks dome eruption.

First described by Verhoogen (1937), the Goat Rocks dome is thought to have been extruded during or after a November 1842 eruption that produced a lithic ash that fell 100 km southeast of the volcano (Table 2; Crandell 1987). The dome presumably did not grow after 1857, the date of the last significant eruptive activity at the volcano before 1980 (Tables 1, 2). Yet evidence supporting the dome's ca. 1842 extrusion date and any possible 1842–1857 growth has been scant. The oldest tree Crandell (1987) found growing on pre-1980 Goat Rocks fan deposits started growing before 1876. The apparent youth of this and other trees in the first-generation pine forest on the fan suggested that the dome was young. Among historical accounts, Paul Kane's painting of a March 1847 eruption from a vent below Mount St. Helens' summit in the approximate location of the Goat Rocks dome has been interpreted as an extrusive eruption (Vaughan 1971; Hoblitt et al. 1980; Crandell 1987). But field evidence linking Kane's painting with 1840s dome activity has been lacking.

Crandell (1987) described the pre-1980 Goat Rocks dome and its environs as consisting of four zones: (1) the dome; (2) the barren fan of rock debris that extended downslope from the dome to about 1350 m; (3) the fan below this altitude, which supported the young pine forest; and (4) the adjacent mature forest rooted on older deposits, into which fingers of the debris fan extended (Fig. 2). From stratigraphic and paleomagnetic evidence, Crandell concluded that the fan deposits originated as hot rock avalanches from the dome, some of

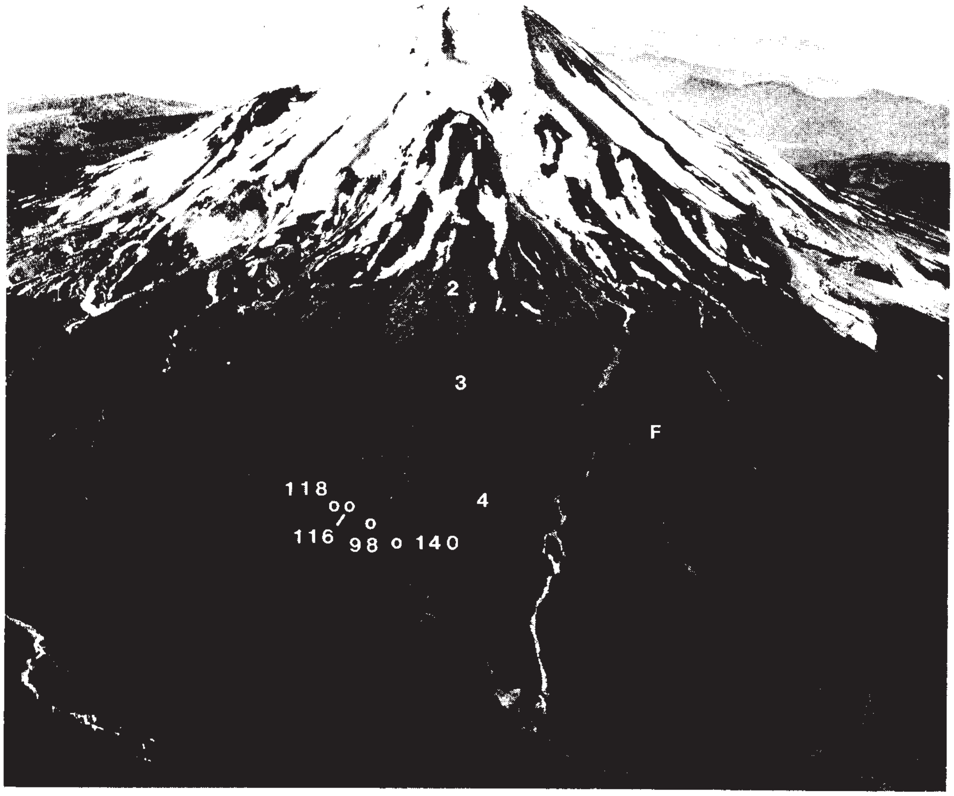

Fig. 2. Aerial view of the northwest flank of Mount St. Helens on 12 July 1970 showing (1) the Goat Rocks dome, (2) its barren debris fan, (3) the lower fan colonized by young pine trees, and (4) adjacent mature forests. Numbers show known collection sites of cores from trees rooted on debris fan lahars (Table 3, trees 40–98 and -140) or from trees that survived fan emplacement (trees 40-116 and -118). *F* shows location of previously reported trees cored on the "floating island" lava flow (Yamaguchi et al. 1990). Copyrighted photograph by the late Leonard H. Delano, Portland, Oregon

Table 1. Dates for major events of Mount St. Helens' Goat Rocks eruptive period (1800–57)

Event[a]	Year	Evidence
Layer T tephra erupted (D)	1800	Onset of narrow rings in surviving trees (Lawrence 1939; Yamaguchi 1983)
"Floating island" lava flow extruded (A)	1800	Onset of tree-growth anomalies (Lawrence 1941; Yamaguchi et al. 1990)
Unnamed lithic tephras erupted	Nov. 1842	Historical accounts and stratigraphy (Lawrence 1938, 1941, 1954; Holmes 1955; Okazaki et al. 1972; Majors 1980; Mullineaux 1986)
Goat Rocks dome extruded (D)	Post-T; accompanied or followed "floating-island" flow.	Stratigraphy (Hoblitt et al. 1980)
	Probably post-1842 tephra	Young ages of first-generation trees on dome debris fan (Crandell 1987); see text
Last significant eruption	1857	Historical accounts (Holmes 1955; Crandell 1987)

[a] (D), dacite; (A), andesite

which generated pyroclastic flows or lahars that flowed near or into forest zones. While Crandell did not describe associated ash-cloud surge deposits, eruptions of the modern dacite dome in the 18 May 1980 crater show that surges can accompany hot-rock avalanches from growing domes and leave only minimal deposits (Mellors et al. 1988). Thus, surges could also have contributed to fan formation and the destruction of the preexisting forest.

The features Crandell described were destroyed by the debris avalanche of the 18 May 1980 eruption (Lipman and Mullineaux 1981). Before then, more age information on the Goat Rocks dome could probably have been obtained by examining the annual rings of old trees marginal to the debris fan (Fig. 2, zone 4) for evidence of past forest disturbances (Lawrence 1938). Fortunately, during 1938–1940, Lawrence collected cores from several such trees and from young trees growing

Table 2. Historical events at Mount St. Helens possibly related to Goat Rocks dome extrusion

Date	Account	Observer(s)	Reference[a]
Spring or summer 1835	Snowy slopes of volcano blackened; ash fall at Ft. Vancouver	Meredith Gairdner	H
Oct 1835	Intermittent smoke and ash emissions	Samuel Parker	H
22 Nov 1842	Eruption column; southwest flank of volcano darkened	JL Parrish	H, M
25 Nov 1842	Lithic ash fall at The Dalles, Oregon, 100 km southeast of volcano	HB Brewer	H, M
30 Nov and 1 Dec 1842	Eruption witnessed; second ash fall at The Dalles	Daniel Lee, ZA Mudge	M M
5 Dec 1842	Eruption column from flank vent; incandescence; fish killed in North(?) Toutle River[b]	JBZ Bolduc	M
13 Dec 1842	Eruption column from vent on northwest flank	JH Frost	H, M
Oct 1843	Eruption columns from "crater on south flank"	Overton Johnson, WH Winter	H
16 Feb 1844	Eruption column from vent "on side of mountain, about two thirds of the distance from its base"; incandescence	PH Burnett	H, M
30 May 1844	Eruption column	George Gary	H, M
28 Dec 1844	Mountain described as "a burning volcano"	PH Burnett	H, M
13 Sep 1845	Eruption column	HJ Warre	M
26 Mar 1847	Eruption from north flank vent	Paul Kane	H, M, V
30 Mar 1847	Eruption column	Paul Kane	M
21 Mar 1850	Smoke emissions from vents on "north and northeast sides"	*Oregon Spectator*	H, M
Mar 1853	Smoke emissions from "south" flank vent	Charles Stevens	M
10 Apr 1853	Eruption column	Charles Stevens	H
2–3 Aug 1853	Smoke emissions from northwest flank vent	George Gibbs	M
26 Aug 1853	Smoke emissions from "crater" on northeast flank	TJ Dryer	M
23(?)–25 Feb 1854	Smoke and ash emissions	Portland *Oregonian*	H
17 Apr 1857	Eruption column	Steilacoom, WA, *Republican*	H

[a] *H*, Holmes (1955); *M*, Majors (1980); *V*, Vaughan (1971)
[b] The latter observation, together with the northwestern viewpoint of observer (mission, Fig. 1), suggest the vent was on the north flank (Majors 1980)

on the debris fan (zone 3) with the intention of dating it. Although Lawrence did not publish his findings, he saved his cores and field notes to the present. Here we present these and related data, and describe their implications for the age of the Goat Rocks dome.

Description and analysis of Lawrence's cores

Descriptions of the trees Lawrence cored on and marginal to the Goat Rocks dome debris fan were obtained from his notes and aerial photographs (Fig. 2 and Table 3). Two of the three young trees rooted on the fan were lodgepole pine; one was a Douglas fir. Two older trees marginal to the debris fan were both Douglas fir. A soil profile between the latter trees contained a 13-cm layer of fine ash (Table 3).

Lawerence's cores were mounted and sanded following standard procedures (Stokes and Smiley 1968; Swetnam et al. 1985; Phipps 1985). Exact calendar years were then assigned to rings within cores by ring counting combined with "cross dating". The latter method involves matching climatically controlled ring-width and -density patterns in cores with control patterns present in living trees. It ensures against dating errors caused by rare missing rings (Fritts 1976; Schweingruber 1988; Yamaguchi 1985, 1991). Cross-dated ring widths in cores from the two trees next to the debris fan were measured to the nearest 0.01 mm and plotted.

The control ring pattern was similarly quantified by cross dating and measuring ring widths in 46 cores from 25 old-growth Douglas fir in the forest 28 km east of the volcano (Fig. 1), beyond the known fallout zones of Goat Rocks period tephras. To quantify tree-growth trends caused by yearly climatic variation, decay curves were fitted to all measurement series by least squares. Measurements were then divided by curve values and averaged among all cores and trees following standard procedures. Ring widths were not simply averaged because of varying tree ages and declining radial growth rates over three lifespans (Fritts 1976; Graybill 1982; Sheppard and Jacoby 1989).

Potential modern analogs

To understand how an ash-cloud surge might have affected the growth of the old trees marginal to the debris fan sampled by Lawrence, in 1992 we collected and examined cores from six old-growth Douglas fir along the edge of forests that survived the 18 May 1980 surge, 15 km northeast of Mount St. Helens (Fig. 1). The upper crowns of sampled trees killed by heat (Fig. 3; see also Lipman and Mullineaux 1981).

Table 3. Field descriptions of trees Lawrence cored on or marginal to the Goat Rocks dome debris fan during 1938–1940. Tree locations shown in Fig. 1 (except for 01)

Core number	Species[a]	Specific geomorphic setting
Trees rooted on the Goat Rocks dome debris fan		
38-01	PICO	Near edge of debris fan
40-98	PICO	Oldest PICO on finger of lowest part of debris fan; core from 15 cm above soil surface
40-140	PSME	46-cm tree[b] "on east edge of kipuka at lower end of Goat Rocks fan"; core from 46 cm above soil surface
Trees in older forest marginal to the debris fan[c]		
40-116	PSME	152-cm tree near west edge of old forest; there were only young trees between this tree and finger of the Goat Rocks fan
40-118	PSME	122-cm tree in tongue of old forest between lowest fingers of the Goat Rocks fan

[a] PICO, *Pinus contorta* (lodgepole pine); PSME, *Pseudotsuga menziesii* (Douglas fir)
[b] Tree sizes are diameters measured 1.4 m above ground
[c] Description of soil profile between trees 40-116 and 40-118:

6– 0 cm	Litter and duff
0–13	"Newish" fine ash
13–16	Decayed duff
16+	Ash and decaying pumice lapilli [layer T?]

To similarly document how abrasion and/or burial by lahars might have affected Lawrence's trees, in 1987 we cored 15 old-growth Douglas fir along the edges of forests in the Pine Creek and Muddy River drainages southeast of the volcano (Fig.1). The trunks and roots of these trees were either abraded to varying extents or passively buried (without apparent abrasion) by cool 18 May 1980 lahars (Fig. 3; see also Lipman and Mullineaux 1981; Pierson 1985). In several cases, cored trees were adjacent to others that died from lahar-induced injuries. Thus, abrasions experienced by sampled trees probably include the most severe injuries that Douglas fir can withstand. Since growth rings do not form on portions of tree trunks that have been stripped of bark, all cores were collected from the downstream bark-covered sides of trees.

Because Lawrence noted the 13-cm layer of fine ash near the base of the Goat Rocks dome debris fan, in 1992 we also cored two old-growth Douglas fir that survived 11–12 cm of fine (sandy-silt textured) tephra deposition from the 18 May and other 1980 eruptions on the southeast flank of the volcano (Fig. 1; Lipman and Mullineaux 1981). We sampled these trees to evaluate the potential role of fine tephra fall in inducing growth changes among the trees sampled by Lawrence near the Goat Rocks dome debris fan.

To establish controls for all modern analogs (the above master ring chronology for Mount St. Helens ends in 1981), in 1992 we cored three old-growth Douglas fir at a second control site 29 km southeast of the volcano (Fig. 1). This area received only trace amounts of 1980 tephra fall (Lipman and Mullineaux 1981). All modern analog cores were processed identically to Lawrence's cores from old trees next to the debris fan. Post-1980 control cores were processed identically to prior control cores.

Interpretation of Lawrence's cores

The dates of formation of the innermost rings in Lawrence's cores from trees rooted on the Goat Rocks debris fan range from 1855 to 1879 (Table 4). The two trees Lawrence sampled adjacent to the fan margin contain an abruptly starting series of anomalous narrow rings (core 40–118) or narrow rings and one missing ring (core 40–116). The ring anomalies in both trees start with the 1843 ring and persist for ten to eleven years (Fig. 4a, b).

Such sudden narrowing of rings records a time of tree injury. The persistence of the narrow rings shows that both trees were damaged severely enough for growth to be suppressed for a decade. The missing ring in core 40–116 is a symptom of physiological stress (Fritts 1976). Core 40–116 also contains traumatic resin canals in its 1845 ring (Fig. 5). Such features commonly form in developing growth rings shortly after wounding (Kuroda and Shimaji 1983). For example, they are also present in the 1980 rings of seven of the 15 sampled trees that were abraded by 18 May 1980 lahars.

No similar narrow-ring patterns or ring anomalies are present in trees at the control site (Fig. 4c) or in other portions of the cores from trees marginal to the Goat Rocks dome debris fan. The lack of such patterns in control cores shows that climatic phenomena did not cause the anomalous ring patterns. The lack of other ring anomalies in trees marginal to the fan also shows that the trees were injured only once, during late 1842 or early 1843. These years fall within the 1800–1857 possible interval of dome extrusion and debris fan growth.

Interpretation of modern-analog cores

The ring-width responses of trees that survived scorching by the 18 May 1980 surge (Fig. 6a) are strikingly similar to those in Lawrence's cores. Post-1980 missing rings are present in two of the trees.

In contrast, the rings of trees abraded or partially buried by lahars vary greatly (Fig. 6b, c). Among the abraded trees, only one or two contain growth responses similar to those of trees marginal to the Goat Rocks fan. Remaining trees either show growth increases or lack clear responses. Of the two passively buried trees, one shows no response; the other shows a growth increase due to the death of nearby trees and resulting decreased competition for light and water. Generally, growth responses do not correlate well with apparent severities of tree injury. They may relate better to proportions of mortality among competing trees after lahar passage.

Trees impacted by 11–12 cm of fine 1980 tephra fall lack apparent changes in growth rates (Fig. 6d). Thus, if the fine tephra noted by Lawrence near the Goat Rocks dome debris fan was deposited by tephra fall, it could

Fig. 3. Potential modern analog trees. Left: Living Douglas fir singed by 18 May 1980 surge cloud, 15 km northeast of Mount St. Helens (tree 5 at right center, tree 6 at left center). Note killed trees in foreground (July 1992 photograph). *Top right:* Douglas fir abraded by 18 May Pine Creek lahar. Lahar viewpoint tree 1, 8 km southeast of pre-1980 summit. *Shovel* is 1 m tall. *Bottom right:* Douglas fir partially buried by 18 May Pine Creek lahar. Note sparse, sickly tree crown. Pine Creek tree 3, 6 km southeast of pre-1980 summit (September–October 1987 photographs). Ring-width responses of all trees shown in Fig. 6

Table 4. Dates of formation of innermost rings in cores from trees rooted on the Goat Rocks dome debris fan

Core	Inside-ring date
38-1	1855[a]
40-98	1879[b]
40-140	1873[b]

[a] Core closely passes pith (center ring)
[b] Pith date

not have caused the narrow and missing rings in trees there. Cores at the second control site confirm that post-1980 narrow rings among trees singed by the 18 May surge are anomalous (Fig. 6e).

Synthesis

The 1855–1879 innermost-ring dates of cores from trees rooted on the Goat Rocks dome debris fan contain one date (1855) older than the 1876 innermost-ring date reported by Crandell (1987). These tree-ring dates thus corroborate and revise Crandell's 1876 limiting date for Goat Rocks dome extrusion.

It seems likely that the new limiting tree-ring date closely estimates the age of the Goat Rocks dome fan. Because surviving lodgepole pine trees were nearby (zone 4) to provide seed sources, the recolonization of the margins of this surface by seedlings of this pioneer species should have occurred rapidly. Similar settings created at Mount St. Helens in 1980 are presently being recolonized by abundant tree seedlings (Halpern and

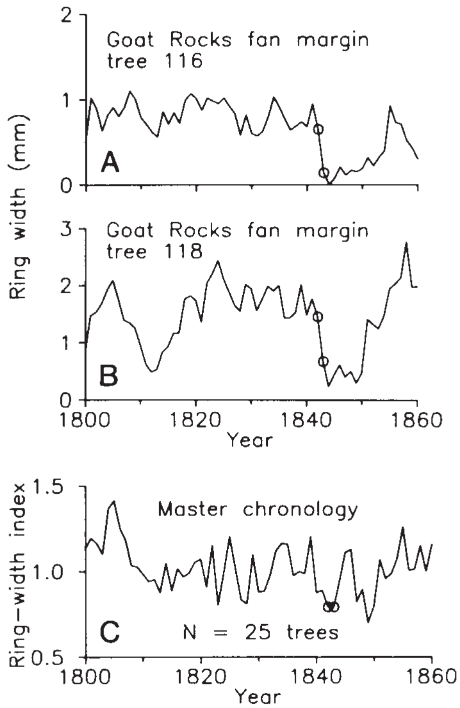

Fig. 4. A–C Ring widths in Douglas fir adjacent to the Goat Rocks dome debris fan (**A, B**) compared with those in control trees (**C**). Circles contrast 1842–1843 ring-width changes in debris-fan trees with the lack of change in control trees. The 1844 missing ring in **A** is plotted as a ring of zero width. Ordinal units in **C** are dimensionless due to standardization procedures used to remove age trend before averaging to determine the common growth pattern shared by many trees (see text)

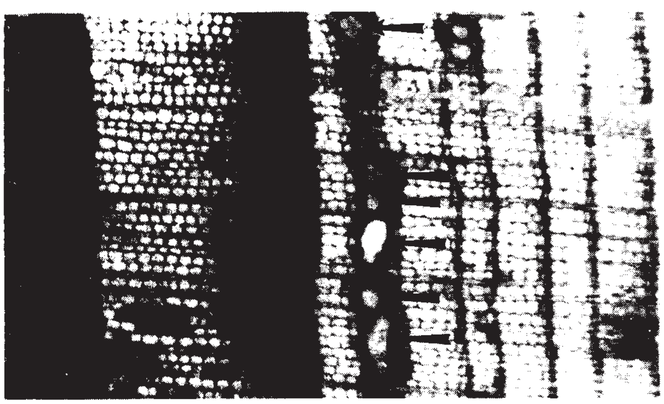

Fig. 5. Detail of core 40–116 showing traumatic resin canals (arrows) in 1845 ring. Bark lies to right; normal 1842 ring at left is 0.65 mm wide; 1844 ring is missing

Harmon 1983; DK Yamaguchi, 1982–1992 field observations). Significantly, Lawrence's oldest tree rooted on the fan started growing about 18 years later than the oldest tree he cored on a forested island on the nearby "floating-island" lava flow (Fig. 2; an innermost ring date of 1837; Yamaguchi et al. 1990). Because sampled debris-fan margins were closer to upwind (westerly) seed sources (0 km as compared to 0.2–0.5 km for the lava-flow island), they should have reforested more quickly than the flow island. Thus the younger ages of trees on the debris fan suggest that the Goat Rocks dome was active at least two decades after the 1800 lava flow.

A probable specific date for some activity is provided by the anomalous narrow rings that start with the 1843 ring in the old trees adjacent to the Goat Rocks dome debris fan, and by the missing ring and subsequent traumatic resin canals in one of the trees. These sequences show that a tree-injuring event occurred along the margins of the Goat Rocks fan about this time. Tree injury occurred either late in 1842, after seasonal (May–September) ring formation for this year was complete, or early in 1843, before much of this ring could have formed. But what kind of disturbance was it?

Narrow or missing ring series in forest trees growing near volcanoes can result from multiple causes including: (1) nonvolcanic factors, e.g. adverse climate or defoliation by insects; (2) tephra fall; or (3) injury from volcanic flowage deposits (surges or lahars). For trees growing adjacent to the Goat Rocks dome debris fan, nonvolcanic causes can be ruled out, because control trees (Fig. 4c) as well as examinations of the ring patterns of hundreds of other Douglas fir in forests near Mount St. Helens during related studies (e.g. Yamaguchi 1993) show that the post-1842 narrow-ring patterns are anomalous. The deposition of the 13-cm of fine ash noted by Lawrence between the two old sampled trees, if tephra-fall ash, also cannot have been the cause of injury because trees that experienced similar tephra fall in 1980 lack unusually narrow rings. This finding is consistent with prior studies of pre-1980 Mount St. Helens tephra fall deposits (layers Wn, We, T, and set X) which collectively show that heavy, coarse tephra fall (e.g. >30 cm of lapilli with diameters >16 mm) is necessary to induce distinctive narrow-ring patterns in Douglas fir (Yamaguchi 1985, 1993). The elimination of the above possibilities leaves ash-cloud surges or lahars as the likely causes. While Lawrence did not note lahar deposits in his soil pit (Table 3; his 1938 report shows that he was cognizant of them), nearby diverging lahar streams (Fig. 2) show that his pit was probably on higher ground that escaped lahar emplacement.

We cannot state with certainty the cause of injury of trees adjacent to the Goat Rocks dome debris fan because relevant field sites no longer exist. But the strong similarity between the ring responses of trees scorched by the 18 May surge and those in trees near the fan, and the lack of similarity among most trees abraded or buried by 18 May lahars, suggest that the fan trees recorded a surge. The surge probably originated as a hot rock avalanche from the dome. The 13-cm of fine ash noted locally by Lawrence supports this interpretation, for a surge could well have left this deposit.

Two additional lines of evidence make it seem unlikely that abrasion by lahars could have induced the ring anomalies in trees adjoining the Goat Rocks dome debris fan. For the abrasion explanation to work, open scars on tree trunks had to have healed during the century that elapsed before Lawrence cored them so that they were not visible to him. Moreover, Lawrence's cores had to have missed intersecting closed scars pre-

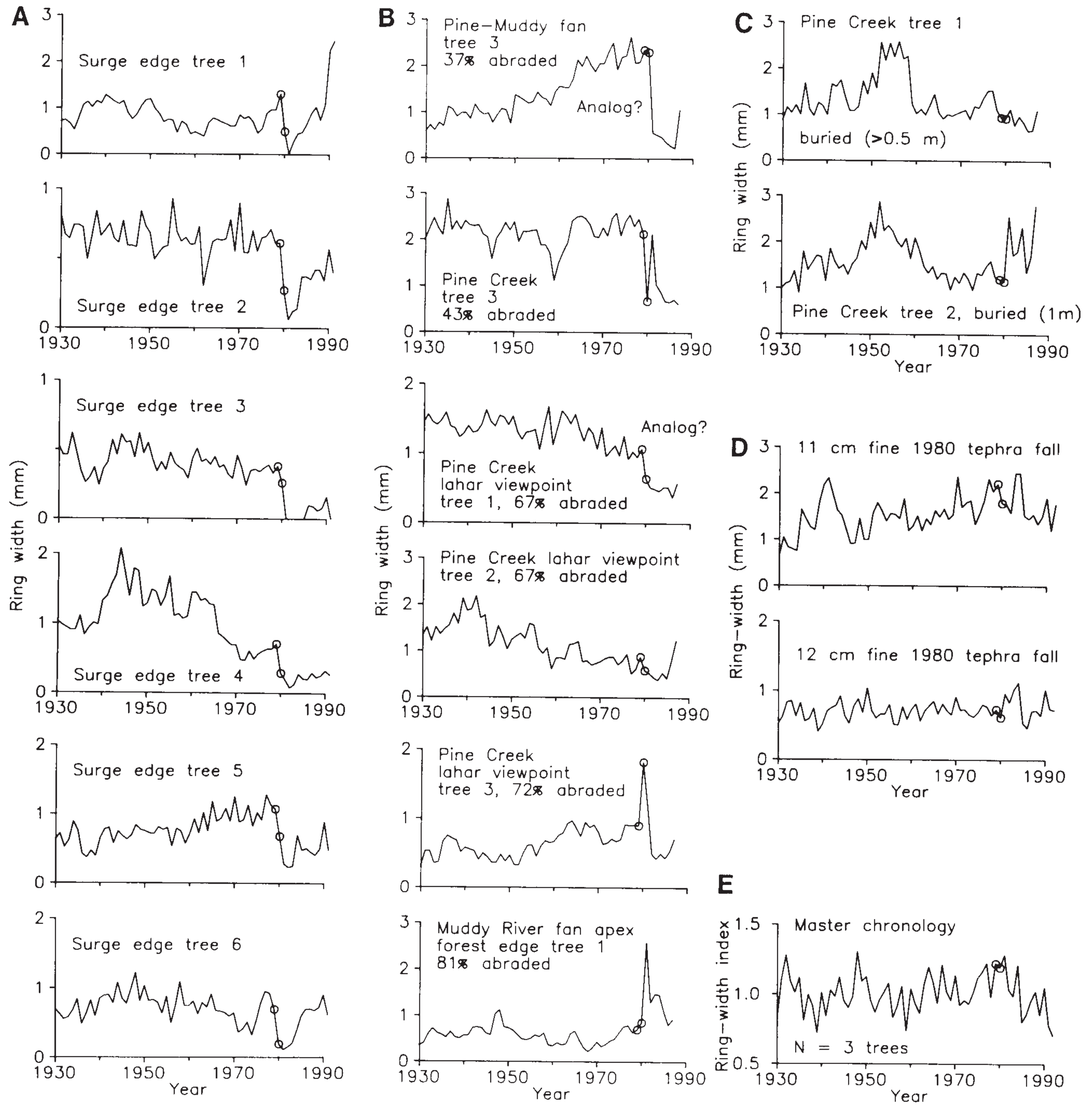

Fig. 6. A–E Ring widths in representative Douglas fir surviving 18 May 1980 volcanic disturbances. *Circles* contrast 1979 (pre-eruption) and 1980 (post-eruption) rings. **A** Trees singed by surge cloud. **B** Trees abraded by Pine Creek and Muddy River lahars. Percentages show amounts of tree circumferences abraded; "Analog?" denotes ring responses similar to those in trees near the Goat Rocks dome debris fan. **C** Trees partially buried by Pine Creek lahar. **D** Trees impacted by 11–12 cm of fine tephra fall from the 18 May and other 1980 eruptions. **E** Control ring-width series

served internally, as circumferentially incomplete rings, in both trees. The scars would otherwise be present in his cores (e.g Means 1989).

Conceivably, the roots of the trees near the debris fan could also have been scorched by a hot lahar. Modern analogs of this possibility, however, did not occur at Mount St. Helens in 1980. Such tree-ring records are thus not available for comparison.

Significance

The tree-ring evidence presented above confirms the youth of activity of the dome previously evident from photographic and historical records (Fig. 2 and Table 2), and from prior stratigraphic and tree-ring studies (Table 1). The ring patterns of the trees surviving emplacement of the Goat Rocks dome debris fan provide the first field evidence that the dome was active in late 1842 or early 1843. These data therefore link historical accounts of mid nineteenth century volcanism at Mount St. Helens with the Goat Rocks dome. Conceivably, the dome might have originated in the 1830s or even earlier. The simplest interpretation of the 1835 historical accounts (Table 1) is that they record initial dome extrusion. Hot avalanches or lahars either did not accompany 1835 dome growth, or were small flows that didn't reach tree-sampling sites. Alternatively, 1835 flowage deposits may have gone down other paths, or were overridden in 1842–1843.

The 1842–1843 dating of Goat Rocks dome activity supports and revises the dacite-andesite-dacite petrologic cycle interpretation of Mount St. Helens' Goat Rocks period proposed by Pallister et al. (1992; see Hopson and Melson 1990, for an alternative interpretation). First, it constrains that cycle (Table 1) to no more than 43 years. The date's recency additionally strengthens Crandell's (1987) inference that the 1800 dacitic T tephra was erupted from a different vent than the one that gave rise to the Goat Rocks dome. Our interpretation is that the T tephra vent became plugged by the andesitic magma that produced the 1800 "floating-island" lava flow. This forced residual dacitic magma in the compositionally zoned magma chamber (Pallister et al. 1992) into an alternate conduit. The second conduit produced the unnamed 1842 lithic tephra and the Goat Rocks dome. This scenario is consistent with the lack of continuity of the lava flow with the dome (Fig. 2).

Acknowledgements. Kenneth Phillips and Elizabeth Lawrence helped with the 1938-1940 fieldwork. The 1840s control ring-width series (Fig. 4c) was assembled while Yamaguchi was funded by a Graduate and Professional Opportunities Program (GPOP) fellowship at the University of Washington. Fieldwork investigating the growth responses of trees abraded by 1980 lahars was conducted while Yamaguchi was a National Research Council–US Geological Survey Research Associate at the Cascades Volcano Observatory, Vancouver, Washington. Completion of this study at INSTAAR was partially supported by a grant from the University of Colorado Program Enrichment Fund. Connie Woodhouse drafted Fig. 1, and Marion Reid measured rings in trees near the Goat Rocks dome debris fan for Fig. 4. Fig. 2 is photograph 70723 of Delano Horizons, Portland, Oregon. C Dan Miller, Richard Waitt, Dwight Crandell, Donal Mullineaux, and Clifford Hopson reviewed earlier versions of the manuscript.

References

Crandell DR (1987) Deposits of pre-1980 pyroclastic flows and lahars from Mount St Helens volcano, Washington. US Geol Surv Prof Pap 1444, 91 pp

Fritts HC (1976) Tree rings and climate. Academic Press, New York, 567 pp

Graybill DA (1982) Chronology development and analysis. In: Hughes MK, Kelly PM, Pilcher JR, LaMarche VC Jr (eds) Climate from tree rings. Cambridge Univ Press, Cambridge, UK, 21-28

Halpern CB, Harmon ME (1983) Early plant succession on the Muddy River mudflow, Mount St Helens, Washington. Am Midl Nat 110:97-106

Hoblitt RP, Crandell DR, Mullineaux DR (1980) Mount St Helens eruptive behavior during the past 1500 yr. Geology 8:555-559

Holmes KL (1955) Mount St Helens' recent eruptions. Oreg Hist Quart 56:196-210

Hopson CA, Melson WG (1990) Compositional trends and eruptive cycles at Mount St Helens. Geoscience Canada 17:131-141

Kuroda K, Shimaji K (1983) Traumatic resin canal formation as a marker of xylem growth. For Sci 29:653-659

Lawrence DB (1938) Trees on the march, notes on the recent volcanic and vegetational history of Mount St Helens. Mazama 20. 12:49-54

Lawrence DB (1939) Continuing research on the flora of Mount St Helens: a progress report. Mazama 21. 12:49-54

Lawrence DB (1941) The "floating island" lava flow of Mount St Helens. Mazama 23. 12:56-60

Lawrence DB (1954) Diagrammatic history of the northeast slope of Mount St Helens, Washington. Mazama 36. 13:41-44

Lipman PW, Mullineaux DR, eds (1981) The 1980 eruptions of Mount St Helens, Washington. US Geol Surv Prof Pap 1250, 844 pp

Majors HM (1980) Mount St Helens series. Northwest Discovery 1:68-108

Means JE (1989) Estimating the date of a single bole scar by counting tree rings in increment cores. Can J For Res 19:1491-1496

Mellors RA, Waitt RB, Swanson DA (1988) Generation of pyroclastic flows and surges by hot-rock avalanches from the dome of Mount St Helens volcano, USA. Bull Volcanol 50:14-25

Mullineaux DR (1986) Summary of pre-1980 tephra-fall deposits erupted from Mount St Helens, Washington State, USA. Bull Volcanol 48:17-26

Okazaki R, Smith HW, Gilkeson RA, Franklin JF (1972) Correlation of West Blacktail ash with pyroclastic layer T from the 1800 AD eruption of Mount St Helens. Northwest Sci 46:77-89

Pallister JS, Hoblitt RP, Crandell DR, Mullineaux DR (1992) Mount St Helens a decade after the 1980 eruptions: magmatic models, chemical cycles, and a revised hazard assessment. Bull Volcanol 54:126-146

Phipps RL (1985) Collecting, preparing, crossdating, and measuring tree increment cores. US Geol Surv Water-Resources Invest Rep 85-4148

Pierson TC (1985) Initiation and flow behavior of the 1980 Pine Creek and Muddy River lahars, Mount St Helens, Washington. Geol Soc Am Bull 96:1056-1069

Schweingruber FH (1988) Tree rings: basics and applications of dendrochronology. Reidel, Boston, 276 pp

Sheppard PR, Jacoby GC (1989) Application of tree-ring analysis to paleoseismology: two case studies. Geology 17:226-229

Stokes MA, Smiley TL (1968) An introduction to tree-ring dating, Univ Chicago Press, Chicago, 73 pp

Swetnam TW, Thompson MA, Sutherland EK (1985) Using dendrochrondology to measure radial growth of defoliated trees. US Dep Agric Handb 639:1-39

Vaughan T, ed (1971) Paul Kane, the Columbia wanderer: sketches, paintings, and comment, 1846-1847. Oregon Hist Soc, Portland, 80 pp

Verhoogen J (1937) Mount St Helens, a recent Cascade volcano. Calif Univ Dep Geol Sci Bull 24. 9:263-302

Yamaguchi DK (1983) New tree-ring dates for recent eruptions of Mount St Helens. Quat Res 20:246-250

Yamaguchi DK (1985) Tree-ring evidence for a two-year interval between recent prehistoric explosive eruptions of Mount St Helens. Geology 13:554-557

Yamaguchi DK (1991) A simple method for cross-dating increment cores from living trees. Can J For Res 21:414-416

Yamaguchi DK (1993) Old-growth forest development after Mount St Helens' 1480 eruption. Res Explor 9:in press

Yamaguchi DK, Hoblitt RP, Lawrence DB (1990) A new tree-ring date for the "floating island" lava flow, Mount St Helens, Washington. Bull Volcanol 52:545-550

Editorial responsibility: W Hildreth