Geoscience Canada

# A Decade of Dome Growth at Mount St. Helens, 1980-90

Donald A. Swanson

Volume 17, Number 3, September 1990

URI: https://id.erudit.org/iderudit/geocan17_3art07

See table of contents

Publisher(s)

The Geological Association of Canada

ISSN

0315-0941 (print)
1911-4850 (digital)

Explore this journal

Cite this article

Swanson, D. A. (1990). A Decade of Dome Growth at Mount St. Helens, 1980-90. *Geoscience Canada*, *17*(3), 154–157.

Article abstract

The growth of the dacite dome at Mount St.Helens between 1980 and 1986 has been more intensively studied than that of any other dome-building eruption. The growth has been complex in detail, but remarkably regular overall. This paper summarizes some of what has been learned and provides many references to additional information. Whether dome building has ended is an open question, particularly in view of the renewed, though minor, explosive activity of late 1989and early 1990.

# A Decade of Dome Growth at Mount St. Helens, 1980-90

Donald A. Swanson
*David A. Johnston Cascades Volcano Observatory*
*United States Geological Survey*
*5400 MacArthur Boulevard*
*Vancouver, Washington 98661*

## Summary

The growth of the dacite dome at Mount St. Helens between 1980 and 1986 has been more intensively studied than that of any other dome-building eruption. The growth has been complex in detail, but remarkably regular overall. This paper summarizes some of what has been learned and provides many references to additional information. Whether dome building has ended is an open question, particularly in view of the renewed, though minor, explosive activity of late 1989 and early 1990.

## Introduction

Volcanic activity continued intermittently through the decade at Mount St. Helens following the catastrophic events of May 18, 1980. This long-lasting dacitic eruption took place in 21 distinct eruptive episodes, each preceded by increasing seismicity and rates of ground deformation. Sub-plinian eruption columns and minor pyroclastic flows characterized the episodes of May 25, June 12, July 22, August 7, and October 16-18, 1980. Small dacite domes formed after the June and August explosions, but were largely destroyed by the July and October explosions, respectively (Moore *et al.*, 1981). A longer-lived, composite dome began to grow within a few minutes after the last explosion of October 18. Since then, 16 different dome-building episodes have taken place. Most of these episodes lasted only several days and were separated by quiet periods of a few weeks to 1 year; however, two of the dome-building episodes were complex, each adding at least two distinct lobes of dacite to the dome during periods of prolonged activity lasting three weeks (March-April 1982) and one year (February 1983-February 1984), respectively. At the time of writing (May 1990), the dome has not grown since October 1986, although small phreatic explosions occurred in December 1989 and January and April 1990.

## General Physical Characteristics

The dome presently is about 1060 m by 860 m wide, rises 267 m above its vent, and has a volume (including flanking talus) of about $74 \times 10^6$ m$^3$ (Swanson and Holcomb, 1990). The total volume of all erupted material, including tephra and debris removed from the dome by explosions and large rockfalls, is about $77 \times 10^6$ m$^3$. The dome formed in a shallow depression on the floor of the inner crater that was created on May 18, 1980. With time, the dome filled the depression and eventually spread onto a northward slope averaging about 13°. At present, the north base of the dome is about 83 m below the vent, and the total relief on the dome is about 350 m.

Typical episodes of dome building produced volumes of $1.2\text{-}4.5 \times 10^6$ m$^3$; the largest two episodes resulted in 5.8 and $6.1 \times 10^6$ m$^3$ (in May and October 1986, respectively). Most episodes consisted of both endogenous (internal) and exogenous (extrusive) growth. The volumetric ratio of endogenous to exogenous growth increased over time as the dome became larger and more able to store new magma. Endogenous growth probably accounts for 30-40% of the dome overall and more than 70% of the volume added during 1985-86.

The extrusions formed short (200-400 m), thick (20-40 m) lava flows, termed lobes, that piled up on one another and generally did not reach the crater floor before crumbling into hot talus (Swanson *et al.*, 1987a, figures 3 and 5). Most of the lobes were fed from the summit area of the dome, but several came from eccentric vents high on the flanks. The lobes moved so slowly, generally less than 5 cm per minute, that their advance could be seen only through a theodolite telescope or with time-lapse photography. Effective viscosities of $10^9\text{-}10^{10}$ Pa s were calculated from measured flow rates on known slopes. Many lobes have subvertical columnar jointing exposed in the walls of explosion craters (Figure 1). Most lobes have a one to two metre-thick scoriaceous carapace and a relatively dense interior (Swanson *et al.*, 1987a, figure 4), but each lobe extruded in September 1984 and later either lacked such a carapace or had only patchy scoria. This change in pattern has been ascribed to increased pre-extrusion degassing starting in September 1984 (Swanson and Holcomb, 1990; Anderson and Fink, 1989); such degassing may take place primarily in the ascending magma column, if it stalls for a few days within a few hundred metres of the surface before erupting (Anderson and Fink, 1989, 1990).

## Ground Deformation

Remarkable ground deformation, accompanied by seismicity (Malone *et al.*, 1983; Endo *et al.*, in press) and distinctive thermal patterns on the dome (Swanson *et al.*, 1985, p. 412), preceded each episode of dome growth. These events initially recorded the early rise of magma and resulting slow endogenous growth of the dome. Presumably, this magma had been stored in the feeder conduit since the previous period of extrusion. Displacement rates of the dome and surrounding crater floor, and rates of seismic energy release, accelerated almost exponentially until rapid endogenous growth (as rapid as $2\text{-}3 \times 10^6$ m$^3$ per day for several hours) and extrusion began (Chadwick *et al.*, 1983; Swanson *et al.*, 1983). Entry of magma into the dome caused spreading and subsidence; only rarely did slight uplift occur. The subsidence reflects the relatively low shear strength of the hot core of the dome.

Deformation of the adjacent crater floor resulted in radial extension cracks and tangential thrust faults (Figure 2). Thrusting was directed away from the dome, and thrust blocks were bounded by radial cracks that exhibited early extension and late strike-slip (tear) displacement (Chadwick *et al.*, 1983; Chadwick and Swanson, 1989). Displacement rates of tens of centimetres per day were common on the thrusts during the final days before extrusion. Finite-element modelling (Chadwick *et al.*, 1988) suggests that deformation of the crater floor could have resulted from shear stress along the conduit walls generated by ascending magma with a high effective viscosity. All deformation took place within a few hundred metres of the dome, and the flanks of the volcano recorded no displacement above measurement error (Iwatsubo *et al.*, in press). These observations indicate that any deep magma body, if present, exerted little or no influence on ground-surface deformation.

## Ascent Rates and Earth Tides

A currently unresolved conflict exists regarding the depth of magma storage and the rate of magma ascent to the surface. Seismic evidence suggests that magma rose into the dome from a depth of 1-2 km at a rate of about 25-40 m per hour, although earthquakes occur in a depth range of 0 to 13 km (Endo *et al.*, in press). Amphibole-stability relations suggest deeper storage (7 km) and more rapid rise rates (65-70 m per hour) (Hill and Rutherford, 1989).

Dome-building episodes and their precursory periods tended to begin 3-5 days after the fortnightly earth-tide maximum at new or full moon (Swanson *et al.*, 1987b). Apparently the magmatic system was in such delicate balance that, at a critical stress level, small, but rapidly changing, tidal-stress loads could "trigger" precursory events culminating in episodes of dome growth. No tidal influence on the timing of small explosions is apparent.

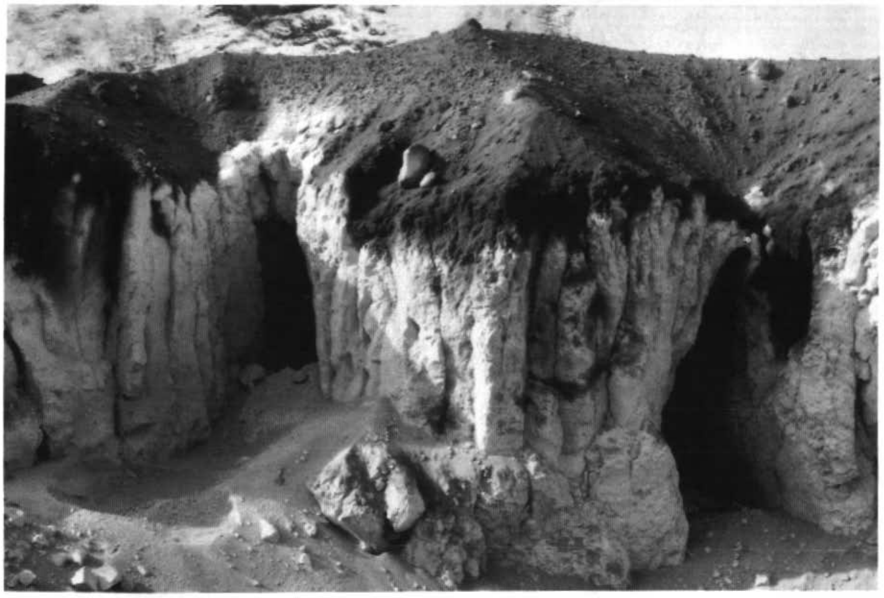

**Figure 1** *Vertically columnar dacite lobe exposed in wall of crater formed by sector collapse in February 1983 and enlarged by explosions throughout 1983. The explosions deposited 5 m of tephra (dark) above lobe.*

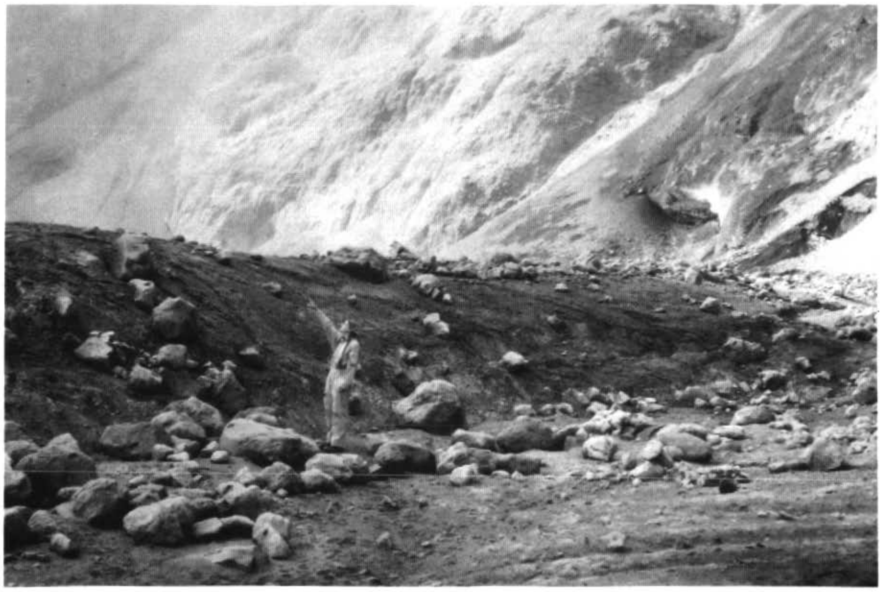

**Figure 2 (a)** ***(middle)*** *Small wrinkle, an incipient thrust fault, on crater floor. Some wrinkles developed into large thrusts as in Figure 2b.*

**(b)** ***(lower)*** *Toe of large thrust fault (Outward Bound thrust; Chadwick and Swanson, 1989) formed in 1982 on crater floor. Observer points toward dome. This fault enlarged from a wrinkle similar to that in Figure 2a in about 1 week. Large blocks were emplaced by rockfalls from dome and by relatively large explosions.*

### Regularities in Growth Patterns

Certain aspects of dome growth were quite regular despite the episodic activity (Swanson and Holcomb, 1990). The long-term volumetric growth rate was approximately constant during three stages: A, $1.8\times10^6$ m$^3$ per month from October 1980 to the end of 1981; B, $1.3\times10^6$ m$^3$ per month from March 1982 to March 1984; and C, $0.6\times10^6$ m$^3$ per month from March 1984 to October 1986. The switch from one stage to the next reflected changes in style of eruption, magma composition, or associated seismicity. For example, the switch from stage A to stage B coincides with the start of a weakly defined increase in $SiO_2$ content with time (Swanson and Holcomb, 1990) and with an unusual period of deep earthquakes (Weaver *et al.*, 1983) that culminated in a magmatic explosion on March 19, 1982 (Waitt and MacLeod, 1987), ending the longest period of inactivity to that time. The switch from stage B to stage C corresponds with the end of a year of continuous growth (Swanson *et al.*, 1987a), broadly correlates with proportionally greater endogenous growth during eruptive episodes, and possibly correlates with increased pre-extrusion degassing as suggested by less scoriaceous lobes (Anderson and Fink, 1989). Moreover, the recurrence interval between eruptive episodes changed from stage to stage; during stage A the interval was roughly constant (63±14 days), but during stages B and C the recurrence intervals each lengthened exponentially (Swanson and Holcomb, 1990). These correlations are unexplained, but most likely reflect processes within the magma reservoir itself, rather than external processes such as changes in regional tectonic stress rates or orientations.

The long-term growth rates were approximately linear and volume predictable during each growth stage, with standard deviations (s.d.) of $10^6$ m$^3$ or less (Swanson and Holcomb, 1990). In this context, volume predictability (the ability to predict the volume produced by an event on the basis of the time elapsed since the previous event) is best ascribed to gradually increasing magma pressure before an event and rapidly decreasing magma pressure during the event. The reduced supply rate with time implies slower buildup of magma pressure, which is primarily a function of volatile content. Slower buildup suggests that the parent magma was "running out of gas" during the early and mid-1980s. Correlation-spectrometer (COSPEC) measurements of the gas plume from the volcano indicate that the discharge of $SO_2$ drastically lowered between 1980 and 1984 and remained near or at the detection limit of 5-20 tonnes per day until measurements were discontinued in 1988 (Casadevall *et al.*, 1983; Cascades Volcano Observatory, unpublished data). This pattern suggests that either the gas content of the parent magma was lowering during the early 1980s or that the amount of magma remaining in the reservoir was declining owing to eruption, solidification, or lateral draining. Another factor in reducing the rate of growth may have been the increasing crystallinity of the magma (Cashman, 1988; written communication, 1990), which would have decreased the mobility of the magma and made it more difficult to erupt.

The diameter and height of the dome varied predictably with time. Ratios of height to diameter generally ranged from 0.227 to 0.292. These ratios agree with those of Japanese domes (Moriya, 1978) and are less than the upper limit of 0.32 derived from Moriya's data, equivalent to the repose angle of talus. The shape of the dome is likely controlled by the net effective viscosity and tensile strength of the hot core, cool outer shell, and flanking talus. Modelling by Iverson (1990) suggests that the outer shell is the most important factor.

### Magnetic Studies and Rate of Cooling

The magnetic-field anomaly associated with the dome is intensifying with time faster than can be explained by conductive cooling (Dzurisin *et al.*, 1990). Convective loss of heat to circulating air, rain, and snowmelt is demanded, consistent with the observed seasonal variation in cooling rate. Dzurisin *et al.* (1990) conclude that the magnetized carapace of the dome thickens at rates of 0.02-0.04 m per day, mainly by convective heat loss along fractures that propagate downward during cooling. Fracturing associated with dome growth greatly accelerates cooling, so that parts of the magnetized carapace thicken as rapidly as 0.30 m per day. They estimate that the dome will be completely magnetized (cooled below the blocking temperature of about 350°C) in 18-36 years, provided that it remains inactive.

### Explosions and Rockfalls

Minor explosions initiated seven dome-building episodes, and more than 420 small, unpredicted explosions took place between episodes of dome building. Small craters were excavated during some periods of frequent explosions (Figure 1). At other times, explosions issued from open cracks and formed no craters. Several explosions were associated with small sector-collapse events (Swanson *et al.*, 1987a, figure 7). A typical small explosion started with rumbling sounds from within the dome, which gave nearby observers 10-15 seconds to run for cover before the explosion actually occurred. Some periods of activity were too intense for observers to be within several hundred metres of the dome. The ejecta consist of nonvesicular to, rarely, pumiceous dacite similar to that in the dome. One 46.8-kg ballistic block was thrown 1.07 km (horizontal distance) from its vent. Much larger blocks were confined to the immediate vicinity of the dome (Figure 2b). Energy calculations for some explosions, using the methods of Wilson (1972, 1980), suggest overpressures equivalent to the weight of the dome. This suggests that groundwater was important in driving the explosions, but whether they were phreatic or phreatomagmatic is difficult to assess and, to some extent, a meaningless distinction. Is a pumice lapillus generated by decompression of the *interior* of the dome during a groundwater-triggered explosion considered magmatic, phreatic, or phreatomagmatic? Many explosions occurred in spring and early summer, but others occurred in the winter, and no clear relation exists between explosions and rate of snow melting. Most of the explosions occurred during slight seismic unrest — so slight, in fact, that some such periods are recognized only in hindsight. Hot ballistic ejecta from several of the larger explosions melted snow to form lahars that flowed from the crater (Swanson *et al.*, 1987a, figures 6 and 7).

Two small explosions took place during a period of slightly heightened seismicity on December 7-10, 1989, the first eruptive activity of the dome since October 1986. Another explosion occurred on January 6, 1990, and possibly another small one (unconfirmed as of this writing) on April 25. The small explosions of December and January differed from those of comparable size in the early 1980s by causing measurable deformation of parts of the dome (SEAN, 1989a, b). The December and January explosions both produced only lithic ejecta. A small percentage of the January ejecta contains fresh brown glass unlike that of the dome, and its bulk chemical composition is slightly more mafic than that of dacite erupted from the dome since 1981 (J.S. Pallister, written communication, 1990). How this material relates to the dome and conduit system is under study.

Several large hot rockfalls during periods of rapid dome growth generated small lithic pyroclastic flows and surges that moved hundreds of metres from the base of the dome (Mellors *et al.*, 1988). No explosions accompanied these events. Dust plumes from the large rockfalls blew tens of kilometres downwind, where their deposits resemble those of explosive ash eruptions.

### Chemistry

The magmatic ejecta of 1980, including those of May 18, have an average water-free whole-rock silica content of 63.66% (s.d.=1.14, n=27). The October 1980-October 1981 dome has an average silica content of 62.84% (s.d.=0.34; n=37), and the 1982-86 dome, 63.31% (s.d.=0.45; n=32). Silica gradually increased from the end of 1981 to the latest extrusion in October 1986, though with considerable scatter (Swanson and Holcomb, 1990). The calc-alkaline, augite-hornblende-hypersthene dacite has a large number of crystals, as much as 50 volume per cent of the dome (Cashman, 1988). It contains 3-5% inclusions, chiefly fresh gabbro (some cumulate), but including vein quartz, hornfelsed Tertiary volcanic rocks, and older Mount St. Helens dacite and andesite (Heliker, 1984). The dacite also carries single crystals, clots, and "megacrysts" derived from the inclusions or cognate to the magma. Detailed work underway by J.S. Pallister is designed to sort out the influence of these several factors on the whole-rock compositions.

## Predictions

The repetitive nature of dome growth at Mount St. Helens, and the clear precursors before each episode of growth, led to an ability to predict the events from 1 to 3 weeks in advance (Swanson *et al.*, 1983, 1985). All eruptive episodes after that of May 18, 1980, except for a minor extrusion in June 1984, were anticipated several tens of minutes to, more generally, a few hours in advance on the basis of increased seismicity. Starting in early 1981, the episodes of dome growth were foreseen first (1.5-3 wk) by accelerating ground deformation near or on the dome. Several days later, seismometers one or more kilometres away were recording increased seismicity. A seismometer was installed on the dome in early 1986 and thereafter recognized precursors at the same time or earlier than did the ground-deformation measurements. This experience suggests that, at volcanoes in general, the most sensitive and reliable monitoring data are obtained closest to the vent and should be gathered by a combination of telemetered information and on-site measurements and observations.

The recent geologic record of Mount St. Helens suggests that it could continue to erupt episodically for many decades, despite the present period of quiet. Accordingly, monitoring at some level must be maintained for years to come. Many tourists climb the volcano throughout the year, so that — perhaps surprisingly to some — monitoring is more important now than ever before and will continue to be so until the eruption has clearly ended. Meanwhile, small explosions are possible at any time. In the immortal words of Yogi Berra, "It ain't over 'til it's over." How we will know when it's over is an open and important question.

## Acknowledgements

The entire staff, past and present, of the Cascades Volcano Observatory is responsible for the observations and interpretations summarized in this paper, I am only the Observatory's spokesman and ghost writer.

## References

Anderson, S.W. and Fink, J.H., 1989, Hydrogen-isotope evidence for extrusion mechanisms of the Mount St. Helens lava dome: Nature, v. 341, p. 521-523.

Anderson, S.W. and Fink, J.H., 1990, The development and distribution of surface textures at the Mount St. Helens dome, *in* Fink, J.H., ed., Lava Flows and Domes: Springer-Verlag, Berlin, IAVCEI Proceedings in Volcanology 2, p. 25-45.

Casadevall, T., Rose, W., Gerlach, T., Greenland, L.P., Ewert, J., Wunderman, R. and Symonds, R., 1983, Gas emissions and eruptions of Mount St. Helens through 1982: Science, v. 221, p. 1383-1385.

Cashman, K.V., 1988, Crystallization of Mount St. Helens 1980-1986 dacite: a quantitative textural approach: Bulletin of Volcanology, v. 50, p. 194-209.

Chadwick, W.W., Jr., Archuleta, R.J. and Swanson, D.A., 1988, The mechanics of ground deformation precursory to dome-building extrusions at Mount St. Helens: 1981-1982: Journal of Geophysical Research, p. 4351-4366.

Chadwick, W.W., Jr. and Swanson, D.A., 1989, Thrust faults and related structures in the crater floor of Mount St. Helens volcano, Washington: Geological Society of America, Bulletin, v. 101, p. 1507-1519.

Chadwick, W.W., Jr., Swanson, D.A., Iwatsubo, E.Y., Heliker, C.C. and Leighley, T.A., 1983, Deformation monitoring at Mount St. Helens in 1981 and 1982: Science, v. 221, p. 1378-1380.

Dzurisin, D., Denlinger, R.P. and Rosenbaum, J.G., 1990, Cooling rate and thermal structure determined from progressive magnetization of the dacite dome at Mount St. Helens, Washington: Journal of Geophysical Research, v. 95, p. 2763-2780.

Endo, E.T., Dzurisin, D. and Swanson, D.A., in press, Geophysical and observational constraints for ascent rates of dacitic magma at Mount St. Helens, *in* Ryan, M.P., ed., Magma Transport and Storage: John Wiley and Sons.

Heliker, C.C., 1984, Inclusions in the 1980-83 dacite of Mount St. Helens, Washington, M.S. thesis, Western Washington University, Bellingham, 185 p.

Hill, P.M. and Rutherford, M.J., 1989, Experimental study of amphibole breakdown in Mount St. Helens dacite with applications to magmatic ascent rate determinations: Continental Magmatism Abstract Volume, New Mexico Bureau of Mines & Mineral Resources, Bulletin 131, p. 131.

Iverson, R.M., 1990, Lava domes modeled as brittle shells that enclose pressurized magma, with application to Mount St. Helens, *in* Fink, J.H., ed., Lava Flows and Domes: Springer-Verlag, Berlin, IAVCEI Proceedings in Volcanology 2, p. 47-69.

Iwatsubo, E.Y., Topinka, L. and Swanson, D.A., in press, Slope-distance measurements to the flanks of Mount St. Helens, late 1980 through 1989, *in* Ewert, J.W. and Swanson, D.A., eds., Monitoring Volcanoes: Techniques and strategies used by the staff of the Cascades Volcano Observatory, 1980-1990: United States Geological Survey, Bulletin.

Malone, S.D., Boyko, C. and Weaver, C.S., 1983, Seismic precursors to the Mount St. Helens eruptions in 1981 and 1982: Science, v. 221, p. 1376-1378.

Mellors, R.A., Waitt, R.B. and Swanson, D.A., 1988, Generation of pyroclastic flows and surges by hot-rock avalanches from the dome of Mount St. Helens volcano, USA: Bulletin of Volcanology, v. 50, p. 14-25.

Moore, J.G., Lipman, P.W., Swanson, D.A. and Alpha, T.R., 1981, Growth of lava domes in the crater June 1980-January 1981, *in* Lipman, P.W. and Mullineaux, D.R., eds., The 1980 Eruptions of Mount St. Helens, Washington: United States Geological Survey, Professional Paper 1250, p. 541-547.

Moriya, I., 1978, Morphology of lava domes: Bulletin of the Department of Geography, Kanazawa University, Japan, v. 14, p. 55-69 (in Japanese).

SEAN, 1989a, Mt. St. Helens Volcano: SEAN Bulletin, v. 14, no. 11, p. 22-23.

SEAN, 1989b, Mt. St. Helens Volcano: SEAN Bulletin, v. 14, no. 12, p. 18-19.

Swanson, D.A., Casadevall, T.J., Dzurisin D., Holcomb, R.T., Newhall, C.G., Malone, S.D. and Weaver, C.S., 1985, Forecasts and predictions of eruptive activity at Mount St. Helens, 1975-1984: Journal of Geodynamics, v. 3, p. 397-423.

Swanson, D.A., Casadevall, T.J., Dzurisin, D., 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, p. 1369-1376.

Swanson, D.A., Dzurisin, D., Holcomb, R.T., Iwatsubo, E.Y., Chadwick, W.W., Jr., Casadevall, T.J., Ewert, J.E. and Heliker, C.C., 1987a, Growth of the lava dome at Mount St. Helens, Washington, (USA), 1981-1983, *in* Fink, J.H., ed., The Emplacement of Silicic Domes and Lava Flows: Geological Society of America, Special Paper 212, p. 1-16.

Swanson, D.A., Dzurisin, D. and Stoopes, G., 1987b, Influence of fortnightly earth tides on dome building at Mount St. Helens: Hawaii Symposium on How Volcanoes Work, Hilo, Hawaii, January 19-25, Abstract Volume, p. 245.

Swanson, D.A. and Holcomb, R.T., 1990, Regularities in growth of the Mount St. Helens dacite dome, 1980-1986, *in* Fink, J.H., ed., Lava Flows and Domes: Springer-Verlag, Berlin, IAVCEI Proceedings in Volcanology 2, p. 3-24.

Waitt, R.B. and MacLeod, N.S., 1987, Minor explosive eruptions at Mount St. Helens dramatically interacting with winter snowpack in March-April 1982, *in* Schuster, J.E., ed., Selected Papers on the Geology of Washington: Washington Division of Geology and Earth Resources, Bulletin 77, p. 355-379.

Weaver, C.S., Zollweg, J.E. and Malone, S.D., 1983, Deep earthquakes beneath Mount St. Helens: evidence for magmatic gas transport?: Science, v. 221, p. 1391-1394.

Wilson, L., 1972, Explosive volcanic eruptions — II. The atmospheric trajectories of pyroclasts: Geophysical Journal of the Royal Astronomical Society, v. 30, p. 381-392.

Wilson, L., 1980, Relationships between pressure, volatile content and ejecta velocity in three types of volcanic explosion: Journal of Volcanology and Geothermal Research, v. 8, p. 297-313.