dome lavas contrasts with the decreasing silica content of the products of the explosive activity during 1980 (*9*). In all eruptions where dome growth has followed explosive activity, including the March 1982 eruption (Table 1), the major-element chemistry of the dome lava has been identical to that of the accompanying explosive products (*9*). This similarity suggests that both types of activity result from the movement to the surface of a single body of magma; we envision a small plug ascending in a conduit, where magma high in the column is slightly more volatile-rich (that is, explosive) than the material lower down.

Major-element variation diagrams for 1981 and 1982 dome lavas show trends similar to those of the 1980 products (*9*). The lack of chemical variation since 1980 suggests that all eruptions are being generated from a single, relatively homogeneous magma body, probably at a depth of only 1 to 2 km (*10*). The results of analyses of emitted gases suggest that its volume exceeds 0.3 km^3 (*11*). Because the trend since the end of 1980 has been toward the eruption of more homogeneous material, it seems that chemical and mineralogic variations of the June 1980 "mixed magmas" (*7, 8*) were most likely caused by the mixing of pockets of remnant-evolved magma from the 18 May 1980 eruption. Seismic data (*10*) suggest that new material may have been intruded at depth during the activity of March 1982. Petrologic data, however, indicate that, if such an intrusion occurred, either this new material has not yet reached the surface or it is identical to material already residing in the shallow chamber.

The results of analyses of solid products of the last eruptive episode [the 19th century Floating Island andesite and Goat Rocks dacite (*12*)] lie along trends delineated by the 1980 lavas (Fig. 2b). This correspondence supports the suggestion (*9*) that the activity for 1980 through 1982 represents continued evolution of the magma body that caused the eruptions of the past few centuries. Although on the basis of past eruptive episodes a declining SiO_2 content might be expected as a trend for future activity (*12*), there is no evidence for the continuation of the trend toward lower-SiO_2 magma initiated in 1980 (*9*). In short, the chemical homogeneity of recently erupted materials suggests that the shallow magma system has reached a temporary steady state that will probably continue for the near future. The simplest model to account for such a steady state involves a slowly cooling and crystallizing body of magma. Volatiles concentrated in the melt during this process may sufficiently decrease the density of part of this body to drive the sporadic rise of some of this material to the surface (*11*).

Petrologic changes in eruptive products have been monitored at Bezymianny volcano in Kamchatka; lavas from the Bezymianny dome Novy were chemically homogeneous over 20 years (1956 through 1976) of periodic dome growth, while exhibiting distinct changes in crystallinity, both in the ratios of phenocryst phases and in the development of second-generation phenocrysts (*13*). In 1976, a decrease in the SiO_2 content of the Bezymianny dome lava accompanied a change in eruptive products.

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Monitoring the 1980–1982 Eruptions of Mount St. Helens: Compositions and Abundances of Glass

Abstract. *The Mount St. Helens eruptive sequence of 1980 through 1982 reflects the tapping of successively less water-rich, more highly crystallized, and more viscous, highly phyric dacitic magmas. These changes reflect both syn- and preeruption processes. The decreasing water content points to a continued decline in the volume and intensity of explosive pyroclastic activity. This decreasing water content appears to be composed of a long-term trend established during a long period of repose (about 130 years) imposed on short-term trends established during short periods (about 7 to 100 days) of repose between eruptions in the present eruptive cycle. The last two eruptive cycles of this volcano, the T (A.D. 1800) and W cycles (about A.D. 1500), exhibited similar trends. These changes are inferred from a combination of petrographic, bulk chemical, and electron- and ion-microprobe analyses of matrix and melt-inclusion glasses.*

The dacitic to andesitic eruptions of Mount St. Helens in 1980 through 1982 are characterized by short periods of activity, lasting a few days, separated by much longer periods of quiescence, characterized by ongoing volatile emissions. The mode of eruption has changed in a systematic way and can be divided into five phases (Table 1). These phases form a convenient framework in which to view (i) the changes in the extent of crystallization, (ii) the inferred H_2O contents of matrix and melt-inclusion glasses, and (iii) the preeruption H_2O contents of the bulk magma.

I focus here on the use of compositional changes in the matrix glasses of the eruptive products and melt inclusions in crystals and in the bulk rocks as a tool in volcano monitoring. Glasses in the matrix and in melt inclusions show systematic changes in composition with time. Melt inclusions provide unique information on preeruption volatile compositions and are a guide to preeruption magma compositions. The pyroclastic samples provide material that erupted from some depth and then was rapidly quenched. They furnish insight into the state of the magma chamber prior to eruption. Dome samples, on the other hand, reflect a slower and shallower emplacement process, resulting in a longer cooling history and more extensive degassing. The highly phyric nature of even the least crystalline samples (40 percent crystals) reflects extensive preeruption (intratelluric) crystallization. The glasses have evolved to their final eruption composition through a combination of cooling and H_2O loss, both factors contributing to increased crystallinity and increased viscosity through time.

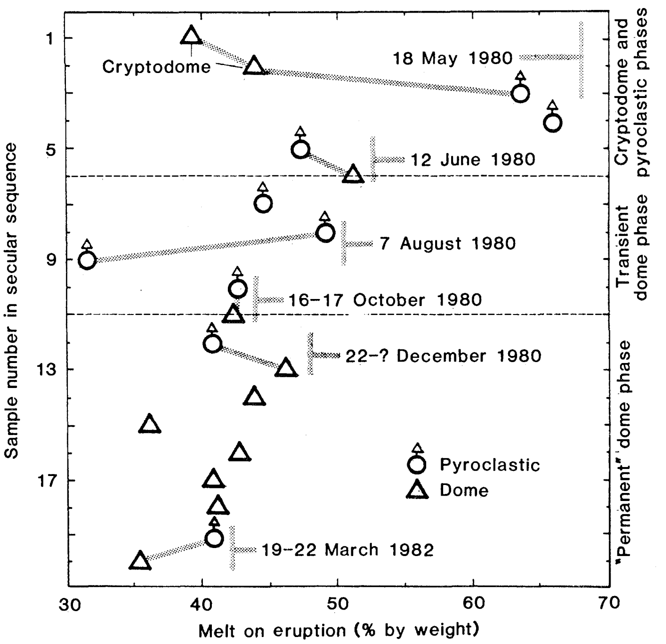
The bulk rock compositions became progressively more basic during the early phases of the eruption from 18 May 1980 to 18 October 1980 (*1*, *2*). During that time, the SiO_2 content decreased from 64.4 to 62 percent. The bulk composition has not changed perceptibly since then. The rocks in this sequence are highly phyric augite-hornblende-hypersthene dacite and andesite. Plagioclase is by far the dominant phenocryst, and alkali feldspar and quartz have not been noted in thin section. Augite phenocrysts are extremely rare in the cryptodome and 18 May 1980 pyroclastic phase, but they have become more abundant through time. Iron-titanium oxide geothermometry (*3*) indicates no clear trend with time, with indicated temperatures of about 960° ± 40°C.

The amount of matrix glass, which is equivalent to the percentage of melt on eruption, has decreased through time (Fig. 1). This decrease may be determined by modal analysis (*2*) or from the K_2O content of the matrix glass and bulk rock (Tables 2 to 4). The K_2O behaves primarily as an incompatible element during the crystallization of the sequence. Thus the crystallinity is proportional to the K_2O content of the glass. Small amounts of K_2O occur in hornblende, but the amount and abundance of hornblende are too small to change the results significantly.

Melt inclusions are common in the phenocrysts, particularly in plagioclase. They range from < 1 μm to over 100 μm in diameter. Analysis of inclusions smaller than 10 μm has not proved possible by the method used here, which involves constant moving of a focused electron microprobe beam to minimize alkali and H_2O loss (*4*). I infer that the H_2O contents are equal to the sum of matrix glass, which is assumed to be totally degassed, minus the sum of melt-inclusion glass (Tables 2 to 4). A similar method has been used by Anderson (*5*). Direct determinations of hydrogen in melt inclusions in hornblende by ion

Table 1. An eruptive mode-petrologic classification of the eruption sequence of Mount St. Helens between 1980 and 1982.

Phase	Dates (length of phase)	Phase name (analysis number)	Description
1	27 March to 18 May 1980 (51 days)	Cryptodome emplacement	Growth of bulge, periodic small phreatic explosions (*14*). No essential ejecta. Ejecta totally crystalline.
2	18 May 1980 (a few minutes)	Cryptodome destruction (analyses 1 and 2, Table 2)	Catastrophic phreato-magmatic explosions. Ejection of much of the cryptodome as the "blast facies" gray dacite. 40 to 0 percent melt.
3	18 May and 25 May 1980 (25 days)	Plinian pumice eruptions (analyses 3 and 4, Table 2)	Breaching of "main" magma batch as white pumice in mainly Plinian eruptions. Tapping of H_2O-rich (5 to 7 percent) melt-rich (60 percent) magma.
4	12 June to 17 October 1980 (126 days)	Transient domes (analyses of Table 3)	Alternation between melt-rich (50 to 60 percent melt), H_2O-rich (5 to 2 percent) magmas in pyroclastic dome-destroying eruptions followed by emplacement of H_2O-poor (1 to 2 percent), melt-poor (40 percent), dome-forming magmas.
5	17 October 1980 to 14 May 1983 (576 + days)	Dome building (analyses in Table 4)	Repeated eruptions of viscous H_2O-poor (1 to 3 percent), melt-poor (40 percent) magmas, with rare pyroclastic eruptions, smaller in volume and lower in H_2O and melt than in the previous phase. The eruption is now in this phase.



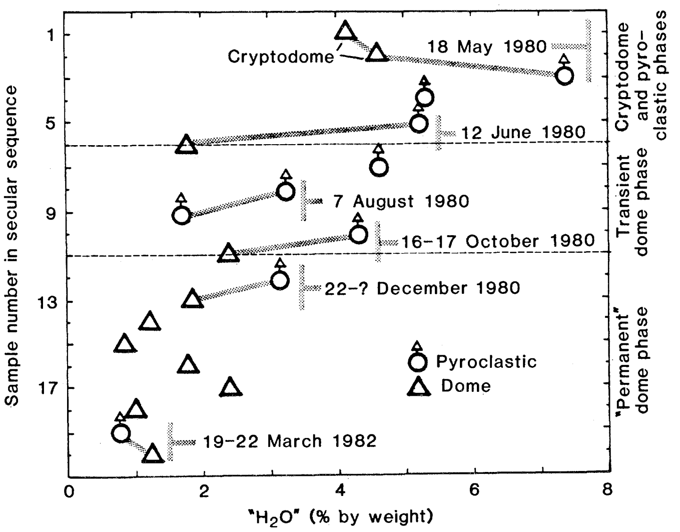


Fig. 1 (left). Melt content in samples from the eruptive sequence of 1980 through 1982. Samples connected by shaded bars were erupted sequentially during the indicated eruptive episode. Melt content has been calculated on the basis of the analyses in Tables 2 to 4. The 15 eruptive events between 18 May 1980 and 19 March 1982 are represented. Sample numbers on the *Y*-axis correspond to analysis numbers in Tables 2 to 4. Fig. 2 (right). The inferred H_2O content of average melt inclusions in the same sequence based on the difference between the sums of matrix and melt-inclusion glasses in Tables 2 to 4. Rocks erupted sequentially in the same episode are connected by shaded bars (15 eruptive episodes between 18 May 1980 and 19 March 1982).

microprobe gave concentrations in the range of 3 to 7 percent calculated as the H_2O equivalent (*6*); these results are in accord with the values obtained on these samples by the differences-in-sums method used here.

Melt-inclusion compositions do not a priori reflect the composition of the magma from which they were derived. During rapid crystal growth, components excluded from the crystal structure may be enriched at the liquid-crystal interface. Postentrapment crystallization of the host crystal and newly crystallized phases may also alter the original melt composition. This process has contributed to the highly evolved composition of melt inclusions in some dome samples, as revealed by the presence of visible overgrowths on capsule walls and by the presence of microlites in some. The close similarity between the compositions of melt inclusions and matrix glass in the 18 May 1980 pumice except for H_2O (Table 2, analysis 3) demonstrates that the former process has not had a major effect on the melt-inclusion compositions.

A decrease in the average H_2O concentration of the preemplacement magmas through time is suggested by melt-inclusion analyses (Fig. 2). For each eruptive episode starting with a pyroclastic phase and ending in dome emplacement (phase 4), the pyroclastic samples typically show higher water concentrations than the dome samples (12 June 1980, 16 to 17 October 1980, and 22 December in Fig. 2). In other words, each eruptive episode in such sequences first tapped H_2O-rich and then H_2O-poor magmas. The pumice-dome pair of 19 to 22 March 1982 is an exception to this relation.

The decrease in the inferred H_2O content of the preeruption magma correlates with the general decline of pyroclastic activity. Thus, monitoring of long-term eruptions in terms of analyses of melt inclusions and matrix glasses may be of value in eruption prediction (*7*).

Samples from the cryptodome contain about 40 percent highly fractionated matrix glass (Fig. 1). The probable high H_2O content of the melt inclusions in plagioclase and the marginal decomposition of hornblende phenocrysts are consistent with degassing of an originally H_2O-rich magma sometime during the rise and emplacement of the cryptodome. The transition from highly fractionated glass to less fractionated, microlite-free glass in the 18 May 1980 air-fall tephra sequence downwind from Mount St. Helens (*8*) correlates with the sequence cryptodome-Plinian pumice phase reported here for hand-specimen samples collected on the cone itself in both air-fall and pyroclastic surge deposits.

Eichelberger and Hayes (*9*) reported an inferred H_2O content of 0.7 to 1.7 percent (by weight) in the magma that gave rise to the pre-Plinian blast of 18 May 1980. These values are in accord with those of the highly fractionated matrix glasses of the blast-facies samples (Table 2, analysis 1 and 2). The melt inclusions, on the other hand, are not highly fractionated and have a considerably higher H_2O content. These two samples were ejected catastrophically, and thus the matrix glass compositions probably reflect extensive preeruption degassing, giving rise to H_2O contents similar to those inferred by Eichelberger and Hayes (*9*) on the basis of hydrodynamic equations of motion of juvenile ejecta. The H_2O-rich, largely undegassed magma, represented in the melt inclusions

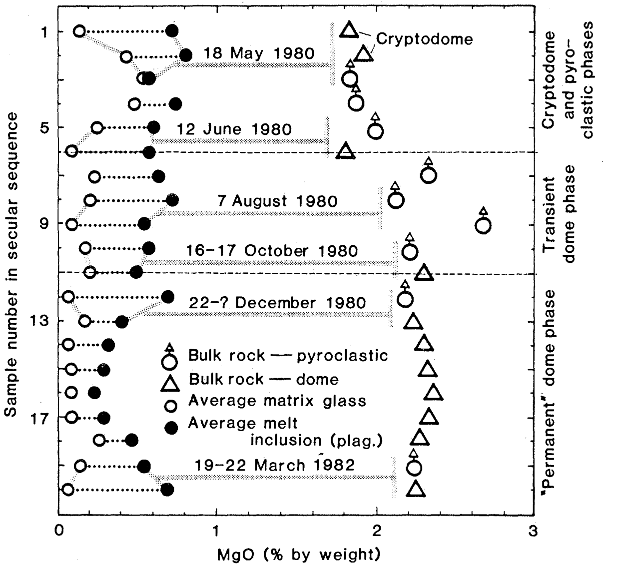


Fig. 3. The MgO content of bulk rocks and average matrix and melt-inclusion glasses in the same sequence. Rocks erupted sequentially in the same eruption episode are connected by shaded bars (15 eruptive episodes between 18 May 1980 and 19 March 1982); *plag.*, plagioclase.

Table 2. Bulk composition (percentages by weight) from fusion or classical wet analyses (those for which FeO and Fe_2O_3 values are given) compared with "moving beam" electron microprobe average analyses of glasses for various samples from the eruptive sequence of 1980 through 1982. Each set of three analyses refers to a single sample: first analysis, the bulk rock; second, the average composition of the matrix glass; and third, the average composition of melt inclusions in plagioclase. The data set includes samples from the cryptodome and the pyroclastic phase samples from the 1980 eruptions and from the T (A.D. 1800) and W (A.D. 1500) pumices. The presence of normative corundum in some of the glass analyses probably reflects sodium loss during analysis; N.D., not determined; USNM, U.S. National Museum.

Analysis	SiO_2	Al_2O_3	FeO*	MgO	CaO	K_2O	Na_2O	TiO_2	P_2O_5	MnO	Sum
	18 May 1980 gray dacite "blast facies" (USNM 115379-37), fusion analysis										
1	64.26	17.51	3.90	1.81	4.79	1.28	4.68	0.53	0.10	N.D.	98.86
	79.60	11.76	1.39	0.15	0.42	3.24	2.55	0.32	0.12	N.D.	99.55
	73.64	10.97	2.54	0.68	0.77	2.91	3.44	0.47	0.10	N.D.	95.42
	18 May 1980 gray dacite "blast facies" (USNM 115379-34), fusion analysis										
2	63.97	17.56	4.11	1.89	4.97	1.27	4.67	0.61	0.12	0.07	99.24
	77.37	11.73	1.46	0.43	0.71	2.89	3.55	0.34	0.19	N.D.	98.67
	68.99	13.49	2.68	0.76	1.72	2.22	3.69	0.51	N.D.	N.D.	94.06
	18 May 1980 white pumice lapillus (USNM 115379-8-1), FeO = 2.60, Fe_2O_3 = 1.51										
3	64.02	17.69	3.96	1.80	4.91	1.29	4.47	0.62	0.10	0.06	98.92
	72.66	14.86	2.41	0.54	2.64	2.04	4.68	0.38	0.09	N.D.	100.30
	67.96	14.29	2.05	0.54	2.52	1.89	3.27	0.31	0.09	N.D.	92.92
	25 May 1980 pumice lapillus (USNM 115379-32-1), FeO = 2.44, Fe_2O_3 = 1.75										
4	63.58	17.80	4.01	1.83	4.96	1.25	4.58	0.63	0.11	0.06	98.81
	70.80	14.46	2.40	0.49	2.50	1.90	4.59	0.39	0.08	N.D.	97.61
	67.91	14.14	2.41	0.69	2.17	1.91	2.58	0.35	0.12	N.D.	92.28
	T pumice										
	63.09	18.12	4.47	2.08	5.23	1.37	4.84	0.64	0.17	N.D.	100.01
	74.32	13.81	1.63	0.34	1.73	2.54	3.74	0.29	0.04	N.D.	98.44
	69.09	13.52	1.49	0.36	1.88	2.14	3.49	0.28	0.06	N.D.	92.31
	W pumice										
	66.93	17.64	3.41	1.25	3.95	1.52	4.70	0.47	0.14	N.D.	100.01
	75.45	13.49	1.55	0.28	1.60	2.36	3.73	0.23	0.05	N.D.	98.75
	70.26	12.61	1.38	0.29	1.43	2.20	3.35	0.19	0.05	N.D.	91.75

*Total iron calculated as FeO.

Table 3. Analyses of the transient dome phase. See Table 2 for further details.

Analysis	SiO_2	Al_2O_3	FeO*	MgO	CaO	K_2O	Na_2O	TiO_2	P_2O_5	MnO	Sum
12 June 1980 pumice (115379-1-4), bulk; FeO = 2.78, Fe_2O_3 = 1.60											
5	62.70	18.04	4.22	1.97	5.31	1.22	4.47	0.66	0.10	0.07	98.76
	75.99	12.54	1.80	0.26	1.31	2.57	3.63	0.43	N.D.	0.04	98.57
	69.23	13.05	2.17	0.58	1.69	2.28	3.91	0.37	N.D.	0.05	93.33
12 June 1980 dome fragment (115379-40), fusion analysis											
6	63.42	18.31	4.22	1.80	5.34	1.29	5.08	0.60	0.11	N.D.	100.17
	76.54	12.82	1.59	0.13	1.20	2.52	3.99	0.37	0.08	N.D.	99.24
	73.09	12.21	2.29	0.57	1.34	2.66	4.70	0.40	0.12	N.D.	97.38
22 July 1980 pumice lapillus (115377-1), FeO = 3.11, Fe_2O_3 = 1.6											
7	62.86	17.67	4.55	2.29	5.35	1.22	4.52	0.68	0.13	0.08	99.35
	77.55	12.70	1.69	0.24	1.22	2.73	2.56	0.40	0.09	N.D.	99.18
	70.67	12.71	2.35	0.61	1.58	2.38	3.67	0.47	0.12	N.D.	94.56
7 August 1980 pumice (115414), FeO = 2.85, Fe_2O_3 = 1.69											
8	63.47	17.60	4.37	2.11	5.19	1.22	4.53	0.64	0.09	0.08	99.30
	75.26	12.74	1.80	0.22	1.41	2.47	4.29	0.40	0.09	N.D.	98.68
	71.90	12.70	1.90	0.35	1.23	2.63	4.34	0.35	N.D.	0.01	95.43
7 August 1980 pumice (115415), fusion analysis											
9	60.46	18.60	4.70	2.64	6.40	1.01	4.93	0.71	0.13	N.D.	99.58
	77.69	11.76	1.40	0.11	0.79	3.17	3.29	0.36	0.09	N.D.	98.66
	74.48	11.14	2.43	0.52	0.93	2.91	4.02	0.49	N.D.	N.D.	96.92
16 October 1980 white pumice (115418-1-1), FeO = 3.00, Fe_2O_3 = 1.56											
10	63.08	17.63	4.40	2.16	5.31	1.23	4.61	0.64	0.11	0.08	99.25
	77.82	11.79	1.53	0.19	0.81	2.88	3.15	0.38	0.05	N.D.	98.60
	71.37	11.94	2.63	0.54	1.24	2.29	3.74	0.41	0.12	N.D.	94.28
17 October 1980 dome fragment (115418-60), FeO = 3.12, Fe_2O_3 = 1.59											
11	62.86	17.80	4.55	2.27	5.28	1.25	4.44	0.67	0.14	0.08	99.34
	77.66	12.16	1.60	0.20	0.84	2.96	3.60	0.41	0.08	N.D.	99.51
	74.76	11.52	2.24	0.49	0.89	2.96	3.84	0.35	0.07	N.D.	97.12

Table 4. Analyses of the dome growth phase. See Table 2 for further details.

Analysis	SiO_2	Al_2O_3	FeO*	MgO	CaO	K_2O	Na_2O	TiO_2	P_2O_5	MnO	Sum
22 December 1980 pumice (115427-1), FeO = 2.94, Fe_2O_3 = 1.6											
12	62.97	17.74	4.38	2.14	5.35	1.23	4.64	0.66	0.11	0.08	99.30
	78.67	11.05	1.38	0.08	0.63	3.01	3.34	0.32	0.08	N.D.	98.56
	72.76	11.17	3.03	0.66	1.08	2.85	3.34	0.36	0.14	N.D.	95.39
22 December 1980 dome (115427-4), fusion analysis											
13	63.78	17.44	4.70	2.21	5.10	1.30	4.80	0.65	0.09	N.D.	100.07
	77.96	11.56	1.66	0.18	0.67	2.81	3.07	0.39	0.08	N.D.	98.38
	74.37	11.46	2.18	0.40	0.79	3.01	3.90	0.41	N.D.	N.D.	96.52
February 1981 dome (115434), fusion analysis											
14	62.51	17.75	4.73	2.27	5.34	1.30	5.11	0.72	0.11	N.D.	99.84
	77.14	11.66	1.50	0.06	0.68	2.95	3.59	0.40	0.03	N.D.	98.01
	75.16	11.22	1.98	0.31	0.84	3.08	3.69	0.40	0.07	N.D.	96.75
11 April 1981 dome (115439), FeO = 2.95, Fe_2O_3 = 1.92											
15	62.58	17.88	4.68	2.29	5.39	1.20	4.54	0.71	0.09	0.08	99.44
	77.77	11.40	1.33	0.09	0.53	3.31	3.97	0.40	0.06	N.D.	98.86
	76.63	11.15	2.04	0.29	0.74	3.14	3.63	0.39	N.D.	N.D.	98.01
20 June 1981 dome (115465), FeO = 2.76, Fe_2O_3 = 2.18											
16	62.95	17.55	4.72	2.31	5.43	1.23	4.47	0.70	0.10	0.08	99.54
	76.73	11.61	1.55	0.11	0.72	2.89	3.63	0.37	0.06	N.D.	97.67
	74.25	11.47	1.77	0.24	0.86	3.18	3.68	0.39	0.07	N.D.	95.91
7 September 1981 dome (115525), FeO = 3.08, Fe_2O_3 = 1.76											
17	62.72	17.88	4.66	2.29	5.32	1.22	4.51	0.68	0.14	0.08	99.50
	77.05	11.72	1.60	0.10	0.72	2.99	3.98	0.40	0.05	N.D.	98.61
	74.28	11.78	1.80	0.29	0.95	2.82	3.90	0.35	0.06	N.D.	96.23
30 October 1981 dome (115543-109), FeO = 3.08, Fe_2O_3 = 2.75											
18	62.68	17.78	4.63	2.23	5.38	1.23	4.50	0.70	0.14	0.08	99.35
	77.29	11.28	1.59	0.27	0.71	2.99	3.45	0.41	0.06	N.D.	98.05
	73.96	10.97	2.26	0.47	0.89	3.13	4.76	0.46	0.09	N.D.	96.99
19 March 1982 pumice (115659-2), FeO = 3.19, Fe_2O_3 = 1.58											
19	62.77	17.74	4.61	2.19	5.32	1.25	4.47	0.70	0.14	0.06	99.25
	77.16	10.51	1.13	0.15	0.84	3.05	3.33	0.27	N.D.	0.05	96.49
	73.47	11.15	2.26	0.53	0.96	2.88	4.07	0.39	N.D.	N.D.	95.71
20 to 22 March 1982 dome (115543-125), FeO = 3.20, Fe_2O_3 = 1.56											
20	62.94	17.70	4.60	2.20	5.33	1.25	4.56	0.68	0.15	0.07	99.48
	77.79	11.16	1.35	0.06	0.57	3.50	3.88	0.36	N.D.	0.03	98.70
	75.30	9.52	2.90	0.68	1.17	3.21	4.07	0.55	N.D.	0.07	97.47

and immediately below the cryptodome cap produced the ensuing Plinian phase.

In all samples except the 18 May 1980 pumice (Table 2, analysis 3), the melt inclusions are less fractionated on an anhydrous basis than the matrix glasses. Figure 3 shows this relation in terms of MgO content. This difference reflects a higher H_2O content in melt inclusions, as outlined above, and crystallization of matrix melt during extensive degassing. The matrix and melt-inclusion glasses most likely have undergone the same time-temperature cooling process. For the 18 May 1980 pumice the similarity in the MgO content of the matrix and melt inclusions indicates incorporation of most of the melt inclusions just prior to catastrophic expulsion. Evidently, quenching occurred on eruption, preventing matrix melt crystallization even though the magma degassed.

Crystal fractionation probably did not occur in magmas with the physical properties of those in the sequence. The composition of the matrix glasses combined with the inferred H_2O contents prior to eruption allow calculation of preeruption viscosities (*10*). Minimum liquid viscosities ($10^{3.32}$ poise) were reached in the most voluminous (0.2 km^3) magma batch, which erupted during the Plinian pumice phase of 18 May 1980. Even for this magma, crystal settling velocities for a plagioclase crystal 0.2 mm long, a typical plagioclase phenocryst size in the sequence, is about 200 m per 100 years. This calculation fails to take into account shear stress considerations and the abundance of phenocrysts, both factors that tend to further decrease or even prohibit crystal settling in such a magma. Thus crystal fractionation, if it occurred, happened under lower viscosity conditions, such as a total andesitic and dacitic melt with high H_2O. Therefore, some other process of fractionation may well have been involved (*11*).

The melt-inclusion analyses reported here are the average of 15 to 30 individual melt-inclusion measurements in plagioclase phenocrysts in 20 samples. There is a range in the inferred H_2O content in each set of melt-inclusion analyses. For example, the inferred H_2O content in 18 May 1980 pumice (Table 2, analysis 3) ranges from 3 to 11 percent. This range is far larger than the analytical uncertainty and may reflect a changing H_2O content in the magma. One plausible explanation takes this variability into account. A Mount Hood sample (*12*), largely liquid andesitic magma with about 4.5 percent H_2O, began crystallizing at a pressure of 3 kbar; the H_2O

content then increased to about 7.5 percent with the crystallization of about 40 percent (by weight) crystals, first plagioclase and hypersthene and then hornblende. Such an increase in H_2O content may also be reflected in the inversely zoned margins of many plagioclase phenocrysts. The cap of the Mount St. Helens magma body "leaked," giving rise to the cryptodome. Finally, with mounting H_2O pressure, the catastrophic eruption of 18 May 1980 occurred. The Mount Hood andesite (*12*) has a SiO_2 content of about 60 percent; the 18 May 1980 samples have a content of 64 percent. Thus, the parallels between the experimental data used here and the actual 18 May 1980 magma are tentative. This scenario envisions pressures of over 3 kbar at the time of the eruption. This is equivalent to a depth of at least 9 km, but the pressure may have been reached at much shallower depths, generating short-lived overpressures. I envision an interplay of such overpressures with tectonic events, giving rise to the pre–18 May 1980 phreatic phase and the 18 May 1980 catastrophic explosion.

The T pumice (A.D. 1800) and W pumice (A.D. 1500), products of the initial phases of the last two eruptive cycles of Mount St. Helens, also tapped initially H_2O-rich magmas (Table 2) (*13*). Analyses of melt inclusions in a sample from Goat Rocks dome (T cycle) show the same low H_2O contents as in the current sequence and thus also reflect the emplacement of highly crystallized viscous, H_2O-poor magmas. The pre–18 May 1980 summit dome samples (part of W-cycle eruptives) examined so far have proven unsuitable for electron microprobe analyses. They have undergone extensive hydrothermal alteration, resulting in crystallization and compositional alteration of melt inclusions.

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Deep Earthquakes Beneath Mount St. Helens: Evidence for Magmatic Gas Transport?

Abstract. *Small-magnitude earthquakes began beneath Mount St. Helens 40 days before the eruption of 20 March 1982. Unlike earlier preeruption seismicity for this volcano, which had been limited to shallow events (less than 3 kilometers), many of these earthquakes were deep (between 5 and 11 kilometers). The location of these preeruptive events at such depth indicates that a larger volume of the volcanic system was affected prior to the 20 March eruption than prior to any of the earlier dome-building eruptions. The depth-time relation between the deep earthquakes and the explosive onset of the eruption is compatible with the upward migration of magmatic gas released from a separate deep reservoir.*

Volcanic earthquakes have been used as the basis for eruption prediction at many volcanoes. Predictions typically are based on either the rapid increase in the number of shallow, small-magnitude earthquakes or the upward migration of earthquake locations to shallower depths (*1, 2*). At Mount St. Helens, all the eruptions since the renewal of activity in March 1980 have been preceded by swarms of shallow earthquakes, harmonic tremor, or both (*2–4*). Neither earthquakes deeper than 5 km nor evidence of the upward migration of seismic foci were observed prior to any eruption of this volcano before 1982.

The eruption of Mount St. Helens on 20 March 1982 was preceded by shallow volcanic earthquakes, but there were two distinct differences from the sequence of events observed in earlier dome-building eruptions. First, the increase in seismicity began well in advance of either changes in geodetic measurements or tilting of the crater floor near the lava dome (*5, 6*). This contrasts with the observations of the 1981 dome-building eruptions, when measured distances between points near the lava dome and a fixed reference point showed significant acceleration in the rate of contraction before the number of shallow volcanic earthquakes began to increase above the background frequency (*4, 5*). Second, this was the first eruption of Mount St. Helens preceded by deep earthquakes (depth, > 5 km). The 1980 explosive eruptions were followed by swarms of deep earthquakes (*3*); the other dome-building eruptions were neither preceded nor followed by deep earthquakes that could be related to the eruption.

The seismic network at Mount St. Helens includes six stations on the immediate cone and ten stations at distances out to 40 km. The data are recorded on an event-triggered digital computer system. The large number of stations on the mountain and the fine resolution of the digital data permit accurate determination of earthquake locations beneath the crater. The velocity model is a modification of one developed for the Cascade Range (*7*). The hypocenters for a total of 493 earthquakes beneath Mount St. Helens between 1 February and 23 March 1982 were calculated. Data for 262 well-recorded events were included in this study (*8*).

The shallow preeruption earthquakes are centered near the lava dome (Fig. 1); similar patterns have been observed before all the other dome-building eruptions and two of the 1980 explosive eruptions (*3*). The shallow volcanic earthquakes have coda magnitudes of less than 3.0, and they cluster in the upper 3