Reports

Mount St. Helens, Washington, 1980 Volcanic Eruption: Magmatic Gas Component During the First 16 Days

Abstract. *Eruption plumes of Mount St. Helens, Washington, showed low rates of sulfur dioxide emission, and ash leachates had low ratios of sulfur to chlorine. These data and the nonvesicularity of ash fragments are indicative of only a small eruptive magmatic component. The low amounts of soluble fluorine on the ashes pose no health problems. Violent magmatic activity is possible, and thus continued geochemical monitoring is advised.*

Eruptions of steam and ash from Mount St. Helens, Washington, began on Thursday, 27 March 1980 at 12:36 P.S.T. (*1*). Information made available at U.S. Geological Survey (USGS) press conferences in Vancouver, Washington, indicated that the ash from the eruptions was comminuted fragments of old rock from the volcanic cone rather than new magmatic material (*2*). This result emphasized the possibility that the eruptions were phreatic and that there was little or no magmatic component. Our studies of the gases from the eruptions during the first 2 weeks have clarified this point.

Sulfur dioxide was measured in plumes from 11 eruptive events between 30 March and 12 April 1980. We also noted the odor of H_2S when flying beneath portions of some plumes. The SO_2 measurements were made with a correlation spectrometer (*3*) mounted in a low-wing aircraft or a helicopter. In the former instances, the measurements were made from traverses below and at right angles to the plume. In the latter, the traverses were made vertically beside the plume. Responses recorded during the 27 traverses made between 30 March and 5 April indicated a very low rate of SO_2 emission, with a mean of 30 tons per day (*4*). On many traverses, SO_2 was not detected by our spectrometer. During the period 9 through 11 April, a visible continuous plume was observed that contained a measurable SO_2 component of approximately 3 tons per day. Several small eruptions were also measured and found to be producing SO_2 at a rate of 30 tons per day. We conclude that the rate of SO_2 emission was very low during the first 2 weeks of activity at Mount St. Helens. Other actively erupting volcanoes produce SO_2 at the rate of thousands of tons per day (*5*).

Analysis of water-soluble constituents washed from volcanic ash collected before it has been rained on provides another method of detecting magma-derived constituents in volcanic plumes (*6*, *7*). The Cl^-, SO_4^{2-}, and F^- contents of ash leachates from the Mount St. Helens eruption are compared with leachate values from nine other circum-Pacific volcanic eruptions in Table 1. Factors affecting the concentration of soluble material on volcanic ash, in addition to the concentration in the plume, include the amount of ash relative to gas, the size distribution of the ash, the nature of the ash surfaces, the temperature of the plume, and the distance the ash has traveled in the plume both vertically and horizontally (*8*). The amounts of Cl^-, SO_4^{2-}, and F^- on Mount St. Helens ash are not unlike those on ash from other eruptions that had magmatic components. The amounts of Cl^- and SO_4^{2-} on Mount St. Helens ash, however, are much less than the amounts on ashes collected during the first weeks of the major eruptions of Pacaya in 1965 and Irazú in 1963. Because of the variables affecting the amounts of solubles on the ash, it is the S/Cl ratio that best allows comparison of eruptions of different styles. The 4 April S/Cl ratio is lower than that for any other eruption (Table 1). Although there is a change between 4 and 12 April, the S/Cl ratio remained low compared to that of many major magmatic eruptions, and we therefore conclude that the magmatic component was minor. Scanning electron microscopic analysis of Mount St. Helens ash samples revealed essentially no vesiculated material.

Soluble fluorine on volcanic ash has harmed people and animals in Iceland (*9*). The Mount St. Helens ash is low in soluble fluorine. The amount is comparable to that of many Central American volcanic eruptions but less than that of some Central American and Icelandic eruptions and much less than that of the extremely fluorine-rich eruption (1400 to 2000 parts per million) of Hekla, Iceland, in 1970 (*9*). The data suggest that Mount St. Helens ash, in the amounts being produced in these early eruptive stages, presents no health problem with respect to soluble fluorine. The continued determination of fluorine in ash leachates as a check on the potential health hazard is encouraged.

On the basis of a study of the eruptive

Table 1. Soluble materials on volcanic ash [in parts per million (ppm) relative to the weight of the ash washed]. All data are for ash never rained on.

Volcano	Date of eruption	*N*	Cl^- (ppm)	SO_4^{2-} (ppm)	F^- (ppm)	S/Cl	Reference
Mount St. Helens (*14*)	4 April 1980	1	600	110	8	0.06	This report
Mount St. Helens	12 April 1980	1	980	640	8	0.22	This report
Cerro Negro, Nicaragua	1968	14	257	202	17	0.26	(*6*)
Cerro Negro, Nicaragua	1971	40	777	541	14	0.23	(*7*)
Pacaya, Guatemala	October 1965	1	1,240	2,600	44	0.69	(*6*)
Pacaya, Guatemala	1968	4	174	203	41	0.39	(*6*)
Santiaguito, Guatemala	1967–1968	9	977	1,202	4	0.41	(*6*)
Fuego, Guatemala	1971	62	189	152	4	0.27	(*7*)
Fuego, Guatemala	1974	31	140	1,590		3.8	(*5*)
San Miguel, El Salvador	April 1970	12	7,114	3,040	9	0.14	(*4*)
Irazú, Costa Rica	March 1963	2	11,160	21,720	8	0.65	(*4*)

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history of Mount St. Helens, it was predicted that the volcano was likely to erupt, possibly before the end of this century (*10*). The early activity observed at Mount St. Helens is similar in character to the eruption of Lassen Peak Volcano in California during the period 1914 to 1921 (*11*). During the first year of Lassen's activity, approximately 150 phreatic eruptions sent cold ash and steam columns to heights as great as 3000 m above the crater. No report was made of sulfur or acid fumes during that period. Magmatic activity began on 19 May 1915 with a violent pyroclastic eruption of dacitic magma. Nuée ardente–type eruptions followed on 20 and 22 May. Then the eruptive activity subsided with minor periods of heightened activity, until at least February 1921. Our observations of Mount St. Helens are certainly consistent with the possibility that the current eruptive style may evolve into eruptions with a larger magmatic component.

Volcanic gas geochemistry can provide indications of increasing magmatic contributions to eruptions. At Mount Etna in Sicily, the rate of release of SO_2 has been shown to increase before magmatic eruptions (*12*). The S/Cl ratio in leachates is related to SO_2/HCl ratios in volcanic gas (*13*). Monitoring the SO_2 emission and measuring the S/Cl ratio in leachates could provide important premonitory indicators of a magmatic eruption. Therefore, continued geochemical monitoring of Mount St. Helens is advised.

RICHARD E. STOIBER
STANLEY N. WILLIAMS
LAWRENCE L. MALINCONICO
Department of Earth Sciences,
Dartmouth College,
Hanover, New Hampshire 03755

References and Notes

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14. The first sample was collected by D. Swanson (USGS) and made available to us by T. Casadevall (USGS). The second sample was collected by L.L.M. with logistical support provided by a USGS helicopter and D. A. Johnston (USGS).
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Contact Metamorphism by an Ophiolite Peridotite from Neyriz, Iran

Abstract. *Ophiolites are conventionally regarded as fragments of former oceanic lithosphere. Mineralogical and field evidence indicates that peridotite of the Neyriz ophiolite was intruded at high temperature into folded crystalline limestones, forming skarns. This excludes the formation of the ophiolite at a mid-ocean ridge but is consistent with its origin by intrusion during continental rifting.*

Basic and ultrabasic rocks of an ophiolite complex are exposed in the Neyriz region of southern Iran where they were emplaced by thrusting during the late Cretaceous (*1*). One unusual aspect of this ophiolite is the presence of skarns at the contact between crystalline limestones and the ophiolite peridotite. These skarns have been interpreted (i) as remnants of an intrusive contact of prethrusting (*1, 2*) or postthrusting (*3*) age, (ii) as the product of metamorphism at the base of an obducted ophiolite (*4*), or (iii) as the result of fortuitous association with the ophiolite during subduction (*5*). The mineral assemblages reported (*1*) suggest other possible origins, such as calcium metasomatism associated with serpentinization or regional metamorphism of impure limestones. The origin of these skarns is critical to the interpretation of the Neyriz ophiolite and the evolution of the Zagros mountain chain and they are of more general interest as ophiolite-related metamorphic rocks, yet their detailed mineralogy is unknown. I report mineralogical data from new skarn localities that indicate contact metamorphism of limestone by the ophiolite peridotite.

Mountain-size marble blocks are exposed just east of Tang e Hana, a small village 30 km northwest of Neyriz. They contain large-scale close folds plunging steeply southwestward and rest on peridotites with a subhorizontal tectonized contact offset locally by small steep faults. All specimens of peridotite that I have examined from this area are wholly serpentinized harzburgite, often with a compositional banding of originally orthopyroxene-poor and orthopyroxene-rich layers. Ricou (*1*) also concluded that the peridotite is harzburgite, although reporting a few specimens with up to 10 percent diallage. About 2 km from the westernmost skarn locality is an isolated hill (about 1 km^2 in area) of partly serpentinized, mylonitized, harzburgites and lherzolites.

The marble-peridotite contact truncates the folds in the marble blocks, and two groups of skarns are found within 30 m of it. Type 1 skarns occur within the serpentinized harzburgite, whereas type 2 skarns occur within the marbles. Type 1 skarns are clinopyroxenites and clinopyroxene-marbles. The pyroxenites resemble rodingite "dikes"; they are subparallel to the marble-serpentinite contact and are composed of coarse, equigranular, pale-green pyroxene with a few scattered grains of chrome spinel. The pyroxene-marbles occur as angular fragments up to 0.5 m in diameter containing only calcite and idioblastic, randomly oriented grains of pyroxene. Some fragments contain areas of undeformed, serpentinized harzburgite in which the contact between harzburgite and marble is marked by a zone (2 to 3 mm) of clinopyroxene partly altered to chlorite and calcite and completely undisturbed except where crosscut by later veins of calcite and chlorite. Type 2 skarns are subcircular wollastonite-pyroxene-calcite bodies up to 10 m in diameter. They are exposed on flat surfaces, and their three-dimensional form is unknown; they are very coarse-grained and have a granoblastic polygonal texture typical of high-temperature metamorphic rocks. Their contacts with the marbles are sharp, completely undisturbed, and marked locally by pegmatitic calcite. Garnet replaces wollastonite along some cleavage traces and grain boundaries, and adjacent dark-green pyroxene is patchily altered to a paler variety. Irregular subplanar zones crosscut the rocks in which plagioclase, garnet, and calcite are associated with poikilitic, altered pyroxene and wollastonite.

I interpret the field relations as in-