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Evidence for degassing of fresh magma during the 2004–2008 eruption of Mount St. Helens: Subtle signals from the hydrothermal system

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ABSTRACT

Results from chemical and isotopic analyses of water and gas collected between 2002 and 2016 from sites on and around Mount St. Helens are used to assess magmatic degassing related to the 2004–2008 eruption. During 2005 the chemistry of hot springs in The Breach of Mount St. Helens showed no obvious response to the eruption, and over the next few years, changes were subtle, giving only slight indications of perturbations in the system. By 2010 however, water chemistry, temperatures, and isotope compositions (δD and $\delta^{18}O$) clearly indicated some inputs of volatiles and heat associated with the eruption, but the changes were such that they could be attributed to a pre-existing, gas depleted magma. An increase of ~1.5‰ in the $\delta^{13}C$ values of dissolved carbon in the springs was noted in 2006 and continued through 2009, a change that was mirrored by a similar shift in $\delta^{13}C$-CO_2 in bubble gas emissions. These changes require input of a new source of carbon to the hydrothermal system and provide clear evidence of CO_2 from an undegassed body of magma. Rising trends in $^3He/^4He$ ratios in gas also accompanied the increases in $\delta^{13}C$. Since 2011 maximum R_C/R_A values are ≥6.4 and are distinctly higher than 5 samples collected between 1986 and 2002, and provide additional evidence for some involvement of new magma as early as 2006, and possibly earlier, given the unknown time needed for CO_2 and He to traverse the system and arrive at the springs.

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1. Introduction

The 2004–08 eruption of Mount St. Helens began on September 23, 2004 with a swarm of shallow volcano-tectonic earthquakes (Scott et al., 2008). Five days later cracks were observed on the surface of Crater Glacier (Dzurisin et al., 2008) and on October 1st an ash-rich explosion punctured the glacial ice (Schneider et al., 2008). Airborne measurement of gas emissions on October 7th documented the presence of a coherent plume of CO_2, $SO_2 \pm H_2S$ (Gerlach et al., 2008), and on October 11 solid lava extruded onto the crater floor, initiating a new phase of dome building. Over the course of the eruption 7 "spines" of solid lava grew and collapsed producing a new dacite dome in the crater. Growth of the new dome impinged on Crater Glacier, deforming the ice, which eventually split into two arms. In 2008, the two arms of the glacier rejoined on the crater floor north of the new dome (Walder et al., 2008; Dzurisin et al., 2015). A period of seismicity during late December 2007 through January 2008 heralded the end of the eruption. A spasmodic burst on January 27–28 may have resulted from the plug sealing the conduit (Dzurisin et al., 2015).

Monitoring work performed during and after the eruption included remote and in-situ measurements of seismicity, deformation, plume gas efflux, measurements of stream discharge, and collection of rock, water and gas samples. During July 2005 we collected the first post-eruption water samples from a few of the hot springs and thermal seeps in Loowit and Step Canyons (Bergfeld et al., 2008). In subsequent years more extensive sampling campaigns were conducted to sample all of the hot springs in The Breach of Mount St. Helens (the area between the toe of Crater Glacier and Loowit and Step falls), and other warm and cold springs around the volcano (Fig. 1). The hot spring studies were conducted on a mostly annual basis through August 2015. Infrequent discharge measurements on Loowit Creek continue to date.

We present new results from this ~10 year study conducted throughout the 2004–2008 eruption and on through 2016. Results from earlier geochemical investigations are also given to help assess changes related to the eruption. The work presented here focuses primarily on the water chemistry of the hot springs in The Breach but also includes information on the dissolved flux of magmatic components in Loowit Creek, water chemistry from warm and cold springs around the volcano, and gas chemistry from small bubbling vents in the hot springs and a few gases collected on the dome. Many, but not all of the changes we've recorded do not require an influx of new magma and can be attributed to shallow

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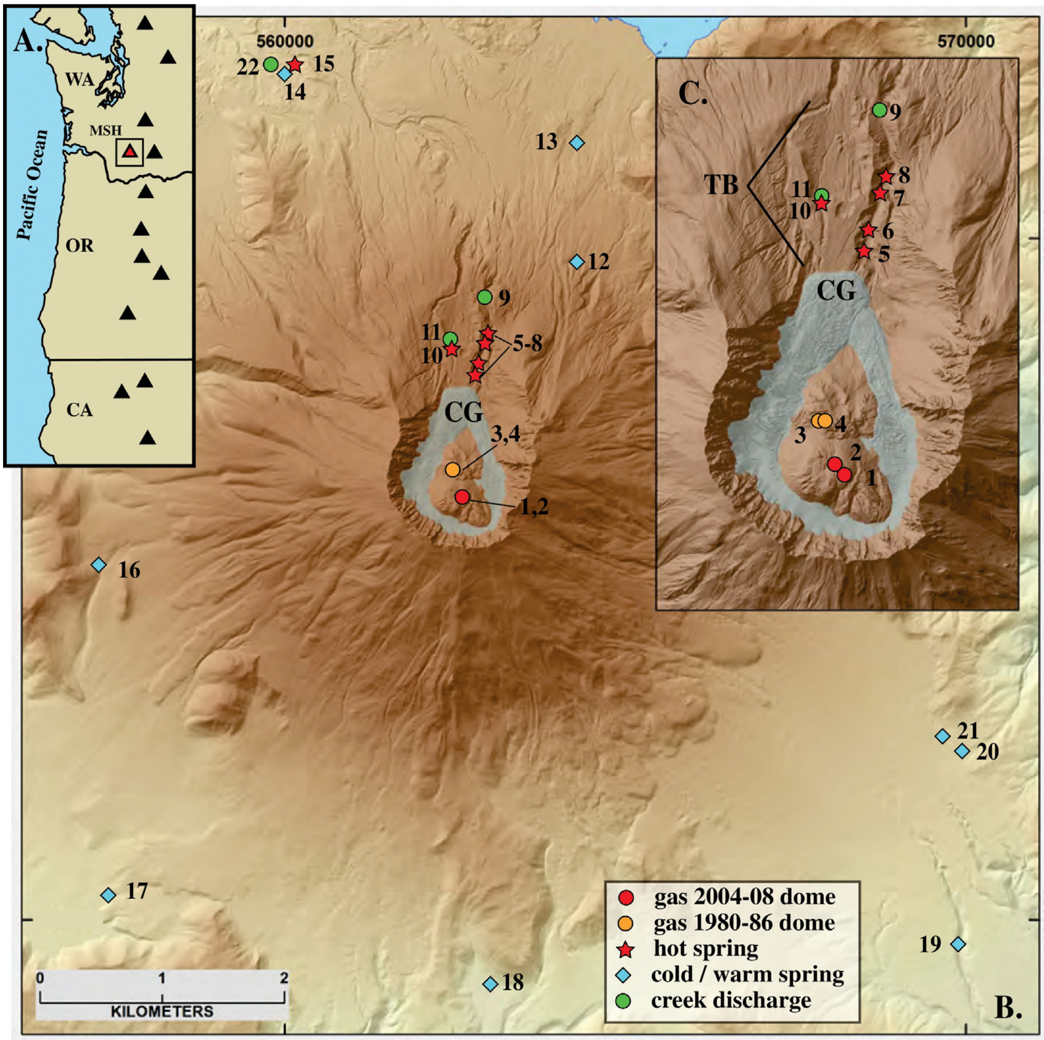

Fig. 1. Maps of Mount St. Helens and surroundings after Mosbrucker (2014) that include generalized locations of springs, gas vents and creeks where samples were collected for this study. A. Regional inset map showing the location of Mount St. Helens (red triangle) in relation to other volcanoes in the Cascade Range. B. Map showing sample sites on Mount St. Helens and regional springs away from the edifice. C. Inset map of the area around the crater gives more details on sample locations with The Breach of Mount St. Helens. Numbers for sample sites correspond to numbers listed in Table 1, TB = The Breach (area between Crater Glacier and Loowit and Step falls), CG = Crater Glacier.

processes associated with 2004–08 eruption. These chemical and physical changes can occur rapidly and are sometimes short-lived. In contrast, carbon and helium isotopic compositions indicate that there is a deeper source of magmatic volatiles that began to enter the shallow system by 2006.

2. Background on geochemical sites

2.1. Springs and creeks in The Breach

Following the 1980s eruptions of Mount St. Helens (MSH) downcutting of avalanche deposits in The Breach on the north side of the volcano created Loowit and Step canyons. Thermal springs were first observed in Loowit Canyon during the summer of 1983 (Thompson, 1990), and between 1983 and 1991 the springs were sampled every year. The springs in Step Canyon are cooler and have lower discharge than those in Loowit Canyon and sample collection on those springs was sporadic. After 1991 the sampling frequency at all springs diminished, and until 2005 the only available pre-eruption geochemical data for the springs are from samples collected in 1994 and 2002. Results from these and other early studies are published in other papers including, Thompson (1990), Shevenell and Goff (1993), Goff and McMurtry (2000) and are summarized in Bergfeld et al. (2008).

The majority of hot spring discharge at MSH comes from 4 sets of springs in Loowit Canyon that issue near the west bank of Loowit Creek. During most of this study 2 sets of springs in the upper part of the canyon emerged from well-defined vents, whereas the springs lower in the canyon discharged over broad areas. By 2015 the toe of Crater Glacier advanced to a point in upper Loowit Canyon that glacial rock debris began to cover the uppermost hot springs.

Other thermal springs were occasionally observed on the east bank of Loowit Creek. In recent years, these east bank springs were cooler and more dilute than the springs that discharge along the west canyon wall. Because of the irregular nature of the sample collection the results are not discussed in this report.

The head of Loowit Creek is sourced by cold dilute water from precipitation and glacial melt, but is located fairly close to the input from the uppermost hot spring. Loowit Creek discharge measurements are made close to the point where the creek spills over a large waterfall (LCAF), roughly 500 m below the lowest set of hot springs (Fig. 1 site 9; Table 1). The record of Loowit Creek discharge starts in August 1985 and includes 58 discrete measurements that span over 30 years. Over 70% of the measurements took place during the months of July through October.

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