Timescales of depressurization and ascent at the onset of the Huckleberry Ridge Tuff

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I. Introduction

The fine-grained ash to fine lapilli fallout deposit at the base of the Huckleberry Ridge Tuff (HRT: ~2.1 Ma; ~2,500 Km^3 Yellowstone Plateau Volcanic Field [1]) contains evidence for intrafall reworking, reflecting episodic initial explosive activity associated with the voluminous ignimbrite-dominated HRT eruptions. Each layer of reworking is interpreted to represent an eruption hiatus during the opening explosive phases, with a collective duration on the order of weeks to months [2]. To better quantify the timescales associated with this initial start/stop behavior, as well as to reconstruct the decompression history prior to the caldera-forming phases of the eruption, we combine these detailed field relations with microanalytical techniques, focusing on the behavior of volatiles (H_2O & CO_2).

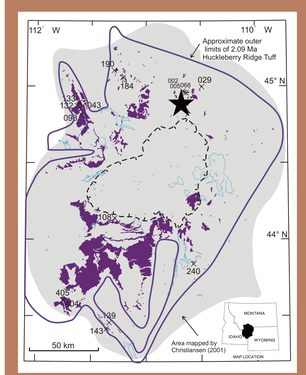
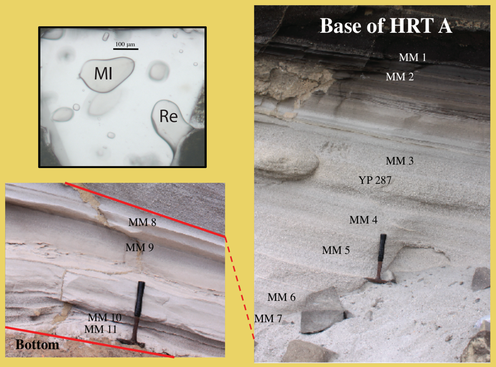
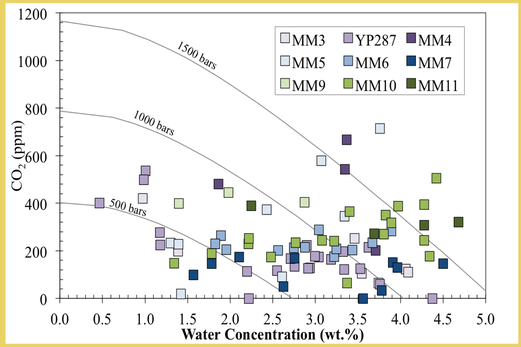


Figure 1: Outline of the approximated outer limits for the 2.1 Ma eruption of the HRT. Star marks the location of the 2.5 m fall deposit prserved beneath the welded base of the HRT ignimbrite.

II. Methods & Analysis

Loose but glass-coated quartz crystals have been sampled from ten horizons in the fall deposit. Melt inclusions (MI) and reentrants (Re) were analysed for major and trace elements as well as volatile concentrations Individual MI analyses allow for reconstruction of melt compositions during crystallization, whereas Re (unsealed MIs) provide insights into the evolution of the magmatic system leading up to quenching on eruption.





MIs containing the highest volatile concentrations (~4 to 4.4 wt% H_2O, 400-600 ppm CO_2) imply minimum saturation pressures of 140-170 MPa, equivalent to depths of 5-7 km; however, each horizon also contains MIs with lower and more varied volatile concentrations. Variability in MI data for the rapidly diffusing elements (H and Li) is attributed to diffusive loss during pre- or syn-eruptive decompression and in the earliest stages of the HRT eruption. We used this scatter in MI, along with gradients in Re, to calculate timescales of decompression.

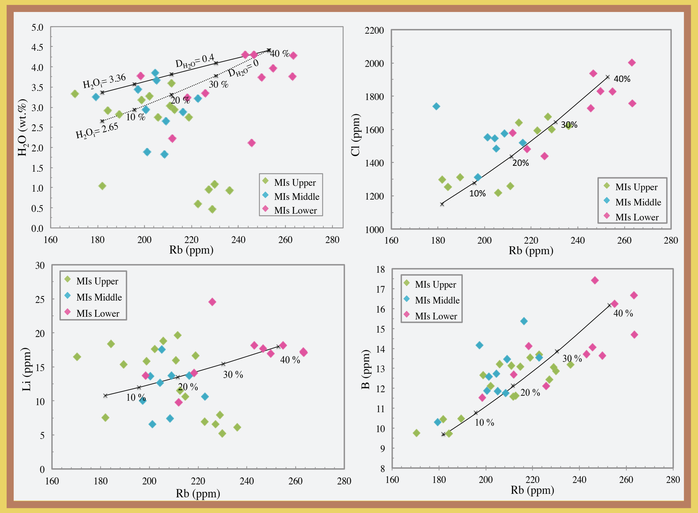


Figure 2: Volatiles and light elements plotted vs. Rb. Concentrations of B and Cl, which do not diffuse through quartz on relevant timescales, show variations consistent with fractional crystallization. These trends require ~40% crystallization of the less evolved MIs (found in the middle and upper portions of the fall deposit) to yield the more evolved compositions of MIs in the earliest fall layer sampled (< 2-3 cm from base). Li is a fast diffusing element and shows possible gains and losses. Many H_2O values are low compared to the fractional crystallization curves, in contrast to B and Cl, and this suggests loss by post-entrapment H diffusion through the quartz host.

III. Modeling & Results

Using a diffusion model [3], the timescales for H_2O loss by diffusion from the majority of MIs are on the order of 1-6 days, with some values of up to several weeks. However, fitting of diffusion profiles [4] to transects of H_2O and CO_2 measured along Re lengths suggests decompression rates of 0.05-0.007 MPa/s, where faster decompression rates are often associated with deeper initial storage conditions, providing timescales of final ascent between 1 and 3 hours. Timescales represented by MI and Re are consistent throughout the fallout deposit.

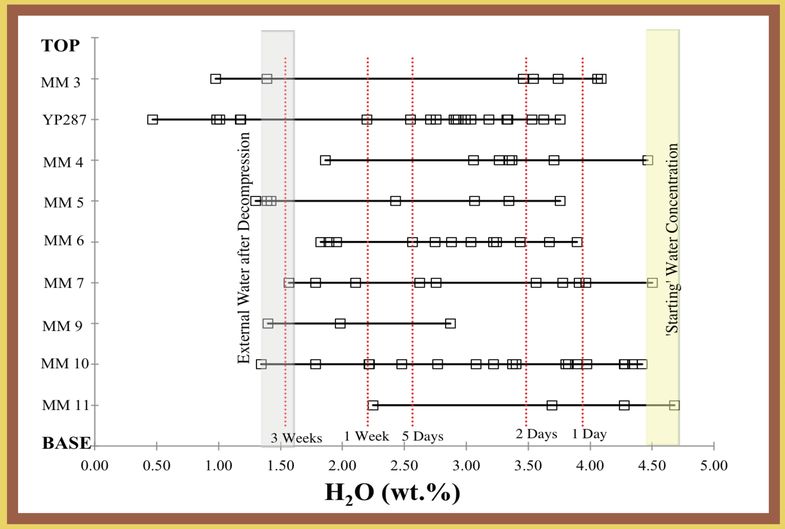
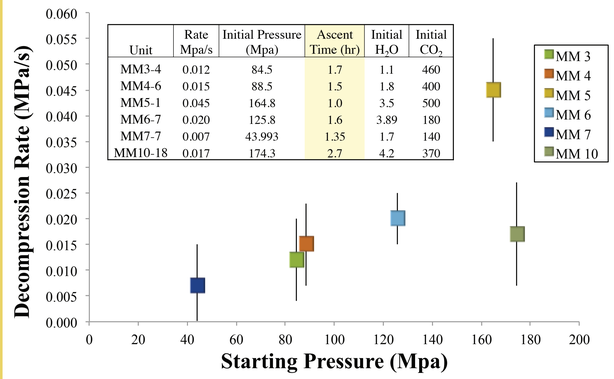


Figure 4 (right): Modeling H_2O and CO_2 gradients in Re allow for determination of a decompression rate, which can be used to infer a timescale of ascent. These timescales appear to be consistent throughout the fall deposit, and are much faster than those inferred through MI. Interior water concentration is used as an initial condition, along with a fragmentation pressure of 10 MPa (when diffusion ends in the model).

Unit	Rate Mpa/s	Initial Pressure (Mpa)	Ascent Time (hr)	Initial H_2O	Initial CO_2
MM3-4	0.012	84.5	1.7	1.1	460
MM4-6	0.015	88.5	1.5	1.8	400
MM5-1	0.045	164.8	1.0	3.5	500
MM6-7	0.020	125.8	1.6	3.89	180
MM7-7	0.007	43.993	1.35	1.7	140
MM10-18	0.017	174.3	2.7	4.2	370



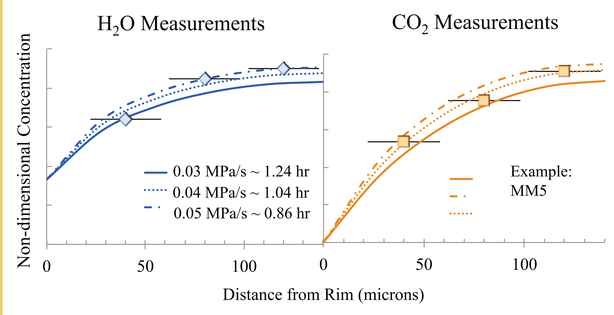


Figure 3 (above): Ranges in water concentrations represented by the nine layers sampled stratigraphically, starting from the very basal (<1 cm) fall deposit. Scatter in H_2O is generally similar between layers, with highest MI values continuously going upward ~4.5 wt. % and dropping in the following units. This scatter can be used to determine a timescale if the following three things can be estimated: (1) initial concentration (2) external concentration and (3) diffusivity of the species in question. Starting and external water concentrations are estimated using the spread in H_2O data, and we used diffusional coefficient of 10-11µm/s, as this value constrains the experimentally observed rate of hydrogen diffusion during heating in quartz phenocrysts [5]. In this approximation, a 100 µm MI is modeled in a 600 µm quartz grain.

IV. Implications for the eruption of the Huckleberry Ridge Tuff

Here we present a geochemical application for determining the decompression history prior to caldera formation through analysis of the first-erupted fraction of the HRT fall deposit. Timescales from MI and Re indicates that decompression of the HRT can be broken into a two-stage ascent history: a slower initial decompression preserved as melt inclusions reequilibration and then the final ascent preserved as a gradient in reentrants, implying a complicated and prolonged unlocking process, perhaps representing the formation of a network of conduits.

This suggests that applying similar geochemical techniques to other early fall deposits from very large explosive eruptions could help inform ongoing debates about eruption triggers and the controls on when and why caldera collapse occurs. Interestingly, times implied by Re and MI are on a similar order of magnitude to the start/stop timescales implied by the erosional surfaces.

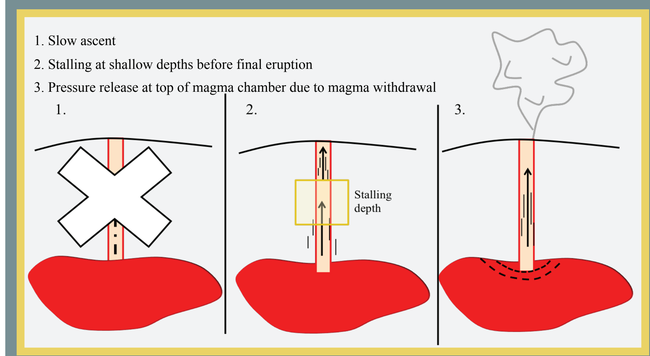


Figure 5: Three potential scenarios for decompression induced water loss, where scenario 1 would apply to a situation where MI and Re preserved similar timescales. Our data suggests either scenario 2 or 3, with 2 being the most likely because of the high degree of water loss in MI in several of the layers.

[1] Christiansen, US Geol Surv Prof Pap 729-G [2] Wilson (2009), AGU Fall Meeting, #V23C-2085. [3] Cottrell et al. (2002), G3, 4, 1-26. [4] Liu et al. (2007), JGR, 112, B06204. [5] Severs et al. (2007), Chem. Geol, 237, 358-371.