EXPLOSIVE VOLCANIC ERUPTIONS INTO THE MARTIAN ATMOSPHERE: TRACKING ASH AND WATER ICE. L. Kerber[1] and J. W. Head[1], J.-B. Madeleine[2], F. Forget[2], L. Wilson[3], J.S. Levine[4]. Department of Geological Sciences, Brown University, Box 1846, Providence, RI 02912 (laura_kerber@brown.edu), [2]Laboratoire de Météorologie Dynamique du CNRS, Université Paris 6, Paris, [3]Lancaster Environment Centre, Lancaster University, LA1 4YQ, UK. [4]NASA Langley Research Center, Hampton, VA 23681.

Introduction: Volcanism has been an important geologic process for most of martian history, both because of its contributions to the surface geology as well as its contributions to the martian atmosphere. Volcanoes provide a major pathway by which volatile species are outgassed from planetary interiors, and it is likely that martian volcanoes have contributed significant amounts of H_2O, CO_2, and SO_2 to the atmosphere over geologic time [e.g., 1, 2, 3]. It is estimated that volcanism related to Tharsis alone produced 3 x 10^8 km^3 of volcanic products, which, (assuming 2% magma water content by weight) would imply a release of 1.8 x 10^{19} kg of water vapor, equivalent to a 120-m-thick global layer [1].

In addition to contributing volatiles from the martian interior, volcanoes have been shown to interact extensively with the martian cryosphere [4, 5]. Volcano-ice interactions can result in enhanced volcanic explosivity and an additional release of water vapor [5]. These processes can deliver significant amounts of water to parts of Mars where it might not normally accumulate, potentially resulting in fluvial networks, glacial systems, or even the preferential preservation of magnetic signatures [6].

The martian highland paterae have been interpreted as the products of explosive volcanism based on their resemblance to terrestrial ash sheets and their friable, erodible surfaces [7, 8]. In addition, several friable layered deposits have been hypothesized to be formed of volcanic ash, such as the Medusae Fossae Formation [7, 9, 10, 11, 12]. Small-scale examples of explosive volcanic activity include pseudo-craters and smooth mantles identified near the tops of volcanoes such as Hecates Tholus and Arsia Mons [13, 14, 15].

Quantitative models of explosive eruptions into the martian atmosphere, developed over the past several decades by numerous authors, have created a sophisticated framework for determining the rise-heights of inertial and convecting plumes for a limited number of martian atmospheric profiles [16, 17, 18]. Rapid improvement of Mars global circulation models (GCMs) has made it possible to extract a large number of realistic climate profiles differing by season, location, altitude, and climate scenario, allowing for the first time detailed simulations of eruptions from specific volcanoes. The presence of a water cycle in GCMs also allows for the modeling of volcanically-derived water from its eruption into the atmosphere through its accumulation, loss, or eventual deposition on the surface.

To this end, we combine a Mars Global Circulation Model (GCM) [19] with a semi-analytical explosive eruption model for Mars [16, 17]. Here we describe several applications of this combination model, focusing on the utility of the model to contribute to the identification of units of geological interest.

Methods: The explosive model [16, 17] determines the rise-height of the eruption column and the release heights for volcanic clasts of various sizes based on atmospheric profiles provided by the GCM. The GCM also provides time-dependent wind profiles which transport each particle from its point of departure from the plume to its final deposition on the surface. The GCM accepts ash particles as well as volcanically-derived water particles as tracers (specified by their mixing ratios). Water particles are permitted to nucleate on dust particles and eventually to accumulate on the surface (if they are stable).

Friable Layered Deposits. Simulations were first run from the Hesperian-aged volcano Apollinaris Patera (-8ºS, 174ºE), chosen because of its proximity to the Medusae Fossae Formation (MFF), a fine-grained and friable deposit hypothesized to be composed of pyroclastic material [9, 10, 11, 12]. Additional simulations were run from other volcanoes near the MFF and near other friable deposits elsewhere on Mars. The effects of season, atmospheric pressure, grain size, vent altitude and volcano latitude were explored under present orbital conditions. Each simulation was run for one year. An average mass-flux for a volcanic eruption with a stable convecting plume, 10^6 kg/s, was used in the eruption model to determine the rise-height of the plume. At the point where the clasts were released into the GCM for dispersal, the mass flux was changed in order to erupt the entire volume of the nearby friable layered deposit over the course of one year. This change was made in order to simulate the effects of many short eruptions (days to months) taking place over random times of the year over hundreds of millions of years, or the lifetime of the volcanic center. In the particular case of Apollinaris Patera, the presence of a magnetic anomaly associated with the volcano, together with an early Hesperian surface crater-age date, would suggest a fairly long-lived period of activity for the volcanic center [6, 19, 20].

Eruption of Water Vapor. Simulations were run from various volcanoes modeling the explosive eruption of water vapor. A magma water content of 2 wt % was assumed, with a mass flux of 10^6 kg/s and a duration of ten days. A simulation of an eruption from Elysium Mons run continuously through one year showed that deposition and sublimation of ice remained close to steady-state.

Results: *Friable Layered Deposits.* Eruptions from Apollinaris Patera result in an ash distribution that matches the distribution of the Medusae Fossae Formation fairly well (Fig. 1). The distribution is best matched if the ash particles are of slightly lower density (700 kg/m^3, equivalent to a pumice), if the eruption is strong (producing a high plume), and if the fragmentation is aggressive, favoring a particle-size distribution that is weighted towards the smaller sizes. The results shown are for particles less than 160 µm. Other nearby volcanoes have much higher altitude vents, giving them a wider dispersal. Any of these could have contributed material to the Medusae Fossae Formation. However, none of these distributions explains the preferential accumulation of material to the west of the Tharsis rise (Fig. 1).

Eruption of Water Vapor. Eruptions from Elysium Mons result in an ice deposit which is much more localized than similar ash dispersal simulations (Fig. 1, 2). In terrestrial eruptions, both atmospheric and volcanically-derived water will nucleate as ice crystals on volcanic ash particles [21]. If the water or ice reaches the surface without subliming, it may accumulate into a deposit which is a mixture of water, ice, and ash (muddy rain) [21]. Water released during martian eruptions may also be deposited with ash, probably as ice [22]. During the simulated eruption, the water released from the volcano settles to the ground forming millimeters of ice. Much of this ice quickly sublimes away, but if it were codeposited with ash or quickly buried, it would be possible for some of it to be preserved [23].

Conclusions: The addition of the global circulation model to the explosive model aids in the modeling of specific volcanoes to solve geologically relevant questions. The combination model has been used to explore the effects of season, atmospheric pressure, ash grain size, vent height, and volcano latitude on ash and water-ice distributions in eruptions from Apollinaris Patera, Elysium Mons, and other major martian volcanoes. Ash distribution modeling can provide constraints for the origin of some friable deposits; and modeling ice accumulation can aid in the interpretation of terrains hypothesized to be ice-rich.

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Acknowledgements: We gratefully acknowledge support for this work from NASA Graduate Student Research Program (GSRP) grant NNX09AJ11H.

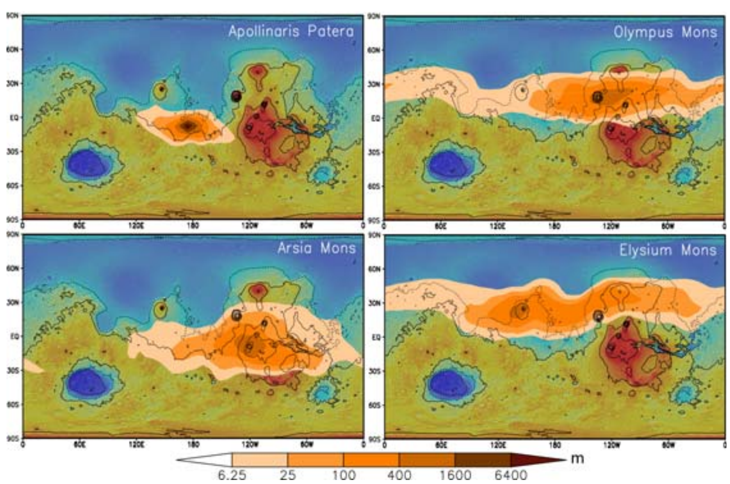

Figure 1. Simulated ash distributions erupted from Apollinaris Patera and other possible sources for the Medusae Fossae Formation. Volcanoes were erupted for one year. The other volcanoes produce widespread ash deposits, some of which overlap with the MFF (particularly the ash deposit of Arsia Mons). However, an eruption from Apollinaris Patera would deposit most of its material in the Medusae Fossae Formation, without a large amount of material deposited elsewhere.

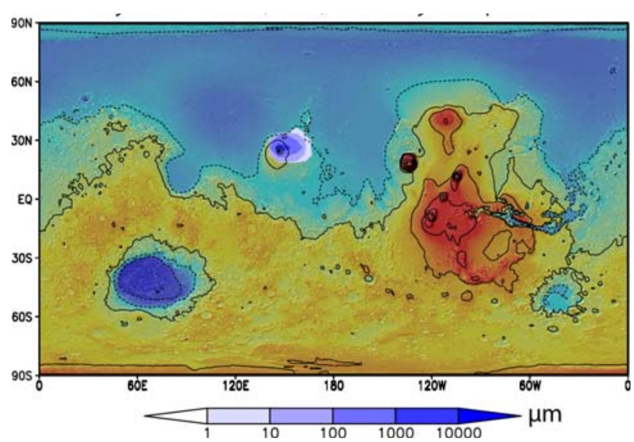

Figure 2. An eruption of water ice from Elysium Mons. The water ice tends to keep a steady state during the eruption of the volcano, subliming away rapidly after the volcano has ceased erupting. If the ice were codeposited with ash, it is possible that the ice could be protected from sublimation and would accumulate into ice-rich layers.