EXPLOSIVE MAGMA-WATER INTERACTION ON MARS: INSIGHT FROM A YOUNG PYROCLASTIC DEPOSIT IN ELYSIUM PLANITIA. P. Moitra[1], D. G. Horvath[1], J. C. Andrews-Hanna[1], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, pmoitra@lpl.arizona.edu

Introduction: A recent explosive volcanic eruption has been proposed in the Elysium Planitia region of Mars [1-3]. The deposit is located around one of the Cerberus Fossae (7.9°N, 165.8°E) close to the Zunil crater (Fig.1). Based on the areal extent and symmetric distribution of this deposit around the fossa, along with a low albedo, and high-calcium pyroxene signature in CRISM spectra, it has been interpreted as a pyroclastic deposit.

Fig. 1. Viking visible imagery of the Amazonian Cerberus mantling unit (ACm) at top left. The unit is symmetric around one of the Cerberus Fossae. Also, visible is the Zunil crater at the lower right corner.

The model age from the crater size-frequency distribution place it in the late Amazonian time period (0.2 – 4.0 Ma), and the superposition relationship between the deposit and Zunil crater secondaries suggests an age younger than the Zunil (<1 Ma). Thus, the deposit is interpreted as the youngest pyroclastic deposit (and indeed, youngest volcanic eruption product of any sort) on Mars. Following [3], we use Amazonian Cerberus mantling unit (ACm) to refer to the deposit here.

Terrestrial observations demonstrate that the vast majority of explosive eruptions of magma driven by juvenile water are accompanied by effusive eruptions and/or edifice construction [4]. We find no evidence for lava flows, or edifice or scoria cone construction associated with the ACm unit. These indicate that eruptions involving only juvenile magma were likely not the case for this deposit. Therefore the most likely mechanism for this eruption has been hypothesized as a phreatomagmatic eruption from the explosive interaction of magma with surrounding ground water or ice. This is consistent with the geologic history of the Ely-

sium Planitia region. Massive aqueous floods at Athabasca Valles [5] to the west of ACm and in eastern Elysium Planitia [6] to the east of the ACm deposit demonstrate the existence of large volumes of groundwater in the recent past. Also, the presence of rootless cones or pseudocraters provides evidence for abundant ground water or ice in the region [7]. Further details on the morphology and interpretation of this deposit can be found in [3].

In this study, we investigate the conditions, required for such explosive magma-water/ice interaction and subsequent phreatomagmatic eruption during the formation of the ACm deposit.

Magma-water interaction: From [3], the thickness-area relationship provides a bulk volume estimate of the ACm deposit in the range of $\sim10^7$-10^8 m^3 (Fig. 2). Considering that phreatomagmatic eruption deposits are often lithic-rich (with a large fraction of country rock), an estimate of 10% volume of juvenile magma [4] leads to V $\approx 10^6$-10^7 m^3 that likely interacted with water during this eruption. This volume is at the upper limit of the erupted magma volume during phreatomagmatic eruptions on Earth [8, Fig. 2], but also overlaps with the volumes of sub-Plinian eruptions and is at the lower end of Plinian eruption volumes. However, based on the lack of effusive flows or edifice construction, we favor the phreatomagmatic interpretation.
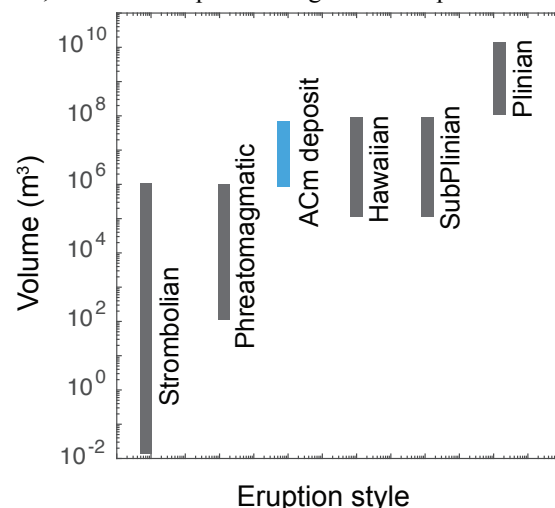
Fig. 2. Volume comparison of various eruption styles of basaltic magma on Earth [8,9] and the volume of the ACm unit. Although volume of magmatic eruptions overlap with that of the ACm deposit, the absence of volcanic edifice or scoria cone structure indicates a phreatomagmatic style eruption.

The eruption conditions, in particular, the atmospheric pressure and gravity are different between Earth and Mars. However, the atmospheric pressure likely changes the boundary condition during magmatic eruptions, affecting the secondary magma fragmentation and eruption column height, and would have less effect on a phreatomagmatic eruption style. Eruption explosivity during phreatomagmatic eruptions depends on the available thermal energy and its exchange between the hotter magma and the colder water/ice. If the eruption volume is limited by the energy available to fragment the country rock, then no systematic difference is predicted between eruption volumes on Earth and Mars. On the other hand, if fragmented country rock is already available (as in a diatreme), the eruption is limited by the energy available to fragment the juvenile magma, and accelerate and erupt the country rock. In this case, the source depth and volume of the eruption would scale with the inverse of gravity, and thus for a given initial volatile content explosive activity would initiate about 3 times deeper and erupt a volume ~3× greater than that on Earth. The volume of the ACm deposit at the upper bound of terrestrial phreatomagmatic eruption volumes may be related to the lower gravity, but is also possibly a consequence of the fissure conduit geometry that allowed a larger surface area for explosive magma-water interaction causing a larger volume of extruded material.

From laboratory based Molten Fuel Coolant Interaction (MFCI) experiments with natural magma as the molten fuel and water as the coolant, it has been proposed that the required ratio between water mass and melt mass for explosive interaction is in the range of ~ 0.01-0.20 [10-13]. Using the conservative estimate of the volume of juvenile magma ($V \approx 10^6$ m^3), we estimate a water volume in the range of $3\text{-}60\times10^4$ m^3. Based on terrestrial observations, we assume an interaction and eruption duration in the range of ~10 seconds to one hour, leading to a flow rate of water in the range of ~8 to 6×10^4 m^{3}s^{-1} for continuous magma-water interaction. These values are orders of magnitude lower than the flow rates discharged into the Athabasca Valles outflow channels [14], and therefore can be reasonably justifiable. Due to the fissure geometry of the conduit, the flow can be viewed as one-dimensional. Only the magma at shallow depths in the conduit can interact explosively with the water, so we assume flow in the top 1 km of the aquifer toward the observed 30 km long fissure, leading to flow velocities of ~10^{-6} – 10^{-2} m/s for a porosity of 10%. These low water flow velocities could be brought about by a confined aquifer pressurized by its connection to aquifers at higher elevations [5], or by tectonic pressurization

due to the elastic deformation of the host rock around the dike [14]. Scaling the models of [14] for a 30-km-long fissure and aqueous interaction over only 1 km of depth, tectonic pressurization from a large dike intrusion can supply a water discharge to the fissure up to 7×10^3 m^{3}s^{-1}, and would scale approximately linearly with the dike width. Thus, the hydrological response to the dike intrusion alone should provide adequate water to drive the phreatomagmatic eruption through MFCI, provided that the condition of a saturated and confined aquifer was met.

An alternative possibility could be the entrainment of ice-saturated regolith at shallow crustal depths, similar to magma entraining water-laden sediments during some phreatomagmatic eruptions on Earth [4]. Mechanical and thermal erosion due to wall shearing as a result of magma migration through the fissure, or due to magma convection as it stalled at a shallower depth could possibly result in such entrainment. Subsequent melting of the ice would cause the explosive magma-water interaction.

Synthesis: Based on observations and from our preliminary estimates, we hypothesize that a dike with small volume of magma stalled at a shallow crustal depth [15]. The volume of magma was small such that it did not cause massive melting, collapse and subsequent floods [5]. Magma interacted with the water causing the explosive phreatomagmatic style eruption.

Similar eruptions may have been common around Cerberus Fossae in earlier intrusive events, but only the most recent event is recorded due to the erodible nature of the deposit and the history of recent dust deposition and erosion. Thus, this deposit has potential to shed light on magma-water interactions and phreatomagmatic eruptions that may once have been common in Elysium Planitia as well as elsewhere on Mars.

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