

ROLES OF MAGMATIC VOLATILE, GROUND ICE AND IMPACT TRIGGERING ON THE DYNAMICS OF THE MOST RECENT EXPLOSIVE VOLCANIC ERUPTION ON MARS. P. Moitra^{1,3}, D. G. Horvath^{2,3}, J. C. Andrews-Hanna³. ¹Department of Geosciences, University of Arizona, Tucson, AZ; ²Planetary Science Institute, Tucson, AZ; ³Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ; pmoitra@arizona.edu

Introduction: Recent volcanism on Mars has dominantly been effusive in nature, with the youngest lava flows observed in Athabasca Valleys and eastern Elysium Planitia [1-2]. A mantling deposit around one of the Cerberus Fossae fissures in Elysium Planitia (the Cerberus Fossae mantling unit or CFmu; 7.9°N, 165.8°E; Fig. 1), has been interpreted to be pyroclastic in nature [3-5]. This deposit has therefore provided an opportunity to explore the conditions for explosive martian eruptions in the recent past. The superposition relationships indicate that the age of CFmu is younger than the nearby Zunil crater (<1.0-2.7 Ma [6-8]). The crater size-frequency distribution indicates an even younger age of 46-222 ka [5], thus making it the youngest volcanic feature on Mars.

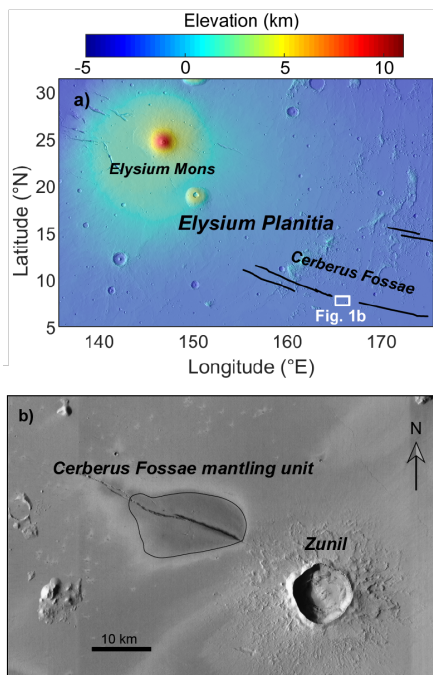


Fig. 1. (a) The location (7.9°N, 165.8°E) of the Cerberus Fossae mantling unit (shown by white rectangular box) along one of the Cerberus Fossae fissures (shown by solid dark lines). (b) Context camera imagery of the Cerberus Fossae mantling unit (CFmu). Also visible is the nearby Zunil crater. The black solid boundary indicates the approximate lateral extent of CFmu.

While there is an abundance of aeolian features in the region, the CFmu differs from these in that it extends 6 km in the dominant upwind direction (N-NE; Fig. 1b), differing from the surrounding aeolian features with negligible upwind components at the 20- σ level [5].

Thus, a simple aeolian interpretation of the deposit can be ruled out. Lava flow features are not found, while a high-calcium pyroxene signature is present in CRISM spectra. These observations along with the volume and thickness profile of the deposit [5] indicate that a highly explosive basaltic eruption might have caused the formation of CFmu.

As the youngest and best-preserved pyroclastic deposit on Mars, this is an ideal target for investigating explosive martian volcanism. Volcanic scoria cones and maar-type craters, typical landforms from magmatic and phreatomagmatic eruptions, respectively, are not observed. Accordingly, we investigate the conditions and feasibility for both the magmatic and phreatomagmatic eruptions for the formation of the CFmu. Furthermore, the proximity of CFmu to Zunil suggests the possibility of impact triggering, which is also explored here.

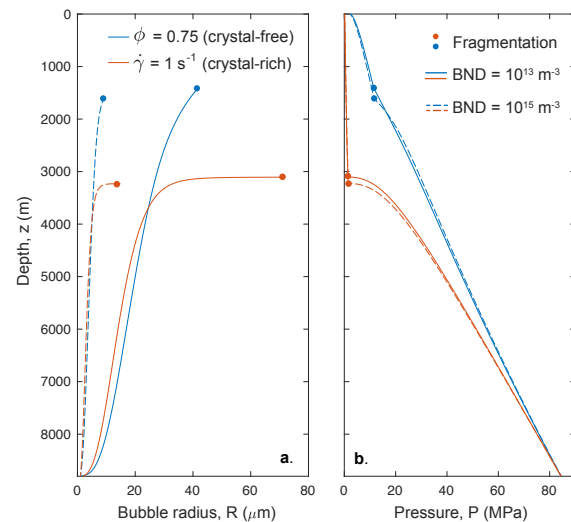


Fig. 2. Representative results from crystal-free and crystal-rich magma ascent modeling. ϕ is the gas volume fraction, $\dot{\gamma}$ is the strain rate surrounding the growing bubbles in magma, and BND is the bubble number density per unit volume of melt.

Eruption driven by dissolved volatiles in magma:

Using a numerical model of coupled bubble growth and ascent of magma through a volcanic fissure, we evaluate the effect of dissolved volatiles in the magma on the dynamics of the explosive eruption. We assume H_2O as the only dissolved volatile and varied for a range of suitable values [10]. We evaluate two magma fragmentation criteria: 1) a critical gas volume fraction for a crystal-free magma [11], and 2) a critical strain rate criterion for crystal-rich magma [12].

We find that for a likely range of dissolved water contents, explosive magma fragmentation and the formation of pyroclasts are expected for both crystal-free and crystal-rich systems (Fig. 2). Also, the modeled exit velocities of gas-pyroclast flows are similar to the ones required for the observed lateral extent of the deposit under martian atmospheric conditions [11].

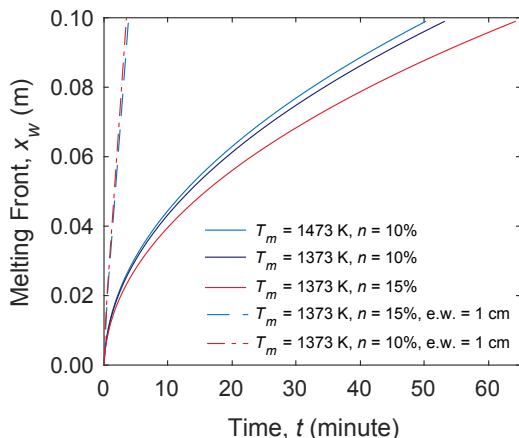


Fig. 3. Ice-melting front, x_w as a function of time, t . T_m is the magma temperature, n is the regolith porosity, and e.w. is the entrainment width.

Explosive magma-water interaction: For a phreatomagmatic eruption, we model heat transfer from magma in a dike to the surrounding regolith. Recent studies on terrestrial eruptions have shown that the phreatomagmatic eruption of pyroclasts requires a relatively shallow (<500 m) and direct interaction between magma and water [13]. The presence of ground ice down to a few hundred meters of depth is indicated by the ejecta lobes from the Zunil crater [6] and evidence for lava-ground ice interaction in nearby flows [9]. Thus, we propose a model in which the dike melts ice in the surrounding regolith, and the resulting water-saturated regolith is entrained in the magma. This entrainment process contributes to the explosivity of the eruption and accelerates the heat transfer from the dike to the surroundings in comparison to a simple conductive model. We assume ~10-15% ice-filled regolith porosity. The amount of water required is estimated from the empirical ratio between magma and water required for energetic explosions [14] and the volume of the deposit [5]. Our model results show that the melting of ice and the entrainment of water-rich regolith may take only a few minutes (Fig. 3) and is within the range of needed time scales for such eruptions.

Impact-triggering: The close proximity of the deposit to Zunil crater (15-30 km) along with the age of CFmu younger than Zunil indicate the possibility that the eruption was triggered [15] by the Zunil crater-forming impact. Geological evidence for a protracted period

of recent volcanism [2] including this deposit, and seismic evidence for possible ongoing magmatic activity suggest the possibility of a long-lived magma source. Thus, it appears possible that magma was present in the subsurface at the time of the Zunil impact. Using a scaling analysis, our calculations show that the impact-induced seismic energy density at the distance of CFmu from Zunil, for a range of suitable seismic efficiencies, exceeds the triggering threshold [16] for magmatic eruptions (Fig. 4).

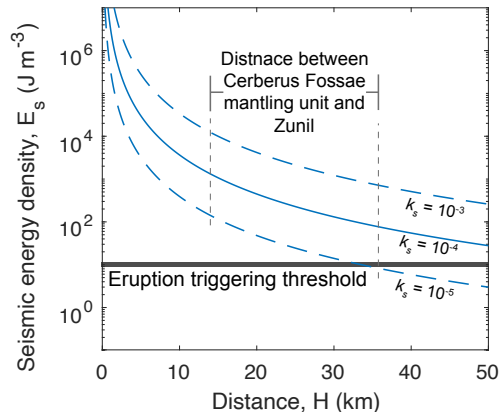


Fig. 4. Seismic energy density as a function of distance from the impact. k_s is the seismic efficiency.

Conclusions: We find that both magmatic and phreatomagmatic styles of eruptions could be viable mechanisms for the generation of the CFmu. We also show that the Zunil crater-forming impact might have triggered the eruption. Such explosive eruptions might have been common on Mars [17], but older deposits would have been easily lost to erosion and/or burial. The very recent volcanic deposit CFmu indicates that the magma source may still be active today, and may be a likely source of the seismicity observed by SEIS on the In-Sight lander [18].

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