EXPLORING THE MECHANISM BEHIND THE MOST RECENT EXPLOSIVE VOLCANIC ERUPTION ON MARS: VOLATILE SOURCE AND IMPACT TRIGGERING.

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Introduction: Elysium Planitia is an active volcanic region on Mars, with the youngest lava flows observed in Athabasca Valleys and in the eastern Elysium Planitia regions [1-2]. A very recent pyroclastic deposit has been discovered [3-4] around one of the Cerberus Fossae fissures in Elysium Planitia (7.9°N, 165.8°E) close to the Zunil crater (Fig. 1). The deposit, referred to as the Cerberus Fossae (CF) mantling unit, mantles the surrounding volcanic plains. It is nearly symmetrical around the fossa, in contrast to the strongly asymmetric wind-streaks visible around some of the other fissures and craters in the region. Lava flow features are not found, while a high-calcium pyroxene signature is present in CRISM spectra. These observations along with the volume and lateral extent of the deposit [3-4] indicate that a highly explosive basaltic eruption caused the formation of the CF mantling unit.

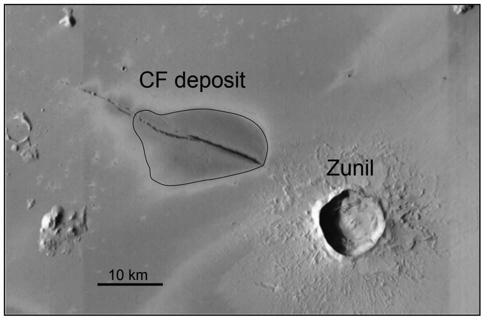

Fig. 1. Context camera imagery of the Cerberus Fossae (CF) mantling unit. The black solid boundary is for guiding the eye only, indicating the lateral extent of the deposit. Also visible is the nearby Zunil crater.

The superposition relationships indicate a deposit age younger than Zunil (<1.0-2.7 Ma [5-7]), thus making the CF mantling unit the youngest volcanic feature yet identified on the surface of Mars. The crater size-frequency distribution on the deposit itself supports an even younger age of 53-210 ka [4]. The young age suggests that this volcanic system may still be active today. Recent analyses of marsquakes from the InSight mission found both of the locatable sources to be in the Cerberus fossae region [8], adding further support to the possibility that this volcanic system is active today.

The pyroclastic deposit indicates an explosive style of volcanic eruption, in contrast to the effusive lava flows that dominate in the region. Thus, understanding the dynamics of such an eruption can potentially shed light on the role of volatiles on martian volcanism in the recent past. As the youngest and best-preserved pyroclastic deposit on Mars, this deposit is an ideal target for an investigation of explosive martian volcanism. The proximity of the youngest volcanic eruption to one of the youngest large craters on Mars also suggests the possibility of impact triggering of the eruption. In this study, we examine the eruption dynamics responsible for the formation of the deposit, including the roles of juvenile and external water, and the possibility of impact triggering.

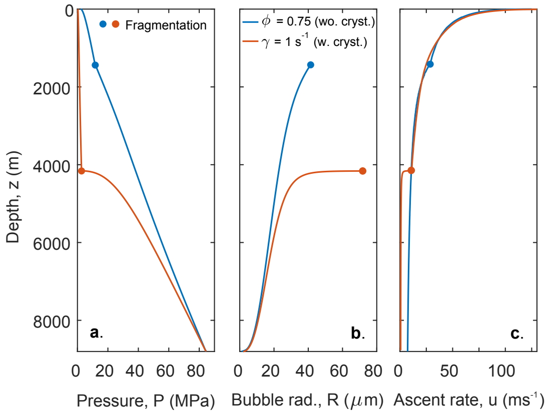

Fig. 2. Representative results from crystal-free and crystal-rich magma ascent modeling during explosive eruptions. ϕ is the gas volume fraction and γ is the strain rate around growing bubbles in magma.

Volatiles and the eruption process: The fragmentation of ascending magma during an eruption is critical for non-explosive to explosive eruption transition and generation of pyroclasts. Such explosive fragmentation and eruption of basaltic magma is either driven by volatiles such as H_2O dissolved in magma (magmatic eruption), or by interactions between magma and groundwater (phreatomagmatic eruption). Scoria cones and volcanic edifices, and maar-type craters, typical landforms from magmatic and phreatomagmatic eruptions, respectively, are not observed. However, the presence of ground ice down to a few hundred meters of depth is supported based on the ejecta lobes from the Zunil crater [5] and evidence for lava-ground ice interaction in nearby flows [9], and therefore an interaction between magma and melted ground ice is possible. Accordingly, we investigate the conditions and feasibility for both the magmatic and phreatomagmatic eruptions for the formation of the CF mantling unit.

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. H_2O was assumed as the dissolved volatile and was varied for a range of values [10]. Two magma fragmentation criteria are evaluated: 1) a critical gas volume fraction for a crystal-free magma [11], and 2) a critical strain rate criterion for crystal-rich magma [12], considering that the high-calcium pyroxene signature in CRISM spectra may indicate crystals either present within the magma or sourced from the country rock.

Our model results show that for a reasonable range of dissolved water contents, magma fragmentation and generation of pyroclasts are feasible for both crystal-free and crystal-rich systems (Fig. 2). The exit velocities of gas-pyroclast flows are comparable to values required for the observed lateral extent of pyroclasts under martian atmospheric conditions [11].

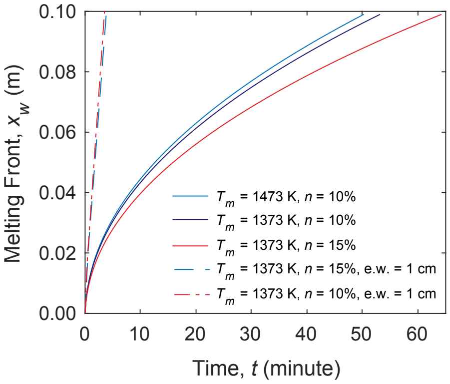

Fig. 3. Propagation of the ice-melting front, x_w as a function of time, t. T_m is the magma temperature, n is the regolith porosity and e.w. is the entrainment width.

Explosive magma-water interaction. We assume that magma within a dike stalled at a shallow depth beneath a paleo-lava flow surface, consistent with the proposed non-eruptive intrusive activity along the Cerberus Fossae [13]. Recent studies on terrestrial eruptions have shown that the eruption of pyroclasts requires a relatively shallow (<500 m) and direct interaction between magma and water [14]. However, at such shallow depths all water would be in the form of ice, thus we propose a new eruption mechanism in which the ice-saturated regolith loses its cohesion and is entrained in the magma as the ice melts. This mechanism introduces an advective mode of heat transfer at a given entrainment width, and results in a much more rapid delivery of water to the magma.

Accordingly, we model the heat transfer from magma in dike to the ice in the pore space of surrounding martian regolith up to a few hundred meters depth. The water-saturated regolith is entrained in the magma, assuming ~10-15% ice-filled regolith porosity. The amount of water required to be entrained is estimated from the empirically obtained mass ratio between magma and water required for energetic explosions [15]. Our model results show that the melting of ice and the entrainment of water-rich regolith may take less than 5 minutes (Fig. 3), which is within the range of needed time scales for such eruptions.

Impact-triggering: The close proximity (15-30 km) of this young eruption to one of the youngest large impact craters indicates the possibility of eruption triggering [16] by the Zunil crater forming impact. Geological evidence for a protracted period of young volcanism [2] including this deposit, and seismic evidence for possible ongoing activity, support the possibility of a long-lived magma source. Thus, it appears likely that magma was present in the subsurface at the time of the Zunil impact. Using scaled analysis, we estimate that the range of seismic energy densities at the distance of CF unit from Zunil, for a range of seismic efficiency, are on the order of 10^{-1}-10^{4} Jm^{-3}. Such energy densities are orders of magnitude larger than the seismic triggering thresholds for magmatic eruptions [17].

Conclusions: Using observational constraints and numerical models, we find that both magmatic and phreatomagmatic style of eruptions could be viable mechanisms for the generation of the CF mantling unit. Our analysis also suggests that the Zunil impact event might have triggered the eruption. Such explosive eruptions might have been common on Mars [18], but older deposits would have been easily lost to erosion and/or burial. The very recent volcanic deposit further suggests that the magma source may still be active today, providing a likely source of the seismicity observed by SEIS on the nearby InSight lander [8].

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