A LATE-AMAZONIAN PHREATOMAGMATIC TEPHRA DEPOSIT IN ELYSIUM PLANITIA, MARS.

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While the largest and most prominent Martian volcanic eruptions occurred during the Noachian and Hesperian epochs (4.1-3.0 Ga), Amazonian-aged activity has been prevalent at select regions. In particular, Elysium Planitia contains some of the youngest effusive volcanism on Mars [1, 2]. Ancient pyroclastic deposit are abundant elsewhere [e.g., 3], but, to date no pristine pyroclastic deposits have been observed anywhere on Mars.

Here we report on a visibly smooth, low albedo feature in Elysium Planitia roughly symmetric about a Cerberus Fossae fissure (7.9°N, 165.8°E) near Zunil crater (Fig. 1a), which we interpret as a recent pyroclastic deposit (herein referred to as the Amazonian Cerberus mantling unit or ACm). The ACm is surrounded by a high albedo, low thermal IR band of dust, which we interpret to be the exposed edge of a dust layer underlying the main low albedo deposit (Fig. 1b). This is consistent with Zunil secondaries in this region that preserve a paleo-dust deposit in their ejecta [4] as well as general circulation models that predict a thicker past dust layer during high obliquity in Elysium Planitia [5]. The texture of the surrounding large-scale effusive flows (ACo after [2]) appears to be buried by the ACm and its underlying dust deposit. Curvilinear troughs and ridges, 10s of meters across, are observed in the deposit near the fissure, but superposition of Zunil rays suggests that this texture is associated with underlying inflated lava flows [1] or paleo-aeolian features in the underlying dust layer [6]. CRISM spectra over an exposed portion of the ACm resemble spectra of high-calcium pyroxene, which is commonly associated with unweathered volcanics [e.g., 7]. Neither edifice nor cone construction is observed along the fissure [see 8]. Based on these observations, we explore three possible formation scenarios for the ACm.

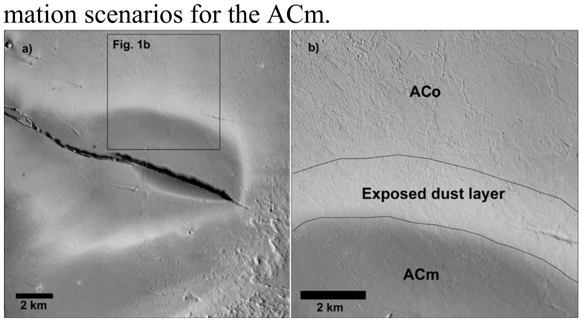

Fig. 1. a) CTX imagery of the ACm unit and **b)** the contact of the ACm with older effusive flows (ACo).

Interpretations of the origin: *Aeolian scour and deposition.* Topographically influenced wind streaks due to craters, other Cerberus fossae fissures, and positive relief in Elysium Planitia are predominantly in a northeast to southwest orientation (Fig. 2a). Elongation is variable in the downwind (southwest) direction (~1-25 km), and limited and relatively uniform (~1 km) in the upwind direction (Fig. 2b). This is consistent with aeolian deposition or scour altering the surface downwind of topographic obstacles, while limited upwind scour is controlled by topographically generated eddies. The ACm is the only feature that is inconsistent with this pattern, with elongation of ~6 km and ~11 km in the upwind and downwind directions, respectively (Fig. 2b). The nearly symmetric nature of the deposit is most consistent with an active source at the fissure.

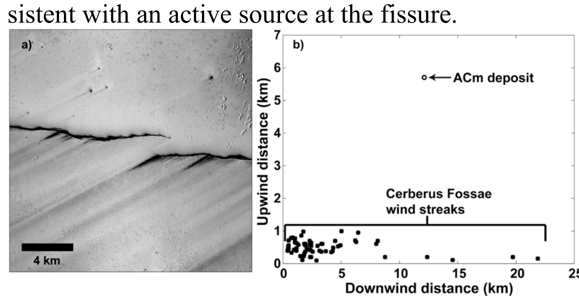

Fig. 2. a) CTX imagery of wind-related streaks at a Cerberus Fossae fissure to the east of the ACm and **b)** the relationship between the upwind and downwind elongation distances at the Cerberus Fossae compared to the geometry of the ACm.

Zunil impact origin. Given the proximity of the Zunil crater to the ACm, we explore the possibility that the Zunil impact formed the ACm unit. Impact related streaks have been associated with fresh craters. These features not only scour and deposit but also exhume material [9]. However, the broad rounded front of ACm in the direction facing Zunil and the 15-km-width of the deposit in the perpendicular direction are unlikely the abundant radial texture of narrow (~1 km) impact wind features radiating out from fresh impact craters.

Pyroclastic eruption. The symmetric distribution of the ACm unit around a Cerberus Fossa in the Elysium Planitia region of Mars, where some of the youngest volcanism has been reported [e.g., 1, 2], is morphologically and geographically consistent with a pyroclastic origin. Pyroclastic fall deposits on Earth and Mars should be fundamentally similar: broad deposits 10s to 100s of kilometers wide, mantling the underlying topography [10]. Visibly the ACm has diffuse margins and appears to mantle the volcanic plains (Fig. 1), consistent with tephra deposits on

Earth. Based on the observations, a pyroclastic origin for the ACm is favored, thus we further explore the volume, age, and eruption style of the ACm deposit.

Thickness and volume estimates: Bright ejecta craters on the deposit are interpreted to have excavated to the underlying dust layer (Fig. 3a). The excavation depths of these craters provide upper bounds on the local deposit thickness and indicate that the majority of the ACm is substantially less than 1 m in thickness (Fig. 3b). The thickness estimates from the bright ejecta craters are fit well by empirical relationships between area and deposit thickness for various eruptions on Earth [e.g., 11; Fig. 3b]. The thickness–area relationship for the ACm provides volume estimates between $4.40x10^7$ and $1.50x10^8$ m^3.

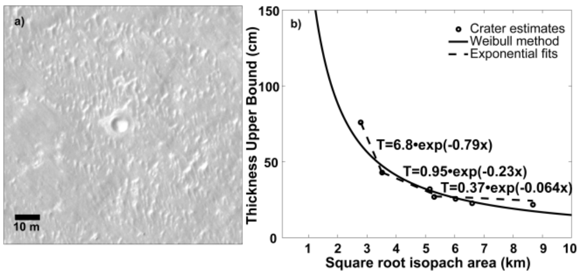

Fig. 3. a) A bright ejecta crater and **b)** the thickness estimates as a function of the isopach area based on the bright ejecta crater distribution.

Age estimates: The stratigraphic position of the deposit relative to Zunil is somewhat difficult to determine. Zunil secondaries and rays are observed on the deposit, though the relative thinness of the deposit and the lack of bright ejecta from Zunil secondaries and rays indicate that the deposit mantles and therefore is younger than Zunil (<0.1-1.0 Ma) [4]. Stratigraphically, Zunil is younger than all documented effusive eruptions in the region, making this deposit the youngest volcanic eruption product on Mars. An age estimate based on the Hartmann production function for small primary craters [12] places this deposit at 0.2 Ma. Recent estimates of the present-day cratering rate [13] increase this age estimate to 4 Ma. In general, the crater model age of 0.2-4 Ma is consistent with the superposition relationships.

Phreatomagmatic or magmatic: The lack of appreciable edifice construction along the fossa and lack of lava flows associated with the deposition of the ACm suggests that little to no magma reached the surface during this eruption [see 8]. Edifice construction is ubiquitous with explosive magmatic eruptions (driven by juvenile water) on Earth [e.g., 14]. Phreatomagmatic eruptions (driven by ground or surface water or ice) on the other hand are poorly sorted, discrete events that usually involve more of the country rock than magma [e.g., 15]. These have characteristic low profiled tephra rings composed of ballistic and fallout material with no evidence for lava or edifice construction, much like the ACm.

We propose that a dike, sourced from a deeper magma chamber, interacted with a subsurface aquifer or ground-ice resulting in a phreatomagmatic plume along the fissure. Further discussion on the physics of this eruption can be found in an accompanying abstract [8].

The primary styles of volcanic eruptions along the other Cerberus fossae are effusive, low viscosity flood lava from eruptive dikes. Pressurized aqueous floods also occurred, potentially due to deeper stalled dike intrusions pressurizing regional aquifers. One possible interpretation for the ACm is that it is an intermediary of these two end-members, in which a smaller dike stalls at shallower depths where magma-water interaction results in explosive eruptions reaching the surface and the broad distribution of ballistic country rock and ash fallout.

Predictions for InSight: Approximately eleven episodes of effusive volcanism have been noted over the past ~250 Ma in central Elysium Planitia with a recurrence interval between ~1.3 Myr and 61 Myr [1, 2]. The youngest age estimate for the ACm is less than the shortest recurrence interval in central Elysium Planitia, thus it is possible that the magma chamber or mantle source that contributed to the eruption of the ACm is still active today. Microseismic earthquakes (M<2) are commonly associated with recent volcanic activity on Earth. The migration of magma along the Snake River plain has contributed to 36 microseismic events between 1972 and 2007 [16], relative to the most recent eruption at ~0.7 Ma. The young age of the deposit relative to volcanic areas on Earth that remain seismically active today suggests that seismic activity associated with the ACm magma source may be observed by SEIS on the nearby InSight lander (~1750 km to the southwest).

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