OBSERVATIONS OF GULLY DEVELOPMENT IN GASA – A RAYED CRATER.

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Introduction: Gasa crater is the result of a recent impact event in Mars latest Amazonian, approximately 1.25 Ma, and coincident with the last glacial phases of Mars most recent ice age. During the most recent ice age (2.1-0.4 Ma) an ice-rich mantling deposit was emplaced equatorward to the mid-latitudes. Meltwater from degradation of this deposit has been implicated in gully formation. The fresh morphology of Gasa crater provides an ideal contrast between dry mass wasting processes that have dominated downslope movement on the equator-facing slope and the gullied pole-facing slope, which has developed a large bajada. We suggest that this asymmetry is due to the insolation-dependent degradation of local ice and snow deposits. These gullies indicate that the development of extensive gully systems can occur on a timescale of perhaps a few hundred thousand years.

Geologic Setting: Gasa (35.72°S, 129.45°E) is a very fresh ~7-km diameter impact crater which occurs within the simple to complex crater transition on Mars [1] with a crisp rim-crest, a well-defined flat floor, and no evidence of substantive infilling (depth-diameter ratio of 0.12). Gasa is located within an older ~18-km diameter crater in eastern Promethei Terra on Noachian cratered terrain. The outer (un-named) host crater has muted topography, a low depth:diameter ratio (0.07), evidence of latitude-dependent mantling, gullies, and polygonally patterned ground [e.g., 2] which are all evidence of extensive Amazonian modification [e.g., 3].

Rays: Radiating from Gasa are extensive ray patterns (Fig. 1) visible in nighttime THEMIS infrared data [4]. The population of rayed craters, like Gasa, on Mars is limited [5]. Generally, the distinctiveness of crater rays arises from both compositional and maturity differences [e.g., 6]. The thermophysical distinctiveness of martian rays [5,7,8] is attributable to thermal inertia differences with surrounding terrain (low TI rays) hence rays are most apparent in nighttime thermal infrared data [9]. The distribution of identified rayed craters [5] suggests that the occurrence or persistence of rays is dependent on substrate. Intermediate to high background thermal inertia and intermediate albedo appear to be the important criteria regarding the distinguishability of rays (see mapping results of Mellon et al. [10] and Putzig et al. [11]). This is consistent with most of the Tornabene et al. [5] detections occuring in volcanic terranes. Rays on Mars can be homogenized with the surrounding environment or obscured from view by multiple geomorphic processes known to be active on the martian surface. To date, Gasa crater (Fig. 1) is located farther poleward (35.7°S) than any other identified rayed crater. The absence of identified rayed craters in the mid and high latitudes is consistent with recent resurfacing events in these regions due to deposition of latitude-dependent mantling deposits, which are discussed further below.

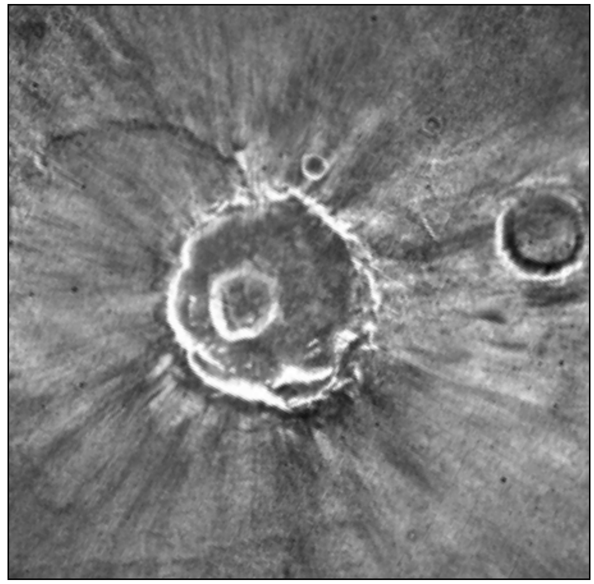

Figure 1: THEMIS (Thermal Emission Imaging System) nighttime thermal infrared data show a pattern of fresh rays emanating from the ~7-km-diameter inner crater (Gasa).

Age: The Gasa-forming impact event created a smooth near-rim ejecta deposit. This deposit is ideal for crater-retention dating because of its smooth surface and gentle topography. Using HiRISE data, 289 craters were identified on 11.63-km^2 of the smooth ejecta deposit with the largest crater 61 m in diameter. Employing isochrons of Hartmann [12], this crater size-frequency distribution implies a best-fit age of 1.25 Ma for the Gasa crater impact event. While there is some uncertainty in the production rate of small craters, recent direct observations of small crater formation [13] suggest that inferred recent cratering rates are unlikely to be in error by more than a factor of a few [14,15], all of which is consistent with preservation of the rays [5,7].

Latitude-dependent Mantling: Mars' mid- to high-latitude latest Amazonian geomorphology is characterized by ice-related processes and landforms including a pervasive ice-rich mantling unit observed in the larger crater encompassing Gasa as well as on the surrounding terrain. This mantling unit was first identified in global maps of surface roughness [16] and described from visual observations [17,18,19,20]. While the process of vapor diffusion governs the stability of ground ice deposits [e.g., 21], geological evidence suggests that the ice-rich mantling unit is the result of atmospheric deposition rather than vapor diffusion into regolith pore space. Evidence of extensive atmospheric deposition of ice is provided by Gamma Ray Spectrometer (GRS) data of ice abundances that far exceed reasonable pore space volumes [e.g., 22], observations of massive ice by the Phoenix lander [23], and recent repeated observations that have identified new mid-latitude impact craters that expose a nearly pure ice substrate that is observed to sublimate upon exposure [24]. A theory of recent obliquity-driven ice age climate cycles was proposed by Head et al. [20] that relates broad deposition of ice-rich mantling deposits and other features to larger obliquity variations that occurred most recently > 400 ka [25].

Potential Sources of Meltwater for Gullies: Melting of latitude-dependent mantling deposits has been proposed as a source of water for gullies [19,20,26,27,28,29]. From a process standpoint, this scenario is comparable to previously proposed sources of meltwater including ground ice [30] and ancient snowpacks [31]. It has also been proposed that gullies can be late-stage features that develop during the wane and retreat of alpine-like glaciers [28,32,33]. Evidence supporting this process model includes well-developed arcuate ridges interpreted as moraines below cirque-like alcoves that would have been ideal accumulation zones for glacial systems [28,32,33]. While in a recent study [34], small-scale surficial gullies were documented whose incision is limited to the mantling unit and which lack alcoves. These gullies provide independent evidence that melting and degradation of ice-rich mantling deposits is an important source of meltwater, sufficient for some gully formation.

Independent evidence exists for the development of gullies in association with glacial systems (with commensurately large accumulations of ice in the past) as well as from localized melting of latitude-dependent mantling deposits. What distinguishes the formation of mid-latitude gullies – what is the minimum time required to form gullies, and how much meltwater is required? Analysis of Gasa crater and observations of its gullies help address these questions because the age of the crater and its stratigraphic relationship with respect to latitude-dependent mantling deposits are known.

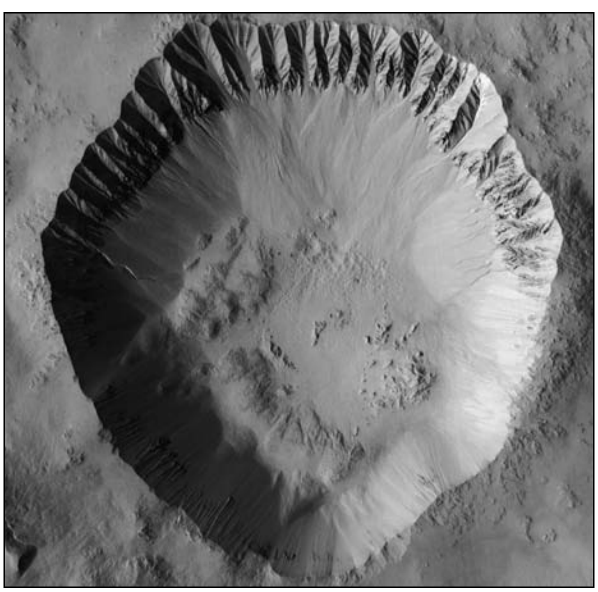

Figure 2: Context camera scene of Gasa crater and gullies illustrates fundamental orientation-dependent asymmetries.

10 Observational Constraints from Gasa (Fig. 2): (1) Gasa postdates regional deposition of latitude dependent mantling deposits. Crater rays (Fig. 1) and clusters of secondaries are observed on this deposit. (2) Interfluves between gully alcoves are not mantled and contain bedrock exposures and boulders. (3) Alcoves and channels are best developed on the pole-facing orientation with progressively less-developed gullies off axis. (4) Gully alcoves have crenulated the crater rim-crest; crenulation is not observed on un-gullied rim segments. (5) Downslope movement of material is significantly more extensive on the gullied portion of the crater wall. (6) Gully channel cutoffs and channel-fills are observed. (7) Feeder channels in gully alcoves also exhibit preferred poleward orientations. (8) Channel diversions are observed in association with gully fan deposits. (9) In contrast, the equator-facing wall has only minor vertical striations. (10) Talus cones and landslide deposits are observed predominately in association with the equator-facing slope.

Conclusions: The formation of the Gasa gullies required an aqueous phase [e.g., 35], most likely derived from melting of snow and ice deposits. The age and stratigraphic position of Gasa suggest that the crater was not subject to pervasive latitude-dependent mantling. Therefore, we suggest that localized deposition and concentration of seasonal snow deposits were the source of meltwater for these gullies. Meltwater generation was highly dependent on slope orientation and insolation history [36,37] (Fig. 2). Periods of melting, perhaps only coincident with obliquity peaks [20,30], was sufficient to fully form these gullies in the recent geologic past.

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