UNIQUE CHRONOSTRATIGRAPHIC MARKER IN DEPOSITIONAL FAN STRATIGRAPHY ON MARS: EVIDENCE FOR ~1.25 MA OLD GULLY ACTIVITY AND SURFICIAL MELTWATER ORIGIN.

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Introduction [1]: Since their discovery, a variety of formation hypotheses have been proposed to explain the diversity of gully observations. These hypotheses can be divided into three broad categories: entirely dry mechanisms [2,3], wet mechanisms invoking groundwater release [4,5], and wet mechanisms invoking surficial meltwater [6,7,8]. It has been difficult to differentiate between these hypotheses and test their validity using past observations [9]. Also uncertain is the age of Mars gullies and thus their specific link to recent climate history. Although they appear to have formed contemporaneously with latitude-dependent mantling deposits thought to have been emplaced during recent "ice ages" [10,11,12,13,14], the area of individual gullies themselves is too small to obtain reliable ages using crater size frequency distributions. We document here a unique geological setting that provides new insight into these relationships.

Gully-Fan Stratigraphy: In eastern Promethei Terra (~35°S, 131°E), an ~5 km-diameter crater is observed with a single well-developed gully system and several smaller gullies in its north-northeast wall. This gully system (composed of a small western gully and larger eastern gully) shows evidence for incision into the crater wall and has multiple contributory subalcoves and channels. The low-slope depositional fan (Fig. 1) associated with this gully system is significantly larger than the others. The gully fan is composed of multiple lobes with distinct lobe contacts, incised channels, and channel fill deposits – all features similar to those observed in terrestrial alluvial fans: cone-shaped deposits of fluvially transported sediments that accumulate at distinct breaks in slope [15,16]. Secondary craters (~1–25 m-diameter) are pervasive in the vicinity of the gully, but only a portion of the fan itself has superposed secondaries, implying that at least some portions of the depositional fan were deposited both before and after the emplacement of the secondaries. The individual depositional lobes of the fan can be divided into two groups (Fig. 1): a lobe that predates the secondary crater population (1) and younger lobes (2-4), distinguished by stratigraphic contacts and cross-cutting relationships, that are superposed on the lobe with secondary craters. These multiple lobes that post-date the secondary crater population make the emplacement date of the secondary craters a robust maximum age for the youngest lobes of this fan, and therefore the most recent activity of the gully system.

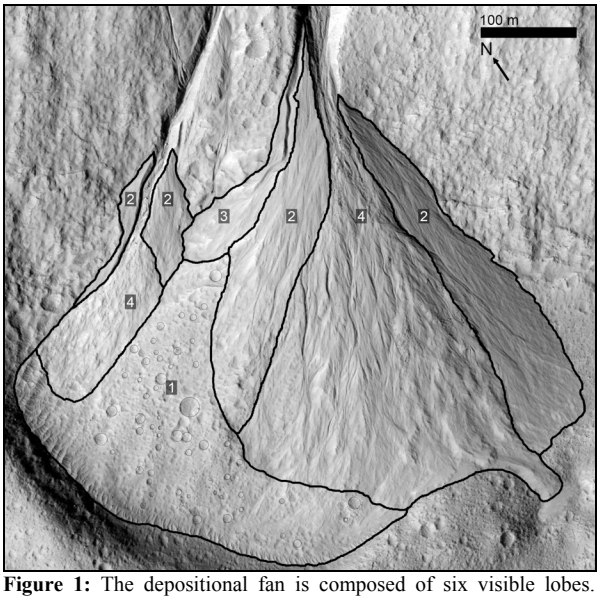

Figure 1: The depositional fan is composed of six visible lobes. Lobe 1 is the oldest visible lobe and retains a dense population of secondary craters. The superposing un-cratered lobes (2–4) post-date emplacement of the secondary craters and require episodes of more recent gully activity [HiRISE: PSP_002293_1450].

Source and Age of Secondary Craters: Regional reconnaissance was undertaken to determine the origin of the secondary craters utilizing the orientation of crater clusters and cluster patterns. This search led to the discovery of a previously unidentified rayed crater complex consisting of two superposed very fresh caters, an ~18 km-diameter outer crater and an ~7 km-diameter inner crater located at ~35.7°S, 129.4°E, ~100 km southwest of the gully system. Distinctive rays are observed in THEMIS nighttime thermal infrared data, but are not observable as albedo contrasts in visible data, consistent with other identifications of young rayed craters on Mars [17,18]. This crater complex is also located in a similar thermophysical setting to previously identified rayed craters: intermediate albedo and thermal inertia, implying an intermediate dust cover [19].

We interpret the inner crater as the source of the rays and secondary craters of interest, and younger than the most recent episode of latitude-dependent mantling deposition at this low latitude. Morphological observations suggest that the outer crater predates the end of an obliquity-controlled period of latitude-dependent mantle deposition, while the inner crater appears to post-date the most recent period of mantle

deposition [11]. To test this proposition quantitatively we performed crater counts on smooth near-rim units of the inner crater. These units north and south of the inner crater both yield crater retention (CRE) ages of ~1.25 Ma (Fig. 2) based upon isochrons of Hartman [20]. Some uncertainty exists in the production rate of craters at this size range; however, recent observation of small crater formation [21] has provided observational evidence that inferred recent cratering rates on Mars are unlikely to be off by more than a factor of a few [22,23]. Thus, including the inferred uncertainty in production rates, the age range for the chronostratigraphic marker is between 0.6 and 2.4 Ma.

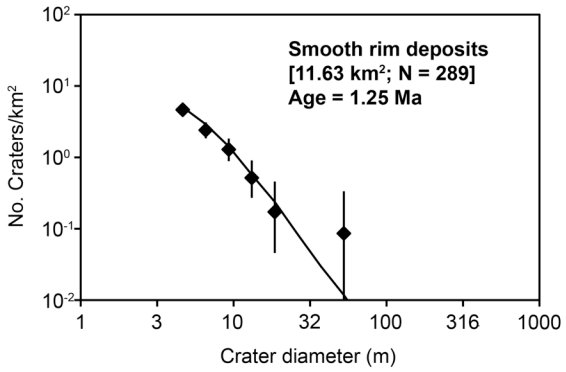

Figure 2: Incremental size-frequency plot of smooth near-rim deposits of the inner crater yields a crater retention age of ~1.25 Ma, placing the formation of this crater in a period of obliquity-controlled mantle accumulation and modification.

Discussion and Conclusions: Fan morphology indicates that multiple periods of activity were required for its construction and that the secondary craters were emplaced during an intermediate period in fan formation. The presence of multiple superposing crater-free lobes requires several episodes of gully activity post-dating emplacement of the secondary craters. Therefore, the emplacement of the secondaries provides a firm maximum age on the most recent activity of this gully system. Approximately 100 km to the southwest, a 7 km-diameter rayed crater was identified that is interpreted to be the source of the secondaries.

Impact crater size-frequency distributions (Fig. 2) place this crater's formation in the waning stages of the most recent period of latitude-dependent mantle accumulation and modification [11]. The higher amplitude obliquity variations during this period favor both the deposition and melting of top-down ice-rich deposits amenable to gully formation [6,11]. These stratigraphic relationships imply that at least some gullies on Mars have been active in very recent periods of the Late Amazonian during recent "ice ages" [e.g., 11,24].

The multiple episodes of gully-related depositional fan activity mapped in this study imply that gullies are not catastrophic landforms that formed in single events (i.e., as one-time debris flows or outbursts of groundwater). The distinctive alluvial fan-style morphology, fluvial channel sedimentary structures, and alcove incision make dry mass wasting processes implausible for the formation of the gully system. The multiple episodes of activity required by the fan stratigraphy documented here cast doubt on groundwater discharge scenarios that are less likely to generate episodic releases. Rather, small amounts of surficial meltwater derived from snow and ice accumulation is suggested by the insolation geometries of gully systems and most plausibly can account for multiple periods of recent activity required by these observations. Modeling by Williams et al. [25] shows that Martian snowpacks can reach melting temperatures under a variety of conditions and produce small amounts of meltwater. Freshly uncovered snowpacks under current conditions, snowpacks at higher obliquities, and windblown snow proposed by Head et al. [8] to seasonally concentrate in gully channels, can all lead to small amounts of meltwater [e.g., 7]. These multiple avenues of surficial meltwater generation and our stratigraphic observations place recent gully activity during the most recent deposition and modification of latitude-dependent ice-rich mantling deposits.

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