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Origin and significance of decameter-scale polygons in the lower Peace Vallis fan of Gale crater, Mars

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ABSTRACT

Decameter-scale polygons are extensively developed in the Bedded Fractured (BF) Unit of the lower Peace Vallis fan. The polygons occur in a likely extension of the Gillespie Lake Member, north of Yellowknife Bay, the section first drilled by the Mars Science Laboratory (MSL) mission. We examine hypotheses for the origin of these polygons to provide insight into the history of Gale crater.

The polygons are ∼4–30 m across, square to rectangular, and defined by ∼0.5–4 m wide, generally straight troughs with orthogonal intersections. Polygon networks are typically oriented-orthogonal systems, with occasional nearly circular patterns, hundreds of meters across. Potential origins include cooling of lava, and for sedimentary units, syneresis, unloading, weathering, desiccation, impact processes, and cold-climate thermal contraction. Cold-climate thermal contraction is the hypothesis most consistent with the sedimentary nature of the BF Unit and the polygon morphology, geometry, networks, and apparent restriction to the coarse-grained Gillespie Lake Member. A periglacial setting further provides the best analogs for the circular networks and is consistent with geologic context and MSL data.

Most of the decametric polygons appear to be ancient. They are confined to the Hesperian BF Unit, and only a few of their bounding fractures extend into younger or recently exposed units. In this regard, they differ from the majority of proposed thermal-contraction polygons on Mars, as those are generally thought to be young features, and, accordingly, the history of formation, preservation and reactivation of the decametric polygons is likely to be more complex than that of any proposed young polygons on Mars. The decametric polygons in the BF Unit may represent landforms developed in a cold but still comparatively wet interlude between a clement early Mars and the much drier and colder planet of today.

1. Introduction

The Mars Science Laboratory (MSL) mission began its exploration of Gale crater by traversing east from its landing site to Yellowknife Bay (YKB). YKB is at the edge of a geologic unit noted by MSL team members prior to landing for its relatively high thermal inertia (TI) coupled with its position distal to, and downslope from, the Peace Vallis alluvial fan that enters the crater from its northern rim (Fig. 1) (Grotzinger et al., 2014). The high thermal inertia unit was mapped in Anderson and Bell (2010) and also was identified in the 4th Landing Site workshop for MSL (Fergason, 2010). Subsequent investigation using the instrument suite on MSL's Curiosity rover led to the interpretation that the strata at YKB are composed of fine-grained sedimentary rocks that formed in an ancient lake with neutral pH and low salinity (Grotzinger et al., 2014). To provide additional insight into the history of the alluvial fan and YKB, image data from the High Resolution Imaging Science Experiment (HiRISE) and Context (CTX) cameras on Mars Reconnaissance Orbiter were used to study the entire high TI unit, now named the Bedded Fractured (BF) Unit (Fig. 1C and D).

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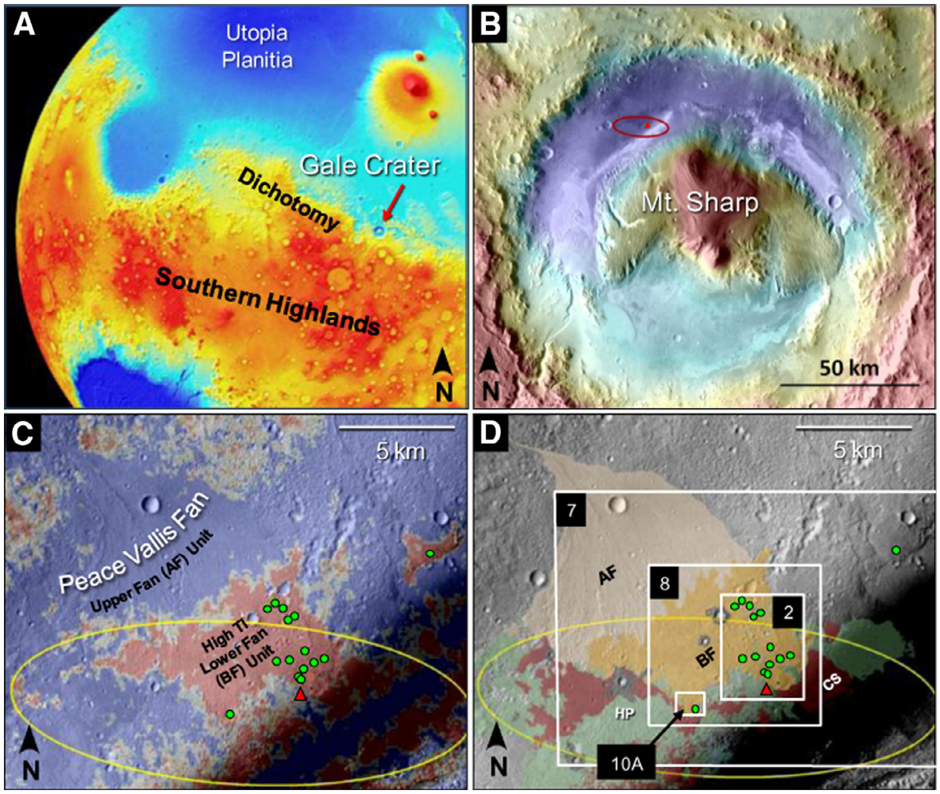

Fig. 1. Geologic context. (A) Regional setting on basemap of elevation; elevation from the Mars Orbiter Laser Altimeter (MOLA), with reds > −3000 m and blues < −4000 m. (B) Gale crater. MOLA elevation overlaid on Daytime Infrared (IR) from the Thermal Emission Imaging System (THEMIS). Colors are for elevation, with reds > 0 m and blues < −4000 m; red oval, MSL landing ellipse; red triangle, MSL landing site. (C-D) Peace Vallis fan; green dots, circularly organized polygons (CPs); yellow oval, landing ellipse; red triangle, MSL landing site. (C) Thermal inertia (TI) on Context Camera (CTX) mosaic; colors are for TI, with reds > 420 J m^{-2} K^{-1} $s^{-1/2}$ and blues < 370 J m^{-2} K^{-1} $s^{-1/2}$. (D) Geologic units on CTX mosaic; AF, Alluvial Fan Unit; BF, Bedded Fractured Unit; CS, Cratered Surface Unit; HP, Hummocky Plains Unit (Grotzinger et al., 2014). Locations of Figs. 2, 7, 8, and 10A shown, though Fig. 7 extends ~2 km farther east.

Using HiRISE images, pervasive decameter-scale polygons, including distinctive circular networks, were observed over much of the BF Unit. Potential hypotheses for the origin of these polygons include (1) thermal contraction associated with cooling lava, (2) syneresis of sediments, (3) unloading of bedrock, (4) weathering of sedimentary rocks, (5) desiccation of sediments, (6) impact-related processes, and (7) cold-climate, thermal contraction of sediments or sedimentary rocks (Hallet et al., 2013; Oehler, 2013). Here we assess each of these hypotheses, as the various possible origins have important implications that differ markedly from one another with regard to the geomorphic and geologic development of Gale crater.

2. Regional setting

Gale crater is a 154 km-diameter impact crater located at 5.4°S latitude and 137.9°E longitude. It is located on the dichotomy that separates the southern highlands from the northern lowlands (Fig. 1A). The impact that created Gale is thought to have occurred in the Late Noachian to Early Hesperian, ~3.8 to 3.5 billion years ago (Ga) (Thomson et al., 2011; Le Deit et al., 2013). Numerous investigators have speculated that the martian lowlands might have contained a northern ocean in the Noachian, when the climate was comparatively wet (see works summarized by Fairén et al., 2003; Dohm et al. 2009; Fairén, 2010; Oehler and Allen, 2012, 2014). Gale is the deepest mid-sized crater to straddle this boundary and the possibility of an ocean at the northern boundary of the crater would profoundly affect its history. But the possibility of a northern ocean is still debated. Recent work suggests that oceans on Mars, if they existed, may have been characterized by high solute concentrations that allowed long-term stability of liquid water, even at temperatures below 273 K (Fairén et al., 2009, 2011). Alternatively, an ancient martian ocean may have been ice-covered for much of its history, with only episodic interludes of surface liquid water, perhaps due to pulses of magmatic heating and/or influx of massive quantities of sediment and fluid (Parker et al., 2010; Parker and Calef, 2012; Clifford et al., 2013; Petijean et al., 2014; Salvatore and Christensen, 2014; Rodríguez et al., 2015).

Gale is surrounded by incised valleys that cross the highlands and have been interpreted as the product of rivers that flowed north toward the lowlands. Many of these valley networks pre-date the Gale impact (Newsom et al., 2015), but several of the smaller examples, such as that associated with the Peace Vallis alluvial fan, cross the Gale ejecta and crater rim (Anderson and Bell, 2010) and are thought to represent Hesperian fluvial activity (Grant et al., 2014). Recent analysis of the Peace Vallis fan system suggests that, though snowmelt may have been an important source of water, the amount of runoff needed to produce the fan (with the sorting and fluvial/lacustrine deposits described by MSL) exceeds that which could be stored as a single snow pack and requires a full hydrologic cycle that may have been active for at least 1000 years (Palucis et al., 2014, 2016).

Hydrologic modeling suggests that Gale crater is uniquely situated for significant groundwater influx, from aquifer-recharge sourced from precipitation belts thought to have been extant at the end of the Noachian and into the Hesperian (Andrews-Hanna et al., 2012a, 2012b). These precipitation belts were modeled using an Earth-General Circulation Model coupled with martian surface topography, which allowed prediction of atmospheric circulation