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Reconstructing the aqueous history within the southwestern Melas basin, Mars: Clues from stratigraphic and morphometric analyses of fans

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ABSTRACT

New details of the aqueous history in the southwestern Melas Chasma elevated basin have been revealed from analysis of high-resolution image, topographic and spectral datasets. We have identified eleven fan-shaped landforms that reflect various depositional environments. A distinctive marker bed with inferred indurated aeolian bedforms is within the stratigraphic record of presumed lacustrine deposits. This observation, taken together with the stratigraphic succession of fan-shaped deposits indicates fluctuating lake levels with, at a minimum, early and late-stage lake highstands. Tributary drainage pattern in the western valley network changed from a dendritic to a meandering system, recording a shift in fluvial activity that is consistent with fluctuating lake levels. Only a few hydrated minerals have been detected in the study region, the most common being opal which appears to represent younger alteration and deposition within the basin. Landform scale was used to estimate average discharge (~30 m^3/s), formative discharge (200–300 m^3/s), and fan formation timescale, which further inform the duration of lacustrine activity within the basin. Warm surface conditions and precipitation recharge of source basins is required to generate and sustain this long-lived lake over periods of at least centuries to millennia during the Late Hesperian to Early Amazonian.

1. Introduction

The martian surface contains widespread fluvial landforms that reflect past erosion and deposition by running water (e.g., Carr, 1996). Standing bodies of water on the surface of Mars have long been postulated to be associated with valley networks and outflow channels (e.g., McCauley, 1978; Cabrol and Grin, 1999; Mangold and Howard, 2013). Water bodies spanning a wide range of sizes, from oceans (e.g., Parker et al., 1989, 1993; Baker et al., 1991; Baker, 2001), to lakes (e.g., Cabrol and Grin, 1999) to small-scale, shallow water bodies (e.g., inter-dune playas; Grotzinger et al., 2005, 2006) have been proposed. However, a fundamental uncertainty has been the duration of water bodies on Mars, a critical constraint that has important implications for former climate conditions and for assessing habitable environments.

One region on Mars that has a prolonged record of aqueous activity, reflected in the morphology and chemical composition, is the Valles Marineris canyon system. The canyon system is associated with the circum-Chryse outflow channels that formed by catastrophic floods largely during the Hesperian (Rotto and Tanaka, 1995; Nelson and Greeley, 2001). Some researchers have proposed the Valles Marineris troughs and chaotic terrain as source regions for the water that flowed through the outflow channels (e.g., McCauley, 1978; Carr, 1979; Robinson and Tanaka, 1990). Lakes or playas may have existed within the canyons at various times (see literature review in Lucchitta, 2010). Additional mineralogical evidence for aqueous activity in this region includes the presence of hydrated minerals, including various clays and sulfates that have recently been detected in several troughs of Noctis Labyrinthus (Weitz et al., 2011, 2013; Thollot et al., 2012), along the wallrock and floor in western Melas and eastern Ius Chasma (Metz et al., 2009; Roach et al., 2010; Weitz et al., in press), within Coprates Catena (Grindrod et al., 2012), Capri Chasma (Weitz et al., 2012) and Candor Chasma (Murchie et al., 2009c). The thick layered sediments found within many of the chasmata consist of sulfates that may have formed from chemical weathering (e.g., acidic aerosols interacting with basaltic dust trapped within ice/snow deposits; Niles and Michalski, 2009) or from the evaporation of large quantities of water and/or ice (e.g., Gendrin et al., 2005; Mangold et al., 2008b; Andrews-Hanna et al., 2010). Morphological evidence of water flow on the surface has been recognized in isolated locations in Valles Marineris. Dendritic valley networks attributed to surface runoff have been identified on several Hesperian plateaus surrounding the canyon system (Mangold et al., 2004,

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2008a; Weitz et al., 2010; Le Deit et al., 2010) and within one basin in Melas Chasma (Quantin et al., 2005). Fan-shaped landforms at the termination of valley networks in the southwestern Melas basin have been interpreted as subaqueous deposits (Quantin et al., 2005; Metz et al., 2009).

In this study, we focus on the aqueous history preserved within the southwestern Melas basin through analysis of the morphology and stratigraphic relationships of valley networks and fan-shaped landforms. These fluvial landforms provide us with an opportunity to better understand water activity and associated climatic conditions in this region. We examined high-resolution images, topographic data and complimentary visible and near-infrared reflectance data of key regions to refine our understanding of the sequence of events within this basin. A particular emphasis of this study is documentation of the diversity of fan-shaped landforms, which reflect various depositional environments. Some components of these fan complexes have been detailed in prior studies (e.g., Quantin et al., 2005; Metz et al., 2009), but this is the first investigation to look at all fans within the basin, characterize their morphology based on meter-scale images, evaluate their origin, and synthesize a history for the basin based on superposition relationships of the fans. We estimate paleodischarge, filling time, and lacustrine lifetime constrained by the preserved morphology.

2. Background

Three settings have been identified for hypothesized martian lakes: at the end of outflow channels, at the end of convergent drainage of valley networks, and within canyons (McCauley, 1978; Lucchitta et al., 1986; Lucchitta, 2010; Parker et al., 1989, 1993; Scott et al., 1995). Only a few locations have geomorphic evidence of deposits postulated to have a lacustrine origin (Cabrol and Grin, 2001; Malin and Edgett, 2003; Moore et al., 2003; di Achille and Hynek, 2010). Of these examples, researchers have placed particular emphasis on studying fan-shaped landforms at or near valley network termini within closed topographic basins as potential deltaic deposits. High-resolution image and topographic data have been instrumental in evaluating the origin of these fan-shaped landforms, whether from alluvial transport, mass-wasting, glacial processes, volcanic processes or subaqueous deposition (Leverington and Maxwell, 2004; Malin and Edgett, 2003; Moore and Howard, 2005).

An ideal study site for investigating hypothesized lacustrine environments on Mars is located in the central part of Valles Marineris in an elevated, enclosed basin ~2 km above the canyon floor (Fig. 1). The geomorphic evidence at southwestern Melas Chasma has widely been recognized as consistent with a postulated paleolake (Mangold et al., 2004; Quantin et al., 2005). The plethora of inferred aqueous landforms located within the Melas basin is part of the reason southwestern Melas Chasma received a high science value ranking as a candidate landing site for the Mars Science Laboratory (MSL) rover (Quantin et al., 2006; Grant et al., 2010) and for the 2020 Mars rover (Williams and Weitz, 2012; Williams et al., 2014). Because this region was targeted as a potential landing site, a wealth of data covers the features and deposits within the basin. Valley networks converge from the east and west into the 30 × 120 km basin and terminate in fan-shaped landforms (Fig. 2). In addition, the basin has layered beds that are probable lacustrine deposits. Cross-cutting relationships exist between multiple channel networks and fans within the basin, which can be used to better constrain the sequence of events that shaped this region.

The most detailed basin-wide study to date of the site was conducted by Quantin et al. (2005). This work used Thermal Emission Imaging System (THEMIS) images and Mars Orbiter Laser Altimeter (MOLA) topographic data to characterize the size, extent, planimetric pattern and local slope of the valleys along the wallrock. Valley networks to the east and west of the basin terminate in a closed depression. Quantin et al. (2005) mapped the valley networks that enter the basin from the west (their 'eastern valley network') and measured a drainage density of 1.5 km^{-1} for this system. Layered beds within the basin have shallow dips (0.5–3.5°) oriented towards the basin center, consistent with lacustrine deposits draping a pre-existing topographic basin (Quantin et al., 2005). The order-of-magnitude agreement in volume estimates of the eroded material from one watershed, the 'eastern valley network', and the layered beds within the basin suggests the layered beds could be lacustrine strata composed of reworked material transported from incision of the upland valleys (Quantin et al., 2005). Quantin et al. (2005) document cross-cutting relationships of valley networks on the west side of the basin that reflect a complex, poly-phase fluvial history of the region. Crater counts of the landforms within Melas Chasma yield a maximum age of Hesperian (~3.5 Gyr; Quantin et al., 2005). While the terrain these valleys dissect is Hesperian (2.9–3.7 byr old; Hartmann and Neukum, 2001), the valleys could have formed in the Late Hesperian to Early Amazonian when other valley networks in the Valles Marineris region were active (e.g., Fassett and Head, 2008; Mangold et al., 2008a).

Several fan-shaped landforms are present within Melas Chasma (Fig. 2). Quantin et al. (2005) discussed two of these fan-shaped landforms (fans C and J1 in Fig. 2), proposed two distinct water levels (−1720 and −1540 m MOLA aerocentric elevation values) based in part on the apex of these depositional fans, and estimated a maximum lake water volume of 157 km^3. Metz et al. (2009) interpreted fans (A and B in Fig. 2) within an erosional window in the western fan complex to be deep sublacustrine in origin with a morphology similar to those seen in the Mississippi submarine fan complex (Twichell et al., 1992; Nelson et al., 1992). In addition, Metz et al. (2009) suggest two fans within the eastern fan complex (fans G and H in Fig. 2) may be deltaic or sublacustrine in origin. Exposed stratal relationships also reflect the depositional environment within the Melas basin. Steeply inclined beds in the northwest part of the basin have clinoform geometries which may represent either a delta complex or a channel-levee system (Dromart et al., 2007). Now that the Melas basin has been completely covered by HiRISE and CTX images, we are able to expand upon these initial studies and analyze the entire lacustrine system at meter-scale resolution to provide a comprehensive interpretation of all features within the basin.

3. Methods

We examined several data sets representing a range of spatial and spectral resolution to understand the morphological, mineralogical, and stratigraphic context of the fans within the Melas basin. Images of the study site were obtained from the Mars Odyssey Thermal Emission Imaging System (THEMIS, Christensen et al., 2004) images from the infrared (IR, 100 m/pix) and visible (VIS, 18 m/pix) cameras, Mars Express High Resolution Stereo Imager (HRSC, up to 2.3 m/pix; Jaumann et al., 2007), Mars Reconnaissance Orbiter (MRO) High Resolution Imaging Science Experiment (HiRISE, up to 25 cm/pix; McEwen et al., 2007), MRO Context Imager (CTX, 6 m/pix; Malin et al., 2007) and Mars Orbiter Camera (MOC, 1.5–12 m/pix; Malin and Edgett, 2001). We have co-registered available images from the CTX and HiRISE cameras to a THEMIS daytime IR mosaic basemap. Contacts between different deposits observed in HiRISE and CTX images of the basin have allowed us to determine stratigraphic relationships. Color HiRISE products were also utilized and include enhanced RGB and IRB images (McEwen et al., 2007).