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Formation of an Hesperian-aged sedimentary basin containing phyllosilicates in Coprates Catena, Mars

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ABSTRACT

The extensive light-toned deposits in canyons and troughs in Valles Marineris provide evidence of formation through water-related processes. As such, these deposits offer a window to past conditions on Mars. We study a small outcrop of light-toned deposits in a closed trough in Coprates Catena, a chain of collapse pits to the south-east of the main Valles Marineris system. A well-exposed sequence of deposits on the base of the north wall of the trough offers a 220 m section for geochemical and morphologic analysis. Using CRISM data we identify the presence of both phyllosilicates and sulfates and/or opaline silica in the light toned deposits, which vary in relative strength with elevation. We observe a trend in the dominant mineralogical signal, with Al phyllosilicates occurring near the base of the deposits, both below and above a band of Fe/Mg phyllosilicates, before a transition to more sulfate- or opaline silica-rich material near the top of the section. This trend likely reflects a change in the chemistry of the water in which the deposits formed. Using a HiRISE Digital Elevation Model, we find that the layers in the light-toned deposits on both sides of the trough dip gently towards the center of the trough, with a dip direction that aligns with the strike of the trough, suggesting that the light-toned deposits formed after the trough. Our general morphologic and mineralogical observations fit well with significant amounts of water in the trough. The deposits are too small to be dated using crater counting techniques, however, our crater analysis suggests that the plains in which the trough formed are probably Late Hesperian in age. If the chemistry of the light-toned deposits reflects the primary depositional mineralogy, then this and other small troughs in Coprates Catena might provide evidence of limited phyllosilicate formation in this region towards the end of the Hesperian era on Mars.

1. Introduction

The canyons and troughs of Valles Marineris often contain distinctive, layered deposits of light-toned material (e.g. McCauley et al., 1972; Nedell et al., 1987; Lucchitta et al., 1992, 1994). These light-toned deposits (LTDs) are most often found towards the center of chasmata, and despite sometimes having heights almost as large as the surrounding canyon walls, LTDs usually show evidence of having undergone significant erosion (Lucchitta et al., 1992). A number of hypotheses have been put forward to explain the origin of these LTDs, including formation by volcanic (Chapman and Tanaka, 2001; Komatsu et al., 2004), aeolian (Peterson, 1981), lacustrine (McCauley, 1978; Komatsu et al., 1993; Lucchitta et al., 1994), or mass wasting (Sharp, 1973; Nedell et al., 1987) processes. LTDs have also been suggested to be the erosional remnants of older material that has been cut by chasmata formation (Malin and Edgett, 2000). The wide variety of LTD morphology revealed by increasingly high-resolution observations implies that multiple processes might be responsible for the formation of different LTDs. One of the most important debates regarding LTDs is determining their time of formation relative to the canyons in which they are hosted, and indeed the rest of the martian geological timescale. If LTDs predate the formation of the chasmata, then they could be Noachian in age, with their exhumation occurring later in the Hesperian (e.g. Malin and Edgett, 2000, 2001; Montgomery and Gillespie, 2005; Catling et al., 2006; Adams et al., 2009; Montgomery et al., 2009; Jackson et al., 2011). The consensus seems to prefer a LTD formation mechanism that occurs during or after chasma opening, probably during the Hesperian to Amazonian periods (e.g. Scott and Tanaka, 1986; Komatsu et al., 1993; Lucchitta et al., 1994; Schultz, 1998; Chapman and Tanaka, 2001; Fueten et al., 2005, 2008, 2010, 2011; Harrison and Chapman, 2008; Okubo et al., 2008; Flahaut et al., 2010; Okubo, 2010). Interest in LTDs in Valles Marineris has continued with the recent discovery

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of abundant hydrated minerals within the LTDs, with the possible formation mechanisms suggesting the role of water at some point in the past (e.g. Gendrin et al., 2005; Bibring et al., 2006; Murchie et al., 2009a).

This paper addresses the formation and timing of a small outcrop of LTDs in a closed trough in Coprates Catena. Although the small size of these LTDs compared to some of the deposits in other larger chasmata has limited their observation, the advent of recent high resolution data allows us to study in detail the mineralogical and morphologic evolution of these deposits. The study trough also contains a distinctive fan deposit, suggesting the occurrence of water at some point (Di Achille et al., 2006; Weitz et al., 2006), and therefore we specifically address the question of whether the LTDs are evidence of a lacustrine environment (see Lucchitta (2009a,b), for recent summaries). The implications from the results of this study are then placed into a broader chronologic and geologic context, with the aim of contributing towards our understanding of the evolution of water on Mars.

2. Data and methods

We first prepared a Digital Elevation Model (DEM) from HiRISE stereo pair PSP_007917_1650 and PSP_009631_1650 using the method of Kirk et al. (2008). This method involves pre-processing the raw Experimental Data Records (EDRs) in the freely-available Integrated Software for Imagers and Spectrometers (ISIS) image processing routines (http://isis.astrogeology.usgs.gov), before using the commercial SOCET Set image analysis software (http://www.socetset.com) to produce a DEM with elevation postings every 1 m. This DEM was used to produce orthorectified versions of PSP_007917_1650 at 0.25 and 1 m/pixel, which served as base maps for detailed interpretation. Using the method of Okubo (2010), we assume 1/5 pixel correlations with 0.279 m/pixel in the more oblique image to determine a vertical precision of 0.19 m for our HiRISE stereo DEM. We also tied the absolute elevations in this DEM to MOLA. Where possible we carried out structural mapping of the DEM using the method of previous studies (e.g. Fueten et al., 2005, 2008; Okubo, 2010) and the Orion structural analysis software (http://www.pangeasci.com). We also produced two 20 m/pixel CTX DEMs using a similar method as above for a regional overview of the topography surrounding the immediate study area.

We analyzed a single Compact Reconnaissance Imaging Spectrometer for Mars (CRISM: Murchie et al., 2007) image that covered the study area (FRT00011DF2). Another CRISM image (FRT0000 7203) covers the fan deposit in the west of the trough, but noise levels prevented spectral signatures diagnostic of any mineral. The CRISM image used is centered at 15.02°S, 300.04°E and was taken on L_s 240.7. We used the commercial software package ENVI (http://www.ittvis.com) with the CRISM Analysis Toolkit plug-in (CAT: Pelkey et al., 2007), which is freely-available (http://crism.jhuapl.edu/CRISM_workshop_2009). We use the standard protocol for processing our CRISM data, which we outline here, but is described in detail in previous studies (e.g. Murchie et al., 2007, 2009b; Ehlmann et al., 2009; Roach et al., 2009; Lichtenberg et al., 2010). We concentrated our analysis on the near-infrared wavelengths, as these contain the most water-related absorption features. Briefly, we converted the CRISM data to I/F before applying a photometric conversion to correct for variations in illumination. We then applied an atmospheric correction using the volcano-scan method of McGuire et al. (2009), to minimize atmospheric CO_2 band absorptions. The CRISM image was then de-striped and de-spiked using the CIRRUS routine in CAT, to remove noise and large spikes inherent in the instrument. Spectral parameters, which highlight visible and near-infrared spectral features in some mineral types, were generated in CAT (Pelkey et al., 2007) and, following flattening, used for initial mapping of different hydrated and/or hydroxylated terrains. The results of the spectral summary product analysis were verified by collecting spectra for specific regions of interest (RoI) by averaging a number of pixels from a single unit. These RoIs were chosen after inspection of the spectral parameter maps, as areas that best represented possible changes in mineralogy that corresponded with elevation. The absorption signatures were enhanced by ratioing against a spectrally-bland region (e.g. Bishop et al., 2009; Milliken et al., 2008, 2010; Mustard et al., 2008). To ensure that mineral identifications from RoI spectra were robust, we collected spectra from each unit from the nonmap-projected image by taking the average values of 3×3 pixels, and ratioing these spectra against 3×3 pixel averages of spectrally bland regions in the same detector column. This method of using the same detector column for the numerator and denominator in the spectral ratio reduces the chance of misidentification from detector noise (Murchie et al., 2007). The pixel locations of each set of spectra, and their accompanying bland region, are given in Table 1.

All images were georeferenced and imported into the commercial software suites ArcGIS V9.2 and V10 (http://www.esri.com), and combined with other datasets such as 128 pixel/degree Mars Orbiter Laser Altimeter (MOLA) (Smith et al., 2001) gridded data (MEGDR 128), individual MOLA tracks and shots (PEDR), and Context Camera (CTX) images (Malin et al., 2007) that are approximately 6 m/pixel. Structural analysis was carried out on the DEM and orthoimage using the commercial software ORION (http://www.pangaea-sci.com) and previously-derived methods (Fueten et al., 2005) that have been successfully applied to a number of different areas and data sets (e.g. Fueten et al., 2008, 2010; Okubo, 2010).

3. Observations

3.1. Geologic context

Our study area contains LTDs within a closed trough of Coprates Catena, about 80 km south of the main Coprates Chasma rift system (Fig. 1 inset). The LTDs are located on the floor of a trough that is approximately 47 km long and 15 km wide. This trough has a minimum elevation of about 60 m, giving a total depth from the top of the trough walls to the floor to of about 3.4 km. This trough has been the focus of previous studies (e.g. Di Achille et al., 2006; Weitz et al., 2006) because of the distinctive terraced fan deposit, apparently fed by a contributory valley, which lies towards the center of the trough (Fig. 1). Although both of these previous studies suggest that the fan is a terminal deposit of fluvial activity along the incised valley, they disagree on the exact formation mechanism: Di Achille et al. (2006) argue for deposition on a sheet-flood-dominated alluvial fan, whereas Weitz et al. (2006) invoke a deltaic depositional process. The implications of these different scenarios are important because they determine whether there was ever a significant standing body of water in the trough, and one of the aims of this study is to contribute to this debate.

At least three other putative valleys appear to terminate in the east of the trough, above the location of the LTDs (Fig. 1), although their level of incision is minimal in comparison with the large valley that leads to the fan deposit. For example, the large channel that terminates in the fan deposit has a depth of approximately 900 m, whereas the small channel that enters the study trough from the south above the LTDs is about 50–60 m deep. From crater-counting statistics, the plains surrounding the trough have been estimated as Hesperian in age (Scott and Tanaka, 1986), with the trough and the rest of Coprates Catena having formed later through either continuing extension of the Valles Marineris chasmata system (e.g. Weitz et al., 2006) or volcanic collapse due to subsurface dikes (e.g. Mège et al., 2003). Regardless of the exact