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Quantifying widespread aqueous surface weathering on Mars: The plateaus south of Coprates Chasma

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ABSTRACT

Pedogenesis has been previously proposed on the plateaus around Coprates Chasma, Valles Marineris to explain the presence of widespread clay sequences with Al-clays and possible hydrated silica over Fe/Mg-clays on the surface of the plateaus (Le Deit et al., 2012; Carter et al., 2015). We use previous observations together with new MRO targeted observations and DEMs to constrain the extent and thickness of the plateau clay unit: the Al-clay unit is less than 3 m thick, likely ~1 m, while the Fe/Mg-clays underneath are few tens of meters thick. We also refine the age of alteration by retrieving crater retention ages of the altered plateau and of later deposits: the observed clay sequence was created by surface pedogenesis between model ages of 4.1 Ga and 3.75 Ga. Using a leaching model from Zolotov and Mironenko (2016), we estimate the quantity of atmospheric precipitations needed to create such a clay sequence, that strongly depends on the chemistry of the precipitating fluid. A few hundreds of meters of cumulated precipitations of highly acidic fluids could explain the observed clay sequence, consistent with estimates based on late Noachian valley erosion for example (Rosenberg and Head, 2015). We show finally that the maximum quantity of sulfates potentially formed during this surface weathering event can only contribute minimally to the volume of sulfates deposited in Valles Marineris.

1. Introduction

Infrared (IR) remote sensing and in situ data from past and current Mars orbiter and lander missions have provided extensive evidence for the presence of hydrated minerals on the Martian surface (Poulet et al., 2005; Murchie et al., 2009; Ehlmann et al., 2011; Carter et al., 2013), bringing information on the aqueous history of the planet. A wide range of phyllosilicates have been detected including Fe/Mg smectites (nontronite, saponite, vermiculite), Al-rich phyllosilicates (montmorillonite, kaolinite), hydrated silica, chlorites, serpentine, zeolites, micas (muscovite, illite) and prehnite (e.g. Poulet et al., 2005; Ehlmann et al., 2009; Carter et al., 2013). Hydrated minerals have been detected both on rocks at the surface and in rocks excavated from depths. The conditions of the presence of water on Mars, at the surface or deep in the crust, indicate very different past environments and climate. Of particular interest are kaolinite minerals, which are usually formed through intense leaching. Kaolinites on Mars are often detected on top of Fe/Mg smectites in regions such as Mawrth Vallis, Terra Sirenum, the northern Hellas basin region, south Valles Marineris, south Terra Sabaea, Nili Fossae and the Lybia Montes (Carter et al., 2015). Although it could originate from the *in situ* alteration of material of distinct compositions (e.g., Le Deit et al., 2012), this sequence is generally interpreted as pedogenic weathering of the bedrock (e.g., Bishop et al., 2008; Ehlmann et al., 2009; Noe Dobrea et al., 2010; Loizeau et al., 2010; Gaudin et al., 2011; Loizeau et al., 2012; Carter et al., 2015). Putting constraints on the quantity and time of presence of water at the surface is the next step in the study of the past climate of Mars.

The present study focuses on the clay sequence observed on the plateaus south of Coprates Chasma, central Valles Marineris. Coprates Chasma is a 1000 km long, ~100 km wide and 8 km deep linear trough connecting the ancestral basin of Melas Chasma to the west to Capri Chasma to the east (Schultz, 1991, 1998). Coprates Chasma is characterized by the presence of a central horst within the canyon and the existence of parallel troughs (possibly collapsed pits) to the south collectively referred to as Coprates Catenae. The floor of Valles Marineris is characterized in particular by the presence of large Interior Layered Deposits (ILDs), although Coprates Chasma is less filled by these ILDs than other chasmata (e.g. Lucchitta et al., 1994). Coprates Chasma walls are delimited by normal faults, are particularly well exposed and targeted by the

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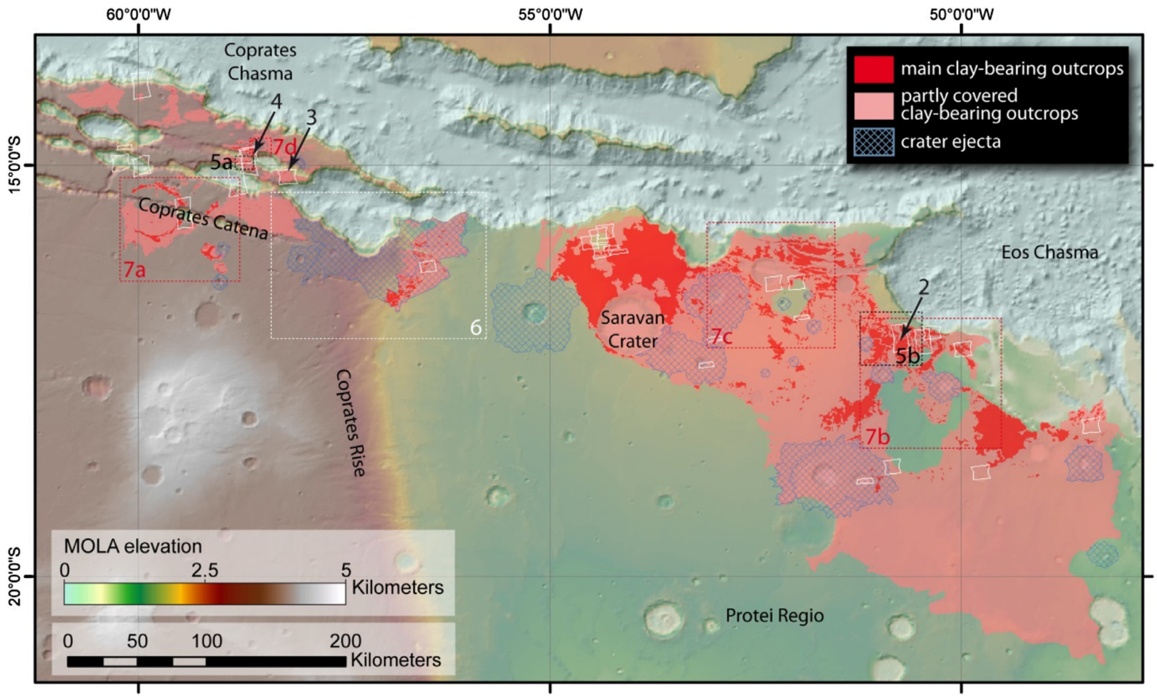

Fig. 1. Map of the clay bearing outcrops to the south of Coprates and Eos Chasmata. In red are continuous bright rocks on which CRISM targeted observations, where available as indicated by small white boxes, detect clays. In pink are similar bright rocks but partly covered by a darker cap. Notice that the clay detections are made on both sides of the Coprates Rise, and extend over more than 850 km from north-west to south-east. The background of the image is a shaded relief of the global MOLA DEM with the MOLA DEM overlain in color. Boxes and numbers indicate the location of the close-ups found at the given figure number. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

MRO instruments, making them a prime target to study the martian crust stratigraphy (e.g., Flahaut et al., 2012). Previous studies revealed the presence of voluminous volcanic products in the upper walls of the canyon (e.g., McEwen et al., 1999; Williams et al., 2003; Brustel et al., 2017), and thanks to the recent CRISM imagery, of Al-rich and/or Fe-rich clays in the uppermost layers that outcrops on the plateaus (Murchie et al., 2009; Flahaut et al., 2012). Le Deit et al. (2012) have previously listed and analyzed a number of outcrops where Al-clays are stratigraphically on top of Fe/Mg-clays on the plateaus on both sides of Coprates Chasma. Our study supplements this survey with more CRISM and HiRISE observations from MRO, making use of DEM imagery to fully characterize the clay stratigraphy, and evaluating the time of pedogenesis. A quantification of the percolating fluids needed for the pedogenesis is proposed thanks to thickness measurements made both in the canyon walls and on the plateaus south of Coprates Chasma (Fig. 1). In addition, we discuss the possible quantity of sulfates produced by the resulting fluids of the surface weathering and their contribution to the sulfates present inside Valles Marineris.

2. Datasets and method

2.1. Datasets

This study uses morphology, surface dating, mineralogy and stratigraphy, requiring the use of imagery, near-IR spectroscopy and topography datasets.

The region covered in this study is large (~800 km × ~400 km), therefore several imagery datasets had to be combined from the regional context to local studies. Thermal imagery was used with the THEMIS (THermal EMission Imaging System, aboard Mars Odyssey) IR night and daytime controlled mosaics available at http://astrogeology.usgs.gov/maps/mars-themis-controlled-mosaics-and-preliminary-smithed-kernels (Fergason et al., 2013). For visible imagery, HRSC (High Resolution Stereo Camera, aboard Mars Express), CTX (Context Camera, aboard Mars Reconnaissance Orbiter, MRO) and HiRISE (High Resolution Imaging Science Experiment, aboard MRO) individual images were used. All images were downloaded and processed with the MarsSI (emars.univ-lyon1.fr, Quantin-Nataf et al., 2017) application founded by the European Union's Seventh Framework Program (FP7/2007–2013) (ERC Grant Agreement No. 280168).

Data from the CRISM (Compact Reconnaissance Imaging Spectrometer for Mars, aboard MRO) spectral imager were used to map the presence of hydrated minerals and characterize their nature through comparison with laboratory spectra. CRISM data were processed through the MarsSI application, which includes processing from the CAT (CRISM Analysis Toolkit) program provided by the CRISM team for radiometric calibration and atmospheric correction (Murchie et al., 2007; Quantin-Nataf et al., 2017). In addition, a column-by-column spectral ratio is also calculated, with the median spectrum of the column as the denominator (assuming that most pixels in the column do not contain hydrated minerals and can be considered as "neutral"). Spectral indexes which detect the occurrence of a given absorption feature are calculated for each CRISM observation, producing parameter maps. Laboratory spectra used in this study have been acquired by Takahiro Hiroi and Carle M. Pieters with the NASA RELAB facility at Brown University.

Topographic datasets from MOLA (Mars Orbiter Laser Altimeter, aboard Mars Global Surveyor), and from stereo-restitution based on CTX and HiRISE images are used. CTX and HiRISE DEMs (Digital Elevation Models) were processed through the MarsSI application (Quantin-Nataf et al., 2017) using the NASA Stereo Pipeline (Moratto et al., 2010)).