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Aqueous Alteration at Libya Montes Reveals Changing Geochemical Environments on Early Mars

D. Tirsch (1), J.L. Bishop (2), J.R.C. Voigt (1), L.L. Tornabene (3), G. Erkeling (4), and R. Jaumann (1,5)

(1) Institute of Planetary Research, German Aerospace Center (DLR), Berlin, Germany (Daniela.Tirsch@dlr.de). (2) Carl Sagan Center, The SETI Institute, USA. (3) University of Western Ontario, London, ON, Canada. (4) German National Library of Science and Technology (TIB), Hannover, Germany. (5) Institute of Geological Sciences, Freie Universitaet Berlin, Berlin, Germany.

Abstract

We analyze the emplacement chronology and aqueous alteration history of distinctive mineral assemblages and related geomorphic units near Hashir and Bradbury impact craters located within the Libya Montes. We use the morphology associated with specific mineral detections to extrapolate the possible extent of the units hosting these compositions. We characterize multiple units consistent with formation through volcanic, impact, hydrothermal, lacustrine, and evaporative processes. Altered pyroxene-bearing basement rocks are unconformably overlain by an olivine-rich unit, which is in turn covered by a pyroxene-bearing capping unit. Aqueously altered outcrops identified here include nontronite, saponite, beidellite, opal, and dolomite. See [1] for a comprehensive discussion.

1. Introduction

The Libya Montes region, located at the southern rim of the Isidis impact basin, is an excellent example of the diverse geological processes that have shaped this part of the Martian surface over time [e.g., 2, 3]. Evidence of fluvial, lacustrine, aeolian, volcanic, impact/basin-forming events and hydrothermal processes, which span most of the geologic time on Mars, can be found in close association with one another. These landforms at Libya Montes are related to both relatively unaltered materials and aqueously altered sedimentary deposits as well as local rocks. Libya Montes provides a geologically diverse setting with multiple spectral observations useful for deciphering the complex geological and aqueous alteration history of this region of Mars with high value for contributing to the global picture of the evolution and climatic history of the planet.

2. Methods

We derive our results from a spectro-morphological mapping project that combines spectral detections from CRISM imagery with geomorphology and topography from HRSC, CTX, and HiRISE data. CRISM compositional maps were prepared using parameters developed previously [4, 5]. Mapping was performed on the combined data sets in ArcGIS with a digitizing scale of 1:20,000. The mineralogical composition of the surface units was deduced from the color coding of the CRISM parameter products (mainly R: D2300, G: OLINDEX, B: LCPINDEX). CTX texture was used to interpret the unit's morphology and extent in places where CRISM data are not available.

3. Results and Discussion

We identified three distinct regional morphologic units (Fig. 1): The stratigraphically lowest unit is the pyroxene-bearing bedrock (Bpx) that represents the ancient Libya Montes highland massif. An olivine-rich layered unit (LUol) has been generally deposited in topographic lows of the Bpx unit where it embays the pre-existing Libya Montes terrain. This unit appears to be related to the banded olivine-rich unit detected at the Nili Fossae region, at Northeast Syrtis and the Isidis basin [1, 6, 7, 8]. This age of the LUol (3.77 Ga, [9]), its layer structure, as well as the fact that it appears to follow the topography are indicative of a flow and are consistent with a volcanic origin [1, 8,10] rather than an impact melt origin [7] (because it is too young to result from the Isidis impact). A recent study by [11] indicates that the unit decreases in thickness with distance from Nili Patera indicating that it might represent olivine-rich ash-fall deposits originating from Syrtis Major. A pyroxene-bearing caprock unit (Cpx) lies stratigraphically and topographically above the LUol unit. Due to its composition and appearance, we favor the interpretation of [7 and 8] that the caprock unit could be attributed to remnants of volcanic deposits generated from later stages of the evolution of the plume associated with Syrtis Major [12]. Since the LUol is always associated with the Cpx unit throughout our mapping region, they are most likely related to each other.

Various aqueous alteration minerals were identified in our study region (Fig. 1): Fe/Mg-smectites mostly crop out from the subsurface or are part of the walls of the ancient Libya Montes bedrock. Due to the widespread occurrence of these phyllosilicate-rich

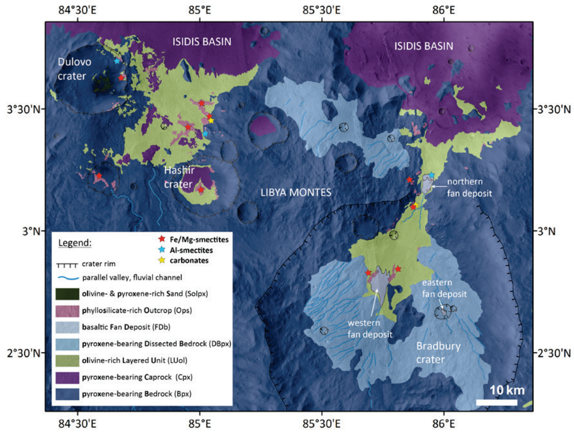

Fig. 1: Mapping of the Libya Montes study region as inferred from spectral and image data.

outcrops, local lacustrine processes, or igneous-induced hydrothermal processes are less likely formation mechanisms [13]. These phyllosilicates may have evolved instead from pervasive near surface alteration through impact-induced low-temperature hydrothermal processes in ancient bedrock material [14]. Al-smectites occur as isolated patches within the bedrock unit and along a discrete layer that crops out along the margins of a fan-shaped deposit. These sites are dominated by beidellite that is likely to have formed from low temperature hydrothermal alteration [15] or burial diagenesis of the bedrock materials at this site because beidellite forms at elevated temperatures [e.g., 9, 16, 17, 18]. Another smaller outcrop at the rear eastern margin of the same fan deposit (Fig. 2) is more consistent with opal. A further spectral signature of a thin bright layer along a nob in the middle of this smaller opal-bearing outcrop could be consistent with hydrated calcium chloride (Fig. 2). It shows absorption bands that are indicative of chloride salt minerals such as sinjarite. Whereas the beidellite at this fan delta might be allochtonous and could have been eroded from altered Libya Montes basement rocks, the opal-bearing deposit detected at the subaerial alluvial fan might have formed in situ through evaporative processes in a hydrothermal or lacustrine system in the course of the aqueous weathering of mafic rocks. The thin bright layer with the unusual spectral signatures attributed to Ca-chlorides reinforces an evaporative formation from brines.

Finally, we found dolomite intermixed with Fe/Mg-smectites that occurs in contact with olivine as it crops out from underneath the LUol. This mineral mixture appears to be the result of alteration of Noachian bedrock by neutral to slightly basic waters, which forms Fe/Mg-phyllosilicates and in some cases carbonates as well [9]. The composition of these altered rocks is likely affected by temperature and fluid chemistry at the time of alteration.

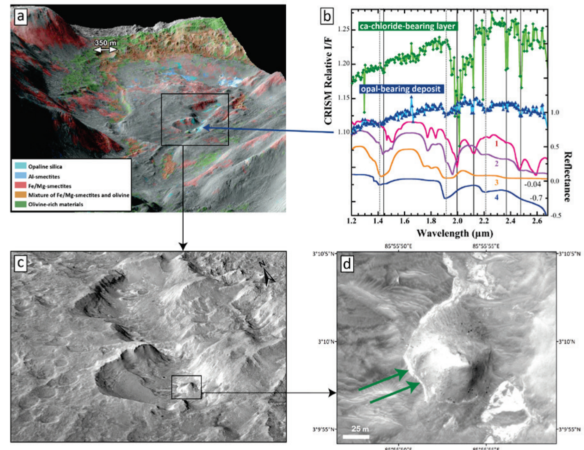

Fig. 2: Calcium-chloride detected within the opal-bearing outcrop located in the fan delta at the Bradbury region.

4. Summary and Conclusions

The diversity of mineral assemblages suggests that the nature of aqueous alteration at Libya Montes varied in space and time. This mineralogy together with geologic features shows a transition from Noachian aged impact-induced hydrothermal alteration and the alteration of Noachian bedrock by neutral to slightly basic waters via Hesperian aged volcanic emplacements and evaporative processes in lacustrine environments followed by Amazonian resurfacing in the form of aeolian erosion [1].

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