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Hydrothermal Activity recorded in Post Noachian-Aged Impact Craters on Mars

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Introduction

The search for past habitable environments for microbial life on Mars requires the assessment of mineral assemblages that have been altered by a water-related process. It has previously been shown that impact-induced hydrothermal systems in the volatile-bearing crust of Mars have the potential to last for up to ~10 Myr [1], resulting in various phyllosilicate alteration phases [2]. Such systems have been associated with complex impact craters of 7 km diameter and above [1,2], which were of interest in this study [4].

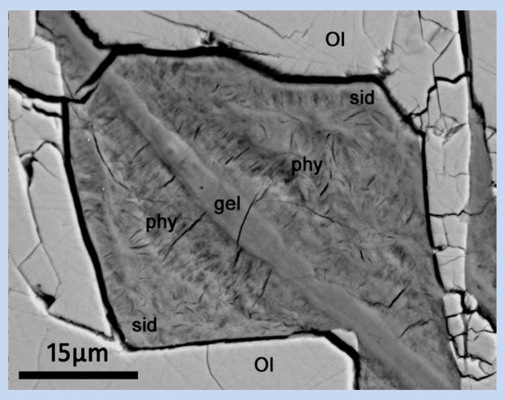


Figure 1: SEM image of the nakhlite meteorite; Lafayette. Olivine, siderite, phyllosilicates and gel are labeled. [5]

The nakhlite meteorite parent rocks have recently been shown to have been partially altered by a hydrothermal brine at ≤200 °C during the last 670Ma [3], in a near surface setting [5], producing the alteration minerals: smectite, serpentine, siderite, gel (figure 1). The presence of the gel indicates that the nakhlites underwent rapid cooling, suggesting an origin at the margins of an impact. It has also been shown by [5] that the phyllosilicate forming stage occurred at habitable temperatures (~50 °C) in a neutral to alkaline diluted brine, which carried elements essential for life [5]. This suggests that two shock events occurred; the first inducing a hydrothermal system that altered the near-surface nakhlite parent rocks and the second launching the nakhlites off Mars. The ejection event was shown to be 11 Myr ago [6] and radiometric dating has confirmed their age to be ~1.3 Ga [6]. Therefore the nakhlites originated from an early to mid Amazonian type locality.

This study [4] used the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) with the aim to identify the type of craters that the nakhlite alteration minerals – smectite, serpentine, siderite, gel – were derived from [5][7][8].

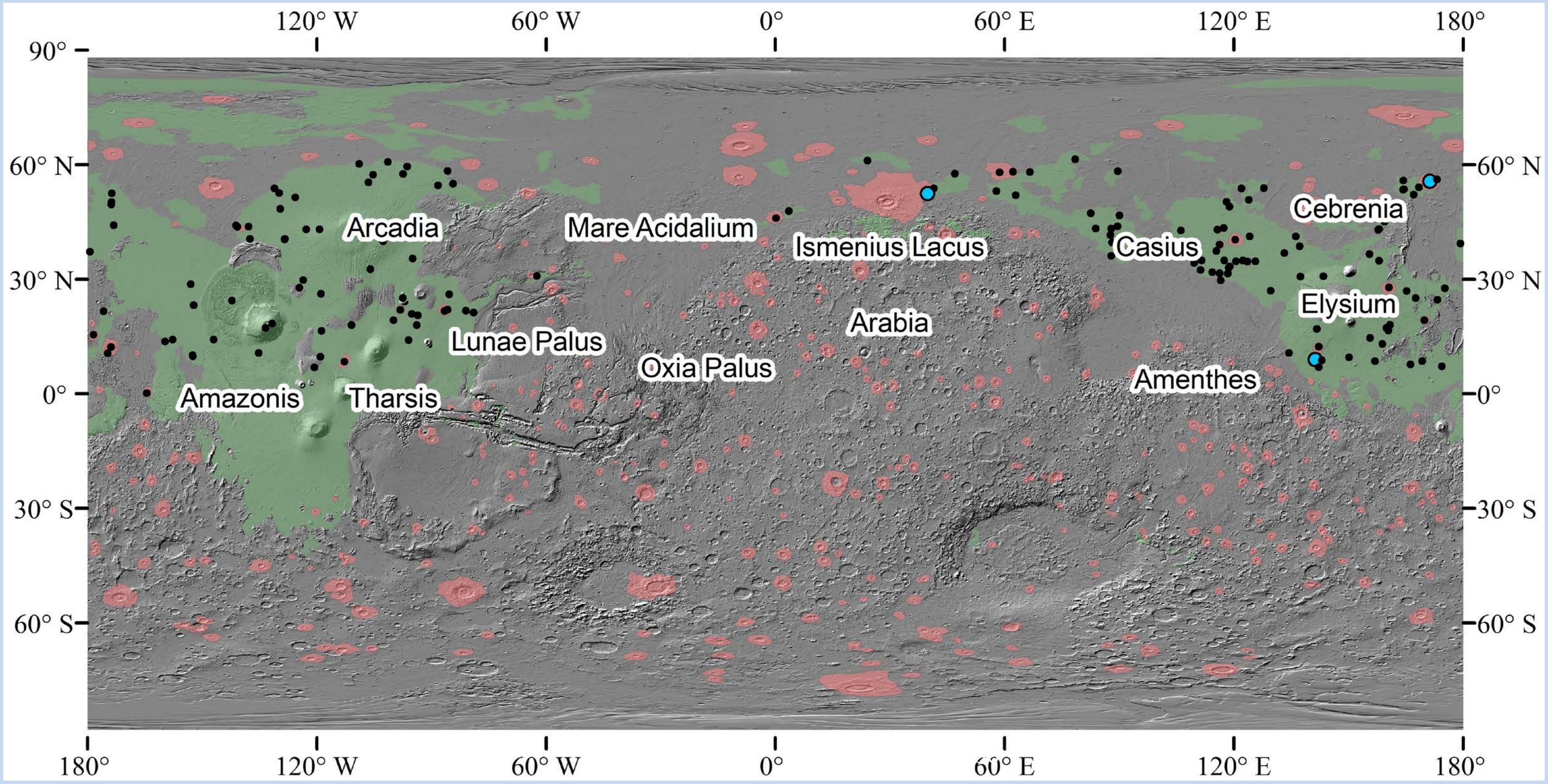


Figure 2: Grayscale MOLA map showing the impact craters analysed in this study. Amazonian-Hesperian terrains are highlighted in green, with Amazonian-Hesperian Impact (AHi) units highlighted in red. Only AHi units overlying Amazonian-Hesperian terrains were considered in this study; map units from [9]. CRISM data from 158 impact craters were studied, with 3 craters showing evidence of hydrated minerals. Black dots indicate impact craters that did not show hydrated minerals; blue dots indicate impact craters that contain hydrated minerals.

Analysis Techniques

144 post Noachian-aged impact craters ≥7 km diameter and 14 smaller craters 3-7 km diameter were selected using the most recent Mars crater database [10] and the latest geologic map of Mars [9] (figure 2), in ArcGIS [4]. CRISM data for this subset of impact craters was then obtained for mineral characterisation in search of shallow hydrothermal alteration, as opposed to the excavation of deeper alteration as previously suggested by [11,12].

CRISM on Mars Reconnaissance Orbiter (MRO) is a visible-near infrared and infrared spectrometer that is capable of acquiring 18 m/pixel images from 362 nm to 3920 nm over 544 channels at 6.55 nm/channel, of a targeted region [13]. More generally CRISM images the surface of Mars at 100 – 200 m/pixel, over the full wavelength range specified above [13].

The CRISM spectral data was processed to remove all instrumental effects and to calibrate scene images to scene radiance, from which I/F data is calculated [14]. The CRISM Analysis Toolkit (CAT) extension to ENVI was used for processing the CRISM I/F data. The photometric and atmospheric effects were corrected by division of the cosine of the solar incidence angle and by scaling the atmospheric transmission of CO_2 based on CRISM observations across Olympus Mons. CIRRUS CRISM Clean was then used, where appropriate, to reduce the noise by destriping and despiking the I/F images. Summary products were then used to identify regions of interest resulting in spectral ratios that are then compared to reference library spectra for mineral identification [14][15].

Unnamed Crater in Ismenius Lacus

The unnamed impact crater central uplift shown in figure 3 is located in Amazonian / Hesperian terrain [9], dated as 0.3 Ga with crater counts by [16]. Summary products derived from CRISM FRT0000BFA6 indicated absorptions at ~1.9 µm and ~2.3 µm (figure 3B) confined to the central structure, including probable megabreccia blocks, rocky alcoves at the head of each of the gullies, and alluvial fans (figure 3) but do not extend on to the crater floor (figure 3C). These absorptions indicate the presence of Fe/Mg phyllosilicates, possibly Fe-serpentines or chlorites.

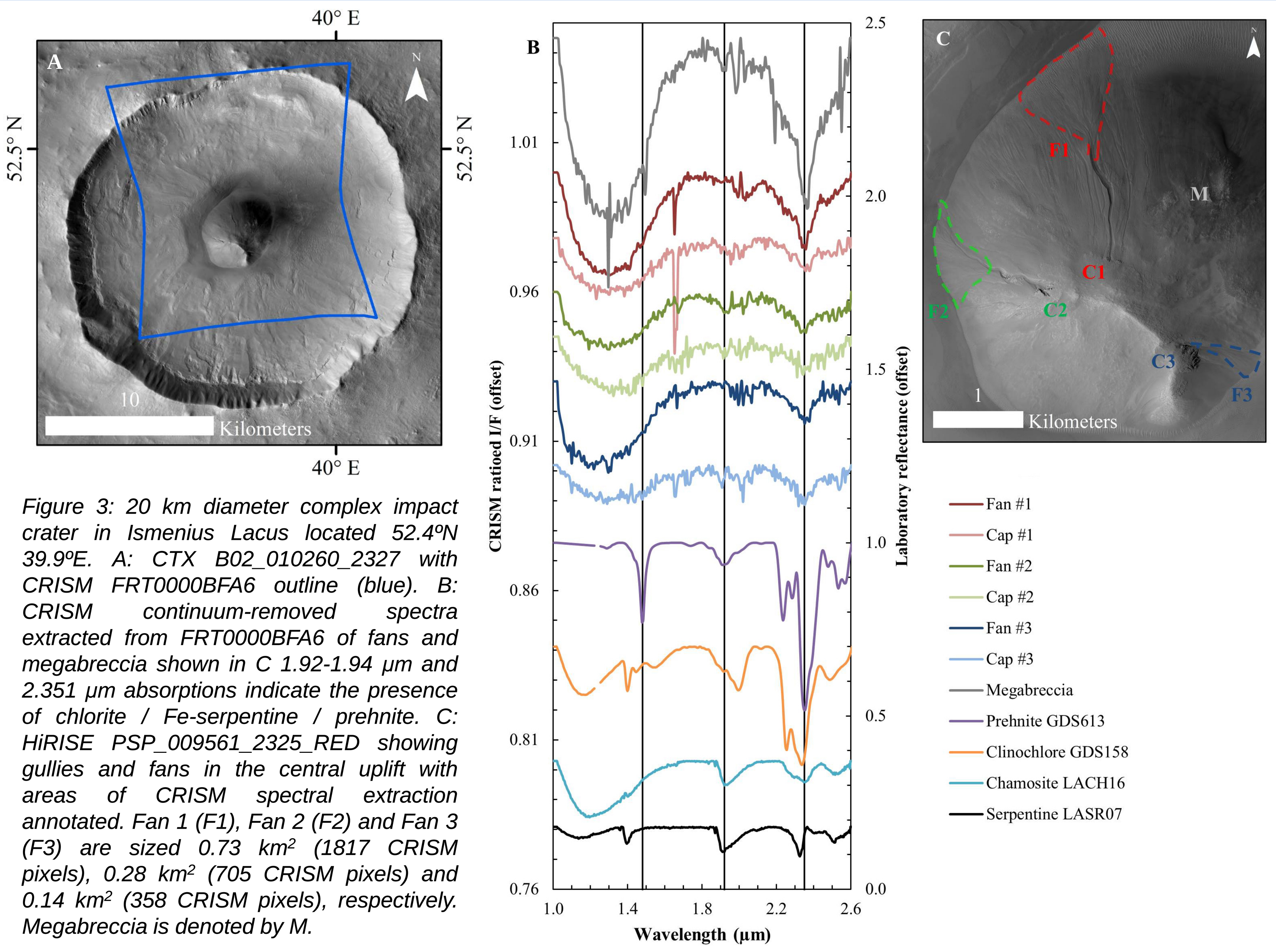
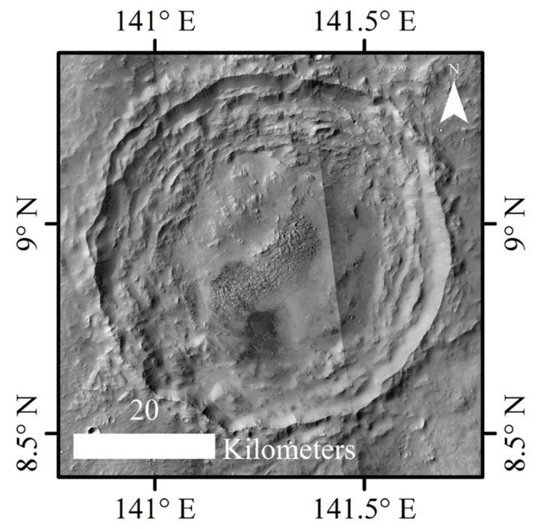


Figure 3: 20 km diameter complex impact crater in Ismenius Lacus located 52.4ºN 39.9ºE. A: CTX B02_010260_2327 with CRISM FRT0000BFA6 outline (blue). B: CRISM continuum-removed spectra extracted from FRT0000BFA6 of fans and megabreccia shown in C 1.92-1.94 µm and 2.351 µm absorptions indicate the presence of chlorite / Fe-serpentine / prehnite. C: HiRISE PSP_009561_2325_RED showing gullies and fans in the central uplift with areas of CRISM spectral extraction annotated. Fan 1 (F1), Fan 2 (F2) and Fan 3 (F3) are sized 0.73 km² (1817 CRISM pixels), 0.28 km² (705 CRISM pixels) and 0.14 km² (358 CRISM pixels), respectively. Megabreccia is denoted by M.

Other Craters

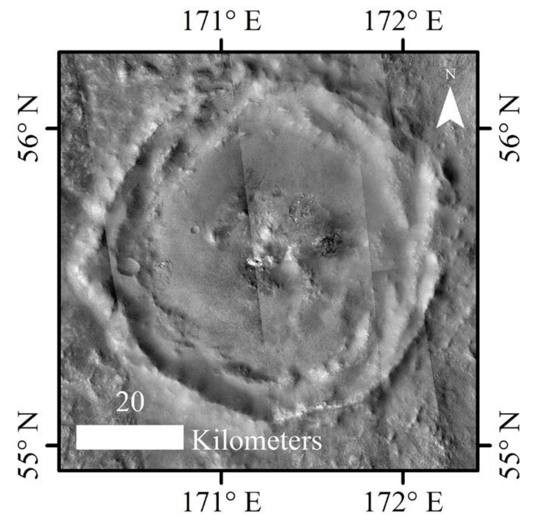
The 50 km diameter unnamed complex impact crater (figure 4) located at 8.93ºN 141.28ºE in Elysium exhibited hydrated minerals in heavily eroded sediment around the southwest region of the central uplift. The sediments appear to postdate the crater with no obvious link to the crater's formation or potential impact hydrothermal activity.

The previously studied [11] 62 km diameter Stokes complex impact crater (figure 5) shows a suite of alteration minerals (serpentine, chlorite, nontronite, kaolinite and montmorillonite) that have been proposed to have formed pre-impact. However, studies have shown that Al-phyllosilicates might form as a result of impact-induced hydrothermal alteration [2] and have been found by MER Opportunity at Endeavour crater [17]. Formation of the Al-phyllsilicates found in Stokes impact crater may have occurred pre- or post-impact.



◄*Figure 4: 50 km diameter complex impact crater located* 8.93ºN 141.28ºE in Elysium. CRISM analysis revealed hydrated minerals in heavily eroded sediments in the central structure.

►*Figure 5: 62 km diameter Stokes complex impact crater.* CRISM analysis revealed a suite of alteration minerals in the central structure.



Conclusions

Gullies, alluvial fans, and uplifted breccia in the central uplift of an unnamed 20 km diamater impact crater (located at 52.42ºN, 39.86ºE in the Ismenius Lacus quadrangle) show spectral evidence for a chlorite or Fe-serpentine that may have formed through erosion and redeposition of impact-induced hydrothermal mineral assemblages during the Amazonian epoch, although the exposure of pre-existing secondary minerals cannot be completely ruled out [4].

The study highlighted here [4] focused on 158 impact craters and found that three of these impact craters showed spectral features that suggest a hydrated mineralogy (figure 2). However, lack of clear spectral signatures due to small regions of interest and surface dust coverage has hindered the investigation [4].

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