Evidence for compositional dikes intruding the emplaced and preserved Noachian crust in Valles Marineris, Mars. J. Flahaut[1], J. F. Mustard[2], C. Quantin[1], H. Clenet[1], P. Allemand[1] and J. H. Wilson[2]. [1]Laboratoire des Sciences de la Terre, UMR CNRS 5570, Université Claude Bernard/Ecole Normale Supérieure de Lyon, 2 rue Raphaël Dubois, 696222 Villeurbanne Cedex, France (jessica.flahaut@ens-lyon.org). [2]Department of Geological Sciences, Brown University, box 1846, Providence, RI 02912.

Introduction: Dikes are expected to be present on Mars from their association with volcanic morphologies and surface deformation [1]. Though dikes are rarely directly exposed on the surface of Mars due to its low erosion [1,2], they can be identified by morphologies representing near-surface manifestations of dike emplacement [3,4,5]. Dozens of giant dike swarms have been reported on Mars, with high concentrations in the volcanic areas of Tharsis and Elysium [1,6,7,8,9]. Recent imaging from the CTX and HiRISE cameras onboard Mars Reconnaissance Orbiter provided the first direct observations of potential eroded and exposed dikes [2,10]. We report here the occurrence of sets of sub-parallel dikes in the lower walls of Valles Marineris, and the composition for those dikes that were observed with CRISM hyperspectral data for the first time. This could present precious clues about magmatic processes in this area and on Mars in general.

Geological context: Dikes were specifically detected in Coprates Chasma, which is an approximalty 1000 km long and 100 km wide canyon located in the central part of Valles Marineris [11]. Coprates Chasma is often studied when looking at tectonic process linked with rifting due to its extent, its great depth and its excellent exposures. Indeed, Coprates Chasma is one of the rare canyons of Valles Marineris that hasn't been filled with large, massive interior layered deposits, presenting good outcrops of wall sections [11,12]. Recent studies have shown that the lower walls of Coprates Chasma exhibit emplaced pristine Noachian crust [12,13,14], characterized by specific morphologies and mineralogies. This bedrock appears to be the containant of dikes.

Dikes were reported on at least two HiRiSE observations (High Resolution Science Experiment, MRO) located in the northern walls and central horst of Coprates Chasma, although more outcrops might be present in the surrounding areas [15]. One of these HiRiSE observations is coupled with a CRISM hyperspectral observation (Compact Reconnaissance Imaging Spectrometer for Mars, MRO), providing some mineralogical context for those detections.

Morphological observations: Dozens of single ridges were identified within the HiRISE observations, which we interpreted to be dikes [15]. They are gathered as swarms, having a roughly East-West orientation, although one of the sets of dikes is oriented N112°. Dikes are generally fragmented in segments of a few hundred meters. The total length of the dikes is about a few kilometers. The dikes are tough to detect outside of the HiRiSE observation; they can be observed in the CTX (Context Camera, MRO) imagery as well, but are more difficult to map due to resolution and imaging quality. Moreover, when dikes do outcrop, it is mostly on nearly dust-free spurs. Widths range from a few meters up to 40 or 50 meters for the widest segments. The dike segments are sub-parallel to each other and are likely near-vertical, as their apparent orientation is unaffected by topography. The dike segments are emplaced 'en echelon', and are separated by fractures. The dikes appear to be filled with a compositionally distinct material, that is bluer and apparently darker in the HiRISE color imagery. Ridges are also observed at a smaller scale, but it is not clear whether they correspond to fractures, faults, and/or smaller-scale dikes [15].

Thus far, dikes are only observed within a massive fractured bedrock that constitutes the lower walls of Coprates Chasma [12,15]. The appearance of this bedrock is consistent with previously reported outcrops of Noachian crust. Exposures of Noachian crust are rare [16], and they often exist in megabreccias in the central peaks of large impact craters [13,16]. Coprates Chasma is relatively unique in that a cross section of the Martian crust is well explosed allowing observations of this pristine crust. The relatively higher albedo of these crustal blocks make the dike identification easier, as the dikes are generally filled with a darker material. Dikes are not observed in the upper walls of Valles Marineris, which are likely composed of layered basalts [12,17] and they would be harder to see by contrast.

The area around the dike seems disturbed on an area that is up to half the dike width, and could be the result of dike-induced dilation metamorphism [15] (Figure 1a).

Spectral signatures: The CRISM hyperspectral observation was processed as described in *Flahaut et al.* [18] to account for atmospheric and photometric contributions. Noise was removed using the despiking and destriping algorithms available under CAT 6.6 for TRR2 datasets [19]. Due to spatial resolution limitations, CRISM targeted hyperspectral data, which have a spatial resolution of 18m/pixel, are the only spectral

data that can be used to characterize dike outcrops, and only the largest dikes described above can be seen and spectrally analyzed. Summary parameters [20] were calculated and the LCPindex (Low-Calcium Pyroxene), HCPindex (High-Calcium Pyroxene), OLindex2 (Olivine) were used to search for mafics.

Figure 1b is an RGB composite of the CRISM scene where olivine-rich areas appear red, LCP-rich bedrock appears green and bluer areas have a higher HCP content, although the LCP/(HCP+HCP) ratio remains high according to the CRISM MGM [21], indicating that the present bedrock is generally LCP-rich. The dike area identified in HiRISE data indicates an enrichment in olivine. Spectra extracted from the CRISM scene are consistent with this distribution; they generally show broad crystal field absorptions in the 0.4 to 2.5 micron domain characteristic of mafic minerals. Spectra from the dike area have a strong, broad 1 micron absorption band, consistent with the presence of olivine [14, 21, 22]. This band is centered at long wavelengths and has a flat-bottomed 1 micron feature, which is commonly observed in Martian olivine [14,22]. The shapes of the dike spectra are especially consistent with fayalite, or large-grained, olivine-rich basalts [14]. The surrounding bedrock is characterized by wide absorption bands centered at 0.92 µm and 2.0 µm. This combination of spectral features indicates an enrichment in LCP, which is commonly found in old Noachian terrains [21,22].

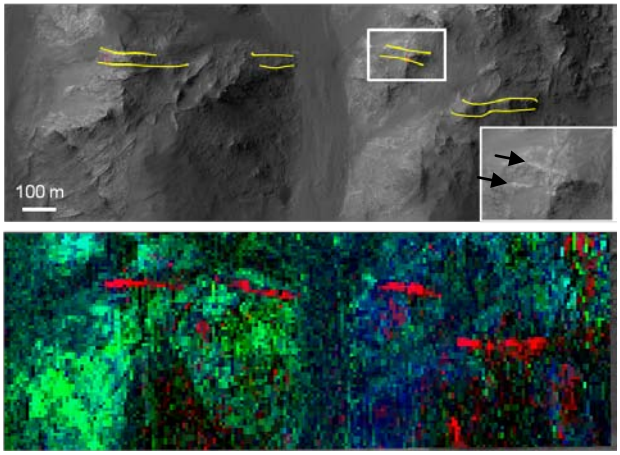

Figure 1: a- Dike outcrop seen with HiRiSE. Black arrows on the close-up point at the metarmorphosed area around the dike. b- Same outcrop seen with CRISM. This CRISM RGB (R=OLindex2, G=LCPindex, B=HCPindex) composite shows that the dike has an olivine-rich signature (red) while the surrounding bedrock is more pyroxene-rich (green and blue).

Discussion: Dikes are generally linked with regional tectonics. Large dikes emplacement has been suggested as a potential mechanism for the formation of Valles Marineris, as the inelastic and elastic extension induced by their formation could result in graben [2,3]. It is widely accepted that the Valles Marineris rifting was formed through extension in the upper crust during the Hesperian, resulting in a nearly East-West graben system [9,11]. Observed dike orientations in Coprates Chasma are roughly East-West, consistent with the graben system. Tharsis is likely to have played a major role in the formation of Valles Marineris, and some of its volcanism could reasonably be contemporary with the formation of these dikes.

The limited repartition of the dikes in the Noachian bedrock indeed suggest that they are older than the formation of the Hesperian lava flows stratigraphically above, as they don't seem to affect these layers [15]. As these Hesperian lava flows form most of the upper wall section in Valles Marineris, the dike must have been emplaced before the canyon opening. In addition, we saw lava flows down the walls of Valles Marineris. Further investigations will be done to test this hypothesis. The occurrence of preserved Noachian bedrock in situ, which is rare on the Martian surface, and compositionally distinct dikes, contributes to the need for future Martian exploration in Valles Marineris.

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