VALLES MARINERIS TECTONIC AND VOLCANIC HISTORY INFERRED FROM DIKES IN EASTERN COPRATES CHASMA MARS. C. Brustel[1,2], J. Flahaut[2], E. Hauber[3], F. Fueten[4], R. Stesky[5], C. Quantin[2] and G.R. Davies[1], [1]Faculty of Earth and Life Science, VU University Amsterdam, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands, Email: c.brustel@vu.nl, [2] Laboratoire de Géologie de Lyon, CNRS/University Lyon 1, 69622 Villeurbanne Cedex, France, [3]German Aerospace Center, Institute of Planetary Research, Berlin, Germany, [4]Department of Earth Sciences, Brock University, St. Catharines, ON, Canada, [5]Pangaea Scientific, ON, Canada.

Introduction: Valles Marineris (VM) is the largest canyon system in the Solar System but the mechanism(s) responsible for its formation remain unclear. It is still debated whether VM was formed by simple normal faulting (as a result of Tharsis load) [1], or in response to magmatic intrusions [2]. Dike emplacement may have triggered crustal extension and graben formation such as the VM troughs. It has been proposed that isolated ancestral basins formed initially and were later connected by rifting [3]**.** This hypothesis is supported by (1) the irregular shape of some troughs (*e.g.*, Melas, Ophir, Capri Chasmata), (2) their average elevation, and (3) the presence of interior layered deposits on their floor. Magmatic intrusions could have provided structural control for these ancestral basins formation [4]. Dikes in VM have recently been reported by [5] who mapped three dikes oriented approx. East-West, similar to VM walls. Previous work [2] suggested that parallel magmatic intrusions could have directly led to the formation of VM by facilitating crustal cutting and bloc subsidence**.** In this case, dikes and grabens should have the same orientation.

In order to understand the role of dikes in the tectonic and volcanic history of VM, the overall distribution, orientations, altitudes and dips of more than a hundred dikes exposed in the walls of the canyon were measured. Eruption rates were estimated using a rheologic model [6].

Study area and methods: Coprates Chasma is a 1000 km long, 100 km wide, linear trough in central VM. The walls of eastern Coprates Chasma are well exposed and have been extensively targeted by Mars Reconnaissance Orbiter (MRO) instruments. The region is fully imaged at ConText camera (CTX) scale.

We used imaging and altimetry data from the CTX, HiRISE (High Resolution Imaging Science Experiment) and MOLA (Mars Orbiter Laser Altimeter) instruments available in the eastern part of Coprates Chasma. Dike dimensions and elevations were measured using ArcGIS tools (@ESRI); azimuths were calculated with the PolarPlots extension for ArcGIS (@Jennessent). Dike dips were measured with the software program Orion [7] where HiRISE Digital Terrain Models (DTMs) were available.

Using methods described in [6], it is possible to estimate the hypothetical amount of magma erupted by a dike, based on its dimensions and assumed magma properties. Since the magma viscosity could not be directly determined, values were chosen to cover the range of viscosities corresponding to fissural eruptions previously studied in the Tharsis region (10 to 1000 Pa.s [6], [8]). The results are used to reconstruct parts of the geologic history of the eastern Coprates Chasma.

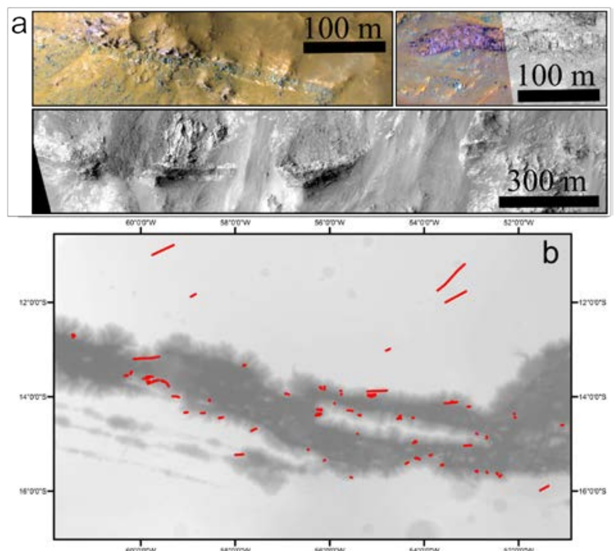

Figure 1: The study area is located in eastern VM, between 11 and 18° latitude and 51 and 61° longitude. **a**- HiRISE observations of dikes in Coprates. **b**- Map of identified dikes (red lines, background: MOLA elevation map).

Results: Over a hundred linear features were mapped as dikes (**Fig. 1b**). Dikes are ubiquitous in the study area and are observed in both the north and south walls of Coprates Chasma, but also in the walls of its central horst. Exposed dikes are narrow (< 80 m), generally linear and appear relatively resistant to erosion. Dikes intrude the bright, massive bedrock unit at the bottom walls, as previously reported by [5]. They are also observed at higher elevations in the walls, where they intrude more recent volcanic layers, and on the surrounding plateaus. Their widths range from small-scale fissures (< 1 m) to wide intrusions (up to 78 m) with an average of 13 m. The longest dike can be traced for 30 km. Dikes can be distinguished from the host rock with HiRISE color images as they are filled with a spectrally distinct material. Distinct

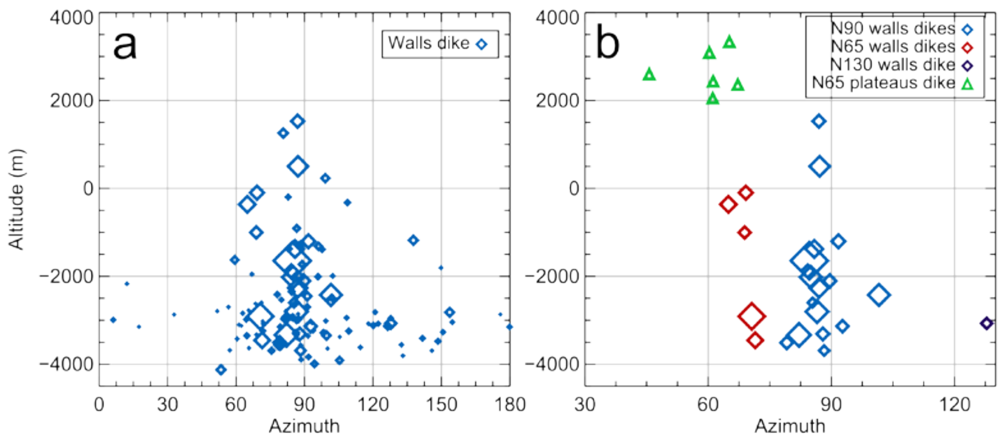

Figure 2: a- Distribution of the dikes mapped in eastern Coprates Chasma. Dikes are plotted as a function of their maximum elevation and azimuth. Diamond sizes represent the dike widths, the smallest being <1 m thick and the largest one ~80 m. **b**- The same plot is shown for wider dikes only (> 20 m). Green triangles represent the dikes mapped on the plateaus.

borders with variable widths outline the largest dikes and are interpreted as contact metamorphism borders (**Fig. 1a**).

Dikes are oriented in all directions but strike mostly 90°, with an average azimuth of 88° (**Fig. 2a**). Scattering in dike orientation is most evident for thinner dikes (< 20 m in width), which could represent filled fractures. Considering only wider dikes (> 20 m in width), two main dike orientations are observed: 90° and 65° (**Fig. 2b**). Dikes striking 90° are observed at elevations below 1500 m in the walls, whereas dikes striking 65° are observed throughout the entire wall section and on the plateaus.

Dike dips were also measured when it was possible using HiRISE DTMs. Fifteen measurements were made on dikes located in the north and south walls and the central horst of eastern Coprates Chasma. Dips range from 55 to 90° with an average of 72°.

Rheologic modeling was used to estimate eruption rates for each dike mapped in Coprates Chasma. Resulting mean dike eruption rates are respectively $8.1.10^5$ $m^3.s^{-1}$, 1.1 10^6 $m^3.s^{-1}$ and $1.5.10^6$ $m^3.s^{-1}$ for viscosities of respectively 10, 100 and 1000 Pa.s.

Discussion: Several lava flows have been identified to the East of Jovis Tholus in the Tharsis region and were erupted from linear fissures up to 20 km long [6]. Calculated eruption rates range from 5.10^3 $m^3.s^{-1}$ up to 10^4 $m^3.s^{-1}$ for an assumed magma viscosity of 100 Pa.s. If we assume a similar viscosity, our average value for Coprates Chasma dikes is 100 to 200 times higher. However, the volcanic events at East Jovis Tholus study are recent (< 200 My). Volcanic activity is expected to have been higher in the Noachian and early Hesperian time, when Coprates Chasma dikes were active [9].

Ridges associated with an early Hesperian lava plain in the region of Hellas Basin have been interpreted to be dikes [10]. Based on dike dimensions, eruption rates ranging between 10^5 and 10^6 $m^3.s^{-1}$ were estimated. These values are similar to the eruption rates we calculated. Based on such eruption rates, dikes in Coprates Chasma would only require a few 100's to 1000's of years to form the ~4 km thick Hesperian lava flows observed at the top of the canyon's wall.

The 65° dikes are observed throughout the wall height and on the plateaus. The 90° dikes have only been mapped at elevations lower than 1500 m, therefore they are likely to be older. We infer that this change in dike orientation records a change in the regional stress field over time. Emplacement of 90° dikes could be related to the early uplift of the Syria Planum province, which was associated with radial dike emplacement over long distance [11]. Many features (faults, volcanic cones) striking 65° are observed in VM, but their orientation remains unexplained.

Conclusion: The opening of VM must have occurred after the dikes' emplacement. It is important to note that the orientation of both sets of dikes does not match the orientation of VM walls (~110°) nor the orientation of the surrounding narrow pit chains that are thought to be caused by dikes. Dikes dips are also not as expected for predicted normal faults. The three different orientations of the dikes and VM suggest variations in the regional stress field over time and that there is not a straightforward relationship between dike emplacement and VM opening.

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