SURPRISING IMPLICATIONS OF DIKE SWARM GEOMETRY FOR THE STRESS HISTORY IN THE VALLES MARINERIS REGION ON MARS. D. Mège[1] and J. Gurgurewicz[2,1], [1]Space Research Centre, Polish Academy of Sciences, Bartycka 18A, 00-716 Warsaw, Poland, dmege@cbk.waw.pl, [2]Institute of Geological Sciences, Polish Academy of Sciences, Research Centre in Wrocław, Podwale 75, 50-449 Wrocław, Poland, jgur@cbk.waw.pl.

Introduction: Because dikes are mainly hydraulic fractures, variations of their orientation at regional scale informs on the variations of the orientation of the principal stress trajectories. HiRISE images are revealing hundreds of dike exposures on the Valles Marineris walls, most of them subparallel to chasma orientation, supporting views of Valles Marineris initiation by rifting parallel to dike swarms, as seen in modern and ancient volcanic rifts on Earth. However, in some areas, mainly in eastern Candor Chasma, dike orientation is oblique, or even perpendicular to chasma orientation, which implies that at some moment(s) in the history of Mars, extension was strongly oblique or parallel to the troughs, not perpendicular.

Vintage data and analysis: Structural and geomorphological analysis of the Martian surface in the visible spectral range using the NASA/Viking images in the 90's, complemented by experimental modelling suggested that the Valles Marineris trough (chasma) system is aligned with a mafic dike swarm, which was named the Syria Planum Dike Swarm [1-2]. Cross-cutting relationships and terrestrial inspiration led to the interpretation that the dikes were injected from the summit of the Tharsis dome, Syria Planum (Figure 1), and may have guided the normal faulting that gave several of the Valles Marineris troughs their graben structure [1, 3-4] within the framework of a plume tectonics model. At that time, the resolution of images, several tens of meters per pixel, was too coarse to identify dikes when exposed, and only the derived volcanic landscapes at the surface could be identified.

Analysis of HiRISE data: Since 2006, the HiRISE telescope orbits Mars in NASA's Mars Reconnaissance Orbiter spacecraft and takes images of Mars at a resolution of 0.25 to 1 m/pixel. Many sites in Valles Marineris have been imaged, some of which show eroded dikes. Mafic dikes were identified in eastern Coprates Chasma [6-7], of orientation predicted by the plume tectonics model. Several dikes exposed on the plateau south of Valles Marineris also follow this trend [8].

Dike analysis along Valles Marineris walls: We have been undertaking a systematic survey of HiRISE images in Valles Marineris in order to identify dikes exposed along the walls and in the troughs, noting their coordinates, orientation, maximum thickness, elevation above the MOLA sphere, and dip angle when not vertical. Segmented dikes are counted as single observations. Seventy-five HiRISE images of Valles Marineris walls have been surveyed to date. They have revealed the presence of more than 300 dikes, of thickness between ca. 1 m (lower detection limit) and 60 m (Figure 2). A few bodies up to 200 m thick may be either dikes or other types of intrusions, with uncertainty resulting from mantling by slope deposits.

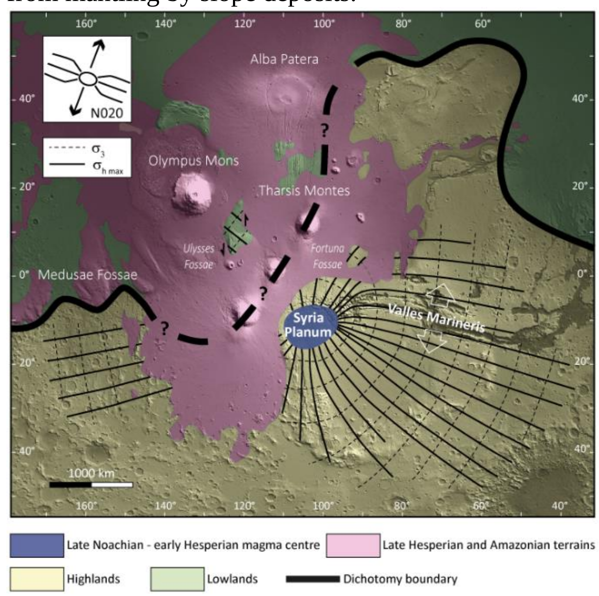

Figure 1. Stress field generated by the Syria Planum magma centre inferred from dike-related landforms [1]. The Valles Marineris grabens were interpreted to form in this context, similar to continental rifts in Large Igneous Provinces [5].

The dikes are mapped from HiRISE images only, which implies that their distribution partly reflects HiRISE image distribution. Several long portions of Valles Marineris walls and floors are not imaged. Nevertheless, it is likely, from the current mapping, that dike concentration is higher in some areas, especially eastern Coprates Chasma and Ophir Chasma, perhaps indicating that these two areas were preferred sites of local magmatic activity. Alternatively, the dikes may have propagated from the Syria Planum area to the Coprates and Ophir chasmata through the western part of Valles Marineris, as implied by Mège and Masson's plume tectonics model [1], but too deeply to be exposed in the western area. Preliminary measurements indicate indeed that most dikes on the Valles Marineris walls are located at a depth > 4000-5000 m below the surface of the surrounding plateau. Although many chasma floors are deeper than this, huge debris slopes mantle the lower part of the walls and in many parts of Valles Marineris bedrock is not exposed at the such depths, which may be the explanation for the absence of exposed dikes in these areas. Wilson and Head [9] calculated that the depth of the level of neutral buoyancy (LNB) of basaltic magma on Mars was estimated at ca. 11 km, which may be considered as a proxy for mean propagation depth. Due to uncertainty on Valles Marineris bedrock composition as well as dike composition (most identified dikes are too thin to have their composition inferred from near-infrared spectra from orbit using the MRO/CRISM spectral imaging instrument), the inferred LNB depth only indicates the great depth of propagation of the Valles Marineris dikes, consistent with the observations.

The dike-related landforms identified by Mège and Masson [1] are generally parallel to Valles Marineris. So are the dikes identified in the survey reported here, which strengthens the plume tectonics model. Nevertheless, some are not parallel to Valles Marineris, and sometimes are additionally parallel to other tectonic structures, such as narrow grabens on the plateau, or the Louros Valles sapping channels. In northern Candor Chasma, unfortunately not yet imaged at HiRISE resolution, the dikes are perpendicular to the Valles Marineris-parallel dikes, and form a true local swarm that indicates that at one moment in the evolution of Valles Marineris, dike dilation and tectonic stretching occurred perpendicular to the tectonic stretching that produced the Valles Marineris grabens. Determining the chronology of dike swarms would help reconstruct the evolution of the crustal stress field with time; unfortunately, only two sites where dike cross-cutting relationships can be determined have been found to date, making this chronology out of reach.

Conclusion: Dike mapping in Valles Marineris reveals an evolving stress field that models aiming at solving either the inverse problem [1, 5] or the forward problem (e.g., [10-11]) had not anticipated. The regional NNE-SSW extension of Valles Marineris predicted by these models is supported by the orientation of many dikes throughout the region; nevertheless, dike mapping reveals that in the details, extension following other directions has also been significant, making the tectonic evolution of Valles Marineris surprisingly more complex than expected.

References: [1] Mège D. and Masson P. (1996) *Planet. Space Sci., 44*, 1499–1546. [2] Mège D. et al. (2003) *JGR-Planets, 108*, E5, doi:10.1029/2002JE001852. [3] Mège D. and Masson P. (1996) *Planet. Space Sci, 44*, 749–782. [4] Ernst R. E. et al. (2001) *Ann. Rev. Earth Planet. Sci., 29*, 489–534. [5] Mège D. (2001) *Geol. Soc. Am. Sp. Pap., 352*, 141–164. [6] Flahaut J. et al. (2011) *GRL, 48*, L15202, doi:10.1029/2011GL048109. [7] Brustel C. et al. (2016) *47th LPSC*, Abstract #2724. [8] Huang J. et al. (2012). *GRL, 39*, L17201, doi:10.1029/ 2012GL052523. [9] Wilson L. and Head J.W., III (1994) *Rev. Geophys., 32*, 221–263. [10] Banerdt W. B. and Golombek M. P. (2000) *LPSC XXXI*, Abstract #2038. [11] Tenzer R. et al. (2015). *EPSL* 425, 84–92.

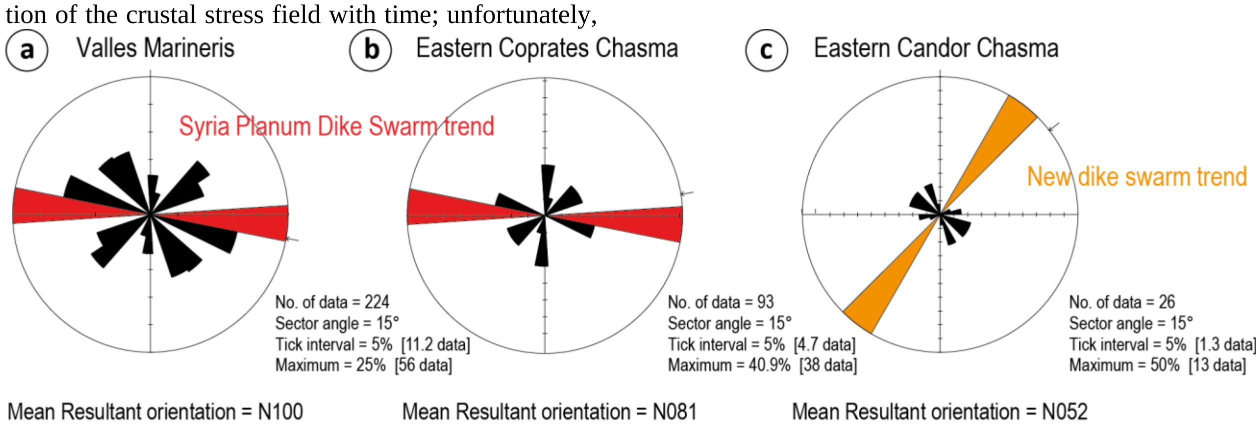

Figure 2. Dike orientation has been measured and binned in sectors 15° wide. (a) Orientation of all the dikes mapped in Valles Marineris to date. The mean orientation is subparallel (N100, arrow) to the mean Valles Marineris trough orientation (N105) and to the Syria Planum Dike Swarm (Figure 1). (b) Dike orientation in eastern Coprates Chasma. More than 40% of the dikes are parallel to the main dike trend as found in (a), although the mean orientation (N081, arrow) is parallel to the local orientation of Valles Marineris (N090). (c) Dike orientation in eastern Candor Chasma. Half the mapped dikes trend perpendicular to Valles Marineris, suggesting that at one moment, dike dilation (and the minimum principal stress trajectory) was parallel, not perpendicular, to the Candor Chasma graben.