ORDER OUT OF CHAOS TERRAIN: THE CASE AGAINST VAST GLACIATION IN VALLES MARINERIS, MARS. L. E. Kissick[1,2*] and P. E. Carbonneau[1], [1]Department of Geography, Durham University, South Road, Durham, UK. [2]Department of Earth Sciences, University of Oxford, Oxford, UK. *lucy.kissick@earth.ox.ac.uk

Introduction: The Valles Marineris of Mars form the largest system of interconnected canyons (or *chasmata*) in the Solar System. A school of thought regarding the possibility of a Late Noachian to Late Hesperian (~3.7-3.0 Ga) polythermal glaciation within the chasmata has emerged over the last decade [e.g., 1, 2, 3, 4, 5]. The hypothesis has been fuelled by reports of: 1) morphology including ice surface trimlines, deep scour, lateral banks, terminal and ground moraines, outwash plains, patterned ground, truncated spurs, hanging valleys, and hummocky terrain [1, 3, 5]; 2) mineralogy including jarosite along the trimline [2]; and 3) structural reorganisation including crestal ridge slumping and gravitational spreading [1, 4].

However, neither precipitation models nor global water budgets can account for such a colossal fill, and the hypothesis has thus far remained unchallenged by additional scrutiny. Here, we present the first thorough case against a Valles Marineris glaciation by describing geomorphological evidence that precludes the existence of a glacier.

Study site: Candor Chaos: This abstract and its corresponding paper [6] focus on Candor Chasma in *Figure 1*, one of the constituent chasmata of the Marineris system, where fractured terrain named Candor Chaos was recently reinterpreted as remnant glacial ice [3]. This interpretation deviates significantly from conventional study: chaos terrain is a feature with no terrestrial analogue found almost exclusively within Marineris and the adjacent Chryse Planitia. It is more traditionally described as the surface manifestation of catastrophic eruptions of a fluid, usually groundwater from an overpressured aquifer [7]. The reinterpretation that chaos terrain is composed of fractured ice is a serious assumption that requires closer analysis; were all such terrain ice, the implications for the global climate and water budget of Mars would be of extreme significance. The presence of a voluminous glacier within Marineris, whether extinct or extant, requires closer scrutiny for the same hydrological and climatological reasons.

Methods: We use Mars Reconnaissance Orbiter Context Camera (CTX) images at 6 m pixel^{-1} resolution, and High Resolution Image Science Experiment (HiRISE) images at 25 cm pixel^{-1} where available, to conduct a simple, in-depth morphological study of the chaos polygons within Central and East Candor. Four chaos terrain sites from the Chryse Planitia region (Aram, Aureum, Hydaspis, and an unnamed crater in Xanthe Terra) are also analysed for comparison with Candor. We also examine additional reportedly glacial features with HiRISE resolution where possible, including trimlines, kettle holes, lateral moraines, and hanging valleys, comparing the morphology of these to descriptions of both terrestrial and established Martian instances. Additionally, we compare the morphology of boulders, craters, and the general landscape in Candor to known rock- and ice-based terrains, the latter which includes the North Polar Layered Deposits and the recently-discovered massive ice of Promethei Terra [8]. This is to better constrain the structure and strength of the substrate Candor's chaotic terrain is comprised of.

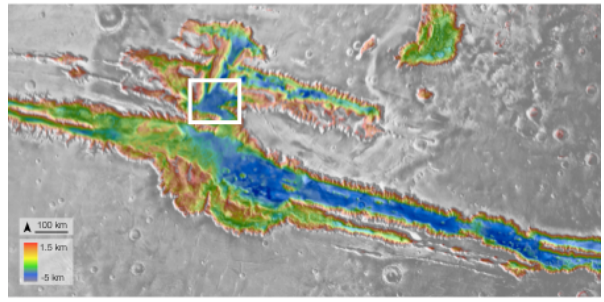

Figure 1: *Valles Marineris with Candor Chaos, the study site, circled. MOLA map atop Viking mosaic.*

Results: We find that the chaotic terrain in Central and East Candor is morphologically indistinguishable from the reference chaos in the circum-Chryse region, with the most exemplar cases displayed in *Figure 2*. We find no significant differences in the structure, morphology, and composition of chaos terrain in Candor and the Chryse Planitia region, which suggests Candor's chaos, like Chryse's, is fractured highland terrain. Layered, boulder-rich scarps in Candor are found to bear no similarity to scarps of massive ice in Promethei Terra or the North Polar Layered Deposits. Other key supports for the glacial hypothesis, including the coincidence of an apparent glacial trimline with the water-bearing mineral jarosite (see *Figure 3*), and the apparent presence of glacial features including kettle holes, sandur plains, lateral moraine, and hanging valleys, are too found to

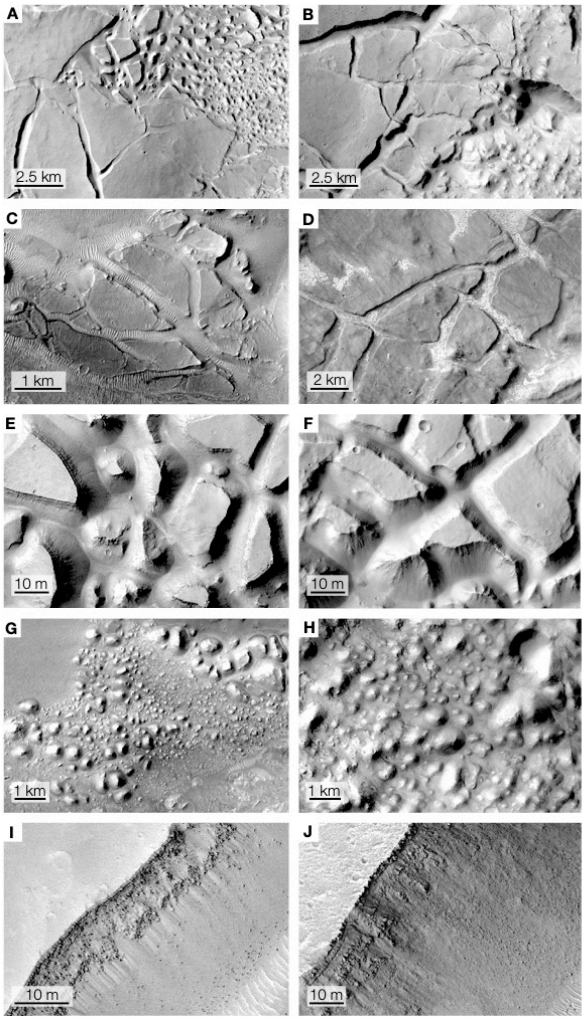

Figure 2: *Morphology of chaotic terrain in Candor (left) compared to chaos terrain across the Chryse Planitia (right). The two are indistinguishable.*

have more plausible explanations with non-glacial origins. These include tectonic reorganisation, groundwater sapping, and chaotic fracturing.

Discussion: Given this morphological indistinguishability, it therefore seems reasonable that the chaotic terrain in Candor is rock-based chaos terrain: a collapse feature following the expulsion of some subsurface fluid, and a common occurrence in neighbouring lowlands and chasmata. Morphological evidence in support of the glacial Marineris hypothesis, therefore, finds more plausible origins through the expulsion of groundwater.

The first implication of this is that we find no evidence in support of the glacial Marineris hypothesis. This conclusion is consistent with a growing view of the Late Noachian-Late Hesperian Martian climate as one cold and dry with limited precipitation [e.g., 9, 10], where ice accumulates in the southern highlands and is drawn away from the northern lowlands.

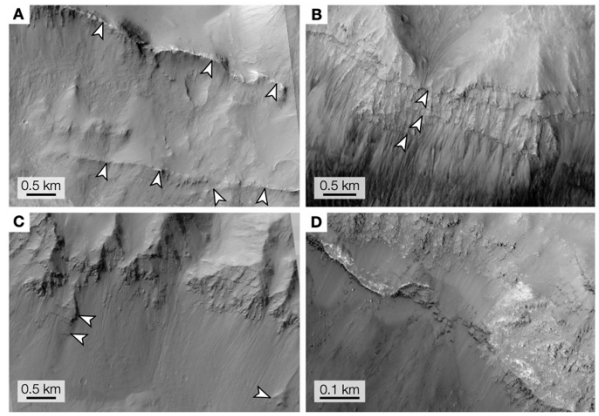

Figure 3: *An example of how features reported as glacial may not withstand high-resolution scrutiny: the 'trimline' feature of Coprates Chasma is vertically discontinuous and is unaffected by superficial events like landslides (see D). Both of these observations suggest the feature is part of the chasma wall's strata.*

A second implication is the presence of groundwater in interior Marineris at some point in time. This is unsurprising given that groundwater pools within deep localities, alongside the myriad sapping channels and mega-outflows that exist radially downgradient of Marineris. This influx of groundwater during the Late Noachian to Late Hesperian could have permitted late-stage lacustrine and/or other forms of aqueous activity in the area independently of climate at a time when water was becoming increasingly scarce.

Conclusions: We conclude that the hypothesis of glaciation within Valles Marineris is inconsistent with both observed morphology and our understanding of the ancient Martian climate, and we find no evidence to support its existence. Instead, we note that the presence of chaos in Candor Chasma points to an intriguing source of groundwater within the chasmata, which researchers of aqueous activity within Marineris may find of significant interest.

References: [1] Mège D. and Bourgeois O. (2011) *EPSL*, *310*, 182-191. [2] Cull S. et al. (2014) *Geology*, *42*, 959-962. [3] Gourronc M. et al. (2014) *Geomorphology*, *204*, 235-255. [4] Makowska M. et al. (2016) *Geomorphology*, *268*, 246-252. [5] Dębniak K. et al. (2017) *Journal of Maps*, *13*, 2995-3007. [6] Kissick L. E. and Carbonneau P. E. (in press) *Icarus*. [7] Carr M. (1979) *J. Geophys Res: Solid Earth*, *84*, 2995-3007. [8] Dundas C. M. (2018) *Science*, *359*, 199-201. [9] Fastook J. L. and Head J. W. (2015) *Planetary and Space Sci.*, *106*, 82-98. [10] Wordsworth R. et al. (2017) *Geophys Res. Let.*, *44*, 665-671.