MARTIAN GULLY ORIENTATION AND SLOPE USED TO TEST MELTWATER AND CARBON DIOXIDE HYPOTHESES. S. J. Conway[1], T. N. Harrison[2] S. R. Lewis[3], R. J. Soare[4], M. R. Balme[3] and A. Britton[3], [1]LPG Nantes, UMR CNRS 6112, Nantes, France (susan.conway@univ-nantes.fr), [2]Centre for Planetary Science and Exploration, University of Western Ontario, London, N6A 5B7, Canada, [3]Department of Physical Sciences, Open University, Milton Keynes, United Kingdom, MK7 6AA, UK, [2]Geography Department, Dawson College, Montreal, H3Z 1A4 Canada.

Introduction: Gullies on Mars are kilometer-scale erosion-deposition systems, most often defined as systems containing an erosional alcove, a channel and a debris apron, or fan [1]. Some gully systems could be up to ~5 Ma old [2,3], and superposition of gullies suggests they have experienced many episodes of activity [e.g., 4,5]. Their similarities to gullies carved by water, or water-rich debris flows on Earth led researchers initially to propose either groundwater [1], or meltwater [6] as possible erosional fluids. Present-day activity observed in gully-systems, however, has been linked more closely with the annual CO_2 deposition-sublimation cycle [7–10]. In this study, we first re-analyze the global data relating to gully-orientation and slope, then use these data to test the meltwater and CO_2 hypotheses with a 1D climate model.

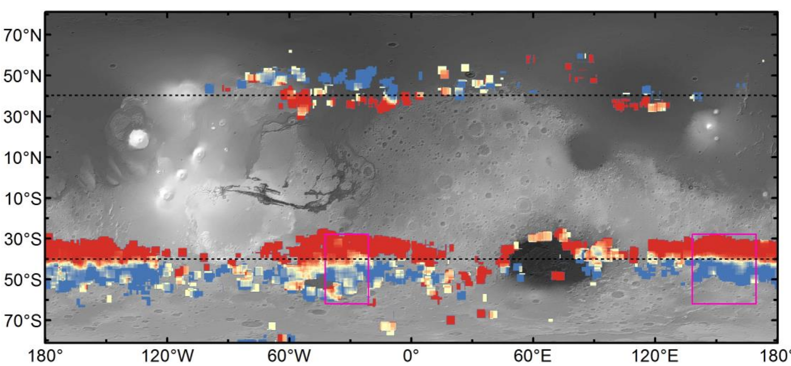

***Fig. 1**: Using a 250 km x 250 km moving window we calculated the ratio between the frequency of pole-facing gullies and the summed frequency of pole- and equator-facing gullies to better visualize the global trends in gully-orientation. Areas where the gully-density falls below 0.3 per 10 km^2 have been excluded. The transition from pole-facing (red) to equator-facing (blue), reported in other works [2,4,5,9,10,12], is consistently located at ~ 40°N/S and much sharper than previously recognised. Basemap: MOLA.*

Re-analysis of global trends and local mapping: We used the global data of Harrison et al. [11] to analyze the relative proportions of pole- and equator-facing gullies within this population (Fig. 1). Previous studies, using more sparse data, found a systematic shift in orientation with latitude, particularly in the southern hemisphere – gullies near 30° face polewards and those at higher latitudes face equatorwards [e.g., 12,13]. Our analysis agrees with this previous work, but reveals a surprisingly sharp transition between pole-facing only to dominantly equator-facing at ~40°. We also find the sparse nature of northern gullies explains the conflicting orientation results of previous studies [13–15], with clear trends only visible in areas with dense populations.

We also examined two areas in more detail: Argyre Planitia and Terra Cimmeria (pink boxes on Fig. 1). In these areas, we mapped the gully-clusters as polygonal outlines [16] on 6 m/pix Context Camera (CTX) images. Using MOLA gridded data, we extracted the slopes of the pixels underlying the gullies (corrected for projection) and here we analyze only those slopes which face either polewards or equatorwards. To account for the variation in gully-density caused by the availability of steep slopes, we normalized the resulting densities by the total number of pixels at a given latitude and slope value. Fig. 2 shows the 8% contour of gully density in these two areas for slope vs latitude.

1D climate model: We use a 1D version of the LMD Mars climate model physics [17,18] to simulate surface temperature on slopes up to 35°, oriented to face north or south, for all latitudes (5° spacing), and for orbital obliquities of 5-55°. We otherwise use current orbital conditions (ellipticity, date of perihelion) and we use a constant thermal inertia [19] of the substrate of 1000 $Jm^{-2}K^{-1}s^{-1/2}$ and a bare soil albedo [20] of 0.2. We extracted two pieces of information from a complete annual cycle: (i) the number of hours during which the surface temperature was below the CO_2 condensation point of 149K. We use these data as a proxy for where CO_2 sublimation processes can be active, since CO_2 needs be deposited on the surface for sublimation to occur under slab-ice [21], or for sublimation to occur within the regolith [22] – two possible mechanisms for mobilizing loose sediment in gullies. (ii) the number of sols for which the daily minimum is below 273K and the daily maximum is above 273K. We use these data as a proxy for where ice could be stable and then melt during freeze-thaw cycles.

Discussion: The distribution of gullies with latitude and slope fits both the distribution of CO_2 and the distribution of freeze-thaw cycles for high obliquity (45° and 55°). However, only the freeze-thaw explains the sharp cut-off at ~40° for equator-facing gullies. At high obliquity the CO_2 distribution extends towards the equator for pole-facing slopes, but there are few recognized gullies equatorwards of 30° latitude. Equally at high obliquity freeze-thaw does not extend sufficiently polewards to explain the high latitude pole-facing gullies. Both hypotheses also fall-down for present-day conditions (~25° obliquity), the extent of CO_2 cannot explain active gullies located on equator-facing slopes and freeze-thaw cannot explain active gullies on pole-facing slopes.

Conclusions and future work: This work supports the results of previous publications, it is likely that a mixture of CO_2 and water related processes are responsible for forming martian gullies [10,23]. We aim to perform a number of tests to assess both the applicability of these simple proxies and to test a wider range of substrate properties (buried ice) and orbital parameters (perihelion and increased atmospheric pressure at high obliquity). In future work we will also include northern hemisphere gullies.

References: [1] M.C. Malin and K.S. Edgett (2000) *Science*, *288*, 2330–2335. [2] D. Reiss et al. (2004) *JGR*, *109*, doi:10.1029/2004JE002251. [3] S.C. Schon et al. (2009) *Geology*, *37*, 207–210. [4] J.L. Dickson et al. (2015) *Icarus*, *252*, 83–94. [5] T. de Haas et al. (2015) *Icarus*, *258*, 92–108. [6] F. Costard et al. (2002) *Science*, *295*, 110–113. [7] C.M. Dundas et al. (2012) *Icarus*, *220*, 124–143. [8] S. Diniega et al. (2010) *Geology*, *38*, 1047–1050. [9] J. Raack et al. (2015) *Icarus*, *251*, 226–243. [10] M. Vincendon (2015) *JGR*, *120*, 1859–1879. [11] T.N. Harrison et al. (2015) *Icarus*, *252*, 236–254. [12] M. Balme et al. (2006) *JGR*, *111*, doi:10.1029/2005JE002607. [13] T. Kneissl et al. (2010) *EPSL*, *294*, 357–367. [14] J.L. Heldmann et al. (2005) *JGR*, *110 doi:10.1029/2004JE002261*. [15] N.T. Bridges and C.N. Lackner (2006) *JGR*, *111*, 09014. [16] A. Britton et al. (2013) *EPSC*, #345. [17]F. Forget et al. (1999) *JGR 104*, 24155–24176. [18] A. Spiga and F. Forget (2008) *GRL*, *35*, L15201 [19] Fergason et al. (2006) *JGR*, *111*, E02S21 [20] Christensen et al. (2001) *JGR*, *106*, 23823–23871 [21] C. Pilorget and F. Forget (2016) *Nat. Geosci*, *9*, 65–69. [22] M.E. Sylvest et al. (2016) *Geology*, *submitted*. [23] C. Dundas (2016) *Nat. Geosci*, *9*, 10–11. [24] C.M. Dundas et al. (2015) *Icarus*, *251*, 244–263.

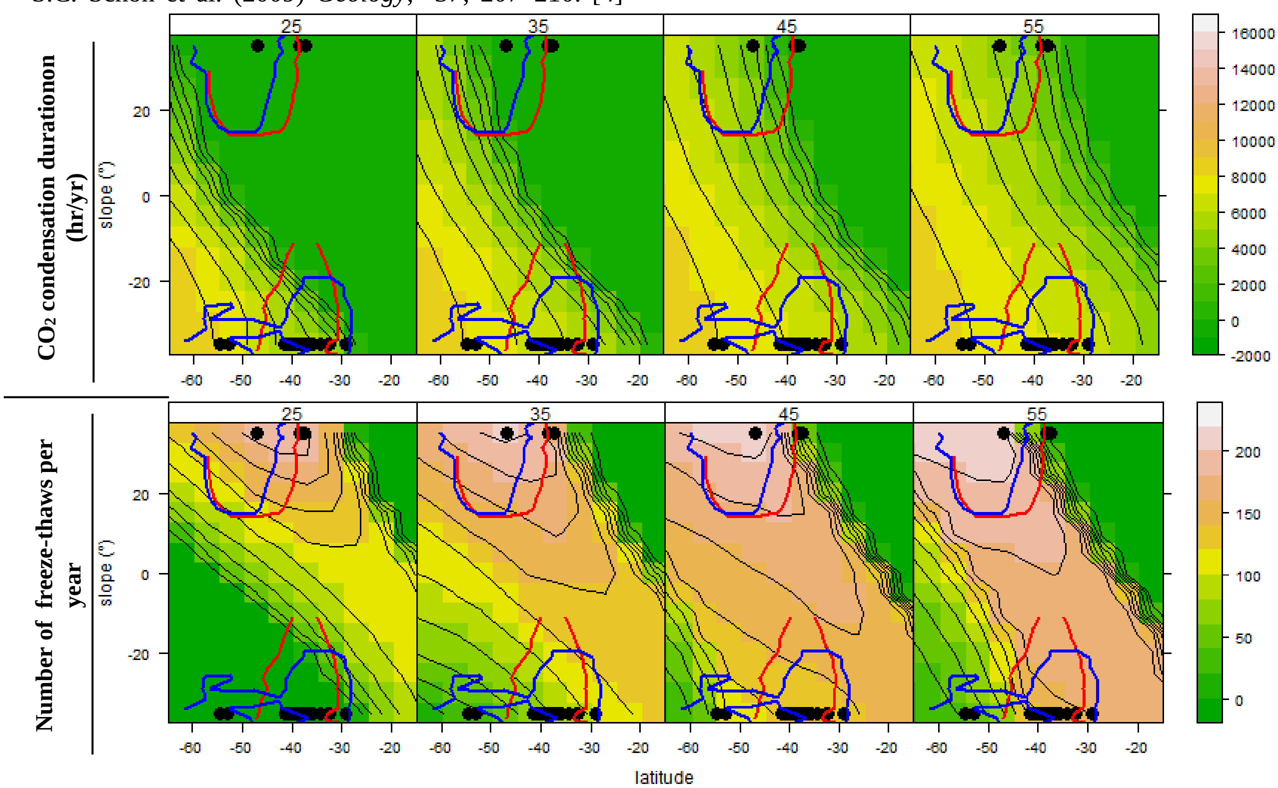

Fig. 2*: Plots of slope angle vs latitude, where negative values of slope indicate pole-facing slopes and positive values equator-facing ones. Blue and red lines are the 8% gully-density contour for gullies in Argyre Planitia and Terra Cimmeria, respectively. Black dots are the active gullies reported in Dundas et al.* [24], *placed at 35° slope. Colour-gradient in the top panels respresents the number of hours with a surface temperature below 149K and for the bottom panels the number of sols where the minimum temperature is less than 273K and the maximum greater than 275K. Numbers at the top of the panels are orbital obliquity in degrees.*