MARTIAN VALLEY NETWORKS AND THEIR LACK OF HEADWATER CATCHMENT AREAS. R. S. Bahia[1] and H. Chen[2], [1]European Space Research and Technology Centre (ESTEC) European Space Agency, Noordwijk, The Netherlands (rickbir.bahia@esa.int), [2]Department of Geography Education, Seoul National University, South Korea (mlqschen@snu.ac.kr).

Introduction: Martian valley networks (VNs) have been noted as evidence for surface run-off and past water cycles on ancient Mars [e.g. 1–3]. The VNs likely predominantly formed as a result of precipitation [e.g. 1,3,4] and, on the flank of volcanoes, volcanic activity followed by groundwater upwelling or ice-melt [e.g., 5, 6, 7]. Predominantly precipitation-fed valleys incising the southern highlands of Mars likely took 10s to 100s of thousands of cumulative years of incision to form [8, 9, 10]. In terrestrial VNs, particularly at the source region of the rivers, there are areas where the hillslope angles are >26º/0.48 m/m (the threshold hillslopes); these areas are referred to as the 'headwater catchment areas' (HCA). In the HCA mass movement processes (e.g., debris flows) are the dominant erosional regime [11], and erosion rates are far greater than below the threshold hillslopes where fluvial processes dominate [11, 12]. Increased erosion rates result in large supplies of sediment to the river, with debris flows being the dominant process for delivering sediment to first- and second order channels [e.g., 13]. For example, 60 to 90% of total sediment yield for drainage basins in northwestern California and western Washington [13] is attributed to mass wasting in the HCA. Most of this is fine sediment (< 2mm), with moderate quantities of coarse sediment (> 2mm) [13]; however, this is sediment source dependent. The addition of this coarse sediment to the rivers, which is then transported in bedload motion, has a substantial impact on increasing the erosion rate [14]; hence, the grain size distribution of sediment supplied to the rivers by the HCAs is a fundamental control on valley gradients and profiles [14].

Considering HCAs have such a large impact on the development of river valleys, in this study, we examine the morphology and morphometry, with specific attention to the potential presence or absence of HCAs, of two Martian VNs, Evros Vallis and Arda Valles, and make comparisons with our measurements of Seo River basin, South Korea. Evros Vallis was chosen as, based on its concavity and drainage density [3, 15] it is hypthosised to be one of the most mature valley networks on Mars. Arda Valles is comparatively immature, and more representative of the general population of Martian valleys [15].

Datasets and Methods: Evros Vallis and Arda Valles VNs were extracted from previously mapped datasets, which used ESA Mars Express Orbiter – High Resolution Stereo Camera (HRSC) images (15 to 25 m per pixel) to map the valleys [3, 15]. To perform drainage network analysis (i.e., identify the extent of the drainage basin) and calculate the local slopes HRSC DEMs were used (~50 to 100 m per pixel horizontal resolution); for Earth, a shuttle radar topographic mission (~30 m per pixel) DEM was used.

Drainage basins were extracted using the Matlab - Topo Toolbox – drainage basins function, which uses surface slope directions for each pixel in the DEM to model the direction of fluid flow to any given pour point. The extent of the pixels that flow towards a given pour point is the outline of the drainage basin. Slope values were extracted for each pixel within the basin using the Matlab - Topo Toolbox - gradient8 function which returns the numerical steepest downward gradient of a DEM using an 8-connected neighborhood. Although Mars' gravity is ~1/3 of that of Earth, the angle of repose, and hence the angle at which debris avalanches occur, is independent of gravity [16]; to identify HCAs, areas were catergorised into those with slopes >26º/0.48 m/m and <26º.

Results: Evros Vallis and Arda Valles lack slopes >26º. In contract, ~25 % of the area of Seo River basin is >26º in slope (Figure 1). The valley walls of the Martian VNs are also shallow in slope (e.g., Evros Vallis' average valley walls slope ~0.05 m/m). The VNs cross-sectional profiles of Evros and Arda both having quite prominent water divides between valleys and flat valley floors, whereas Seo River basin has less prominent water-divides with abundant tributaries between these divides and more V-shaped profiles. Drainage basin analysis revealed that the drainage area at the initiation points of VNs within Evros Vallis basin are (median ≈ 482500 m^2) ~10 times larger than Seo River basin (median ≈ 40000 m^2).

Discussion: Our results concur with previous analysis of Martian VNs, indicating that they are comparatively immature and poorly incised when compared to their terrestrial counterparts [e.g., 1-3, 15]. The cross-sectional profiles of Evros and Arda have geometries similar to those defined as "Youth Stage" under the Davis Cycle of Erosion, whereas Seo River Basin appears to be in the "Early Mature Stage". This finding is supported by the semi-linear elevation profile and low concavity index of Arda Vallis [15], a profile and concavity index comparable to most Martian VNs, which indicates that the valley has

caused little alteration to the pre-defined topography. Although Evros Vallis has a concavity index and elevation profile indicative of a more mature network [15], it appears that it is still relatively immature when compared to Seo River Basin, and that when we in fact compare its profile to the surrounding topography it also appears to reflect the pre-defined topography. This indicates that Evros Vallis may have also caused little topographic alteration to the underlying topography, and thereby be a relatively immature VN.

This immaturity has previously been attributed to a lack of sustained fluvial activity; however, we believe this may be missing a major component of VN development: sediment supply. Our analysis has revealed that both Arda Valles and Evros Vallis have no HCAs. HCAs are the primary source of sediment to the VN [13]. Insufficient sediment, particularly coarse sediment, causes rivers to have very low erosion rates [e.g., 14]. This indicates that, even if fluvial activity is sustained for lengthy periods of time, without sufficient sediment supply the VN shall remain poorly incised and appear immature. Considering Evros and Arda lack HCAs, the lack of potential sediment supply to the VNs, particularly coarse sediment, may have limited the capability of the rivers. Additionally, Mars' lower gravity would cause larger grains to travel in saltation/suspension [17]. These factors add complication to the assumption that their immaturity simply reflect a lack of sustained fluvial activity.

The large drainage area prior to valley incision observed for Evros Vallis may also be a consequence of the lack of HCA; the gentler slopes result in lower fluid flow velocities and the lack of HCAs limits sediment supply. A larger area is, therefore, required to entrench sufficient sediment to initiate incision. Alternatively, the larger drainage area prior to incision may reflect a low rainfall/snowfall intensity meaning a larger area of accumulation is required prior to incision. Additionally, the surface may have a high porosity meaning it is not favorable for subaerial flow. If this is the case, groundwater seepage may dominate resulting in preferential fluid flow via groundwater processes (e.g., subsurface stormflow) before causing channelisation downslope. In semi-arid terrestrial regions with low gradients, preferential flow through macropores (cavities >75 μm in width leading from the surface into the subsurface) can result in substantial contributions of subsurface stormflow to catchment runoff [18]. Further investigations are required to better understand the relationship between large drainage areas and the initiation of Martian VNs.

Conclusions: In this study we examined the drainage basins of two Martian valley networks (VNs): Evros Vallis, Arda Valles, and one terrestrial VN: Seo River Basin. Specific attention was paid to the presence, or lack of, headwater catchment areas (HCAs; areas >0.48 m/m in slope). Our results reveal that Evros and Arda completely lack HCAs, whereas ~25 % of the area of Seo River Basin is >26º in slope. Additionally, we find that both Martian VNs appear relatively immature in cross-section compared to Seo River Basin. Considering HCAs are the dominant provider of sediment to terrestrial VNs, the lack of HCAs in Martian systems may explain their immaturity. Sediment, especially coarse sediment, has a substantial impact on the erosion rate of rivers [17]. The lack of sediment supply to Martian VNs may have had a substantial impact on their capacity to modify the surface of Mars and establish mature VNs.

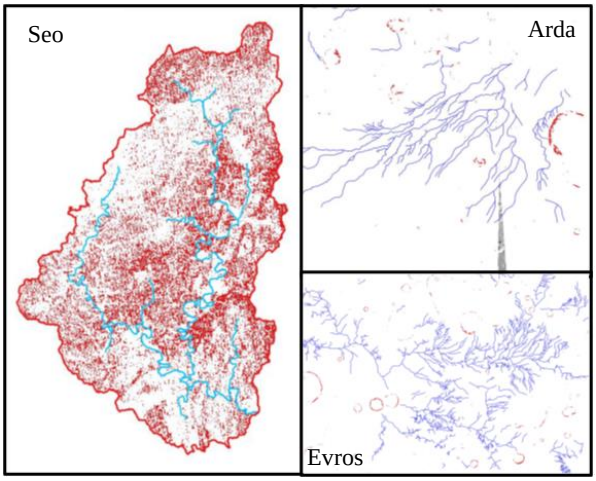

Figure 1. Distribution of HCAs (red = > 26º slopes) for Seo River basin, Arda Valles and Evros Vallis.

References: [1] Milton, D. J. (1973) JGR, 78, 4037–4047. [2] Carr, M. H. (1995) JGR, 100, 7479–7507. [3] Bahia, R. S., et al., (2022) Icarus, 383, 115041. [4] Grau Galofre, A., et al., (2020) Nature Geoscience, 13, 663-668. [5] Bahia, R. S. (2022) PSS, 223, 105592. [6] Fassett, C. I. & Head J. W. (2007) Icarus, 189, 118-135. [7] Gulick, V. & Baker. V. (1989) Nature, 341, 514-516. [8] Kleinhans, M. G. et al., (2010) EPSL, 294, 378-392. [9] Hoke, M. R-T., et al., (2011), Phil. Trans. R. Soc. A., 370, 2193-2212. [10] Orofino, V. G. A., et al., (2018) PSS, 163, 83-96. [11] Bierman, P. R. & Montgomery, D. R. (2014) W.H, Freeman and Company Publishers. [12] Montgomery D. R. & Brandon M. T. (2002) EPSL, 201, 481-489. [13] Macdonald, L. H. & Coe D. (2007) Forest Science, 53, 149-168. [14] Sklar, L. S. & William E. D. (2001) Geology, 29, 1087-1090. [15] Grau Galofre, A., et al., (2020) EPSL, 547, 116482. [16] Kokelaar, B. P. et al., (2017) JGR Planets, 122, 1893-1925. [17] Braat, L. & Lamb, M. P., (2022) EPSC2022-356. [18] van Schaik, N. L. M. B. et al., (2014) Hydrol. Process., 28, 5805-5816.