WATER AND LAVA BOTH SEEM VIABLE FOR THE FORMATION OF ONE OF MARS' DENSEST AND LARGEST CHANNEL NETWORKS H. Bernhardt, D. A. Williams. School of Earth and Space Exploration, Arizona State University, Tempe, USA (h.bernhardt@asu.edu).

Introduction: The Axius Valles (Fig. 1A) on the Malea Planum region's (MPR) northern flank down into the Hellas basin are one of the most extensive and densest channel networks on Mars [1,2]. Previous studies tentatively interpreted the area as pyroclastic deposits dissected by sapped water/lahar flows likely mobilized by volcanic heat [3-8]. However, no detailed morphometric analyses and analog studies have been conducted so far.

Here we present our preliminary findings on the Axius Valles' origin as part of an ongoing, comprehensive investigation of the entire MPR [9].

Physiography and morphometry: The Axius Valles form a mostly parallel pattern of sinuous valleys on a plain of gentle but relatively uniform north-northeast tilt, i.e., long-wavelength dip, at ~0.6 to 0.9° (~1 to 1.6%) towards the Hellas basin floor. In total, ~22,550 km of sinuous valleys dissect this plain (including the Axius Valles and additional channels to the west), resulting in a drainage density of ~0.9 km^{-1}. The channels are up to ~20 km wide and ~100 m deep, although most are narrower and shallower than ~5 km and ~50 m, respectively (sinuous valleys wider than ~10 km were mapped as separate unit). The majority of the valleys originates within, or on the rim of, Amphitrites Patera (Fig. 1A; "AP") between elevations of ~1,200 and ~1,600 m. Smaller subsets originate at or below the rim of Peneus Patera (Fig. 1A; "PP") between elevations of ~0 m and ~600 m, or are traceable further south into the wrinkle-ridged plains of the MPR. The longest continuously traceable valley of the Axius Valles is ~325 km long and follows the topographic gradient from ~600 m above the datum down to ~ -4,800 m. The valleys' sinuosity is relatively low, ranging from ~1 up to ~1.15, and anabranching is very common. In several locations, sinuous valleys are levéed, i.e., bound by ridges that can be up to ~100 m high. The valleys cut through, or are controlled by, degraded, likely Hesperian, crater materials (e.g., craters Wynn-Williams and Pau) as well as wrinkle ridges in numerous locations, whereas they are consistently superposed by fresh, likely Amazonian, crater materials. The wrinkle ridges among the Axius Valles are mostly degraded, i.e., discontinuous and/or muted, but otherwise resemble those on the less dissected plains south of Amphitrites and Peneus Paterae albeit with a significantly lower geographic density. The contact between the less and the more dissected plains is mostly gradational, but often marked by a distinct increase in km-scale roughness and an up to ~200 m high scarp stepping down to the more dissected Axius Valles plain.

Age: According to crater-based model ages (AMAs) and stratigraphic constraints [9,10], the formation of the Axius Valles occurred after wrinkle ridge-formation (<3.8 Ga) and the emplacement of

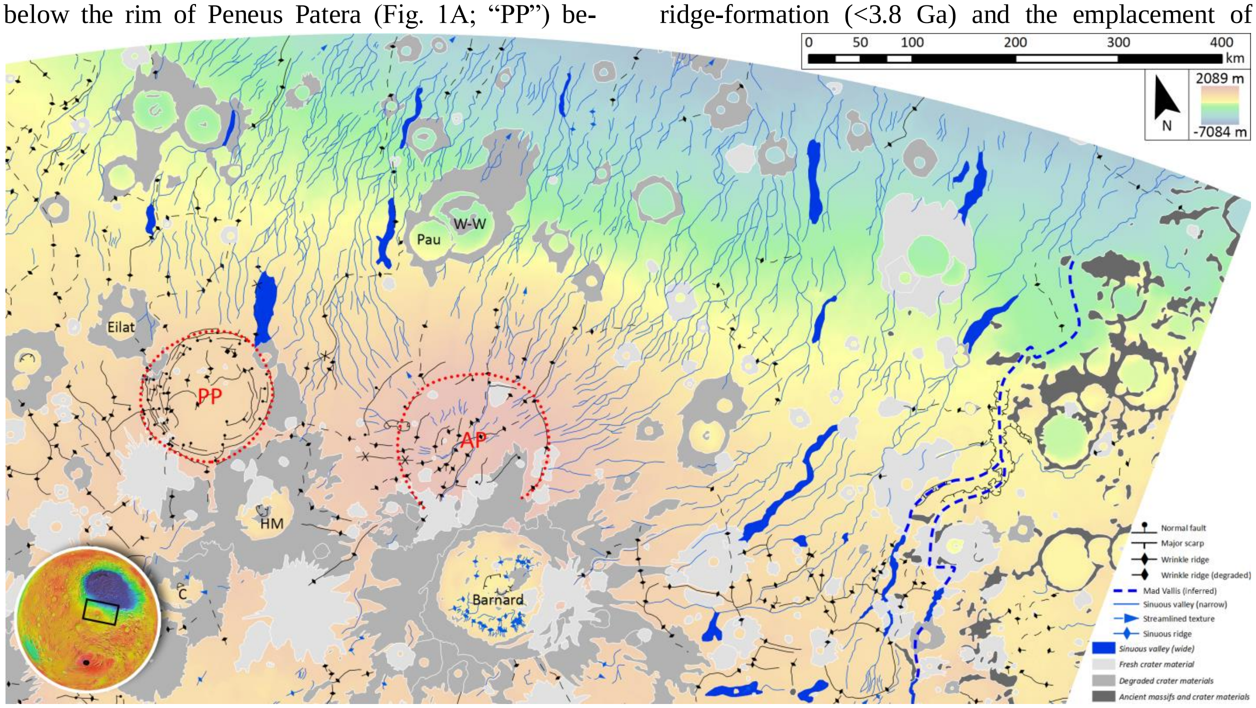

Figure 1: Modified excerpt of our photogeologic map of the Malea Planum region showing the Axius Valles north-northeast of Amphitrites and Peneus Paterae ("AP" and "PP"; dotted red outlines). Craters "W-W" and "HM" are Wynn-Williams and Henry Moore, respectively. Background is the blended MOLA-HRSC Digital Terrain Model from the PDS.

both, streamlined plains (~3.7 Ga) as well as degraded, Hesperian crater materials. Channel formation had ceased by the time Barnard crater was formed (~3.6 Ga) and fresh, Amazonian crater materials were emplaced. This time span between 3.7 and 3.6 Ga ago also overlaps with the AMAs of the upper wrinkle-ridged plains in the Hellas basin [8] and the resurfaced floors of Amphitrites and Peneus Paterae [11].

Discussion: Based on their morphology and location, the Axius Valles have been tentatively interpreted as the result of sapped water or lahar flows that carved into friable pyroclastic deposits [3-7]. An at least partial formation by pyroclastic flows accelerated by an icy substrate was also brought forward [8], although it remains unknown whether such a process could enable flow over 100s of kilometers. Although observations by [8] of a ~95 km long, sinuous, likely inverted ridge as well as two 10s of kilometers wide, digitate, fan-like deposits on the southernmost Hellas basin floor at 75°E 50°S seem to indicate (glacio-)fluvial deposition, these might not be associated with the formation of the Axius Valles at all. The digitate, fan-like deposits are at the branched termini of Mad Vallis (Fig. 1A, dashed blue line), a channel system that is geographically associated with the Axius Valles, but actually traceable over ~1,800 km to the south polar area, i.e., beyond the volcanic centers of Malea Planum. We therefore interpret Mad Vallis and its fan-like deposits to be associated with south polar processes and thus unrepresentative of the formation of the Axius Valles, although several confluences imply it was reused by Axius-related activity.

As for the nature of the Axius Valles-forming activity, diagnostic features such as short, digitate levée-overspill deposits, bulged, lobate flow fronts (both typical for high viscosity flows, i.e., most lavas or mud/sludge), and associated pit-chains (typical for lava tubes, i.e., lava flows) are absent but might have easily been covered by 10s of meters thick dust-ice mantling [12] or eroded by intense deflation [e.g., 13]. In any case, the fact that the channels extend over 100s of kilometers on a slope of <1° seems to favor low viscosity density currents. Water or sludge flows stand to reason especially as ice accumulation models for an ancient martian 1 bar atmosphere predict a several 10s of meters thick ice sheet to form on the highest points of Amphitrites Patera [14]. Combined with volcanic heat, this might have been a source of the water that eroded the Axius Valles, the vast majority of which originate at or in Amphitrites Patera.

Nevertheless, due to the geographic association with this patera – likely one of the largest calderas on Mars [e.g., 11,15] – the plausibility of pyroclastic flows or very low-viscosity lavas such as komatiite and tholeiitic basalt as alternatives to water should be ascertained. Komatiite-type lavas have been inferred for Mars [16] and low-viscosity mafic to ultramafic lavas have been discussed for martian localities, e.g., Gusev crater and Hecates Tholus [e.g., 17,18]. Mantle-derived low-viscosity magmas such as komatiite or tholeiitic basalt [e.g., 19-21] are indicated by the extremely broad and gently sloped shields of Amphitrites and Peneus Paterae (11,15,21] and also an expected product of MPR volcanism, which was likely caused by deep ring-fractures and mantle upwelling related to the Hellas basin-forming event [11,15]. Furthermore, models indicate that komatiite and tholeiitic basalt flows on very shallow slopes should be able to travel up to ~325 km and form ~100 m deep channels if flow durations and 2-dimensional discharge rates are at least several months and ~150 m^2 s^{-1}, respectively [22,23]. In the channels close to the patera summits, whose average width is ~3 km, this would result in a discharge rate of 450,000 m^3 s^{-1}, which is within the spectrum deduced for other large terrestrial, lunar, and martian flows [24,25]. Given the sizes of Amphitrites and Peneus Paterae as potential source areas, as well as the volume of potentially basaltic material filling the Hellas basin (~10^6 km^3 [13]), we submit that such effusion time spans and discharge rates are reasonable assumptions, especially as the given discharge rate would be a peak value, and not constant over the course of a months-long eruption. Lastly, as is the case for overlapping and interacting lava channels on Earth, e.g., on the flanks of Etna or Teide, such networks form sequentially and not all at once, thereby suggesting a volcanic formation of the Axius Valles would have included multiple eruptions, too.

Preliminary Conclusions: The primary parameters of the Axius Valles, i.e., their sinuosity, size, anabranching, levées, and drainage density are not diagnostic and could be explained by multiple types of density currents. The channels' length over a gentle slope implies low-viscosity liquids, i.e., water/sludge or certain lavas. Most of the channels can be traced back to Amphitrites Patera (likely one of Mars' largest calderas) and large volumes of low-viscosity lavas are indicated by the area's morphology. Nevertheless, water/sludge flows remain a viable alternative to lava. However, based on their origin in a hydrogeologically constrained setting on the summit of a caldera, we do not favor previously proposed groundwater/-ice sapping [7] as water source. An alternative is volcanically-induced melting of an ice sheet, which models [14] suggest to have accumulated on Amphitrites Patera in an ancient 1 bar atmosphere.

References: [1] Hynek, B. M. et al. (2010). JGR: Planets, 115(E9), 1–14. [2] Alemanno, G. et al. (2018). ESS, 5(10), 560–577. [3] Tanaka, K. L., & Scott, D. H. (1987). USGS IMAP 1802. [4] K. L., & Leonard, G. J. (1995). JGR: Planets, 100(E3), 5407–5432. [5] Leonard, G. J., & Tanaka, K. L. (2001). USGS Geol. Inv., 2694, 80225. [6] Moore, J. M., & Wilhelms, D. E. (2001). Icarus, 154(2), 258–276. [7] Tanaka, K. L. et al. (2002). GRL, 29(8), 1–4. [8] Bernhardt, H. et al. (2016). Icarus, 264, 407–442. [9] Bernhardt, H., & Williams, D. A. (2019). Ann. M. of Plan. Geol. Mappers#7013. [10] Bernhardt, H. et al. (2019). LPSC#1435. [11] Williams, D. A. et al. (2009). PSS, 57(8–9), 895–916. [12] Willmes, M. et al. (2012). PSS, 60(1), 199–206. [13] Bernhardt, H. et al. (2016). JGR: Planets, 121(4), 714–738. [14] Fastook, J. L., & Head, J. W. (2015). PSS, 106, 82–98. [15] Peterson, J. E. (1978). LPSC, 3411-3432. [16] Reyes, D. P., & Christensen, P. R. (1994). GRL, 21(10), 887–890. [17] Greeley, R. et al. (2005). JGR, 110(E5), E05008. [18] Williams, D. A. et al. (2005). JGR: Planets, 110(5), 1–13. [19] Williams, D. A. et al. (2000). JGR: Planets, 105(E8), 20189–20205. [20] Elkins Tanton, L. T. Et al. (2001). Geology, 29(7), 631. [21] Arndt, N. et al. (2008). Komatiite. ISBN 9780511535550. [22] Huppert, H. E., & Sparks, R. S. J. (1985). J. of Petrol., 26(3), 694–725. [23] Komatsu, G. Et al. (1992). GRL, 19(13), 1415–1418. [24] Whitford-Stark, J. L. (1982). ESR, 18(2), 109–168. [25] Cattermole, P. (1987). JGR: Solid Earth, 92(B4), E553–E560.