History of Outflow Channel Flooding from an Integrated Basin System East of Valles Marineris, Mars. N. Wagner[1], N.H. Warner[1], and S. Gupta[2], [1]State University of New York at Geneseo, Department of Geological Sciences, 1 College Circle, Geneseo, NY 14454, USA. nw4@geneseo.edu. [2]Earth Science and Engineering, Imperial College London, South Kensington Campus, London, SW7 2AZ, United Kingdom

Introduction: The eastern end of Valles Marineris includes diverse terrain formed from extensional forces and collapse due to groundwater release. Capri Chasma, Eos Chaos, Ganges Chasma, and Aurorae Chaos (Fig. 1) were all likely formed due to a combination of these processes [1,2].

Importantly, this region shows evidence that significant volumes of overland water flow travelled through this integrated basin system [3,4,5]. Furthermore, recent studies have suggested that liquid water was at least temporarily stable here [4]. The topographic and temporal relationships between Eos Chaos and its associated outflow channels for example demonstrate that the upstream chaotic terrains pre-date outflow channel erosion, indicating that Eos Chaos contained (at least transiently) surface liquid water [4].

The purpose of this new study is to better understand the aqueous history of the broader region of eastern Valles Marineris. We present an integrated analysis of the morphology, chronology, and paleohydrology of outflow channels, chaotic terrains, and other associated landforms. Our results expand on previous observations of paleo-flooding in this region to include outflow events from not only eastern Valles Marineris [5] and Eos Chaos [4] but also adjacent and downstream basins.

Methods: A geomorphic map covering the eastern Valles Marineris region was constructed in ArcMap at a scale of 1:500,000 using the Thermal Emission Imaging System (THEMIS) Daytime IR Global Mosaic (Fig. 1). This map highlights major terrain types including highland terrains, outflow channel surfaces, and different forms of chaotic terrains.

In conjunction with the regional geologic map, we highlighted specific locations for more detailed mapping using Context Camera (CTX) images at 6 m/pixel. These images were processed, map-projected, and co-registered to the THEMIS global mosaic. A 100 m High Resolution Stereo Camera (HRSC) digital terrain model (DTM), created in [4], was also overlain on the CTX mosaic. The higher resolution mapping effort (at 1:80,000) focused on the outflow channel outlets for the Eos/Capri, Ganges, and Aurorae basins which have near complete preservation of flood grooves, bedrock terraces, streamlined islands, and less commonly, cataracts. The relative chronology of the flood surfaces compared to surrounding terrains was determined using high resolution crater statistics and standard production and chronology functions for Mars [6, 7], including all craters with diameters > 200 m in the count.

For the paleohydrology analysis, the topographic characteristics and dimensions of each channel were measured using the HRSC DTM. Paleo-flow depths were determined based on the observation of trimlines that mark the margins of individual bedrock terraces. These terraces were first identified by [4] and have been mapped here within every outlet channel that exits an upstream basin. The presence of multiple bedrock terraces and trimlines indicates that the channels were formed by progressively deeper incision and also suggests that bankfull estimates of these channels are gross over-estimates. The paleo-discharge of each topographic interval of the floods was calculated based on empirically derived hydrologic equations (e.g. Darcy-Weisbach).

Results: The regional geologic mapping reveals a diversity of terrain types that include multiple forms of chaotic terrain, perched outflow channels, outflow channels on the floors of the basins, remnant highland terrain between the basins, extensional fracture systems, interior layered deposits (ILDs), and smooth basin infill material (Fig. 1).

The floors of chaos basins contain knobby and plateau-like remnants of collapsed highland terrain.

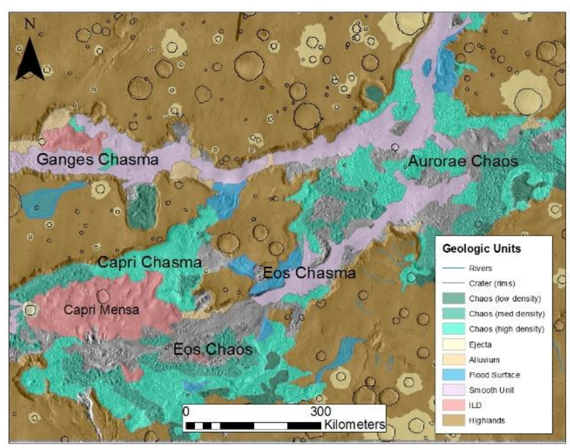

Figure 1: Geologic map (in progress) of the eastern region of Valles Marineris displaying important geographic features and units.

We base this on the observation of layered stratigraphy within the chaotic blocks that is consistent with observed layering in the surrounding highlands. Furthermore, the uppermost surfaces of the more flat-lying plateau-like chaotic remnants show a relatively higher density of impact craters, similar to that exposed on the surrounding highlands. The chaotic terrain occurs at various topographic levels in the region and exhibits highly variable fracture density. We define the fracture density based on the average spacing of the knobs and layered remnants. For mapping purposes, we categorized the chaos terrains by the density of these remnants into low (>10km), medium (~5km), and high (< 1 km) density.

The two largest chaotic terrains, Eos and Aurorae chaos, form basins that source and are connected by outflow channels. Eos Chasma connects both basins, and exhibits multiple bedrock terraces that have been attributed to catastrophic flooding [4]. Here, we have also identified evidence for perched bedrock flood terraces in a localized region on the southern margin of Ganges Chasma, located north of Capri Chasma and Eos Chaos. This flood surface cross-cuts the downstream margin of Columbia Valles, an outflow channel that sources Capri Chasma. Both the Ganges Chasma and Eos Chasma outflow systems converge within Aurorae Chaos. The elevation of the topographically lowest bedrock terraces in Ganges and Eos indicate that Aurorae Chaos (in its present form) set the local base level for incision of these channels. The northern-most margin of Aurorae Chaos also exhibits grooved terrains and perched bedrock terraces suggesting that it is the downstream outlet of all water flow from Eos and Ganges.

Superimposed on the floors of each basin, including Eos and Aurorae Chaos we have identified a continuously smooth geologic unit that embays against remnants of the chaotic terrains, indicating that it post-dates chaos formation. This unit (dubbed here, the smooth unit) has a moderate albedo, relatively moderate thermal inertia, is often covered in wrinkle ridges, and exhibits occasional (sometimes pitted) conical landforms (Fig. 2). These conical features appear most abundant on the floor of Eos Chasma and may be pedestal craters, volcanic in origin, or representatives of other extrusive processes (mud volcanism). Importantly, this basin fill unit also embays against flood grooves on the floor of Eos Chasma indicating that its formation post-dates outflow activity.

Impact crater chronology data for the basin floors, from craters > 2 km in diameter, suggest an Early Hesperian formation age or a model age of 3.5 Ga. In contrast, the surrounding highland terrains date to ~3.7 Ga, or the Late Noachian from D > 2 km. This is consistent with geologic mapping of [8]. The smooth unit provides an Amazonian model age near 1.5 Ga from a count of nearly 2000 craters (10, 272 km^2 area) that are > 200 m in diameter. In contrast, the outflow channels span an age range from 3.0 Ga to about 2.0 Ga using D > 200 m and counting areas in excess of 1000 km^2. These data indicate that the outflow channel surfaces post-date the formation of the chaotic terrain basin floors but pre-date infilling by the smooth unit, consistent with our geomorphic observations. Crater statistics from [4] provide a model age of 3.0 Ga for the upper surface of the large ILD, Capri Mensa.

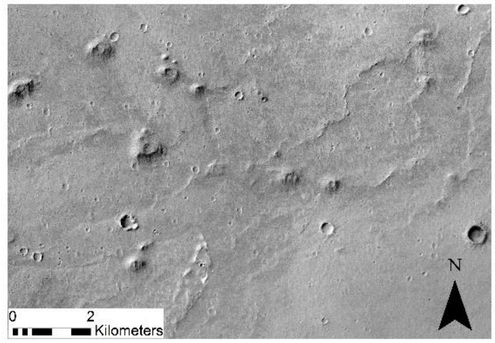

Figure 2: CTX image of the smooth unit that infills the floor of Eos and Aurorae chaos. The unit is noted for its wrinkle ridges and relatively low density of craters. Small pitted conical landforms are also shown here.

Paleohydrologic constraints from the Darcy Weisbach expression provide order of magnitude estimates of the volumetric discharge through the outflow channels. Our analysis accounts for periodic down-cutting of the outlets to form bedrock terraces and trimlines and are not bankfull estimates. However, even using this geomorphic constraint, the discharge estimates are comparable to bankfull estimates taken from the circum-Chryse outflow channels systems at $10^6 – 10^8$ m^3 s^{-1} [9].

Discussion and Conclusions: Ongoing regional and local mapping of the eastern Valles Marineris region confirms that the large chaotic basins here sourced high magnitude flood events. Importantly, the timing of basin formation and outflow channel incision suggests that the basins pre-date flood erosion of downstream bedrock barriers. This implies that the basin themselves were transient sinks for water. Spillover [4] or dam failure of the bedrock sills that existed between these basins created an integrated flood system that ultimately fed other circum-Chryse outflow channels, including the Simud/Tiu system.

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