FLOOD GEOMORPHOLOGY AND HISTORY OF THE EASTERN VALLES MARINERIS REGION OF MARS.
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Introduction: The chaotic terrains at the eastern end of the Valles Marineris graben are among the widest and deepest basins on Mars. Eos Chaos, Aurorae Chaos, Capri Chasma, and Ganges Chasma were all likely formed through the complex interplay of extensional tectonic forces and collapse of the highlands due to groundwater release [1,2].

All basins in this region show some evidence that water, either in a liquid or solid form, was present in the past. Several authors have provided evidence that liquid water was at least transiently stable within the basins, citing evidence for lakes [3,4], deep water fans or deltas [5], catastrophic outflow channels [6,7], and hydrated mineral signatures [8,9]. Other authors have suggested the important role of ice deposition and flow through the region, citing similar landforms (e.g., trimlines) [10] and deposits [11].

Here we continue our efforts to constrain the aqueous history of the eastern Valles Marineris region by providing morphologic, chronologic, and paleohydrologic data for several catastrophic outflow channels. New topographic data and imagery support the hypothesis [7] that progressive vertical incision of pre-existing bedrock sills by catastrophic floods integrated Eos, Capri, and Ganges basins with Aurorae Chaos. We cite evidence for grooved terrains, streamlined islands, interior bedrock canyons, strath terraces, and preserved knickpoints as evidence that turbulent fluid flow incised the margins of the basins. The timing of fluvial erosion, determined by crater chronology, indicates that the basins in this region pre-date the outflow events. This indicates that standing liquid water may have been present within km-deep basins during the period of time leading up to outflow activity.

Methods: We have constructed a 100 m High Resolution Stereo Camera (HRSC) Digital Terrain Model (DTM) that encompasses the entire Eos, Capri, Aurorae, and Ganges basin region. This overlies a near complete Context Camera (CTX) image mosaic at 6 m pixel^{-1}, used here to highlight relevant geomorphic features within a topographic context (Figure 1). Our current mapping efforts are focused on the region of Eos Chasma, the floor of Eos Chaos, Daga Vallis, Columbia Valles, and the southern wall of Ganges Chasma at the junction with Columbia Valles. Mapping of relevant geomorphic landforms and terrains has been carried out at a 1:40,000 scale in ArcGIS. The topographic characteristics of each channel system has been measured and empirically-derived steady flow equations (e.g., Darcy-Weisbach) have been used to estimate the paleo-discharge of each topographic interval of flooding. Crater statistics were obtained for all outflow channels, the surrounding highland surfaces, and smooth terrains that occur on the floor of each basin.

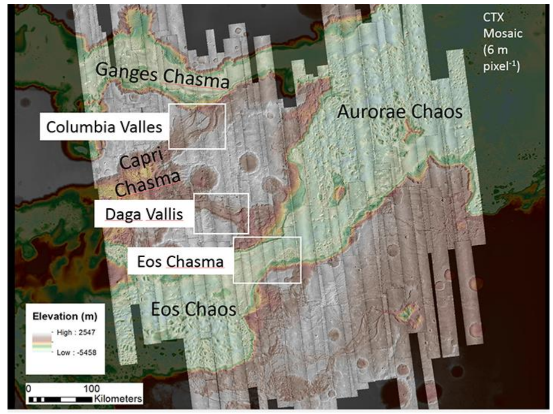

Figure 1: CTX mosaic with topography data from HRSC. Locations relevant to the study are illustrated.

Results: The geomorphic and topographic characteristics of the grooved terrains at Columbia Valles, at the junction of Capri Chasma and Ganges Chasma, suggest progressive vertical erosion by multiple smaller-magnitude flow events with discharges on the order of 10^6 – 10^8 m^3 s^{-1} (Figure 1). This is consistent with previous work at this location by [6]. Well-defined inner channels that are headed by knickpoints suggest that vertical incision was carried out through headward migration of channel headwalls as water flowed over a downstream topographic discontinuity. That discontinuity was related to the existence of a paleo-Ganges Chasma basin. The initiation level of flooding in Columbia, at 1000 m above the datum, suggests flow from a similar level to that of the surrounding highlands. However, the maximum level of incision in Columbia, at -350 m, requires that the downstream paleo-Ganges Chasma basin was at least 1 to 2 km in depth below the highland level by the time Columbia was incised. Through mapping of the southern wall of the Ganges system at the outlet of Columbia Valles we have identified evidence of grooved terrains, interpreted here to represent catastrophic flood grooves, at lower topographic intervals relative to the Columbia outlet. The grooved terrains occur on bedrock (strath) terraces in Ganges, the highest of which cut off Columbia, leaving a hanging valley. This suggests that even after Columbia was incised, ongoing fluvial processes in Ganges lowered the basin floor closer to where it rests today. Crater count data from Columbia Valles suggest resurfacing of Late Noachian to Early Hesperian age highland terrains (N(0.5) value = 3.6 Ga model age using chronology functions from [12]) during the Late Hesperian to Early Amazonian (N(0.5) value = 3.1 Ga model age).

Similar to Columbia Valles, the Daga Vallis bedrock channel, which also extends from Capri Chasma, exhibits longitudinal grooves, abandoned terraces, and inner channels headed by arcuate headwalls (knickpoints). The first appearance of longitudinal grooves at the outlet of Capri Chasma occurs at an identical elevation as at Columbia Valles (1000 m). This suggests a strong topographic control on the initiation of flooding through these two channels. Vertical incision of the bedrock channel and isolation of terraces suggests that bankfull discharge estimates for this system are overestimates. Using the topography data and the assumption that the terraces define unique intervals of flooding, we calculate a discharge of $10^7 – 10^8$ m^3 s^{-1}, similar to Columbia Valles but orders of magnitude lower than when bankfull is assumed. The N(0.5) value for Daga Vallis indicates a similar resurfacing age of 3.0 Ga to Columbia Valles.

Daga Vallis is also a hanging valley at its downstream end where Eos Chasma truncates the grooved terrains of Daga Vallis. However, despite the initial suggestion that the formation of Eos Chasma was unrelated to the outflow events at Daga and Columbia [4, 6], we observe similar grooved terrains, strath terraces, and knickpoints on the southeastern wall, northwestern wall, and floor of Eos Chasma. The highest grooved terrains, which are best preserved on the southeastern wall, emerge from Eos Chaos at an identical elevation of 1000 m. At this location, 500 km from the head of Columbia, we see the same topographic control on flooding. Furthermore, we observe multiple flood trimlines and terraces on both walls at lower topographic intervals down to the base level of the outlet of Eos Chasma with Aurorae Chaos (-4100 m). Discharge estimates, assuming each terrace represents a unique flood interval, provide values of $10^7 – 10^{10}$ m^3 s^{-1}, which is relatively high compared to even bankfull estimates that assume the entire depth of Columbia and Daga. Crater chronology data from the grooved surfaces suggest a similar Late Hesperian to Early Amazonian age (N(0.5) = 2.9 Ga) to that of Columbia and Daga Vallis. The total height of observed terraces within Eos Chasma indicates 4 km of vertical erosion of a preexisting bedrock barrier.

On the floor of Eos Chasma, at the immediate upstream margin with Eos Chaos, we observe grooved terrains that emerge from Eos Chaos at an elevation of -3300 m. These grooves converge on a 200 m to 300 m tall arcuate headwall that we interpret to represent a preserved cataract. The grooved terrains and cataract here indicate that flooding continued to incise even during the final stages of formation of the Eos Chama flood system down to the base level of Aurorae Chaos. This pattern of progressive vertical erosion within Eos Chasma indicates that the paleo-Aurorae Chaos basin was at its current depth during the time of flood activity. A smooth channel fill unit rests downstream, below the headwall on the floor of Eos Chasma. Crater chronology data provides an Amazonian model age of ~1.5 Ga for this unit, suggesting that its formation/deposition is likely temporally unrelated to flood erosion. This date also book-ends the timing of fluvial activity within this system.

Discussion and Conclusions: Ongoing mapping within the eastern region of Valles Marineris suggests that catastrophic floods progressively incised bedrock barriers between the Eos/Capri/Ganges basins and the downstream Aurorae Chaos basin through headward retreat of bedrock channels. The striking topographic continuity between the initiation of all outflow systems that exit Eos and Capri is consistent with earlier hypotheses that lakes were present here [3,4,5,6,7] and that the lakes spilled over into downstream, preexisting basins [6,7]. The chronology data further support the hypothesis that the outflow channels, which formed during the Late Hesperian to Early Amazonian, post-date the formation of the km-deep basins in this region (including the Valles Marineris graben system), which are believed to have initiated in the Late Noachian to Early Hesperian [7,13]. This does not however eliminate the likelihood that the chaos basins continued to subside or were modified after the flooding events. Ongoing work will consist of mapping flood systems within Ganges Chasma and Aurorae Chaos to constrain their relationship to the Eos and Capri systems.

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