Connecting Valles Marineris to the Northern Plains: Linkage by Lake Overspill and Catastrophic Flooding.

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Introduction: Valles Marineris and its satellite grabens represent the largest structurally formed basins on Mars. The basins are natural hydrologic sinks for both groundwater and surface runoff and may have once held lakes [1-4]. While the origin, depth, and chronology of this equatorial water reservoir has been debated for years, its linkage to the massive northern plains basin, and thus global hydrologic legacy, is not established. Linear chasmata (e.g., Eos, Capri, Ganges) connect each basin and exhibit morphologic evidence for catastrophic flooding (Fig. 1). Longitudinal grooves, cataracts, and streamlined bedrock remnants are present on the interior flanks and floors of the chasmata and indicate downstream convergence of flow from the equatorial basins towards the circum-Chryse outflow channels of Tiu and Simud Valles [1, 5, 6] (Fig. 1). Here, we establish specific topographic and chronologic constraints between the timing of basin formation, outflow activity, and deposition of interior layered deposits (ILDs) that directly indicate the presence of km-deep lakes in the basins east of Valles Marineris. We demonstrate that flood incision, formation of the chasmata, and basin linkage was controlled by both overspilling of lake water and the relative base level of initially independent basins. Our data not only provide constraints for the timing of lake development and outflow activity in the Valles Marineris region but for a mechanism that established one of the largest flow routing systems on Mars.

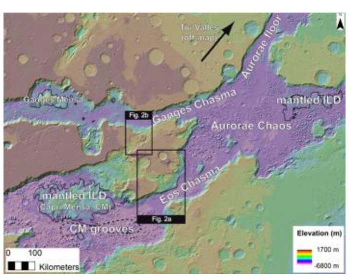

Figure 1: HRSC DTM of the chaos basins east of Valles Marineris.

Methods: Using new HRSC topography data and high-resolution CTX imagery, we mapped all outflow channels associated with the basins east of Valles Marineris at 1:10,000 scale (Fig. 1). The four major outflow channels that emerge from Capri Chasma and Eos Chaos are labeled as flood surfaces A (Daga Vallis), B (Eos Chasma), C (Columbia Valles), and D (southern Eos Chasma; Fig. 2). Impact crater statistics (D > 100 m) were obtained from each flood surface (area of D is insufficient for crater counts) to estimate relative timing of flood resurfacing. Crater statistics were also obtained for the uniquely preserved mantled cap of Capri Mensa, an associated ILD [7, 8] (Fig. 1). Finally, crater statistics from the highly disrupted basin floors of Eos and Aurorae Chaos provided constraints on the relative age of basin floor formation.

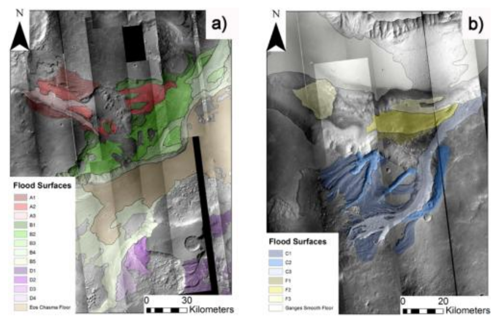

Figure 2: CTX mosaics with mapped flood surfaces for the Eos-Capri system. Each channel contains a series of topographically lower flood surfaces.

Results: Each channel in the Eos-Capri system exhibits topographically distinct terraced, grooved surfaces that were identified by cross-cutting relationships (e.g., A1, A2, and A3). The topographically highest grooved terrains emerge from different locations along the northern and eastern boundaries of Capri and Eos but at a remarkably similar elevation of ~1000 m (Fig. 1, 2). Our topographic analysis refines previous observations from MOLA data [2] and is entirely consistent with overspill from an equipotential lake surface [1, 2]. High resolution impact crater statistics for all channels associated with the Eos-Capri system indicate a statistically identical resurfacing event in the late Hesperian at 3.0 Ga +0.05/-0.06 (average error). This suggests the possibility that the floods, having originated from vastly different locations along the basin rim, were simultaneous. Time synchronous flooding from Capri Chasma (surface A) and Eos Chaos (surface B) is also obvious using the high resolution context provided by combining CTX imagery with HRSC topography. Flood grooves on topographically higher surfaces of surface A are cross-cut by flood grooves of surface B. However, lower grooved surfaces of surface A are also cross-cut by the highest surface B flood grooves. This indicates that north-eastward directed flow out of Eos

Chaos occurred both before and after the south-eastward directed flow from Capri was completed and is consistent with simultaneous lake spillover onto the adjacent highlands.

By comparison to the age of flood resurfacing, the mantled surface of Capri Mensa provides a late Hesperian crater retention age of 3.1 Ga +0.09/-0.13. Hence, layered materials of the ~4-km-tall ILD mound were likely already present while water catastrophically drained across the highlands from the Eos and Capri system. Finally, our crater analysis of the floors of Ganges, Eos, and Aurorae (acquired from craters > 700 m), indicate an average middle Hesperian model age of ~ 3.4 Ga, similar to the general Hesperian age of the chaos basins provided by [10]. The age estimate for formation of the chaos floors at their current depth is robust as it is unlikely that > 700-m-diameter craters would have survived kilometers of subsidence and terrain disruption. Together, the data indicate that formation of km-deep basins and km-tall ILD mounds predated complete flood incision of the adjacent highland terrain. This conclusion requires that the outflow channels formed by spillover of km-deep lakes.

Discussion and Conclusion: Our new topographic, chronologic, and morphologic data demonstrate that the Eos-Capri flood systems were created by lake spillover during which the highland terrain between adjacent basins was vertically incised to create through-going routing systems. We propose that the level of flood incision was controlled by both the base level of the adjoining downstream basin and the elevation of the draining source lake surface. For example, the topographically highest grooved surface of surface B (B1) is perched ~4-km above the floor of Eos Chasma at an elevation of ~500 m (Fig 2a). Progressive incision is indicated by topographically lower terraces in Eos Chasma. Protruding through a smooth unit on the floor of Eos Chasma, surface B5 is the topographically lowest flood grooved terrain that emerges from the Eos system into Aurorae Chaos. The longitudinal grooves on B5 occur at the same elevation as the current floor of southern Aurorae Chaos (~ - 4100 m). This requires that floods that carved surface B incised to this final elevation because the floor of Aurorae Chaos was already at this level. The mechanism of incision of surface B is demonstrated by a broad, 200 - 500 m tall knickpoint on B5. We propose that vertical incision of the inter-highland terrain between Eos Chaos and Aurorae Chaos occurred by knickpoint retreat, the result of a major topographic discontinuity between the elevation of the Eos lake and the floor/lake surface of Aurorae Chaos.

Our observations provide a plausible mechanism for linking massive equatorial lake systems in the eastern Valles Marineris region to the larger circum-Chryse outflow system. Our chronology data suggest that formation of the Eos-Capri basins pre-dated flooding and ILD deposition. We therefore envision a series of pre-existing, structurally isolated km-deep lake systems that became connected only during catastrophic lake spillover. In the case of Eos and Capri, a base level difference was required between the Eos-Capri lake and the floor/lake surface of Aurorae Chaos before lake spillover could have caused significant vertical incision and linkage of the systems. We suggest a possible base level scenario whereby the draining equipotential surface of a lake within the Eos-Capri basin was at a higher level relative to a lake within Aurorae. Alternatively, Aurorae Chaos may have been completely dry and at its current depth once overspill from Eos occurred. In either case, in order for the topographically lowest flood surface of Eos Chasma (B5) to have formed at its current elevation by fluvial erosion, the basin floor of southern Aurorae Chaos must have been nearly completely empty of water.

Importantly, the northern outlet of Aurorae Chaos also contains a series of grooved flood surfaces that empty into Tiu and Simud Valles, indicating that at some time water passed through the Aurorae basin into the circum-Chryse region. We therefore suggest two possible scenarios for linking all chaos basins of the eastern Valles Marineris region by lake spillover to the circum-Chryse region. (1) Release and spill model - Complete vertical incision of the outflow channels from the Eos-Capri system was triggered by downstream drainage of Aurorae Chaos to the north, and (2) Fill and spill model - Overtopping of the Eos-Capri lake into Aurorae Chaos led to fill and subsequent overtopping of Aurorae Chaos into the circum-Chryse region. Both scenarios provide a mechanism for ultimately connecting a massive surface equatorial water reservoir (10^5 km^3 – 10^6 km^3) to the northern plains of Mars.

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