CATASTROPHIC LAKE BREACH FLOODS AND THE EARLY MARS LANDSCAPE. T. A. Goudge[1,2], A. M. Morgan[3,4], G. Stucky de Quay[1,5], and C. I. Fassett[6], [1]Dept. of Geological Sciences & Center for Planetary Systems Habitability, The University of Texas at Austin, Austin, TX; [2]CIFAR Azrieli Global Scholars Program, Toronto, Ontario; [3]Planetary Science Institute, Tucson, AZ; [4]Center for Earth and Planetary Sciences, National Air and Space Museum, Smithsonian Institution, Washington, DC; [5]Dept. of Earth and Planetary Sciences, Harvard University, Cambridge, MA; [6]NASA Marshall Space Flight Center, Huntsville, AL. (Contact: tgoudge@jsg.utexas.edu)

Introduction: Large lakes [*1-3*] and branching fluvial valley systems [*4-6*] formed on Mars in its early history (**Fig. 1**). The majority of paleolake basins from this valley network-forming era filled with water to the point of breaching, leading to the incision of outlet canyons [*1,3*]. These outlet canyons are interpreted to have formed rapidly due to high-discharge, catastrophic lake breach floods that had locally important effects on fluvial systems [*7-10*]. Paleolake outlets also represent some of the largest individual valleys incised during this era of early martian history [*7-9*].

However, at the global scale, it is often assumed paleolake outlet canyons are of local importance only, with most valley incision occurring over long periods of time as a part of a distributed hydrological cycle [*4-6,11-14*]. In this view, valley networks are implicitly treated as playing the same geomorphic role as terrestrial river networks. Here we test the assumption that paleolake outlet canyons are not globally important landforms by assessing the net contribution of lake breach flood erosion to valley incision on early Mars.

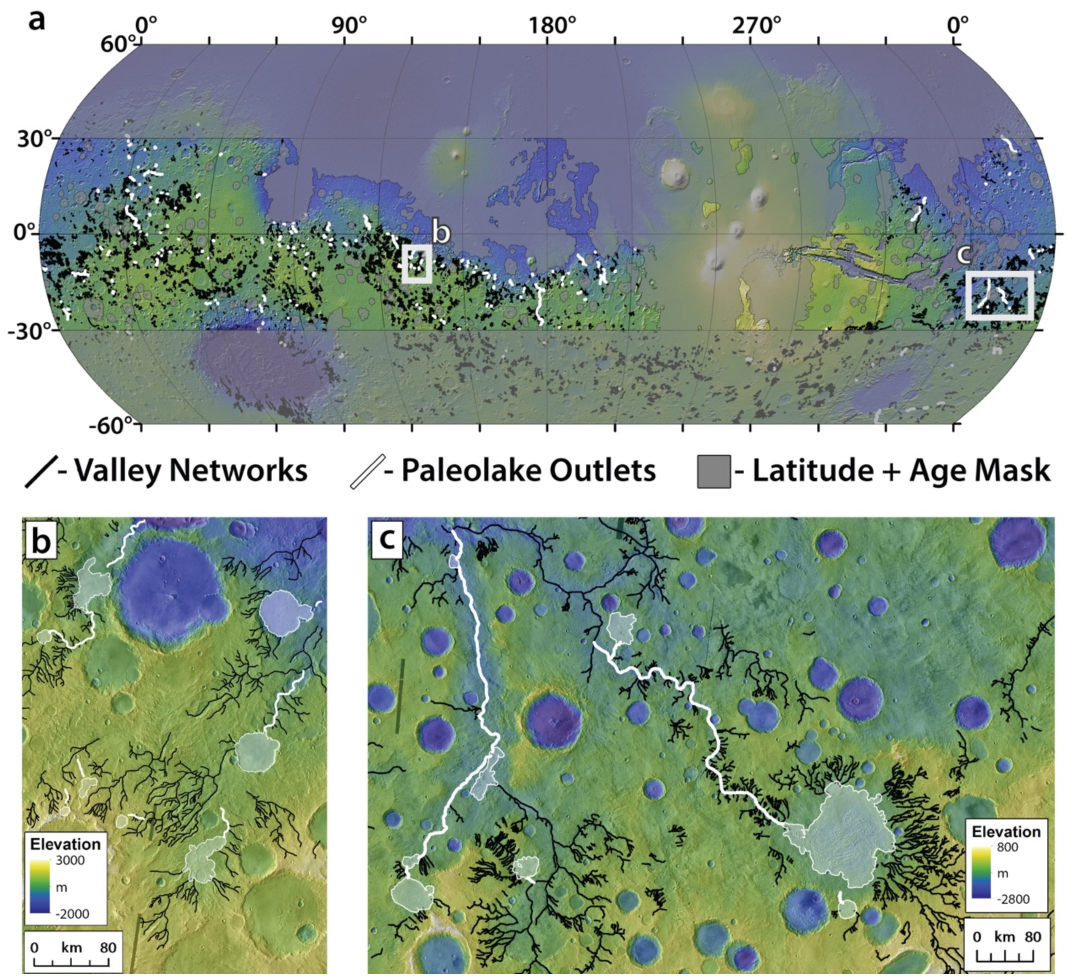

Fig. 1. (a) *Global distribution of analyzed valley networks (black) and paleolake outlet canyons (white). A mask of latitude (poleward of ±30°) and terrain age (younger than Early Hesperian) is shown in shaded grey. Boxes indicate locations of parts b and c.* **(b,c)** *Examples of the early Mars landscape dissected by both valley networks (black) and paleolake outlet canyons (white). Paleolake basin extents shown by semi-transparent white polygons. MOLA [23] overlain on THEMIS daytime IR mosaic [31,32].*

Methods: We used previously compiled catalogs of breached paleolake basins [*3,15,16*] and valley networks [*6,17*], which we manually updated to remove valley segments where our mapping interpretations differed. We also applied a mask, removing valley segments poleward of ±30°, which may be affected by post-incision ice modification [*18,19*], and those incised into post-valley network era (younger than Early Hesperian [*5,6,20*]) terrain [*17*]. We then classified each valley segment that heads at a closed contour as a paleolake outlet canyon formed by lake breach flooding [*1,3,10*]. Each other segment was classified as a 'classic' branching valley network formed by processes of protracted surface flow (e.g., surface runoff [*5,6,12-14*], groundwater [*4,11,14*], sub-glacial melt [*14*], etc.) (**Fig. 1**). Finally, we used a progressive black top hat transformation [*21,22*] to calculate cumulative valley volumes based on MOLA topography [*23*].

Results: We find that paleolake outlet canyons have a total eroded volume of ~1.4 x 10^{13} m^3, compared to a volume of ~4.3 x 10^{13} m^3 for valley networks. Lake breach floods were thus responsible for at least 24% of valley erosion on early Mars (**Fig. 2**), despite representing only ~3% of total valley length. This length-volume discrepancy is explained by the fact that paleolake outlets are systematically deeper than valley networks (**Fig. 2**).

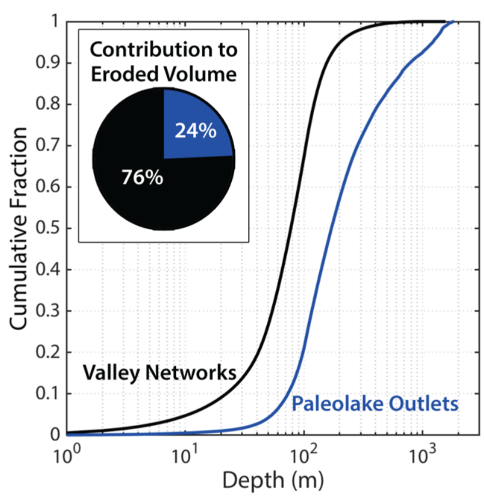

Fig. 2. *Cumulative distribution of depths for valley networks (black) and paleolake outlet canyons (blue). Inset shows the proportion of total valley erosion from early Mars (~5.7 x 10^{13} m^3) contributed from each class.*

Discussion and Implications: Our results indicate that that catastrophic lake breach flooding, and rapid outlet canyon incision, was an important geomorphic process that shaped the early martian landscape during the valley network-forming era. This conclusion leads to several interesting implications for our understanding of early Mars landscape evolution. First, lake breach flooding on Earth has been proposed as an important process in the initial stages of fluvial integration for a landscape of disconnected basins (e.g., basin and range topography) [*24-26*]. Early Mars had a similar topographic structure, with impact crater basins that interrupted topographic slopes at all scales [*3,27*]. Therefore, we suggest the preserved prominence of lake breach floods for valley incision on early Mars points to the general immaturity of the landscape, which was never able to fully integrate.

This conclusion is broadly consistent with much past work on martian fluvial immaturity [*4,5,11-13,27,28*], including commonly noted observations of convex longitudinal valley profiles [*5,11-13*]. Past workers have often interpreted this landscape immaturity, and in particular convex valley profiles, as the signature of a formative martian climate and hydrologic cycle that was unable to supply long-lived runoff [*11-13*]. Here we propose an alternative hypothesis related to the formation of paleolake outlet canyons, which are broadly integrated into many martian valley systems (**Fig. 1b,c**). As lakes breached and rapidly carved deep outlet canyons, valleys on the surrounding landscape would have experienced a drop in local base level, for which a common response is development of valley convexities or knickpoints [*29,30*]. Indeed, such a scenario is commonly observed on Mars, with hanging tributaries flowing into paleolake outlet canyons [*7,9*]. Paleolake outlet canyons, and their global significance, may thus represent both a newly identified signature of landscape immaturity, and an alternative explanation for that immaturity – regional base level perturbations, rather than solely a hydroclimate signature. Importantly, while paleolake outlets themselves may not preserve a paleoclimate signal, the requirement to fill the basins remains, suggesting watershed hydrology may provide better constraints on the early Mars climate[3,15,16].

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