FLUVIAL SILICICLASTIC DEPOSITION ON AN UNVEGETATED PLANET: THE IZOLA OUTCROP (MARS).

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Introduction: Orbital observation has revealed a rich record of fluvial landforms on Mars which demonstrate the former presence of liquid water [1-7], with much of this record dating 3.6–3.0 Ga. Despite widespread geomorphic evidence, few analyses of Mars' alluvial sedimentary-stratigraphic record exist, with detailed studies of alluvium largely limited to smaller sand-bodies amenable to study *in-situ* by rovers [8]. These typically metre-scale outcrop dimensions have prevented interpretation of larger scale channel-morphology and long-term basin evolution, important for understanding the past Martian climate. Here we give an interpretation of a far larger, 1500-m-wide, 190-m-thick sedimentary succession, Izola outcrop, identified from satellite imagery and located in the NW Hellas Basin [9]. These alluvial succession lies within the sedimentary unit of the intercrater plains, investigated by [10], that offer a well-preserved insight into the regional geological history of Mars.

The succession comprises stacked channel and barform packages which together demonstrate that river deposition was already well established >3.7 Ga. Models for siliciclastic deposition are largely based on sedimentary environments on Earth, where physical form and process is near ubiquitously influenced by biology in some way [9]. To help minimalize the influence of biology here, our interpretations of the sedimentary architecture at Hellas stem from tangible observations made from Earth's Precambrian (pre-vegetation) record. The deposits mirror partial terrestrial analogues subject to low-peak discharge variation, implying that river deposition at Hellas was subject to semi-perennial, or even perennial, fluvial flow.

Furthermore, conceptual advances in our understanding of how time is preserved at outcrop suggest active water-conduits may have been maintained for 10^5 years or longer. These results strongly suggest a precipitation-driven hydrological cycle was operational on Mars by the mid-Noachian.

Geological context: The northern part of the Hellas basin displays a topographically flat area, which was characterized during the Late Noachian by sedimentary deposition and later, in the Late Hesperian, by fissural volcanism [10]. Across most of the region, the sedimentary unit [10] rich in Fe/Mg-phyllosilicates covers the basement, is eroded into mesas and erosional windows and is perched by fresh craters, together enabling high resolution stratigraphic and architectural analysis. The Izola outcrop is located at 25.88°S and 54.29°E and faces almost N-S and belongs to the "sedimentary unit" [10].

Methodology: The outcrop has been imaged by HiRISE stereo pairs. Both images have 25.6 cm/pixel resolution so objects down to 77 cm can be resolved. A digital terrain model (DTM) was produced from the HiRISE images ESP_055357_1540 and PSP_003799_1540 using the USGS Integrated Software for Imagers and Spectrometers (ISIS) software and the BAE photogrammetric package SOCET SET according to a previously used methodology [11]. The acquired HiRISE DTM of the Hellas outcrop was of sufficient resolution to enable accurate tracing of beds and plotting of architectural elements. Channels thicknesses were obtained measuring the exact elevation of the channel top and the exact elevation of the channel base using ArcMap 10.6 elevation tools. Channel widths were measured by tracing an edge-to-edge topographic channel profile using the HiRISE DTM. This allowed calculation of true thickness, given that they are bound by almost flat lying, laterally extensive bounding surfaces.

Architectural analysis: Line drawings were only attempted at areas where stratigraphy is clearly visible. Outcrop orientation with respect to paleoflow is not known, so no architectural elements with distinct directional components (e.g., downstream accretion, lateral accretion) were assigned. Sediment grain size is also unknown, thereby prohibiting the distinction between active and abandoned channel-fill deposits. The completed architectural panel enabled the various sediment stacking patterns and lateral relationships to be assessed. Zeroth, first and second order surfaces relate to foreset, set and coset boundaries, respectively, and are not observable from HiRISE imagery. Third- and fourth-order surfaces indicate the presence of macroforms (e.g., a barform deposit) or a channel. Fourth-order surfaces represent the upper and lower boundaries of the macroform or channel, whereas third-order surfaces relate to internal growth increments (indicating flow fluctuation, but no significant changes in predominant fluvial style). Bounding surfaces bind major depositional packages (channel belts).

The sedimentary succession. The outcrop exposes layered sedimentary strata, which display a variety of large-scale stratal architectures consistent with an alluvial interpretation. The outcrop appears to have undergone little post- depositional deformation, has a gentle dip and large-dimensions, so is suitable for the analysis of sedimentary architecture. In the observed stratigraphy, packages bound by lower erosional, channel-shaped (fourth order) surfaces and truncated by flat, erosional (fourth and fifth order) surfaces are attributed to channel-fill deposition. They are 5–15m thick, with observable lateral extents of up to 210m. Internally, packages appear succession-dominated [12], comprising multiple aggrading (third order) surfaces. Final channel banks and former channel margins coalesce, indicating that the original channels laterally migrated. Some channelized packages have a distinct channel wing, which may archive a genetically associated levee or crevasse and thus strengthen the alluvial interpretation. Areas containing clusters of channels are bottomed and topped by laterally extensive (up to 640 m), low relief, fifth-order surfaces, which suggest a change in the type or location of the dominant depositional process. These surfaces probably reflect channel avulsion, in which the location of the active channel changes abruptly. Well preserved barforms and channels implies that the depositing Izola rivers were also characterized by low-peak discharge variability. Episodic flooding events may not have been responsible for deposition, but rather long-term, potentially perennial fluvial flow. Nevertheless, without *in-situ* validation of fluvial deposition, other alternative possibilities such as aeolian deposition and deposition within submarine channels have been considered but deemed less plausible.

Martian vs Terrestrial sedimentary record. The preserved channel-belt architecture, comprising relatively intact channels and barforms, suggests some degree of original channel-belt stability, with naturally shear-resistant sediment such as mud a possible candidate [13,14]. Nevertheless, comparisons between the terrestrial and Martian sedimentary record require careful consideration before application, especially when considering the preservation of alluvial mud on an unvegetated planet and its astrobiological implications. On Earth, chemical weathering and vegetation promote mud production and retention, resulting in an upsurge in mudstone abundance within alluvial stratigraphy in stratigraphic alignment with evolving land plants[15]. Before this time, terrestrial alluvium is predominantly sand-grade or coarser with few preserved muddy floodplain facies [16]. Evidence of relatively stable, deep-channelled drainage on pre-vegetation Earth is being increasingly reported [17], findings which are helping to dispel notions that pre-vegetation rivers were ubiquitously wide and shallow [18], an observation that can now be extended to Mars.

Conclusions. The outcrop comprises at least four possible channel belts and discrete packages of strata bound by laterally extensive (fifth order) surfaces. The architectural interpretation of this so far unique sedimentary succession feeds into ongoing debates about the early Martian climate. Our interpretation of long-lived, deep, perennial or semi-perennial rivers necessitates a climate in which active water-conduits were maintained for 10^5 years or longer. For the first time, orbital data has allowed us to examine, through detailed high-resolution architectural analysis, a large (1500 m by 190 m) pre-late Noachian outcrop, and draw reliable paleoenvironmental interpretations based on sedimentary-stratigraphic evidence. Our observations and analysis favour steady water discharges that are most consistent with a precipitation-driven hydrological cycle.

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References: [1] Carr, M. H. JGR Planets 100, 7479–7507 (1995). [2] Davis, J. M., Balme, M., Grindrod, P. M., Williams, R. M. E. & Gupta, S. Geology 44, 847–850 (2016). [3] Di Achille, G. & Hynek, B. M. Nat. Geosci. 3, 459–463 (2010). [4]. Howard, A. D., Moore, J. M. & Irwin III, R. P. JGR Planets 110, E12S15 (2005). [5] Malin, M. C. & Edgett, K. S. Science 302, 1931–1934 (2003). [6] Mangold, N., Quantin, C., Ansan, V., Delacourt, C. & Allemand, P. Science 305, 78–81 (2004). [7] Salese, F., Pondrelli, M., Neeseman, A., Schmidt, G. & Ori, G. G. JGR Planets 124, 374–395 (2019). [8] Edgar, L. A., Gupta, S., Rubin, D. M., Lewis, K. W., Kocurek, G. A., Anderson, R. B., ... & Williams, A. J. (2018). Sedimentology, 65(1), 96-122. [9] Salese, F., McMahon, W. J., Balme, M. R., Ansan, V., Davis, J. M., & Kleinhans, M. G. (2020). Nature communications, 11(1), 1-8. [10] Salese, F., Ansan, V., Mangold, N., Carter, J., Ody, A., Poulet, F., & Ori, G. G. (2016). JGR Planets, 121(11), 2239-2267. [11] Kirk, R. L. et al. JGR Planets 113, EO0A24 (2008). [12] Gibling, M. R., J. Sediment. Res. 76, 731–770 (2006). [13] Lapôtre, M. G. A., Ielpi, A., Lamb, M. P., Williams, R. M. E. & Knoll, A. H. JGR Earth Surf. 124, 2757–2777 (2019). [14] Matsubara, Y. et al. Geomorphology 240, 102–120 (2015). [15] McMahon, W. J. & Davies, N. S. Science 359, 1022–1024 (2018). [16] Gibling, M. R. & Davies, N. S. Nat. Geosci. 5, 99–105 (2012). [17] Ielpi, A., Ventra, D. & Ghinassi, M. Precambrian Res. 281, 291–311 (2016). [18] McMahon, W. J. & Davies, N. S. Scottish J. Geol. 55, 73–74 (2019).