MER *Opportunity* at Perseverance Valley: Evaluation of Multiple Working Hypotheses for Valley Formation

R. Sullivan[1], R. Arvidson[2], L. Crumpler[3], M. Golombek[4], J. Grant[5], K. Herkenhoff[6], M. Hughes[2], M. Lamb[7], D. Mittlefehldt[8], C. Schröder[9], and the Athena Science Team

[1]Cornell University, Ithaca, NY, USA, rjs33@cornell.edu, [2]Washington University in St. Louis, St. Louis, MO, USA, [3]New Mexico Museum of Natural History & Science, Albuquerque, NM, USA, [4]JPL, Pasadena, CA, USA, [5]Smithsonian Institution, NASM CEPS, Washington, DC, USA, [6]USGS, Flagstaff, AZ, USA, [7]California Institute of Technology, Pasadena, CA, USA, [8]NASA/JSC, Houston, TX, USA, [9]University of Stirling, Stirling, UK.

1. Introduction

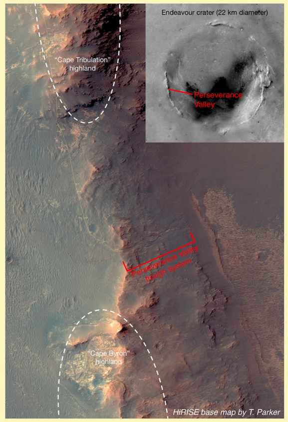
MER *Opportunity* explored Perseverance Valley, a feature identified from orbit as potentially carved by downslope fluid flow, until a major dust storm ended communications with the rover 6/10/18.

Perseverance Valley originates at a low area between two higher-standing degraded rim segments of the Noachian-age, 22 km-diameter Endeavour crater [1-3]. The trough system extends downslope toward the crater interior along a ~17° gradient for ~180 m, spanning 10-20 m [4].

From orbit, individual troughs within the system are low-albedo features tracing patterns that resemble low-gradient, anastomosing fluvial systems on Earth [4-5].

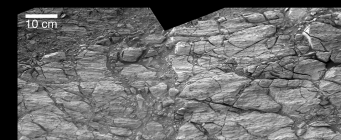
An important working hypothesis for Perseverance Valley, suggested by its orbital appearance and location, is that the trough system was carved by spillover from a body of water perched on the plains to the west, emptying eastward down into the crater [4-6].

The MER team has been considering multiple working hypotheses for valley origins, including possible contributions from dry mass-wasting, aqueous flow in various forms (including debris flows), periglacial processes, faulting/fracturing, and aeolian processes.

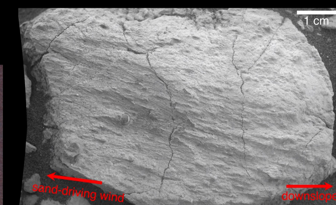


2. Rover Observations at Perseverance Valley

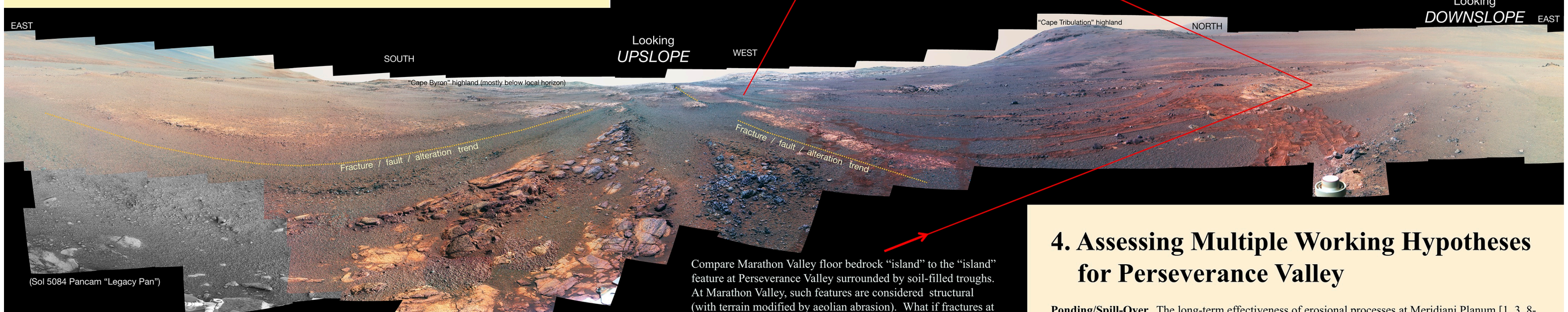
(1) Potential fluvial traces seen from orbit actually are nearly flat lanes of soil with little relief, lying only centimeters below abutting outcrop margins.
(2) Rock weathering by fracturing, possibly due to thermal cycle stresses, is pervasive.
(3) Outcrops and isolated rocks within the trough system exhibit only low relief, generally <20 cm, and in many cases display surface textures of aeolian abrasion from sand blowing uphill out of the crater, rather than textures indicating fluid flow downslope.
(4) From orbit, bright features resembling streamlined "islands" within the trough system are revealed at outcrop scale to have margins commonly defined by straight segments, suggesting influence by fracture and/or faulting.
(5) Instances of contrasting color and/or morphology between adjacent rock units along linear trends suggest structural displacements along fault offsets.
(6) In other places narrow lanes of soil separate linear arrays of rock and rubble that contrast in color and/or texture.



Wind abrasion texture and pervasive rock fracturing-in-place. (Sol4888 Pancam L1)



Aeolian abrasion (etching, and rock tails where internal hardness contrasts exist) is very common. Sand-driving winds have blown upslope. (Sol4900 MI "Mesilla")



(Sol 5084 Pancam "Legacy Pan")

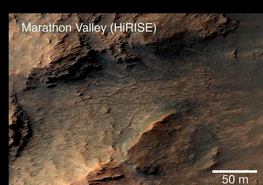
Compare Marathon Valley floor bedrock "island" to the "island" feature at Perseverance Valley surrounded by soil-filled troughs. At Marathon Valley, such features are considered structural (with terrain modified by aeolian abrasion). What if fractures at Perseverance Valley were to reactivate from time to time in an environment of aeolian abrasion?

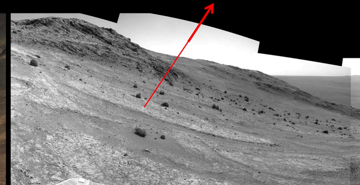
3. Analogs from Marathon Valley

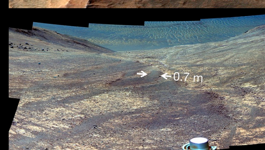
Marathon Valley, another relatively low area of the Endeavour crater rim explored by the rover [18-20], has features informing comparisons with Perseverance Valley, but in a setting with much less regolith cover.

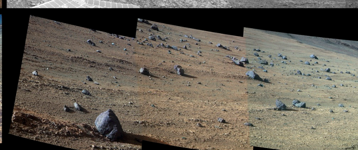
Much of the floor of upper Marathon Valley displays complex fracture patterns in which irregular polygons of bedrock are separated by narrow lanes of soil-filled fractures. Despite the complex structural history implied by these bedrock patterns (likely related to the Endeavour impact and post-impact structural adjustments), overall surface relief is minimal, having been planed-off by aeolian abrasion after any residual vertical movements along fractures had ceased. (Lowering of ground level by aeolian abrasion is also indicated by rock tails extending upslope behind ventifacted boulders that have rolled out on to the valley floor.)

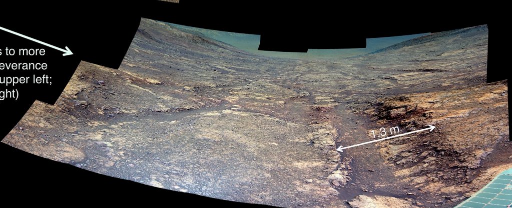
Bedrock polygons on the floor of Marathon Valley bounded by partly soil-filled fractures closely resemble "island" bedrock polygons within the trough system at Perseverance Valley, but are structural, not obviously water-carved or related to spill-over geometries upslope. Larger troughs at lower Marathon Valley [7] with abrupt upslope terminations might have morphological analogs at Perseverance Valley that are partly regolith-filled.




Marathon Valley floor (Navcam sol 4132-4138)




Marathon Valley floor Boulders with rock tails indicating valley floor lowered by aeolian abrasion (sand driven upslope out of the crater) (Pancam sol 4092)



Marathon Valley floor troughs of unknown origin, possibly analogous to more soil-filled features at Perseverance Valley (Pancam sol 4424 upper left; Pancam sol 4461 lower right)

4. Assessing Multiple Working Hypotheses for Perseverance Valley

Ponding/Spill-Over. The long-term effectiveness of erosional processes at Meridiani Planum [1, 3, 8-10] makes it unlikely that the Perseverance trough system represents a low-relief, Noachian-age surface feature still surviving on its original, high-gradient surface that was never lowered by erosion, nor buried by erosional debris from upslope. This has implications for the lake-spillover hypothesis, placing any such ponding/spill-over event *after* the completion of most weathering, such as rim lowering, crater infilling, gradient adjustments, and final pediment formation. However, relatively late-stage ponding should have left corresponding geomorphic evidence for more widespread surface fluid activity in the Endeavour region, but this is not observed. Detailed topographic analysis reveals the western rim dips *away* from the presumed spill-over location, arguing against the presence of a perched catchment. The possibility of a more suitable gradient for an ancient catchment before compaction of the embaying Burns formation rocks is not supported by modeling of sediment compaction dynamics [11]. These timing and catchment problems pose as-yet unsolved problems for the ponding/spill-over hypothesis.

Fracture/Faulting with Aeolian Abrasion. Along with dry mass-wasting and other erosional processes, another concept under consideration interprets the Perseverance Valley trough system as a complex fracture/fault zone [9, 12-13] that also served as a conduit for ancient groundwater flow. In this concept, compositional changes along fracture/fault planes from ancient groundwater interactions resulted much later in shallow troughs at the surface due to altered material weathering out more readily [12]. Additionally, occasional reactivations along the fracture/fault planes since the Noachian might have periodically renewed relief along fault traces against ongoing aeolian abrasion; this possibility is consistent with locations elsewhere along the rover's long traverse where minor fault/fracture activation has occurred on timescales comparable with aeolian abrasion and ripple migration [9, 14]. However, any fracture/faulting concepts are challenged to explain the location of Perseverance Valley subjacent to a low area along Endeavour's rim. One suggestion under evaluation is that this low area between higher rim segments to either side could be a logical place for stress-adjusting fault reactivations to be focused, in response to the higher rim segments on either side gradually unloading mass at different rates, at different times, over a long erosional history [9].

Acknowledgements. This work was supported by the MER Project. The exploration of Perseverance Valley, so far from Opportunity's landing site, was enabled by brilliant engineering during MER hardware and software development many years ago to produce such durable vehicles, and subsequently by 14 years of engineering support dedicated to enable science activities such as those reported here.

References. [1] Hynek, B. (2002) *J. Geophys. Res.*, *107*, E10, 5088. [2] Arvidson, R. (2014) *Science*, *343*, 1248097. [3] Grant J. et al. (2016) *Icarus*, *280*, 22-36. [4] Parker, T. et al. (2017) *LPSC48*, Abstract #2468. [5] Squyres, S. et al. (2018) *LPSC49*, Abstract #1758. [6] Parker, T. and Golombek, M. (2018) *LPSC49*, Abstract #2623. [7] Fraeman, A. (2017) *LPSC48*, Abstract #2196. [8] Hughes, M. et al. (2018) *LPSC49*, Abstract #1563. [9] Sullivan, R. et al. (2018) *LPSC49*, Abstract #2516. [10] Hughes, M. et al. (2019) *JGR*, submitted. [11] Hughes, M. et al. (2018) *Geol. Soc. Ann. Mtg.*, Abstract 138-12. [12] Crumpler, L. et al. (2018) *LPSC49*, Abstract #2205. [13] Crumpler, L. et al. (2019) *this meeting*. [14] Golombek M. et al. (2010) *J. Geophys. Res.*, *115*, E00F08.