MER OPPORTUNITY AT PERSEVERANCE VALLEY: EVALUATION OF MULTIPLE WORKING HYPOTHESES FOR VALLEY FORMATION.

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Introduction to Perseverance Valley: A fundamental science goal of the Mars Exploration Rover (MER) mission has been investigation of the role of water in the martian past, including the evaluation of potentially habitable ancient environments [1,2]. For this purpose the MER Opportunity has been exploring Perseverance Valley, a feature identified from orbit as potentially carved by downslope fluid flow. The rover has traversed ~40% down the valley and was conducting imaging and composition measurements before communication was lost on 6/10/18 during a major dust storm.

The setting for Perseverance Valley is 22 km-diameter Endeavour crater. This Noachian age [3, 4] impact structure has been heavily modified so that only portions of the original rim remain. Erosion has lowered the surviving rim segments, which are embayed by younger sedimentary units (e.g., Burns formation sulfate-enriched sandstones) that surround and bury most of the original impact structure and fill much of the crater interior [5, 6]. Perseverance Valley originates at a low area along Endeavour's western rim, between two rim segments of more rugged, higher-standing relief ("Cape Tribulation" and "Cape Byron"). From this location the trough system extends downslope toward the crater interior along a ~17° gradient for ~180 m, spanning 10-20 m. Viewed from orbit, individual troughs within the system are low-albedo features tracing patterns that resemble low-gradient, anastomosing fluvial systems on Earth. The trough system terminates well before reaching the crater floor. Basal deposits that would be consistent with deposition from flow through the trough system are absent.

The Noachian age and degradational state of Endeavour crater raise possibilities of multiple processes influencing the morphology of Perseverance Valley over a long history [e.g., 5-8]. The MER team has been considering multiple working hypotheses, including potential contributions from dry mass-wasting, aqueous flow in various forms (including debris flows), periglacial processes, faulting/fracturing, and aeolian processes [9-14].

MER Opportunity Exploration. An important working hypothesis for Perseverance Valley, suggested originally 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 [9-10, 13]. Accordingly, the rover first explored the plateau adjacent to Perseverance Valley for evidence consistent with ponding and/or flow toward the slope brink at the head of the Perseverance trough system. Gentle, very low-relief scarps on the plateau adjacent to Perseverance Valley did not display diagnostic fluvial or shoreline sedimentary structures or textures, but observations were incomplete when the changing season compelled moving the rover from the plateau over the brink into the sloping trough system for more favorable sun angles to sustain operational power levels.

In comparison with orbital assessments, rover-based observations [10-16] include: (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) Outcrops and isolated rocks within the trough system exhibit 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. (3) Rock weathering by fracturing in place, possibly due to thermal cycle stresses, is pervasive. (5) 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. (6) Instances of contrasting color and/or morphology between adjacent rock units along linear trends suggest structural displacements along fault offsets. (7) In other places narrow lanes of soil separate linear arrays of rock and rubble that contrast in color and/or texture.

Evaluation of Multiple Working Hypotheses. The degraded Endeavour rim displays a continuum of erosional morphologies from a variety of potential processes, yet characteristics of Perseverance Valley (e.g., complex trough patterns) make this feature distinctive along the Endeavour rim, and this poses important challenges for any proposed origin [12].

Evaluation of multiple working hypotheses at Perseverance Valley is informed by observations and analyses from earlier in Opportunity's mission. Erosional surface textures from abrasion by saltating sand are common at Meridiani Planum. Aeolian abrasion erodes down ejecta blocks of recent impact craters flush with the surface on timescales comparable with megaripple migration (50-200 ka) [17]. This erosional effectiveness implies that the low-relief Perseverance Valley trough system is prominent from orbit because it formed relatively late in martian history, or that if originally much older, some process is renewing its surface relief.

Marathon Valley, another relatively low area of the Endeavour crater rim explored by the rover [18-20], has features informing comparisons with Perseverance Valley in a setting with hardly any obscuring 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. Evidence for lowering of ground level by aeolian abrasion is provided by rock tails extending upslope behind ventifacted boulders that have rolled out on to the valley floor.

The long-term effectiveness of erosional processes at Meridiani Planum 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, such later-stage ponding/spill-over timing is difficult to reconcile with the rarity of the Perseverance trough system at Endeavour: Ponding requires a water supply and collection mechanism much larger in areal extent than the resulting surface reservoir (e.g., regional precipitation and collection by runoff, with or without the development of a substantial groundwater table). Relatively late-stage ponding should have left corresponding geomorphic evidence for widespread surface fluid runoff in the Endeavour region, but this is not observed. Furthermore, 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 an ancient catchment before compaction of the embaying Burns formation rocks is not supported by modeling of sediment compaction dynamics [21].

Conclusions. Timing and catchment problems pose as-yet unsolved challenges to the ponding/spill-over hypothesis. Along with alternatives involving dry mass-wasting and other erosional processes, another concept under consideration interprets the Perseverance Valley trough system as a complex fracture/fault zone that served as a conduit for groundwater flow. In this concept, compositional changes along fracture/fault planes from groundwater interactions resulted much later in shallow troughs at the surface when the altered material weathers out [14]. Alternatively, reactivations along the fracture/fault planes since the Noachian renew relief against ongoing aeolian abrasion; examples of minor fault/fracture activation occurring on relatively recent timescales comparable with aeolian abrasion and ripple migration have been observed elsewhere along the rover’s long traverse [12]. 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 a low area between higher rim segments to either side could be a logical place for stress-adjusting fault reactivations to be focused as a response to the higher rim segments on either side unloading mass at different rates over a long erosional history [12].

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