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IN SITU MAPPING OF THE STRUCTURAL AND STRATIGRAPHIC COMPLEXITIES OF ENDEAVOUR CRATER'S RIM.

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Introduction. Large, complex-type impact craters with preserved uplifted topographic rims are not available for field study on Earth. A 15 km field geologic reconnaissance traverse along the rim of the 22 km-diameter Endeavour crater by the *Opportunity* rover has provided our first look at bedrock structure and stratigraphy of a large impact crater on Mars. Endeavour is of Noachian age and thus provides exposures of crust modified during an early, presumably wet period of Martian history. Two notable characteristics are discussed in the following: (1) the crater rim is divided into topographically and structurally distinct blocks or segments separated by vertical fractures and faults; and (2) the pre-impact substrate is antiformally deformed at the rim with the attitudes of sheets, foliations, and contacts between rim breccias and pre-impact substrates dipping inward toward the center of the crater on one side of the hinge line and outward on the other.

In Situ Study of Crater Rim. Structural and stratigraphic mapping at Endeavour crater is possible because it is at an intermediate stage erosion [1; 2] in which bedrock outcrops of the topographic crater rim are exposed, but the otherwise continuous cover of unconsolidated debris associated with a youthful impact crater is removed. This is information that is unavailable on the deeply eroded and graded examples of complex craters on Earth [3; 4].

Segmented Character of Crater Rim. The exposed rim of Endeavour crater consists of topographic segments between 200 m and 300 m wide, varying in relief from a few tens of meters to 150 m above the surrounding plains of Meridiani Planum [5]. The segmentation arises from these discontinuities in relief and terrain morphology along the rim. Abrupt along-strike termination of outcrops, right- and left-stepping offsets of local topographic rim crests, and changes in strike and dip of local slabs and foliations were mapped at the transitions between these segments on Cape Tribulation. The transitions are coincident with changes in outcrop lithology identified using petrography from Microscopic Images, and from differences in outcrop texture and fabric in Pancam and Navcam scenes. Exposures at the upper end of

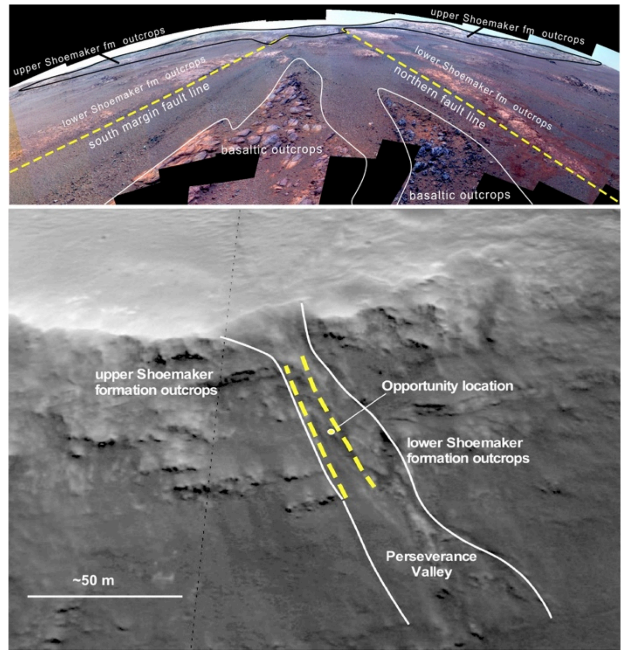

Figure 1. *Upper diagram: View up slope within Perseverance Valley from Opportunity's current position. Linear discontinuities in lithology at outcrop margins are coincident along-strike suggesting valley shape and location is influenced by bedrock structure. Part of sol 5120 Pancam L257 panorama. Lower diagram: Trace on oblique perspective MRO/HiRISE image of faults identified above. White lines show the morphologic margins of Perseverance Valley.*

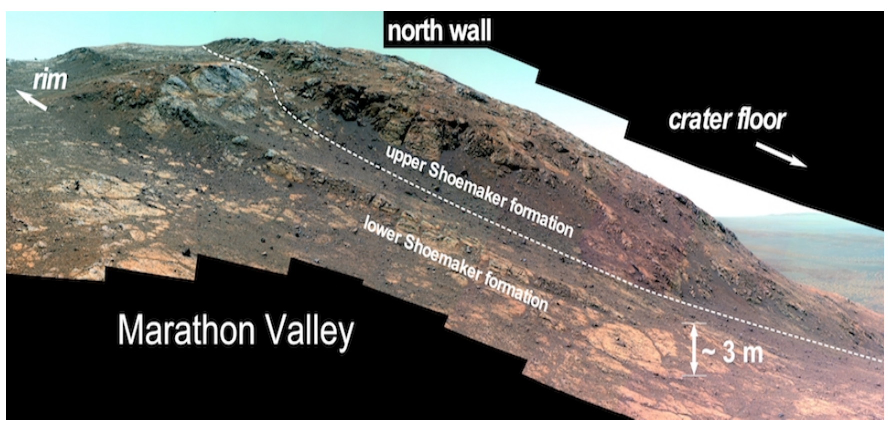

Figure 2. *The contact between upper Shoemaker fm (Endeavour ejecta) and lower Shoemaker fm (pre-impact substrate) as viewed in outcrop on the north wall of Marathon Valley. The images were taken on Sols 4446-4453 using Pancam's 753, 535, and 432 nm filters.*

Perseverance Valley are an example. Here linear contacts between bedrock outcrops of different lithology and pervasive parallel linear fabrics in outcrop are coincident with the linear trough of the valley floor [6] (**Fig. 1**), and associated zones of alteration [7].

Transverse Rim-cutting Faults. Based on these results we propose that the divisions between rim segments are vertical fracture zones and faults with significant throw and likely the results of scissor faults separating blocks that experienced differing magnitudes of uplift during crater formation [6]. Differential uplift is consistent with accommodation of the upward and radial compression of the upper crust during crater formation by a series of discontinuous oblique thrust faults along discreet blocks. The relative motion between blocks would require accommodation by vertical dip, oblique slip faulting, a process noted in the rim of Meteor Crater [8] and other more deeply eroded craters [9].

We proposed that brecciation along these bounding deep crustal faults at the segment transitions results in vertical discontinuities bearing enhanced hydraulic conductivities and thus serve as pathways of fluid transport through crater rims [10]. Interaction with bedrock by fluids preferentially following fracture zones could account for the concentrated areas of aqueous alteration [11; 15] identified in outcrops in and near the segment transitional fracture zones.

Inward-dipping Deformation of Crater Rim. Observations along the rim of Endeavour crater show that the rim consists predominantly of coarse impact breccias (*upper Shoemaker formation*) overlying a pre-impact substrate that includes the *Matijevic formation* [11; 12] and *lower Shoemaker formation* breccias [7]. Mapping of the attitudes of the planar contact between the *upper and lower Shoemaker formation* and the attitudes of pervasive foliations in outcrops at several locations, including Marathon and Perseverance Valleys, shows that inboard of the crater rim units dip inward toward the crater interior (**Fig 2**). This is a somewhat unfamiliar larger-scale characteristic of complex impact craters here seen on Mars.

Inward dips are unanticipated but are not excluded by existing simple models of complex impact craters that otherwise assume monotonically outward-dipping structure. Deep monoclinal structures beneath the tectonic rims of deeply eroded terrestrial impact structures have been documented [9]. An initial working hypothesis for monoclinal inward-dips along the rim of Endeavour is uplift over blind thrust faults previously proposed [8; 9] as occurring at the time of crater formation. The uplift results in asymmetric antiform crustal deformation, along with drag folding of uplifted and ejecta-thickened rims during post-impact tectonic-scale slumping of the rim and walls after crater formation

Summary. Complex crater rim relief is thought to be a nearly equal combination of ejecta accumulation and bedrock uplift [1; 13; 14], an assessment for which observational tests have been limited. Measurements by *Opportunity* of the attitude of the contact *between upper Shoemaker formation* impact breccias and *lower Shoemaker formatio*n pre-Endeavour breccias show that the pre-impact surface and bedrock participated in the uplift via an antiformal deformation that underlies the final crater rim. A new model of complex crater rim structure is therefore emerging (**Fig. 3**) that gives context for understanding the state of erosion and structural influences on geological and geochemical characteristics observed at outcrops along the crater rim. Further observations of the timing and lateral extent are necessary to better understand the mechanism associated with this fundamental, but previously undocumented, deformation characteristic in the *topographic rims* of large impact craters.

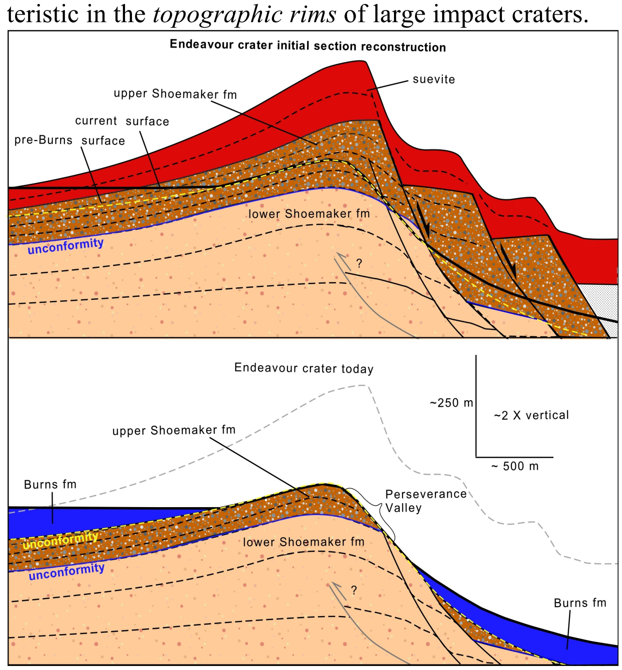

Figure 3. *Upper diagram: Interpreted pre-erosion reconstruction of the geologic section. Lower diagram: Geologic section through rim of Endeavour crater based on Opportunity observations of outcrop lithology, stratigraphy, and structure.*

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