OPPORTUNITY, GEOLOGIC AND STRUCTURAL CONTEXT OF AQUEOUS ALTERATION IN NOACHIAN OUTCROPS, MARATHON VALLEY AND RIM OF ENDEAVOUR CRATER. L. S. Crumpler[1], R. E. Arvidson[2], D. W. Mittlefehldt[3], B. L Jolliff[2], W. H. Farrand[5], V. Fox[2], M. P. Golombek[6], and the Athena Science Team, [1]New Mexico Museum of Natural History & Science, 1801 Mountain Rd NW Albuquerque, NM, 87104, USA, larry.crumpler@state.nm.us, [2]Dept. of Earth and Planetary Sciences, Washington University in Saint Louis, St. Louis, MO, [3]Astromaterials Research Office, NASA Johnson Space Center, Houston, TX, [5]Space Science Institute, Boulder, CO, [6]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

Introduction: In its 12th year of exploration and 1600 sols since arrival at the rim of the 22 km-diameter Noachian Endeavour impact crater, *Mars Exploration Rover Opportunity* traversed from the summit of the western rim segment "*Cape Tribulation*" to "*Marathon Valley*", a shallow trough dissecting the rim and the site of strong orbital detection of smectites [*1,2*] (**Fig. 1**). In situ analysis of the exposures within *Marathon Valley* is establishing some of the geologic and geochemical controls on the aqueous alteration responsible for smectite detection known to occur in crater rims [*3,4*] throughout Noachian terrains of Mars.

In Situ Geology of Rim: Outcrop ("bedrock") exposures along the rim west of the topographic crest are discontinuously covered with regolith, slope debris, and aeolian deposits, but are sufficiently exposed to establish general character of petrographic variability, throughgoing structure (mostly fractures, a few offsets, and relief discontinuities), and regional attitudes of slab-like layering. Some outcrop slabs are roughly conformal to slopes as a result of levering and rotation of individual slabs. In general the structures are non-conformal, yielding a discontinuous lineated appearance of bright outcrops in high-resolution oribital images.

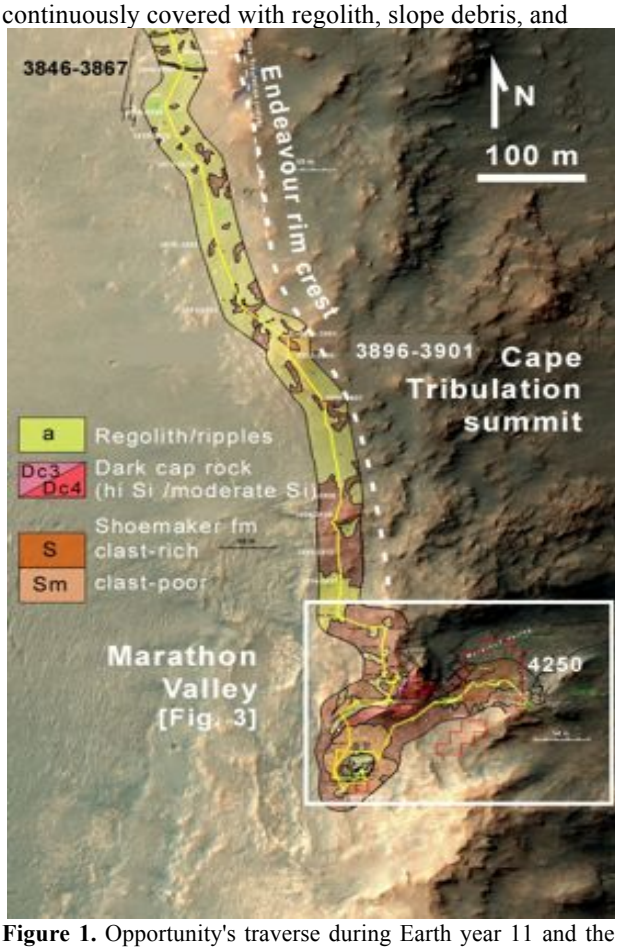

Figure 1. Opportunity's traverse during Earth year 11 and the in situ geologic mapping from *Cape Tribulation* summit to *Marathon Valley, the location of winter 7 investigations*.

The western rim from outcrop observations consists of impact breccias ("*Shoemaker formation*") arranged in 200 to 400 m-long and 200 m-wide rim segments, with left and right-stepping offsets, all of which results in an azimuthally segmented structural fabric [*5*]. Details of the breccias vary, but generally consist of darker clasts up to several centimeters embedded in a matrix of altered fine-grained material and coarse agglomerations of both. While individual outcrops rarely show bedding, slab-like layering of consistent orientation is locally prominent, resulting in a general sense of the arrangement of bedding associated with the ejecta.

Evidence for up to several hundred meters of degradation of the crater rim [*6*] is supported in outcrop by exposure of the steep monoclinal dip (22°) of bedrock layers unconformable with outward rim slopes (~10°) at *Pillinger Point* and near the *Cape Tribulation* summit. The process by which this planar and laterally expansive pediment formed requires a uniform, but unknown, erosion agent. Other evidence of deep erosion includes *Wdowiak Ridge* along the northwest rim of Marathon *Valley,* where cobble and large-sized basaltic rubble incongruent with dominant rim breccias (*Shoemaker fm*) occur perched on ridges oriented parallel to a pervasive ENE-WSW rim structural fabric. Topographically inverted rubble-filled troughs, pre-impact basaltic ridges, pre-or post impact dikes, or allochthonus ejecta blocks are all possible origins, although the alignment with the common structural fabric and deep rim erosion support the concept of erosional inversion of formerly filled troughs developed along pre-existing fractures.

Marathon Valley: Marathon Valley is a 10 to 15 m-deep trough 200 m long oriented N60E and widening from 50 m at the entrance on the *Cape Tribulation* crest line on the western end to 150 m wide in the middle. Bedrock exposures in *Marathon* Valley (unit Sm, **Fig 2, 3**) are planar layering surfaces. Combined with a network of sub-orthogonal vertical joints the exposures these yield a sub-polygonal and variegated appearance of

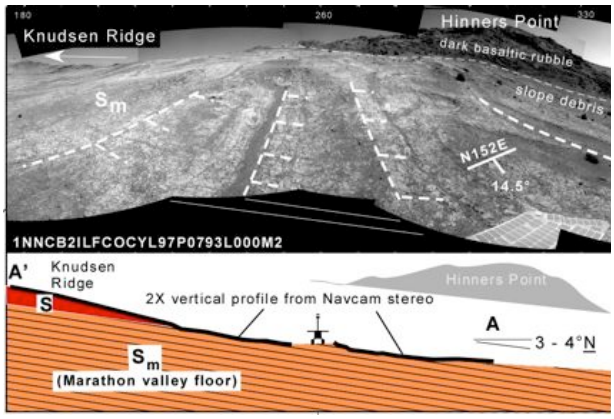

Figure 2. Navcam view west towards the crater rim from inside *Marathon Valley* on sol 4132. Northerly dip component of exposed **finely-layered** (*Shoemaker fm)* breccias is a few degrees. This valley floor unit (Sm) is the site of the most extensive area of the orbital smectite detection [*1,2*]. Profile is based on north-south Navcam ranging across the valley floor.

bright outcrops in high-resolution *MRO/HiRISE* images The flat valley floor slopes 14 degrees east. The floor consists of flat bedrock of *Shoemaker fm* relatively clast-poor breccias broken by layering sheets dipping N60E at approximately 14 to 15 degrees (**Fig. 2**) and a sub-orthogonal set of roughly vertical joints or fractures. Soils and rubble are largely confined to small relief depressions along the joints and edges of layering planes, and constitute a smaller fraction of the bedrock exposures than elsewhere along the Endeavour crater rim. The valley is bounded on the north and south by massive outcrops of breccias and slope debris.

Bedrock exposures within and west of the entrance to *Marathon Valley* consist of broad exposures of planar outcrops nearly conformal with the valley floor resulting in broad outcrop exposures and minor soil overburden, an unusual occurrence in the Endeavour crater rim. Red zones associated with some vertical joints crisscross the outcrops and are enriched in Si and Al, depleted Fe and Mn [*1,7*] and other indications of alteration and oxidation relative to the host rock such as spectral signatures of both fine and coarse-grained hematite [*8*]. The association of red alteration zones and joints is interpreted as evidence for formerly enhanced fluid flow along fractures that leached the breccias and concentrated mobile ions in zones adjacent to fracture walls.

Context of Smectites. The strongest smectite detection in *MRO/CRISM* data [*1,2*] (**Fig. 3)** corresponds with areas of relatively rubble-free broad outcrop exposure on the valley floor and similar exposures to the southwest (**Fig. 2**). The largest exposures are shown in **Fig. 3** and are related to Marathon Valley and areas immediately to the southwest. The enhanced aqueous alteration along fractures may simply reflect valley

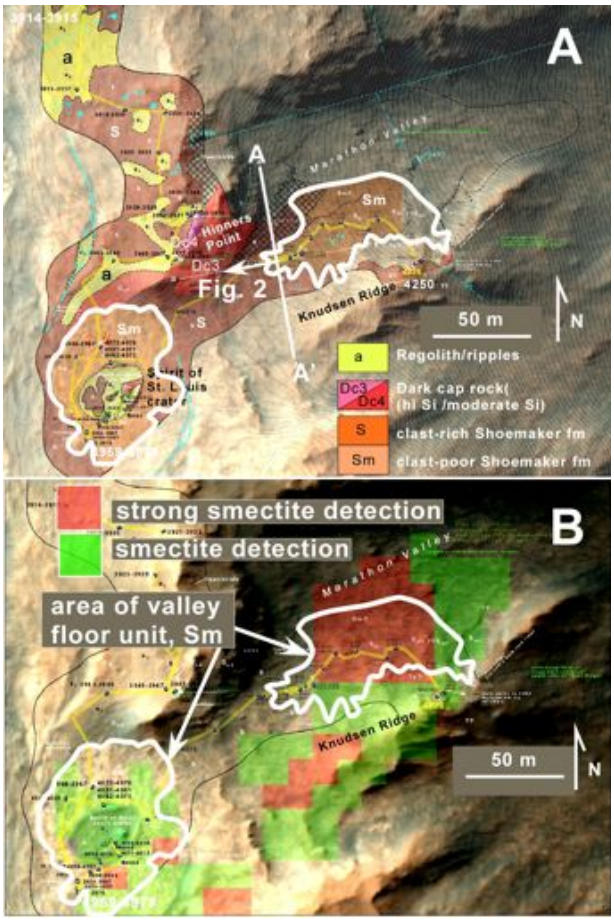

Figure 3. A. Traverse mapping at Marathon Valley. **B. Strong detection of smectite [*1*] correlates with the in situ mapping of valley floor unit Sm (white outline**). Areas of additional strong smectite detection are yet to be studied in situ. Base, MRO/HiRISE image ESP_035408_1775.

development along a complex larger scale fracture that subsequently enhanced regional fluid flow through the rim substrate and the joints in the bedrock.

Conclusions: Pervasive fractures cutting Endeavour's rim provided natural pathways for aqueous fluids in the Noachian environment. In situ geologic mapping and chemical characterization of outcrops by Opportunity within *Marathon Valley* are providing insight into the geologic, geochemical, and structural context of the type of alteration now recognized on the rims of many Noachian craters.

References: [1] Arvidson et al. (2015), AGU; [2] Fox et al. (2014), *8th International Conference on Mars* abstract; [3] Carter, J. et al, (2013). *JGR-Planets*, *118*(4),831--- 858; [4] Ehlmann, B. L. and C. S. Edwards (2014). *Annual Revs Earth and Planet Sci*, 42: 291 -315; [5] Crumpler et al. (2015), 46th LPSC abstract**;** [6] Grant et al. (2015), *Icarus* submitted; [7] Mittlefehldt et al. (2016), *47th LPSC*; [8] Farrand W. H. et al. (2016) *47th LPSC;* [9*]* Arvidson et al. (2015), *Am. Min*, submitted.