

FIELD GEOLOGIC CONTEXT OF OPPORTUNITY TRAVERSE FROM GREELEY HAVEN TO THE BASE OF MATIJEVIC HILL. L. S. Crumpler¹ and MER Athena Science Team. ¹New Mexico Museum of Natural History & Science, 1801 Mountain Rd NW Albuquerque, NM, 87104, USA, larry.crumpler@state.nm.us.

Introduction. Field correlation of lithologies from outcrop to outcrop, geologic mapping of contacts, and subsequent merging of results with orbital data provide stratigraphic context for observations during Opportunity's ninth year of operation [Fig. 1]. Field-based findings along Opportunity's traverse, including gypsum veins, small distributed veins in older rock [1, 2] together with orbital detection of possible phyllosilicate-rich outcrops [3, 4] all occurring *throughout the stratigraphic sequence*, support an interpretation that significant non-acidic water probably moved through cracks and joints over long time intervals or relatively late geologic time.

On its current field campaign following its fourth winter, Opportunity has traversed an additional 1091 m around the north end of Cape York and southward along the east margin to its current location. The textures, structures, stratigraphy, mineralogy, and chemistry of outcrops examined in situ characterize the terrain over the proximal 20 m of the traverse. This enables a reconnaissance transect style of geologic field mapping. The results provide constraints on possible conditions under which the rocks of Endeavour crater were formed, altered, eroded, and subsequently overlain by later materials.

Traverse Stations. Stations along the traverse with significant results include:

Greeley Haven (sols 2795-2946). Opportunity spent its fourth winter at the north end of Cape York on an outcrop of impact breccias, which we identify as part of the Shoemaker Formation. These rocks are fundamentally basaltic breccias bearing some subangular dark clasts in a coarse breccia groundmass. Based on the results of a detailed campaign of APXS [6] offsets and a very large MI mosaic [5] together with subsequent observations elsewhere, the Shoemaker Formation is interpreted to be an impactite from Endeavour crater.

Monte Cristo (sols 2969-2980). A traverse from the winter haven crest of Cape York to the northern marginal contact with the Burns Formation crossed the transitional units to test if gypsum veins tended to be more common in this transitional geologic unit as it appeared from previous observations at the south and west margins of Cape York. Segmented gypsum veins one to two centimeters wide are prolific throughout the transition apron unit. APXS and MI observations of a large vein in this location, "Monte Cristo", support previous observations.

Grasberg (sols 2989-3007). The unconformable contact between the Meridiani Plains sulfate-rich sandstones of the Burns Formation, and the relatively smooth aprons surrounding Cape York is distinguished by a band of light-toned material from a few meters to 10 or more meters wide. A stop at the site named "Grasberg" confirmed through MI and APXS analysis that this band is a material distinct from either the materials of Cape York or the Burns Formation.

Grasberg is an unusual composition with elevated Cl, and a grain-size finer than the MI resolution, in contrast to the coarse sandstone typical of Meridiani. This is a relatively thin (several tens of cm thick) unit that unconformably overlies the slopes of an eroded Cape York. Based on these unique characteristics we have defined this as a distinct map unit ("Gr", Fig. 1) that is easily traceable around the margins of Cape York.

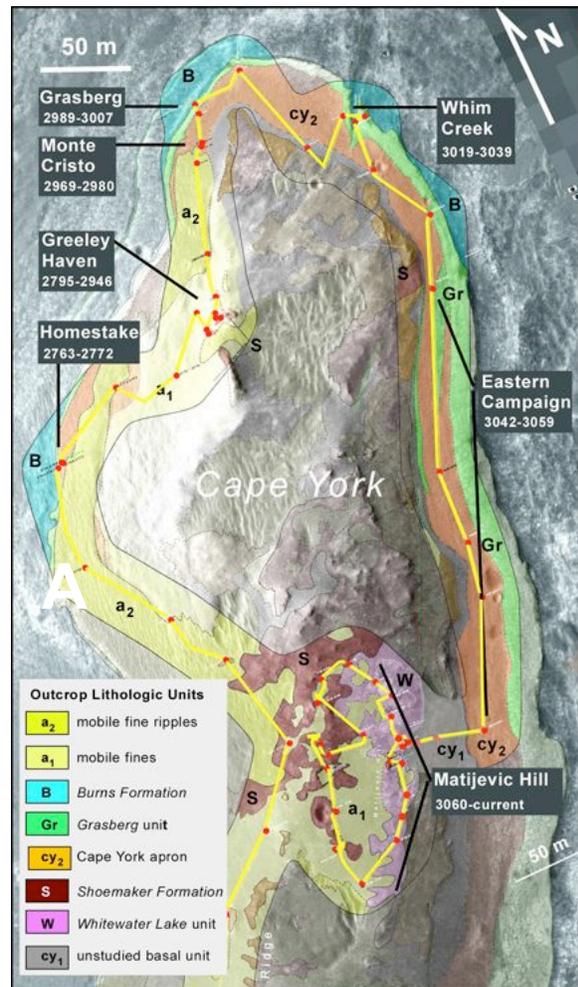


Figure 1. Field reconnaissance transect geologic mapping based on in situ rover-based observations along Opportunity's traverse around the margins and interior of Cape York.

Whim Creek (sols 3019-3039). A broad fracture named "Whim Creek" enabled a simple field test of the inferred stratigraphy based on interpretation of apparent outcrop orientations and relief [Fig. 2]. Here a N28E-trending fracture 1 to 10 m wide and approximately 100 m long intersects the contact between the Burns Formation, Grasberg unit and Cape York apron units. We tested for a northeasterly-plunging angular synclinal geometry of lithologies predicted for a north-dipping Cape York apron slopes (cy₂) overlain by the Grasberg unit (G) and Burns Formation (B) displaced along a graben-like fracture. This is an important result as it demonstrates the ability to perform simple field geologic tests on Mars using techniques commonly used in the field on Earth.

Eastern Campaign (sols 3042-3059). A long term goal of traverse on the eastern margin of Cape York has been the characterization of outcrops where orbital remote sensing implies detection of phyllosilicates [3,4]. As part of this

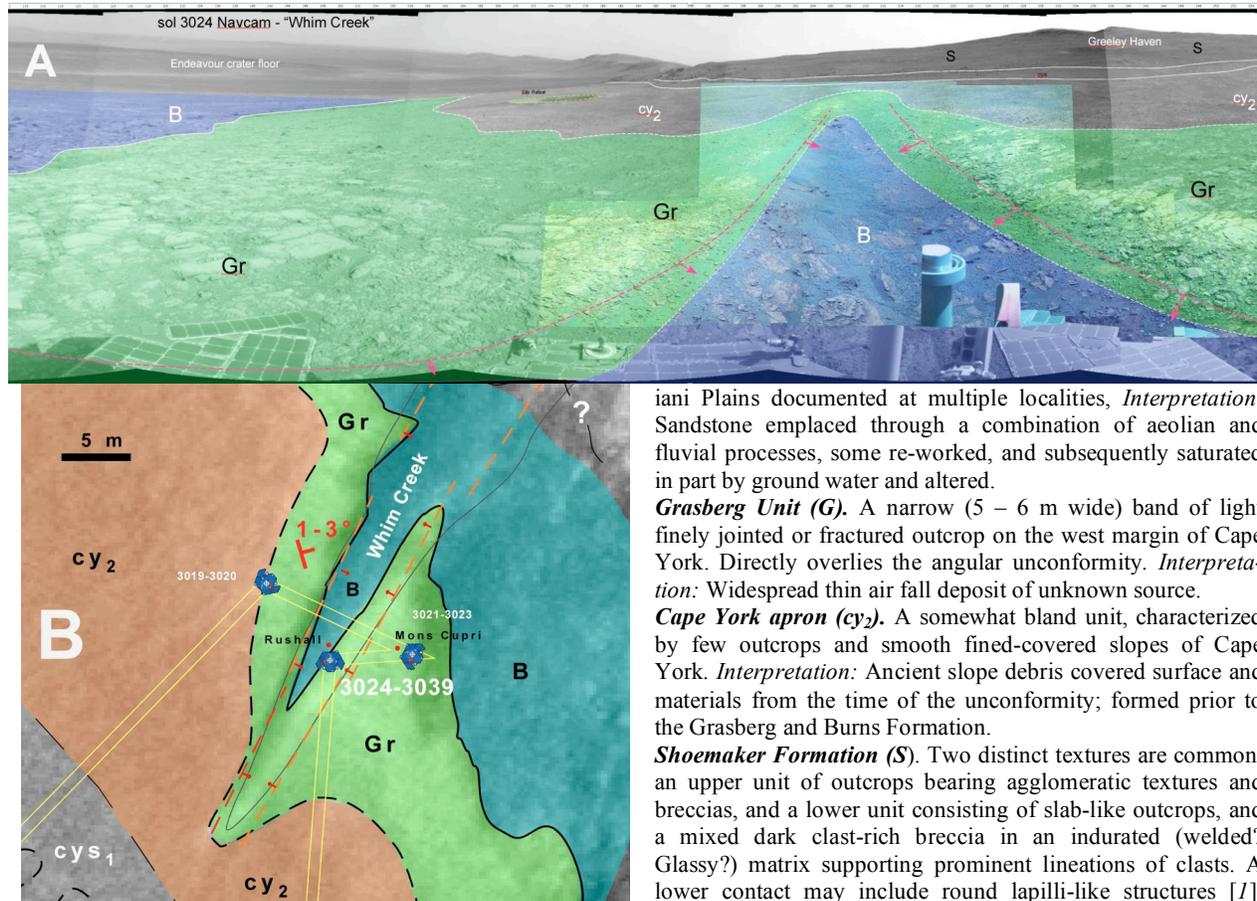


Figure 2. **A.** Perspective geologic mapping on Navcam panorama south along the axis of the Whim Creek fracture. **B.** Map perspective of field results shown in A. Angular plunging synclinal deformation matches prediction for graben-like fracture displacing low angle northeasterly-dipping apron units. Stratigraphic sequence from these results, young to old: B= Burns Fm, Gr= Grasberg unit, cy₂= Cape York slope debris apron unit.

campaign a multi-color panoramic survey of the eastern margin was completed during repeated drives along the eastern apron. The results show that the texture and apparent structure of many outcrops along the east margin appear similar to either the rough breccia-like upper Shoemaker Formation or, the distributed clasts of the lower Shoemaker Formation.

Stratigraphic Units from Outcrop Observations. Based on these and additional traverse observation, we are able to define at least four distinct bedrock units and included correlatable submembers, two late, mobile fines units, and slope forming units of as yet unidentified lithology. In order of apparent descending stratigraphic order:

Drifted mobile (aeolian) fines (a₁). Silt-size and finer mobile materials, locally mixed with *in situ*-derived fines. *Interpretation:* Mix of Aeolian fines and local outcrop erosion products.

Aeolian ripple bed forms (a₂). *Interpretation:* Currently stable oriented accumulations of sand-sized materials transported through saltation.

Burns Formation (B). Well-sorted sulfate- and hematite-rich sandstone. Dark tone arises from abundant mobile dark sand filling irregularities. It is the principal sandstone of the Merid-

iani Plains documented at multiple localities, *Interpretation:* Sandstone emplaced through a combination of aeolian and fluvial processes, some re-worked, and subsequently saturated in part by ground water and altered.

Grasberg Unit (G). A narrow (5 – 6 m wide) band of light finely jointed or fractured outcrop on the west margin of Cape York. Directly overlies the angular unconformity. *Interpretation:* Widespread thin air fall deposit of unknown source.

Cape York apron (cy₂). A somewhat bland unit, characterized by few outcrops and smooth fined-covered slopes of Cape York. *Interpretation:* Ancient slope debris covered surface and materials from the time of the unconformity; formed prior to the Grasberg and Burns Formation.

Shoemaker Formation (S). Two distinct textures are common, an upper unit of outcrops bearing agglomeratic textures and breccias, and a lower unit consisting of slab-like outcrops, and a mixed dark clast-rich breccia in an indurated (welded? Glassy?) matrix supporting prominent lineations of clasts. A lower contact may include round lapilli-like structures [1]. *Interpretation:* Endeavour crater impact breccias and melts.

Whitewater Lake Unit (cy₁). Light-toned, fine-grained (<30μ) and orthogonally jointed massive outcrops restricted to the interior of Cape York on the east margin of Matijevic Hill [1]. Abundant veins, joint plane alteration, and low strength and easily eroded. *Interpretation:* Either impactite or air fall fines or distal ash. Significant evidence for alteration by fluids.

Basal Cape York outcrops (cy₁). Coarse (?), clastic outcrop forming slopes beneath upper beach of Shoemaker Ridge. Few exposures. Not examined *in situ*. *Interpretation:* Lower Cape York bedrock of unknown character; or debris covered slope on a known lithology.

Discussion. Geologic time great enough for significant unconformities to develop separate the sculpting of Cape York and deposition of slope debris, and the deposition of overlapping materials Grasberg and the Burns Formation. Outcrops along the Cape York ridge crest may be impactites associated with Endeavour Crater, but some outcrops could represent pre-Endeavour materials. The widespread occurrence of veins and altered joint plane margins in older rocks, and the prevalence of gypsum veins in Cape York slope debris are evidence for the long-term availability of non-acidic water during evolution and alteration of the observed outcrops.

References: [1] Squyres et al 2013, LPSC 44; [2] Farrand et al, 2013, LPSC 44; [3] Arvidson et al., 2013, LPSC 44; [4] Noe Dobrea et al, 2012, GRL, 39; [5] Herkenhoff et al, 2013, LPSC 44; Cohen et al, 2013, LPSC 44.