NOACHIAN IMPACT BRECCIAS ON THE RIM OF ENDEAVOUR CRATER, MARS: OPPORTUNITY APXS RESULTS. D. W. Mittlefehldt[1], R. Gellert[2], R. E. Arvidson[3], J. F. Bell III[4], W. H. Farrand[5], K. E. Herkenhoff[6], B. L. Jolliff[3], D. W. Ming[1], C. Schröder[7], R. J. Sullivan[8] and the Athena Science Team [1]NASA/Johnson Space Center, Houston, TX, USA (david.w.mittlefehldt@nasa.gov), [2]University of Guelph, Guelph, ON, Canada, [3]Washington University, St. Louis, MO, USA, [4]Arizona State University, Tempe, AZ, USA, [5]Space Science Institute, Boulder, CO, USA, [6]U.S. Geological Survey, Astrogeology Science Center, Flagstaff, AZ, USA, [7]University of Stirling, Stirling, Scotland, UK, [8]Cornell University, Ithica, NY, USA.

Introduction: Mars Exploration Rover Opportunity has been investigating the geology of Meridiani Planum since January 2004, and is currently ~3830% into its primary mission. Opportunity reached the rim of 22 km diameter Endeavor crater at Spirit Point on the south end of Cape York on sol 2681 and began exploring the geology of Endeavour rim. She left Cape York on sol 3316 and arrived at the next rim remnant to the south, Solander Point, on sol 3387 to begin geological investigations at the contact and up onto Murray Ridge. The Burns fm. of Meridiani Planum lies near the top of the plains-forming unit of western Sinus Meridiani [1] and onlaps onto the Endeavour rim rocks (hereafter rim rocks). Endeavour crater would have excavated ~4 km into the existing stratigraphy. Thus, the ejecta that form the rim rocks offer windows into the deeper lithologies of Sinus Meridiani.

Endeavour Rim Stratigraphy and Targets: The rim rocks on Cape York are informally divided into two formations: the lower Matijevic fm. and the upper Shoemaker fm. [2, 3]. The Matijevic fm. is composed of fine-grained deposits containing variable concentrations of mm-sized spherules, and is thought to represent a pre-Endeavour-impact lithology [3]. The Shoemaker fm. is composed of impact ejecta from Endeavour crater [2, 3]. It is subdivided into three members, from the bottom up: (i) Copper Cliff mbr.; (ii) Chester Lake mbr.; (iii) Greeley Haven mbr. We have not yet defined stratigraphic units for Murray Ridge. Here we discuss the polymict breccias of the Shoemaker fm. on Cape York and the breccias from Murray Ridge, with a focus on compositions determined by the Alpha Particle X-Ray Spectrometer (APXS). For the most part, APXS targets were not brushed or abraded. This adds some uncertainty to interpretations of rock compositions owing to the presence of dust, soil, pebbles, and possibly alteration rinds on rock surfaces.

Textures of Impact Breccias: Rocks of the Shoemaker fm. on Cape York are breccias containing cm-sized and larger dark, angular clasts set in the lighter-toned, fine-grained matrix [2, 3]. Rocks with identical textures are found on Murray Ridge (Fig. 1a). There is a linear fabric to the outcrops, possibly due to differential wind erosion. Microscopic views of the rocks show dark, angular to sub-rounded clasts of variable sizes (Fig. 1b). Clasts are fine-grained, although the internal texture of some suggests they may in turn be breccias (Fig. 1b).

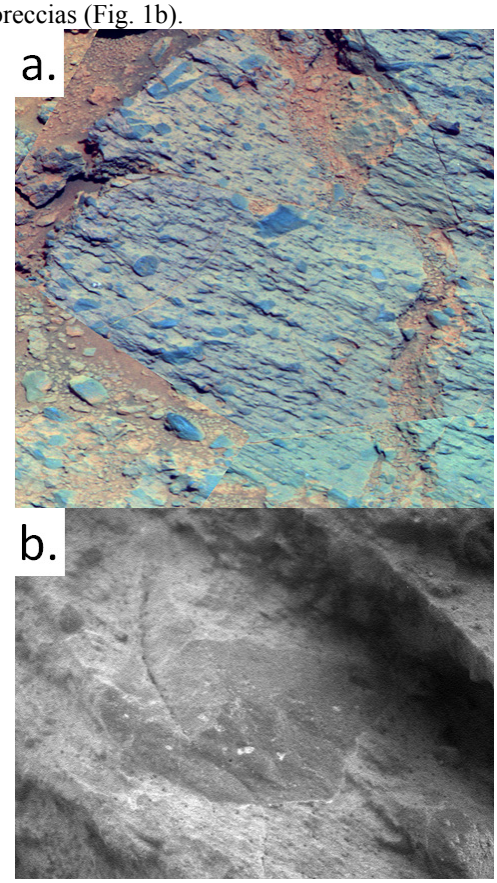

Figure 1. a. Portion of sols 3494-3496 Pancam false-color mosaic of the Moreton Island breccia outcrop on Murray Ridge containing APXS targets Tangalooma and Mount Tempest. b. Portion of sol 3502 Microscopic Imager view of APXS target Mount Tempest showing a 1.6×1 cm angular clast in matrix.

Compositions of Cape York and Murray Ridge Breccias: In general, the breccias of the Endeavour rim are mafic in composition. They follow compositional trends shown by martian basaltic and lherzolitic shergottites, and MER igneous targets Bounce Rock and Backstay, including the Cr_2O_3' vs. mg# (100*molar MgO/(MgO+FeO)) trend shown in Fig. 2a. (The "prime" on the oxides indicates bulk compositions renormalized to a SO_3- and Cl-free basis.) However, the breccias are distinct from Adirondack class basalts from Gusev crater [4]. The protoliths for the

breccias were plausibly a sequence of mafic extrusive and intrusive igneous rocks. However, the compositions are not pristine. All have 4-10 wt% SO_3+Cl, significantly higher than for martian meteorites (<0.5 wt%).

Evidence for Aqueous Alteration: Most of the breccias have FeO′/MnO′ ratios like those of martian meteorites (Fig. 2b). Ferrous iron and Mn^{2+} are homologous species during igneous processes and do not significantly fractionate. Aqueous processes can fractionate Fe from Mn and this is likely the cause for low Mn in one Chester Lake mbr. target, and high Mn in some Greeley Haven mbr. breccias and the one Murray Ridge target. Dark clast targets in the Greeley Haven and Chester Lake mbrs. have higher Mn than nearby matrix-rich targets. This suggests the Fe/Mn fractionation was accomplished in the protoliths, before assembly of the breccias. CIPW normative mineralogies contain lower diopside than do the abraded targets of Adirondack class basalts [4]. Empirically, altered rocks on the Columbia Hills in Gusev crater contain lower normative diopside than do Adirondack class basalts.

Alteration processes on Mars differ from those on Earth. The latter typically occur under moderate pH, high water/rock, leading to Al- and Fe^{3+}-rich residues (arrow E in Fig. 2c), while on Mars alteration occurred under low pH and low water/rock resulting in dissolution of olivine in mafic protoliths (arrow M) [5]. The Shoemaker fm. and Murray Ridge rocks plot on the field of martian mafic meteorites and Adirondack class basalts indicating minimal transport of cations by alteration solutions in the protoliths.

While the data suggest much of the alteration likely occurred in the protoliths before impact excavation, there was nevertheless additional localized alteration after emplacement on the rim. Veins rich in Ca-sulfate crosscut the Copper Cliff mbr. and the underlying Matijevic fm. [3, 6], and highly mobile elements such as Zn show extreme variations between different members of the Shoemaker fm. [2]. Boxwork veins on Matijevic Hills in particular indicate strong alteration resulting in localized enrichments in Al and Si [6].

Variations between different rim segments: The breccias on Murray Ridge are generally similar to Shoemaker fm. breccias for many elements (cf., Fig. 2a) but there are differences (cf., Fig. 2b). Thus, while the Murray Ridge breccias were formed from protoliths generally similar to those of the Shoemaker fm., the two breccia groups represent distinct areal or stratigraphic packages in the pre-impact terrain. Correspondence analysis of the APXS data shows subtle differences between the Murray Ridge breccias and Shoemaker fm. breccias further indicating compositional differences between rim segments [7].

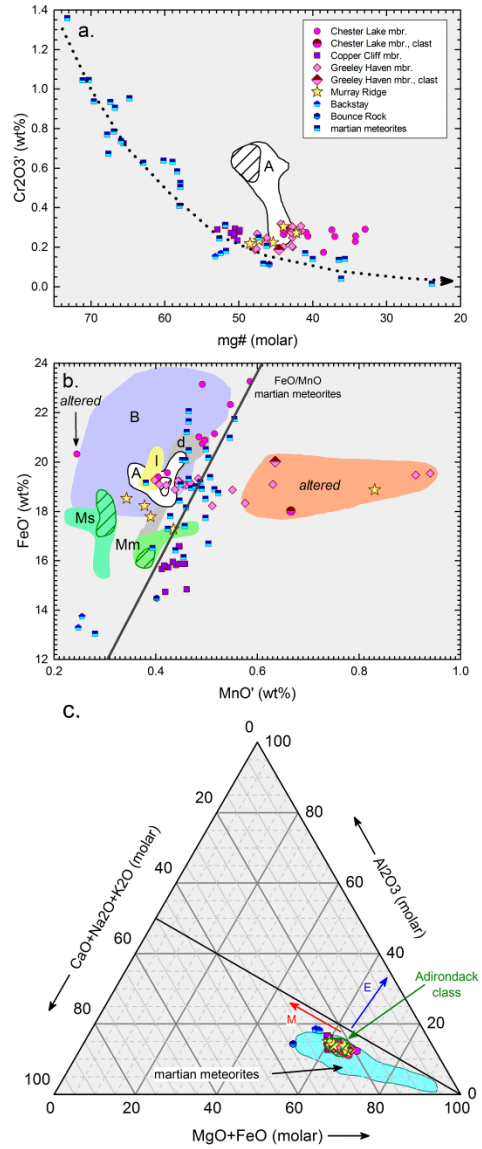

Figure 2. Compositions of Cape York and Murray Ridge rocks compared to martian basalts. Labeled fields are: B - Burns fm.; A - Adirondack class basalts; Mm - matrix-rich Matijevic fm.; Ms - spherule-rich Matijevic fm.; d - dark soils; l - light-toned soils. Crosshatched sub-fields in fields labeled A, Mm and Ms enclose abraded targets.

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