OVERVIEW OF OPPORTUNITY ROVER RESULTS FROM CLAY-BEARING MATERIALS AT ENDEAVOUR CRATER. S. W. Squyres[1], R.E. Arvidson[2], and the Athena Science Team. [1]Cornell University, Ithaca, NY 14853, squyres@astro.cornell.edu, [2]Washington University, St. Louis, MO 63130.

Introduction

Opportunity continues to explore Cape York, a segment of the rim of the ancient crater Endeavour at Meridiani Planum. After wintering near the north end of Cape York, Opportunity has traversed to Matijevic Hill near the southern end. There, Opportunity has performed a traverse loop (Fig. 1), and has conducted initial investigations of several outcrops near the beginning/end point of the loop.

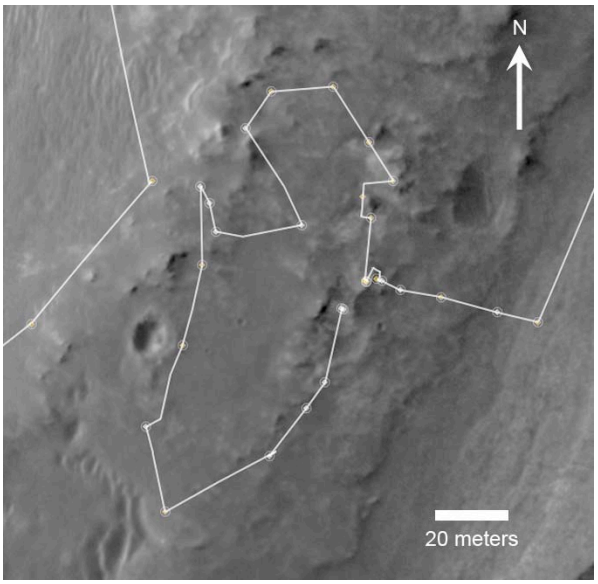

Fig. 1: HiRISE image showing Opportunity rover traverse at Matijevic Hill.

Whitewater Lake

Whitewater Lake (Fig. 2) is typical of most bedrock at Matijevic Hill. These rocks are light-toned, and discontinuously covered with a darker coating. Where exposed in cross section, bedding is expressed as planar lamination. Microscopic Imager (MI) images show the rock to be very fine grained, with grain sizes close to or below the limit of MI resolution (~30 μm/pixel).

Outcrops are typically low-relief, which elsewhere at Meridiani is a sign of high susceptibility to wind erosion. The "specific grind energy" determined using the Rock Abrasion Tool (RAT) is ~2.8 Jmm^{-3}, similar to soft sandstones elsewhere at Meridiani and some of the weakest rocks found by Spirit at Gusev crater.

Whitewater Lake is similar in compositon to average martian soil, and is slightly richer in Si and Al than the Shoemaker formation breccias [1] common at Cape York. The coatings are richer in S and Cl than the underlying rock [2].

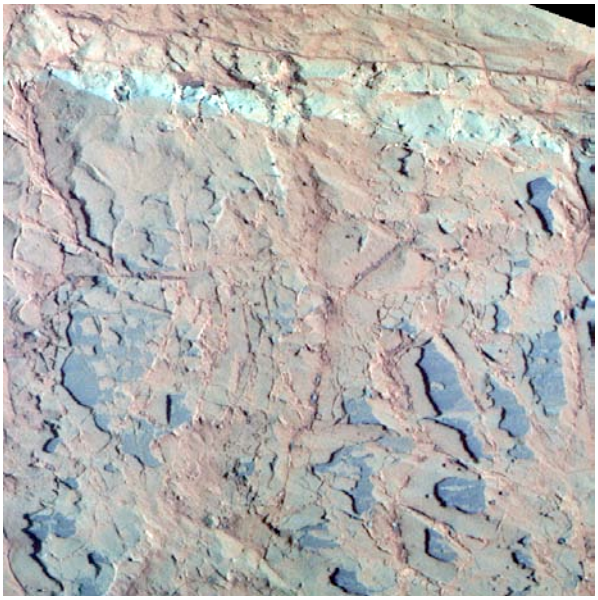

Fig. 2: Pancam false color image of Whitewater Lake. Image width is ~50 cm.

Spherules

Whitewater Lake and similar outcrops contain sparse concentrations of small spherules. In a few locations, however, very dense matrix-supported accumulations of spherules are seen (Fig. 3).

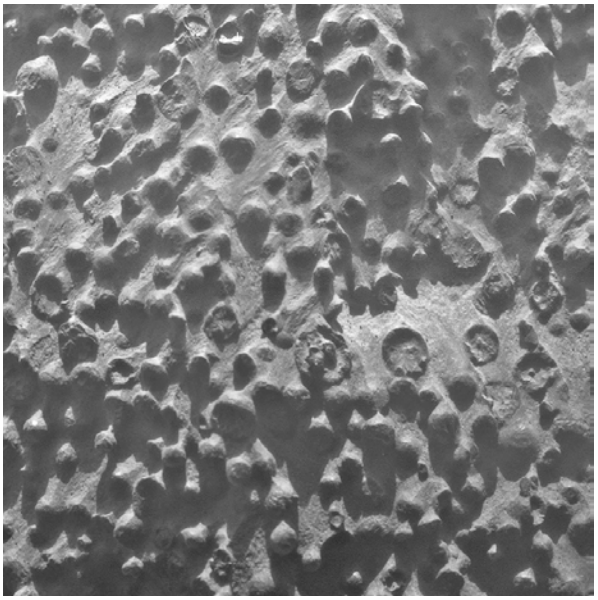

Fig. 3: MI mosaic of spherules in the outcrop Kirkwood. Image width is ~4 cm.

Spherules at Matijevic Hill are typically a few mm in diameter. They are more erosionally resistant than the matrix in which they are embedded, and spherule-rich outcrops are topographically raised as a consequence. Erosion of spherules reveals concentric structure, with a more resistant outer shell, a less resistant interior, and occasional resistant central regions.

The elemental chemistry of spherule-rich outcrops is only subtly different from that of Whitewater Lake. In particular, they show no Fe enhancement [2], demonstrating that the spherules are not hematite-rich concretions like the "blueberries" in the sulfate-rich sandstones of the nearby younger plains. Concentric structure and highly variable concentrations also distinguish the Matijevic Hill spherules from blueberries.

Copper Cliff

The Copper Cliff outcrop lies topographically above Whitewater Lake materials, and appears to overlie them. MI images (Fig. 4) show it to be a breccia, very poorly sorted, with clasts up to a few cm in size. Spherules are present in low concentrations and are in the same size range as those in Kirkwood.

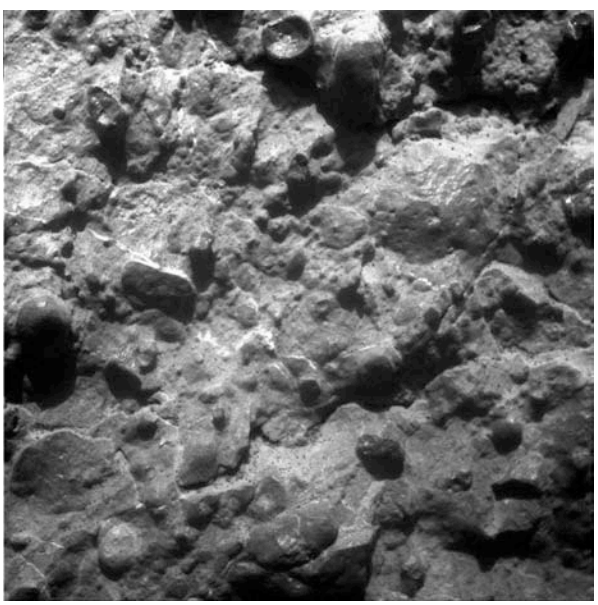

Fig. 4: MI image of the target Onaping at Copper Cliff. Image width is ~3 cm.

Despite it being a breccia, the elemental composition of Copper Cliff differs from that of the Shoemaker formation impactites. It also cannot be reproduced by simply mixing Shoemaker and Whitewater Lake materials. It is therefore a distinct breccia unit.

Veins

All of the geologic units investigated at Matijevic Hill to date locally contain small, light-toned fracture-filling veins [3]. Maximum widths are ~1 cm, and most are much narrower. In Whitewater Lake materials, veins locally form "boxwork" patterns that may reflect pre-existing jointing. Veins show an enhanced "hydration index" [4] in Pancam multispectral data [3], suggesting hydration of the precipitated mineral(s).

Interpretations and Working Hypotheses

Whitewater Lake outcrops coincide closely with a smectite clay signature in orbital CRISM data [5]. We therefore hypothesize that Whitewater Lake is the primary clay-bearing unit at Matijevic Hill. Clays may be present in the coatings, the underlying rock, or both.

Whitewater Lake may be an impactite, but if so its fine-grained nature and laminar bedding suggest that it may be distal ejecta from an impact that predates Endeavour. Other hypotheses include explosive volcanic, eolian, or aqueous origins. We can distinguish among these by more carefully examining bedding, sedimentary structures, cross-stratification, and by determining the origin of the spherules. Stratigraphic relationships suggest that Whitewater Lake underlies and therefore predates the Shoemaker formation breccias, and may predate the Endeavour impact itself. If so, it is the oldest material investigated to date by Opportunity.

The spherules could be impact spherules if Whitewater Lake is an impactite, lapilli if volcanic, or devitrification spherules. They could also be concretions lightly cemented by some material other than hematite. We can distinguish among these hypotheses using multiple APXS measurements (perhaps supported by RAT grinds) and mixing models to separate out spherule composition, and by careful examination of spherule distribution with respect to bedding to search for evidence of hydrodynamic sorting.

We interpret the rocks at Copper Cliff to be Endeavour impact breccias. Their spherules may have been released from the weak underlying clay-rich strata during the impact event. We will search for other similar rocks to determine the full diversity of Endeavour breccias.

The light-toned veins clearly imply fluid flow and precipitation of water-soluble minerals in fractures. They postdate all of the units observed, and so probably postdate the Endeavour impact. Because of their small size, we will also investigate their composition using multiple offset APXS measurements.

References: [1] Squyres, S. *et al., Science* **336**, 570. [2] Cohen, B. *et al., LPSC 44*. [3] Farrand, W. *et al., LPSC 44*. [4], Rice, M. *et al*., *Icarus* **205**, 375. [5] Arvidson, R. *et al., LPSC 44*.