OVERVIEW OF RECENT MASTCAM AND MAHLI VISIBLE/NEAR-INFRARED SPECTROPHOTOMETRIC OBSERVATIONS: BIG SKY TO VERA RUBIN RIDGE. J.R. Johnson[1], J.F. Bell III[2], M. Lemmon[3], [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, jeffrey.r.johnson@jhuapl.edu, [2]Arizona State University, [3]Texas A&M University.

Introduction: The Mast Camera (Mastcam) imaging systems on the Curiosity rover continued acquisition of multispectral images of the same terrain at multiple times of day at five new rover locations between sols 1136 and 1544, expanding on data sets previously acquired along the traverse [1-3]. In addition, the Mars Hand Lens Imager (MAHLI) on the rover arm was used as a goniometer to acquire a new multiple view angle data set on Sol 1904 [cf. 4]. These data sets are being used to investigate the light scattering properties of rocks and soils along the Curiosity traverse using Hapke radiative transfer models [4-5] similar to previous analyses of data from the Mars Exploration Rover Pancam imaging system [6].

Data sets: Mastcam. Images were acquired by the Mastcam-34 (M-34) camera on Sols 1136-1143 while the rover was at the Big Sky and Greenhorn drill hole locations. This data set comprised two-frame mosaics pointed in the sunset and anti-sunset directions at 7 times of sol (**Table 1; Fig. 1**). On Sols 1229-1237 while the rover was at the Gobabeb region at the Bagnold Dunes, mosaics were acquired at 7 times of sol (**Fig. 2a**). On Sol 1356 while the rover was at Hartmanns Valley image mosaics were acquired at 5 times of sol (**Fig. 2b**). On Sols 1462-1463 the rover was drilling the rock Quela, and mosaics were acquired at 6 times of sol (**Fig. 3**). On Sols 1537-1544 at the attempted drill location Precipice, mosaics were acquired at 6 times of sol (**Fig. 4**). All data sets were acquired using filters centered at 445, 527, 751, and 1012 nm, and the images were jpeg-compressed. Each data set provided phase angle coverage from near 0° to ~140° for a variety of rocks and soils in the Murray formation and (including rover tracks and fracture-fill veins) and pristine and disturbed sands in the Bagnold Dunes. Navigation Camera (Navcam) stereo images were also acquired with each data set to provide terrain measurements for computing surface normals and local incidence and emission angles. These will be used to atmospherically-correct radiance data prior to radiative transfer (RT) modeling of surface units [4-7].

Data sets: MAHLI. On Sol 1904 while the rover was at Region 10 of the Vera Rubin Ridge (VRR) traverse, the MAHLI camera was used a goniometer to acquire images at 20 arm positions, all centered at the same location within the work volume, and all from a near-constant distance of 85 cm from the surface [5]. This data set sampled the light-toned, bluish units observed in HiRISE images and included a brushed target ("Oban"). Although it was run at only one time of day (~14:30 LTST), the sequence provided phase angle coverage from ~10° to ~110°. Acquisition of images from 20 different viewpoints also allowed construction of 3D shape models of this scene (**Fig. 5**).

Table 1. Mastcam image sequences used in this work.

Sol	Sequences (mcam0*)	LTST (avg)	Phase angle (avg °)
1136	5076,5078	1102	84,65
1136	5085,5087	1221	64,81
1138	5088,5090	0837	114,45
1139	5148,5150	1320	52,94
1140	5159,5161	1452	31,114
1140	5162,5164	1608	15,132
1141	5167,5169	1704	6,145
1142	5174	1611	11
1142	5177	1703	4
1143	5178	1506	25
1229	5654,5655	1233	74,49
1229	5659,5661	1348	62,32
1229	5662,5664	1608	50,8
1234	5714,5716	1507	53,14
1235	5719,5721	0743	110,135
1236	5726,5728	0939	109,87
1237	5731,5733	1103	92,69
1356	6589,6591	0840	124,24
1356	6592,6594	1155	78,67
1356	6597,6599	1355	50,96
1356	6603,6605	1608	19,129
1356	6607,6609	1652	10,140
1462	7292,7294	1122	72,71
1462	7298,7300	1247	52,90
1462	7302,7304	1435	26,115
1462	7305,7307	1705	10,150
1463	7309,7311	0834	110,40
1463	7315,7317	1556	7,134
1537	7878,7880	0942	88,54
1537	7884,7886	1127	66,70
1537	7896,7898	1313	43,91
1537	7899,7901	1500	19,114
1537	7903,7905	1647	6,137
1544	7929,7931	0743	110,47

LTST=Local True Solar Time

Methods. Mastcam image calibration involved conversion to radiance and reflectance via use of flat field images and onboard calibration targets [8]. MAHLI images can be converted to radiance using radiance scaling factors from calibrated files (DRXX) and MAHLI focus position counts in an algorithm that

rescales the data to match the Mastcam calibration via comparison of sky images acquired close in time.

Color phase composites were created by using calibrated Mastcam images at three phase angles (red=low, green=intermediate, blue=high) at the same wavelength. These show the spatial distribution of back- (red) vs. forward-scattering (blue) properties across the scene (**Fig. 1b**).

Future work. Sky models will be used to compensate for the effects of diffuse skylight using Mastcam measurements of atmospheric opacity and scattering models [4-7]. Geometric registration and projection of the M-34 images will be done using terrain models generated from the Navcam stereo pairs [4] to correct local slopes and facets prior to input to RT models [4-7]. Paired images from the MAHLI goniometer experiment will be used to produce stereo products (e.g., surface normals) for similar corrections.

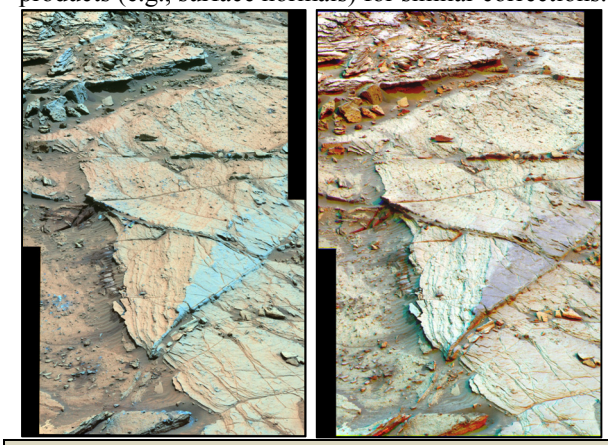

Fig. 1. Big Sky/Greenhorn area: (a;left) West-looking enhanced color mosaic (751, 527, 445 nm) taken at 1702 LTST, Sol 1142; (b;right) phase composite at 751 nm where red materials are more backscattering.

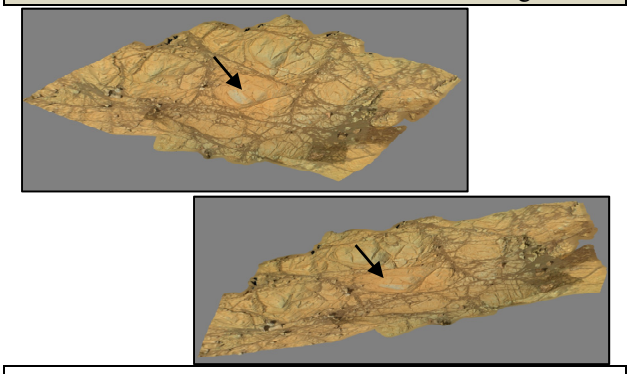

Fig. 5. 3D renderings of Sol 1904 MAHLI goniometer sequence showing brushed Oban target (arrows).

References: [1] Johnson, J. et al., LPSC, abs. #1374, 2013; Johnson, J. et al., LPSC, abs. #1371, 2014; Johnson, J. et al., LPSC, abs. #1424, 2015 [2] Johnson, J., et al., AGU, #P43B-2125, 2015; [3] Johnson, J., et al. 8th Inter. Conf. on Mars, abs. #1073, 2014 [4] Johnson, J.R., et al, AGU, #234925, 2017; [5] Liang, W. et al., AGU, #243233, 2017; [6] Johnson et al., JGR., 2005JE002494, 2006; Johnson et al., JGR, 2006JE002762, 2006; Johnson et al., Icarus, 248, 25-71, 2015 [7] Lemmon, M.T., et al., Icarus, 2014; 8th Intern. Conf. on Mars, abs. #1338; [8] Bell et al., LPSC abs. #1417, 2013.

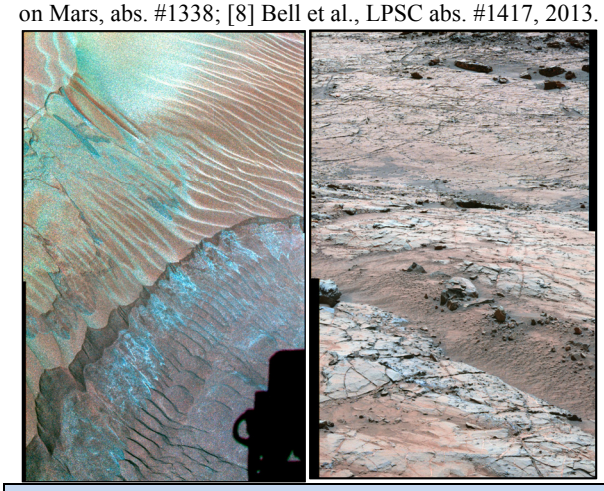

Fig. 2. (*left*) Gobabeb: Anti-sunset enhanced color mosaic taken at 1509 LTST, Sol 1234 (shadow of camera head in lower right among rover-disturbed sands); (*right*) Hartmanns Valley West-looking mosaic taken at 1356 LTST, Sol 1356.

Fig. 3. Quela region: West-looking enhanced color mosaic taken at 0836 LTST, Sol 1463.

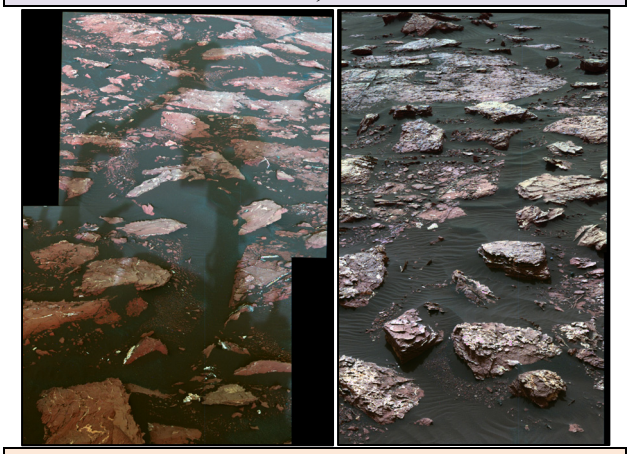

Fig. 4. Precipice area: East- (left) and West- (right) looking enhanced color mosaics taken on Sol 1537 at 1645 LTST and 1501 LTST, respectively. Shadow of camera head and deployed arm visible in left image.