CHARACTERIZATION OF ROCK TARGETS AND COLOR STANDARDS WITH THE MASTCAM-Z FLIGHT INSTRUMENTS.

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Introduction: Mastcam-Z is a pair of mast-mounted, multispectral, zoom-enabled cameras that will be the "eyes" of NASA's upcoming Mars-2020 rover mission [1]. Each Mastcam-Z (Left and Right) takes images through a set of filters spanning visible to near-infrared wavelengths (442-1017 nm); when the full filter set is utilized, Mastcam-Z "spectra" can be extracted that cover 14 unique wavelengths [2]. The Mastcam-Z instrument will help meet the Mars-2020 mission science goals by characterizing the rock type, mineralogy, structure, texture, weathering, and alteration of Mars' surface.

The flight Mastcam-Zs were characterized during a stand-alone radiometric calibration at ambient conditions at Malin Space Science Systems (MSSS) in San Diego, CA during May of 2019 [3]. The Mastcam-Zs observed a "GeoBoard" with a collection of color standards, rock slabs, resolution targets, stereo calibration targets, and education and public outreach (E/PO) materials (Fig. 1). Here we report on the results of the GeoBoard characterization with Mastcam-Z, and we discuss implications for the instrument's expected ability to characterize spectrally diverse rocks and minerals on Mars.

Methods: *GeoBoard Targets:* Color standards included witness samples of the Mastcam-Z calibration target materials, flight spares of the Mastcam-Z primary and secondary calibration targets [4], and samples of the Mars-2020 rover deck paint, in addition to standards by X-Rite and LabSphere. Rock targets included AREF polished slabs from NASA which had also been used in the calibration of the Mars Exploration Rover Pancams [5] and the Mars Science Laboratory Mastcams [6]. A variety of rock targets with naturally-weathered surfaces were included (basalt weathering rinds and coatings, vesicular basalts, stromatolite textures, and fibrous gypsum veins), in addition to cut and polished samples with fine-scale textural details and mineralogic

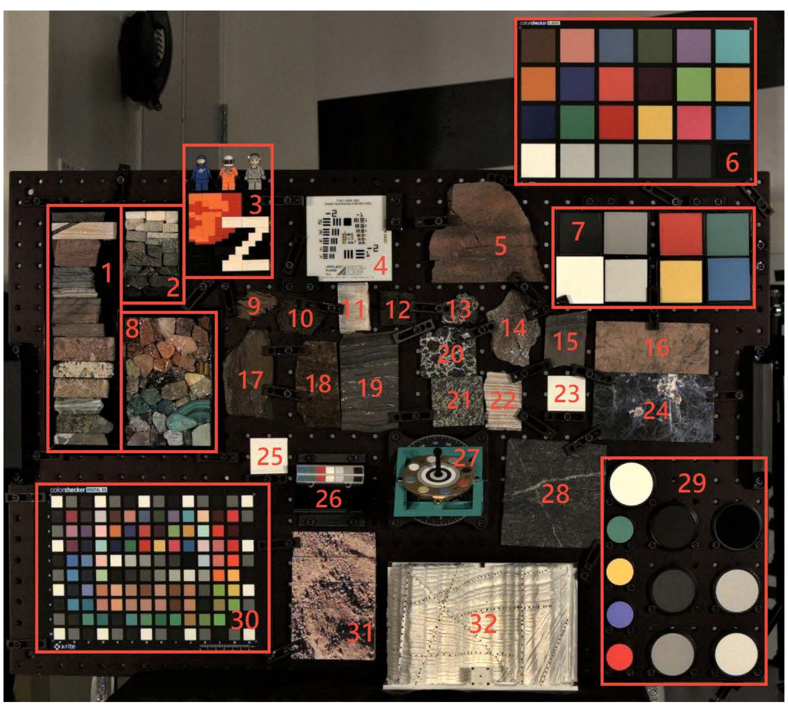

Figure 1: Mastcam-Z Right image (34mm zoom, R0 filter, Bayer RGB color) of the "GeoBoard" used in stand-alone calibration, with targets labeled. Details of the center of the board are shown in Fig. 2, with Mastcam-Z "spectra" shown in Fig. 3.

Mastcam-Z GeoBoard Targets

1 E/PO target: Mock stratigraphic column
2 E/PO target: Grayscale rocks & minerals
3 E/PO target: MCZ Lego logo
4 USAF 1951 resolution target
5 Precambrian cross-bedded sandstone
6 Xrite Color Checker calibration standards
7 Mastcam-Z calibration target materials
8 E/PO target: Rainbow rocks & minerals
9 Vesicular basalt
10 Weathered vesicular basalt surface
11 Natural gypsum vein (selenite)
12 Weathered vesicular basalt surface
13 Carbonate-coated basalt breccia
14 Welded tuff with black glass
15 AREF 082 rock target
16 AREF 247 rock target
17 Weathered Columbia River Basalt surface
18 Weathered Pilbara stromatolite
19 AREF 414 rock target (Banded Iron)
20 AREF 146 rock target
21 AREF 225 rock target
22 Sulfate/carbonate varve
23 Mars-2020 rover deck paint sample
24 AREF 248 rock target
25 Mars-2020 rover deck paint sample
26 Mastcam-Z secondary calibration target
27 Mastcam-Z primary calibration target
28 AREF 175 rock target
29 Labsphere color standard targets
30 Xrite Color Checker calibration standards
31 Stereo calibration target
32 Stereo calibration target

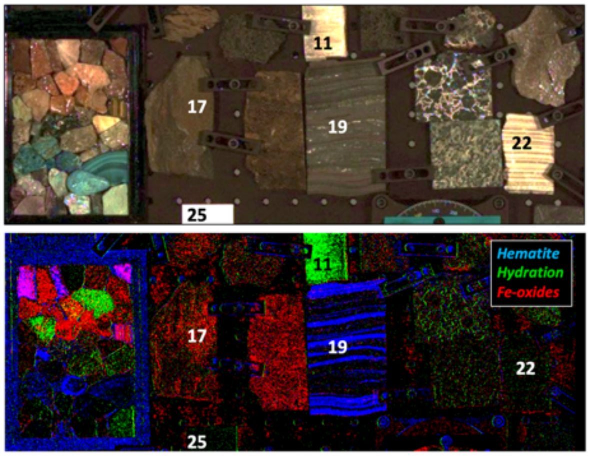

Figure 2: Mastcam-Z Right 34mm zoom image of the center of the GeoBoard. Above: visible color (R0 filter, Bayer RGB). Below: parameter map using the 866 nm band depth (consistent with the ~860 nm hematite absorption), the 939nm/978nm slope (consistent with the narrow ~980 nm H_2O absorption), and the blue to red visible slope (consistent with Fe-oxides) in the B, G and R channels. Locations of numbers represent the ROIs used for spectra in Fig. 3-left.

variability (cross-bedded sandstone, welded tuff with black glass, sulfate/carbonate varve). Space in the upper left of the GeoBoard was dedicated to E/PO targets provided by The Planetary Society.

Mastcam-Z Flight Hardware Observations: Full-filter Mastcam-Z observations of the GeoBoard were acquired at three zoom positions (34mm, 63mm and 100mm) under a variety of lighting conditions (i = 29-60°, e = 0°). Images were calibrated to radiance units using the coefficients derived from the preliminary instrument radiometric calibration [3], and a white reference standard was used to determine relative reflectance. Maps were created (Fig. 2) for a variety of slope, ratio and band depth parameters. Mastcam-Z spectra were extracted by manually selecting regions of interest (ROIs) in the Left and Right camera images and averaging the reflectance values for all the pixels contained in the ROI. Error bars are shown as the standard deviations of the ROIs (Fig. 3).

Lab Spectral Validation: Mastcam-Z spectra of the GeoBoard targets were externally validated using a full-resolution laboratory spectrometer at Western Washington University. An ASD FieldSpec 4 high resolution spectroradiometer, with a spectral range of 350 nm - 2500 nm and resolution of 3 nm VNIR and 8 nm SWIR, was used to collect spectra for the rock targets and color calibration standards. Spectralon SRM-99 was used for a white reference and 200 spectra were averaged to create each spectrum. A custom-built goniometer [7] was used to collect spectra from a range of viewing geometries. The geometry of the spectra shown in Fig. 3 (i=-39°, e=0°) is a replication of the primary illumination geometry used in calibration.

Results: Fig. 2 shows a composite of three parameters that highlight mineralogic variations among the targets. These distinguish the hydrated gypsum vein target (11) from other Ca-sulfates (anhydrite with minor gypsum alternating with carbonate in the varve target 22), they highlight the hematite-bearing layers in the banded iron sample (19), and they distinguish the weathered (oxidized) basalt surfaces (e.g., 17) from unaltered mafics and other spectrally-featureless targets (e.g., the rover deck paint 25). Spectra in Fig. 3 illustrate details of how Mastcam-Z can characterize spectral variability and the prominent absorption features due to iron and hydration. Ongoing calibration efforts will improve relative reflectance spectra and help prepare for surface operations.

References: [1] Bell J.F. III et al. (2020) *LSPC* [2] Rice M.S. et al. (2020) *LPSC*. [3] Hayes A.G. et al. (2020) *LPSC*. [4] Kinch K. *et al.,* submitted to *Space Sci. Rev*. [5] Bell J.F. III (2003) *JGR,* 108(E12), 8063. [6] Bell. J.F. III (2017) *Earth & Space Sci.*, 4, 396–452. [7] Hoza K. et al. (2019) *LPSC*, Abs. #2958.

Figure 3: Mastcam-Z full-filter spectra from calibration (left) compared to full-resolution ASD spectra (right, black solid lines) and the full-resolution lab spectra convolved to the Mastcam-Z bandpasses (right, colored circles)