Progress On Iron Meteorite Detections By The Mars Science Laboratory Curiosity Rover

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Introduction: Prior to encountering Vera Rubin ridge (VRR), the Mars Science Laboratory (MSL) Curiosity rover identified a suite of iron meteorite candidates using images from Mastcam and ChemCam's Remote Micro-Imager (RMI) [1-4]. Twelve of these rocks were verified to contain elevated Fe and Ni from ChemCam LIBS data [2,4]. While on the VRR, nine additional targets were identified through Mastcam imaging [5] and confirmed as iron meteorites by ChemCam [6]. Here we expand that data set with six new finds examined by ChemCam since Sol 2255, as well as other likely candidates identified from Mastcam color images. As discussed previously [5-7], the chemical compositions and areal distributions of iron meteorites can constrain models of physiochemical weathering and the local environments experienced by these "witness plate" rocks since arrival [8-11].

Methods. Mastcam Bayer filter images were used to remotely identify candidate meteorites from as far as 60 m distance, based on the targets' textures and relatively bluish color. When within range, several candidates were targeted by ChemCam LIBS, which also provided RMI images (Fig. 1) and relative reflectance observations (400-840 nm; Fig. 2). LIBS data from as far as 9.2 m distance (Lumphanan; Table 1) were able to detect the strong emission peaks associated with Fe and Ni. Three targets were also observed using all of Mastcam's narrowband filters, as was another region that included three more distant candidates (Stone Row), from which 12-band spectra (445-1012 nm) were recorded (Fig. 2). Decorrelation stretch views of near-infrared filters (751, 867, 1012 nm) were used by [5] for identification of potential iron meteorites. Here we capitalize on the increased availability of lossless Mastcam M100 images recently afforded by large data volume downlinks enabled by the onset of MAVEN and Trace Gas Orbiter spacecraft communication relays.

These images allow improved effective spatial resolution (useful for textural and color evaluations of candidate targets), but also enabled high SNR band depth images using the Green (~550 nm) pixels in the Bayer filter pattern. The weak ~550 nm absorptions in iron meteorite reflectance spectra (Fig. 2) result in anomalously low values in Green band depth images, such that iron meteorites appear dark (e.g., Fig. 3b,d).

New finds: Six new targets were confirmed to be iron meteorites by ChemCam (Fig. 1). LIBS analyses demonstrated Ni contents ranging from 5.7 to 21.2 wt%. Although the rock surfaces were dusty, they exhibited characteristic lustrous blue-gray color, small surface impressions consistent with regmaglypts, and occasional, elongated, erosional pits. Collections of sand within these pits suggest previous episodes of partial burial and exhumation. Mastcam and ChemCam reflectance spectra (Fig. 2) were red-sloped in visible wavelengths (owing to dust coatings) but exhibited flat to positive slopes in the infrared, similar to laboratory spectra of iron meteorites (and unlike basaltic sands). Several targets exhibited nearly identical ChemCam spectra, although LIBS data suggest 3 different groups among the 6 new meteorites despite their close proximity [6]. Only Gometra exhibited purple-hued, patchy coatings associated with ferric coatings [1,11]. Other imaging targets (Table 1) share diagnostic textural and spectral properties (e.g., Fig. 3) and are likely candidates as additional iron meteorite detections.

References: [1] Johnson et al., AGU,#P51E-3989, 2014; [2] Meslin et al. LPSC,#2258, 2017;[3] Wellington et al., LPSC,#2083, 2018; [4] Wiens et al., 80th Met. Soc.,1987,2017; [5] Wellington et al. (2019) LPSC, #3058; [6] Meslin et al. (2019) LPSC,#3179; [7] Schröder, C., et al., LPSC,#6254, 2019; [8] Mansell, and Downes, LPSC,#1035, 2019; [9] Ashley, Elements, 11(1), 10-11, 2015; [10] Lasue et al., LPSC#2132, 2019; [11] Schröder et al., Nature Comm., 7, 2016; [12] Gaffey, M., JGR, 81, 905-920, 1976.

Table 1. Fe-Ni meteorite candidates discovered since Sol 2255 [cf. 5-6]. Colored rows = same rover location.

Name (informal)	Sol	Mcam SeqIDs (multispectral)	Size (cm)	CCAM SeqID	Distance (m)	Ni/Fe peak ratio ± raster std. dev.	Ni (wt%) ± 2σ
Gometra	2259, 2283,2286	12088, 12144, 12153	4	1286	4.4	0.271 ± 0.014	7.6 ± 2.0
Lumphanan	2365, 2374, 2376	12540, 12585,12633	9-10	5376	9.2	0.634 ± 0.047	21.2 ± 5.1
Quirang	2387	12677	2	5386	2.7	0.209 ± 0.014	5.7 ± 1.2
Monach Isles 2	2494, 2550	13249, 13401	11-13	2550	8.3	0.356 ± 0.100	10.4 ± 2.8
Isle_Martin	2494	13248	9	--	10.0	--	--
Stone Row (3)	2504, 2502	13291, 13270	9,11,15	--	15,21,26	--	--
Pladda Isle	2588, 2594/2595	13595, 13643	15	4594	7.0	0.232 ± 0.035	6.4 ± 1.5
Swona	2594/2595	13645	13	3594	5.3	0.621 ± 0.013	20.7 ± 4.5
Stonywynd	2595	13646	9	--	9.8	--	--

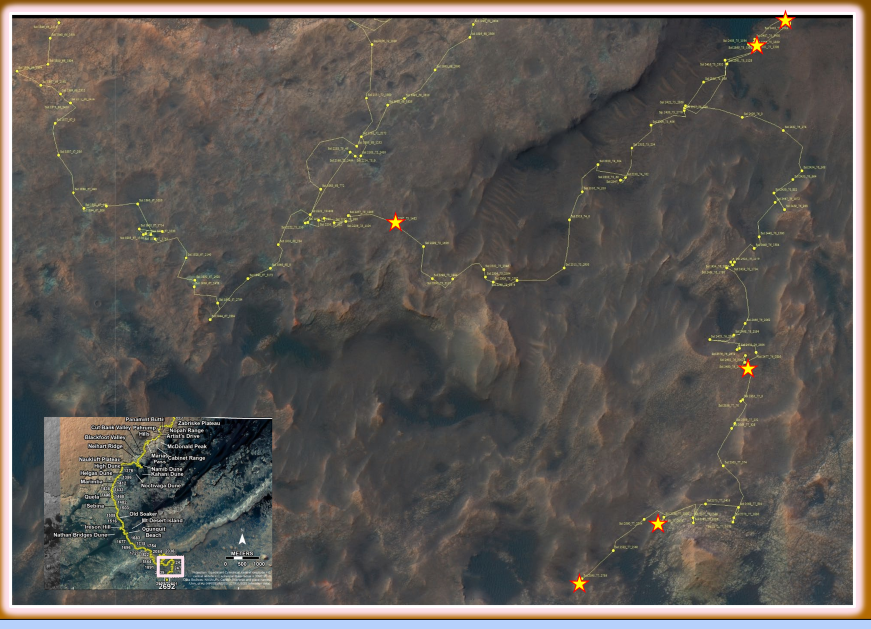

Fig. 0. Curiosity traverse map (inset shows general region), with stars at approximate locations of finds listed in Table 1.

SUMMARY

- A suite of new iron meteorites have been documented by Curiosity along the traverse in the Glen Torridon region
  - Visible/near-infrared spectra were consistent with dusty iron meteorites
    - Only Gometra shows patchy, ferric coatings
  - Six new finds verified with LIBS analyses to show Ni contents of 5-21 wt %
    - LIBS data suggest 3 different compositional groups
- Mastcam Bayer images' Green filter useful as diagnostic tool
  - Green band depth images calculated from calibrated, lossless M100 images show promise for reconnaissance detections of iron meteorites

Colorized RMI | Mastcam RGB | Mastcam "Green" band depth

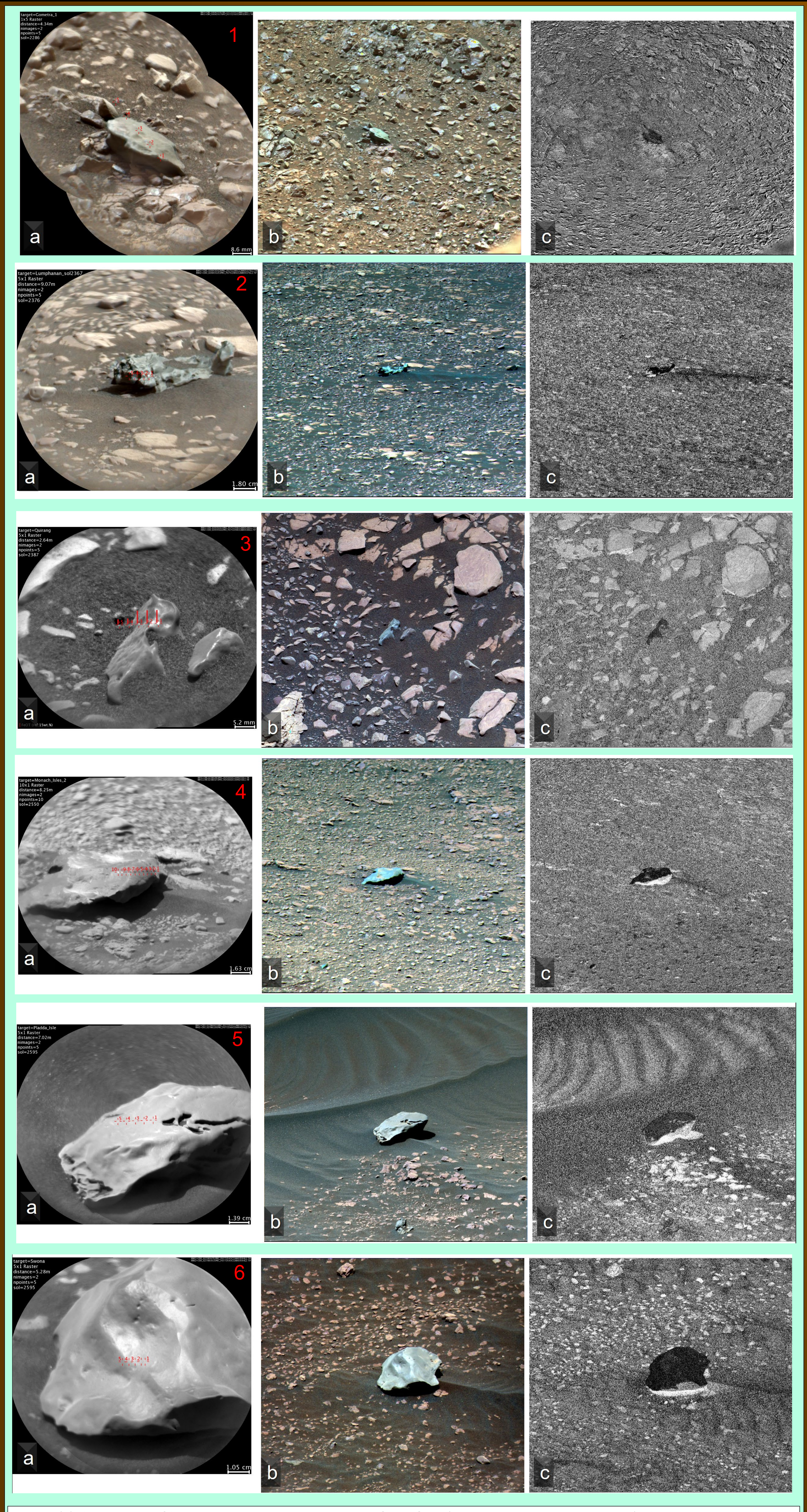

Fig. 1. (a) RMI images of 6 new iron meteorites analyzed by ChemCam (some with Mastcam color data). Red numbered crosses designate individual locations within ChemCam raster observations. Corresponding passive spectra shown in Fig. 2-left. (b) enhanced color Mastcam M100 images; (c) Green filter band depth images (1) Gometra, Sol 2286; (2) Lumpohana Sol 2367; (3) Quirang, Sol 2387; (4) Monach Isles, Sol 2550; (5) Pladda Isle, Sol 2595; (6) Swona, Sol 2595. Scale bars shown in RMI images.

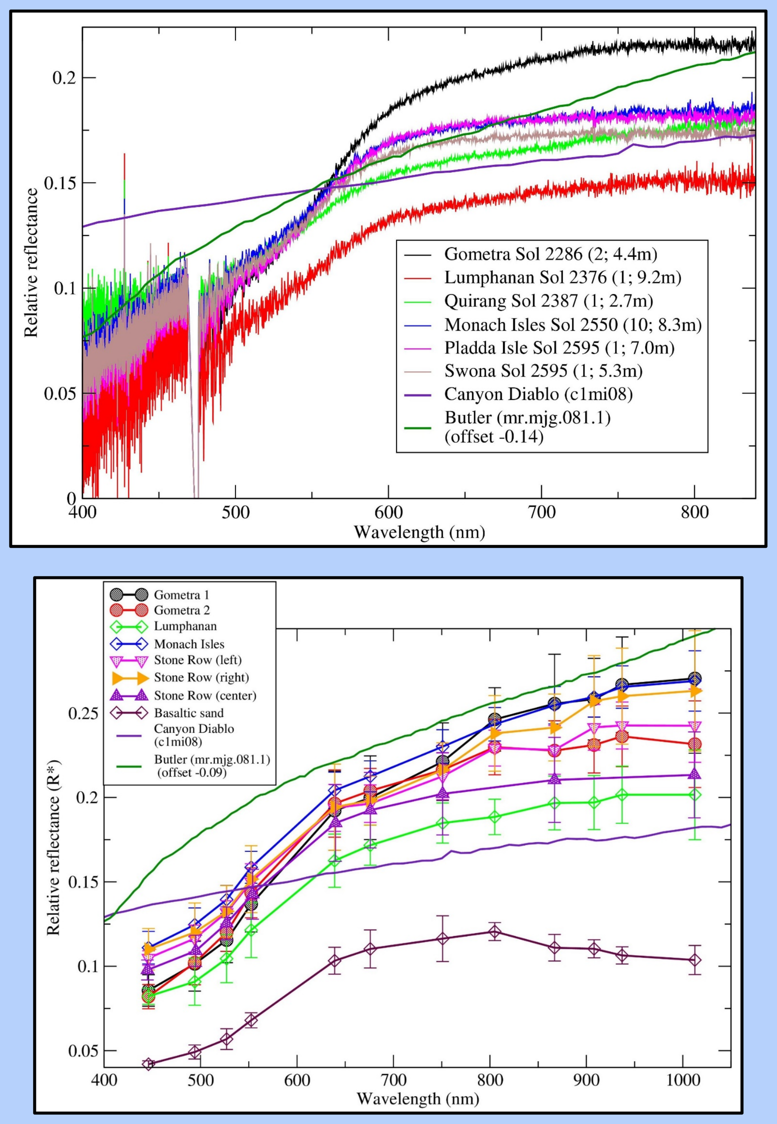

Fig. 2. ChemCam (*top*) and Mastcam (*bottom*) spectra of variably dusty iron meteorites; Mastcam spectra of basaltic sand shown for comparison. RELAB spectra of two iron meteorites also shown [cf. 12], with offsets labeled in legends.

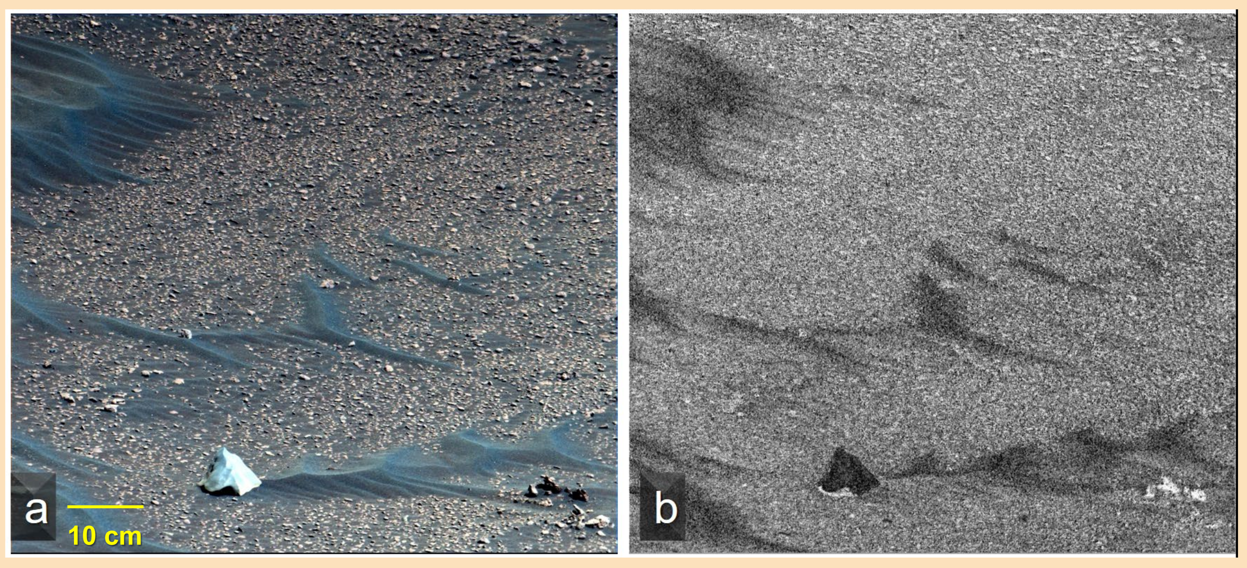

Fig. 4. Mastcam M100 RGB image (Sol 2595, mcam13646) of Stonywind; (*b*) "Green" band depth image made from Bayer RGB image.

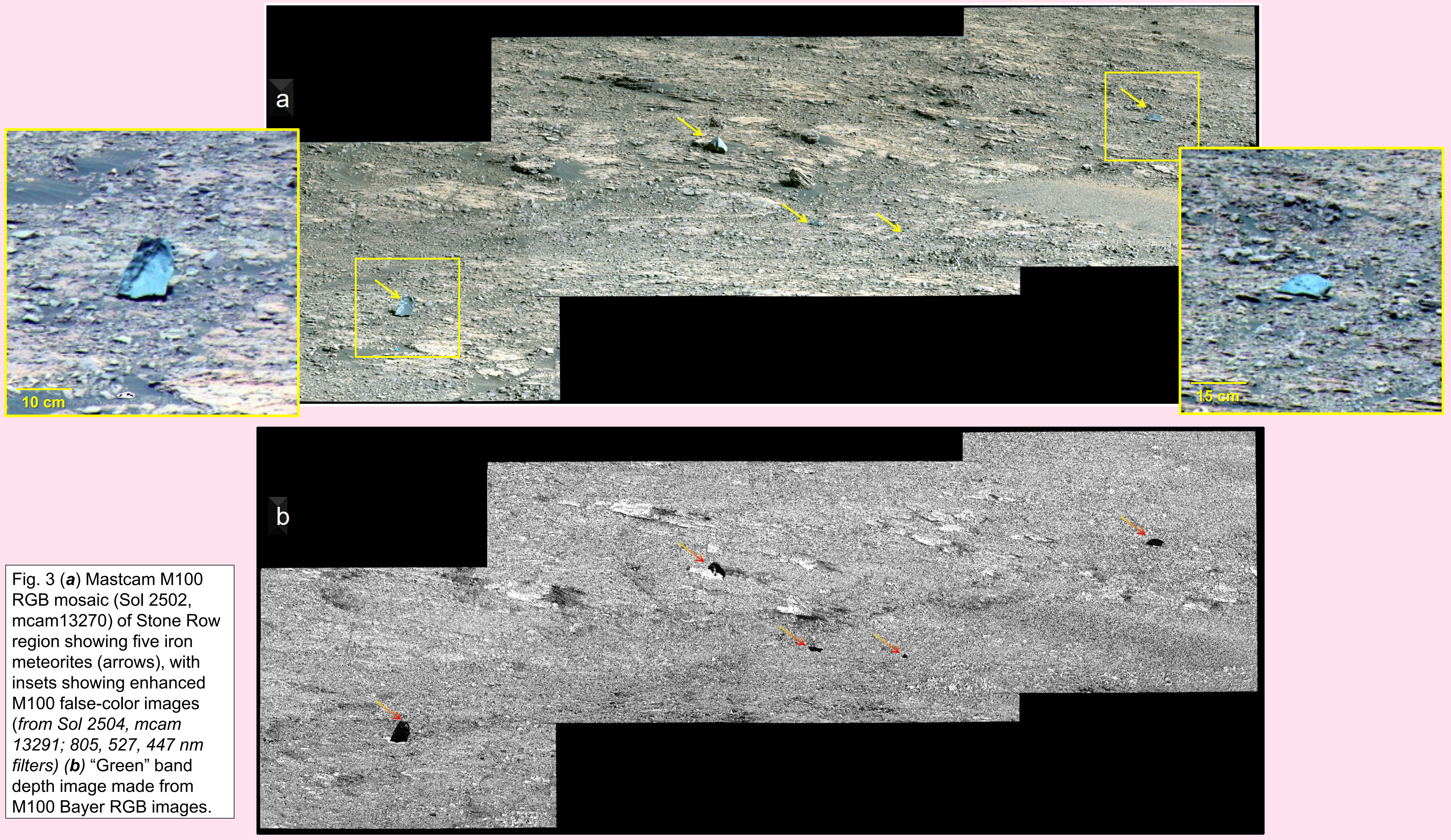

Fig. 3 (***a***) Mastcam M100 RGB mosaic (Sol 2502, mcam13270) of Stone Row region showing five iron meteorites (arrows), with insets showing enhanced M100 false-color images *(from Sol 2504, mcam 13291; 805, 527, 447 nm filters)* (***b***) "Green" band depth image made from M100 Bayer RGB images.