TOPOGRAPHIC EVALUATION OF METEORITE SURFACES ON MARS — EXPLORING AMAZONIAN CHEMICAL AND PHYSICAL WEATHERING PATTERNS.

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Introduction: After more than 15 years of ongoing rover exploration, the occurrence of weathered meteorites on Mars is well-established: More than 45 individual confirmed or candidate meteorites have been identified at three rover landing sites. Together with work addressing recent impacts [e.g., 1] and the determination of soil chemistry having a significant meteoritic component [2], these finds serve to inform a paradigm of Amazonian Mars having remained well open to its extraterrestrial environment. While the contributions and effects of these interactions have yet to be fully characterized, this suite of rocks comprise a unique database useful for exploring a range of atmospheric, surface alteration, and extraterrestrial processes [see 3; this conference]. We focus here on iron meteorite surface morphologies to help resolve Amazonian weathering processes (and their relative timing).

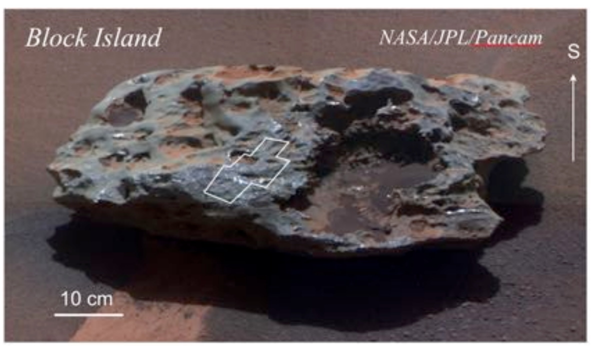


Figure 1. Pancam frame of the Block Island meteorite at Meridiani Planum The New Shoreham Microscopic Imager mosaic area is indicated in white outline.

Weathered meteorites found on Mars enhance understanding of aqueous and physical alteration processes in Amazonian environments near the equator (where all rovers have landed due to engineering constraints). As with any geologic specimen, a close examination of the surface can reveal clues to weathering and other surface-modifying processes and associated exposure history. MER Microscopic Imager (MI) frames are collected as stereo pairs that permit topographic reconstruction of target surfaces as visual anaglyphs and, with processing, Micro-Digital Elevation Models (MicroDEMs). In the special case of the Meridiani suite of iron-nickel meteorites, details of the oxide coatings [4] and other nuances of surface morphology can be assessed in some depth.

In addition, the "overprint" of surface shaping by ablation during atmospheric passage must become known in order to separate such features from those produced by weathering on the surface of Mars since ablation features (e.g., regmaglypts, pits, grooving, and fusion crusts) are indications of unmodified surfaces. Portions of the martian iron suite present an ablated appearance, and this has been used in preliminary discussions to infer surface freshness. However because of 1) the similarity in appearance of some ablation features to those produced by aeolian scouring, and 2) evidence for high volume removal from cavernous weathering [e.g., 5], this hypothesis is being tested using measurements of suspected regmaglypts and associated ablation features in comparison to those of curated terrestrial analog samples.

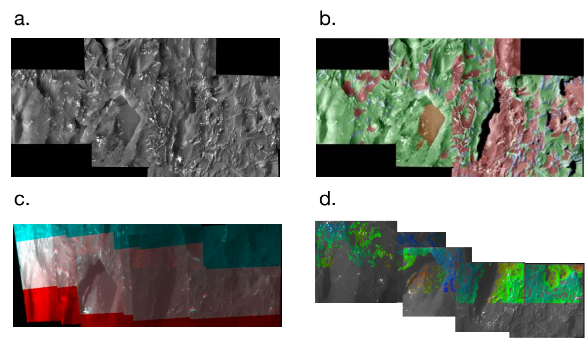
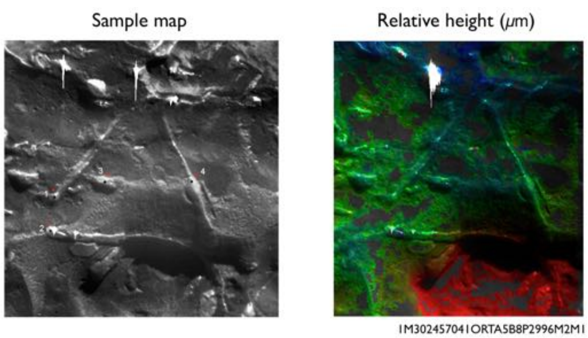


Figure 2. The New Shoreham Microscopic Imager dataset has been revisited to produce anaglyphs and Micro-Digital Elevation Models using respective MI frame stereo pairs. The original mosaic (a) has been mapped to reveal oxide coating coverage, bare metal surfaces, and expressions of the Widmanstätten pattern (b). (c) stereo anaglyph mosaic. (d) preliminary micro-DEM coverage. North is the right; width is approximately 12 cm. Image credit: NASA/JPL/MI/MIPL.

Methods: MicroDEM creation using MI stereo pairs has been performed for the Block Island and Shelter Island meteorites to assess surface topography on a micrometer scale. Since the MI camera is monoscopic, the MicroDEM is generated using simulated stereo by taking two images of a target, one with the camera shifted to a slight horizontal offset. With stereo imaging, the location of each pixel in 3D space can be found. The 3D data is then projected onto a defined vector, representing the normal of a surface plane. The projected data makes up the MicroDEM, displaying the height of each pixel relative to the defined surface plane. Because of surface curvature, the mosaicked version of the MicroDEM must define serveral reference planes and these are taken into account when making local measurements.

In addition, the larger scale surface morphologies of exogenic rock on Mars are being addressed indirectly through comparison with 3D digital models of terrestrial analog samples. Several iron meteorites (Sikhote-Alin, Canyon Diablo, and Bruno) were examined and imaged using standard SLR camera equipment at the Center for Meteorite Studies (CMS) at Arizona State University. Visualization models were created at JPL using multiview photogrammetry (Structure from Motion). Masking to remove non-meteorite sections of the images was key to successful 3D reconstruction. Placing meteorites on a white turntable inside a shadow-free lightbox (AmazonBasics Protable Photo Studio) greatly reduced the effort required for image masking. Agisoft Meshlab and Blender 3D graphic software are used for reconstruction, UV-unwrapping, and visual rendering. Because high-resolution images are used to blanket the point cloud surfaces, the models can be used for intimate visual study in concert with the topographic data (typically of coarser fidelity within the model). Massive iron meteorites weighing many tens of kilograms can be re-oriented easily for direct measurement of any surface feature. Topographic information penetrates to regions deep within recesses due to lighting geometry used at the time of imaging.



Spot	Red (coating height)			Black (pattern height)			ΔZ (μm)
	X	Y	Z (μm)	X	Y	Z (μm)	
1	734.55	574.688758	497.82	738	577.183649	560.76	62.94
2	721.86	586.495278	681.88	727.63	589.156725	784.87	103.00
3	867.16	568.703078	708.58	861.39	571.862473	914.57	205.99
4	1087.4	569.367581	288.01	1074.71	571.695918	569.34	281.33

Figure 3. Example of Widmanstätten pattern within the New Shoreham MI mosaic showing details at the micron scale using MicroDEM examination. Height measurements of the resistant plates (likely either taenite or schreibersite) and the surrounding coating confirm the cross-cutting relationship inferred visually in [5]; see table inset.

Preliminary results: The MicroDEMs have permitted the quantitative re-visiting of features identified and discussed qualitatively in [5], and confirm topographic cross-cutting relationships between the oxide coating and Widmanstätten patterns on Block Island (see Figures 1-3). The finding shows the coating to be genetic to the martian surface environment, forming after landing of the meteorite on the martian surface (i.e., not a fusion crust), almost certainly from exposure to thin films of water or hydrogen peroxide. Additional evidence shows the coating to be in a state of removal in the current epoch, suggesting low strength as expected for an oxide coating, and indicating production in a previous (but recent) epoch.

Morphometrics for quantifying the larger-scale features of meteorite surfaces include the centerpoint to centerpoint spatial distribution of hollows to address the troilite acidification hypothesis outlined in [5-6]; and depth, diameter, and orientation geometry of scallops, flutes and regmaglypts to address ablation-related surface morphologies relevant to post-fall modification severity (important for establishing weathering rate/fall timing relationships), and possible paleowind direction imprints (example as Figure 4).

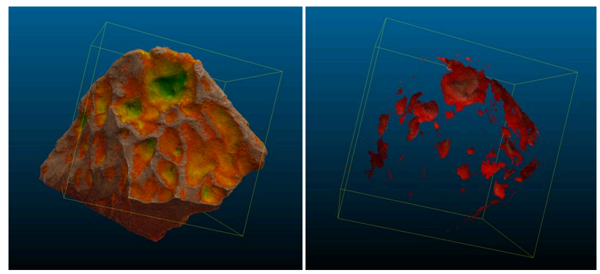


Figure 4. Regmaglypts and other surface hollows from atmospheric ablation can be characterized and isolated digitally on terrestrial analogs, as illustrated here with the 12.7 kg iron meteorite Bruno. Bruno exhibits classic regmaglypt and associated flow structures with striated fusion crust. Center for Meteorite Studies specimen.

Ablation feature morphologies on terrestrial irons can vary depending on size, orientation during fall and fall velocity/duration [6]. However, our preliminary results suggest that these features can be quantified and distinguished from those produced post-fall as environmental modifications. To a first order, at least some of the features identified in our datasets appear to be the result of ablation, and are thus consistent with the premise that Block Island may be close to its original post-fall size. Further analysis should help resolve this question definitively.

References: [1] Daubar I. J., et al. (2013) *Icarus* 225, 506-516. [2] Yen A. S., et al. (2005) *Nature*, 436, 49–54. [3] Schröder C., et al. (2019) This conference. [4] Schröder C., et al. (2008) *J. Geophys. Res*., 113. [5] Ashley J. W., et al. (2011) *JGR* 116. [6] Buchwald (1975) Handbook of Iron Meteorites, 1418 pp., *Univ. of Calif. Press.*