MORPHOLOGIC EVIDENCE FOR MECHANICAL AND CHEMICAL WEATHERING OF THREE NEW IRON-NICKEL METEORITES ON MARS — PROCESS INSIGHTS FOR MERIDIANI PLANUM.
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Introduction and Background: Meteorites found on the surface of Mars are useful for probing a variety of important Mars- and meteoroid-related problems [1]. Arguably their most immediate usefulness to the scientific objectives of the Mars Exploration Rover (MER) mission is that of their alteration history.

Figure 1. Traverse map showing the locations of Block Island, Shelter Island, and Mackinac Island meteorite finds (red-filled circles). The rocks are located near Nimrod crater, eroded to a faintly recognizable ghost feature at Meridiani Planum. Image credit: NASA/JPL/HiRISE.

Approximately 4.2 km along Opportunity’s traverse toward Endeavour crater following its exit from Victoria crater, the first of a suite of three large iron meteorites were identified at locations less than 1 km from each other, and all near the Nimrod ghost crater (Figure 1). In order of discovery, these have been assigned the unofficial working names of Block Island, Shelter Island, and Mackinac Island. This abstract presents morphologic descriptions and discusses interpretations based on morphology and possible weathering history. Associated abstracts presented at this conference discuss the meteorites’ Mössbauer and APXS data [2], photometric properties [3], provenance [4], and context within the MER-B mission at large [5].

Block Island. Opportunity arrived at Block Island on Sol 1961. In broad outline, the iron-nickel rock appears somewhat pillow-shaped, with rounded upper and lower surfaces, and rests as the protective “caprock” of a 4 cm-high hoodoo pedestal. This suggests that the meteorite came to rest on the outcrop and saltating sand differentially eroded the weak sulfate underneath. The largest meteorite yet identified on Mars, it is approximately 60 cm across its long axis, with a calculated hemispherical mass of 425 kg (Figures 2a, 2b). It is heavily pitted, with several of the hollows containing hematite blueberries, and exhibits a distinct dichotomy in its surface roughness. Approximately ⅓ of its exposed surface, including the south-facing portion, appears worn and rounded with smooth outlines to the pits. These rounded edges and pitted surfaces are similar to meteorites with reg-
malaglypts that form by ablation in the atmosphere during entry and descent, although subsequent eolian modification could have also contributed. The presence of blueberries in the hollows to only ~14 cm above the ground surface argues that at some time one or more ripples migrated over the meteorite up to this height (but no higher), and left the granule blueberries (which are too large to saltate) behind. The remaining quarter of the exposed upper surface and its western undersurface appear significantly more rough and angular in their features, and display specular reflections in Pancam imagery not seen on the rounded portions. The pitting across this latter surface is also more angular in outline.

In addition, and perhaps more significantly, Block Island presents a large (~20 cm), cavernous pit within this rougher side. The hollow is approximately oblate in outline, and coalesces with a number of smaller, nearby pit features. It is also rimmed by an irregular network of relict metal protuberances or “skeletons,” and shelf-like structures. Some of these features appear remarkably fragile (Figure 2c). These may suggest that 1) a porphyritic inclusion mass once present has been removed, and 2) a corrosive process may have been involved. MI images show clear indications of a differentially eroded Widmanstätten pattern, and a discontinuous coating is present across much of the meteorite’s surface (Figure 2d). A coating of this kind is also observed on Meridiani Planum (MP; also known as Heat Shield Rock) located 9.6 km to the north of Block Island [6]. The full Instrument Deployment Device (IDD) instrument suite was employed at several target areas over a nearly six-week period on Block Island, and a six-station 360˚ Pancam/Navcam mosaic was acquired prior to departure.

**Shelter Island.** Figure 2e presents a false color Pancam image of Shelter Island, first encountered on Sol 2022. It has a long dimension of ~50 cm, and would have a mass of ~245 kg if it were a hemisphere, but it is more likely closer to half this mass. By contrast with Block Island, this rock does not show a particularly distinct roughness dichotomy, but does include what appears to be at least one inclusion or other resistant mass weathering out of the groundmass, together with large-scale excavations penetrating deeper into its interior than observed in Block Island. This meteorite is generally more weathered than Block Island, with large spires of residual metal betraying extensive erosion along a northeast-southwest axis. Other portions of the rock still appear relatively fresh with smooth surfaces and hollows suggesting those portions were ablated by the atmosphere during entry and descent, and were subsequently protected from erosion. Pancam and Navcam images were collected from three circumferentially spaced standoff positions, together with IDD instrument placement on one surface target location. As with Block Island and MP, Shelter Island presents differentially eroded Widmanstätten lamellae and a surficial coating. This coating, however, appears somewhat more continuous in the target area than was seen on Block Island.

**Mackinac Island.** This meteorite, encountered on Sol 2034, is the smallest of the suite at 30 cm in diameter (comparable to MP), and a hemispherical mass of 50 kg. The rock exhibits an even-more severe example of mass removal showing an excavated interior, appearing similar to cavernous weathering (tafoni), along a southeast-northwest axis (likely significantly reducing its calculated mass), with a metal lacework all that remains of the former mass in some regions (Figure 2f). Mackinac Island was imaged from three standoff positions, but was not targeted by IDD campaign. Portions of Mackinac Island appear smooth with rounded hollows suggesting preservation of atmospheric ablation effects. Finally, like the other meteorites, blueberries are found in hollows suggesting it too was buried at some time after landing by one or more ripples.

**Discussion:** Evidence for weathering processes has been observed on MP, but the qualitative nature and extent of these features has always been ambiguous [6, 7]. These three new meteorites present several lines of evidence to confirm both mechanical and chemical weathering processes at Meridiani Planum. Trolite and/or other inclusions may offer a weaker material for erosive forces to attack. Once initiated, they may then represent a preferred path of erosion and become enlarged with time, eventually resulting in the hollowing effect we see in Mackinac Island. The differences in weathering state between the three along with different weathering faces (north versus northeast versus northwest) may represent different residence times, burial depths, or environments.

It is possible that the fragile features within the cavernous pit on Block Island are the result of very subtle mechanical abrasion effects, but this is difficult to reconcile with the shape and angularity of the features. They are more likely the result of acidic corrosion, which would have occurred at some time after landing at Meridiani. Based on topographic crosscutting relationships with the differentially eroded Widmanstätten pattern, the oxide-rich coatings on Block Island [2] appear to further indicate an aqueous alteration process. More than one exposure event may be represented (e.g. groundwater interaction for the pit versus ice interaction for the coating).

These are preliminary findings. The loss of the Hesperian cratering record at Meridiani suggests 10-80 m of deflation win the past 3 Ga [8], and a history of acidic water interaction with the bedrock earlier in the Noachian [9] suggest that a variety of potential environments might have contributed to the weathering of these meteorites, depending upon when they landed. Continued study of these witness samples may provide further insights into the details of those processes.

It should be emphasized that calculating residence times for meteorites found on Mars is poorly constrained. The only observation at present that provides some constraint is that they were likely buried at some time after landing by the granule ripples at Meridiani, which appear to have been inactive for the past 100 ka [10]. That argues they landed prior to 100 ka, but little argues against their landing > 3 Ga. The discovery of highly weathered meteorites provides a fine example of how extended mission phases for MER continue to yield strong scientific returns.