AMORPHOUS MARS: INTERPRETING GROWING EVIDENCE FOR POORLY/NON-CRYSTALLINE PHASES IN MARTIAN MATERIALS.

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Introduction: Recent results from the CheMin instrument on the Curiosity rover in Gale crater show that approximately half of the sampled basaltic material from an aeolian drift is x-ray amorphous [1]. This adds to a growing list of observations of poorly- or non-crystalline phases (hereafter referred to as amorphous) identified in Martian materials. Laboratory measurements of Martian meteorites, orbital remote sensing, and rover-based observations all have shown evidence for amorphous phases [e.g., 2; 3; 4]. Although the evidence is robust, in some cases it is not clear whether these phases are primary or secondary in origin or perhaps indicative of phyllosilicates. Here we present a new effort to re-examine the many examples of rocks identified by the Spirit rover in Gusev crater that bear evidence of amorphous phases. The goal is to better understand the nature of such materials found elsewhere on the Martian surface.

Spirit Observations: The Spirit rover payload included a suite of instruments capable of measuring bulk mineralogy (Mini-TES), Fe mineralogy (MB), elemental chemistry (APXS), as well as science-oriented cameras for color (Pancam) and microscopic imaging (MI). In addition, a rock abrasion tool (RAT) was used to brush and grind into rock surfaces [5]. The following is a description of the range of rocks in which amorphous phases have been recognized.

Coated rocks. A heavily wind-abraded, large (~1 m long dimension) rock named Mazatzal on the rim of Bonneville crater on the Gusev plains shows the first unambiguous evidence for a coating [6] (Fig. 1). Recent results based on Mini-TES thermal infrared (TIR) spectra [7] demonstrate that the coating is dominated by an amorphous component of basaltic composition that is modeled spectrally as basaltic glass (Fig. 2). Data from the other instruments provide clear evidence that the coating derives from some form of aqueous alteration of the olivine basalt substrate [8], yet it does not present a mineralogy typical of coated terrestrial basalts (e.g., amorphous silica; phyllosilicates). It may however be analogous to leached rinds suggested for sand grains in Acidalia Planitia and Siton Undae [9].

Phyllosilicate-associated rocks. The West Spur of the Columbia Hills is dominated by layered clastic rocks known as Clovis class. Despite clear evidence for aqueous alteration, Mini-TES spectra of these rocks are well modeled using a basaltic glass spectral component with an abundance of ~50% [10] (Fig. 2). A new analysis of visible/near infrared (VNIR) spectra from the orbiting CRISM instrument reveals that much of the West Spur shows evidence for Fe-rich phyllosilicates [11]. Such phases have not been identified in either Mini-TES or MB spectra [12], so the conflicting observations remain unreconciled.

A similar situation exists with the Independence class rocks on the north side of Husband Hill. Here Mini-TES spectra are modeled with dominantly amorphous phases that include aluminous opal and perhaps maskelynite in addition to basaltic glass [13] (Fig. 2). The APXS chemistry of these rocks is distinct from all others encountered by Spirit, showing evidence for as much as 80% montmorillonite following subtraction of the elements associated with accessory Mg-sulfate, apatite, and ilmenite [13]. This contrasts with the tentative identification of 5% montmorillonite modeled in Mini-TES spectra. Such disparity may imply that montmorillonite is present in great abundance but is structurally amorphous [13].

Figure 1. MI/Pancam merge of Mazatzal RAT hole (~45 mm diam.) showing dark coating on left side [6] dominated by an amorphous phase(s) [7].

Pyroclastic rocks. The Home Plate feature in the inner basin of the Columbia Hills is a 1-2 m high plateau of layered pyroclastic rocks ~80 m across with a moderately altered alkali basalt composition [14]. Mini-TES spectra are modeled with basaltic glass at ~40% abundance [15] (Fig. 2). The identification of a major glass component is consistent with evidence for explosive emplacement (lapilli; a volcanic bomb sag) and suggests that it is a primary amorphous phase.

Opaline silica rocks. Adjacent to Home Plate are hydrothermally-derived rocks rich in opaline silica [4] that occur as eroded, stratiform outcrops with brecciated microtextures in some cases that resemble siliceous sinter [16] (Fig. 3). The unambiguous spectral characteristics of opal-A dominate the Mini-TES spectra (Fig. 2) and provide unequivocal evidence of an aqueous origin. The absence of microcrystalline quartz or paracrystalline silica phases demonstrates the persistence of amorphous silica on the Martian surface for billions of years [16], a situation unknown on Earth.

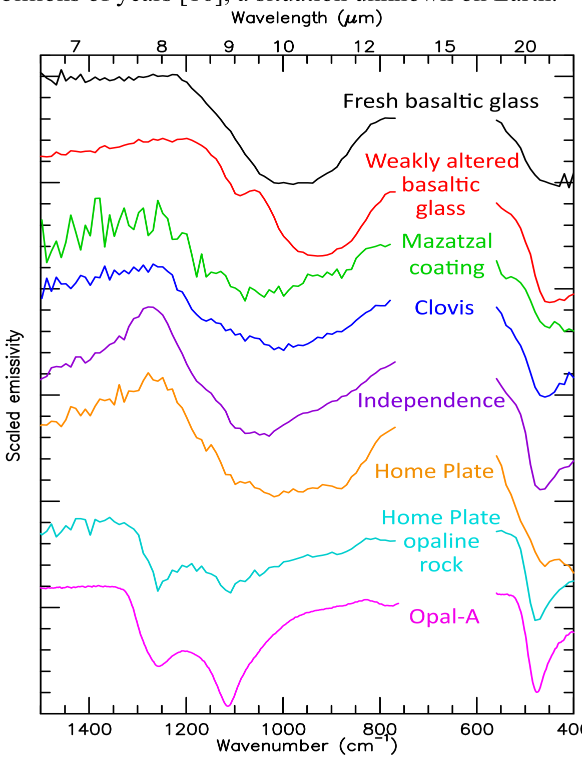

Figure 2. Mini-TES spectra of amorphous materials in Gusev crater and laboratory spectra of materials that resemble them. Region of CO_2 absorption is excluded.

Discussion: Rocks encountered by Spirit that contain abundant amorphous phases represent a microcosm of observations from across Mars. Coatings have been invoked to explain various remote sensing observations and are substantiated in at least one definitive example with Mazatzal. Clovis class rocks encapsulate the persistent disparity between VNIR and TIR detections of phyllosilicates. Home Plate rocks provide ground truth for both explosively emplaced basaltic rocks and hydrothermally-derived products.

With recent funding from the Mars Data Analysis Program, we are revisiting the Mini-TES spectra and accompanying data of rocks with amorphous phases. We will use an expanded set of reference materials of amorphous phases that were not available when initial analyses were undertaken and modeling techniques that proved useful in our recent study [7]. Results will be presented that are expected to help address disparities or ambiguities in the interpretation of these rocks and provide a basis for broader interpretations of remotely sensed data and perhaps new Curiosity results.

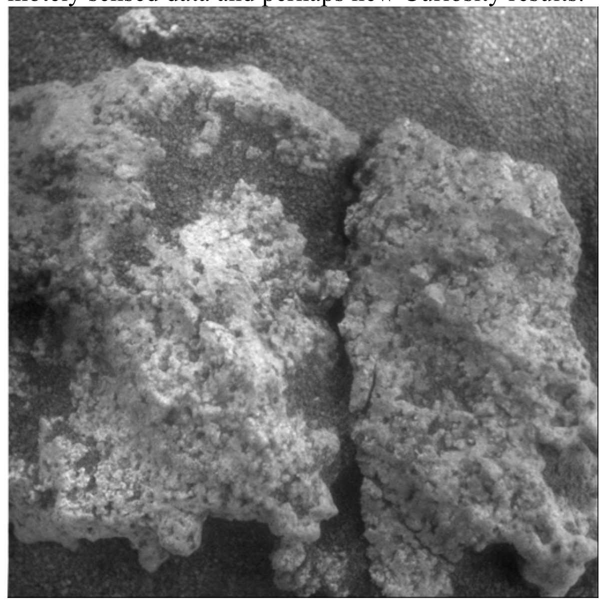

Figure 3. MI image (~3 cm across) of opaline rock with brecciated microtexture similar to sinter [16].

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