MARTIAN IMPACT CRATERING AND MARTIAN LAYERED SEDIMENTS. D. M. Burt[1], L. P. Knauth[2], and K. H. Wohletz[3] [1]School of Earth and Space Exploration, Arizona State University, Box 871404, Tempe, AZ 85287-1404, dmburt@asu.edu, [2]same, knauth@asu.edu, [3]Los Alamos National Laboratory, Los Alamos, NM 87545, wohletz@lanl.gov,.

Introduction: Continued exploration by the two Mars rovers Spirit (near a feature called Home Plate inside Gusev Crater) and Opportunity (in the vicinity of and now inside an impact crater called Victoria, Meridiani Planum area) has revealed layered, fine-grained sediments that appear to resemble each other closely, consistent with earlier rover exploration in those areas. Common characteristics include fine grain size, fine layering, abundant cross-beds (mainly at shallow angles, but also with apparent trough shapes), salty nature (locally especially sulfate-rich at Meridiani Planum), enrichment in acid sulfates (identified as mainly jarosite at Meridiani and unspecified inside Gusev) and local presence of tiny spherules in the rock (far more abundant and hematitic at Meridiani). A feature so far unique to Meridiani sediments seems to the extremely local presence of tiny crystal-shaped cavities in the layered rocks; features unique to Home Plate are the presence of a single small impact sag in bedding and of very slightly coarser-grained rocks at the very base of the exposed section (similar, less resistant layered rocks appear to lie beneath).

Despite this extremely close family resemblance, layered sediments at the two areas have been ascribed to totally different causes. For Home Plate, phreatomagmatic volcanic surge deposition is favored [1], with possible eolian sedimentation at the top, whereas for Meridiani Planum, the favored explanation [2,3] involves an extremely complex series of events involving acid playa lake sedimentation and salt evaporation, wind transport and deposition of mixed soluble salt grains, multiple episodes of ground water rise and fall through these salty sediments, wind erosion of salty sand grains and more evaporation, surface water flow that didn't dissolve any salts, and formation of hematitic concretions over a wide area in perfectly permeable salt-sands. A more recent idea for Meridiani has it being a super-giant desert oasis, fed by evaporating artesian acid springs from a planetary-scale confined aquifer.

One problem with these completely different explanations for very similar appearing rocks is that orbital imaging has revealed that they are far from unique [4]. That is, thick sequences of very similar appearing ancient layered rocks rich in sulfates (and with occasional cross-beds visible even in orbital images, and some intermediate boulder beds) appear to be widespread in the equatorial regions of Mars, near the topographic edge of the heavily cratered Southern Highlands. The conventional explanations have mainly included some combination of sedimentation by wind, water, glaciation, or explosive volcanism. Beginning with talks in 2004, we suggested a far simpler idea – impact surge sedimentation [5,6] caused by intense impact cratering during the tail end of the Late Heavy Bombardment at about 3.8 Ga. This simple explanation is consistent with the heavily cratered nature of Mars and accounts for virtually all features observed to date, without the improbabilities and inconsistencies inherent in some alternative explanations. An objection often voiced for this explanation is that there are virtually no terrestrial analogs, owing to constant tectonic and erosional destruction of non-marine soft layered rocks (including impact-derived sediments). Surge deposits associated with recent volcanic and nuclear explosions therefore provide the best observable terrestrial analogs. Ancient lunar impact materials provide a poor analog owing to the Moon's lack of atmosphere and subsurface volatiles.

On cold, dry, yet volatile-rich Mars, with its utter lack of tectonics, rainfall, or chemical weathering, impact-derived fine sediments appear subject only to extremely slow erosion by the wind, as possibly observed at both rover landing sites and from orbit. The distal facies of an impact surge cloud derived from a frozen, salty and/or briny basaltic target could account for all of the sedimentary features observed by the rovers [5]. Likewise, phenomena associated with vapor condensation in the steamy surge cloud could explain the blue-gray hematitic spherules at Meridiani, including their uniform sphericity and size, general lack of clumping, Ni-enrichment, high temperature origin indicated by shiny (specular) hematite, and huge lateral extent [5]. The acid sulfates can be explained via either direct acid condensation in the sulfur-rich surge cloud or by weathering of impact-excavated sulfides [6]. Diagenesis and weathering (including preferential frost leaching of chlorides, possibly leaving the crystal cavities) would have followed impact deposition.

Home Plate area, Gusev Crater: Cross-bedded sediments in this area have been related [1] mainly to interactions of basaltic magma with briny groundwater (phreatomagmatic or hydrovolcanic explosions). Evidence in favor of this volcanic surge hypothesis is the basaltic nature of the fragmental rocks in the vicinity, what appears to be an isolated bedding sag ("bomb sag") resulting from a piece of ballistic ejecta, the non-horizontal nature of much of the bedding (original dip is characteristic of many damp surge deposits) and the local presence of some extremely silica-rich fragments reported from a small swale called "Silica Valley" (stratigraphically beneath Home Plate proper). These rocks are presumed to record the effects of hydrothermal alteration. Finer grained rocks on top of Home Plate have been described as having a possibly eolian nature [1], despite their lack of large dune forms, perfect conformity with the steeply dipping surge beds beneath, and apparent lack of a means of cementing them (damp surge beds are basically self-cementing).

Other problems with this hypothesis include the complete lack of volcanic features in the vicinity (no explosion craters or maars, tuff rings, cinder cones, lava flows, or other volcanic constructs) and the lack of direct signs of hydrothermal alteration (no quartz veins, alteration haloes, or siliceous mounds, for example). Also, hydrothermal alteration of basalt typically doesn't produce silica rocks – rather it forms blue-green and green trioctahedral clay minerals and micas, plus epidote and possibly albite. Finally, given their common formation during impacts, ballistic ejecta are hardly unique to exploding volcanoes, as was inferred.

All the rocks imaged by the Spirit Rover to date are fragmental, and range from accumulations of large blocks to very fine-grained cross-bedded sediments. Available exposures provide little evidence that the fragmental siliceous rocks formed by hydrothermal or hot springs alteration of basalt in place. Therefore, they probably represent a mechanical mixture with the basalt, excavated by impact elsewhere. The simplest hypothesis is that all of the fragmental rocks seen to date are impact-derived. In addition, some of the highly vesicular ejecta blocks scattered across the surface could be fragments of impact melts, rather than of basaltic lava flows.

Meridiani Planum: Available evidence generally fails to support the extremely complex series of aqueous events suggested to have formed the layered rocks at Meridian Planum [2,3]. The beds are flat-lying and salty, as in a playa lake, but little else supports the interpretation. None of them resemble lake beds or evaporite beds, even where excavated by impact cratering, because they are sandy and invariably cross-bedded (both impossible for standing water). The salt mixture, apparently consisting mainly of nearly insoluble Ca-sulfate and highly soluble Mg-sulfates, seems incompatible with a playa lake origin (instead it resembles a mechanical mixture), as is the near lack of chloride salts (despite a high Br/Cl ratio indicative of extreme fractional crystallization of chloride salts). The highly acid lake or ground waters needed to precipitate jarosite appear incompatible with the highly fragmented basaltic regolith of Mars. The failure of soluble salts to recrystallize into larger crystals is inconsistent with repeated brine immersion, as is the continued friability and apparent permeability of the beds. (Recrystallized salts in evaporite beds are the least permeable rocks known – the best cap rocks for petroleum and natural gas deposits, and a preferred site for nuclear waste storage.)

Inferred surface flow of salty sands in water currents appears inconsistent with the horizontal nature of the surface and the lack of a braided stream pattern or any other channels (not to mention solubility problems for the salts). The sole evidence for such surface flow, alleged trough-shaped cross-beds or "festoons" appear ambiguous in origin (they also form in surge deposits) and many appear to be simple topographic artifacts caused by the constant elevation of the PanCam instrument. An aqueous concretionary origin for the hematitic spherules is inconsistent with their perfectly spherical shape, their failure to clump together in masses, their strict size limitation of about 5 mm, their uniform and extremely widespread distribution in the rocks, their Ni-enrichment, and their apparent high-temperaturre or hydrothermal origin (high content of shiny or specular blue-gray hematite). Actual hematitic concretions tend to be reddish-brown lumps or ellipsoids, commonly of highly irregular shape, size, and distribution. The spheroids at Meridiani in many respects resemble widely-distributed accretionary lapilli formed by terrestrial impact craters, such as Sudbury, Alamo, and Chicxulub, just as the cross-bedded sediments resemble distal surge deposits formed by volcanic or nuclear explosions. Their surface appears to have been reworked many times by later impact events, possibly burying coarse ejecta.

Conclusion: Given the problems with the "vanished volcano" explanation for Home Plate and the "vanished playa" explanation for Meridiani Planum, and the abundantly cratered nature of Mars, we hypothesize that most of the finely layered, cross-bedded ancient rocks of Mars formed as impact-derived sediments, mainly impact surge and/or fallout deposits. Intense cratering on a planet with an atmosphere and abundant subsurface volatiles should have deposited such rocks.

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