IMPACT SURGE AS THE SIMPLEST OF THE PROPOSED HYPOTHESES FOR THE ORIGIN OF SEDIMENTS AT THE OPPORTUNITY LANDING SITE ON MARS.

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Introduction: Following its original interpretation that sediments at the Opportunity landing site on Mars were deposited by evaporation of salty surface water [1], the Mars Exploration Rover (MER) Athena team team now argues for a "remarkably complex" sequence of events involving eolian deposition of medium to coarse sand grains where each grain is composed of a uniform mixture of sulfates and basaltic particles <100 microns in size [2,3]. Following deposition, diagenetic alteration occurred in an acidic aquifer that rose and fell up to 4 times. Festoon cross lamination is considered evidence that at least one rise surfaced and flowed short distances on the surface. Hematite-rich spheroids are still interpreted as concretions that replaced preexisting grains. The scenario requires and invokes adjacent playa lakes where sulfate formed by evaporation.

Difficulties. The new scenario, while not unreasonable, has difficulties including: 1) Surface flows are based on the questionable [4] assertion that aqueous flow is uniquely indicated by small-scale festoon cross bedding. Additionally, some of the claimed festoons are clearly erroneous (Fig 1.)

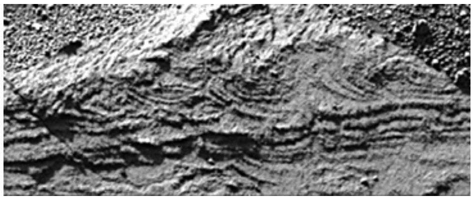

Fig 1. Erosional topography etched into boulder of flat laminated sands yields countour–like patterns misinterpreted as festoon cross bedding. JPL MER news release, 1/6/06

2) Planar and low angle crossbedding is the dominant sedimentary structure. While present in ancient eolian sandstones on Earth, such flat laminated sand is rarely dominant relative to the more common high angle cross sets. 3) The scenario invokes vanished playa lakes to account for the inferred evaporitic origin of the sulfate. Sulfate is turning out to be common on Mars, even on canyon walls [5]. A process other than vanished playa lakes seems necessary. Sulfate is not uniquely evaporitic on Earth where it occurs as arid region weathering of sulfides in mine dumps, in hydrothermal deposits, in pyroclastic rocks [6], impact ejecta [7] and even as fracture fills in the deep ocean. 4**)** The identification of the well rounded primary grains 0.1 to 1.0 mm [2] is problematical. Sulfates have perfect cleavage and should be more angular if truly detrital. The "grains" more strongly resemble diagenetic growths or wind-abraded efflorescences. 5) A process that would *uniformly* mix basaltic grains <100 microns into sulfate grains is difficult to envision. Even if the basalt mud were a component of the grains, density differences make it unlikely that its distribution would be so completely uniform in far-migrating wind ripples. In any case, acid waters would completely alter such tiny basalt particles into clay minerals. 5) Zolotov [8] has presented a compelling argument that regional acid aquifers on Mars are untenable because acid would be quickly neutralized by reaction with basaltic material. Furthermore, any analysis of diagenetic history requires detailed and reliable mineralogical knowledge of the cements and recrystallization products combined with careful textural analysis of thin sections with a petrographic microscope. Attempts to construct complex diagenetic scenarios without such knowledge should be considered tentative possibilities rather than confirmation of large amounts of water. Diagenetic scenarios involving only small amounts of acid interstitial waters over long times provide an alternative general explanation for crystal growth and dissolution [4]. 6) No surrounding recharge area is identified for the enormous acid aquifer.

Alternative hypotheses: Two alternative hypotheses have emerged so far: 1) fumarolic alteration of a volcanic base surge in hydrothermal fluids [9] and 2) slow, cold arid-region weathering of an impact surge deposit [4]. Although possible, the volcanic base surge has major difficulties including: 1) Volcanic base surges extend out only several crater diameters. No nearby volcanoes are apparent in orbital imagery. Silicic volcanic craters on Earth can blow out, collapse into calderas, and get covered with their own ejecta to become concealed, but this is not a likely scenario for basaltic volcanoes because they do not have this eruptive style. 2) The apparent sulfate excess driving the hypothesis is based on closed system alteration. It is less tenable if components can enter and leave the system over the 3 billion years available. 3) Alunite and other predicted reaction products have not been detected.

Further evidence for impact surge: The impact surge scenario [4] has none of the problems above and remains a simple interpretation using a minimal number of hypotheses. It involves small amounts of water consistent with the post-Noachian "cold and dry" paradigm, and invokes only processes previously known or inferred for Martian history.

Changes in the vertical sedimentary sequence exposed at Burns Cliff are common in terrestrial base surge deposits. High angle cross sets are commonly overlain by low angle cross beds and flat beds (Fig 2).

Fig. 2. Flat beds and low angle crossbeds overlying high angle crossbeds in base surge deposit, Coronado Mesa, Superstition Mountains, Arizona. Similar scale as base of Burns Cliff.

All sedimentary structures observed at Burns Cliff are common in base surge deposits, including "pinstripe lamination" (Fig.3).

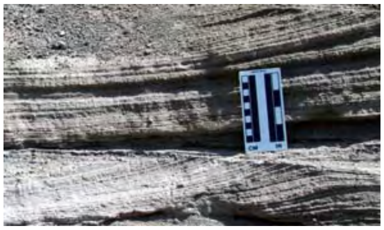

Fig. 3. Pinstripe lamination and low angle crossbedding in terrestrial base surge deposit. Kilbourne Hole, NM

The smaller population of spherules imaged on sol 633 (Fig. 4) have the "crinkled" outline of thin-walled accretionary lapilli [10].

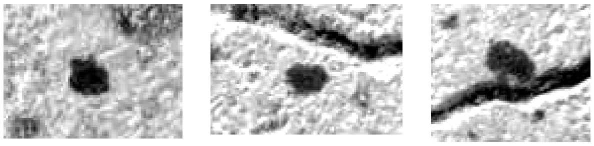

Fig. 4. Crinkled spherules, Sol 633. Spherules are 1 mm or smaller. Crinkled outlines in terrestrial examples represent initially thin-walled accretionary lapilli.

All new observations remain consistent with the spherules being impact accretionary lapilli and condensation spherules.

The abundant sulfate in the deposits is consistent with the Roger Burns "gossan" analogy [11] suggesting that jarosite, hematite, and sulfates should form as a martian weathering product of sulfides. The impact surge scenario provides an emplaced deposit rich in reactive sulfdes. Subsequent exposure to > 3 billion years of Mars weathering explains the pervasive acid alteration and the inferred mineralogy. A rare bulls-eye hit on a sulfide cumulate target could also account for the iron spherules, rich amounts of sulfate and the consiquent uniqueness of the orbital TES signature. Additional masses of sulfate are probably lodged in the megaregolith as a result of the great evaporation event [12] and were incorporated as part of the impact surge load.

Polygonal desiccation cracks are common in terrestrial base surge deposits (fig 4). They occur at various scales both on bedding plane surfaces and as three-dimensional networks. Examples that similarly post-date deposition appear common on the Meridiani deposits and do not require karsting or the other special explanations suggested by McLennan et al. [3]

Fig. 4. Polygonal cracks on surge top, Coronado Mesa, Superstition Mountains, Arizona

Selvages and vein like features noted as special diagenetic events [3] are also common in base surge deposts. (Fig 5).

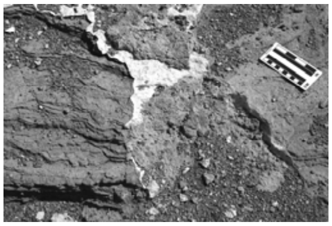

Fig. 5. Fracture-fill in base surge deposit. Kilbourne Hole, NM

Impact Surge as the current simplest explanation. The impact surge hypothesis requires only 1) an impact or impacts known to be common on Mars, 2) the great evaporation event already inferred from the D/H ratio [12,13], and 3) arid, cold weathering over several billion years. A rare iron impactor or a rare direct hit on a martian sulfide cumulate helps explain the high hematite content of the spherules and thus the uniqueness of the orbital TES hematite signature, but neither are essential.

The new Athena Team interpretation requires vanished playas, generation of < 100 micron basaltic "mud", uniform mixing of this mud with playa sulfate prior to eolian transport, eolian deposition primarily via wind ripples rather than dunes, ground water intrusion without making concretions followed by more eolian reworking, emergence of ground water that flowed over the surface (and thus a warm climate), and subsequent rise and fall of groundwaters of variable chemistry to form hematite concretions and diagenetically rearrange the soluble phases.

The volcanic fumarole interpretation requires volcanic base surges on a scale never before observed or inferred followed by concealment of the explosion site and followed by hydrothermal alteration over an area of tens of thousands of km^2.

Because of instrumental limitations, the inevitable absence of actual mineral identifications and standard petrographic analyses together with the usual difficulty of interpreting ancient sedimentary events means that multiple hypotheses should remain in play. At this time, we suggest that impact base surge provides the simplest explanation and seems to be compatible with all available data and observations. Layered sequences observed from orbit and layered blocks and outcrops at the Spirit Site may also have formed from impact surges.

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