THE ORIGIN OF THE MERIDIANI SEDIMENTS: THE KEY FOR UNDERSTANDING THE FORMATION OF SULFATES AND LAYERED DEPOSITS ON MARS. P. B. Niles[1], J. Michalski[2], [1]Astromaterials Research and Exploration Science, NASA Johnson Space Center, Houston, TX 77058; [2]Institut d'Astrophysique Spatiale, Université Paris Sud, Orsay, 91405, France. (*paul.b.niles@nasa.gov)*

Introduction: Following the discoveries made by the Opportunity rover at Meridiani Planum, members of the MER science team proposed that the Meridiani deposits are playa evaporites reworked by eolian processes[3]. Alternate hypotheses have also been proposed to explain the deposits at Meridiani Planum, and these have highlighted serious problems with the provenance of the sedimentary material in the proposed playa hypothesis[3]. These problems include: indications of cation-conservative weathering, the lack of a topographic basin, the intimate commingling of the most soluble and least soluble salts, and the overall scale of the deposit[4, 5]. These observations are important challenges to the playa scenario, and suggest that the sediment was derived from a different source.

Model Description: We propose a new model for the provenance of the sediments at Meridiani Planum, which is based in principal on geochemical ideas pioneered by Burns[8], and sedimentological ideas proposed by Tanaka[9]. In our model, the sediments now located at Meridiani Planum were sourced from a nearby, massive dust/ice deposit that was located adjacent to Meridiani Planum. This massive dust/ice deposit formed through precipitation of ice around dust grains and aerosols during a period of high obliquity, and resembled the polar layer deposits that exist today in the martian north and south polar regions. Suspended dust in a Noachian atmosphere provides nucleation points for ice crystals to form which is an important driver for the precipitation of water ice in the present day polar caps[10] and would have been more prevalent on ancient Mars.

Exposure of the ice deposits to sunlight during the summer seasons allowed for radiant heating of dark grains within the water ice matrix. A similar effect has been observed where radiant heating of soil grains, trapped in ice deposits in Antarctica, causes melting and migration resulting in the formation of aggregates[2] (Fig. 1). The radiant heating led to the formation of thin water films sufficient to allow for reaction with the volcanic aerosols or sulphide minerals to create acidic solutions. The ice matrix provided a physical barrier enclosing each grain or aggregate of grains within a closed system environment at low temperatures with low water/rock ratios. The acidic solutions weathered silicate grains to form poorly crystalline aluminosilicates and sulfates[8]. The cold temperatures of the polar environment provided a mechanism for limiting water/rock ratios while simultaneously forming more concentrated solutions through freezing of excess solution.

Figure 1. An ice core from Antarctica with an aggregation of soil grains (Photo Credit: Hans Paerl, University of North Carolina at Chapel Hill). These grains have migrated through the ice to form this aggregate by means of radiant heating[2]

A climactic shift (due to polar wander or obliquity changes) then led to conditions which favoured net sublimation of the massive ice deposit rather than deposition. The sublimation residue was made up of sand sized agglomerates of fine-grained, chemically weathered, and highly hydrated siliciclastic material mixed with sulfate salts. This material was reworked by eolian or impact activity. Burial of these highly hydrated phases caused the release of structural water that allowed limited diagenesis and blueberry formation to occur, but also prevented wholesale re-equilibration of the deposit and complete conversion of jarosite to hematite[11]. Small amounts of additional water may also have been supplied by brief ice melting events allowing for the possibility for surface runoff[3].

The ice-weathering model resolves many problems of previous hypotheses including the large scale of the deposit, the source of the sediment, its compositional similarity across large lateral distances, the cation-conservative nature of the weathering processes, the presence of acidic groundwaters on a basaltic planet, the accumulation of a thick sedimentary sequence outside of a topographic basin, and the low water/rock ratio needed to explain the presence of very soluble minerals and elements in the deposit.

The cation-conservative nature of the weathering that modified the silicate materials has been noted by other authors[1, 5] and places a strong constraint on the provenance and weathering of the sedimentary material. The variations in the chemical composition of the deposit has been modelled as either 1) a mixture between a weathered basaltic component and a sulfate-rich evaporite component[3], or 2) an addition of SO_2 to a pristine basaltic composition[5]. The fact that this assemblage has retained its basaltic cation abundances (Fig. 2) despite extensive modification to the original basaltic mineralogy suggests that the weathering took place under extremely low water/rock ratios[1, 4, 5]. A unique feature of weathering dusty material within a polar ice cap should be cation-conservative weathering on a centimeter scale due to the closed system environment provided by the icy matrix. The cold temperatures should act to limit water/rock ratios resulting in an intimate mixture of silicate and sulfate minerals[8]. This also provides an explanation for the close association of minerals with different solubilities because each grain or small agglomerate of grains is weathered in its own encapsulated environment. Also, if the acidic solutions occurred as small pockets within a polar ice deposit, they would be effectively isolated from the alkaline basaltic crust of the planet.

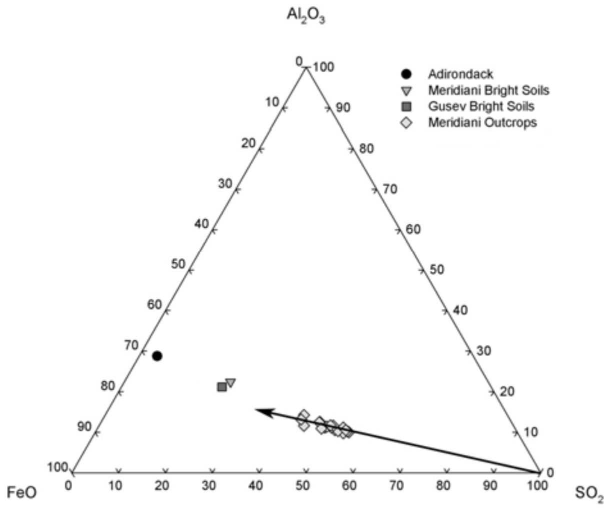

Figure 2. Ternary plot of the molar Fe, S, and Al composition of Meridiani Planum sediments[1] and other martian materials[6, 7]. The arrow traces a constant FeO vs. Al_2O_3 ratio on the ternary diagram. The Meridiani sediments plot along this constant ratio indicating that iron has not been fractionated from aluminium as one might expect from aqueous alteration in an open system. This shows that the Meridiani sediments can be seen as having a cation composition resembling basalt with SO_2 added. The variation observed in the Meridiani sediments is solely due to changes in $MgSO_4$ content. Uncertainties on data points are smaller than the size of the points.

Implications: The formation process of the sedimentary deposits in Terra Meridiani acted on such a large scale that it necessarily requires consideration of the broader regional and global geologic picture of Mars. Remote sensing studies have linked the Meridiani deposits to a number of other martian surface features through mineralogic similarities, geomorphic similarities, and regional associations. Although they are separated by more than 1000 km; Aram Chaos and Valles Marineris each contain sulfate paired with hematite that has spectral features identical to the hematite found in Terra Meridiani[12, 13]. The thermal infrared spectrum of each of these areas shows an alignment of the hematite c-axis, which is rare in terrestrial rocks and is probably caused by spherule growth[11]. The uniqueness of their thermal infrared signatures and the distance between these deposits suggest that all of these deposits share a common formation process which must have acted over a large area of Mars.

The weathering model proposed here could potentially explain the origin of many layered sulfate deposits detected on Mars. Most of the sulfate deposits on Mars share common characteristics: they are layered, occur in mounds and ridges, and lack an obvious provenance[14]. In these deposits the sulfates are exposed in spectrally detectable layered deposits, some of which may reflect the original morphology of layered ice deposits. Layered sulfate deposits may also have formed through eolian or impact reworking and transport of sublimation residue or through episodic fluvial processes driven by limited melting of ice. The modern polar sulfate deposit is mineralogically and geomorphologically different from the other sulphate deposits on Mars, but its proximity to a massive ice deposit and its distribution in an erg deposit make it a potential modern analog. This view of sulfate formation in Meridiani and elsewhere on Mars draws a direct comparison between ancient and modern geologic processes and suggests sulfate minerals could have formed on Mars during a past cold and desiccated climate.

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