CONSTRAINTS ON THE EXTENT AND TIMING OF GROUNDWATER DIAGENESIS IN THE BURNS FORMATION, MERIDIANI PLANUM.

S. M. McLennan[1], R. E. Arvidson[2], B. C. Clark[3], M. P. Golombek[4], J. P. Grotzinger[5], B. L. Jolliff[2], A. H. Knoll[6], S. W. Squyres[7], N. J. Tosca[1] and the Athena Science Team. [1]Dept. Geosciences, State University of New York, Stony Brook, NY, 11794-2100 (Scott.McLennan@sunysb.edu); [2]Dept. Earth & Planetary Sciences, Washington University, St. Louis, MO, 63130; [3]Lockheed Martin Corporation, Littleton, CO, 80127; [4]Jet Propulsion Lab, California Institute of Technology, Pasadena, CA; [5]Div. Geological & Planetary Sciences, California Institute of Technology, Pasadena, CA, 91125; [6]Dept. Organismic & Evolutionary Biology, Harvard University, Cambridge, MA, 02138; [7]Dept. Astronomy, Cornell University, Ithaca, NY, 14852.

Introduction: One of the most significant discoveries of the Mars Exploration Rover *Opportunity* is the preservation of late Noachian sulfate-rich sandstones, informally named the Burns formation, on the Meridiani Plains [1,2]. Stratigraphic, sedimentological and compositional characteristics of these sedimentary rocks point to deposition in an aeolian dune – sand sheet – interdune/ playa environment that had a dynamic groundwater system that at times breached the martian surface to produce subaqueous depositional environments [1-3].

The purpose of this paper is to review the diagenetic history preserved within the Burns formation and report on diagenetic features encountered since leaving Endurance crater.

Sedimentary Rocks of the Burns formation: Sandstones of the Burns formation consist of well-sorted medium to coarse sand-sized grains, individually composed of fine-grained, basaltic material that was chemically altered (i.e., no remaining igneous minerals) and cemented by sulfate salts prior to aeolian and aqueous reworking [1-3]. In effect, sand grains are intrabasinally recycled sedimentary lithic fragments. Within arid aeolian environments, such grains are common products of desiccating playa lakes [4]. The grains are mineralogically highly labile. This is clearly shown by the observation that grain boundaries are entirely obliterated during formation of diagenetic isopachous sulfate cements around hematitic spherules.

During and subsequent to deposition, these sandstones were influenced by multiple, temporally distinct, groundwater-mediated diagenetic processes including (from oldest to youngest) [3]:

1. syndepositional precipitation of mm-scale highly soluble evaporite crystals (mineral with solubility comparable to Mg-sulfates), analogous to halite crystals that precipitate from groundwater capillary fringes in sabkha-like aeolian systems [5];
2. syn- to post-depositional crystallization of pore-filling evaporitic sulfate cements;
3. crystallization of mm-scale highly spherical hematitic concretions;
4. formation of secondary porosity due to dissolution of highly soluble sulfate salts;
5. formation of later generations of isopachous cements and zones of pervasive recrystallization in contact with concretions and nodules composed of cemented sandstone. At about the same time, decimeter-scale stratigraphically controlled diagenetic zones of secondary porosity and recrystallization formed, notably at the Whatanga contact [2].

At Endurance crater, the Burns formation also exhibits stratigraphic variations in chemical composition consistent with vertical diagenetic redistribution of sulfates and chlorides [6].

Beyond Endurance crater - Waning Diagenetic Influence? Since leaving Endurance crater, Opportunity has traversed southward, moving topographically higher and thus most likely stratigraphically higher, albeit probably by no more than a few meters. (At time of writing, *Opportunity* is in the vicinity of Erebus crater.) Sedimentary rocks that have been encountered are broadly similar to those observed in Eagle and Endurance craters. They possess sedimentary structures characteristic of the sand sheet facies (e.g., low angle planar cross beds) and interdune subaqueous facies (e.g., small-scale festoon cross lamination) characteristic of the upper unit of the Burns formation. Whether these are stratigraphically equivalent or a separate interdune cycle is not yet clear [7].

Textural differences of the exposures near Erebus crater compared to those to the north include the presence of small (<0.5mm) relatively dark and moderately rounded grains and mm-scale angular features that may be small evaporitic crystals.

There are also marked changes in preserved diagenetic textures. Notable among these are the changes in size, number and shape of hematitic concretions. Just north of Erebus crater, hematitic concretions became smaller, closer to 1 mm diameter (rather than 4-5 mm typical of Eagle and Endurance exposures) and more abundant with as many as 10-15 concretions exposed in a single RAT hole (compared to 2-3 typically seen in Eagle and Endurance). The overall effect is that concretion volumes within the outcrop are not markedly different. Concretions remain generally spherical but typically have far more irregular shapes than seen previously.

At the current location, just northwest of Erebus crater, concretions appear to be absent from the outcrop or are too small to be seen with the Pancam. MI images of targets Ted and Hunt confirm the apparent absence of even small concretions, at least locally. Whether this is a continuation of a stratigraphic trend, marking upward waning of at least one groundwater recharge episode, or represents a distinctive unit within the Burns formation remains to be seen with further exploration.

History of Groundwater Recharge: Figure 1 illustrates the suggested history of groundwater recharge within the Burns formation. At least four recharge events can be documented or inferred. If the sand grains are derived from pene-contemporaneous desiccating playa lakes, at least one early recharge event that breaches the surface can be inferred. A second recharge is required to explain the deflation surface represented by the Wellington contact separating lower and middle units of the Burns formation [2]. The subaqueous interdune sediments preserved in the upper unit at Eagle crater represents a third recharge that is about 7 m above the base of Burns Cliff. At Eagle and Endurance, concretions are found uniformly across all facies and thus represent a fourth distinctive recharge event. If the subaqueous facies exposed at Erebus crater turns out to represent a distinct higher stratigraphic unit, then an additional recharge would be indicated. No cross-cutting relationship has been observed to determine the relative timing of concretions and the interdune facies exposed at Erebus crater.

In terrestrial settings, aeolian groundwater systems are very sensitive to tectonic, eustatic and climatic influences, with the latter commonly driven by Milankovitch forcing [e.g., 8,9]. During the Noachian, regional tilting of Meridiani Planum, associated with loading of the Tharsis plateau, would have created sufficient topography to provide the hydrostatic head required to initiate and sustain large-scale groundwater flow [10], assuming that liquid water was available. Within the Burns formation, stratigraphic and microtextural observations point to a groundwater table that fluctuated repeatedly on the scale of meters. Although the relative timing of recharge is reasonably well constrained, absolute timing is not. The origin of higher order fluctuations in the level of the groundwater table could be related to a variety of processes including groundwater flux, sediment flux, subsidence and, perhaps less likely, tectonic fluctuations.

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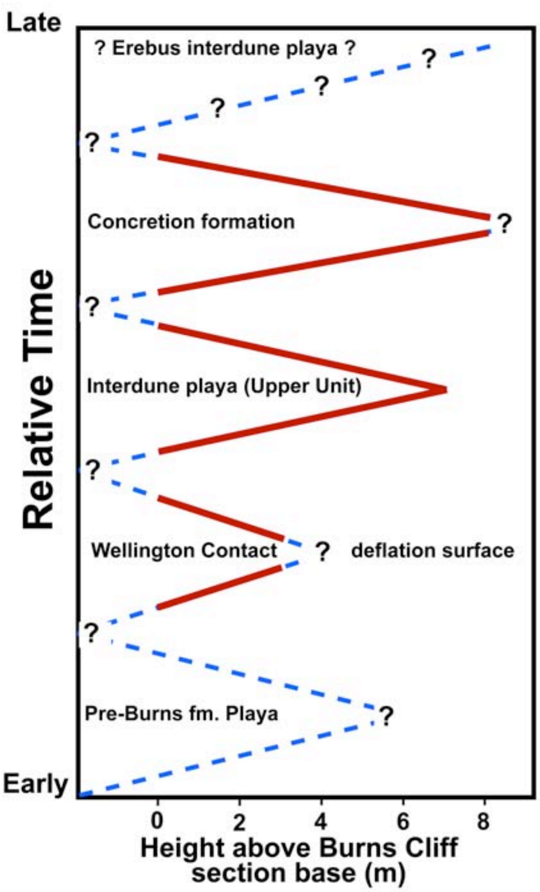

Figure 1. Schematic diagram showing the history of groundwater recharge in the Burns formation. Horizontal axis shows stratigraphic height of groundwater table above lowermost exposure of the Burns formation in Endurance crater and the vertical axis is relative time. Red lines are documented changes in groundwater table height and dashed blue lines are inferred or possible changes in groundwater height.