INTRACRATER LAYERED DEPOSITS IN ARABIA TERRA, MARS INDICATE POTENTIAL WET, COLD, CONDITIONS IN LATE NOACHIAN-EARLY HESPARIAN

S. B. Cadieux[1,2] and L. C. Kah[1], [1]University of Tennessee, Department of Earth and Planetary Sciences, Knoxville Tennessee, [2]Indiana University, Department of Geological Sciences, Bloomington Indiana (sbcadieux@gmail.com).

Introduction: Craters within Arabia Terra, Mars, contain hundreds of meters of layered strata showing systematic alternation between slope- and cliff-forming units. Hypothesized origins of these intercrater layered deposits include lacustrine deposition [1, 2, 3], aeolian deposition [4, 5], volcanic airfall deposition, and/or impact surge deposition [6]. Athough depositional origin remains uncertain, the geomorphic expression of these successions suggests either alternation of two distinct lithologies or deposition of a broadly uniform lithology that experienced differential cementation.

Recent interpretations of these stratal packages rely, in part, on utilizing the fundamental nature of sedimentary deposition, wherein basin tectonics, sediment deposition, and changes in base level (i.e. the position below which sediment is retained, and above which sediment is eroded) result in changes in the amount of space available for sediment accumulation.

Rhythmic stratal patterns in Becquerel Crater (7°W 22°N) have been attributed to astronomical forcing of regional climate [7], although a clear depositional model has yet to be presented. Here, we reanalyze stratal packaging in Becquerel Crater and compare results with two additional crater successions (Fig. 1). Results show that strata within Danielson Crater (7°W 8°N) and an unnamed crater at 1.2°W 9°N (Crater X) do not record the hierarchical packaging that was attributed to astronomical effects in Becquerel Crater. Regional climate forcing may still play a role, however, in sediment accumulation. We suggest that similar depositional styles in these craters may be linked by a model for sediment accumulation in which episodic melting of ground ice raised local base level, stabilized aeolian sedimentation, and resulted in differential cementation of accumulated strata.

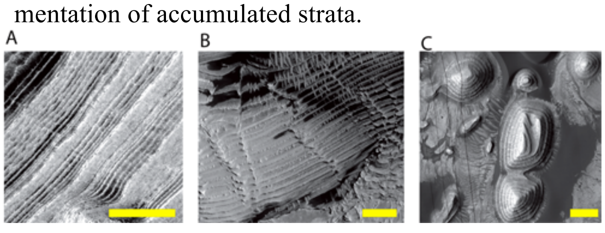

Fig. 1: A) Subframe of PSP_001546_2015. Becquerel Crater, 7ºW 22ºN; B) Subframe of PSP_002733_1880. Danielson Crater, 7ºW 8ºN; C) Subframe of PSP_002047_1890. Crater X 1.2ºW 8.9ºN. Scale bars equal 200 m.

Methods: HiRISE DEMs of a portion of layered deposits in each crater were used to identify bedded intervals, compute regional dips, and determine stratigraphic thicknesses. Details of individual layers are typically obstructed in regions with high dust cover; benched erosional expression of strata, however, is easily recognized. Recessive/resistant couplets are commonly highlighted by the presence of secondary, low-albedo material that mantles the less indurated, lower interval of the couplet.

Regional dip of recessive/resistant couplets were determined by selecting three points along the contact between resistant interval and the overlying recessive interval and extracting three dimensional coordinates from the DEMs. The dip corresponding to the plane was calculated using traditional 3-point problem methods. Couplet thicknesses were then determined using a series of geometric relationships using elevations and pathway distances extracted from HiRISE DEMs.

Results: Distinctive bundling of couplets is observed only in Becquerel Crater; in Danielson and Crater X, exposed strata show stacked couplets of strikingly uniform erosional expression. Couplets were divided into lower and upper 'cap' units to measure stratigraphic thickness of half-couplets. The upper 'cap' unit is significantly thinner than the lower unit in both Becquerel and Danielson Crater ($p<0.05$). There is no significant difference in thickness between upper and lower units in couplets of Crater X ($p=0.48$).

Couplet thicknessness are clustered around the mean, and show no distinct upsection trend for any of the craters analyzed. Even Becquerel Crater bundles, which are defined by a thicker/more resistant capping interval, reveal no clear trends in couplet thickness.

Interpetations: In the absence of active basin subsidence in a thick martian crust, the crater depth represents the local maximum accommodation space available for sediment infilling. Stacking of individual layers, or couplets, thus represents either: (1) incomplete filling of accommodation space by sediment whose input varied in such as way to produce couplets, or (2) a progressive increase in accommodation space that was completely filled by available sediment input.

With no recognizable fluvial networks entering these craters, and no systematic difference between the character of couplets from the base to the top of the successions, we reject the possiblility of a fluvial input into a deep-water lake (hypothesis 1 above). Rather, we suggest that layered strata reflect a combination of aeolian and *in situ* aeolian or lacustrine deposition within a closed basin environment, with sediment accumulation driven by fluctuation of an air-water interface within a ground- or surface-water reservoir.

At the level of this investigation, lacustrine and aeolian environments cannot be differentiated. In terms of aqueous input, both scenarios require a progressive rise of the air-water interface from either ground- or surface water sources. In this model, which is consistent with observations from the MER-B sites [4], sediment deposition fills or exceeds available accommodation space and evaporation at the aqueous interface drives lithification of the upper sediment package, resulting in formation of a complete depositional couplet. Each couplet, therefore, represents complete filling of accommodation space, and deposition of successive couplets requires production of additional accommodation space. With no active tectonic forces to cause subsidence, accommodation space thereby must be produced due to increasing aqueous input.

It is critical to note that the depositional model inferred here demands that an aqueous interface must have continued to rise throughout the period of deposition. The similarity of couplets throughout these thick layered packages requires requires repetition of depositional parameters over extended periods of time. Together, these observations suggest the possibility of either prolonged or episodic aqueous conditions.

Previous work suggests long-term groundwater upwelling as a mechanism for sediment accumulation, but this scenario [5] requires surface temperatures to remain above freezing across the low to mid-latitudies for long periods of time, facilitating both precipitation-induced reacharge of aquifers and groundwater evaporation at the surface. In order to fill craters at numerous stratigraphic levels across Arabia Terra [8] and to satisfy requirements of a progressively rising aqueous interface, an ever increasing liquid groundwater reservoir would certainly result in widespread subaqueous conditions in the northern highlands.

Here, we suggest an alternative scenario in which groundwater-driven accumulation of strata could occur within a predominantly frozen groundwater reservoir envisioned for a cold early Mars [9]. In this scenario, individual craters provide temporary accommodation space for deposition of aeolian sediment (Fig. 2). With even minor warming – likely resulting from astronomically driven changes in solar input – melting of ground ice near the martian surface would occur. This activated groundwater layer would percolate downward into the crater, pool within aeolian sediments, and act to stablize aeolian sediments. It is unlikely that melting would occur in the crater substrate, however, because aeolian sediments would have insulated the crater floor from solar heat input. As in the warm, groundwater scenario, evaporation at the aqueous interface would drive cementation and formation of a depositional couplet. Meltwater exceeding aeolian sediment thickness would result in short term lacustrine deposition, and any sediment deposition above this interface would have been susceptible to deflation.

In this ground-ice model, an interval of cooler climate and re-freezing of the active layer would reestablish the impermeable conditions necessary to sustain deposition of another aeolian layer. Subsequent warm intervals would drive establishment of another active layer, and development of an additional depositional couplet (Fig. 2). The ground-ice/melt model presented here is consistent with observations of stratal packaging, as well as with previous interpretations of astronomical forcing of sedimentary packages [7], and supports the potential for mixed aeolian and lacustrine deposition on a cold, wet Mars.

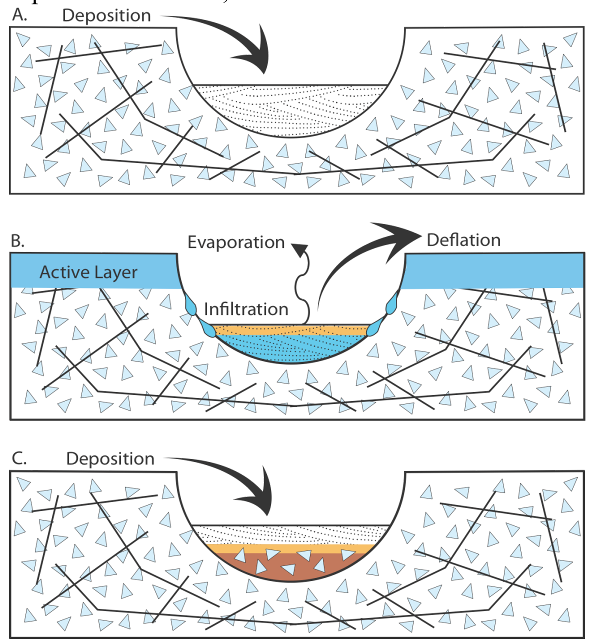

Fig. 2. Ground-ice/melt model for intracrater sediment deposition. A) Aeolian sediment temporarily accumulates in crater; subsurface pore and fracture networks are ice-filled. Sediment is unconsolidated and susceptible to deflation. B) During warmer climates, melting of near-surface ground ice creates an active groundwater layer. Groundwater percolates into the crater, pooling at the sediment/ice interface. Evaporation drives mineral precipitation and sediment lithification at the aqueous interface, forming a sedimentary couplet; extraneous sediment is susceptible to deflation. C) Cooler climate cause active layer, as well as potential sediment pore fluids, to re-freeze, allowing initiation of next depositional stage.

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