THE INFLUENCE OF CLIMATE AND SEDIMENTATION ON THE DEPOSITIONAL ENVIRONMENT WITHIN GALE CRATER, MARS: IMPLICATIONS FOR THE SEDIMENTARY SEQUENCE OBSERVED BY CURIOSITY. D. G. Horvath[1] and J. C. Andrews-Hanna[1], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ. (dhorvath@lpl.arizona.edu)

Gale crater is a spatially and temporally unique sedimentary basin on Mars, located at the dichotomy boundary. Crater retention ages and crater degradation supports an early Hesperian age, but cannot rule out a late Noachian age. The central sedimentary mound in Gale crater (Aeolis Mons or informally Mount Sharp) preserves one of the best records of the early Mars climate and hydrology. Aqueously altered clays and sulfates make up the lower portion of the mound, while the bulk of the upper mound is consistent with anhydrous aeolian sediment [1, 2, 3]. The transition from phyllosilicates to aqueously altered sulfates (between -4100 and -3900 m elevation [3]) and from aqueously altered sulfates to anhydrous sediment (approximately -3400 m) may represent a gradual climatic change during sediment deposition within Gale crater [1, 2, 3]. This transition from more clay rich layers to sulfate-bearing units is consistent with the layering observed in Meridiani Planum [e.g., 4].

Mars Science Laboratory (MSL) observations of the lower clay layers (approximately -4450 to -4140 m elevation) within Mount Sharp (the Murray formation) suggests that the Murray formation is consistent with a lacustrine depositional environment [5]. Mineralogical variability within the Murray is consistent with varying degrees of post-depositional alteration [6], lateral facies change [7], and/or differences in the depositional environments [8]. A distinct variation in composition was observed in the Sutton Island member (-4375 to -4275 m), where sulfate-enrichment in the mudstone matrix and desiccation cracks were observed suggesting markedly drier surface conditions and subaerial exposure [8, 9].

However, depositional facies and inferred surface conditions alone do not provide a direct constraint on climate. In addition to climate, the depositional environment is a function of the local and regional hydrology, which is affected by the evolving state of the depositional basin as it is filled with sediment. In this study, we use a surface-subsurface hydrological model [10] to investigate the climatic conditions required to form lakes in Gale crater and its evolution over time. This hydrological model was coupled to a landscape evolution model, focusing on the deposition of sediment in sub-aqueous and sub-aerial environments, allowing us to explore the influence of sedimentary infill on lake formation and hydrology.

Methodology: *Hydrological model.* The hydrological model included subsurface and surface components of the hydrologic cycle [10], forced by evaporation potential and precipitation rates from semi-arid and arid regions on Earth (NLDAS-2). Previous work showed that the formation and extent of lakes are primarily dependent on the ratio of potential evaporation and precipitation (or the aridity index; $\phi = E_P/P$) [10].

Pre-Aeolis Mons topographic model. We model the topography of Gale crater prior to the emplacement of Mount Sharp using a similar-sized complex crater, to restore the pre-fill geometry of the crater floor and central peak.

Crater infill model. The erosion of the crater rim and deposition of crater fill was modeled using a landscape diffusion model [11] for subaerial sedimentation and erosion, a simple lake sedimentation model based on the lake depth and geometry [12] for subaqueous sedimentation, and an evaporite-cementation model based on the evaporative water column where the water table approached the surface [13]. This simple model allows us to explore the influence subaerial and subaqueous sediment infill has on the depositional environment within Gale crater as a function of climate.

Results: Prior to any crater infilling, under semi-arid climates ($\phi < 5$), a single large lake forms in the deep, northern portion of Gale crater, embaying the entire northern half of the central peak (Fig. 1a). Lake levels are predicted to reach -4000 m elevations, at the level of the transition from the phyllosilicates to the layered sulfates [3]. Arid climates ($5 < \phi < 20$) predict a single shallower (up to 100's of meters in depth) lake within the deepest northwestern portion of Gale crater (over which Curiosity traversed; Fig. 1b). Hyper-arid climates ($\phi > 20$) predict only small, scattered, and shallow lakes in northern Gale crater (Fig. 1c), with lake formation in the deepest portion of Gale failing to reach the base of the Murray formation (-4450 m).

As sediment infills Gale, a transition in the depositional environment with elevation is observed as the accommodation space within Gale is decreased (Fig. 1g-i). Above the transition from phyllosilicates to layered sulfates (-4100 to -3900 m [3]), deep lakes are observed under semi-arid conditions (Fig. 1d, g) in conflict with observations. In contrast, hyper-arid conditions predict subaerial evaporite cemented material over elevations in which mudstones are observed within Mount Sharp, and thus are too dry (Fig. 1f, i). Interestingly, arid climates predict deep lake deposits at the base of the Murray formation (Fig. 1b, h), transitioning to shallow lake deposits and subaerial evaporite cemented materials at higher elevations, compatible with observations. (Fig. 1e, h). The shallow lakes predicted up section for the arid case may represent intermittent periods of a lacustrine depositional environments and shallower playa-like settings, dependent on shorter-term variability in climate. This setting is consistent with the observed increase in sulfate content and desiccation cracks in the Sutton Island member [8, 9] and shallow redox stratified lakes [7], while still in agreement with the largely lacustrine setting observed throughout the Murray formation. The model notably predicts a lateral facies change approximately coinciding with the edge of the present-day mound, suggesting that local conditions may be very sensitive to horizontal position within the deposit.

Discussion: These results suggest that the observed vertical stratigraphy is compatible with a scenario in which Gale crater formed after the majority of valley network formation, in the early Hesperian, with an arid climate throughout the sequence. Early lacustrine environments were enabled by the depth and unique location of Gale crater, while the transition to sulfate rich sediment is the result of a decrease in accommodation space as sediment fills Gale. Alternatively, the model results are also consistent with Gale forming near the end of valley network formation in the late Noachian, with semi-arid climates contributing to the early lacustrine deposits, and a transition to arid and perhaps hyper-arid climates contributing to the shift to sulfate deposition. Most importantly, this work shows that observed changes in Mount Sharp stratigraphy may be the result of short- or long-term climate change, lateral changes in the depositional environment, and/or changes in basin hydrology due to the infilling of the crater. Interpretation of the sedimentary record requires consideration of the full hydrological system of the Gale crater lakes.

References. [1] Milliken, R. E. et al. (2010), *GRL, 37*, L04201. [2] Thomson, B. J. et al. (2011), *Icarus, 214*, 413-432. [3] Fraeman, A. A. et al. (2016), *JGR, 121*, 1713-1736. [4] Grotzinger, J. P. et al. (2005), *EPSL, 240*, 11-72. [5] Grotzinger, J. P. et al. (2015), *Science, 350*. [6] Rampe, E. B. et al. (2017), *EPSL, 471*, 172-185. [7] Hurowitz, J. A. et al. (2017), *Science, 356*. [8] Rapin, W. et al. (2019), *Nat. Geosci., 12*, 889-895. [9] Stein, N. et al. (2018), *Geology, 46*, 515-518. [10] Horvath, D. G. and Andrews-Hanna, J. C. (2017), *GRL, 44*, 8196-8204. [11] Howard, A. (1994), *Water Resour. Res., 20*, 2261-2285. [12] Lehman (1975), *Quarter. Res., 5*, 541-550. [13] Andrews-Hanna, J. C. (2007), *Nature, 446*, 163-166.

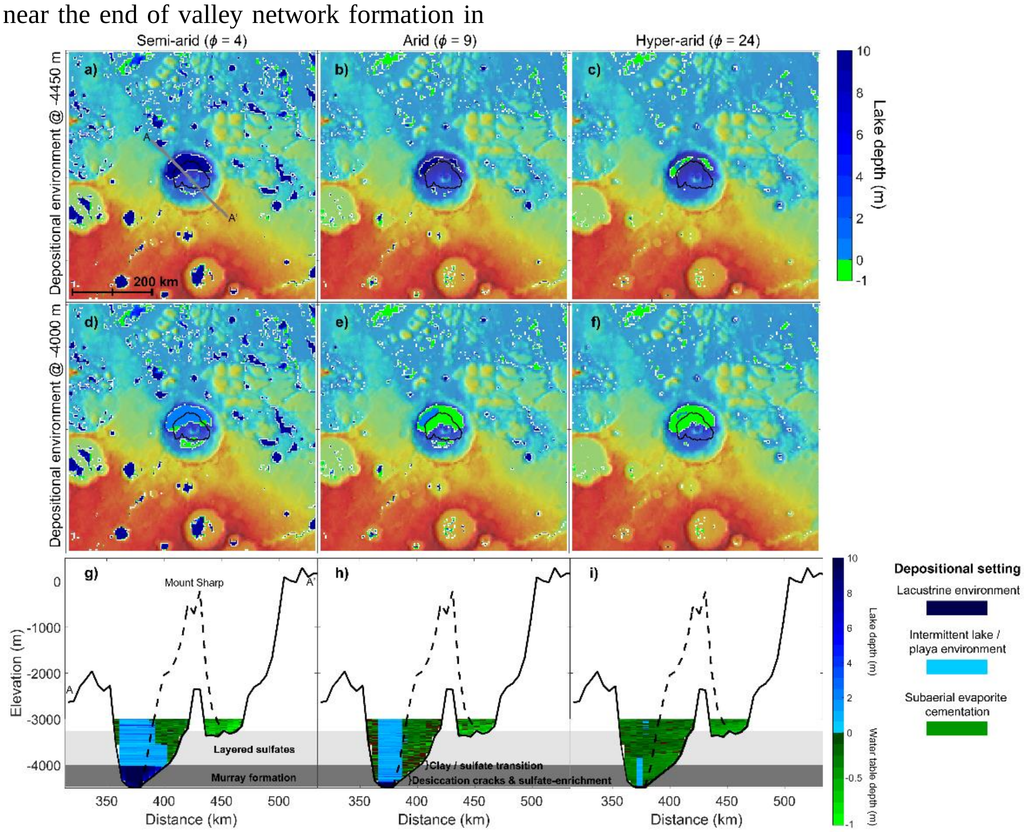

Fig. 1. Depositional environment at a)-c) the base of the Murray formation (-4450 m elevation) and d)-f) the clay / sulfate transition (-4000 m) in Gale crater for semi-arid ($\phi = 4$), arid ($\phi = 9$), and hyper-arid ($\phi = 24$) climates. The current extent of the mound is outlined in black [2]. g)-i) Profiles (transect shown in Fig 1. a) showing the depositional setting (shown as lake depth and water table depth) in Gale crater as a function of elevation.