ORIGIN AND EVOLUTION OF SEDIMENTS IN GALE CRATER THROUGH ICE-HOSTED PROCESSES.

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Introduction: Sedimentary deposits record aqueous and atmospheric processes related to the climate evolution of Mars. Gale crater is the designated landing site for the Mars Science Laboratory (MSL) rover, which will study the large sedimentary deposit preserved inside the crater and will help provide insight into the global geologic history of Mars including the critical Noachian-Hesperian transition [1, 2].

The MSL payload will provide critical observations of rock textures, geochemistry, mineralogy, and isotope geochemistry to test the several ideas put forward to explain the origin of the Gale crater sediments: lacustrine sediments [3, 4], playa sediments [5], spring deposits [6], pyroclastic deposits [7], paleo-polar deposits [8], and ice-dust mixtures [9], with possible combinations of some or all of these ideas.

In this work, we further develop a uniformitarian hypothesis for the origin and evolution of the Gale crater sediments through ice-dust deposition and weathering that can be tested by the MSL rover.

Low Latitude Ice Deposits: The variation in orbital obliquity on Mars through history requires that at certain periods of high orbital obliquity the polar regions received greater solar insolation than the equatorial regions [10]. This high orbital obliquity would almost certainly result in the movement of ice away from the modern poles to regions surrounding the equator [11]. It seems likely, given the frequency and magnitude of the obliquity variations, that a substantial geological record would be produced by this process.

North Polar Deposits as an Analog: The martian polar regions contain polar layered deposits which have been suggested to record the last 900,000 years of obliquity variations [12]. The basal unit (BU) that lies stratigraphically below the modern north polar layered deposits has been suggested to be a paleo-polar deposit and thus the sublimation lag of a layered ice deposit [13]. This provides a direct analog to what should be left behind by ancient equatorial ice deposits.

The basal unit is finely layered with alternating light and dark bands that contain undulating textures that resemble cross-bedding [14]. Dark dune-forming material mantles the base of BU scarps and may contain sulfate minerals [15]. The BU is speculated to be the source of material supplying the Olympia Undae dune field and thus may be the source of sulfate minerals identified in this region [15, 16]. Numerous fans of material also lie at the base of BU scarps often displaying sinuous features with positive topography that have been interpreted to represent debris flows due to mass wasting [14].

Mineralogy: Gale crater sediments display many of the same features described above including the sulfate mineralogy [2], however, the Gale crater sediments also contain substantial phyllosilicate minerals primarily concentrated near the base of the mound [2]. An ice-weathering model [17] that has been proposed to explain sulfate mineral formation at Meridiani Planum and the north polar region [15] could also be used to explain phyllosilicate + sulfate formation in Gale crater. Co-deposition of sulfur rich aerosols and dust particles inside ice deposits could lead to limited closed system weathering and formation of highly hydrated sulfate rich material. Removal of the ice and burial would result in dehydration and release of substantial water [18]. Water may also be released during ephemeral ice melting events.

Thermodynamic modeling of the interaction between water and Meridiani-type sediments indicates that at low water/rock ratios, any available Ca^{2+} would be removed through $CaSO_4$ precipitation leaving the fluid highly enriched in more soluble Mg^{2+} (Fig. 1). This produces mildly acidic Mg-SO_4-rich fluids which could move downwards and supply Mg^{2+} ions for phyllosilicate formation during interaction with unaltered fine grained mafic phases and alkalinisation (Fig. 2).

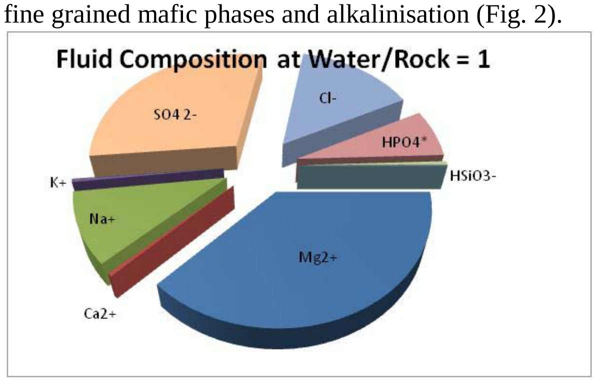


Figure 1. Relative composition of dissolved components after calculation of water-rock interaction using thermodynamic free-energy minimization software GEOCHEQ. Water-rock mass ratio is 1 and rock composition used was average composition measured at Meridiani Planum. Iron and calcium are depleted in the fluids due to precipitation of iron oxides and gypsum.

Proposed Formation History (Fig. 2): 1) Some time after the crater was created ~3.55 Ga[19], it filled with dust and ice and sulfur rich aerosols. This occurred repeatedly over a period of time and many obliquity cycles with many sequences of erosion and redeposition. 2) In this way the lower mound layers were formed from reworking of sublimation residue through eolian and fluvial processes as liquid water became stable during brief periods. The sediments concentrated at the center of the crater as the ice retreated back from the crater walls. 3) Following a period of heavy erosion, another sequence of icy layers were laid down in a series of obliquity cycles building a tall central mound. 4) As the mound grew, hydrated weathering products released water driving diagenesis and ephemeral melting events drove channel formation and fed ephemeral lakes. 5) This stack of sediments was then eroded down to form the present mound configuration.

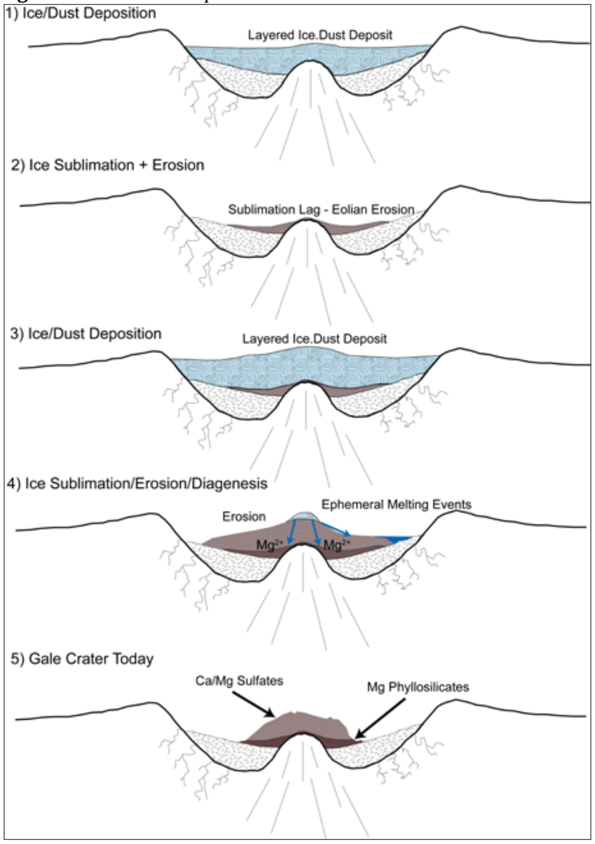
Discussion: The lowermost beds near the outer edges of the Gale crater sediment stack downlap away from the central mound [20] which on Earth typically indicates deposition of sediments into a standing body of water. However, for Gale crater the flow is from the center of the crater, contrary to what would be expected by delivery from fluvial systems. An ice-hosted airfall mechanism could potentially deposit sediments conforming to topography and therefore the downlap relationship observed is a natural consequence during the growth of the sedimentary stack from the center of the crater outwards (Fig. 2_5). Observations of repeating stratigraphic layering in the mound [21] also suggest that sediment deposition was driven by obliquity variation cycles.

There are several lines of evidence that suggest multiple episodes of erosion and deposition in Gale crater and that, although the mound is higher than parts of the rim of the crater, it need not have been completely filled with sediment [22]. Multiple episodes of erosion and burial can be observed in the sediment stack with landslide scarps being buried by subsequent sediment deposition and mound growth [22]. In addition multiple valleys are carved into the mound with no clear source- an indication that ice may have been present.

The nature of Gale crater as a closed basin neccessitates that any material eroded from the sediment mound inside the crater must then be transported up and out of the crater to in fact be removed from the system. This sets a constraint on the grain size for the Gale sediments to be smaller than sand in order to be lofted out of the crater [1, 23]. The fine grain size is also consistent with the erosional textures observed on the mound [1, 23].

Future MSL Observations: MSL will make several observations that will test this hypothesis. Similar to Meridiani Planum, the sediments should be fine grained with chemical compositions that closely resemble martian dust. There should be no segregated beds of pure carbonate, sulfate, or other salt in the main mound suggesting a playa environment or subaqueous deposition. Limited evidence for water/rock interaction and a mineral assemblage of mixed solubilities and mineralogies. Bedding that conforms to topography and largely dips away from the center of the crater. Abundant unconformities suggesting many multiple cycles of deposition and erosion.

Figure 2. Formation sequence of Gale crater sediments



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