INTTEGRATED ASSESSMENT OF DEPOSITIONAL SETTING OF THE PAHRUMP HILLS SUCCESSION IN GALE CRATER, MARS – MULTIPLE DEPOSITIONAL SEQUENCES IN AN EVAPORITIC LAKE

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Introduction: An extensive dataset of physical and geochemical observations exists for the mudstone-dominated lacustrine strata in the Pahrump Hills area of Gale Crater, Mars [1]. Although sparse by Earth standards, the data portray a new source-to-sink picture in a sequence-stratigraphic and paleogeographic framework.

Approximately 3.5 Gy old, these strata contain five facies associations (Fig. 1) that range from fine to coarse detrital mudstone with abundant sediment-incorporative evaporite pseudomorphs, to medium sandstone, all dominated by first-cycle grains of minimally weathered primary igneous minerals but with four distinct provenances. Bedding in the mudstones comprises planar-parallel beds, current ripples, and wave-induced structures, with common and widespread truncation. The absence of desiccation and synaeresis cracks is probably due to minimal clay-mineral content, as supported by lab experiments. Evaporite minerals formed on and within detrital muds shortly after accumulation by evapoconcentration and cooling [2, 3].

Figure 1: Facies associations in the Pahrump Hills succession and their stratigraphic position.

Key Observations: Of the five facies associations three are mudstone dominated with distinct ranges of grain size, bedding, and composition. Mudstones dominate the section by volume (~85%), are largely of detrital origin from a mafic igneous provenance that experienced only minor chemical weathering, and contain minimal amounts of clay minerals. The latter are dominated by a 10 Å phyllosilicate that we modeled as talc-like kerolite. Phases of likely diagenetic origin include opal-CT, phyllosilicates, sulfate minerals, and possibly carbonate minerals. Constituting < ~15% of the rock, these minerals provide essential insights into environmental conditions at time of accumulation and early burial. Most of the diagenetic minerals are compatible with evaporation processes and span a wide range of solubilities, from calcium sulfate (+carbonate) and silica (opal-CT) through kerolite (Mg-silicate) to Fe and Mg sulfates. The variety of observed crystal pseudomorph shapes suggests that multiple evaporite minerals were probably present initially. Traces of shortite have been detected by CheMin in both FA1a and FA1b (Fig. 1), and the pyramidal-triangular crystal pseudomorphs at Pahrump Hills (Fig. 2) are reminiscent of shortite-rich beds of the Eocene Green River Formation on Earth (Fig. 3). They point to the tantalizing possibility that shortite may have been abundant in the original deposits. The implications of potential initial presence of shortite (Na2Ca2(CO3)3) are profound, because it suggests that carbonates were able to precipitate from lake waters.

Figure 2: Layers of x-tal pseudomorphs (A) and details from selected areas (B). D’, E’, and F’ detail views of rhombic, triangular, and pyramidal shapes presumed to have been evaporite minerals originally.

Observed mineral assemblages and geochemical modeling, as well as physical sedimentology and stratigraphy, indicate a Type-III brine-evolution path.
Figure 3: For comparison with Fig. 2: Green River Formation mudstone with layers of shortite (A) and crystal molds and crystals on bedding planes (B, C).

(Mg > Ca) with a Na-SO₄-Cl endpoint, analogous to the Saline-Valley or Death-Valley systems on Earth [4]. The general absence of preserved carbonate minerals, however, suggests that “Lake Gale” had a slightly different brine-evolution path, with some acid-saline episodes. Observed cyclicity may have been driven by wetter/warmer to drier/colder alternations and may have been seasonal, yearly, decadal, centennial, millennial, or some combination thereof.

Figure 4: Main provenances (A and B) are distinguished via contrasting sets of minerals and chemical composition. Right of strat column: Presumed source of sediments, changes in external drainages over time, intensity of chemical weathering, and potential source materials. Blue rhombs mark location of drill samples.

Provenance: River waters coming into the lake likely had relatively low solute concentrations, and the growth of authigenic minerals depended on concentration processes in the lake basin itself. Main contributors to the solutes in the runoff waters were likely volcanic glass (basaltic), impact glass (modified basalt), and forsteritic olivine (Mg, Fe and silica). Groundwater probably had higher concentrations of solutes.

Evaluating provenance and weathering within the context of stratigraphic and sedimentologic constraints resulted in the basic relations summarized in Fig. 4.

**Stratigraphic Packaging:** The succession contains 16 parasequences in five depositional sequences with all the sequence-stratigraphic elements known from terrestrial strata. Two of the sequence boundaries are unconformities that record significant shifts in the behavior and paleogeographic configuration of the fluvio-lacustrine system. This contrasts with the previous view that all facies are genetically related [1]. Most of the variability in rock composition can be attributed to stratigraphic changes in provenance.

**Facies Recurrence:** Mudstone facies very similar to FA1a and FA1b (Figs. 1 and 2) has also been observed ~400 m higher in the stratigraphic section in the transition to the Sulfate Unit [5] (Fig. 5).

Figure 5: Mudstone with resistant laminae enriched in tiny concretions and likely x-tal pseudomorphs. Left image from Sol3322 (-3990m), right image from Sol3211 (-4027m). Compare with Fig. 1.

**Conclusions:** We interpret the Pahrump strata as an Evaporative lake facies association that accumulated in an underfilled lake basin with closed surface hydrography but through-flowing groundwater in the study area. Lake waters were saline to hypersaline, and lake levels, shorelines, and salinities fluctuated greatly at various temporal scales. Finding similar facies in the transition to the Sulfate Unit suggests that evaporitic conditions persisted at least up to this level. Thus, the Mt. Sharp succession so far shows not necessarily a direct climatic shift to increasingly dry conditions, but rather various, yet plausibly coeval, records of recurrent conditions of a long-lived lacustrine system.

**References:**