HIGH THERMAL CONDUCTIVITY OF WATER-SATURATED PORE SPACE IN MOUNT SHARP STRATIGRAPHY REDUCES BURIAL TEMPERATURES DURING SEDIMENT ACCUMULATION.

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Introduction: Strata investigated by the Mars Science Laboratory (MSL) science team in the lower Mount Sharp Group[1] suggest that Gale Crater fill material accumulated as sedimentary deposits in a variety of ancient environments[2]. The detection of smectite clays[3]–[5] and the absence of illite and other phases in the lower stratigraphy examined by MSL, and even at higher stratigraphic levels, suggest that the burial temperatures were anomalously low for a scenario in which the crater is completely filled [6]. Partial crater fill models, low early Mars surface temperatures, or limited groundwater activity could explain the observed clay alteration states[6], [7]. This work explores another possible explanation. In terrestrial examples, water-saturated clastic rocks typically have higher thermal conductivities than dry rock. Accounting for higher thermal conductivity values, representative of groundwater saturation, throughout part or all of the Mount Sharp stratigraphic column results in lower burial temperatures (Figure 1).
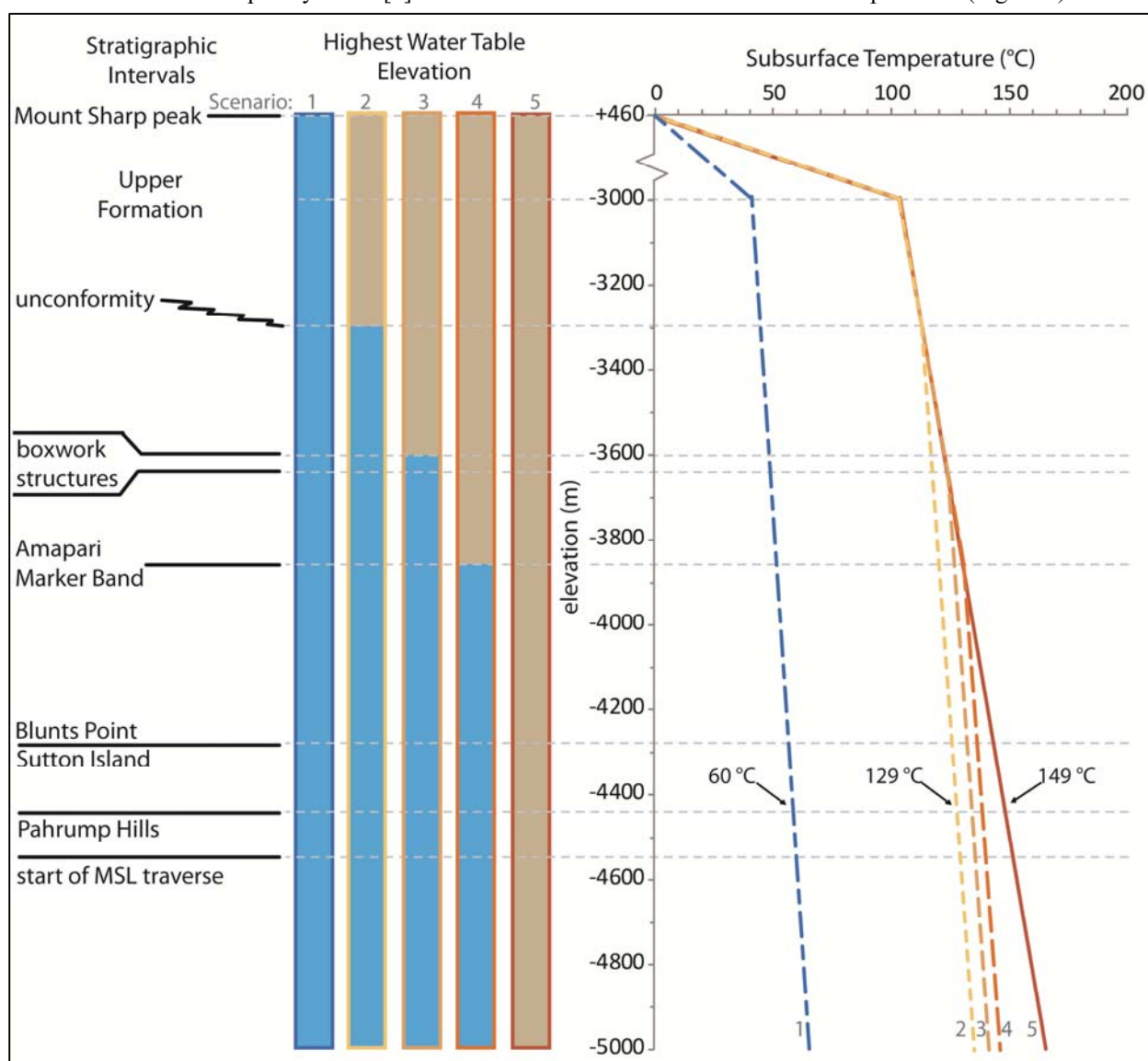

Figure 1: Subsurface temperature profiles (right), assuming Gale Crater has been filled with clastic sediment to the level of the current peak of Mt Sharp. Scenarios of different levels of maximum groundwater saturation are shown in the central columns, where blue represents fully saturated pore space and tan represents fully open pore space.

Thermal Conductivity: For clastic rocks with no pore fluid, the thermal conductivity (k) is typically 1-3 W/m°C, depending on the porosity and mineral composition[8], [9]. Measurements of k of water-saturated sandstones and mudstones give k values from 2-7 W/m°C[8], [10]. The precise k of saturated rocks depends on the porosity and grain size and can vary significantly between otherwise similar rocks types. With this in mind we do not attempt to determine the exact k of saturated Gale Crater rocks but instead use a general value of $k = 5$ W/m°C as a representative value for Gale Crater rocks with water-saturated pore space and $k = 2$ W/m°C for dry rock.

Temperature-Depth Profile: For the scenarios presented here, the temperature-depth relationship is calculated as 1-dimensional steady state heat conduction for a 2-layer model with different layer thickness (l) and k for each layer. At the base of the lower layer, temperature at depth z is calculated as

$$T(z) = T_0 + \left(\frac{Q l_1}{k_1} + \frac{Q l_2}{k_2}\right) - \left(\frac{\rho H l_1^2}{2 k_1} + \frac{\rho H l_2^2}{2 k_2}\right)$$

where T_0 is the average surface temperature of early Mars, Q is heat flow, H is crustal heat production, and ρ is the rock density. As heat flow (Q) and heat production (H) change through time, 3.5 Ga is used as the approximate time of full crater fill and previously published models[11], [12] are used to determine appropriate Q and H values for that time. Density is set at 2500 kg/m^3, a typical density for basalt[6], and 0°C is used for the T_0 of early Mars.

Results and Discussion: We calculated temperature-depth profiles for two end-member scenarios and a variety of intermediate scenarios, three of which are shown here (Figure 1). The two end-member cases assume a full stratigraphic column of water-saturated pore space and, on the other end, no influence of groundwater in any part of the stratigraphy (columns 1 and 5, respectively).

The difference in burial temperatures between the two scenarios for the top of the Pahrump Hills member (elevation: -4437 m) is 90°C. The temperatures at this depth in a completely dry profile (149°C) would be associated with smectite conversion into illite or chlorite[4], [6]. At the temperature at Pahrump Hills in a fully saturated stratigraphic column (59°C), smectite clays would be stable, with the possibility of minor chlorite transition[4], [6] is near the threshold temperature for the smectite to illite conversion. In this scenario, smectite could be preserved at depth even in a full crater-fill model.

A colder early Mars scenario would shift the temperature profiles so that for $T_0 = -50$°C, the entirety of the strata above the regional unconformity that has been mapped from orbit[13], referred to as the Upper Formation[1], as well as the section below the unconformity to the boxwork structures would have subsurface temperatures < 0°C, which would limit groundwater activity and alteration processes.

The intermediate scenarios (1 – 3) assume no groundwater influence in the Upper Formation, and water saturation throughout most of the Lower Formation[1]. There is extensive evidence for diagenesis and groundwater activity throughout the stratigraphy that MSL has traversed so far[2], [4]. Above the current extent of the MSL traverse, the boxwork structures[14] identified from orbit are interpreted to be precipitated fracture fill, which indicates extensive groundwater activity up to an elevation of approximately -3600 meters, just 300 meters below the unconformity.

So far, no strong diagenetic signatures have been identified in the Upper Formation and it is an open question whether an early Mars groundwater table would have affected the upper units of Mount Sharp. A shown in the plot in Figure 1, the presence or absence of groundwater in the Upper Formation has the most significant influence on the burial temperatures in the lower Mount Sharp stratigraphy.

The scenarios presented here do not account for the potential drying out of the stratigraphic column before Mount Sharp exhumation, which would increase the temperatures at depth as the groundwater subsided. The precipitation of sulfates and other cementation would affect k but are not accounted for in these examples. Ongoing work will investigate these more complex scenarios and explore the potential impact of heat conduction from fluid migration within the stratigraphy.

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