Modelling ejected martian biomarkers impacting Phobos

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MODELLING EJECTED MARTIAN BIOMARKERS IMPACTING PHOBOS.

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Introduction: Phobos' proximity to Mars and short orbital period has led to the hypothesis that Phobos could sweep up particles ejected from large impacts on the martian surface [1]; models suggest that Phobos' regolith could include up to ~250 ppm of martian ejecta material [2,3]. Furthermore, considering Mars' potentially habitable past [4], it is not unreasonable to suggest that biologically-significant compounds could have been included within material ejected from Mars. It is therefore possible that samples collected from Phobos, by missions such as JAXA's Martian Moons eXploration (MMX) [5], could contain martian biomarkers [6]. Such material is significant for astrobiology and unravelling Mars' geological past; therefore, further clarity of the feasibility of this transfer process is necessary before returned samples and *in situ* spacecraft data are analysed.

Here we present numerical investigation using the iSALE-2D shock physics code [7-9]. Previous modelling has been limited to simulating martian ejecta particle trajectory intersections with Phobos [2,3], which therefore lacks consideration of whether conditions within impacting particles are favourable (or not) for biomarker survival. In this study we simulate the temperature and pressure regimes of martian ejecta impacting the surface of Phobos to gauge the survivability of biomarkers in the impactors.

Methods: We simulated the vertical impact of spherical martian-like particles into Phobos-like targets, at a resolution of 50 grid cells per projectile radius, for 0.1 s to ensure that the peak temperature and pressure had been reached in the impacting particles.

Martian-like impactor: Two relevant materials available in iSALE were used: basalt, as the best estimate for Mars' global surface composition and serpentine, representative of martian sedimentary rock types more likely to contain preserved organic material [e.g. 10]. Parameters with poorly constrained values included impactor diameter and the serpentine impactor density.

Phobos-like target: Phobos' mean gravity (0.0057 m s^{-2}) and surface temperature (200 K) can be reasonably estimated [11], and we can be confident that its surface consists of a regolith similar to other small airless bodies in the Solar System [12]. Otherwise, properties such as regolith density, porosity, strength, composition, and regolith layer depth are largely uncertain, because of the lack of direct sampling from Phobos' surface thus far.

A series of preliminary simulations were conducted to test how pressure and temperature conditions within the projectile differ as physical parameters were varied through realistic ranges (Fig. 1). Shock heating is thought to be the dominant sterilization mechanism during impact, rather than pressure [13-15], so "best" and "worst" case scenarios for biomarker survival were determined based on the peak temperatures reached within the projectile. These scenarios were carried forward to encompass the extremes of realistic parameter possibilities, whilst investigating the role of impact velocity.

The real impact velocity of martian ejecta into Phobos depends on multiple factors: ejection velocity & angle, atmospheric deceleration, impact plume intersection, inbound ejecta velocity (ejecta that has not escaped the Mars system), and Phobos' orbital velocity. To allow for these factors the impact velocity was varied between 0.5 and 8.5 km s^{-1}, at 2 km s^{-1} intervals, resulting in 30 simulation runs.

Results: The results of the preliminary simulations, varying projectile and target physical parameters, highlighted serpentine projectile density and the target layer composition, including intrinsic material density, as the variables with the greatest influence on the temperature conditions within the projectile (e.g. Fig. 1). The "best" and "worst" case scenarios saw differences in mean peak temperature of several hundred kelvin and the percentage of the projectile volume reaching different peak temperatures (Fig. 1). The "best" and "worst" case target parameters are displayed in Table 1 and were carried forward to the subsequent simulation focussed on the role of impact velocity.

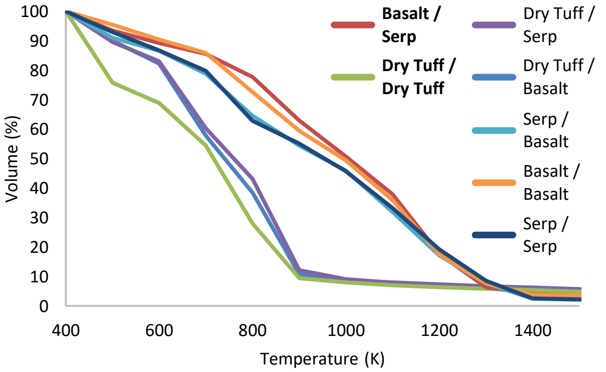

Fig. 1 *Vol. % of basalt projectile, impacting at 5 km* s^{-1} *into various Phobos regolith/interior layers combinations, reaching certain peak temperatures. Basalt / Serp (red) and Dry Tuff / Dry Tuff (green) targets result in the highest and lowest projectile volume reaching intermediate temperatures, respectively.*

	"Best" Phobos Target parameters		"Worst" Phobos Target parameters	
	Regolith	Interior	Regolith	Interior
Material	Tuff	Tuff	Basalt	Serpentine
Depth (m)	2	N/A	1	N/A
Bulk Density (kg m^{-3})	1257	1800	1822	2500
Macroporosity (%)	35	0	35	0
Cohesive Strength (Pa)	300	300	300	10^6
Compressive strength (MPa)	1	1	1	50
Coefficient of friction	0.6	0.6	0.6	0.8

Table 1. *"Best" & "worst" (for biomarker survival) parameter values for the Phobos target derived from preliminary tests.*

Varying impact velocity through the "best" and "worst" case physical parameters showed a variation of mean peak temperature and pressure across the whole projectile throughout the simulation duration of 2917 K and 39 GPa, respectively. The "best" and "worst" case scenarios overall for biomarker survival (lowest / highest mean peak temperature reached within the projectile), were the "best" serpentine projectile impacting the "best" Phobos target at 0.5 km s^{-1} (210 K), and the "worst" serpentine projectile impacting the "worst" Phobos target at 8.5 km s^{-1} (3127 K), respectively. All scenarios where basalt constitutes the projectile fall between the "best" and "worst" overall scenarios with mean peak temperatures of 211 to 1962 K.

As expected, the mean temperatures and pressures increase with increasing impact velocity. Furthermore, they increase at different rates as shown in Fig. 2 such that a porous projectile impacting at a lower velocity experiences a higher peak temperature than a non-porous projectile impacting at a higher velocity.

Discussion: It is likely that the higher temperatures and steeper temperature-pressure increase with impact velocity (Fig. 2) experienced within the "worst" case serpentine projectile impacting the "worst" case Phobos target, are as a result of extensive pore collapse. The "worst" case serpentine projectile has a starting macroporosity of 40%, in contrast to the basalt and "best" case serpentine projectiles assumed to have 0% macroporosity. The pore spaces impede shock front velocity and upon collapse generate isolated temperature spikes [16].

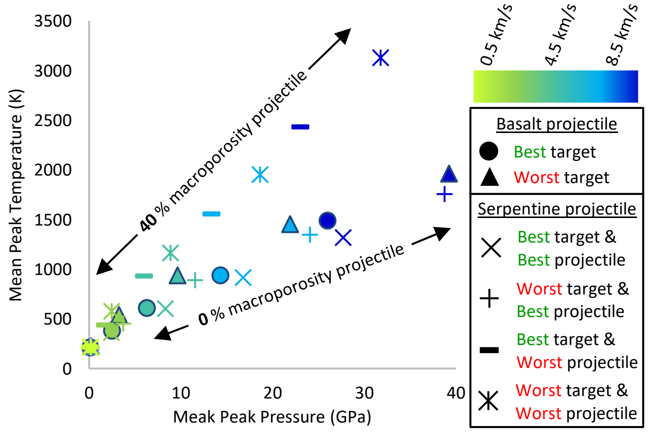

Fig. 2 *Mean Peak temperature vs. pressure for 30 different "best" and "worst" case target and projectile parameters, see key. "Worst" serpentine projectiles sit on a different trendline to basalt and "best" serpentine projectiles owing to varying macroporosity.*

Past flash-heating experiments have shown survival of organics and organisms up to 770-870 K [13,17,18], so projectiles exhibiting temperatures below this threshold are more likely to be favourable for biomarker survival. Above this threshold, decomposition and racemization are likely [17.18]. Of the 30 scenarios tested, impacts up to 4.5 km s^{-1} resulted in ~30-90% of the projectile volume reaching temperatures below this threshold, except for the extreme "worst" serpentine parameter case. Velocities must reach 8.5 km s^{-1} for 100 % of the basalt projectile volumes to exceed this temperature. However, even at this velocity the "best" case serpentine projectiles exhibit a very small proportion of volume below this temperature, implying that even when parameters are extreme, regions of the projectile remain favourable for biomarker survival.

Implications: The results of this study indicate that biomarkers can survive impact-driven transport from Mars to Phobos. Therefore, biomarkers could be collected by future sample return missions such as MMX [5] and, if recognised and analysed, could be significant for unravelling Mars' astrobiological and geological past. Future work will look in greater detail at the spatial distribution of peak temperature within the simulated projectile volumes and experimental validation with light gas gun experiments.

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