THE INFLUENCE OF SHOCK PRESSURE, PRE-SHOCK TEMPERATURE, AND HOST ROCK COMPOSITION ON THE SURVIVAL RATE OF ENDOLITHIC MICROORGANISMS DURING IMPACT EJECTION FROM MARS.

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Introduction: In view of the geological and climatological development of planet Mars, the existence of primitive life in the early history of Mars appears possible. There is also convincing evidence that various types of surface rocks were ejected from Mars by impact processes and transferred to Earth. Previous shock experiments showed that microorganisms were capable to survive impact ejection at pressures of about 5 to 50 GPa [1], which is the pressure range observed in Martian meteorites [2]. We extended our systematic experimental approach to different kinds of rocks and different pre-shock temperatures to determine whether temperature or pressure is the most influential factor for the survival rate of microorganisms during shock loading.

Experiments: Based on the experience with shock recovery experiments at an ambient temperature of 20 °C [1], we performed a new set of experiments at -80 °C in order to obtain a better simulation of the Martian temperature environment (-126 °C to 17 °C). As an extension of our earlier work with gabbro [1] we used other types of host rock: (1) dunite (corresponding to the Martian chassignite meteorites) and (2) a sedimentary rock (sandstone) saturated with water and in dry condition, respectively. Dunite was selected because of a relatively low increase of shock and post-shock temperature after shock loading [2]. Sandstone (porosity of ~ 9 %) served as a porous analogue of the Martian dry and water-saturated regolith.

Results of petrographic analysis: The actual shock pressure was determined from refractive index measurements of the shocked plagioclase and quartz for the gabbro and sandstone host rocks, based on calibration data from [3], and from optical microscopy of olivine in dunite - based on the linear correlation between the intensity of undulatory extinction with shock pressure [2]. Shock and post-shock temperatures were calculated on the basis of data from [4] (Table 1).

The measured shock pressures of gabbro shocked at initial temperature of 20 °C confirm the nominal shock pressures of all experiments. Refractive index data of plagioclase from shock experiments at 30 GPa and an initial temperature of -80 °C are identical to those of experiments at 21 GPa and an initial temperature of 20 °C.

The refractive indices of quartz in the dry and wet sandstone shocked at a nominal shock pressure of 30 GPa show that the actual shock pressure is somewhat lower (27 ± 0.6 GPa and 29 ± 0.3 GPa; Table 1). This is compatible with the calculation of the final peak pressure achieved by the reverberation technique using Hugoniot data of sandstone from [5]. The measured shock pressure of dunite (42 ± 5 GPa) is perfectly compatible with the nominal shock pressure of 41.5 GPa.

Table 1: Conditions for shock recovery experiments with microbes

Nominal shock pressure	Rock type	Measured shock pressure [GPa]	Shock temp. [°C]	Post-shock temp. [°C]
10 GPa	Gabbro	-	21	21
	Sandstone	-	-	-
	Dunite	-	20	20
30 GPa	Gabbro	32 ± 3	41	36
	Gabbro (-80° C)	21 ± 4	-59	-64
	Sandstone (dry)	27 ± 0.6	-	-
	Sandstone (wet)	29 ± 0.3	-	-
41.5 GPa	Gabbro	42 ± 3	75	56
	Dunite	42 ± 5	59	51

- = no data; all experiments at 20 °C except for one (30 GPa)

Results of biological analysis: Our previous experiments with gabbro at an initial temperature of 20 °C showed an exponential decrease of the survival rate of the microorganisms with increasing shock pressure [1]. At an initial temperature of -80 °C and a nominal pressure of 30 GPa the survival rate of *Bacillus subtilis* spores (0.339 %) is four times higher than at an initial temperature of 20 °C.

The survival rate of the microorganisms at a nominal pressure of 41.5 GPa is three times and 45 times higher for *Bacillus subtilis* spores and *Xanthoria elegans*, respectively, in dunite than in gabbro (0,4 %). At 10 GPa the survival rate of *Chroococcidiopsis* in dunite is similar to the one in gabbro. The shock and post-shock temperatures of dunite shocked at 10 GPa are the same as those of gabbro, whereas at 41.5 GPa they are lower in dunite than in gabbro (Table 1). This behaviour reflects an obvious influence of the shock and post-shock temperatures on the survival rate of the microorganisms.

The survival rate of *Bacillus subtilis* spores after shock exposure in dry sandstone (0.4 %) at a measured shock pressure of 27 ± 0.6 GPa is similar to the calculated survival rate in gabbro for 27 GPa. This calculation is based on results of the previous systematic experiments with gabbro. In wet sandstone the survival rate of *Bacillus subtilis* spores is one order of magnitude lower than in dry sandstone. *Chroococcidiopsis* does not survive at 10 GPa in dry sandstone.

Conclusions: Our experiments demonstrate that the survival rate of microorganisms increases with decreasing pre-shock temperature and with decreasing shock and post-shock temperatures as indicated by the higher survival rates in dunite compared to gabbro.

We found no difference in the survival rate of *Bacillus subtilis* spores between the low porosity sandstone and the non-porous gabbro. By comparison, the vegetative cells of *Chroococcidiopsis* did not survive at 10 GPa in porous sandstone, whereas they did in dunite and gabbro. Water saturation of porous sandstone resulted in a decrease of the survival rate of *Bacillus subtilis* spores compared to the dry conditions. This is probably due to an increased pressure pulse duration.

Our data show that the transfer of viable endolithic and epilithic microbes from Mars to Earth is favoured by the low surface and subsurface temperatures of Mars. The experimentally determined survival rates are reasonably high for the Martian temperature conditions and for most of the pressure range observed in Martian meteorites-. Survival rates are higher in ultramafic host rocks (corresponding to chassignites, nakhlites) than in basaltic rocks (e.g., shergottites). Porosity and water saturation in host rocks have a negative influence on the survival rates of microbes.

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