IMPACT EXPERIMENTS IN SUPPORT OF "LITHOPANSPERMIA": THE ROUTE FROM MARS TO EARTH.

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Introduction. Rather advanced knowledge on the physical and geological conditions for the transfer of solid rock fragments from Mars to Earth has been acquired recently by studying (a) the shock history of Martian meteorites [1, 2], (b) numerical models for the meteorites' launch and transfer conditions [3, 4], and (c) the formation and cosmic ray exposure ages of these meteorites [2, 5]. It is therefore safe to assume that sizeable rock fragments [3] have been transferred from Mars to Earth at moderate p-T-conditions throughout its geological history. Shock pressures range from about 5 to 50 GPa and post-shock temperature increases are mostly in the 10 to 600 °C range; however, the temperature effects are limited to rather short times due to rapid cooling during ejection.

As various arguments had already lead to a revival of the 100 years old "panspermia" hypothesis [e.g., 6], the described facts and some pioneering shock and acceleration experiments with primitive microbes prompted the view that the possibility of a transfer of "endolithic" microbes from Mars to Earth has to be taken into consideration seriously [7, 8, 9]. This situation has stimulated the present co-operative project in which three types of microorganisms embedded in a gabbro host rock were subjected to high shock pressures and recovered for the study of the survival rates.

Experiments and samples. We performed shock recovery experiments using a high explosive set-up which has been previously applied to a great variety of silicate rocks and minerals to calibrate residual shock effects [e.g., 10]. The microbial test systems (bacterial endospores of *Bacillus subtilis*, the lichen *Xanthoria elegans* and the cryptoendolithic cyanobacterium *Chroococcidiopsis*) were subjected to shock pressures in the range observed in Martian meteorites [1]. Thin layers of microorganisms were embedded between two 0.5 mm thick plates of gabbro, encased in a steel container, and shocked to 10, 15, 20, 30, 40 and 50 GPa with pressure pulse durations ranging from 0.1 to 1.4 µs. Gabbro was used in the recovery experiments as a good analogue for the relatively coarse-grained basaltic shergottites. After recovery, the actual shock pressure was determined by refractive index measurements of plagioclase grains separated from the shocked gabbro using calibration data from [11]. The survival rates of the microorganisms were quantitatively determined using various biological and microscopic/electron microscopic methods [e.g., 7].

Shock and post-shock temperatures were calculated on the basis of data in [3] and [1]. The shock-induced temperatures in the gabbro host rock are rather low due to the reverberation technique (shock and post shock-temperature increase ΔT of about 5 – 100 °C for less than 1.4 µs and about 5 – 60 °C for several minutes, respectively, for pressures ranging from 10 to 50 GPa). They are clearly lower than in a natural single shock compression scenario. However, the post-shock temperatures achieved in the steel container pertaining for minutes (ΔT = 10 – 350 °C) are most relevant, even more than the high shock temperature induced for less than 1 µs in the thin microbe layer due to its low shock impedance.

Results. The pressure and temperature conditions and the measured survival rates of the microorganisms recovered from the six experiments are presented in Table 1. The basic result is that all three types of microbes do survive the shock compression but the survival rates which decrease exponentially with increasing pressure, approach zero values at different shock pressures. The symbiotic systems of the lichen *Xanthoria elegans* display different survival rates: few hyphens of the mycobionts (0.002 %) survive at 50 GPa whereas the photobionts only reach an upper pressure limit of 31 GPa with a survival rate of 0.18 %. The endospores of *Bacillus subtilis* survive up to 42 GPa with a rate of 0.02 %. *Chroococcidiopsis* survived only at 10 GPa with a rate of 0.39 % although this conclusion is preliminary and more data are required to confirm this result. More details on the biological aspects of these findings are given by [12, 13].

Conclusions. Our data provide evidence of a well-defined but limited launch window for the transfer of rock-inhabiting microorganisms from Mars to Earth by impact ejection involving shock pressures in the range from 5-10 GPa to 45 GPa. Shock and post-shock temperatures in the host rock and microbe layer have to be considered in relation to the low pre-shock temperatures at the surface and subsurface of Mars prevailing currently and probably over certain periods of its history. Assuming a mean surface temperature of − 65 °C post-shock temperatures in gabbro or basalt would raise to roughly -50, -30, +50, and +400 °C at 10, 20, 30, and 40 GPa, respectively. Ultramafic rocks (nakhlites) and some of the shergottites are most favourable and efficient for the transfer of life from Mars to Earth, because they display the lowest degree of shock (5 – 30 GPa) and hence low post-shock heating (ΔT < 100 °C). Our experiments demonstrate that not only the prokaryotic *Bacillus subtilis* spores but also the eukaryotic lichen *Xanthoria elegans* are capable of surviving in all types of Martian host rocks.

The described scenarios are certainly only relevant if life ever existed on Mars. This would have required an at least temporary "warm and wet" Mars in the past. The recent debate on this issue is controversial as discussed and referenced in [14]. We believe that the interpretation of the Mars Exploration Rover "Opportunity" data, i.e. the sedimentary layers with sulphates and clay minerals as impact induced base-surge deposits in a cold and dry environment [14] is not supported by observations in terrestrial impact craters nor by impact-mechanical models. The formation of the sedimentary layered structures by aqueous deposition and hence a once habitable environment in the "Opportunity" landing region is a more likely interpretation. Regardless of the outcome of this quest or data yields important insights into the basic potentials and limitations of "lithopanspermia".

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Table 1: Shock pressure (GPa) and survival rates of three types of microorganisms recovered from shock experiments

	Bacillus subtilis	Xanthoria elegans mycobiont	Xanthoria elegans photobiont	Chroococidiopsis sp.
Experiment 1				
Nominal/measured shock pressure	10±0.3/--*	10±0.3/--	10±0.3/--	10±0.3/--
Survival rate in %	**12.4**	**68.7**	**32.4**	**0.39 – 0.81****
Experiment 2				
Nominal/measured shock pressure	15±0.45/--*	15±0.45/--	15±0.45/--	15±0.45/--
Survival rate in %	**-**	**7**	**7**	**0**
Experiment 3				
Nominal/measured shock pressure	20±0.6/20±6	20±0.6/20±6	20±0.6/20±6	20±0.6/20±6
Survival rate in %	**3.34**	**8.2**	**3.5**	**0**
Experiment 4				
Nominal/measured shock pressure	30±0.9/32±3	30±0.9/32±3	30±0.9/32±3	30±0.9/32±3
Survival rate in %	**0.09**	**2.8**	**0.18**	**-**
Experiment 5				
Nominal/measured shock pressure	41.5±1.2/42±3	41.5±1.2/42±3	41.5±1.2/42±3	41.5±1.2/42±3
Survival rate in %	**0.02**	**0.02**	**0**	**-**
Experiment 6				
Nominal/measured shock pressure	50±1.5/--*	50±1.5/--	50±1.5/--	50±1.5/--
Survival rate in %	**0**	**0.002**	**0**	**-**

Nominal pressure: calculated based on calibration runs in the shock reverberation mode; measured pressure: based on refractive indices of plagioclase from gabbro plates according to [11]; *calibration data for shocked plagioclase not available, **depending on detection method; 0 = below detection limit; - = no data