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Adaptation of an Antarctic lichen to Martian niche conditions can occur within 34 days

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ABSTRACT

Stresses occurring on the Martian surface were simulated in a Mars Simulation Chamber (MSC) and included high UV fluxes (Zarnecki and Catling, 2002), low temperatures, low water activity, high atmospheric CO_2 concentrations, and an atmospheric pressure of about 800 Pa (Kasting, 1991; Head et al., 2003). The lichen *Pleopsidium chlorophanum* is an extremophile that lives in very cold, dry, high-altitude habitats, which are Earth's best approximation of the Martian surface. Samples with *P. chlorophanum* were exposed uninterruptedly to simulated conditions of the unprotected Martian surface (i.e. 6344 kJ m^{-2}) and protected niche conditions (269 kJ m^{-2}) for 34 days. Under unprotected Martian surface conditions the fungal symbiont decreases its metabolic activity and it was unclear if the algal symbiont of the lichen was still actively photosynthesizing. However, under "protected site" conditions, the entire lichen not only survived and remained photosynthetically active, it even adapted physiologically by increasing its photosynthetic activity over 34 days.

1. Introduction

Life could have evolved early in Mars' history, when the planet was warmer and wetter than today, and then retreated to protected (micro-) habitats as Mars became progressively colder and dryer. Likely protected Martian micro-environments which might harbor life include (a) liquid water beneath or in ice, (b) subterraneous aqueous reservoirs (perhaps with elevated heat flow), and (c) openings within rocks [e.g., cracks, fissures, lava tubes, caves (Schulze-Makuch et al., 2005)]. We studied the psychrophilic lichen *Pleopsidium chlorophanum* (Castello, 2003), because it lives in Earth's most Mars-like environmental conditions (low temperatures, high UV fluxes, dryness; see Fig. 1). *P. chlorophanum* preferentially colonizes granites and volcanic rocks of North Victoria Land (Antarctica), at up to 2000 m altitude (Guglielmin et al., 2011). It is mainly found in fissures and cracks, but also on the surfaces of rocks (Fig. 1a–f). The strategy of living in certain specific habitats—especially fissures and cracks—is probably adaptive behavior to protect against desiccation and high UV-fluxes, where just a small amount of scattered photosynthetically active radiation (PAR) can reach the organisms, thus allowing photosynthesis (Fig. 1e and f showing environmental data which were taken in parallel to data of photosynthetic activity of the lichen in niche areas what is shown in Fig. 5a expressed by the column "field conditions: niche site"). The lichen can also resist both temperatures ⩽0 °C, and low water activity (Fig. 1f), as do many species of polar lichens, which remain metabolically active at −17 to −20 °C and can absorb small amounts of liquid water in a snow- and ice-rich environment (Kappen et al., 1996). Extremophilic organisms from various Earth environments have been previously exposed to simulated Martian environmental conditions to study their survival rates and survival strategies (Morozova et al., 2007; Schuerger et al., 2003; Osman et al., 2008; Diaz and Schulze-Makuch, 2006). However, most such experiments were quite short in duration [e.g., 4–7 days (Berry et al., 2010; de Vera et al., 2010; Green et al., 1971)], while ours ran for 34 days, to more closely approximate the "Martian real-world".

2. Material and methods

2.1. The lichen Pleopsidium chlorophanum

The lichen *P. chlorophanum* has been collected at an altitude of 1492 m above sea level at the location "Black Ridge" in the North Victoria Land, Antarctica during the German North Victoria Land Expedition (GANOVEX 10, GPS: 74°23.254′S 163°40.378′E). The lichen was stored at −20 °C before been used in the experiment.

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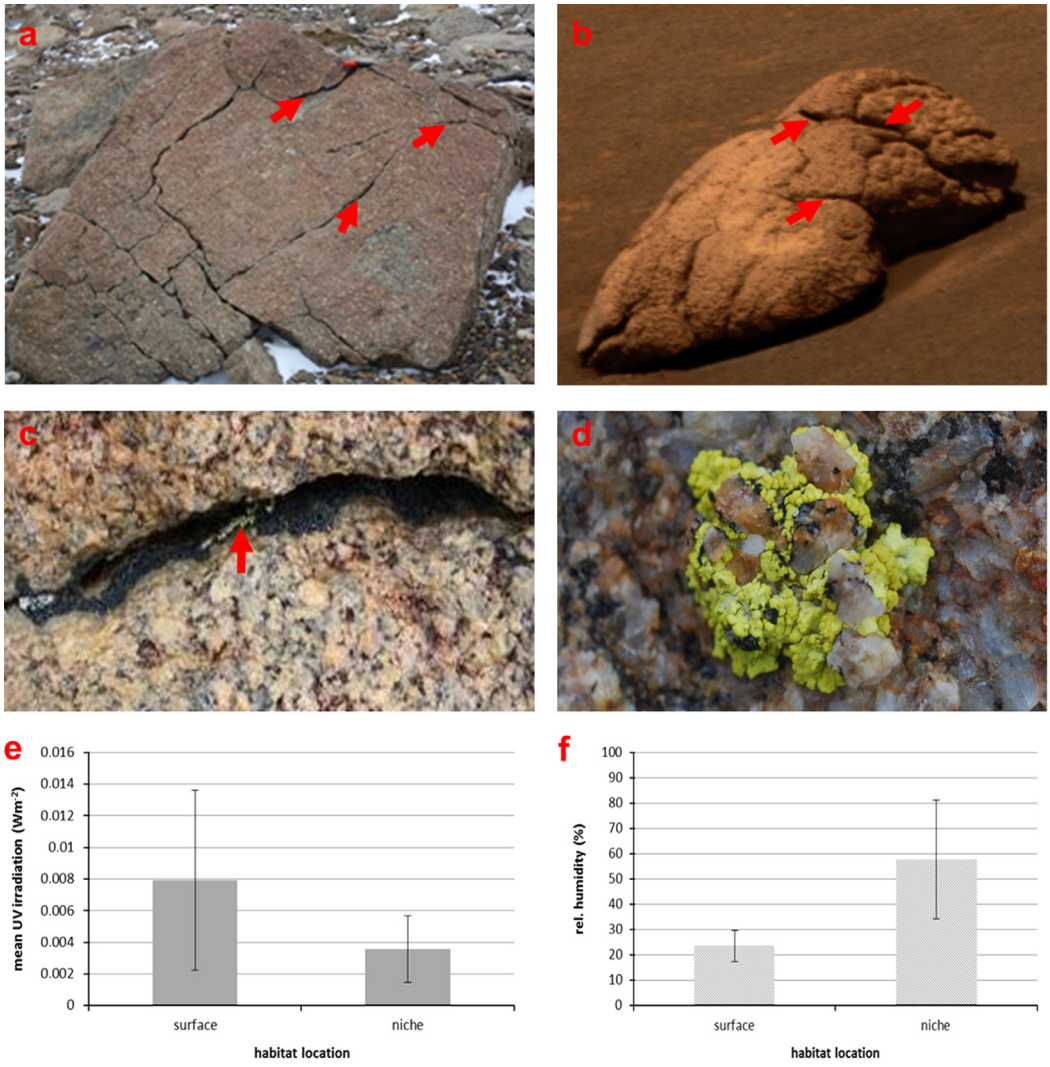

Fig. 1. Characterization of habitat niches of the lichen *P. chlorophanum* in Antarctica and possible niches on Mars. (a) Fissures and cracks as micro-niches (red arrows) in a rock (picture taken in characterized Mars-analog field site in the "Black Ridge Mountains" of North Victoria Land/Antarctica). (b) Fissures and cracks as potential micro-niches (red arrows) in the well-studied rock "Wopmay" within the Endurance Crater on Mars (NASA/JPL(Cornell)). (c) Part of the rock (in (a)) enlarged: a fissure is colonized by organisms in a biofilm, and by numerous lichens, e.g. *P. chlorophanum* (red arrow). (d) *P. chlorophanum* grown on the surface of granite rock. Some areas of the surface are showing semi-endolithic growth of the lichen where rocks are fragmented by the lichen due to increase of its size. The pieces of granite are partly covering the lichen possibly offering protection against UV irradiation. (e) Differences of UV-irradiation in the micro-habitat colonized by the lichen *P. chlorophanum*. The measurements were performed during the summer season (circumpolar sun cycle) in the Black Ridge Mountains (North Victoria Land/Antarctica) during the time where the Sun has its right angle directly positioned above the micro-niche and above the neighbor surface area of the rock with a measurement time of 3 h per sample. The protection within micro-niches against UV irradiation gets obvious. (f) Differences of humidity in the micro-niche versus the rock's surface macro-niche: micro-niche→rh (mean relative humidity)= 57, 79% [measured within temperature range of T=267 K (−6 °C) to 265 K (−8 °C)]; macro-habitat→mean rh=23, 48% [T=281 K (8 °C) to 265 K (−8 °C)].

Before the simulation the lichen was removed from the granite rocks and three lichen samples were prepared for *in situ* measurements under Mars-like niche conditions and three additional samples were prepared for Mars-like surface conditions with exposure to the entire simulated irradiation spectrum. The samples were embedded in a Mars analog soil mineral mixture (S-MRS, Table 2) as described later in Section 2.9 and 2 ml of distilled water was provided for each of the tested samples into the soil before the simulation experiment.

2.2. Mars-like environmental conditions

P. chlorophanum was held in the Mars simulation chamber (MSC) for 34 days, uninterrupted. The MSC atmosphere was 95% CO_2, 4% N_2, and 1% O_2, at 800 Pa (see Kasting et al., 1991), with a diurnal cycling of relative humidity between 0.1% and 75% (Fig. 2, Table 1) and diurnal temperature cycling of 294 K (+21 °C) to 223 K (−50 °C), like temperatures observed in equatorial to mid-latitudes on Mars (McEwen et al., 2011; Head et al., 2003). Lichen samples were embedded in a Mars analog mineral mixture (S-MRS, Table 2) and three of the six lichen samples were also exposed to Xenon lamp radiation that simulated the complete Martian solar spectrum (Fig. 3). Details and information of the MSC and S-MRS are described in Sections 2.3–2.9.

2.3. Experimental description

The experiment was carried out at the Mars Simulation Facility (MSF) of the DLR Institute of Planetary Research in Berlin. The MSF is part of the Department of Experimental Planetary Physics and is used to perform laboratory experiments with controlled time-profiles (e.g., simulated diurnal variations) of temperature down to about 198 K

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