INVESTIGATING THE IMPACT OF UV RADIATION ON HIGH-ALTITUDE SHALLOW LAKE HABITATS, LIFE DIVERSITY, AND LIFE SURVIVAL STRATEGIES: CLUES FOR MARS' PAST HABITABILITY POTENTIAL?

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Introduction: We present data and results from an ongoing project of astrobiological high-altitude expeditions investigating the highest and least explored perennial lakes on Earth in the Bolivian and Chilean Andes [1-2], including several volcanic crater lakes nearing and beyond 6,000 m in elevation. In the next five years, they will provide the first integrated long-term astrobiological characterization and monitoring of lacustrine environments and their biology for such altitude. These extreme lakes are natural laboratories. They provide the field data missing beyond 4,000 m to complete our understanding of terrestrial lakes and biota. Research on the effects of UV has been performed in lower altitude lakes and models of UV flux over time are being developed [3]. Lakes showing a high content of dissolved organic material (DOM) shield organisms from UV [4-5]. DOM acts as a natural sunscreen as it influences the water transparency, therefore is a determinant of photic zone depth [6]. In sparsely vegetated alpine areas, lakes are clearer and offer less protection from UV to organisms living in the water. Transparent water and high UV irradiance may maximize the penetration and effect of UV radiation [7-8]. Shallow-water communities in these lakes are particularly sensitive to UV radiation. The periphyton can live on various susbtrates. While on rocks, it includes immobile species that cannot seek low UV refuges unlike sediment-dwelling periphyton [9-10] or alpine phytoflagellates [11] which undergo vertical migration. Inhibition of algal photosynthesis by UV radiation has been documented in laboratory [12] and showed that phytoplankton production is reduced by formation of nucleic acid lesions [13] or production of peroxides and free oxygen radicals [14].

Our project is providing the field data that is missing from natural laboratories beyond 4,000 m and will complement the vision of the effects of UV on life and its adaptation modes (or lack thereof). The exploration of high-altitude lakes could shed light on early Earth's biological evolution as well. For two billion years, Earth's atmosphere lacked an ozone layer and life was subjected to high UV radiation. These lakes represent an opportunity to observe the evolution of microorganisms in shallow waters that do not offer substantial UV protection. Survival strategies in these lakes might prove very ancient and could be a rare chance to look into our own past. They could also unravel critical information for the search for life on Mars. Their unique environmental analogy to Martian paleolakes of the end of the Noachian era 3.5 Ga ago [15-16] allows to test the habitability potential of aqueous oases on early Mars and better prepare future astrobiological missions.

Physical Environment: The table below summarizes the environmental characteristics of the surveyed lakes. They present excellent analogies with models of early Mars. The lakes are located in a volcano-tectonic and hydrothermal setting.

	Thermales Hot Spring[1]	LB[2]
GPS Coord. Lat	22°46.96'S	22°47.00'S
GPS Coord. Long.	67°48.15'W	67°47.00'W
Elevation (m)	4,328	4,340
Length x Width (km)	0.010 x 0.005	1 x 0.5
Maximum Depth (m)	2	0.5
UV Flux (W/m^2)	81	81
Water Temp. (°C)	+36.2	+14
Air Temp. (°C, min/max)	-30/+12	-30/+12
Atm. Pressure (mb)	600	600
pH	8	7.2
TDS[5] (mg/L)	2,120	22,400
	LV[3]	*LC*[4]
GPS Coord. Lat	22°47.32'S	22°50.03'S
GPS Coord. Long.	67°49.16'W	67°53.00'W
Elevation (m)	4,332	5,916
Length x Width (km)	7 x 3	0.1 x 0.09
Maximum Depth (m)	40	4 to 10[(4)]
UV Flux (W/m^2)	81	89
Water Temp. (°C)	+12.9	+4.9
Air Temp. (°C, min/max)	-30/+12	-40/+3
Atm. Pressure (mb)	600	480
pH	9	8.5
TDS[5] (mg/L)	117,500	1,050

[1]Spring located between Laguna Blanca[(2)] and Laguna Verde[(3)]. [4]Licancabur summit lake. [5]Total Dissolved Solids.

Life Diversity and Food Webs: Geophysical and chemical analyses show that theses lakes differ considerably from each other. This is reflected in a significant differences in species numbers [17]. The 03 samples allowed the identification of macroscopic aquatic invertebrates, phytoplankton, zooplankton, and periphyton and that of the following groups found in large biomass in Laguna Blanca: Cyanobacteria, Bacillariophyceae (diatoms), Dinophyta, Charophyceae (macroscopic green algae), Filamentous green algae, Ciliata, Gastrotrycha, Testacea, Mollusca, Copepoda, Ostracoda, Amphipoda, Oligochaeta, Chironomida, and Heteroptera. The investigation of Laguna Verde and the Summit lake proved that Cyanobacteria and Bacillariophyceae are present. The nature and composition of the food chains in these three lakes are also starting to unravel. In *Laguna Blanca*, zooplankton sampling and investigations show that the crustacean zooplankton (copepods) forms a huge biomass. The following food chain can be outlined: Flamingos - Copepods (feed on Ostracods) - Ostracods (feed on diatoms) - Diatoms (as primary producers). *Laguna Verde* possesses a very simple and ancient type of food chain. Heterotrophyc bacteria - Cyanobacteria (and/or diatoms). The food chain for the S*ummit Lak*e is close to that of Laguna Blanca: Copepods (feed on Ostracods) - Ostracods (feed on diatoms) - Diatoms and Cyanobacteria.

Effect of UV radiation and Survival Strategies: The organisms living in these lakes face extreme environmental factors (e.g., high UV radiation and salt content, ice, sustained wind action). These factors cause a strong selective pressure on both flora and fauna. Species have to develop special strategies or individual adaptation modes. The most conspicuous way of individual adaptation is the enhanced pigmentation observed in the case of several organisms. On the shorelines, cyanobacteria produce yellow, brown or red accessory pigments, which shade and consequently protect their chlorophyll-a from the damage of high UV radiation. The red color of the ostracods and copepods, the black color of the snails can be also attributable to the high UV radiation. Filamentous green algaes produce a bark-like layer on the upper surface of their colony. This dark layer protects the underlying filaments (together with the macroscopic invertebrates) from the radiation. The periphytic diatoms in Laguna Blanca form a yellow, mucilaginous knob-like mass (Fig.1), which is attached on the leaves of aquatic macrophytes and float behind the surface layer. In this colony the cells are protected both from the radiation and from their predators (crustaceans).

The 03' expedition undertook the first step in testing the effect of UV radiation on immobile periphyton living in waters ≤50 cm deep between 4,000 m and 6,000 m elevation. We harvested the underplates of the UV filtering and UV transmitting chambers formed by acrylite submersed sheets that were positioned in 02 at the surveyed lakes to study the evolution of UV exposed *vs*. UV protected microorganisms. Moreover, high rates of deformities and malformation have been discovered in mobile diatom populations (Fig.2).

Fig. 1: Mucilaginous periphytic diatom mass attached to the macrophyte which dominates Laguna Blanca.
Credit: 2003 Licancabur Expedition Team.

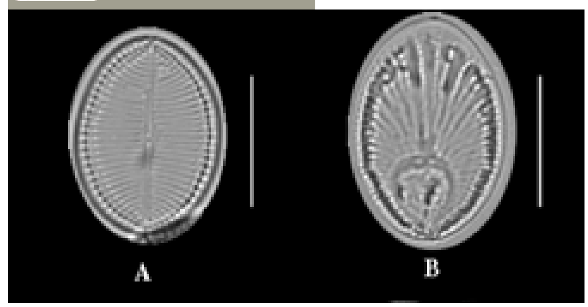

Fig. **2** Diatoms (LB). A: Cocconeis placentula, normal valve, LM; B: Teratological (abnormal) valves. Scale: 10 µm. Credit: 2002 Licancabur Expedition Team.

Next to these chambers we positioned in 03 two submersible, logging ELDONET UV dosimeters, one at the level of the lagunas and one at the Licancabur summit lake. They provide information about the environment (UVB: 280-315 nm, UVA: 315-400 nm, PAR: 400-700 nm, temperature). Their goal is to help better understand the spatial and temporal variability of the in-water optical properties influencing UV attenuation. Common in marine and low lake environments, these stations have never been deployed as high as the summit of Licancabur and are recording unprecedented data about these extreme high-altitude lake environments.

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