HIGH LAKES PROJECT - IMPACT OF CLIMATE VARIABILITY AND HIGH UV FLUX ON LAKE HABITAT: IMPLICATIONS FOR EARLY MARS AND PRESENT-DAY EARTH. N. A. Cabrol[1,2], E. A. Grin[1,2], L. Bebout[1], G. Chong[3], C. Demergasso[3], E. Fleming[1], V. Gaete[3], J. Gibson[4], D-P Häder[5], J. Mack[6,7], E. Minkley[8], E. Pinto[3], K. Rose[8], I. Ukstins Peate[9], C. Tambley[10], C. Williamson[7], J. J. Wynne[2,11]. [1]NASA Ames Research Center, CA; [2]SETI Carl Sagan Center, CA; [3]Universidad Catolica del Norte, Centro de Biotechnologia, Antofagasta, Chile; [4]University of Tasmania, Australia; [5]University of Erlangen, Germany, [6]USGS, CA; [7]University of Miami, OH; [8]Carnegie Mellon University, PA; [9]University of Iowa, IA; [10]CHEP, Chile; [11]Northern Arizona University. Email: Nathalie.A.Cabrol@nasa.gov.

Project Overview: The High Lakes Project (HLP) is a multi-disciplinary investigation supported by the NASA Astrobiology Institute (NAI). HLP studies eight lakes between 4,200 m and 6,000 m elevation in the Central Andes of Chile and Bolivia. Since 2002, seven high-altitude expeditions have been conducted, including the scuba diving exploration of the Licancabur lake (5,916 m) in 2006. The project involves 50 scientists from 26 institutions in 9 countries, and has developed a sustained E/PO program engaging schools and undergraduate to post-doctoral students. Its primary objective is to understand the impact of increased environmental stress on lake habitats and their evolution during rapid climate change as an analogy to early Mars. Their unique geophysical environment and little studied ecosystems have added new objectives to the project over the years, including (1) the assessment of the impact of low ozone/high solar irradiance in non-polar aquatic environments, (2) the documentation of poorly known ecosystems, and (3) the quantification of the impact of climate change on terrestrial lake environments and ecosystems.

Here, we present HLP's main results over seven years of investigation (2002-2008), focusing on the environmental factors that make the lakes unique and representative of an end-member class. The interannual evolution of their habitats provide insight into likely physical and chemical behaviors of residual martian lakes at the Noachian/Hesperian transition. Studying their microbial ecosystems provide insight into possible adaptation strategies against increasing pressure in a rapidly changing environment that could be relevant to early Mars. Moreover, these lakes are located in one of the regions of Earth most impacted by climate change and their geography (latitude and altitude) results in some of the most challenging geophysical environments on the planet. Understanding the adaptation mechanisms (or lack therefore) of their ecosystems to significant interannual variability provides data to help assess the potential impact of climate change at a local as well as a global scale.

Early Mars Analogy and Relevance: The study of terrestrial analog environments supports the design of investigation strategies and life detection methods for planetary exploration. Over the past decades, orbital and ground missions have provided multiple lines of evidence showing that water was abundant early in the history of Mars and that the planet was habitable for life as we know it [*e.g.,* 1-4]. However, phyllosilicates disappeared from the stratigraphic record around 3.7 Ga ago [5] replaced by sulfate deposits, then by ahydrated ferric oxides (olivine) about ~3.2 Ga ago [6-7]. This succession suggests that no further large-scale weathering occurred after that period but transient and localized aqueous processes likely associated with high-obliquity cycles were still possible. There is evidence supporting water activity in later geological periods [e.g., 8-11] but only episodically and as lower magnitude events possibly driven by magmatic pulses [12] and/or obliquity changes [13-14]. Within the past five years, newly formed deposits in Centauri Montes could be consistent with limited flow in present days, although they do not constitute on their own definitive proof [15].

Using the HLP lakes as a relevant Earth analogy, lakes on early Mars could be envisioned as favorable sites for the development of life and its preservation in the fossil record [*e.g.,* 16-21]. While martian lakes ultimately disappeared, how long they remained habitable as their water column shrank may have controlled life's ability to transition to new environments, i.e. by adapting to more protected habitats that offered radiation refuge and moisture retention, such as within sediments, rocks (endoliths), or underground.

Better understanding the magnitude and impact of environmental stress on aquatic life during rapid climate change and the threshold of habitability in lakes is, thus, part of an essential step in the design of future missions that will search for traces of life on Mars with the Mars Science Laboratory (MSL). This question motivated the development of HLP, a multi-disciplinary investigation of high-altitude lakes located in an environment presenting some of the best terrestrial analogs to early Mars. No terrestrial site can be defined as a perfect analog to Mars but many of the important parameters sought for to model early Mars are present in the Central Andes where some of the closest environmental analogies to the end of the martian wet period are encountered, such as a thin atmosphere (600-480 mb); enhanced evaporation, high solar irradiance; strong yearly temperature variation (ΔT)

i.e. ~50-65 °C; sudden and sharp daily temperature variations; seasonal ice-cover; and sulfur-rich, volcanic and hydrothermal environment [22-23].

Results: Data between 2003 to 2008 show that solar irradiance is 165% that of sea level with averaged maximum UV-B reaching 4W/m^2. UV flux (UVA+UVB) is double that of present-day Mars at the equator and UVB only half that of Mars in the same region. Short UV wavelengths (260-270 nm) were detected on the ground and peaked at 14.6 mW/m^2. The maximum erythemally-weighted daily dose recorded (23 KJ/m^2) is close to seven times that of Antarctica during ozone hole events. High solar irradiance occurs in an atmosphere permanently depleted in ozone falling below ozone hole definition (220 Dobson Units equivalent to 40% depletion) for 33-36 days/year and is between 30-35% depletion the rest of the year. The impact of strong UVB and UV erythemally-weighted daily dose on life is compounded by the broad daily temperature variations with sudden and sharp fluctuations, and an enhanced yearly negative water balance (evaporation = 1,200 mm/yr average). The year-round combination of environmental variables define these lakes as existing in end-member extreme environmental conditions. Six years of monitoring clearly established that interannual climate variability has a critical impact on water balance and chemistry with notable changes in yearly ion concentrations and pH resulting from low and variable yearly precipitation. In such an environment, they host surprisingly abundant and diverse ecosystems including a significant fraction of previously undescribed species of zooplankton, cyanobacterial, and bacterial populations. Among the samples collected, 17% are unknown at the phylum level and 70% at the genus level.

References: [1] Squyres, S. et al., *Science, 306 (3),* 1698 (2004); [2] Knoll, A. et al., *EPSL, 240,* 179 (2005); [3] McLennan, S. et al., *EPSL, 240,* 95 (2005); [4] Des Marais, D. et al., *36th LPSC, 2353,* (2005); [5] Bibring, J-P. et al., *Science, 307,* 1576 (2005); [6] Christensen, P. et al., *Science, 300,* 2056 (2003); [7] Mustard, J. et al., *Science, 307,* 1594 (2005); [8] Carr, M. *Water on Mars*, Oxford Univ. Press (1996); [9] Malin, M. & K. Edgett, *Science, 302,* 1931 (2000); [10] Baker, V. *Science, 412,* 228 (2001); [11]Murray, J. et al., *Nature, 434,* 352 (2005); [12] Dohm, J. et al., In: *Superplumes: Beyond plate tectonics*, Springler Netherlands, 523 (2007); [13] Haberle, R., *JGR, 103 (28),* 467 (1998); [14] Jakosky, B. et al., *Science, 310 (5373),* 1439 (2003); [15] Malin, M. et al., *Science, 314, (5805),* 1573 (2006); [16] Farmer, J., *Palaios, 10, (3)* 197 (1995); [17] Farmer, J., *LPI Cont. No. 1062,* 110 (2000); [18] Des Marais, D., and J. Farmer, In: M. Meyer and J. Kerridge, Eds. *An Exobiology Strategy for Mars Exploration*, 21 (1995); [19] Farmer, J., and D. Des Marais, *JGR-Planets, 104 (E11),* 26,977 (1999); [20] Cabrol, N., and E. Grin, *Icarus, 149,* 291 (2001); [21] Cabrol, N., and E. Grin, In: *Water and Life on Mars*, Chapter 10, 181, Springler-Verlag (2004); [22] Cabrol, N. et al., In: *The Geology of Mars, Chapter 14: Evidence from Earth-Based Analogs*, (Chapman, M. Ed), CUP, 349 (2007); [23] Cabrol, N. et al., *JGR-Biogeosciences Special Issue on the High Lakes Project* (in press).

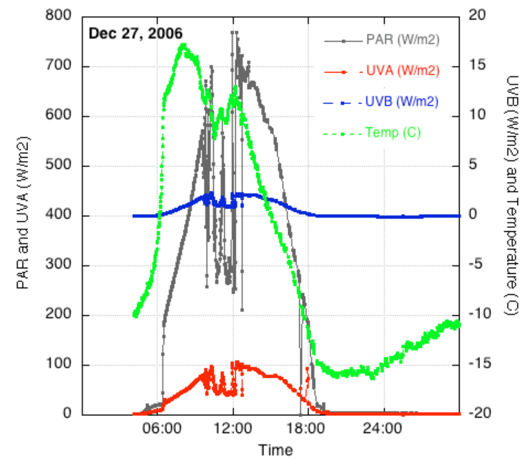

Figure 1: Evolution of UV and temperature at the summit of the Simbad volcano (5,870 m, Chile). Results are averaged every minute.

Figure: Microalgae from the Simbad lake. Red and green fluorescence shows two different types of pigments protecting the cell wall and the chloroplasts from UV radiation reaching 165% that of sea level at the water surface where the organism commonly floats. *Credit image: 2008 HLP; Alex Echeverría, UCN, Antofagasta, Chile. Olympus FV1000 confocal system with modulate spectral detection. Channel 1 (green): excitation: 488 nm; Emission/Detection range 497-527 nm; Channel 2 (red): Excitation 543 nm, Emission/Detection range 600-630 nm.*

Ackowledgments: HLP is supported by the NASA Astrobiology Institute (NAI) grant No. NNA04CC05A. The team is particularly grateful to the NAI for featuring the 2008 expedition on their website.