SHORT TIME SCALE EVOLUTION OF MICROBIOLITES IN RAPIDLY RECEDING ALTIPLANIC LAKES: LEARNING HOW TO RECOGNIZE CHANGING SIGNATURES OF LIFE. N. A. Cabrol[1,2], E. A. Grin[1,2], G. Borics[3], A. Kiss[4], D. Fike[5], G. Kovacs[6,1], A. Hock[7,1], K. Kiss[8], E. Acs[8], R. Sivila[9], E. Ortega Casamayor[10], G. Chong[11], C. Demergasso[11], J. Zambrana[12], M. Liberman[9], M. Sunagua Coro[12], L. Escudero[11], C. Tambley[11], V. Angel Gaete[11], R. L. Morris[1,2], B. Grigsby[13], R. Fitzpatrick[13], and G. Hovde[1,2]. [1]NASA Ames, [2]SETI Institute, [3]Env. Protec. Inspect.Trans-Tiszanian Reg., Hungary, [4]University of Budapest, Hungary,[5] MIT, [6]Stanford University, [7]UCLA, [8]Hungarian Academy of Sciences,[9]SERNAP, Bolivia, [10]CSIC, Blaines, Spain, [11]Univ. Catolica Norte, Chile, [12]SERGEOMIN, Bolivia, [13]Schreder Planetarium, Project ARISE. Email first author: ncabrol@mail.arc.nasa.gov.

Introduction: As part of the exploration of high altitude lakes as analogs to Martian paleolakes environment [1], we are investigating a remarkably large and diverse field of lacustrine stromatolites located at 4,365m in the Bolivian Altiplano (22°47'00S and 67°47.00'W).The field is composed of both early Holocene fossil structures located on paleoshorelines and present-day active cyanobacterial communities on the shore and at the bottom of the current Laguna Blanca and Verde. Its physical environment, broad diversity of morphologies, and their associated spatial heterogeneity, origin, and scale offer a unique opportunity to explore microbialites in conditions reminiscent of early Earth and Mars. At this altitude and latitude, UV radiation levels are enhanced (40% higher than sea level) and harmful to microorganisms living in shallow waters which provide only minimal protection from UV. Similar conditions prevailed on early Earth when the ozone layer had yet to be formed in the atmosphere. Compared to those studied at sea levels, these stromatolites could yield new insights about the earliest terrestrial forms of life. Moreover, the combination of physical and geological environment of this site is exceptionally analogous to conditions believed to be prevalent on Mars at the end of the Noachian (3.5 Ga ago), allowing to test the potential for forming stromatolites in martian paleolakes and learn how to identify their fossil record remotely. Our overarching goal is to generate new astrobiological information on high-altitude stromatolites as clues to early biospheres with implications for Earth and Mars. Our two central objectives are: (1) to characterize the biological, geological, and mineralogical features and significance of this field, and to identify geo-signatures such as morphology, geology, chronostratigraphy, mineralogy and biosignatures, and (2) to facilitate remote-sensing and ground robotic detection capabilities for future astrobiological missions to Mars.

Description: A ≥100 km^2 field of fossil stromatolites occupies most of the ancient terraces of the former paleolake that originally included the now mostly separated Laguna Blanca and Verde in the Bolivian Altiplano. Their distribution is stratigraphically discontinuous: the structures are widespread on the oldest terraces, disappear from some intermediate shoreline levels and reappear on younger ones. These pauses are often associated with sharper stratigraphic transitions (e.g., larger terraced shorelines and thicker deposits), changes in grain-size and nature of material on the deposits. The discontinuity seems to be correlated to environmental changes of diverse origins (e.g., climate, volcanic activity, lake physical and chemical properties).

Fossil Record and Active New Colonies: C^{14} was performed on samples of the main terrace and indicates an age of 15,330 ± 210 years. Smaller stromatolites located stratigraphically closer to the current shore are dated 11,210 ± 120 years. These results are consistent with the large paleolake being formed during the Holocene altiplanic wet climate episode [2-6]. Below this stratigraphic level, and closer to the current active shoreline, the density of fossil structures decreases. However, the survey of Laguna Verde and Blanca shows the existence of modern cyanobacterial communities forming stromatolitic structures on the present-day shore in active hydrothermal springs and extensively on the shallow lakebed where abundance of (sometimes coalescent) round cyanobacterial colonies are observed building domes resembling stromatolites.

Diversity in Shape and Size: The short spatial and temporal scale variability in distribution of the stromatolites is associated with an exceptional diversity of forms and sizes for the fossil structures ranging from 10 cm to 20 m (Figs. 1 and 2). Both stromatolites (laminated) and thrombolites (clotted structures [7]) are observed. Microscopic examination shows that cyanobacterial filaments formed most of the structure within the laminations. Their morphology shares many characteristics of the Precambrian stromatolites. In addition to cyanobacteria, other layers are mixed and have diatoms and ostrocod shell fragments. Mineralogical variations within the lamination of individual structures are indicative of changes in the environment within short geological periods of time. Future detailed sampling and analysis of the stromatolites along stratigraphic transects through the paleoterraces and at the lamination scale will help understand the magnitude of the changes and their implications for the microorganic communities. In upcoming campaigns the discontinuity of this field at such short temporal scale added to sharp stratigraphic relationships will also allow to test the sensitivity to rapid environmental changes of one of the most ancient forms of life. In less than 15,000 years, precipitation rates decreased from 500 mm.y^{-1} to ≤200 mm.y^{-1} [1]. The extent of the original lake gives a water volume close to 3 km^3. Both lagunas now combine only ~0.3 km^3. Most of the volume was lost in the past 10,000 years as inferred from our paleobathymetry and C^{14} analysis. In spite of these short geological time-scale variations and physical environment, cyanobacteria, one of the most ancient terrestrial forms of life, colonized these shores and survived up to the present. Understanding how they survive could provide precious clues for Mars.

Moreover, the textures observed in the samples share many features of Precambrian stromatolites, including Mesoproterozoic specimens from the Billyakh Group, Siberia [9] which possess dendritic textures similar to those observed in the lagunas as well as micron-scale lamination similar to that found on the edge of the examined dendrites. While the Mesoproterozoic stromatolites formed in a peritidal marine environment and the lagunas stromatolites formed in a shallow lacustrine and arid environment, the morphological resemblance between them suggests that the physical parameters that played a role in forming the specimens at the lagunas may be important to understand the depositional environment of the Mesoproterozoic samples.

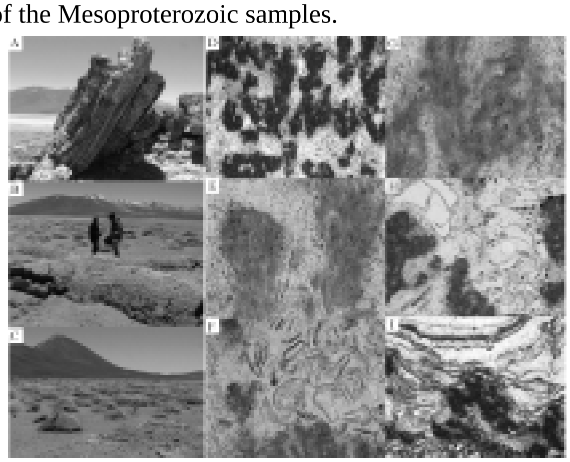

Fig. 1: A. 5-m collapsed stromatolite (LV); B. Cross-shaped structure; C: 50 cm-high domes (Licancabur in the background); D-I: Photomicrographs of a stromatolite fragment. D: Dendrites (dark gray) consist of micrite with cyanobacterial filaments throughout. Calcite cements fills the area and contains abundant cyanobacterial filaments. Occasionally, dendrites penetrate into the calcite cement layers, and sometimes connect successive dendrite layers. (Scale photo, S: 2.5 mm); E: Close up of dendritic micrite structures revealing cyanobacterial filaments (black) throughout the structure. These filaments are also found throughout the calcite cement (S: 625µm): F: Diatom hash at the termination of additional micritic structures (S: 625 µm); G: (same as E, S: 625µm); H: Ostrocod and diatom hash at the termination of micritic structures (S: 1.25 mm); I: Fine-scale laminations observed at the edges of the sample (S: 2.5 mm).

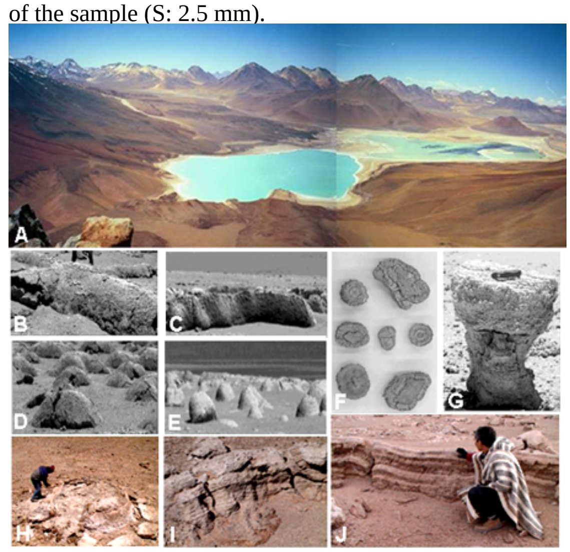

Fig. 2: View of Laguna Verde from the slope of the Licancabur summit lake. A. Laguna Verde and Blanca and former shorelines are clearly visible from this vantage point. The eastern limits of the lake (to the right) are not visible on this photo. Fossil stromatolites circle the paleolake and show a large diversity of forms: B. Cross shaped structure can reach 10-15 m in size and 1 m in height; C: elongate (10-20 m); D: Dome-shaped, in average 1m to 2 m at the base and 90 cm in height. Larger structure were observed (see D); E: "termite dome" structures, with comparable dimensions to D; F: The smallest laminated dome structures found (1-10 cm); G: columnar shape (~ .70 m in height); H: the largest domal structures were found close to the current shore. This one was about 5 m at its base; I and J: laminated eroded and collapsed structures.

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