3-19-2013

Impact and Signatures of Deglaciation on the Cryosphere, Landscape, and Habitability of Earth and Mars

Nathalie A. Cabrol
SETI Institute/CSC and NASA Ames Research Center

Andrew G. Fountain
Portland State University, andrew@pdx.edu

J. S. Kargel
University of Arizona

Citation Details

Cabrol, Nathalie A.; Fountain, Andrew G.; and Kargel, J. S., "Impact and Signatures of Deglaciation on the Cryosphere, Landscape, and Habitability of Earth and Mars" (2013). *Geology Faculty Publications and Presentations*. 46.
https://pdxscholar.library.pdx.edu/geology_fac/46

IMPACT AND SIGNATURES OF DEGLACIATION ON THE CRYOSPHERE, LANDSCAPE, AND HABITABILITY OF EARTH AND MARS.

N. A. Cabrol[1], A. G. Fountain[2], J. S. Kargel[3], and the Members of the Deglaciation Study Steering Group. [1]SETI Institute/CSC and NASA Ames Research Center, Space Science Division, MS 245-3, Moffett Field, CA 94035-0001, USA. Email: Nathalie.A.Cabrol@nasa.gov; [2]Department of Geology, Portland State University, Portland, OR, 97207-0751, USA. Email: Andrew@pdx.edu; [3] The University of Arizona, Department of Hydrology and Water Resources, Tucson AZ 85721-0011, USA. Email: kargel@hwr.arizona.edu.

Overview: Rapid environmental changes result in accelerated transformation of habitats and geomorphological processes, and drive their spatio-temporal redistribution. Although solar insolation on Mars, and presumably its climate and environment, fluctuate with a higher amplitude than equivalent oscillations of Earth (Fig. 1), the consequences of the rapid climate change currently experienced by our planet are detectable over the timescale of a human lifetime. Habitable environments are modified at a rate that may outpace that of biological evolution [1], and the very active effects of climate change on Earth's cryosphere may provide a readily observable proxy for what has cyclically happened on Mars.

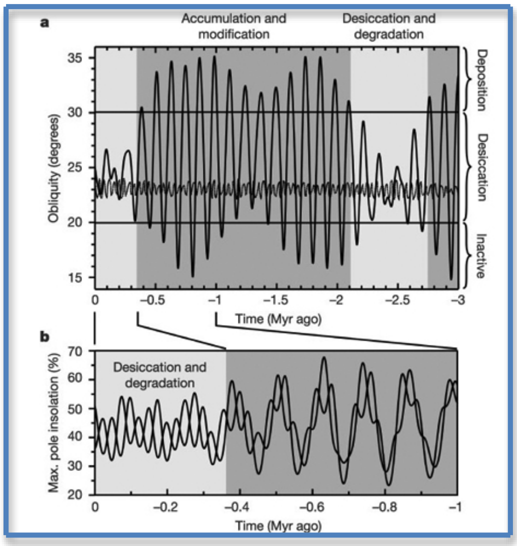

Fig. 1* – (a)** *Obliquity variations of Mars for the past 3 Myr, with glacial (accumulation and modification; dark grey) and interglacial (desiccation and degradation; pale grey) periods marked. Low-amplitude line between 22° and 24° represents the obliquity range on Earth during the comparable period of history.* ***(b) *Maximal insolation of the north and south poles of Mars for the past 1 Myr. [2, Fig. 4, with permission of Nature].*

While studies of past climates demonstrate that abrupt changes have occurred frequently in Earth's history, their record is dispersed and incomplete. By contrast, current climate change gives us the opportunity to characterize, as they happen, the physical, geological, and biological transformations of Earth's habitability, and teaches us how to detect similar signatures on Mars. What is learned from our planet may ultimately help the design of future missions (payloads, methods, technologies) and the selection of landing sites for the search for past and/or present life on Mars. Similarly, the nested scales, and multi- to hyperspectral resolution approach of astrobiology to the study of deglaciation may foster new techniques for monitoring Earth.

This potential has led to the creation of the Deglaciation Study Steering Group commissioned and sponsored by the NASA Astrobiology and Cryosphere Divisions. Its goal is to bridge the two Divisions around science questions relating to planetary deglaciation.

Deglaciation on Present Earth, and Past and Recent Mars: One of the main characteristics of climate change is the rising average temperatures of Earth's atmosphere and oceans – or global warming [3]. Its most unequivocal consequences are deglaciation, aridification, and sealevel rise [4].

This process is relevant to the climate history of Mars. Although Mars has experienced a cooling trend from past to present, high obliquity has led to repeated warmer pulses that allowed snow precipitation and accumulation [5-6]. The latest of these periods (10-100My) has left glacial features [7-13] and ground ice destabilization [14]. Evidence of glacier activity was found in early geological terrains as well [e.g., 15-17]. As ice and meltwater disappeared, Mars was once again characterized by aridity, with landscapes dominated by aeolian processes similar to what occurs on Earth in late stages of deglaciation [e.g., 18-20].

Due to the partial loss of its atmosphere, the implications of this process for the environment would have been different on early Mars compared to modern times. During the Noachian, conditions favored the formation of glaciers, valley networks, and lakes under a thicker atmosphere, relatively warmer temperatures, and more available liquid water than during subsequent geological times. Early deglaciation may have provided water sources for increased surface runoff, outflow, infiltration, aquifer recharge, and spring discharge.

In modern times, warming had lead to snow precipitation and the local accumulation and preservation of ice possibly up to the present day (Fig. 2). These late cycles may also have played a major role in the restoration of some, albeit limited and localized, subsurface water circulation, and in the formation and redistribution of habitats for life. As a result, when identified, these sites should be considered of the highest priority for the search of life by a rover in 2020.

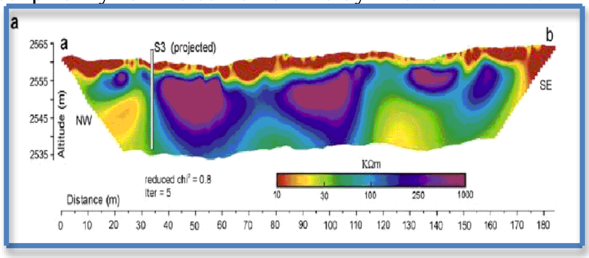

Fig. 2. *3D resistivity tomography of the Foscagno rock glacier in Italy. The scale from red to purple shows increasing residual ice concentrations. Debris-covered, and rock glaciers preserve ice, as well as some subsurface liquid water circulation long after the surface ice is gone. [21: Fig. 6a, p. 514 – With permission of Quat. Sci. Rev., Elsevier].*

Understanding and Exploring Deglaciation on Earth and Mars – Some Key Questions: Considering the already existing archival resources of Earth Orbiting, and Mars mission datasets, a natural first step is to envision the science questions about deglaciation that can be documented by remote sensing on both planets.

Example questions include:

I – Surface Habitat

1. What are the biogeochemical and ecological changes in response to deglaciation for streams, lakes, and soils?

(a) How does microbial ecosystem change affect the spatial and spectral response of deglaciated landscapes?

2. What are the watershed sources, composition, and texture of chemical weathering products associated with deglaciation?

(a) How, and how fast does deglaciation affect the evolution of parent-rocks and soils as sources of sediments in runoffs and lakes, and what is the response of aquatic habitats (e.g., water transparency changes);

(b) What are the temporal, spatial and spectral changes of the thermal response for rocks and soils in deglaciating areas, and their thermal feedback?

II – Marine Habitat

1. What are the biogeochemical and ecological changes in response to deglaciation in ocean?

III – Atmosphere/Surface Interaction

1. How does deglaciation affect the optical properties of the atmosphere and water column in continental and marine habitats?

(a) How changes in transparency, whether in the atmosphere or water column affect the amount, wavelengths, and optical depth for light available to life and/ or biologically-damaging?

2. How does deglaciation modify the water cycle at the ecosystem scale?

(a) What are the changes in snow mass, snowmelt, snow covered area, overland runoff, base flow, evaporation (including soil evaporation), sublimation, relative humidity, dry enthalpy, ground temperature, and surface emissivity.

These are only a sample of the questions that can help bridge Astrobiology and Earth Sciences around the theme of planetary deglaciation. Our presentation will focus on a detailed description of the theme and its implications, how science questions can help bridge both disciplines, and how they are relevant to both. We will also discuss how the community can contribute to this effort.

References: [1] Kelly, M. W., et al., 2011, *Proceed. of the Royal Society B*: *Biol. Sci.,* 2011; [2] Head, J. W., et al., *Nature*, 426, 797-802, 2003; [3] I. P. C. C., *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. In: J. J. MacCarthy, et al., Eds.), Cambridge, UK, 2001. [4] I. P. C. C., *Contribution of Working Groups I, II, and III to the Fourth Assessment Report on the Intergovernmental Panel on Climate Change*, In: R. K. Pachauri, A. Reisinger, Eds.), Vol. Synthesis Report, 2007; [5] Haberle, R. M., et al., 35th *Lunar Planet. Sci. Conf.*, abstract #1711, 2004; [6] Forget, F., et al., *Science*, 20, 368-371. 2006; [7] Fastook, J. L., et al., *Icarus*, 198, 305-317, 2008; [8] Head, J. W., Marchant, *Geology*, 31, 641-644, 2003; [9] Neukum, G., et al., *Nature*, 432, 971-979, 2004; [10] Shean, D., et al., JGR, 110, E0500, 2005; [11] Baker, V. R., *Nature*, 434, 280-283, 2005; [12] Garvin, J. B., et al., *Met., Plan. Sci.*, 41, 1659-1674; 2006; [13] Dickson, J. L., et al., *Geology*, 36, 411-414, 2008; [14] Mustard, J. F., *Nature*, 412, 411-414, 2001; [15] Lucchitta, B., JGR, 89, B409-B418, 1984; [16] Kargel, J. S., Mars: A warmer wetter planet, Praxis-Springer, Chichester, UK, 2004; [17] Fairén, A. G., et al., *Nature Geoscience*, 1-4, 2011; [18] Dardis, G. F., Irish Geog. 19, 51-56, 1986; [19] Abbott, M. B., et al., *Quat. Sci. Rev*., 19, 1801-1820, 2000; [20] Chauhan, O. S., Cur. Sci., 84, 90-93, 2003; [21] Ribolini, A. et al., Quat. Sci. Rev., 29, 507-521, 2010.

Additional Information: N. A. Cabrol and A. G. Fountain are Co-Chairs of the Steering Group on Deglaciation. They will respond to questions about this activity via email prior to the conference, or in person at the LPSC.