PROGRESSIVE CLIMATE CHANGE ON TITAN: IMPLICATIONS FOR HABITABILITY J. M. Moore[1] and A. D. Howard[2], [1]NASA Ames Research Center, MS 245-3, Moffett Field, CA 94035 jeff.moore@nasa.gov, [2]Dept. of Environmental Sciences, Univ. of Virginia, Charlottesville, VA 22904-4123, ah6p@virginia.edu

Introduction: Titan's landscape is profoundly shaped by its atmosphere and comparable in magnitude perhaps with only the Earth and Mars amongst the worlds of the Solar System. Like the Earth, climate dictates the intensity and relative roles of fluvial and aeolian activity from place to place and over geologic time. Thus Titan's landscape *is* the record of climate change. We have investigated three broad classes of Titan climate evolution hypotheses (Steady State, Progressive, and Cyclic), regulated by the role, sources, and availability of methane. We [1] favor the Progressive hypotheses, which we will outline here, then discuss their implication for habitability.

Progressive hypotheses have been suggested for supplying Titan's methane-rich atmosphere that do not rely on continuous replenishment. *McKay et al*. [2] considered that the warming sun may have been key to generating Titan's atmosphere over time. They hypothesize that Titan experienced a Triton-like phase 3 Gyr ago, where Titan's surface may have been covered by methane and possibly nitrogen ices. The surface would have gradually warmed as the solar luminosity increased, releasing methane into the atmosphere. *Lorenz et al*. [3] concur that nitrogen may have been collapsed out of Titan's atmosphere in the past due to the faint young sun, and/or because ancient methane was photochemically destroyed at a rate faster than it could be supplied to the atmosphere. The gradual increase in solar luminosity and irradiation-induced lowering of the surface albedo may have released frozen volatiles to the atmosphere over time. *Moore and Pappalardo* [4] argued that there have been no conclusively identified volcanic features seen on Titan, as well as reviewed the range of recent geophysical analyses indicating a cold, quiescent interior, and concluded that Titan's landscape is consistent with these theories. A simple Progressive scenario would be that Titan was Triton-like until recent geologic time when solar warming (perhaps abetted by a large impact event) rapidly created a thick atmosphere, initially with much more methane than at present, resulting in initial global fluvial erosion that has over time retreated towards the poles with the removal of methane from the atmosphere (e.g., [5,6]).

Geological Observations: The types of terrains seen on Titan may be difficult to reconcile with a simple steady-state scenario. For Titan to have still-recognizable cratered terrains *and* ongoing fluvial activity could imply one or more of at least three possible explanations: (1) alkane fluvial erosion on Titan is extremely inefficient relative to that by water on the Earth and Mars; (2) fluvial erosion very rarely (or briefly) occurs on some regions on Titan; and/or (3) it has started raining on Titan only in geologically recent times. We [7] proposed that Hotei and Tui Regiones are sites of sub-equatorial paleo-lakes, and they suggested the loss of low-latitude lakes was due to irreversible loss of methane available for precipitation. These observations, coupled with the latitudinal distribution of landform types across Titan (incompletely eroded bedrock exposures favoring low latitudes, while the higher latitudes and poles are dominated by sediment), leads us to favor the progressive hypotheses [1].

Implications for Habitability: If indeed Titan's present climate is only a few hundred of millions—or even a few tens of millions [8]—of years old, the ability of self-replicating and metabolizing organisms on or just beneath the surface (in the lakes, aquifers, or otherwise) to reach such states of organization may be challenged. If such organisms *do* exist, then though they would presumably be very different in chemistry than terrestrial organisms, their existence could be taken as an indication that life (even unlike we know it) can arise very quickly. The other possible challenge to the rise and sustenance of such organisms posed by the progressive hypotheses is that cryo-volcanism or other sources of internal heating at or near the surface, are not required (and may not exist), calling into question whether essential energy gradients capable of supporting metabolism would be present. (Of course, it is conceivable that atmospheric processes alone might create a biologically useable disequilibrium.) Thus, a Titan in which the present climate is a relatively modern development provides an important test for the virility of life in the cosmos.

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