TITAN'S GOO-SPHERE: GLACIAL, PERMAFROST, EVAPORITE, AND OTHER FAMILIAR PROCESSES INVOLVING EXOTIC MATERIALS. J.S. Kargel[1] (kargel@hwr.arizona.edu), R. Furfaro[2], C.C. Hays[3], R.M.C. Lopes[3], J.I. Lunine[4], K.L. Mitchell[3], S.D. Wall[3], and the Cassini RADAR Team, [1]Dep't. of Hydrology & Water Resources, Univ. of Arizona, Tucson, jkargel1054@earthlink.net, [2]Dep't. of Aerospace & Mechanical Engineering, Univ. of Arizona. [3]Jet Propulsion Laboratory. [4]Dep't. of Planetary Sci., University of Arizona.

Introduction: We introduce a new Geologic Operating Organon (*GOO*) for Titan based on the low-temperature activity and physical mobility of many hydrocarbon and organic substances; this conceptual model derives insight from processes on Earth, Mars, Triton, and elsewhere. Titan's atmospheric photchemistry and crustal volatile chemistry produce a complex assemblage of condensable volatile and involatile materials [*1-3*], generally carbonaceous, that are mobilized surficially and in the upper crust [*3*]. We refer to these materials as *goo*, which is prone to exchange between solid, liquid, dissolved, and vapor states. Some goo substances are soluble in liquid methane and ethane or are volatile on Titan's surface; some are solid but might be soft enough to undergo ductile flow.

Our knowledge of the composition and temperature-dependent physical properties of goo is limited, but some exotic carbonaceous materials on Titan may exhibit familiar geologic behavior. Cassini RADAR indicates strong latitude control on landforms' distribution, consistent with climatic control of deposits and processes. RADAR images of Titan's north polar region (e.g., lakes,[*4-5*]) suggest analogs of Earth's permafrost and glacial terrains, thus implying polar volatile deposition and sublimation- and melt-controlled development. At lower latitudes marine, evaporite, karst, and eolian processes may be prevalent.

We estimate possible rheologies of key solids and co-condensed solids/liquids based on homologous melting temperatures, molecular weight, and chemical analogs among paraffin waxes, asphalt, plastics, and other familiar hydrocarbon and organic mixtures. We interpret Titan's polar landscapes as polar volatile deposits responding both to top→down climate-driven and bottom→up geothermal processes familiar from the cryospheres of Mars and Earth.

What is goo? Webster defines *goo: (Informal) n. A thick or sticky substance.* We define *goo: (Technical) n. Condensed substances near or on planetary surfaces that are repeatedly cycled among different phase states and moved among various reservoirs and physical configurations*. Titan goo consists mainly of photochemical tholins and geologically processed, condensible hydrocarbons, organics, and hydrocarbon-soluble noncarbonaceous volatiles. Goo cycles between solid ←→ vapor, solid ←→ liquid, liquid ←→ vapor, or dissolved ←→ solid states on Titan's surface and in its upper crust and troposphere. Some goo materials (e.g., solid ethylene and propane or mixtures with ethane) may have a waxy, plastic, or Webster-type gooey rheology near Titan's surface, like candle wax, asphalt, low mass polyethylene, or ice in familiar Earthly circumstances; some goo might exhibit brittle-ductile and flakey behavior; others (probably benzene) might be as brittle as glass or crystalline silicates. Liquid methane may flow in streams more fluid than liquid water; polymerized liquid goo may be viscous. Titan's main goo solvents are liquid methane and ethane; precipitable solutes may include propane, acetylene, ethylene, carbon dioxide, and hydrogen cyanide.

Hydrocarbon lakes may be complex mixtures and produce evaporitic deposits when the main solvent (especially methane) evaporates. Dissolution of thick deposits of evaporites, such as ethylene precipitated and re-dissolved by methane, may produce karst [*5*].

Metamorphosed goo may include high-mass alkanes and benzene derivatives, such as napthalene and anthracene; we refer to these materials as *gun*k if they are brittle, involatile, and insoluble in methane/ethane near Titan's surface. Gunk having melting points above that of ice may exit the goo-ological cycle and form inert deposits. Gunk may be eroded, with involatile, insoluble crustal ices, and form clastic deposits (e.g., sand dunes, moraines, or cobbly beaches).

Cryolavas may include aqueous or hydrocarbon/organic solutions/slurries mobilized from the deep interior, or liquid hydrocarbons/organics formed by fusion of upper crustal goo. Low-melting-point crustal goo (e.g., acetylene, ethylene, or the benzene-napthalene eutectic) may be erupted cryovolcanically.

Titan observations and geomorphologic analogs

Titan RADAR images support compelling similarities of some polar lake-dotted landscapes [*4*, Fig. 1a] to thermokarstic lowland permafrost in Alaska [Fig. 1b] and on Mars, glacial thermokarst [Fig. 1c], or karstic lake basins [*5*]. Other north polar terrain [Fig. 2a] may be similar to alpine glacial landscapes in Alaska [Fig. 2b]. A link to polar volatiles is indicated by the global distribution of these terrains on Titan.

Polar goo glaciers and goo permafrost on Titan? Methane and ethane may freeze under possible polar climates; even if they don't, polar volatile goo condensates may include ethylene, acetylene, and propane. For example, solid cubic acetylene's vapor pressure would produce roughly the amount seen in the atmosphere (~2 ppm). Having a strong temperature depend

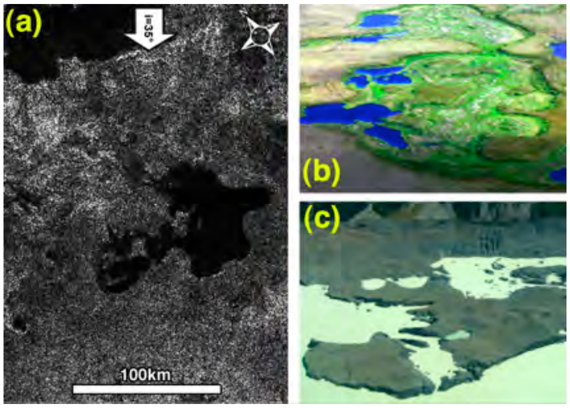

Fig 1. (a) Cassini RADAR image of Titan's north polar area of scalloped lakes and connecting drainages. (b) Thermokarst basins of lowland permafrost, Yukon Delta National Wildlife Refuge, Alaska. (c) Glacial thermokarst, Tasman Glacier, New Zealand.

ence, acetylene might saturate at the poles and form thick deposits. Long-term photochemistry can produce kilometer-thick deposits of acetylene over 8% of Titan's surface. Thus, acetylene glaciers are possible.

Universalities of key processes. We are defining universalities of geologic processes and applying them to the goo-ology of Titan. Here we give an example describing glacier formation and characteristics, which should apply to hydrocarbon glaciers on Titan as well as ice glaciers on Earth. Snow-accumulation glaciers are defined as: *n. A perennial mass of surficial volatile solids condensed from the atmosphere, as part of a global volatile cycle, and exhibiting morphologic signs of flow under the force of its own weight.* Glaciers may also include gases, liquids and involatile solids. Whereas tholins may form a type of glacier unrelated to volatile cycling, we now consider glaciers formed by precipitation in a goo-ological analog of Earth's hydrological cycle. The glacier substance must have a vapor pressure and condensed source reservoir sufficient to drive significant atmospheric transport from sources to condensation points. The atmosphere must be unsaturated over part of the reservoir and oversaturated at the glacier, where temperature tends to be subfreezing and precipitation occurs as snow. Net mass balance over an accumulation/ablation cycle must be positive (snowfall must exceed evaporation and melt runoff). The glacier substance must be soft enough and must accumulate into a mass thick enough that it flows under its own weight. Goo glaciers will occur in some systematic relationship to topography, latitude, elevation, and global atmospheric circulation relative to a source reservoir. They will be responsive to changes in accumulation rate and mass balance driven by fluctuations in climate or geothermal environment.

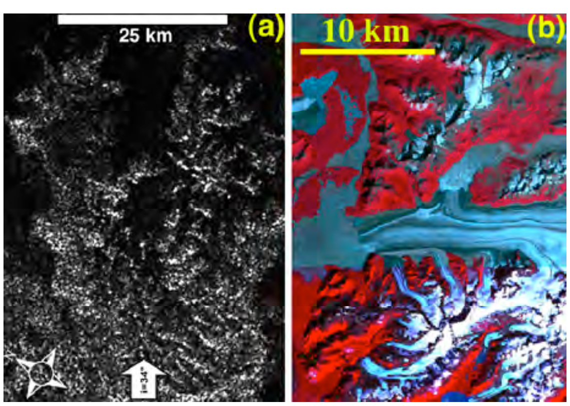

Fig 2. (a) Cassini RADAR scene of Titan's north polar area highlights possible cirque-like features. (b) ASTER VNIR scene showing analogs in the Alaskan Chugach Range.

Goo-permafrost requires mean annual temperatures below the freezing point of a key permafrost volatile. Vapor saturation must stabilize the deposit against sublimation loss. Like ice-rich permafrost on Earth, goo permafrost may contain involatile matrix (analogous to silt, sand, or boulder debris). Goo permafrost is not required to but may creep under its own weight. A continuum exists between glaciers and permafrost on Earth, and it should on Titan, too. Thawing permafrost and glaciers on Earth produce thermokarst lake basins; similar terrain may form on Titan. Exactly how hydrocarbon lakes affect hydrocarbon terrain is uncertain, as it depends on phase equilibria, radiative transfer, the thermodynamics of interactions, and climate.

The erosional power of Earth's glaciers, e.g., the formation of scoured bedrock and alpine landforms, is largely due to the sliding of wet-based glaciers. Many melt-related terrestrial type permafrost and glacial features may occur in glaciated terrains on Titan, if the deposits have compositions such that surface or basal melting occurs. The low thermal conductivity (compared to ice) of paraffin waxes, crystalline methane, solid benzene, and some other solid hydrocarbons and organics would aid basal geothermal melting of thick (hundreds to thousands of meters) deposits of goo.

Conclusions. Landscapes on Titan, a natural petrochemical refinery, may be explained by hydrocarbon/organic analogs of Earth's hydrosphere and lacustrine, marine, fluvial, glacial, periglacial, volcanic, evaporite, karst, and eolian activity. Intracrustal polymerization, metamorphism, and anatectic melting may alter Titan's photochemical hydrocarbon ratios.

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