ASSESSING CRYOVOLCANIC RESURFACING OF TITAN. A. G. Davies[1], D. L. Matson[1], C. Sotin[1], J. C. Castillo-Rogez[1], and T. V. Johnson[1]. [1]Jet Propulsion Laboratory-California Institute of Technology, ms 183-501, 4800 Oak Grove Drive, Pasadena, CA 91109, USA (email: Ashley.Davies@jpl.nasa.gov; tel: 818-393-1775).

Introduction: A quantitative assessment is made of "cryovolcanism" as a resurfacing process on the saturnian moon Titan. The geologically young surface of Titan indicates that much resurfacing has taken place. However, to date, there has been no unambiguous detection of active "cryovolcanism", such as the emplacement of a "cryolava" flow. The dense Titan atmosphere makes this kind of observation very difficult. In addition, the *Cassini* nominal mission has focused on mapping as much as possible of the Titan surface with SAR at ~300 m/pixel and optical instruments (ISS and VIMS) at ~10 km/pixel resolution. The detection of surface modification is hampered by a lack of repeat coverage by *Cassini* instruments at high spatial resolutions. Also, active areas may be very small and therefore difficult to detect. We are therefore modelling the thermal emission from a wide range of active and inactive cryolavas in order to determine process detectability as a function of eruption size.

Observations: The case for currently ongoing volcanic activity on Titan is best made by citing the occurrence of some photometric variability seen in data from VIMS [1-3]. Other data obtained by VIMS [4-5] and, more recently, by the *Cassini* Radar [6] indicate that these sites are distinctively different from other landforms on Titan. Apparent albedo changes have been seen by VIMS in two locations, and at the first have been documented to be time-variable. It has been suggested that this brightening may be due to the deposition of surface frosts, or similar coatings, or possibly low-lying fog [1-3].

Voyager images of plumes on Io, *Galileo* observations of flow emplacement on Io, and *Cassini* observations of the plumes of Enceladus are all examples of conclusive evidence of endogenic volcanic activity in the outer solar system. But, for Titan, without any observations of eruptive processes in action, direct characterization of "cryovolcanism" is not possible. Furthermore, there is a lack of general agreement about the characteristics to be expected for the eruption and emplacement processes. Thus, one is forced to rely upon analysis supported by models and geological analogues on other solar system bodies. These analogue models are adjusted to a Titan setting.

Required resurfacing rate: The required resurfacing rate turns out to be modest. Taking the age of Titan's surface as 500 My, consistent with the age ranges previously derived [7, 8], and its surface area of 8×10^{13} m^2, one obtains the minimum resurfacing rate required as 0.17 km^2 yr^{-1}, or 53 cm^2 s^{-1}.

Geological analogues: The justification for the use of the analogues described below relies upon the curious fact that the viscosity of an ammonia and water mixture at ~170 K is similar to that of basaltic magma [9]. Envisioned cryovolcanic eruption processes on Titan have been studied using models of Titan's interior [10-12]. We choose eruption rates spanning terrestrial history as end member analogues.

For the first analogue we take typical basaltic flows at Kilauea, HI, for which surface coverage rates of 1 m^2 s^{-1} are not unreasonable. This rate is still greatly in excess of the required coverage rate and would be sufficient to resurface Titan almost 200 times in half a billion years, also erasing all impact craters. We note that, assuming that the flows are 1 m thick, resurfacing at this rate with material from Titan's crust (≈50 km thick) would use about 0.4% of the crust volume. To be consistent with the age of the surface, the efficiency with which this process can resurface new territory is no more than about half of one percent. This could be effected by most of the eruptions recovering the same area repeatedly, or by periods of inactivity.

For an analogue at the other end of the effusion scale we choose the Deccan Traps, a large igneous province (LIP) in India. There, areal coverage rates were likely of order ~1000 m^2 s^{-1}. Applied to Titan, this rate covers the surface 2×10^5 times in 500 My (and processes ≈4 times the volume of a 50 km-thick crust), an even less likely scenario than analogue 1. To be consistent with the age of the surface, the efficiency of this process can be no greater than ≈0.005%.

The two analogues suggest that only a relatively very small amount of effusive activity is required to globally resurface Titan in 0.5 Ga, assuming that activity is evenly distributed across the surface. If activity is taking place at even lower effusion rates (a fraction of a m^2 s^{-1}) than the Kilauea analogue, then detection of the resulting thermal emission or radiometry may be very difficult. We have begun modelling how such activity would appear to remote-sensing instruments.

Modelling cryovolcanic processes on Titan: If volcanic processes are indeed emplacing new cryomagmatic material on the surface of Titan, such activity might be detected by recognizing their signatures, in particular, thermal anomalies on the surface and/or in the atmosphere; a unique morphology that is characteristic of the volcanic processes or has changed; or spectroscopic features that identify likely cryolava compositions. Of these signatures, and given the capabilities of the instruments on the *Cassini* spacecraft, detection of anomalous thermal emission is the most likely way in which an active cryolava will be identified.

Modelling thermal signatures. One reason for our modelling is to establish whether such cryovolcanic processes, such as the emplacement of large Venusian-like domes or what extent and thickness of lava flows would even be detected by *Cassini* instruments, and if not detectable, what sensitivity and wavelength range would be needed in orbit and in the Titan atmosphere (a balloon or aerobot) to make an unambiguous detection of an active flow of a given size.

Modelling lava emplacement is a very complex process under the best circumstances, but in the Titan case this effort is hampered by a lack of constraints on possible lava composition, and values of physical and rheological properties that can be significantly temperature-dependent. As laboratory work proceeds on constraining lava physical properties and reducing parameter space, comparative geomorphology exercises may further constrain cryolava composition. During the course of our investigations, we found that atmospheric convection plays a dominant role in the heat loss from the flow's upper surface [13]. We modelled the solidification and cooling process of a candidate cryolava using a finite element code [14]. Integrating over the temperature distribution found on a large active flow yields the integrated thermal emission spectrum (Figure 1) (see [15]).

The thermal emission as a function of wavelength from an emplaced lava body depends on a number of factors as it is derived from the temperature distribution on the surface and includes the mode of emplacement of the material (explosive or effusive, and if effusive, laminar or turbulent emplacement), the duration of the eruption, the variability of discharge rate, the thickness of the lava body, and even the average wind velocity. Emplacement and final form is additionally controlled by the physical and thermal characteristics of the lava, especially viscosity, thermal conductivity, and yield strength, all of which may vary with temperature, and local topography (slope).

Regarding how candidate cryolava materials behave under Titan conditions, the JPL Ices Physical Properties Laboratory is working to determine the thermo-physical parameters of candidate lavas, and we will use those results to further refine model inputs.

With a water-ammonia cryolava, our modelling shows that a newly emplaced lava flow that covered 100 km^2 in 10^5 s (for example), has a peak thermal emission at 14 µm. An atmospheric window at 19 µm can be used to detect thermal emission from the flow surface, which, although made up of a range of temperatures, exhibits a brightness temperature of ~205 K, well below modelled crust (i.e., magma source region) temperatures (e.g., [11]). As time proceeds, the wavelength of peak thermal emission increases, Fig. 1. The Cassini CIRS instrument (and just possibly VIMS) may well be able to detect such an event, the "smoking gun" of active lava emplacement, as there is considerable thermal emission enhancement over the Titan background surface at 94 K. However, if effusion and areal coverage rates are very much smaller than this example, then the events may be too small to be recognized.

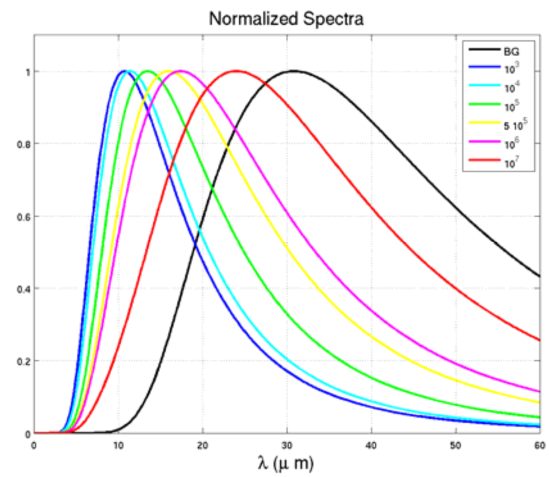

Figure 1. Example of normalized thermal emission from active H_2O-dominated cryolava flows of different eruption durations on Titan [15]. *Other cryolava compositions can be simulated by the model. The black line is the 94 K background spectrum. Times given in the key are eruption duration in seconds.*

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