METHANE CLATHRATE DESTABILISATION BY HEAT FROM LAVA FLOWS: IMPLICATIONS FOR SUPPLYING TITAN'S ATMOSPHERIC METHANE. A. G. Davies[1], C. Sotin[1], M. Choukroun[1], D. L. Matson[1], T. V. Johnson[1], [1]Jet Propulsion Laboratory-California Institute of Technology, Pasadena, CA 91109, USA (Ashley.Davies@jpl.nasa.gov).

Introduction: As previously noted [1-3], Titan may have an upper crust rich in methane clathrates which would have formed early in Titan's history [2,3]. With an estimated mass of ~2 x 10^{17} kg, methane is a major component of Titan's atmosphere. The abundance of methane, which photodissociates, and the presence of ^{40}Ar require replenishment of these atmospheric components over geologic timescales. One possibility is that volcanic processes release these gases from Titan's interior, although so far there is no conclusive evidence of ongoing volcanic activity: no "smoking gun" has been observed. Still, some process has recently supplied a considerable amount of methane to Titan's atmosphere. We have been investigating the emplacement of proposed "cryolavas" of varying composition to, firstly, examine how such a volcanic process behaves thermally in order to determine event detectability via remote sensing, and, secondly, to model the penetration of the thermal wave into a methane-rich substrate. Destabilisation of clathrates would release methane into the atmosphere and liberate trapped argon.

Modelling: We previously adapted models of solidification and heat loss from lava flows to determine not only the rate of cooling of a cryolava or impact melt on Titan [4] but also the expected thermal signature and its temporal evolution from "cryolava" emplacement [5]. These calculations modelled the surface temperature as a function of time as an upper crust formed and thickened, and included the atmospheric control of heat removal. We have now incorporated into the model the calculations of the formation of the crust at the flow base and the penetration of a thermal wave into the flow substrate (adapting methods described in [6]). Table 1 shows solidification and cooling times as a function of flow thickness. Figure 1 shows the surface cooling profiles for two examples of 16%NH_3-2H_2O cryolava, showing more rapid cooling (green and red lines) after solidification. Figure 2 shows the evolution of the post-solidification temperature profile for the 3.1 m flow and the penetration of the thermal wave into the substrate. Also shown in Figure 2 is the destabilisation isotherm. It takes ≈40 days for this flow to reach total solidification, with a top crust thickness of 1.52 m and a base thickness of 1.58 m. The surface temperature has fallen to 101 K from the eruption temperature of 251 K. The environment temperature is 93.7 K [6].

Destabilisation of methane clathrates: The destabilisation temperature of methane clathrates as a function of pressure and temperature [e.g., 1]. It is not the absolute lithostatic pressure that is the controlling factor, but the methane partial pressure: at the surface, this is about 5% of atmospheric pressure. In the substrate, the destabilization temperature is ≈150 K. The depth of penetration of the 150-K isotherm is roughly 40% of the thickness of the cryolava flow. This allows us to calculate the volume of methane mobilized by a lava flow, and the extent of lava flows needed to resupply atmospheric methane.

Table 1: Solidification as function of flow thickness

Total solidification time	Top crust thickness	Base crust thickness	Total thickness	Surface T at solidification
s	m	m	m	K
5584	0.04	0.06	0.1	212.2
103474	0.23	0.27	0.5	142.0
383818	0.47	0.53	1.0	118.3
8905120	2.48	2.55	5.0	98.0
3.38E+07	4.88	4.96	9.8	95.6
8.34E+07	7.70	7.79	15.5	94.9
1.40E+08	9.99	10.09	20.1	94.3
3.15E+08	15.01	15.13	30.1	94.1
4.06E+08	17.06	17.19	34.2	93.5

Methane release: A 10-m-thick cryolava covering 100 km^2 would raise 3 x 10^8 m^3 of substrate methane clathrates to the destabilization temperature in ~10^8 s. With a density of 920 kg/m^3, and about 13% of the mass being methane, the mass of methane released is 4 x 10^{10} kg. This is an impressive amount, but it would take 5 million similar events to yield the current total mass of atmospheric methane. Of greater import is the fact that the area covered is six times that of Titan. If all the flows were, instead, ~60 m thick, then Titan only needs to be completely resurfaced once. The idea of initially supplying all of Titan's atmospheric methane through the destabilization of clathrates by flow substrate heating seems to be unlikely. However, the potential reservoir of methane clathrates is sufficient to resupply atmospheric methane, and requires only one 10-m flow event ~40% of the time to do so. This and other processes (impact, intrusive) are deserving of further study as a means of replenishing atmospheric methane.

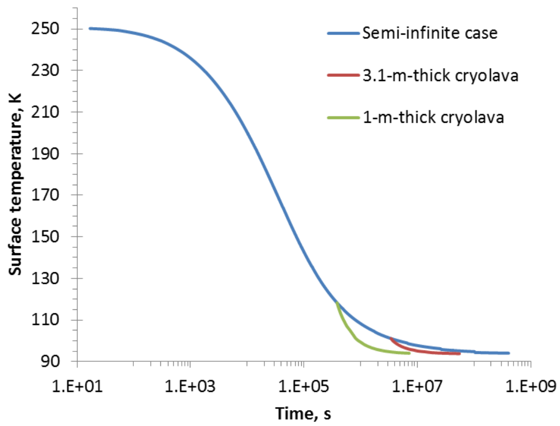

Figure 1. Surface cooling curve for two example cryolavas on Titan (see [4]). Cooling is faster after total solidification (see [6]).

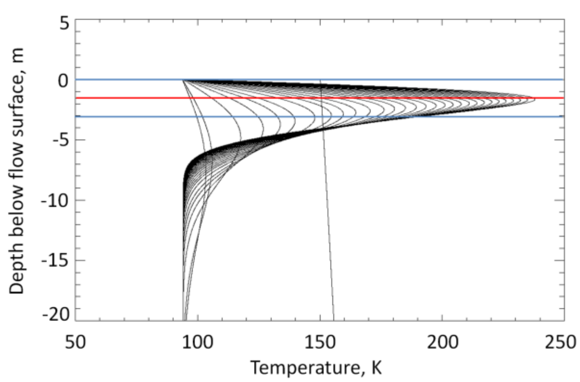

Figure 2. Post-flow solidification cooling curves for 3.1-m-thick cryolava flow. The solid line at ≈150 K is the methane clathrate destabilization curve. Blue lines = flow top and base surfaces. Red = center line.

Discussions: A huge volume of "cryolava" covering a large portion of Titan's surface is needed to explain the current atmospheric methane content. We can speculate that a phase of massive resurfacing within the last 500 MYr [7] supplied such a pulse of atmospheric methane, the decayed remnant of which is seen today. However, with no large number of volcanic edifices (or any wholly-convincing edifices of a purely volcanic nature), a lunar mare-type lava flood event may have generating the apparently flat, featureless plains observed in *Cassini* radar data [8,9] that cover ~30% of Titan's surface may provide a mechanism for producing a massive pulse of methane into the atmosphere. These plains, appearing somewhat bland in radar data, could have provided sufficient methane if formed of cryolavas some 180 m deep overlying a layer of methane clathrates at least 60 m thick. This said, we do not yet have a mechanism for generating and delivering such a huge volume of material to the surface of Titan.

Other volcanic processes may contribute to clathrate destabilization. We are examining the thermal wave propagation from turbulent flows, where mechanical erosion into the substrate could potentially release more methane than the flows modelled above. Intrusive events are being considered. With a sill-like intrusion, the volume of clathrates that is destabilized is approximately twice that mobilised by a surface flow of the same thickness: methane is mobilised both above and below an intrusion. The burial of activity also reduces the chances of detection: on Earth, a rule-of-thumb for the ratio of intrusive to extrusive volcanic activity is ~10:1.

Conclusions: (1) A near-global-scale resurfacing event ~0.5 BYa involving cryolavas hundreds of m thick would be required to yield sufficient methane from thermal destabilization of clathrates to explain current atmospheric abundances. (2) However, meeting the current global methane replenishment rate is certainly feasible from thermal interaction between cryolavas and methane clathrate deposits on a relatively modest scale, one that might be hard to detect.

Questions: Many questions remain. Are the "radar-flat" plains [9] indeed cryovolcanic in nature, or formed from some other processes (hydrologic, lacustrine or aeolian?). How would a cryolava emplacement event appear to spacecraft instruments (e.g., [5])? What originally produced Titan's atmospheric methane, and was it in any way "cryovolcanic"? What are the current replenishment mechanisms?

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