Composition of Titan's dry lakebeds: what can be inferred from the solubility theory.

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Introduction

Since the eighties , the existence of liquid hydrocarbons at the surface of Titan has been suspected [1]. Thanks to the Cassini orbiter RADAR system, dark patterns were observed in the north polar region of the main satellite of Saturn [2]. These features, presented a very low reflectivity in the RADAR wave lengths domain and a morphology similar to Earth's lakes one. Consequently, they have been interpretated as hydrocarbon lakes, this interpretation has been reinforced by the observation of a specular reflection of sunlight through the 5-μm window [3]. Such lakes have also been detected in the south hemisphere polar area [4], but they show a smaller surface coverage. Already, during the first RADAR lakes detection, the presence of features that ressemble to dry lakebeds have been noticed. A strong correlation between RADAR dry lakebeds and surface patches bright at 5-μm has been found [5]. This brightness associated to high reflectivity in the 2.8–μm window relative to the 2.7–μm window, seems to be characteristic of very low water ice abundance relative to the rest of Titan [6, 5]. The neighbouring terrains having a different aspect in infrared VIMS observations. In summary, all of this suggests the formation of an evaporitic layer of organic matter in the Titan's liquid empty lakebeds.

Other observations speak in favor of the existence of evaporation processes from lakes. For instance, evidences for active shoreline processes have been reported [7, 6]. On the theoretical side, several authors have developped models that take into account a possible evaporation of lakes [8, 9]. The question of the composition of potential lakebeds evaporites is still widely opened; the present paper is dedicated to what can be answered with the help of the solubility models including evaporation of methane and ethane. First we will describe our model, next we will present and discuss our preliminary results.

Method

We consider a lake as a liquid phase with only two volatile compounds: methane and ethane; the roles of nitrogen, argon and carbon monoxyde are neglected. The species which are supposed to dissolved in the methane-ethane mixture are those indicated in Table 1. This inventory comes from photochemichal models, these compounds are in solid state under the thermodynamic con-

ditions of the Titan's surface. Methane and ethane evaporate at respective evaporation rates F_{CH_4} and $F_{C_2H_6}$ supposed to be known at each time t.

Table 1: Solids assumed to be dissolved in the lakes and their properties.

Species	Precipitation rate	Melting temperature	Enthalpy of melting
	molecules.m^{-2}.s^{-1}	(K)	(kJ.mol^{-1})
HCN	$1.3 \times 10^{8\,(a)}$	260.0	8.406
C_4H_{10}	$5.4 \times 10^{7\,(a)}$	136.0	4.661
C_2H_2	$5.1 \times 10^{7\,(a)}$	192.4	4.105
CH_3CN	$4.4 \times 10^{6\,(a)}$	229.3	6.887
CO_2	$1.3 \times 10^{6\,(a)}$	216.6	9.020
C_6H_6	$1.0 \times 10^{6\,(b)}$	279.1	9.300

$^{(a)}$Lavvas et al. (2008a, 2008b); $^{(b)}$Vuitton et al. (2008).

The quantities of CH_4 and C_2H_6 that evaporates during the time interval between t and $t + \Delta t$ are computed and new mole fractions $X_i^{(new)}$ of solutes are derived. These updated values are compared to the mole fractions at saturation ($X_{i,\mathrm{sat}}$) which are provided by the equation

$$\ln \Gamma_i X_{i,\mathrm{sat}} = \frac{\Delta H_{i,\mathrm{m}}}{R T_{i,\mathrm{m}}} \left(1 - \frac{T_{i,\mathrm{m}}}{T} \right) \qquad (1)$$

If $X_i^{(new)} > X_{i,\mathrm{sat}}$, then we fix $X_i^{(new)} = X_{i,\mathrm{sat}}$, the exceeding material is assumed to fall instantaneously to the lake bed, the other mole fractions are ajusted to insure $\sum_i X_i = 1$. Taking into consideration the matter precipating, the composition of the sedimentation layer ($X_{i,\mathrm{sed}}$) at time $t + \Delta t$ can be easily calculated. The procedure is repeated until all the initial quantity of solvent is gone. For the sack of simplicity, we consider here an ideal solution, i.e. a solution for which the activity coefficients Γ_i equal the unity for all species. The calculation is conducted over the evaporation time-scale $\tau_{CH_4 + C_2H_6}$, that way a precise knowledge of evaporation rate F_{CH_4} and $F_{C_2H_6}$ is not required. This is a very helpful assumption as these rates depend on numerous and unknown parameters: temperature difference between lake and atmosphere, actual atmospheric mole fraction of methane and ethane, the speed of wind, etc [8, 9].

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Results and Discussion

We have considered two kinds of initial liquid mixtures. On one hand, we chose a mixture with dissolved solids mole fractions scaled to precipitation rates; forcing benzene, the compound with the lowest mole fraction at saturation, having an initial mole fraction (X_{liq}^{ini}) equal to half of its saturation value. On the other hand, we took a mixture in which all the species had the same abundance, fixed to half of the benzene saturation value (see Tab. 2). All computations were performed at temperature $T = 90$ K, typical of the lakes regions.

Table 2: Initial liquid mixtures used in this study. The notation $x.y(-n) = x.y \times 10^{-n}$ has been used.

Species	$X_{i,\text{sat}}$ (ideal)	Mixture type 1		
		X_{liq}^{ini}	X_{sol}^{ini}	X_{sed}^{fin}
CH_4	–	9.997 %	–	–
C_2H_6	–	89.973 %	–	–
HCN	$6.5\,(-4)$	$1.1\,(-4)$	$3.7\,(-1)$	$1.7\,(-2)$
C_4H_{10}	$1.2\,(-1)$	$1.0\,(-4)$	$3.4\,(-1)$	$5.6\,(-1)$
C_2H_2	$5.4\,(-2)$	$6.2\,(-5)$	$2.1\,(-1)$	$3.4\,(-1)$
CH_3CN	$3.7\,(-3)$	$9.2\,(-6)$	$3.1\,(-2)$	$5.1\,(-2)$
CO_2	$8.7\,(-4)$	$5.8\,(-6)$	$1.9\,(-2)$	$2.3\,(-2)$
C_6H_6	$2.2\,(-4)$	$1.4\,(-5)$	$4.6\,(-2)$	$5.7\,(-3)$
		Mixture type 2		
		X_{liq}^{ini}	X_{sol}^{ini}	X_{sed}^{fin}
CH_4	–	9.993 %	–	–
C_2H_6	–	89.941 %	–	–
HCN	$6.5\,(-4)$	$1.1\,(-4)$	$1.67\,(-1)$	$1.3\,(-2)$
C_4H_{10}	$1.2\,(-1)$	$1.1\,(-4)$	$1.67\,(-1)$	$4.5\,(-1)$
C_2H_2	$5.4\,(-2)$	$1.1\,(-4)$	$1.67\,(-1)$	$4.5\,(-1)$
CH_3CN	$3.7\,(-3)$	$1.1\,(-4)$	$1.67\,(-1)$	$7.2\,(-2)$
CO_2	$8.7\,(-4)$	$1.1\,(-4)$	$1.67\,(-1)$	$1.7\,(-2)$
C_6H_6	$2.2\,(-4)$	$1.1\,(-4)$	$1.67\,(-1)$	$4.3\,(-3)$

Taking as initial values the X_{liq}^{ini}'s in table 2, we have run the algorithm described in the previous section. We compare the final composition of the evaporite (X_{sed}^{fin}) to the composition of solids initially dissolved in the liquid (X_{sol}^{ini}). In the case of the "type 1" mixture, three species undergo a strong enrichment: C_4H_{10}, C_2H_2 and CH_3CN. Concerning the "type 2" mixture, the final layer of evaporite is depleted in all species excepted in butane and acetylene, which each represents 45% of the free surface composition. In both cases the prominent molecules at the surface are butane and acetylene.

The behavior of C_4H_{10} and C_2H_2 is due to their high mole fraction at saturation, during the evaporation process they can remain dissolved a longer time.

A lakebeds formation dominated by percolation of hydrocarbons solution into the icy crust of Titan is a possibility [15]. But it is difficult to imagine that percolation leave solutes at the surface while ethane and methane penetrate into the crust. However percolation could drain most of the lake liquid, leaving evaporation finish the job, a scenario that could lead also to an enrichment in C_4H_{10} and C_2H_2. Snowfalls (i.e. precipitations of atmospheric solids) can also affect the Titan's surface composition, but there is obviously no reason for concentrate geographically these falls onto empty lakebeds and an uniform composition should be detected over lakebeds and surrounding terrains.

Simplified dynamical models indicate that a convective mixing could appear in the lakes during winter [9]. In this occurence and if the nucleation is homogeneous, the solid particles could remain suspended in the liquid along the convective episode. At the end, the deposition of solids precipitates yields to a evaporite composition unchanged compared to that of the initial dissolved solids. However the heterogeneous nucleation (i.e directly on the surface of the lakebed) is much more easy than homogeneous nucleation (i.e. in the volume of the lake), thus the formation of precipitates directly on the lakebed is a reasonnable assumption. The question of the kinetics of that formation is still an open question that dedicated laboratory experiments could answer in a definitive way.

This work suggests, if the evaporation is the dominant physical process causing the formation of Titan's dry lakebeds, that the top layer of evaporite should enriched in butane and acetylene.

References

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