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On the minimum age of Titan's lacustrine depressions

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Abstract

Titan's surface is dotted with hundreds of lacustrine depressions of yet unknown origin. Here we investigate the possibility that they actually originate from the dissolution of a solid surface layer in Titan's liquids (here methane). Using this hypothesis we try to determine a minimum age for Titan's lacustrine depressions.

1 Introduction

Titan, Saturn's major moon, is the only planetary body of the entire Solar System able to bear liquids on its surface with the Earth. Hydrocarbon lakes and seas have been discovered in 2005-2006 thanks to the Cassini spacecraft imaging instruments [1, 2, 3], and exhibit various morphologies. On the one hand, lacustrine depressions, in which liquids lie sometimes and form lakes, have often lobate and steep-sided contours, and a size extending up to a few 100s of kilometers. Their depth varies from a few meters/10s of meters up to a few 100s of meters. On the other hand, Titan's seas are several 100s of kilometers wide and possess dendritic contours, which clearly underlines an origin probably different from that of the lacustrine depressions. These two extreme morphologies are represented in Fig. 1.

Several hypotheses have been proposed to explain how so familiar lacustrine depressions have formed on Titan. These include cryovolcanic [4, 5], thermokarstic [6], karstic [5], evaporitic [7] and karsto-evaporitic [8, 9] processes. In the present work, we explore the hypothesis of the formation of Titan's lacustrine depressions through karstic or karsto-evaporitic processes, based on the dissolution Titan's surface, and try to evaluate the time required to dissolve entirely a surface layer soluble in liquid methane under Titan's surface conditions.

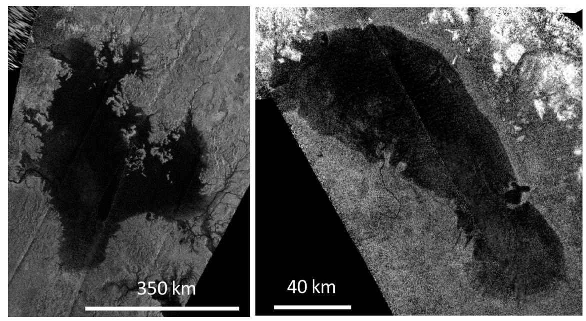

Figure 1: Titan's lakes and seas. Left: the dendritic sea Ligeia Mare. Right: the lobate lacustrine depression Ontario Lacus.

2 Methods

The amount of dissolved material depends on the availability of the liquid. Here we take into account only liquid methane, which falls onto the surface by rains with given precipitations rates $\tau_{\mathrm{CH_4}}$ (m.year^{-1}).

For a given methane molar volume, the total amount of methane (in moles) fallen down during one year can be expressed as:

$$n_{\mathrm{CH_4}} = \frac{\tau_{\mathrm{CH_4}}}{V_{\mathrm{m}}(\mathrm{CH_4})} \qquad \text{[mol/year]} \tag{1}$$

Considering x_i as the saturation mole fraction of a dissolved species i, the maximum amount of compound i that can be removed from Titan's surface during one year, is expressed by:

$$n_i = x_i \frac{\tau_{\mathrm{CH_4}}}{V_{\mathrm{m}}(\mathrm{CH_4})} \tag{2}$$

We infer the maximum height $h_{\mathrm{max},i}$ (in meters) of the removed materials i in one year by using:

$$h_{\mathrm{max},i} = V_{\mathrm{m},i}\, n_i = x_i \frac{\tau_{\mathrm{CH_4}} V_{\mathrm{m},i}}{V_{\mathrm{m}}(\mathrm{CH_4})} \qquad \text{[m/year]} \tag{3}$$

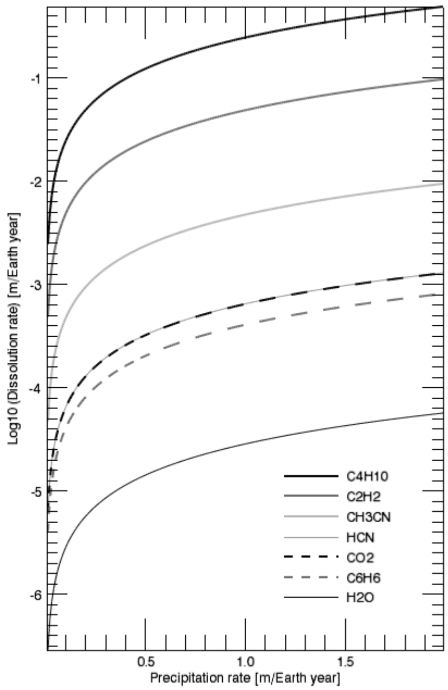

Figure 2: Dissolution rates as a function of the methane precipitation rates (m/Earth year).

The saturation mole fractions x_i of the different solutes used in this work have been calculated by using:

$$\ln \Gamma_i x_{i,sat} = -\frac{\Delta H_{i,m}}{RT_{i,m}}\left(\frac{T_{i,m}}{T} - 1\right) \qquad (4)$$

We use an ideal solutions hypothesis where $\Gamma_i = 1$ at first approximation, $\Delta H_{i,m}$ is the melting enthalpy and $T_{i,m}$ is the melting temperature of each compounds.

3 Dissolution timescales

We consider several hydrocarbons and nitriles produced in Titan's atmosphere: hydrogen cyanide (HCN), acetylene (C_2H_2), butane (C_4H_{10}), benzene (C_6H_6), acetonitrile (CH_3CN). We also considered the possible dissolution of a water and carbon dioxide icy substrates. The calculated amounts of dissolved material as a function of methane precipitation rates are given on Fig. 2.

According to this simple model, butane, acetylene and acetonitrile are the most soluble compounds in liquid methane at 90 K. Benzene is almost as soluble as hydrogen cyanide and carbon dioxide ice in liquid methane. The least soluble compound in liquid methane is water ice.

Table 1: Amount of dissolved materials (m) after 1 Myr on Titan for 2 precipitation rates (m/Earth year).

	$\tau_{CH_4} = 3$ cm/yr	$\tau_{CH_4} = 30$ cm/yr
HCN	21.3	213.0
C_4H_{10}	8 045.8	80 458
C_2H_2	1 593.2	15 931.9
CH_3CN	155.4	1 553.6
C_6H_6	13.4	133.6
CO_2	21.3	211.9
H_2O	0.9	9.4
total	9 851.1	98 511.4

Most of the GCMs developed so far predict a fairly small amount of methane rains on Titan, of about a few cm up to a few 10s of cm per Earth year [10, 11, 12]. Given precipitation rates of 3 and 30 cm/Earth year (i.e. 1 and 10 m/Titan year), and assuming that the amount of rains remained constant over time, the maximum theoretical quantity of dissolved compounds after 1 Myr is calculated and given in Table 1.

If all the material is available onto the surface, the total maximum height of dissolved materials after 1 Myr would be comprised between 10 km and 100 km, largely exceeding the amount of dissolved material required to create a 100 to 300 m-deep depression under these simple approximations. If τ_{CH_4} has remained low, the time required to dig such a depression would be 1-3$\times 10^4$ years. If τ_{CH_4} has always been high, this time would decrease tenfold.

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