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Dissolution on Titan and on Earth: Towards the age of Titan's karstic landscapes

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Abstract

The morphology of Titan's lacustrine depressions led to comparisons with terrestrial depressions developed by karstic dissolution. We tested this hypothesis by computing dissolution rates of Titan's solids in liquid methane. We inferred from these rates the timescales needed to create dissolution landforms of a given depth. Dissolution would be a very efficient geological process to shape Titan's surface, on timescales generally shorter than 100 Myrs, consistent with the youth of Titan's surface (<1 Gyr).

1. Introduction

In 2006, the Cassini spacecraft imaged for the first time the lakes and seas of Titan [1]. Some lacustrine depressions are small, rounded, often interconnected, and deprived of apparent connections with fluvial channels [2]. They appear dark or bright to the imaging systems, depending on their surface roughness and composition [3,4,5].

The morphology of these lacustrine depressions led to analogies with terrestrial karstic, evaporitic or karsto-evaporitic terrestrial landforms [2,4]. All these terrestrial landforms share the fact that dissolution triggered their development. Labyrinthic terrains seen on Titan are also similar to terrestrial karst landforms, suggesting a dissolution origin [6]. In the present work, we test the relevance of dissolution as a major landshaping process on Titan by comparison with dissolution on Earth. Our idealized model allows us to determine rough timescales for the development of dissolution landforms at the surface of Titan [7].

2. Methods

We use the formulation of White et al. [9], relating the denudation rate of a solid (DR_S) to its solubility (m_S), molar volume ($V_{m,S}$) and a net precipitation rate (τ, ρ_L being the density of the liquid):

$$DR_S = \rho_L \,.\, V_{m,S} \,.\, \tau \,.\, m_S \quad [\text{m/yr}] \qquad (1)$$

All variables are computed by thermodynamics at the relevant conditions for Titan (91.5 K) and the Earth (25°C), with the exception of the precipitation rates, taken from terrestrial databases and from the climate model of Schneider et al. [11] for Titan. We consider the Ideal (IST) and Regular Solutions Theory (RST) for Titan [9] and an Electrolyte Solution Theory (EST) for terrestrial minerals [10] to compute solubilities.

On Titan, we consider either pure compounds or a mixed layer of solid organics in contact with the liquids. The composition of the mixed layer is computed according to a linear mixing scheme where each percent of a given solid at the surface results from its accumulation rate at the surface scaled by its production rate in the atmosphere [12,13].

3. Results

Figure 1 shows examples of denudation rates estimated for pure acetylene in various liquids (methane, ethane and propane) compared to those of common soluble minerals in liquid water. Acetylene has a behaviour between that of terrestrial carbonates and salts according to the RST. We performed the same calculations for various hydrocarbons and nitriles. Most of the simple hydrocarbons seem to be quite soluble in those liquids, whereas polar molecules such as nitriles would be much less soluble, depending on the liquid considered.

From denudation rates of pure solids in liquid methane and the precipitation pattern given by the GCM of Schneider et al. [11], we evaluate denudation rates of pure solids and of a mixed layer of organic solids (with various compositions) over a Titan year at 6 different latitudes.

Assuming an average depth of 100 m for the lacustrine depressions, Figure 2 shows their estimated timescale of formation by dissolution. The IST and RST give significantly different results, as the IST gives usually higher solubilities than the RST (Figure 1). The asymmetry with latitude is due to the climate difference between the northern and southern hemispheres. Although this asymmetry should be smoothed by periodic climate oscillations [14], it is relatively consistent with the observed repartition of potential dissolution landforms observed on Titan. The maximum timescales needed to dissolve 100 m of solids in methane rains would be lower than ~105 Myr in the polar regions, with the exception of the low southern polar latitudes, which would require longer timescales (~375 Myr).

4. Conclusion

We built a thermodynamic-climatic model to determine the dissolution rates and timescales of Titan's organic solids exposed to methane rains. Solid hydrocarbons would behave like common terrestrial salts in water, while nitriles would be less soluble in Titan's liquids. Titan's surface is unlikely pure. By considering mixtures of hydrocarbons and nitriles at the surface, we evaluated dissolution timescales to develop 100m-deep landforms, such as lacustrine depressions, that indicate that Titan's karstic landscapes could be young (< 100 Myr), which is consistent with the youth of the surface (< 1 Gyr) inferred from crater counting [14].

Acknowledgements

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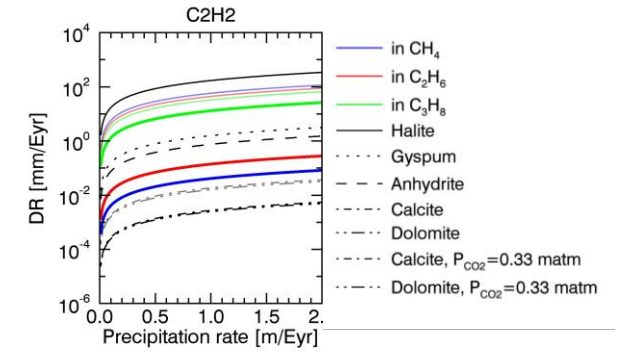

Figure 1: Denudation rates of acetylene in Titan's liquids according to the IST (light color curves) and the RST (bold color curves) compared to those of common soluble terrestrial minerals in water.

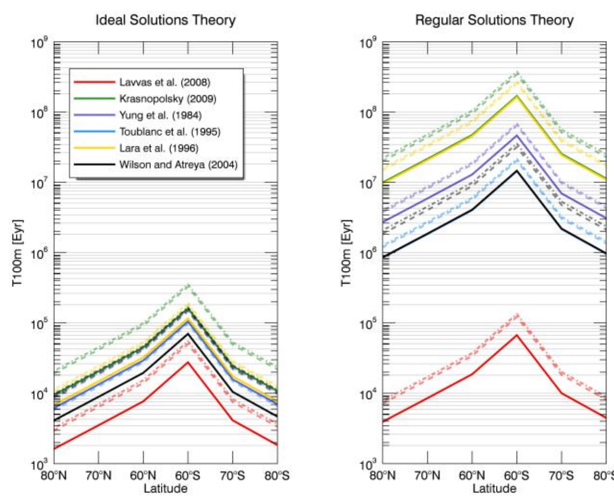

Figure 2: Dissolution timescales to form 100 m-deep depressions on Titan in a surface layer composed of mixed organic solids in contact with methane rains. Methane precipitation rates are those of Schneider et al [11] at 6 different latitudes. The composition of the surface layer is estimated from the accumulation rates at the surface of molecules computed from their production rates in the atmosphere (models listed on the figure).