IS TITAN'S SHAPE CAUSED BY ITS METEOROLGY AND CARBON CYCLE? M. Choukroun, C. Sotin, Jet Propulsion Laboratory, California Institute of Technology (4800 Oak Grove Dr., MS 79-24, Pasadena, CA 91109, USA, E-mail: mathieu.choukroun@jpl.nasa.gov).

Introduction: The *Cassini* mission has obtained data on Titan's shape [1] and gravity field [2], which differ significantly from the pre-Cassini expectations. Particularly, Titan is more oblate than one would expect based on its spin rate and tidal deformation [e.g., 3]. Global circulation models [e.g., 4,5] show that precipitation of ethane and other hydrocarbons produced by the photolysis of the atmospheric methane [6] occurs primarily close to the poles. *Cassini* observations of a polar hood in the North (winter pole at the arrival of Cassini) as well as lakes distributed mainly above 60° lat. support these models. The amounts of liquid hydrocarbons inferred are, however, orders of magnitude lower than predicted by photochemical and evolution models, suggesting that liquids are trapped in the subsurface, which may be initially composed of methane clathrate hydrates [7]. Recent laboratory experiments [8,9] show that ethane can substitute methane in clathrate hydrates, increasing the density of the reacted clathrate. We will present new results [10] on: 1) the likelihood for such exchanges to occur at Titan's conditions; 2) their geophysical implications in terms of subsidence and shape; 3) their implications for Titan's hydrocarbon cycle.

Methane-ethane substitution in clathrate hydrates at Titan's subsurface conditions: In order to assess the relevance of the clathrate-state exchanges shown at laboratory conditions by [8,9] to Titan, we first compared the thermal state of the subsurface with the phase diagrams of methane, ethane, and their respective clathrate hydrates in Figure 1. The thermal profiles are deliberately interrupted at 250 K, where conditions may be suitable for convection within the ice shell below. From the surface down, all pressure-temperature conditions are within the stability field of methane and ethane clathrate hydrates as shown by [11]. Furthermore, ethane clathrates are more stable than methane's down to 10 km, which suggests that the methane-ethane substitution is thermodynamically favored. A kinetic model based on the experimental data of [9] shows that the substitution can occur fast enough, even close to the surface, to affect the entire methane clathrate reservoir over geologic timescales [10].

Associated subsidence at the poles: The density of clathrate hydrates increases as substitution proceeds, from 920 kg.m^{-3} (methane) to just over 1000 kg.m^{-3} (ethane), while the molecular volume remains the same [12]. Thus isostatic compensation is expected to occur, and would result in subsidence of the ice shell, localized around the areas subject to precipitations from the atmosphere.

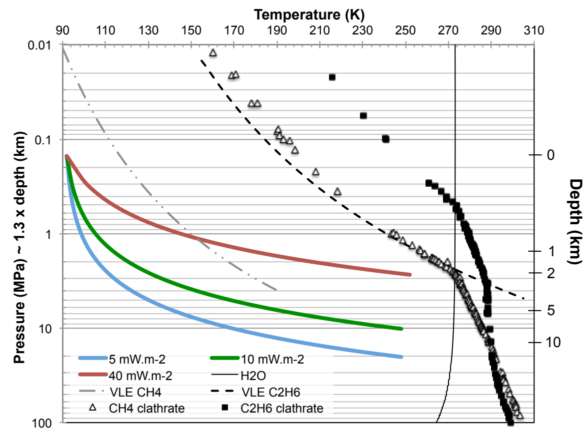

Figure 1. Phase diagram showing the stability of methane and ethane clathrates, the melting curve of water ice, the vapor-liquid equilibria (VLE) of methane and ethane, and possible thermal profiles through Titan's subsurface. Conductive profiles have been calculated using a surface temperature of 92 K, a thermal conductivity of 0.5 W.m^{-1}.K^{-1} for methane clathrates, and surface heat flux values of 5, 10, and 40 mW.m^{-2}.

Isostatic compensation modeling: We developed a Pratt-type isostatic compensation model, assuming hydrostatic equilibrium below the ~ 5-km thick [7] methane clathrate hydrate crust. Since the major precipitations are concentrated around the poles, we calculated the subsidence associated to both the substitution and the trapping of liquids within the porosity ϕ. The three variables in this model are: 1) the ethane mass that percolates within the subsurface (assumed equal to the ethane produced); 2) the latitudinal extent of precipitations from the poles; and 3) the porosity of the crust, which has been taken as an averaged constant value for simplicity. The resulting subsidence as a function of ethane mass, expressed as equatorial-polar radius differences by accounting for Titan's flattening due to its rotation, is shown in Figure 2.

Timescales of subsidence and mass balance: The process we investigate involves compounds produced by the atmospheric photochemistry. The rates at which methane escapes from the atmosphere and is consumed by these reactions, and ethane and other hydrocarbons are produced, are constrained by several models that rely on Cassini data [e.g., 6]. Furthermore, the kinetics of these reactions are limited by the solar flux, not by the methane amounts in the atmosphere. Therefore, it seems reasonable to extrapolate the photochemistry rates over geologic timescales, in first approximation. This allows translating the ethane amounts required to induce a given subsidence into i) the methane amounts required to generate the ethane, and ii) the time necessary for the photolysis to produced the ethane. These two parameters are also indicated in Figure 2.

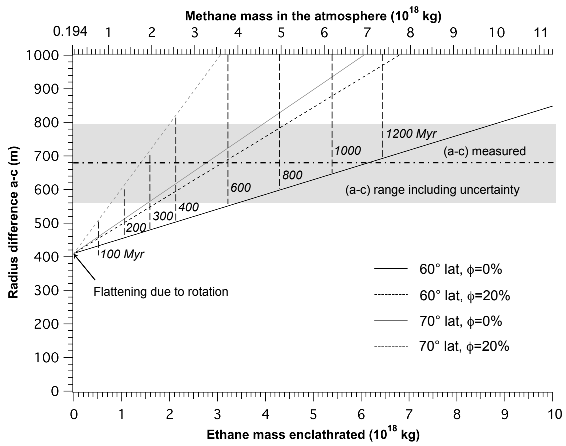

Figure 2. Titan's flattening calculated as a function of the ethane mass (lower horizontal scale) substituting to the methane and trapped in the crust pores (porosity of 0 and 20% considered). The corresponding cumulated amounts of atmospheric methane, i.e. not necessarily continuously present, involved in the process are represented on the upper horizontal scale. For comparison, a 50-m thick global liquid hydrocarbon layer on Titan's surface represents 2.71×10^{18} kg. The time required to produce the ethane mass needed is indicated by the vertical dashed lines.

Implications for Titan:

Global shape: Combining our isostatic compensation model with the photochemistry rates, and comparing with Titan's shape data [1], we derived the following implications: 1) Subsidence at the poles due to methane-ethane substitution in clathrate hydrates down to 1-3 km is consistent with Titan's measured oblateness; 2) Both the latitudinal extent of hydrocarbon precipitations and the subsurface porosity affect largely the amounts of ethane that need to percolate and react with methane clathrates; 3) This process can explain Titan's shape if methane has been present in the atmosphere during 300-1200 Myr of Titan's history at the present photochemical rates.

Hydrocarbon cycle: Methane-ethane substitution in clathrates is an additional source of methane for the atmosphere. As ethane diffuses into the subsurface clathrate hydrates to replace methane, this methane diffuses outside of the structure. It is then dissolved within the surrounding liquids and will eventually evaporate into the atmosphere. Each ethane molecule involved in this process requires the photolysis of two methane molecules (a little over two, accounting for the other photochemistry products), and then allows the release of one methane molecule by the substitution. Therefore, this process recycles methane, in amounts up to ~ 48%, depending on the liquids trapped in the porosity. This implies that the substitution cannot solely account for the replenishment of Titan's atmospheric methane, but it would significantly contribute to sustaining the presence of methane in the atmosphere. This suggests a revision of Titan's hydrocarbon cycle, shown in Figure 3, to reflect the importance of interactions between atmospheric products and Titan's subsurface materials.

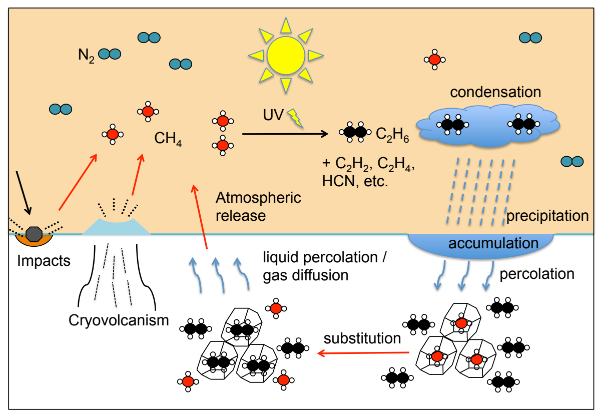

Figure 3. Proposed revision of the hydrocarbon cycle on Titan, including methane-ethane substitution in subsurface clathrates.

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