MOUNTAIN BUILDING ON TITAN. G. Mitri[1], M. Bland[2], and R. M. Lopes[1], [1]Jet Propulsion Laboratory, California Institute of Technology (4800 Oak Grove Dr. Pasadena California, Giuseppe.Mitri@jpl.nasa.gov), [2]Lunar and Planetary Laboratory, University of Arizona (1629 E. University Blvd. Tucson Arizona).

Introduction: Cassini remote sensing observations on Titan yield evidence of features of relatively high topography interpreted as mountains [1]. The mean topographic height observed with the Cassini Radar instrument during T3 (February 2005) and T8 (October 2005) is 864 m and the topography ranges between 123 m to 1930 m [1]. Both isolated blocks and linear chains of mountains 200 **-** 300 km long [1] are observed on Titan's surface. The Descent Imager Spectral Radiometer (DISR) has shown that the topography close to the Huygens probe landing site is ~100-150 m higher than the surrounding plains [2]. During the T20 flyby, the VIMS instrument observed large mountain chains (150 km long and 30 km wide) at the south of Titan's equator [3].

Four scenarios for Titan's orogenesis are proposed [1]: (i) compressional crustal deformation; (ii) horsts; (iii) secondary impact ejecta; and, (iv) mesas. The presence of mountain chains suggest that the dominant mountain building process is compressional crustal deformation. Successive denudation-accumulation controlled by erosion and weathering can modify the morphology of mountains though time. Here we investigate if the compression crustal deformation can produce topography on Titan.

Internal structure and radial contraction: The interior of Titan (radius 2,575 km) is likely differentiated in a rocky interior, a high pressure HP ice layer (with phases III, V, and VI), an ammonia-water subsurface ocean, and a surface ice-I shell [e.g., 4,5]. In Titan's early history, ammonia and other volatiles were released in the liquid layer during the accretion and differentiation stages [6], and at the present time an ammonia-water subsurface ocean could be present [4,5,7]. Fig. 1 shows a model of Titan's internal structure.

Present radiogenic and tidal heating from the rocky interior is actually of the order of 600 GW [7]. During Titan's early history, the heat flux was higher [7], leading to the assumption that Titan has experienced a cooling over time. The density of the ice-I layer is 920 kg m^{-3}, HP layer is 1300 kg m^{-3} and liquid layer is 1000 kg m^{-3}. During the cooling of Titan and freezing of the ice-I and HP layers, these differences in density led to a global volume change. We compute the radial variation of Titan during this secular cooling adopting the thermal model of the ice-I shell developed in ref. [5]. We assume maximum initial ammonia mass concentration in the liquid layer that range between 0 and 5%, consistent with ammonia concentration observed in comets and modeling results of Titan's current orbital eccentricity [7]. We use the dependence of the melting temperature on the ice-I shell thickness as in ref. [8].

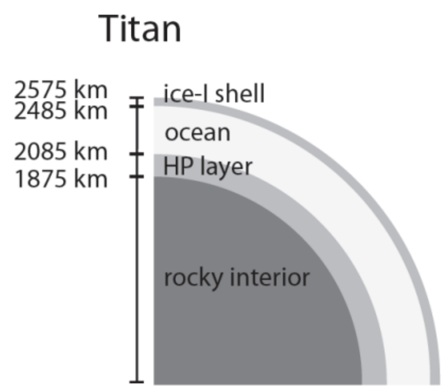

Figure 1 *Model of Titan's internal structure [5]. Titan is differentiated into a rocky interior and an outer water layer of ~700 km depth. The depth of the ice high pressure layer and the ice-I shell is determined as in ref. [8].*

Fig. 2 shows the heat flux from the interior versus Titan's radius. We assume that the dominant creep mechanism of the ice is diffusion creep. The ice grain size is 1 mm, and the initial ammonia-water concentration is 5%. Fig. 2 shows also the thickness of the ice-I shell. The white and grey areas of Fig. 2 show where the heat flux is transported by thermal conduction and thermal convection in the ice-I shell, respectively. There are several key points. First, the response in Titan's radius, changing as a function of the variation in internal heat flux, depends on the thermal state (conductive and convective) of the ice-I shell. Second, the Onset-I transition in ice-I shell implies that two solutions exist for a range of heat flux and consequently, a conductive-convective transition of the ice-I shell causes a jump in radius of Titan. Third, at the Onset-II of convection in the ice-I shell, no steady-state solution exists for a range of heat flux for the ice-I shell and the radius of Titan. A full description of the Onset-I and Onset-II of convection in the ice-I shell and the implication for the Titan's geology is in ref. [5].

Interestedly, Fig. 2 demonstrates that Titan's secular cooling produces radial contraction. Consequently, crustal compressional deformations of the ice-I shell can occur during the secular cooling of Titan.

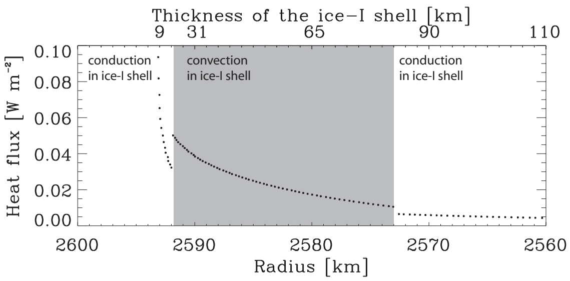

Figure 2 *Heat flux versus the radius of Titan. The plot shows also the thickness of the ice-I shell. Grey and white areas show where the heat is transported though the ice-I shell by thermal convection and conduction, respectively. The ice grain size is 1 mm and the initial ammonia-water concentration is 5%.*

Mountain building: We simulate the two dimensional compressional crustal deformation in a state of plain strain of Titan's ice-I shell using the Tekton (version 2.3) finite-element code [9]. The model considers elastic-viscous-plastic and composites rheologies of the water ice [10]. The elastic behavior of the ice is characterized by the Young's modulus E ($9 \cdot 10^9$ Pa) and the Poisson ratio ν (0.314). The constitutive rheologies of the viscous flow are based on laboratory measurements [11,12,13]. Plastic deformation is modeled with Drucker-Prager yield criterion with a cohesion $C = 10\,\text{MPa}$ and an angle of internal friction $\varphi = 30^\circ$.

Fig. 3 shows the topography produced with a compressional crustal deformation of the ice-I shell. The initial two-dimension domain is 100 km per 25 km with a spatial resolution of 333 m for each element. The strain is 0.158, and the contraction time is 10^6 yr (corresponding to time scale of a freezing ice-I shell [5]). The plots are for two temperature gradients in the ice-I shell: 2 K km^{-1} and 10 K km^{-1}. For low temperature gradients in the ice-I shell (few K km^{-1}) compressional crustal deformation produces a topography of the order of several tens of meters and a wavelength of the order of several kilometers. For higher temperature gradients (order of ten K km^{-1}), the topography simulated is of the order of several kilometers with a wavelength of the order of fifty kilometers. An initial analysis suggests that compressional crustal deformation due to radial contraction of the satellite can produce topography on Titan.

Conclusions: We have simulated mountainous topography of the order of meters to several kilometers depending on strain rates and temperature gradients in the ice-I shell. Compressional crustal deformation as a consequence of Titan's radial contraction during hot periods of its thermal evolution produces a topography height of several kilometers. This topography encompasses the observed topography on Titan.

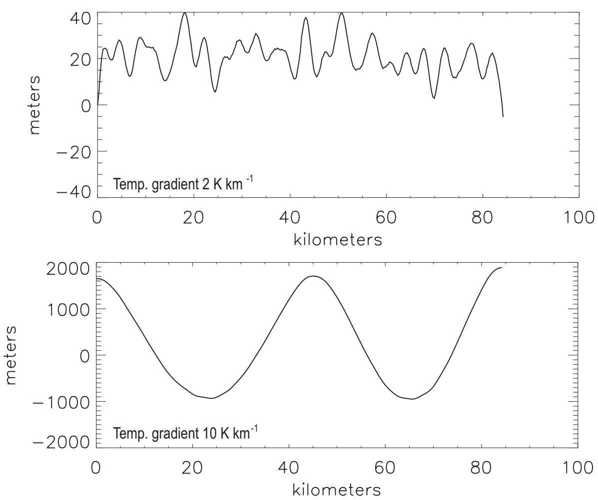

Figure 3 *Topography for compressional crustal deformation of Titan. The grain size is 1 mm, the strain is 0.158 and the compressional time is 10^6 yr. The temperature gradients in the ice-I shell are 2 and 10 K km^{-1}.*

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