TITAN TRANSMOGRIFIED. C. A. Wood, Planetary Science Institute, 1700 East Fort Lowell, Suite 106, Tucson, AZ 85719-2395; cwood@psi.edu

Titan's Global Crustal Thickening Event: Based on a variety of estimates of the age of events affecting its atmosphere, Hörst [1] deduced that Titan underwent a fundamental transformation about 500 m.y. ago. No explanation for what that event could have been; I propose that it was a rapid Global Crustal Thickening Event (GCTE) predicted by a geophysical model of Titan's internal evolution. Tobie, Lunine & Sotin (TLS [2]) predicted that ~500 m.y. ago the onset of convection led to rapid cooling of the interior and consequent rapid thickening of the crust from ~10 km to more than 50 km. I propose that this catastrophic event occurred, completely resetting Titan's geologic processes, transforming its surface from a smooth icy ball into what evolved to become the landscape we see today. In this scenario, before the GCTE the crust was too thin and weak to preserve mountains, impact craters and other topographic excesses that formed. Massive eruptions of cryomagmas (flood basalt equivalents) through Titan's thin crust created a smooth icy world that self-repaired whenever deformed by crater or mountain formation. Titan's recorded geologic history began only after the GCTE when a thick crust began to preserve newly created landforms. Titan's surface age [3, 4], derived from crater counts, dates the GCTE to about 0.5 b.y. ago. Note that that uncertainty in the timing of crustal thickening in the TLS model, in Hörst's estimates of when the atmosphere changed, and in crater count ages mean 500 m.y. is an approximate date rather than being exact.

New interpretations: Traditionally, Titan's young surface age was interpreted to mean that most of the thousands of impact craters and other features that must have formed over the last 4.5 billion years were erased by a variety of geologic and atmospheric processes such as fluvial erosion, mass wasting, infill by wind-blown sand and deposition of material from the atmosphere. Accepting the TLS/GCTE model leads to a totally different interpretation of Titan's youthful surface age: the present landscape formed entirely during the last 0.5 b.y. and little remains of the previous 4 b.y. old surface. Titan's older terrains were not catastrophically erased at one time, they were quickly removed one by one as they formed.

Landform formation after the GCTE:

Mountains. Mountains are stratigraphically Titan's oldest landform [5] and according to this new interpretation could only be preserved after the GCTE when the crust thickened enough to support them. Their formation occurred before significant non-ice material accumulated, hence mountains are made largely of ice, as indicated by spectral data and their high degree of volume scattering [6] and have only minor coatings by other materials. The proposed origin of mountains by contraction [7] would occur after the GCTE began when the icy crust began to thicken.

Titan's mountains are old; is it possible that Titan's mountain-forming era was limited to a short period about 500 m.y. ago as the crust was thickening from a weak 10 km until it became too thick and strong for mountain formation? Can mountains form today?

Blandlands. The most pervasive geologic unit on Titan appears as nearly featureless expanses, concentrated in temperate regions [8]. These plains were originally called blandlands, but now are classified as Undifferentiated Plains. IR and microwave measurments demonstrate that blandlands surfaces are organic-rich, probably deposited by aeolian processes [8]. The question is how deep do these deposits extend and what is beneath them? Depth can be probed by looking at impact crater ejecta. Soi, the only crater totally surrounded by blandlands, has only an icy rim [9], whereas rims of other craters contain water ice and organics [9]. Soi overwhelming excavated crustal water ice, suggesting that blandland organic-rich deposits need only be thick enough to spectrally hide the underlying ice.

According to the GCTE proposal, eruptions of thin sheets of icy water magmas were frequent and widespread before about 500 m.y. ago. They cooled to become relatively smooth and featureless pervasive plains. The defining characteristics of landlands - being widespread and nearly featureless - is explained if pre-GCTE icy sheets underlie them. Presumably these icy plains have since been covered by aeolian and atmospheric deposits tens of meters to a few km thick.

Lopes et al [8] doubt that blandlands are icy deposits because spectral and radar data do not match ice. However, the wavelengths used probe only the top microns to meters. I propose that blandlands consist of two distinct layers: underlying relatively flat and extensive ice layers, and a surface coating of organic sediments meters to a kilometer thick. Multi-wavelength data characterize the top coating but not the underlying ice layers. Radar altimetry and photogeology confirm that the sedimentary coating rests on an expansive, featureless plain. Lopes et al [8] deduce that blandlands are younger than impact craters and labyrinths because blandlands embay them. Again, the sedimentary layer capping blandlands is created by different processes and at different times from the underlying flat ice plains. Craters, with their icy rims, excavated into the lower blandlands plains, and later may have been embayed by the sedimentary layer, including deposits on the floors of craters with intact rims.

An intriguing question is why blandlands are not everywhere on Titan, since presumably at the end of the GCTE the entire surface was made of smooth ice flows. The existence of patches of blandlands at the equator and in polar regions suggests that originally smooth plains were global but have been covered or erased by dunes and mountains near the equator, and seas and labyrinths in polar regions. Dunes are limited to equatorial areas due to drying atmospheric circulation patterns [10]. Radar altimetry suggests that some dunes rest on remarkably smooth surfaces [11].

Labyrinths are high plateaux deeply incised by erosion, and composed of low-dielectric constant organic materials spectrally similar to blandlands [12]; most occur near polar regions. Such areas are also where rainfall, surface (lakes) and subsurface (aquifers) liquids are abundant, enhancing dissolution and erosion of organic terrains leading to karstic labyrinth formation [13]. Pre-GCTE icy smooth plains were modified where atmospheric and geologic processes are most intense (equatorial and polar regions, respectively); they remain visible as blandlands where there is no effective transformation processes.

Volcanism. Volcanism would have been widespread and nearly continuous before the GCTE thickened the crust and cut off easy access of cryomagma plumes and impact-created conduits to Titan's surface. There is little evidence for post-GCTE volcanism and what there is has produced mountainous cones and relatively thick flows (e.g. Sotra Patera, Doom Mons and Mohini Fluctus) [14]. A second style of likely volcanism occurs as hundreds of 5-20 km wide deep pits near the North Pole [15]. These pits have elevated rims and a series of floors at different levels, unlike terrestrial karstic sinkholes (cf. [16]) but characteristic of explosions and collapses associated with formation of calderas and maars on Earth, Venus, Mars and Io.

Rare volcanic cones such as Sotra may occur over local hot spots, and the polar pits are in a region of somewhat thinned crust [17] that may have facilitated the rise of cryomagma. Massive thin cryomagma flows apparently no longer erupt on Titan. The magma that reached the surface during the last 500 million years constructed mountainous cones and thick flows. On Earth such morphologies are associated with lower eruption rates or more viscous lavas; on Titan both may be responsible. Titan flows composed of water ice, ammonia and methanol are calculated to be more viscous than pure water flows [18]. Should such mixed composition flows be more prevalent after the GCTE, and would the thicker crust affect the eruption rate, promoting cones and thick flows?

The methane problem. Decades ago, Yung et al. [19] calculated that methane in Titan's present atmosphere can only survive for tens of millions of years due to the atmospheric escape of hydrogen through photolysis. This means that methane, presumably from Titan's interior, must be replenished, but no ongoing mechanism has been confirmed. The GCTE interpretation suggests another explanation. During 4 billion years of nearly continuous volcanism, huge quantities of methane escaped from the interior into the atmosphere. This would explain the mystery of how Titan's atmosphere today can hold 5% methane when that amount should chemically breakdown and disappear within about 30 million years [19]. Perhaps 5% is all that remains from nearly continuous pre-GCTE eruptions. If the present methane abundance has a 30 m.y. lifetime, we can crudely estimate that the methane abundance at the time of the GCTE 500 my ago was 500/30 = ~ 15-20 times as much as today. If this were so, and methane replenishment is insignificant today, in the next few tens of millions of years all of the atmospheric methane will be removed and Titan will dry up and have a nearly pure nitrogen atmosphere [20].

Comments: If the GCTE occurred all calculated erosion, hydrocarbon production, and similar process rates are too low, perhaps by an order of magnitude. Titan may be experiencing geologically rapid landscape changes. The speculative GCTE was the most important event in titan's history, if it occurred. Various lines of evidence compiled by Hörst [1] identified that at about 500 m.y. ago a fundamental change affected Titan. If not the GCTE, what?

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