TROUBLE ON TITAN – SPECULATIVE INTERPRETATION OF HOW IT WORKS AS A WORLD.
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Introduction: Cassini has been in orbit around Saturn for 8 years, making 80 passes near Titan. In any previous spacecraft investigation that would have provided more than enough data to establish a strong understanding of how a planet or moon works. Not so for Titan. Although various types of landforms are recognized on Titan, there is incomplete understanding of their origins. Additionally, geophysical models of Titan's interior are suggestive rather than determinative of interior structure and thermal history. I here review geologic and geophysical evidence to arrive at a best guess of how Titan works as planetary body.

Geophysics: Titan's density, moment of inertia and temperature imply that it is composed of about ~40% water ice and ~60% silicate rock, with the rock forming a core, and water being the mantle and crust.

Geology: Titan has a greater diversity of geologic landforms than any body in the solar system other than Earth. Impact cratering and volcanism, the two most fundamental planetry processes, are relatively rare. Impact Craters: Fewer than a dozen certain impact craters have been discovered, and only a few dozen other likely ones have been identified; clearly one or more processes remove the craters that must have formed, judged by comparison with Saturn's heavily pitted other moons [1]. All of the possible impact craters have incomplete rims, appearing to have been heavily modified. Some likely impact crater walls have been cut by rivers and another is flooded by liquid.
Volcanism: No unambiguous volcanic flows and craters have been seen on Titan, although there is strong morphological evidence that Sotra Facula [2], Hotei Regio [3], and some small crater-containing lakes near the north pole [4] are volcanic. Other obvious flow features may be volcanic or sedimentary in origin [5], as is true for relatively featureless temperate zone plains (mottled plains of [6]); diagnostic features are not visible in the 500 – 1000 m resolution radar images.
Tectonics: Radar bright mountains occur in lines [7] and in broader areas. Mountain chains are evidence of internal tectonic forces, so Titan's interior has influenced its surface. The mountains are all eroded as evidenced by surrounding talus piles. Few fractures or linear features indicative of tectonics are seen on Titan, with exceptions being linear traces along mountain fronts in Xanadu and the generally straight edges of the dark H pattern (Fensal and Aztlan) visible on ISS images. The boundaries between dark, dune-filled areas and brighter terrain are sometimes straight but there is little evidence for how the boundaries formed.

Titan differs from most other worlds in having an extensive and active hydrological cycle, with methane/ethane taking the familiar role of water [8]. Methane-rich clouds have been observed to rain [9], and many apparent river courses and liquid lakes and seas demonstrate the likely existence of a strong fluvial cycle. The squishiness of the Huygens probe landing site, and detection of released methane, show that the ground is damp with methane in at least one place [10].

Dunes: One unambiguous landform is widespread across the equatorial regions of Titan. Dark dunes occur in long longitudinal exposures [11]. Unlike on Earth, Mars and Venus where the dune sand is eroded from surface rocks, Titan's sand-size material is commonly believed to be agglomerated hydrocarbon particles that fall out of the atmosphere [12]. This material must have fallen everywhere but dunes only occur within +/- 30° of the equator. Either the sand particles are somehow transported to the equatorial regions or they are not visible unless in dunes. Dunes overlap most other terrains and, with lakes, are the youngest features on the world [6].

The remaining terrains on Titan – the majority of the surface – are hilly or smooth areas with no particular evidence of their origin [6].

Geology of Other Worlds: During the last 50 years the surfaces of Mercury, Venus, Earth and Mars have been mapped by spacecraft, as has the Moon and dozens of other moons, astroids and comets. Hard bodies in the solar system fall into three categories, small objects whose geology is 100% dominated by impact cratering, those larger than 500+ km in diameter that have experienced volcanic and tectonic processes as well, and Earth, Mars and Titan, which have also been dramatically sculpted by atmospheric and fluvial processes. The interiors of Earth and Mars have had a long history of contributions to their surfaces by erupting lavas to construct volcanic plains and cones, and stressing crusts to generate massive tectonic surface disruptions. And in addition, the interiors have released gases and liquids that made the atmospheres and hydrospheres.

Speculative Geology of Titan: Titan's similarity to Earth and Mars in its array of hydrologic surface processes suggests that it too has experienced significant degassing from its interior. This is consistent with the continuing existence of atmospheric methane which is irreversibly broken down by solar radiation. Methane must be replenished on timescales of 10^8 years [13], so its source – most likely volcanism – must continue to be active. This is consistent with the interpretation of caldera halos of various ages in Titan's north polar regions, including some little modified ones [3]. Sotra Facula also has well-defined flows and caldera, implying a youthful age [Lopes et al., in progress].

Accepting that volcanism does occur on Titan – and there are various models to explain it and late stage timing, e.g. [14; 15] leads to speculative but reasonable interpretations that the widespread relatively smooth plains in Titan's temperate zones are volcanic flows, perhaps produced by very fluid lavas that left little evidence of flow forms or vents.

If substantial volcanism has occurred on Titan, rather than rare leaks to the surface, it is likely that the heat necessary for melting may also have led to tectonic activities. Although tectonism appears to only be expressed in the linear forms of mountain ranges and sparse fractures on mountain fronts, other evidence may be there and not understood. For example, sparse topographic data show that some of the equatorial regions filled with dark dunes are lower than surrounding bright material. If this is generally true the largely east-west extent of the dune areas (and also mountain chains) implies an equatorial tectonic pattern of linear depressions. Titan's equatorial mountain chains also have orientations that are roughly east-west. Could this be due to extension associated with the equatorial topographic bulge [16]?

Conclusions: It is a reasonable speculation, based upon interplanetary comparisons, the existence of likely volcanic landforms, and the need for methane replenishment in the atmosphere, that volcanism has been widespread in Titan's history. This could also explain the paucity of impact craters – thousands that must have formed may have been covered by fluid lava flows. Additionally, concentrations of mountains, and dunes in linear depressions, near the equator imply a global tectonic force. Interior models have not posited it, but a single cell of convection with material and heat rising at the equator and then subsiding at the poles could explain the global topography, and the equatorial extension.

References: [1] Wood C. A. and others. (2010) *Icarus 206,* 334-344. [2] Lopes, R.M.C. and others (2011) *EPSC Abstracts 6*, 303-4. [3] Wall, S.D. and others (2009) *Geophys. Res. Lett. 36*, L04203. [4] Wood, C.A. and others (2007) *LPS XXXVIII*, #1454. [5] Stofan, E. and others (2009) *LPS XXXX*, #1043. [6] Lopes, R.M.C. and others (2010) *Icarus 205*, 540-558. [7] Radebaugh, J. and others (2007) *Icarus 192*, 77-91. [8] Lunine, J.I. and S.K. Atreya (2008) *Nature Geoscience 1*, 159-164. [9] Turtle, L. and others (2011) *Science 331*, 1414. [10] Lorenz, R.D. and others (2006) *Meteorit. Planet. Sci. 41*, 1705. [11] Lorenz, R.D. and many others (2006) *Science 312*, 724-727. [12] Niemann, H.B. and others (2005) *Nature 438*, 779-784. [13] Lunine, J. and others (2009) in R.H. Brown et al. (eds*) Titan from Cassini-Huygens*, Springer; 35-59. [14] Mitri, G. and others (2008) *Icarus 196*, 216-224. [15] Lunine, J.I. and J. Castillo-Rogez (2012) "Titan's actively dehydrating interior and its volcanic and astrobiological implications". EGU 2012, in prep. [16] Zebker, H. and others (2009) *Science 324*, 921.