The Dynamic Interiors of Titan and Enceladus: Implications from Cassini-Huygens Observations and Future Prospects of Investigation

FRANK SOHL[1] and HAUKE HUSSMANN[2] and MATTHIAS GROTT[1]
[1]*DLR, Institute of Planetary Research, Berlin, Germany*
[2]*IfP, Westfälische Wilhelms-Universität , Münster, Germany*

The geology, composition, and volatile inventory of a planet or satellite provide valuable information about its internal constitution, thereby complementing geophysical constraints such as its mean density and moment-of-inertia (MoI) factor. Surface manifestations of endogenic activity are particularly useful to infer the interior structure of outer solar system satellites. The mean densities of the Saturnian moons Titan and Enceladus indicate that their interiors are composed of ice and silicate-metal in nearly equal amounts by mass, but reliable estimates of their MoI factors to infer the degree of internal differentiation are still pending. From Cassini remote-sensing observations, however, it is obvious that both Titan and Enceladus have been subject to intense endogenic activity in the course of their evolutions [1,2].

Titan's surface shows a number of cryovolcanic units and tectonic features that can be related to endogenic activity, as revealed by imaging during the descent of the Huygens probe [3] and Cassini ISS, VIMS, and SAR imaging [1,4,5]. The detection of ^{40}Ar by the Huygens GCMS [6] suggests methane replenishment of Titan's atmosphere by degassing of the interior [7]. The latter may involve episodes of methane clathrate dissociation and cryovolcanic activity coupled to the satellite's thermal-orbital evolution [8]. Titan's orbital eccentricity is remarkably high, thereby suggesting a relatively recent origin and/or moderate tidal heating of the satellite's interior over time. Finally, Titan is likely to harbour a cold, extended internal liquid reservoir, similar to those first proposed for the large icy satellites of Jupiter, but more enriched in ammonia [9,10]. Following such lines of circumstantial evidence, Titan's interior has been concluded to be fully differentiated by primordial core overturn and subsequent separation of ice and rock components [11].

The surface of Enceladus suggests that the satellite underwent intense resurfacing in the past. Additionally, the detection of water-vapour geysers [12] shows that the south polar region of Enceladus is cryovolcanically active even at present [2]. In particular, the presence of non-condensable volatile species in jet-like plumes, like molecular nitrogen, carbon dioxide, and methane, suggests an aqueous internal environment at elevated temperatures of about 500 to 800 K, thereby enabling aqueous, catalytic chemical reactions [13]. Possible venting mechanisms are sudden decompression of near-surface reservoirs of liquid water [2], chlathrate decomposition [14], or other cryovolcanic processes [15]. Taken together, this strongly suggests that Enceladus's interior is differentiated into a silicate-metal core overlain by a water-ice liquid shell [16]. However, the energy source required to initiate and to keep the activity at a level comparable to that observed today over geologic periods of time is not well understood. Though tidal heating in the presence of a global subsurface ocean combined with radiogenic heating in the silicate component can explain the thermal energy release at a rate of 3-7 GW as observed by Cassini CIRS [17], the concentration of geologic and thermal activity towards the south-polar region remains elusive. As an alternative, the internal liquid reservoir might be confined to beneath the south-polar region, thereby explaining the associated circular topographic depression [18]. Furthermore, it has been shown that Enceladus's asymmetric geologic and thermal activity can be associated with degree-1 convection of the outer ice shell [19]. If the interior were only partly differentiated with silicate-metal cores of less than 120 km radius, the convective heat flow would be consistent with the observed heat release in the south-polar terrain.

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