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Interior models of Titan and the atmospheric ^{40}Ar abundance

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Abstract

Gravity data from Cassini have provided a moment of inertia for Titan too large for a fully differentiated body [1]. Others have suggested that the ice and rock are not completely separated, in a layer above an anhydrous silicate core [2]. We have proposed a model in which the core of Titan is partially hydrated, and maintained so against radiogenic heating by the leaching of ^{40}K from the rock into the overlying ocean [3]. Here we estimate the amount of ^{40}Ar outgassed into the atmosphere over time in the context of such a model.

1. Interior model

In our model [3] we assumed an early hydration of the rocky material accreted in Titan, which is warranted if Titan accreted short-lived radioisotopes. Hydrothermal alteration of rocky material is expected to be a rapid and extensive process [3, 4]. We considered that Titan's core is initially dominated by antigorite. Dehydration is delayed until 3.5 billion years after formation and, considering the large latent heat involved in that process, it may last for hundreds of My. An alternative model [5] recently suggested that Titan's core has at present a chondritic composition. However, it is likely that the most volatile compounds generally found in chondritic material (e.g., salts, organics) would not be part of the core over the long term. Salts are soluble and a large fraction would remain in Titan's ocean early on, instead of settling in the rocky core. The enrichment of the ocean in solutes is likely responsible for the induced magnetic field detected at all three Galilean satellites [6, 7]. Our models show that a few hundred My after differentiation, Titan's core temperature could become greater than the melting temperature of hydrated salts and organics, leading to a first phase of dehydration and the escape of volatiles and alkaline elements from the core into the high-pressure layer. As a result, a large fraction of the rock's content in potassium is likely in Titan's ocean and possibly also in the high-pressure layer. A limited sized dehydrated inner core exists, surrounded by a hydrated silicate outer core whose rate of dehydration is limited by the leaching of radioisotopes into the oceanic layer (and, later, ice layer) above it. The amount of potassium leached into the ocean is about 30% of the total potassium contained in the silicate core.

2. Results

The abundance of ^{40}K leached into the ocean is 3 x 10^{18}g, about a factor of twenty less than the saturation limit in a water ocean with a base at 2100 km radius and a top some 50 km below the surface. Over the past billion years one half-life has elapsed, and with ^{40}Ar as one of two decay products, the resulting predicted atmospheric abundance relative to N_2 is several times larger than the measured GCMS abundance [8]. The excess argon could have formed clathrate hydrate in the high-pressure ice layer at the base of the ocean (the upper crust is likely already saturated in methane and ethane clathrate hydrate [9, 10]), but also may be dissolved in a subsurface water-ammonia ocean. The latter is made possible by the strong depletion in the abundance of primordial argon (mass 36, 38) associated with the origin of Titan's nitrogen as ammonia [8], making ^{40}Ar the dominant isotope.

3. Discussion

The argon outgassing we calculate from our model is less than, but within a factor of ten or closer, that measured by Huygens. There is nothing in the measured ^{40}Ar abundance that contradicts our partial dehydration model, because the excess ^{40}Ar produced from the leaching of ^{40}K from the core is easily taken up in the ocean or high-pressure ice base, or both. As noted above, this is a consequence of the strong depletion in non-radiogenic argon. An issue is whether the more modest ^{40}Ar depletion provides a test between those competing models that also satisfy the moment of inertia constraint.

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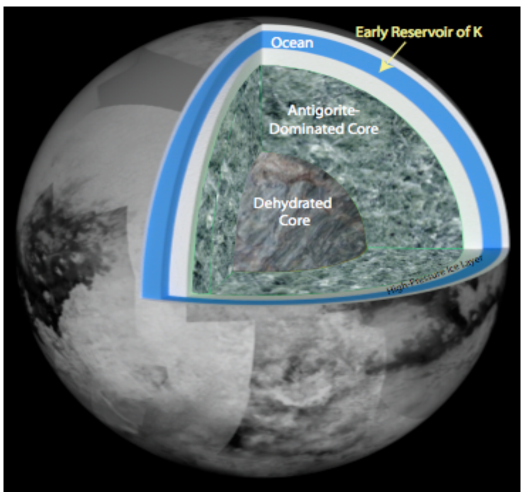

Our model of Titan's interior based after geophysical constraints and accounting for the aqueous alteration of the rocky phase during the first differentiation stage. That event likely resulted in the separation of a potassium-rich reservoir just below the surface. At a later stage, part of the hydrated material started dehydrating, resulting in the release of hot water enriched in impurities. Our models suggest that that event started relatively recently and is ongoing.