TRITON'S POST-CAPTURE THERMAL HISTORY; William B. McKinnon and L.A.M. Benner, Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, Saint Louis, MO 63130.

The amount of tidal heating a captured Triton undergoes depends on the capture mechanism. If the mechanism is gas drag [1,2], the question becomes how much further orbital evolution occurs under the influence of the gas. In principle, the orbit can completely circularize and attain essentially its present angular momentum state due to gas drag alone. If so, Triton will be trivially internally heated by tidal dissipation over the time scale of gas drag evolution ($<10^6$ years, as shown in a companion abstract [3]). Triton's surface will be ablated by shock-heated gas, but the amount of mass lost is not large for a body of Triton's size [e.g., 4]. Of course, unless gas drag evolution halts, Triton's orbit will continue to decay. For capture by collision with a pre-existing regular satellite [5], all subsequent evolution is driven by tidal dissipation except for further collisions. During orbital evolution by gas drag, collisions may also occur with satellites that have formed or are in the process of forming.

We consider Triton's orbital evolution after either the capture collision or the dissipation of the gas (a proto-Neptunian nebula in our preferred model [6]). A simple model with constant Q/k, where Q is the tidal dissipation factor (assumed to be 100) and k is the potential Love number (assumed appropriate for a uniform, solid rock-ice body), predicts that that a Triton evolving inward from Neptune's sphere of influence takes almost 10^9 yr for its orbit to circularize, much longer than early estimates for a Triton of 1750-km-radius [2]. As is known, the tidal heating is ferocious in this model and Triton cannot stay solid, so more complex models are necessary. Even for initial orbits that extend to the edge of Neptune's sphere of influence, the tidal energy dissipated during individual passes close to Neptune is, time-averaged, comparable to the radiogenic power in this rock-rich body. For orbits with $a \lesssim 1200\ R_N$, where a is semimajor axis, tidal power dominates for the nominal Q/k model.

We track the thermal evolution of a convecting Triton during this period of initial heating using standard parameterized convection techniques [e.g., 7]. Once Triton is convecting, and assuming that accretional heating has not already triggered differentiation, we find Triton very close to melting without tidal heating [8]. Choosing rheological parameters that minimize the likelihood of melting (e.g., non-Newtonian viscosity, ignoring the stiffening effect of the abundant rock fraction) and varying the time of capture, melting begins no later than ~25 m.y. from the start of tidal evolution, after a has declined to only $\sim 1600\ R_N$. If tidal evolution starts at closer distances, melting begins promptly. Only if Triton is captured cold will melting be delayed, perhaps ~100 m.y., and until a reaches $\sim 1000\ R_N$.

At the onset of melting, differentiation is partially self-sustaining as the gravitational energy of unmixing is approximately 30% of that needed to melt Triton's ices. Dissipation increases dramatically once melting commences: the Maxwell time of water ice at near-solidus temperatures is shorter than the effective tidal forcing period at perihelion, unmixing creates many transient and dissipative multiphase regions (e.g., ascending slush and descending mud diapirs), and the opening up of an internal ocean allows k to increase substantially. The result is a differentiated Triton in under 10^7 yr (and possibly much less), with a liquid water ocean capped by a thin, dissipative, conductive ice shell, overlying a rock core. We note that had Triton differentiated prior to capture (and one can argue that this is likely because of stiffening of the viscosity caused by the rock fraction and the presence of low melting point ices [e.g., 8]), the end result would be the same but the onset of (renewed) melting could occur > 100 m.y. later. A pure-ice mantle runs hotter for the same heat flux because less work is done against gravity, but tidal and radiogenic heating of the core is largely unavailable initially to drive mantle convection.

Continued tidal heating in the core causes it to heat up and melt as well. The ultimate tidally heated configuration for Triton is nearly totally molten. A thin water-ice shell tops a liquid water mantle, and thin rock shell tops a liquid silicate core; this lower shell may be negatively buoyant, though, and may turn over as on a lava lake. There may be an inner core of liquid iron-sulfur, but no iron shell. We ignore for the time being any other ices (e.g., NH_4, CH_4, N_2) that might form various surface oceans.

Once Triton melts, and it needs only a small portion of the total orbital energy potentially available to it, its orbital evolution slows. This seeming paradox results from the fact that dissipation in a liquid Triton is largely confined to the thin solid shells described above. The hot, near-solidus portions of both shells are quite dissipative ($Q \sim 1$) under tidal forcing, with overall effective Qs of ~10 [cf. 9]. However, because the shells are at most only a few km thick, the average Q of Triton itself is much higher, $\geq 10^3$. Of course, k is at its maximum for a liquid body, but the total effect is still to stretch out Triton's early thermal and orbital evolution. Triton may thus stay hot for an extended length of time (>500 m.y.), preventing any early cratering record from being retained [10,11].

The geological evidence from Triton is consistent with massive tidal heating [12]. Whether tidal heating is required to explain the absence of heavily cratered terrains depends on the composition of the surface. If there is a crust of lower melting point ices greater than a few km thick, then continuing volcanic and other activity can probably destroy any ancient crater population. If, however, portions of Triton's exposed surface are water-ice "bedrock," then tidal heating is necessary. Further work should involve more detailed characterization of the volatile ices during the tidal heating epoch. They exert an important control on the surface temperature of the water mantle, and the possibilities for an atmospheric greenhouse (and no ice shell at all) are not remote.

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