PUZZLES OF TRITON; David J. Stevenson and Amar S. Gandhi, 170-25, Caltech, Pasadena, CA 91125.

Introduction. The remarkable encounter of Triton by Voyager II, especially the images returned [1], pose some interesting puzzles: (1) Is there a "signature" of Triton's origin in its composition or surficial appearance or both? (2) What is the origin and nature of the extensive resurfacing and why is it so prominent on Triton compared to other outer solar system satellites? (3) What is happening on the surface now? What is the nature of the "geysers"?

Origin of Triton: Where is the CO? The unusual orbit of Triton suggests capture [2] which in turn suggests formation in a solar nebula environment that should contain CO. This appears to be consistent with the observed high density of Triton [3], but then we have a puzzle: Why is N$_2$/CO observed [4] to be so large on Triton? There are several possible resolutions: (i) Solar nebula volatile species were never efficiently incorporated or were subsequently expelled by hydrodynamic loss during heating. The N$_2$ on Triton is then derived by the impact decomposition of NH$_3$, a marginally adequate process [5]. (ii) CO was preferentially destroyed by hydrothermal reactions at the interface between the primordial hot H$_2$O-rich ocean and the pervasively volcanic rock core during the epoch of severe tidal heating following capture. Thermochemical calculations analogous to those by Holland [6] for early earth show that this is possible. (iii) Solar nebula did not contain CO in that region, or any CO present was converted to hydrocarbons, presumably by Fischer-Tropsch reactions [7]. (iv) CO remains tied up as clathrate inside Triton. Of these four possibilities, the first is implausible because the complete disengagement and loss of enclathrated CO should not be that efficient; and the third is implausible because it runs counter to other evidence, especially the presence of CO in comets but also the problem of getting the right density of Triton (though this may have other explanations [8]). The fourth possibility does not work since some CO will always follow N$_2$ in a volcanic process because of the partitioning between gas and clathrate [9], and the observation is that CO is either absent or in much smaller amounts still. We are left with the need for in situ destruction of CO by hot water, which makes the process special to Triton and means that Triton is different from Pluto by virtue of its severe heating episode. In other respects (volcanic history, present surface), it seems likely — as discussed below — that no other signature of the capture event remains.

Thermal History of Triton. We have carried out extensive modeling of Triton's thermal history, including the following effects: Parameterized subsolidus convection in both the rock core and a primarily water-ice outer shell, chondritic heat sources, and early tidal heating spike, latent heat of freezing, and high pressure water-ice phases. A typical thermal history is shown in the figure: the uppermost curve is heat flux out of the core and the remaining two curves are surface heatflow with and without ocean freezing (with being represented by the profile that has a "step" added to it). The most striking feature of these calculations is the long-lived water ocean beneath an outer ice shell: In these calculations, it persists until ~2.0 × 10$^9$ yr bp. It persists even longer, up to and beyond the present time, if NH$_3$ is present. These results arise from the fact that Triton has a large rock core (~1100 km in radius) compared to its total size. The large energy source and modest surface radius lead to a surface heatflow comparable to a much larger "conventional" icy satellite (e.g., Ganymede). The presence of more volatile constituents allows for the possibility of volcanic processes and resurfacing, as tentatively suggested some years ago [10]. In short, the surface of Triton can be geologically young due to chondritic radiogenic heating alone. The tidal heating spike plays no role. However, some puzzles remain. It is far from clear how an NH$_3$-H$_2$O fluid would become buoyant, given the expectation that the overlying ice is primarily ice I. Presence of sufficient N$_2$ within and above this ice may help load down the lithosphere but this is not likely to be sufficient. It is possible that dissolved volatiles in the ocean, especially
N₂ and CH₄, may play a crucial role in the volcanic process in a way analogous to the proposed eruption process on Europa [11].

**Present Day Surface of Triton** With the presence of both N₂ and CH₄ solids, the interesting question arises: How are these ices distributed? Solar energy drives N₂ into the atmosphere, because it is more volatile, but gravity causes viscous foundering of N₂ ice mass because it is twice as dense as CH₄ ice. It seems likely that patches of CH₄ ice rise to the surface buoyantly over geologic time [12], and are then darkened by UV and cosmic rays. Surface exposures of CH₄ will accordingly be much warmer than N₂, both because they are darker and because they are not much cooled by continual solar-powered sublimation. Nitrogen ice beneath CH₄ “traps” will be heated, partially sublime and conceivably explode through, creating geyser activity. This mechanism has a greater prospect of some longevity (hours or more) and strength than the suggested solid-state greenhouse mechanism [1]. However, the real puzzle here lies in the question of how much total CH₄ and N₂ are present. Depending on the answer to this question, one could envisage volcanic processes directly comparable to those responsible for geysers on Earth, whereby magma (NH₃-H₂O in this instance) fluxes a volatile (N₂ in this instance). The geysers are most likely solar-powered, as advocated above, but the possibility of an internal heat contribution cannot yet be excluded.

References