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CRYOVOLCANISM ON TRITON

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Introduction. The Voyager 2 images of Triton revealed evidence of past cryovolcanic activity, some of it very recent in relative geological terms [1,2]. Observations of atmospheric plumes and associated dark streaks vented from the surface allow the possibility that explosive cryovolcanism was occurring at the time of the encounter (although non-volcanic explanations are also plausible [1]). Here we discuss some of Triton's cryovolcanic morphologies and a model of volatile-driven explosive ammonia-water volcanism.

Cryovolcanic morphologies. The most dramatic cryovolcanic features on Triton are the vast smooth-floored, closed depressions (Figure 1). Clearly some type of cryogenic "lava" has been extruded and contained by the lakes' walls. A complexly pitted region occurs near the center of the lava lake; an associated feature may be a collapsed lava tube. Similar pitted areas occur in Triton's other lava lakes. These pits could be indicative of late cryoclastic (explosive) volcanism. Low-relief domes are scattered across the lakes' floors. The morphologies of the lava lakes and of adjacent terrains indicate a multi-staged history of tectonic collapse and cryovolcanic flooding, sometimes with overflow onto adjacent regions.

Figure 2 shows a region characterized by deep, irregular, rimless volcanic depressions, with adjoining smooth areas. A highly viscous substance (or one with a high yield strength) produced flow front escarpments several hundred meters high and flowed around obstacles of comparable height. Two cryovolcanic craters in the region have associated collapsed lava tube-like features. One volcanic crater has a central lava dome, another indication of the immobile character of these cryolavas. Tectonic alignment of several craters suggests a similarity to terrestrial fissure eruptions. Triton's fissures are part of a global volcano-tectonic grid. Elsewhere, this grid is expressed as viscous dike-like intrusions and dike swarms (FDS 11396.27), broad linear volcanic plateaus, and lobate fissure flows, in one case 34 km long and 28 km wide (FDS 11394.51).

The unique "cantaloupe terrain" [1] consists of linear to quasi-circular ridges, aligned pits, and pitted ridges, all forming a net-like pattern crossed by the global volcano-tectonic grid. Thick flow-like features appear to emanate from the global fracture zone, extending for over 200 km and inundating parts of the cantaloupe terrain. Pitted ridges may be fissures along which explosive eruptions have occurred. Interspersed through this and other terrains are shorter dark flow-like features with little or no observable vertical relief. These units include the darkest material on Triton [1], suggesting a radiation-darkened carbonaceous composition quite distinct from the other, more predominant and apparently more viscous flows. Evidence for cryoclastic deposits include a major fracture which appears to be subdued by mantling material at its northeast end (FDS 11395.09), and other smooth, subdued terrain nearby.

Cryolava compositions. The high apparent viscosities of the erupted liquids argues against liquid N_2, CH_4, or CO, or mixtures of them, as the dominant chemical constituent. Pure water, even with suspended ice, is probably also much too fluid to generate the thick lava flows and domes observed on Triton. Ammonia-water liquids containing other chemical constituents or suspended ice might have the required rheology [3]. Croft argues persuasively on independent grounds that Triton's cryolavas are fundamentally aqueous [4]. The similarities of the flow thicknesses on Triton, Miranda, and Ariel, especially after gravity scaling, suggests similar cryolava compositions.

Volatile-driven explosive cryovolcanism. Volcanic craters and plumes on Triton may indicate that many eruptions were explosive. This would require a minor or trace volatile component such as CH_4 or N_2 acquired, for instance, by partial melting in the presence of methane clathrate. Unfortunately, the solubility of these gases in ammonia-water mixtures is unknown; however, gas solubility data exist for pure water and liquid ammonia solvents [5-10]. The solubilities of CH_4 and N_2 in ammonia-water mixtures should be on the order of 0.1-2.0% by mass at 176 K and 500-1000 bars (corresponding to likely conditions of partial melting). The bubble content of an ascending magma increases rapidly as it nears the surface because of the pressure dependence of gas solubilities. The magma disintegrates into an accelerating gas-driven spray of cryoclastic particles if the bubble content exceeds about 75% by volume [11].

To illustrate the potential for explosive cryovolcanism on Triton, consider a simple model. Equate the hydrostatic pressure, P_{ext}, to the lithostatic pressure, $\rho_c gh$, where ρ_c is the crustal density (0.95 g cm-3), g is the gravitational acceleration (78 cm s^{-2}), and h is the depth. This simplifying assumption implies a specific shape to the conduit [13], but the general qualitative outcome of the model should not be lost for its specificity. The internal gas pressure in a bubble, P_{int}, has two components, P_{ext} and P_γ, where the latter is due to surface tension. An expression may be derived giving the volume fraction, ϕ, of gas in the foaming liquid:

$$\phi = [(XRT)/M(\rho_c gh+2\gamma/r)]/\{[(XRT)/M(\rho_c gh+2\gamma/r)] + 1/\rho_l\},$$

where X is the mass fraction of the volatile component, R is the gas constant, T = 176K, M is the volatile's molecular mass (16 for CH_4), ρ_l is the density of the liquid in the absence of suspended bubbles (about 0.95 g cm^{-3}), γ is the surface tension of the liquid at 176 K = 72 dynes cm^{-1} [13], and r is the radius of the bubbles (we assume two values, 0.01 and 1 cm). Figure 3 shows that the critical 75% volume fraction of bubbles required for magmatic disintegration is achieved at a depth of about 40 meters for 0.1% CH_4 and 800 meters for 2% CH_4, almost independent of bubble size (surface tension turns out to be unimportant for satellites as large as Triton).

The salient point of Figure 3 is that explosive eruptions of ammonia-water magmas may produce craters some hundreds of meters deep and may vent ash clouds into the atmosphere of Triton if the magmas contain approximately 1% volatiles. Alternatively, phreato-magmatic interactions of ammonia-water liquids with surficial methane or nitrogen ice [14] may produce explosive cryovolcanic landforms.

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References. [1] Smith, B.A. et al., 1989, Science 246, 1422-1450. [2] Strom, R.G., S.K. Croft, and J.M. Boyce, 1990, LPS XXI. [3] Kargel, J.S. and S.K. Croft, 1989, LPS XX, 500-501, and submitted to Geochim. et Cosmochim. Acta. [4] Croft, S.K., 1990, LPS XXI. [5] Bolshakov, P.E. and E.S. Lebedeva, 1940, Acta Physicochimica U.R.S.S., 12, 501-512. [6] Davis, D.S., 1941, Ind. Eng. Chem., 33, 1454-1455. [7] Culberson, O.L., 1951, Petroleum Transactions, AIME, 192, 223-226. [8] Pray, H.A., C.E. Schweikert, and B.H. Minnich, 1952, Ind. Eng. Chem., 44, 1146-1151. [9] Lefrancois, B. and C. Vaniscotte, 1960, Genie Chimique, 83, 139-145. [10] Dean, J.A. (ed.), 1979, Lange's Handbook of Chemistry, 12th ed., Table 10-1. [11] Houghton, B.F. and C.J.N. Wilson, 1989, Bull. Volcanol. 51, 451-462. [12] Wilson, L. and J.W. Head III, 1981, Jour. Geophys. Res., 86, 2971-3001. [13] Efremov, Yu.V. and I.F. Golubev, 1962, Zh. Fiz. Khim. 36, Part 2, 999-1000. [14] Stevenson, D.J., 1982, Nature, 298, 143-144.

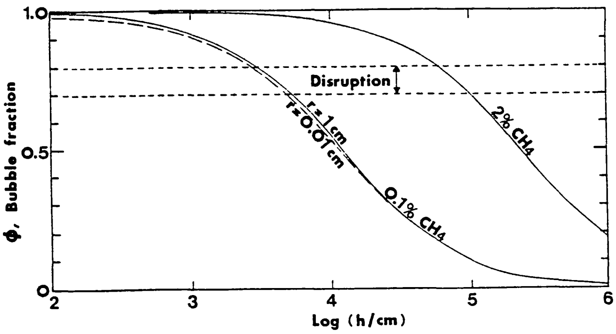

Figure 1. Cryogenic "lava" lake on Triton (above, left).

Figure 2. Volcano-tectonic fissures, explosive vents, flow fronts, and flow-mantled terrains on Triton (above).

Figure 3. Volatile exsolution model for 0.1% and 1.0% CH_4 in ammonia-water magma ascending in Triton (left).