N94-16311

TIDAL INTERACTION: A POSSIBLE EXPLANATION FOR GEYSERS AND OTHER FLUID PHENOMENA IN THE NEPTUNE-TRITON SYSTEM;

W.D. Kelly, C. L. Wood, MS B12 Lockheed Engineering and Sciences Company, Houston, Texas 77058-3711

Discovery of geyser-like plumes on the surface of Triton was a highlight of Voyager 2's passage through the Neptune planetary system [1-4]. Remarkable as these observations were, they were not entirely without precedent. Considering the confirmed predictions [5] for the 1979 Voyager Jovian passage, it was logical to consider other solar system bodies beside Io where tidal effects could be a significant factor in surface processes. It was our intuition [6] that the Neptune-Triton gravitational bond acting at high inclination to the Neptune equator and the fact that Neptune was a fluid body with significant oblateness would produce tidal and mechanical forces that could be transformed into thermal energy vented on Triton's surface. Prior to the Voyager flyby, others have noted that capture and evolution of Triton's orbit from extreme eccentricity to near circular state today would have resulted in significant tidal heating [7], but these analysts disregard current day forces. Our calculations indicate that the time varying forces between Neptune-Triton fall midway between those exerted in the Earth-moon and Jupiter-Io systems, and considering the low level of other energy inputs, this source of internal energy should not be ignored when seeking an explanation for surface activity. In each planet-satellite case, residual or steady-state eccentricity causes time-varying stresses on internal satellite strata. In the case of Jupiter the residual eccentricity is due largely to Galilean satellite interactions, particularly Io-Europa, but in the case of Neptune-Triton, it is the effect of Triton's inclined orbit about an oblate primary.

Since the Neptune flyby, two candidate explanations for geyser-like plumes have been offered:

1) a subsurface nitrogen greenhouse process in which heated nitrogen surface ices are evaporated and boiled off through vents [2,8,9] ; and,

2) a less widely accepted dust-devil hypothesis [10], vortices forming in the rarefied Triton atmosphere.

The first theory has at least one shortcoming in so far as the mechanism suggested is limited to surface regions of a few meters depth in crystalline nitrogen. Considering the magnitude of the releases and their frequency of occurrence, it is possible that solar heating would not provide an adequate fluid reservoir. Such objections are reasons to re-examine tidal mechanisms. Tidal effects were studied using a method developed for analyzing time varying effects of the micro-gravity contours located about the center of mass of a spacecraft [11] (e.g., the Space Station Freedom Laboratory). Ellipsoidal contours of constant micro-g levels were identified as a function of satellite or spacecraft orbit true anomaly. Fluctuations in contour semi-axes and orientation with orbital motion were taken as tidal force indicators.

Secondary effects also considered were the effects of the tidal bore on the Neptune planetary ocean. Tidal bores in this system [12] would be 8 times higher than corresponding terrestrial tides, displacing mass perhaps tens of thousands of kilometers into the planetary interior since there is no clear demarcation between atmosphere and "surface". Perhaps it is only a circumstantial connection, but it is worth noting that large Neptune atmospheric features observed in low latitudes as deep as several bars pressure are carried east to west [13-14] up to 325 mps, roughly synchronous with Triton's retrograde rotation about Neptune (301 mps). Without doubt the Neptune-Triton tidal bond is significant for Neptune "meteorology", but our calculation of bore height as a gravitational potential perturbation is significantly smaller than the observed effect of the rotationally induced re-distribution of Neptunian mass that probably dominates the J_2 gravity term. Still, this "off-axis" tidal distribution could contribute to a residual forced eccentricity for Triton not included in our tidal stress calculations.

When comparing the relations [15] below (summarized in table-1),

$$\sigma_{obl} = 12/\pi \ J_2 \ (r_{pl}/r_{sat}) \ \mu_{pl} \ m_{sat}/a^4 .$$

$$\sigma_{ecc} = 2/\pi \ e \ \mu_{pl} \ m_{sat}/(a^3 \ r_{sat})$$

NEPTUNE-TRITON TIDAL INTERACTION: W.D. Kelly, C. L.Wood

where subscripts sat and pl designate satellite and planet, (m) the mass, (r) the surface radius and (a) the mean distance of the two bodies, it can be seen that tidal stresses for the earth's moon based on eccentricity (σ_{ecc-1}) are about 2.6 times larger than those for Triton based on oblateness (σ_{obl}), but the rotational rate of Triton about its primary is about five times more rapid.

Table -1   Relative Satellite Physical Factors

	$\sigma_{obl} / \sigma_{ecc-1}$	$\sigma_{ecc} / \sigma_{ecc-1}$	ω / ω_1	$(\omega/\omega_1)^2$	Tidal bore (scale)
Luna	-	1.0	1.0	1.0	1.0
Triton	1 / 2.666	-	4.65	21.6	8.07
Io	-	36.69	15.44	238.5	45.23
Europa	-	8.49	7.67	58.8	6.12

The effect of tidal forces perturbing a spherical mass of uniform density (analogous to a satellite with a solid or icy surface) can be derived with a correction to the equation of hydrostatic equilibrium. Superimposed on these equilibrium forces are those of the time varying tidal forces exerted by the gravitational field of Neptune. The magnitude of these forces can be mapped out into time varying ellipsoidal contours[11] of constant micro-g contours. Revising the hydrostatic equations accordingly

$$d\,P'/dr = -\rho\,[g(r) + \Delta g_t(r)] = -\rho\,[4/3\,\pi\,\rho\,G\,r + r^2\,k_1\,(1 + k_2 \sin \omega_0 t)]$$

where the time varying tidal pressure exerted in the satellite interior is

$$\Delta P'(r) = -\rho/3\,\,r^3\,k_1\,k_2 \sin \omega_0 t + constant = \rho/3\,\,k_1\,k_2 \sin \omega_0 t\,(r_0{}^3 - r^3)$$

with k_1 and k_2 scaling factors for the planet-satellite system, ρ the density, r distance from the satellite center of mass, ω_0 orbital angular rate, g for gravitational accelerations, and P' combined hydrostatic and tidal pressures.

REFERENCES
[1.]   Kerr, R., Science, Vol. 245, pp. 928-930.
[2.]   Smith, B. A. et al., Science, Vol. 246, pp. 1422-1449.
[3.]   Soderblom, L. A. et al, Science, Vol. 250, 410-415, 19 October 90.
[4.]   Hansen, C. J., et al. , ibid., pp. 421- 424.
[5.]   Peale, S. J., Cassen, P. , Reynolds, R. T., Science, Vol. 203, pp. 892-894, March 79.
[6.]   Kelly,W., Letter to AAAS/Science, 27 July 92 (unpublished).
[7.]   Chyba, C. F. et al., Astronomy and Astrophysics - Letters, Vol. 219, L23, 126 (1989).
[8.]   Kirk, R. L., Brown , R. H., Soderblom, L. A., Science, Vol. 250, pp 424- 429, 19 October 90.
[9.]   Brown, R. L., et al. " Energy Sources for Triton's Geyser-Like Plumes", Ibid. pp. 431- 435.
[10.]   Ingersoll, A. P., Tryka, K. A. "Triton's Plumes: the Dust Devil Hypothesis", Ibid., pp. 435- 437.
[11.]   Kelly, W. D., Lockheed Engineering and Sciences Company, Technical Report 30224, April 92.
[12.]   Lamb, H., "Hydrodynamics", Dover Press, 6th edition, New York.
[13.]   Hammel, H. B., et al., Science, Vol. 245, pp. 1367-1369.
[14.]   Suomi, V. E., et al., Science, Vol. 251, pp. 929-932, 22 Feb. 91.
[15.]   Ojakangas, G, private communication, 29 June 92.