DIFFERENTIAL THERMAL STRESSES: A SOURCE FOR EARLY EXTENSIONAL TECTONISM ON THE SATURNIAN AND URANIAN SATELLITES John K. Hillier and Steven W. Squyres, Center for Radiophysics and Space Research, Cornell University, Ithaca NY 14853

An examination of the major Uranian and Saturnian satellites shows that most of them have undergone extensional tectonism and resurfacing in the past. Only Iapetus and Umbriel do not exhibit clear evidence of at least some extensional tectonism and resurfacing (1,2) and even in these cases the lack of evidence may be due to insufficient resolution. Differential thermal stresses due to uneven cooling of a satellite following accretion, warming by radiogenic heating and, in the larger satellites, expansion due to ice II → ice I phase transitions in the satellite's interior caused by such warming are examined as possible sources for some of the tectonism and associated resurfacing observed on these satellites.

Starting from an initial accretional temperature profile (3), the satellites' temperature profiles initially evolve by thermal heat conduction. Solid state convection, when it occurs, is handled using the procedure outlined in Ellsworth and Schubert (4). The effects of both radiogenic heating in the silicate fraction (assuming a carbonaceous chondritic chemical abundance for the silicate fraction) and the release of latent heat from any ice II → ice I phase transitions which occur are included in the model.

The consequent thermal stresses built up in the satellites are calculated assuming the satellites to have a viscoelastic rheology and that deviatoric stresses are initially zero. The radial, σ_r, and tangential, σ_T, stresses beyond the lithostatic stress are found by integrating:

$$\frac{d\sigma_r}{dt} = \frac{2E}{1-v}\left[\frac{1}{R_{Sat}^3}\int_0^{R_{Sat}} r^2\frac{d\alpha}{dt}dr - \frac{1}{r^3}\int_0^r r^2\frac{d\alpha}{dt}dr - \left\{\frac{\sigma_r}{12\mu} + \int_0^{R_{Sat}} \frac{\sigma_r}{12}\frac{d(\frac{1}{\mu})}{dr}dr - \int_0^r \frac{\sigma_r}{12}\frac{d(\frac{1}{\mu})}{dr}dr\right\}\right],$$

$$\frac{d\sigma_T}{dt} = \frac{E}{1-v}\left[\frac{2}{R_{Sat}^3}\int_0^{R_{Sat}} r^2\frac{d\alpha}{dt}dr + \frac{1}{r^3}\int_0^r r^2\frac{d\alpha}{dt}dr - \frac{d\alpha}{dt} - \left\{\frac{\sigma_T}{12\mu} + \int_0^{R_{Sat}} \frac{\sigma_r}{12}\frac{d(\frac{1}{\mu})}{dr}dr - \int_0^r \frac{\sigma_r}{12}\frac{d(\frac{1}{\mu})}{dr}dr\right\}\right],$$

where

$$\alpha = \alpha_l\Delta T + \frac{1\Delta\rho_{pt}}{3\rho}U(r - r_b(t)),$$

E is Young's modulus, v is Poisson's ratio, α_l is the linear coefficient of thermal expansion, μ is viscosity, ΔT is the change in temperature from the initial temperature, $\Delta\rho_{pt}$ is the difference in density between the ice I and ice II dominated regions, r_b is the position of the ice I - ice II phase boundary, U is the step function and t is time. In the expression for α, the first term takes into account the effects of thermal stresses while the second accounts for shifts in the ice I - ice II phase boundary. Note that the extension is positive in the above equations. The total stress is found by subtracting the lithostatic stress from the results calculated above.

The lithostatic stress is calculated assuming a simple two layer model with a constant density ice II - rock core and ice I - rock mantle. The position of the ice I - ice II phase boundary is determined from the equilibrium relation (4):

$$P(MPa) = 0.917T(K) - 1.762$$

and is found after each time step using an iterative procedure until a self consistent solution is obtained.

Table 1

Satellite	$\sigma_T$max(MPa)	Satellite	$\sigma_T$max(MPa)
Iapetus	51.6	Oberon	53.7
Rhea	30.0	Titania	62.9
Dione	6.6	Umbriel	18.4
Tethys	3.4	Ariel	28.1
Enceladus	0.4	Miranda	0.0
Mimas	0.2		

Table 1 shows the maximum near surface extensional tangential stresses reached in each of the major Uranian and Saturnian satellites within the first 200 Myr. The results shown are for accretion in a gas free (cold) nebula. In all cases, the radial stresses remain nearly lithostatic. On the smaller satellites, only small stresses develop, probably insuffcient in strength to fracture ice if accretion occurs in a gas free nebula. However, if accretion occurs in a gaseous (warm) nebula, extensional stresses of at least several megapascals (tens of bars) develop very quickly (within a million years) on these satellites, sufficient in strength to fracture ice. On the intermediate to lage satellites, large near surface extensional stresses of several tens of megapascals accrue within 200 million years, easily strong enough to fracture ice. Figure 1 shows the temperature and stress evolution of a typical large satellite, Titania. As can be seen, the material just under the fracture zone is the warmest in the satellite and therefore may be buoyant and mobile enough to reach and flow out onto the surface through any fractures which are created. Thus, differential thermal stresses following accretion may provide a viable mechanism for creating an early episode of extensional tectonism and associated resurfacing which is observed on many of the Saturnian and Uranian satellites.

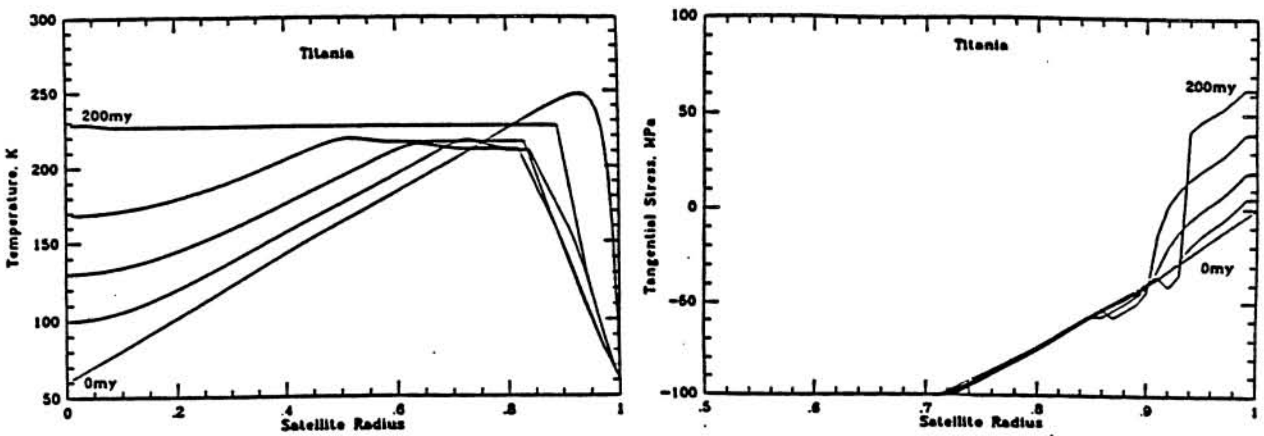

Figure 1: Temperature and stress evolution of a typical large satellite, Titania. Note that extensional stresses are positive. Shown are the temperature and stress profiles at 0, 20, 50, 100, and 200 million years.

References

1) Squyres, S.W. and S.K. Croft (1986), in *Satellites* (J.A. Burns Ed.), 293-341.

2) Smith, B.A. (1986), *et al.*, *Science*, **233**, 43-64.

3) Squyres, S.W., *et al.* (1988), *JGR*, **93**, 8779-8794.

4) Ellsworth, K. and G. Schubert (1983), *Icarus*, **54**, 490-510.