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# Tidal Evolution of Planetary Satellites

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Early in the history of the Solar System, Europa and Ganymede may have evolved through a 3:1 mean-motion commensurability (Tittemore 1990b), which would have been encountered prior to the establishment of the current Laplace resonance involving Io, Europa and Ganymede. If Europa and Ganymede passed through the 3:1 mean-motion commensurability, the orbital eccentricities of both satellites may have increased to large values during a phase of chaotic behavior, after which the satellites would have escaped from the resonance. In spite of the relatively large $J_2$ of Jupiter, Europa and Ganymede are sufficiently massive and distant from the planet that resonances at the 3:1 mean-motion commensurability interact strongly, leading to chaotic behavior via the same kinds of dynamical mechanisms present at resonances among the Uranian satellites (see Tittemore and Wisdom 1988, 1989, 1990; Tittemore 1990a).

As a result of the large eccentricity increases possible during the evolution of Europa and Ganymede through the 3:1 mean-motion commensurability, tidal heating may have melted water ice in the mantles of both satellites, and stresses on the lithospheres of both satellites due to tidal deformation may have been sufficient to cause extensive fracturing, making resurfacing possible. This may account for the post- heavy bombardment geological activity on both Europa and Ganymede. In addition, the effects of resonance passage on Ganymede may provide an explanation of the Ganymede-Callisto dichotomy – that is, Ganymede has had a much more active geological history than Callisto, despite the fact that the two have similar bulk properties – by providing Ganymede with an intense source of internal heat and lithospheric stress not present in Callisto.

This model is consistent with a number of suggested mechanisms for the resurfacing of Ganymede. For example, if both Ganymede and Callisto were deeply differentiated during accretion, they both may have undergone a convective instability during freezing of the ice mantle proposed by Kirk and Stevenson (1987). If this instability occurred during heavy bombardment, the evidence would have been obliterated by impact craters. If tidal heating later on led to the remelting of Ganymede's ice mantle after the cessation of heavy bombardment, a second episode of diapirism may have occurred on Ganymede only as the mantle refroze.

Alternatively, if Ganymede and Callisto were only partly differented during accretion, both may have possessed an "accretional trigger" (Mueller and McKinnon 1988). Tidal heating may have been sufficient in Ganymede to "pull the trigger" and initiate runaway differentiation (*e.g.* Friedson and Stevenson 1983), while Callisto remained only partly differentiated. During runaway differentiation. further melting of the ice and global expansion of Ganymede (*e.g.* Squyres 1980) would have occurred, and as pointed out by Mueller and McKinnon (1988), after runaway differentiation Ganymede may have been susceptible to the convective instability of Kirk and Stevenson (1987) as the mantle froze again.

Either way, the combination of melting and fracturing due to tidal effects and the resurfacing mechanisms described above may explain the timing and duration of the late resurfacing of Ganymede, which in turn provides an explanation of the Ganymede-Callisto dichotomy.

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