TERRACE WIDTHS ON GANYMEDE AND MARS: THE STRENGTH AND COMPOSITION (?) OF PLANETARY CRUSTS.

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Several studies in the past few years point to the important constraints detailed morphologic measurements of craters can place on the material properties (and hence compositions) of planetary crusts. A particularly prominent example is the pronounced and systematic differences in crater depths and simple-complex transition diameters observed between craters on icy and rocky planets and satellites [1,2]. This difference may prove valuable as a physically-based means of estimating rock-ice ratios on planets such as Mars. Another important morphological parameter may be terrace widths [3]. According to the non-inertial slip-line model of terrace collapse of [3], terrace width (W) is related to a crust 'cohesion' or effective yield strength (c). A simple numerical approximation [3] is given by

$$W = c/\rho g\,[(1 + 16\lambda^2)/16\lambda^2] \qquad (1)$$

where ρ is target density, g is surface gravity, and λ is the crater depth diameter ratio just prior to collapse of the terrace. Studies of terraces on Mercury and the Moon [3,4] indicate crustal yield strengths of between 10 and 30 bars. These values are roughly consistent with yield strength estimates based on crater simple-complex transition diameters [1,2,5], and indicate a self-consistency in the results. For Mars, the estimated crustal yield strengths are between 5 and 15 bars [6], approximately half that for Mercury and the Moon.

Ganymede. Morphologically, the occurrence of terrace structures on Ganymede differs considerably from terrestrial examples [2]. The type occurrence of terraces on the Moon is exemplified by craters such as King and Tycho, in which the terraces form more or less continuous multiply concentric arcuate (and coherent!) fault blocks, resulting in a step-like rimwall topography. More than half a dozen terraces can be identified in some craters. On Ganymede, no crater has been identified with more than one terrace. Part of this is a result of the anomolously shallow depths of Ganymede craters (with respect to the Moon) [2]. This terrace is usually located near the base of a prominent rim scarp. Terrace structure is also highly variable around individual craters. Terraces are often found only in restricted sectors of the rimwall structure, replaced elsewhere by incoherent slump blocks or a simple, steep and very narrow rimwall scarp (i.e., no slump features at all). Thus rimwall collapse on Ganymede is considerably less organized than on other planets.

Despite this behavior, obvious terraces exist on Ganymede and their widths can be measured (Fig. 1). These terraces are between 1 and 6 km, similar to those on the Moon [3]. The increasing trend of terrace width with crater diameter suggests that some unidentified terraces may be present in smaller craters. Less well developed terraces in two craters on Ariel and Rhea have also been tentatively identified and measure 4-6 km across (Fig. 1). Virtually no other true terraces are observed on the smaller icy satellites because of gravity scaling [2].

Eq. (1) can be used to model these terraces in terms of crustal properties, namely yield strength. (In this case the problem of using the outer-most terrace [3] was eleviated by the occurrence of only one terrace in these craters). Before that can be done, λ, or the precollapse depth/diameter ratio, must be estimated by restoring the terrace geometrically. Precollapse crater diameter (D') can be detemined by subtracting the terrace widths from the observed crater diameter. Precollapse crater depth (d') was approximated by calculating the apparent volume of the 'missing' terrace block and restoring it to the crater floor. The estimated yield strengths based on this analysis are between 0.1 and 0.5 bars for Ganymede craters, and ~1.5 bars for the two craters on Ariel and Rhea (Fig. 2). These are 1-2 orders of magnitude weaker than estimated yield strengths on the terrestrial planets [3,4,6], but fully consistent with yield strengths for icy satellite crusts based on other crater morphologic parameters [1,2]. The lower density of ice and the shallow depths of craters on Ganymede indicate that much less stress is necessary to initate terrace formation on icy satellites than on the Moon. This reinforces the general observation that craterforms in icy crusts differ in a fundamental way from their rocky counterparts due almost entirely to the unusual material properties, namely the extremely low mechanical strength, of water (and other) ices [7,8].

Mars. Studies of Martian craters have pointed to several unusual morphological aspects, including proposed terrain softening, lobate ejecta, and central pits, to advocate the existence of frozen water within the shallow martian regolith [e.g., 9]. Unfortunately, valid alternative mechanisms not involving water ice have been presented to explain each of these phenomenon [e.g., 10]. The lack of a physical model or reference frame for the effect of water ice on the cratering process itself has hampered these studies. I propose that the detailed morphologic measurements recently obtained [1,2] (especially the pronounced differences between rocky and icy planet craters) provide for the first time a direct physical basis and reference standard from which the study of crater morphology on Mars can be used to attempt to constrain the water-ice content of the martian regolith. Terrace studies are not ideal for this purpose because of their variable nature, but some preliminary inferences may be possible. On average, estimated yield strengths for Mars are lower than those for Mercury or the Moon by a factor of 2 [6]. They are considerably higher than for Ganymede, however, by a factor of 30-50. This suggests that the contribution of water-ice in the martian regolith is significant but not overwhelming. A more accurate assessment, including the estimation of an ice-rock ratio, will require examination of other morphologic parameters (which are likely to be more meaningful and will required detailed new studies), and laboratory mechanical and cratering experiments in mixed ice-rock targets.

References: [1] Schenk, P. *J. Geophys. Res*., 94, 3813-3832, 1989. [2] Schenk, P., *Lunar Planet Sci. XXI*, 1081-1082, 1990; *J. Geophys. Res*., in press, 1991. [3] Pearce, S. and H. Melosh, *Geophys. Res. Lett*., 13, 1419-1422, 1986. [4] Leith A. and W. McKinnon, manuscript to be submitted, 1991. [5] Melosh, H. *J. Geophys. Res*., 87, 371-380, 1982. [6] Posen, S. *Mars Coll*. (abstr.), 1987. [7] Kirby, W. et al., *J. Physique*, 48, C1-227-C1-232, 1987. [8] Lange M. and T. Ahrens, *J. Geopys. Res*., 88, 1197-1208, 1980. [9] Squyres, S., and M. Carr, *Science*, 231, 249-252, 1986. [10] Zimbelman, J., *Icarus*, 71, 257-267, 1987.

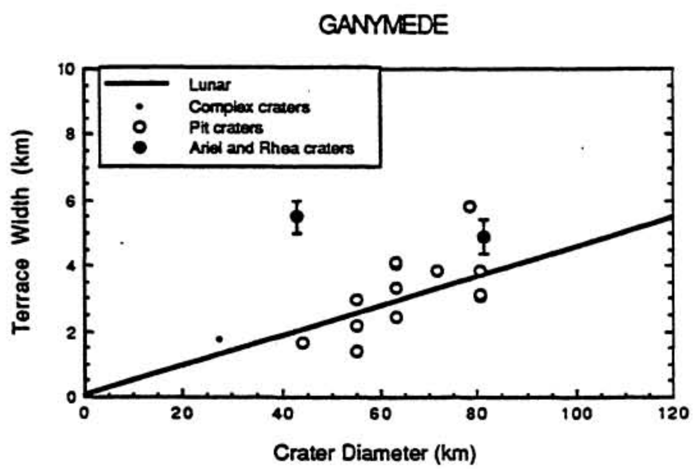

Figure 1: Terrace widths on Ganymede, Ariel and Rhea. Lunar best-fit from [3].

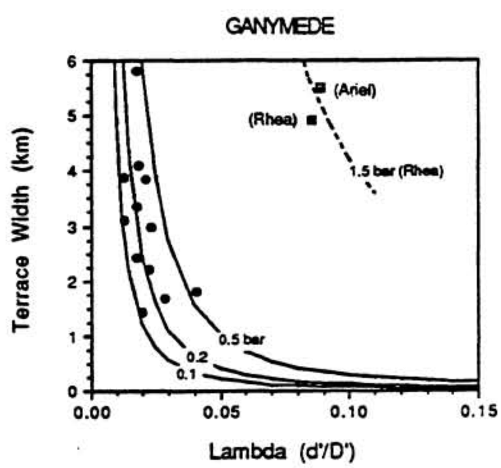

Figure 2: Terrace width vs. λ. Contours are of yield strength.