EARLY THERMAL HISTORIES OF GANYMEDE AND CALLISTO, Quinn R. Passey, CalTech, Pasadena, CA 91125, and E.M. Shoemaker, USGS, Flagstaff, AZ 86001

High resolution Voyager images of Ganymede and Callisto reveal relatively heavily cratered surfaces; the form of some craters is similar to that of lunar craters, but most craters on Ganymede and Callisto are much shallower than lunar craters of similar size (1). Many shallow craters display bowed-up floors (2), which are diagnostic of topographic relaxation under conditions where the effective viscosity of the relaxing medium is either uniform or decreases with depth (3).

*Data*--. Representative photoclinometric profiles of craters that are preserved in various stages of relaxation are shown in Figure 1. During relaxation, the crater floor first rises (Stage 1), then bows up slightly (Stage 2), then is strongly arched so that it rises above the pre-crater level near the center (Stage 3, designated as > PCL on Figures 1,2, and 3), and finally flattens out at the level of the surrounding terrain (Stage 4). Profiles for a total of 363 craters on Ganymede's heavily cratered terrain and 153 craters on Callisto were obtained, and the craters were catagorized according to number, size, and stage of relaxation (Figures 2 and 3). By utilizing a proposed cratering time scale (4) it is possible to estimate the time interval during which the relaxation of craters of various size occurred. For example, from Figure 2, 60% of the 10 km craters located on Ganymede's heavily cratered terrain have not relaxed to the stage where the floor is bowed up; these craters are estimated to have formed in the last ~ 3.77 GY. Ten km craters with slightly bowed up floors formed between ~3.77 and ~3.83 GYA; ten km craters that display floors arched above the pre-crater level (> PCL) formed between ~3.83 and ~3.85 GYA, and extremely flattened 10 km craters were formed prior to ~3.85 GYA. Because of exponential decay of the cratering rate adopted for the proposed time scale in this time period (4), the observed crater frequencies yield high resolution in time. Similar relations are found for craters of other sizes, except that the timing is different. For Callisto, 15 km craters displaying bowed up floors are estimated to have formed prior to ~4.07 GYA.

*Numerical Model for Crater Relaxation*--. Relaxation of topography where effective viscosity is a function of depth has been studied by several authors (3,5,6). The model used in this study allows for the viscosity to be an exponential function of depth, as described by Brennen (6), but also allows the viscosity gradient to vary with time.

A comparison of the model results with the data from the photoclinometric profiles of craters (Figures 2 and 3) yields the following results. The viscosity at the top of Ganymede's lithosphere is $1 \pm 0.5 \times 10^{26}$ poise. In order to reproduce the degree of flattening versus crater diameter (Figure 2), the e-folding depth of viscosity at the time of the oldest preserved craters (~ 3.87 GYA) must have been about 0.5 km; presently it is about 10 km. The characteristic e-folding time for increase of the e-folding depth is approximately $10^9$ years. For Callisto, the viscosity at the top of the lithosphere is between $10^{26}$ and $10^{27}$ poise. The e-folding depth of viscosity at the time of the oldest preserved craters (~4.10 GYA) was between 0.5 and 1.5 km,the present e-folding depth is between 10 and 30 km, and the characteristic e-folding time for increase of the e-folding viscosity depth is between $10^8$ and $10^9$ years.

*Inversion of Viscosity Gradient to Thermal Gradient*--. The lithospheres of Ganymede and Callisto are inferred to be composed of $H_2O$ ice. Although ice does not behave like an ideal Newtonian fluid at high temperatures and stresses, at the temperatures and stresses of concern near the surfaces of Ganymede and Callisto (i.e. 120 K and $\leq 10^6$ N m$^{-2}$), the predominant deformation mechanism is creep by boundary diffusion; this behavior is approximately Newtonian (7). With the assumption that the material behaves like a Newtonian viscous fluid, it is possible to invert the calculated e-folding depths of viscosity to thermal gradients. An exponential viscosity gradient can be approximated by a linear thermal gradient; the relation between e-folding depth of viscosity and thermal gradient is shown in Figure 4. Hence, the derived history of the viscosity gradient can be converted to a thermal gradient history (Figure 5). On Ganymede, the thermal gradient decayed from ~10 K/km near 3.9 GYA to less than ~ 0.5 K/km by 3 GYA. On Callisto, the thermal gradient decreased from $\geq$ 4 K/km near 4.1 GYA to less than ~0.3 K/km by 3 GYA.

Passey, Q.R., and Shoemaker, E.M.

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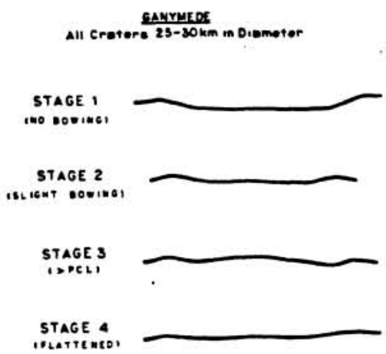


Fig. 1 – Representative profiles of craters that are preserved in various stages of relaxation.

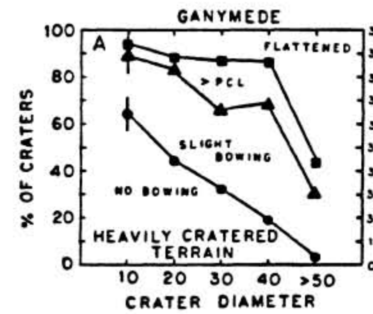


Fig. 2 – Craters on Ganymede's heavily cratered terrain are catagorized here according to number, age, size (in km), and degree of relaxation.

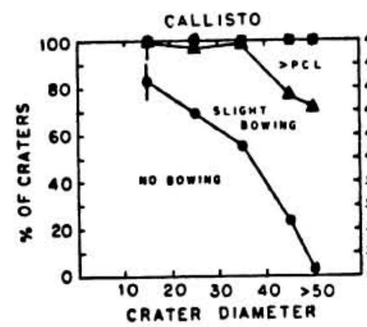


Fig. 3 – Same as Figure 2 except for craters on Callisto.

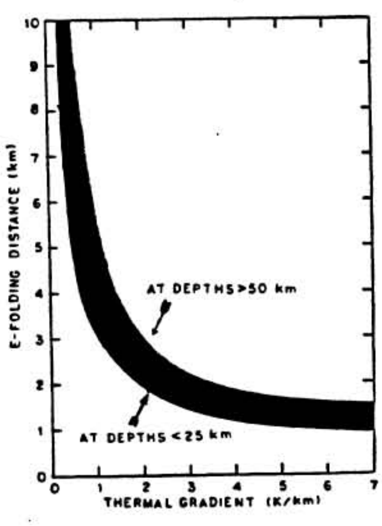


Fig. 4 – Relation between e-folding depth and thermal gradient for ice.

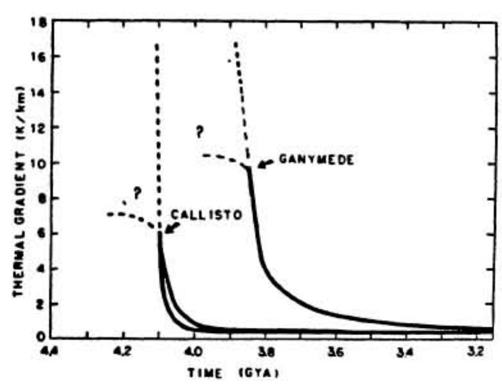


Fig. 5 – Derived thermal history for Ganymede and Callisto.