POPULATIONS OF SMALL CRATERS ON EUROPA, GANYMEDE, AND CALLISTO: INITIAL GALILEO IMAGING RESULTS

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The first third of Galileo's orbital tour of the Galilean satellites has provided images with much better resolution than Voyager. Because of the fragmentary return so far (e.g. contextual frames for high-resolution images are scheduled for future orbits), it is premature to fully assess the distributional and stratigraphic correlations (e.g. any apex/antapex variations) of crater populations and spatial densities. This work studies the "snapshots," on various terrains, of crater size-frequency and morphology statistics at scales ranging from 50 m (in one case) to >10 km which provide insight about the geology and impact history of the satellites, even as the data continue to guide selection of imaging parameters for the remainder of the mission.

We present preliminary crater counts for various terrains on Ganymede (including Uruk Sulcus, Galileo Regio, and the "unnamed sulcus"), Europa, and the Valhalla region of Callisto. A single generalization is that craters < several hundred m diameter are unexpectedly underabundant, never approaching saturation densities even on the terrains of Ganymede and Callisto that appear saturated by large craters. In detail, the processes that have degraded and/or erased small craters vary rather remarkably from satellite to satellite and on the different terrains of each. While we presume that roughly the same impactor population is responsible for most cratering on the three satellites, the relative importance of secondary cratering and of Shoemaker-Levy-9-like comet fragments remains to be learned. We present evidence that many 6-15 km diameter pits on Europa may not be impact craters (instead they may be collapse features, for example)[2].

Differential diameter-frequency relations are presented in Fig. 1 in the "Relative Plot" format [1], where height on the plot indicates spatial density of craters and unity is geometric saturation (never practically achieved on real surfaces; the curve for Ida that is shown approaches practical limits R≈0.3).

Cratering on Europa. Craters and pits in global and medium-resolution G1 and G2 (first two orbits) images of Europa show that its surface is relatively very youthful. Voyager conclusions [3] that large craters are very rare are sustained. There is a spatially non-uniform population of pits (first seen by Voyager, with hundreds more now seen in Galileo's G1 near-terminator images), which have diameters around 9 km. The mono-modal size distribution of the pits (Fig. 1) and a spatial avoidance of pits and lineaments imply that most pits are not of impact origin. Many may be collapse features. A C3-orbit image centered on wedge-like features (with 0.4 km resolution) shows only two impact craters >2 km diameter in a 50,000 km^2 region. Although this region may be young, the two craters cannot be due to a plausible power-law-like projectile population that would also have produced the vastly more numerous pits seen in G1 images, unless one or both regions are exceptionally anomalous; this again implies that the pits are not impact craters. Even the somewhat more heavily cratered regions imaged at high resolution during orbit E4 would be 100 times younger than pitted terrains (assuming they are primary craters following a typical power-law production function and assuming constant cratering rate) if the pits are impact craters. Inferences [4] from the pits that numerous, somewhat larger craters have viscously relaxed away and provide evidence for the thickness of an ice layer atop a Europan ocean, would be invalidated if most pits are not of impact origin. Large craters may well have viscously relaxed, but there are not many of them.

Higher resolution E4-orbit images show variable -- but generally low -- densities of small (few hundred m) craters; they appear to be impact craters (either primary or secondary). They do not exhibit a full range of degradational states, suggesting that the processes that remove small craters do so relatively suddenly (e.g. by local tectonic or flooding processes); several craters appear to be partly overlapped by endogenic features (ridges or flow fronts). A high-resolution image of a feature that looks like a 6 km diameter pit in moderate resolution contextual images reveals it to be an irregularly shaped, tectonically controlled depression unrelated to an impact.

Cratering on Ganymede. The Uruk Sulcus grooved terrains are cratered at sizes <1 km with a relatively steep size distribution (differential power law index ~-4); spatial densities are similar to those observed on Gaspra, distinctly less than saturation. Such crater densities vary by factors of a few on adjacent units, but are confused by superimposed clusters of craters. One cluster, possibly secondaries associated with a large crater to the southwest, has craters with diameters in a narrow size interval, 0.5 to 2 km, unlike the very steep power-law populations usually associated with secondaries; possibly this observation is related to a general absence of evidence of ejecta from many craters on Ganymede.

Galileo Regio is characterized by a high density of large craters (several km in diameter and larger), but the processes (tectonic and otherwise) that have so severely degraded them has likewise swept the slate clean for recratering by a modest population of smaller craters, similar to that expressed on Uruk Sulcus. Indeed, at smaller spatial scales, Galileo Regio is no older than the older terrains of Uruk Sulcus.

The unnamed sulcus, imaged at 11 m/pixel, is remarkably devoid of small craters, despite numbers of several-hundred-m diameter craters that are similar to the other studied terrains on

Ganymede. The small craters are mostly fresh, hence they are not being diminished by continuous degradational processes. A combination of relative youth and a shallow-sloped production function at small sizes may explain the unexpectedly low crater density; we await later contextual images of this region.

Cratering on Callisto. Despite having a surface nearly saturated with large craters, the localities of Callisto imaged at high resolution so far, generally in the Valhalla region, are covered with a pervasive blanket of apparently erosional debris that has filled in much of the larger-scale topography and created relatively young surfaces (similar to the youth of Europa) for small-scale cratering. A spectrum of morphologies among the small craters implies that the process that is creating the gently rolling plains on Callisto is acting fairly continuously. The larger (multi-km) craters are disappearing both due to infilling by the blanketing material as well as by *in situ* disaggregation and mass-wasting of the crater walls [5, 6]. Comparisons of crater counts inside and exterior to Golum Catena may indicate a production population undergoing continuing degradation within the comparatively recent feature, while remnants of larger, older disaggregating craters add to the counts exterior to the catena. The larger (~1 km) crater remnants are most numerous on the Valhalla graben image, of the high resolution Callisto data acquired so far.

Inter-satellite Comparisons and Ages. 100-m scale craters are rare (R~1-3%) on all terrains imaged at high-resolution so far, on all three satellites. Until there is better information about the size distribution of impactors in the Jovian environment (especially of sizes that make sub-km craters), it is difficult to disentangle the possibility that most satellite surfaces (at these scales) are unexpectedly young from the possibility that small comets and other impactors are unexpectedly depleted as compared with simple extrapolations from larger sizes. We hope to learn more about the absolute impact rates, but for the moment they remain very poorly known. Possibly we are witnessing a record of an intense early bombardment, with very low subsequent impact rates, in which case most units (except those on Europa that are almost wholly devoid of craters) could be quite old. Alternatively, if much of the cratering record has been established at a relative constant impact rate, then many of the surfaces could be subject to various on-going processes that renew them (at scales of tens to hundreds of meters) on time scales of tens to hundreds of millions of years, making the Galilean satellites even more geologically "active" than had been supposed based on Voyager data. The degradational and resurfacing processes show various styles, ranging from discontinuous ridge-forming processes on Europa to continuous landform degradation on Callisto.

References: [1] Crater Analysis Techniques Working Group (1979) *Icarus* **37**, 467-474. [2] C.R. Chapman, W.J. Merline, B. Bierhaus, S. Brooks, & J. Keller (1996) Presentation at Europa Ocean Conf., San Juan Capistrano CA, Nov. 12-14 (abstract booklet, p. 19). [3] M.C. Malin & D.C. Pieri (1986) In *Satellites* (ed. J.A. Burns & M.S. Matthews, U. Ariz. Press), 689-717. [4] E.M. Shoemaker (1996) Europa Ocean Conf., San Juan Capistrano CA, Nov. 12-14 (abstract booklet, p. 65). [5] K.C. Bender *et al.* (1997) *LPSC XXVIII*, submitted abstract. [6] J. Moore *et al.* (1997) *LPSC XXVIII*, submitted abstract.

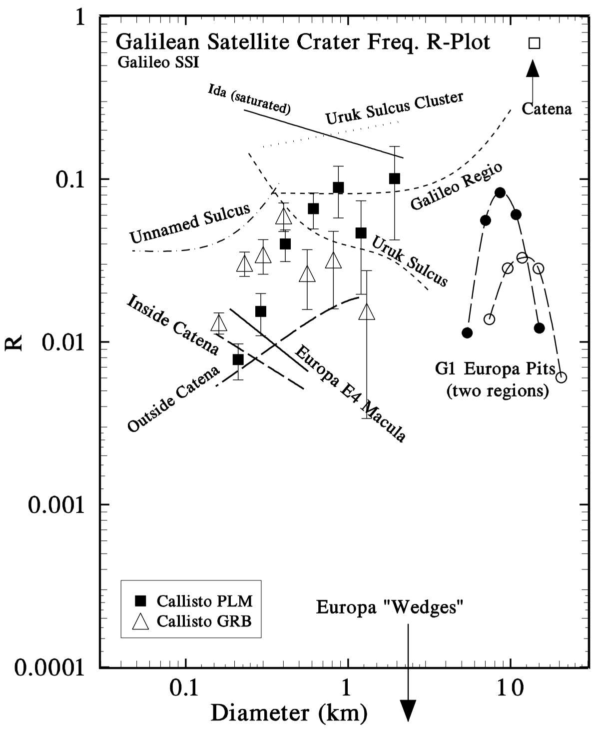

Fig. 1. R-plot (differential frequencies divided by D^{-3}) of preliminary crater counts on Europa, Ganymede, and Callisto. Representative data with error bars are shown for two localities on Callisto imaged at high-resolution during the C3 encounter. Other counts are represented by curve fits. Arrows point to single data points for the two isolated craters on the Europa "wedges" C3 image and for the three Gomul Catena craters shown in a Callisto image sequence.