THE AGE OF EUROPA'S SURFACE; E.M. Shoemaker, Lowell Observatory, Flagstaff, AZ 86001

Recent discoveries of extinct comets now permit a robust estimate of the cratering rate on Europa. When this rate is combined with observations of the crater density on Europa's surface, the crater retention age can be obtained for craters of different sizes and for diverse parts of the surface. It can be shown that 10-km craters have been lost by viscous relaxation, a loss which requires a steep thermal gradient and which indicates the presence of an ocean below about 10-km depth.

Cratering on the Galilean satellites is dominated by the impact of extinct Jupiter-family (J-f) comets. The term extinct comet is here applied to objects of asteroidal appearance which have not been observed to exhibit cometary activity and which revolve on Jupiter-crossing orbits. In the past 14 years, the number of discovered extinct J-f comets has risen from 1 to more than 25. The total population of extinct J-f comets brighter than B(1,0) = 18 is estimated at 3000 ± 1500, about 18 times larger than the estimated population of active J-f comets (1). In addition, there are now both observational and theoretical grounds to expect that extinct Halley family (H-f) comets contribute significantly to the cratering rates on the Galilean satellites (1). Taking the mean geometric albedo of comet nuclei in the blue band as 0.03 and the mean density of comet nuclei as 1.2 gm cm^{-3}, the crater production rate on Europa, estimated by the methods of Shoemaker and Wolfe (2), is as follows:

Impactors	N	Γ $10^{-17} km^{-2} yr^{-1}$	Cp $10^{-14} km^{-2} yr^{-1}$
Active J-f comets	170 ± 100	7.9	1.3 ± 0.8
Extinct J-f comets	3000 ± 1500	5.4	16.2 ± 8.1
Active H-f comets	30 ± 20	2.9	0.1 ± 0.1
Extinct H-f comets	390 ± 250	2.9	1.1 ± 0.7
Long-period comets	230 ± 150	2.9	0.7 ± 0.5
			19.4 ± 10.2

N is the population of J-f comets to B(1,0) = 18 or the annual rate of perihelion passage of H-f and long-period comets to B(1,0) = 18.
Γ is the estimated mean rate of production of craters 10-km in diameter and larger per unit body of the population to B(1,0) = 18.
Cp is the estimated mean rate of production of craters 10 km in diameter and larger.

It may be seen that extinct J-f comets account for about 80% of the estimated crater production.

The surface of Europa is remarkable for the absence of recognizable craters more than a few tens of km in diameter. As noted early on, this circumstance could be due either to rapid viscous relaxation of large craters, to the wholesale resurfacing of Europa, or to a combination of both processes (2). The Voyager 2 images, now supplemented with marginally better Galileo images, indicate that both viscous relaxation and resurfacing have contributed importantly to crater loss. Locally, craters about 10-km in diameter are moderately abundant but are not accompanied by much larger craters. Crater densities at D ≥ 10 km are as high as $\sim 0.5 \times 10^{-4}$ km^{-2}. This density implies a retention age for craters ≥ 10 km of $(3 \pm 2) \times 10^8$ yr. In the same area of moderately abundant 10-km craters, the density of craters ≥ 6.4-km is $(5.3 \pm 0.6) \times 10^{-4}$ km^{-2}; the retention age for ≥ 6.4 km craters is $(1.1 \pm 0.6) \times 10^9$ yr. Hence 10-km craters have almost certainly been lost by viscous relaxation.

Elsewhere on Europa, the ≥ 10-km crater densities and densities of smaller craters are more than an order of magnitude below that of the highest observed densities. It is highly unlikely that craters much smaller than 10 km can disappear by viscous relaxation. Moreover the lineae are very rarely interrupted by craters. Large parts of Europa evidently have been resurfaced within the past 100 million years.

From the viscosity relations presented for ice by Passey and Shoemaker (3), a thermal gradient steep enough to reach the melting point of water at about 10-km depth would be required for 10-km craters to flatten beyond recognition in times of the order of 10^8 yr. That gradient is consistent, therefore, with the 10-km thick ice crust solution of Cassen, Reynolds, and Peale (4) but not with the continuously solid model for Europa. The presently available crater data are now sufficient to strongly imply the presence of a global ocean.

References:
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(3) Passey, Q.R., and Shoemaker, E.M. (1982), Craters and basins on Ganymede and Callisto: Morphological indicators of crustal evolution, in Morrison, D. (ed.), Satellites of Jupiter, Univ. Arizona Press, Tucson, Ariz., P. 379-434.
(4) Cassen, P., Reynolds, R.T., and Peale, S.J. (1979), Is there liquid water on Europa?, Geophys. Res. Lett., vol. 6, P. 731-734.