LIFETIME OF ORGANIC MOLECULES AT THE SURFACE OF EUROPA E. S. Varnes and B. M. Jakosky, Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309-0392.

Introduction: The possible existence of an ocean beneath the surface of Jupiter's icy moon Europa has fueled scientific interest in this tiny world. Liquid water is a crucial element in the development of life on Earth, and if present on Europa, increases the likelihood of finding life there as well. Hydrothermal vents on the Europan ocean floor could provide habitat for microbes as well as generate significant quantities of organic molecules, as they do on Earth. In a recent publication, Johnson et al. [1] estimated the density of organic molecules sputtered from the surface of Europa, and implied that their detection could verify the existence of organics in a sub-surface ocean. In the context of developing spacecraft missions, it is therefore important to understand the nature of organic molecules on Europa's surface.

Europa is exposed to a significant amount of particle bombardment from Jupiter's magnetospheric plasma. Voyagers 1 and 2 encountered ions and electrons in its vicinity with energies ranging from a few eV to hundreds of MeV. A number of experiments have been conducted on the irradiation of icy surfaces, see [2] for a recent review, resulting in the production of organic molecules. However, these studies utilize ice mixtures which contain a considerable fraction of carbon initially. While spectroscopic evidence clearly shows the presence of carbon compounds on Ganymede and especially Callisto [3], evidence of carbon on Europa remains ambiguous. It is therefore fair to say that the Europan surface is depleted in carbon relative to its neighboring satellites. The purpose of this study is to analyze the effects of particle bombardment on organic molecules in the carbon-poor environment of Europa, and to determine whether such molecules can survive dissociation.

Methods: The abundance of organics near the surface of Europa can be approximated by taking into account the time scale of dissociation, the depth to which organics may be exposed, and the contribution of exogenic material to the organic inventory.

Lifetime of organics: We treat Europa as an unshielded body upon which plasma is incident isotropically. The energy intensity of the hot plasma electrons and ions in the vicinity of Europa reported by Mauk et. al [4] amounts to 54 $ergs \cdot cm^{-2} \cdot s^{-1} \cdot sr^{-1}$, or ~ $1.1 \cdot 10^{11}$ $keV \cdot cm^{-2} \cdot s^{-1}$. In addition, utilizing the number densities of lower-energy ions and electrons found by Bagenal [5], and the approximate velocities of incident ions and electrons, the total particle flux is about $1.1 \cdot 10^{10}$ $cm^{-2} \cdot s^{-1}$. From this energy flux, the bond energies of organic molecule constituents, such as C-H and C-C, and a rough estimate of the molecular cross-sections, the lifetime of organics can be estimated. This dissociation time-scale is between tens of hours and several years, depending upon whether the flux of relatively low-energy plasma is included in the calculation. The energy is deposited up to ~ 0.5 cm in the surface, thus organic molecules within this top layer can be destroyed.

Depth of exposure: Taking into account both the depth of particle penetration and the depth of surface mixing from a Europan analog to lunar gardening, we can constrain the depth to which organics are exposed to bombardment. On a time scale of 10^7 years (the cratering age of the surface of Europa), the lunar regolith is mixed several times to a depth of about one centimeter. The impactors which result in the gardening of the lunar regolith are in the millimeter diameter range, while the large-scale evolution is dominated by impactors between 10 and 1000 cm in diameter [6]. It is difficult to assess the abundance of such small impactors onto Europa, as there exists no observational evidence of cratering at such fine resolution. However, observations show that the surface of Europa is depleted in 100-m craters by 1-2 orders of magnitude [7]. This may be the result of both removal processes and an underabundance of smaller impactors. If gardening sized impactors are also depleted by an order of magnitude, then the depth of turnover must also be scaled down by the same factor. However, Lange and Ahrens [8] have demonstrated experimentally that crater volumes formed in icy surfaces are enhanced by about a factor of ten over those in basaltic surfaces, accelerating the growth of regolith on icy bodies. In that case, the turnover depth is expected to be about a centimeter if tiny impactors are depleted, or about 10 centimeters if they are not depleted. Thus, organic molecules present within the top 1-10 cm of the ice can be gardened to the surface where they will be destroyed.

Accretion of exogenic organics: With the assumption that comets are ~ 10% organic carbon by mass, and neglecting destruction of organics on impact, comets are the primary source of exogenic organics delivered to Europa. An estimate of the upperlimit of organics from gardening-size bodies, making similar assumptions about organic content, yields an incident mass one to two orders of magnitude smaller than for comets. In order to approximate the cometary mass influx rate, we derive a cratering rate that is a function of time and crater diameter; using the methods of Chyba et al. [9], the incident organic mass rate should be approximately 10^5 kg/yr.

Steady-state abundance: The steady-state abundance of organics present in the mixing layer of Europa's surface can be approximated by considering the dynamical equilibrium between the supply of cometary organics and the destruction of organics to the depth of exposure. We find that the abundance of organics in the surface layer should be roughly a part in a thousand, assuming that the depth of exposure is ten centimeters. Of course, this includes only organic molecules that are cometary in origin.

Conclusions:

• The lifetime of organic molecules at the surface of Europa is very brief geologically due to the intense radiation environment, resulting in the depletion of organics near the surface.

• Organics present in the top few centimeters may be of an exogenous source, and cannot be construed as evidence of endogenous organic creation at depth. Likewise, organics present in the atmosphere from sputtering would not necessarily constitute evidence of sub-surface production.

•We find that the top few centimeters of the surface should contain a small, but measurable, quantity of organic material. This exogenous, or possibly chemically altered endogenous, source of organics could be supplied to a sub-surface ocean by periodic burial via re-surfacing events over geological time scales. However, we did not investigate this possibility in detail.

•We expect, qualitatively, that the fraction of organics present at the surface layer should increase moving outward to Ganymede and Callisto, as observation shows that particle intensity decreases with increasing distance from Jupiter. However, the situation is more complicated on the outer two Galilean satellites: Ganymede has an intrinsic magnetic field that deflects a large fraction of the incident plasma, and Callisto, being only partially differentiated [10], cannot necessarily be considered a carbon-poor environment (thus organic production due to irradiation cannot be neglected).

References:

[1] R.E. Johnson et al. (1998) *Geophysical Res. Let.*, 25, 3257-3260. [2] G. Strazzulla (1997) *Adv. in Space Res.*, 19, 1077-1084. [3] T.B. McCord et al. (1998) *JGR*, 103, 8603-8626. [4] B.H. Mauk et al. (1996) *JGR*, 101, 7685-7695. [5] F. Bagenal (1994) *JGR*, 99, 11043-11062. [6] F. Hörz et al. (1991) In the *Lunar Sourcebook* (ed. G.H. Heiken, D.T. Vaniman, & B.M. French, Cambridge U. Press), 61-120. [7] C.R. Chapman (1998) *Meteoritics & Planet. Sci.*, 32, A27. [8] M.A. Lange and T.J. Ahrens (1987) *Icarus*, 69, 506-518. [9] C.F. Chyba et al. (1994) In *Hazards Due to Comets and Asteroids* (ed. T. Gehrels, U. of Ariz. Press), 17-27. [10] J.D. Anderson t al. (1998) *Science*, 280, 1573-1576.