LIGHT AND HEAT IN CRACKS ON EUROPA : IMPLICATIONS FOR PREBIOTIC SYNTHESIS. J. I. Lunine and R. D. Lorenz, Lunar and Planetary Lab., University of Arizona, Tucson, AZ 85721-0092.

We examine the difficult problem of organic synthesis in Europan oceans by considering the propagation of light in the growing ice cover over Europa's ocean after cracks expose the ocean to space. [1] found that a biologically-useful amount of light would reach the base of the thickening ice until about 1000 days after a crack formed. We extend their work by including the presence of a porous snow cover above the ice, a low-emissivity surface, low melting-point fluids and locally-enhanced tidal heating: these effects can increase the longevity of the 'photic zone' by three orders of magnitude, and conceivably indefinitely.

The notion that Europa contains a liquid water ocean submerged beneath its crust, and hence may harbor life, has driven renewed interest in advanced technology missions to this lunar-sized moon of Jupiter. The idea that a liquid water mantle might sustain biology depends upon poorly-understood characteristics of Europa, including the amount of organic material available in the liquid mantle, and sources of energy both for synthesizing pre-biological molecules in forming, and sustaining life.

The availability of suitable organic matter as the raw material for life on Europa depends sensitively on the nature of the Jovian nebula, and contribution from solar-orbiting debris after formation. Models of the circum-Jovian nebula [2] suggest rather high temperatures in the region of Europa during formation, such that trapping of carbon-bearing species in water ice or silicates was inefficient. Therefore, Europa may have formed relatively bereft of organic material. Addition of carbon-bearing molecules trapped in ices or silicates of Jupiter-family comets could be a potential source, though the high impact velocities deep in the Jovian gravity well and low escape velocity of this moon suggest that retention of organic material added after formation from solar orbit may have been very difficult.

Countering this pessimistic assessment are the Galileo images which suggest the presence of rather slow moving, viscous flows in and near crack regions. These are not characteristic of liquid water, but could be the result of ammonia-bearing flows, wherein viscosities much higher than liquid water can be obtained [3]. The present of ammonia argues for a cooler origin of Europa than that given in [2], allowing for the addition of more carbon-bearing material during Europa's formation. Furthermore, the apparent progressive darkening of the centers of surface cracks seen in Galileo images suggests that carbon-bearing material is present below the surface (and welling up in the cracks). Available energy sources for life on Europa include solar, geothermal heat and electrical energy [1]. Although life forms exist today near terrestrial submarine vents, the pre-biotic synthesis of complex organic compounds in such environments has not been demonstrated. Indeed, the production of biogenically-relevant molecules such as amino acids, under such conditions, appears to be very limited [4]. This seems also to be the conclusion of recent work by Shock et al. [5] who find that the synthesis of organic molecules deep in Europa require somewhat narrow limits on liquid water mantle temperatures. It may be that the formation of life on Europa required a shallow environment in which sunlight was present, at least for limited periods of time. In the remainder of the abstract we explore just how much sunlight might be available during crack formation.

A liquid water or brine ocean may lie below Europa's icy surface, and crustal depths of ~10km are often quoted [6]. At such depths no light is expected. However, as investigated by [1], episodic puncturing of the ice crust may allow light to leak in. The global frost production of 0.1 mm per year inferred [6] from spectroscopic evidence corresponds to an area of liquid of 5 km^2 exposed per year, presumably from cracks [1]. Additionally, [7] suggests that 10km diameter craters form at a rate of ~$2x10^{-13}$ $km^{-2}yr^{-1}$, or a few every million years : craters much larger than this are likely to puncture the crust.

Exposure of the liquid surface to space would lead to instantaneous boiling, as discussed by [1]. Further, crack formation and propagation may well be associated with the release of volatiles, notably CO_2. Indeed [8] suggests that gas release may be *required* to allow crack propagation to the surface. One interpretation of the diffuse margins of dark bands on Europa seen in Galileo images [9] is that they indicate snow formed by material spraying geyser-like from a crack.

This has important implications. [1] noted that a layer of bubbly ice would form at first, then a more-or-less clear ice sheet would grow downwards. While they compute the optical attenuation of the bubbly layer as well as the clear layer, they did not explore the thermal effect of a blanket of porous material (bubbly ice, snow, frost etc.) on the ice growth. [10] examined this factor, noting that while snow has a much higher absorption coefficient, typically 2.8 m^{-1} ,it has a low thermal conductivity, ~0.02 Wm^{-1} K^{-1}. The numbers are juxtaposed for the corresponding values for clean ice. A thick snow layer slows the growth of the ice, but also blocks more sunlight. These competing effects seem to maximise the time during which a biologically-useful amount of sunlight (assumed [1] at 0.5% of the terrestrial solar constant) for thin (~0.1m) snow layers. The sunlight threshold at the ice-ocean interface is reached at typically 30-80m depth, depending on the thickness of the snow layer.

Additional factors could further slow the growth of the ice sheet. Raising the surface temperature by influencing the optical properties (albedo or emissivity) of the snow has a minor effect. Lowering the freezing temperature to values consistent with ammonia in the ocean roughly doubles the exposure time. Salts might do the same (though with a smaller increase in exposure time due to the smaller melting point depression.)

Geothermal heating could significantly retard growth of the ice sheet (the flux released by the freezing ocean becomes the difference between the flux conducted through the ice and the geothermal heating). The strongest source of geothermal heat is likely to be tidal heating, and Stevenson [11] has recently pointed out that classic ('Q') globally-averaged models do not reflect what is actually happening on Europa, where tidal dissipations is likely to be concentrated in cracks where the crust is weak and flexes easily. [5] suggests a global-average dissipation of ~0.04 Wm^{-2}. If this is concentrated in cracks covering 1-10% of the surface, then the corresponding geothermal fluxes are 10-100 times this value - the latter can considerably enhance the ocean light-dose by retarding ice-sheet growth (indeed, with a 0.4m snow cover and a 4 Wm^{-2} heat flow, the ice sheet stops growing at 50m thickness.)

High geothermal fluxes, combined with some of the other factors, could create some permanently-illuminated crack regions (i.e. the flux is high enough to keep the ice thin enough to allow the sunlight in). However, in such cases our model assumptions (e.g. that the snow-ice boundary is cold enough that the snow does not anneal into ice) may not hold.

In conclusion, some cosmochemical and geochemical factors argue against organic synthesis on Europa. However, it is of interest that, under favourable circumstances, liquids may be illuminated for hundreds or thousands of years, similar to the periods for which organics and ice may interact in impact-generated melt pools on Titan [12]. While liquid water existed in meteorite parent bodies for much longer time periods [13], useful amounts of sunlight may not have reached those layers, and sunlight-assisted organic synthesis would not have occurred. Europa and Titan might thus be much more promising sites for discovering light-driven, proto-biological organic synthesis.

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CASE	Time (years) for illumination >0.5% L_0	Total Light Dose (GJ) while illumination >0.5% L_0
Reynolds [1] (~no snow)	5	0.13
[9] 0.4m snow	55	1.7
[9[0.1m snow	82	4.0
0.4m snow, surface emissivity=0.7 (not 1)	57	1.9
0.4m snow, freezing temp =200K (not 273K)	98	3.0
0.4m snow, heat flow=0.4 Wm^{-2}	60	1.9
0.4m snow, heat flow=4.0 Wm^{-2}	219	7.0