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Radiation-induced changes in Europa surface analogs exposed to high-energy electrons

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Abstract

The icy moon Europa is a key target for habitability investigations in our Solar System. However, Jupiter's magnetosphere exposes Europa to a high flux of energetic particles, which can greatly modify the physical and chemical properties of Europa's surface and shallow subsurface, making them harsh and unhabitable environments. Through a collaboration with the National Institute of Standards and Technology (NIST), the Medical Industrial Radiation Facility (MIRF) was used to investigate the effects of high- energy electrons on salt-rich ice analogs at Europa-relevant temperatures. Here, we focus mainly on radiation-induced changes in material properties.

1. Introduction

It is estimated that energetic electrons bombard Europa's surface with a flux of approximately 1×10^8 MeV $cm^{-2}s^{-1}$ [1,2]. Electrons penetrate much further than protons or heavier ions of the same energy, and therefore have a greater effect on the near subsurface.

The linear accelerator used in our experiments can reach 25 MeV, which is approximately the maximum energy of electrons that impact the trailing hemisphere of Europa. 25 MeV electrons can penetrate up to 12 cm in crystalline ice with a density of 0.92 g/cm^3, and upon interacting with the material can be converted into secondary radiation (photons and electrons), of which photons (bremsstrahlung) can reach farther depths than primary or secondary electrons.

2. Material and Methods

To determine the effect of MeV electron irradiation on these different ice compositions, we have exposed pure H_2O, $NaCl:H_2O$, $Na_2SO_4:H_2O$, $MgSO_4:H_2O$ (granular), and $MgSO_4\cdot7H_2O$ (polycrystalline, epsomite) ices (by mass) to 10.5 to 25 MeV electrons, with energy fluences of 6 to 12×10^{16} MeV cm^{-2} accumulated over about 600 seconds of irradiation. An energy fluence of 8×10^{16} MeV cm^{-2} is equivalent to that received by one square centimeter on Europa's trailing hemisphere over the course of approximately 25 Earth-years.

To quantify the effect of the radiation changes on the surface, we use a Leeb Hardness rebound tester (DynaPOCKET, GE Inspection Technologies). This method is compatible with inhomogenous or rough surfaces and is only in contact with the surface for a fraction of a second. Leeb Hardness (HL) measurements take into account the velocity before (v_i) and after (v_r) rebound off of the surface: $HL = 1000 \times C_R = 1000 \times \frac{v_r}{v_i}$ where C_R is the coefficient of restitution.

3. Results and Discussion

As expected, we found that the coefficient of restitution (and therefore the hardness and calculated yield strength) increases as the temperature of the ice is lowered. The hardness of ice also increased with incorporation of salts such as $MgSO_4$, NaCl, and Na_2SO_4.

When the ice samples were exposed to MeV energy radiation, however, all ice samples exhibited a "softening" (or lowering of hardness) (see Figure 1). This softening was correlated with a visual change in surface texture and could be due to radiation-induced sputtering or dehydration and/or to amorphization, which could weaken the ice structure. Based on the relatively linear dose dependence in Figure 1, we surmise that the individual salt additives in these water-ice mixtures are not the main drivers of the radiation-induced softening. Rather, the softening likely depends on the loss of loosely-bound excess water, which could undergo ejection more readily than water molecules in the crystal lattice of salthydrates (such as epsomite). The radiation softening observed in our study could be due to phenomena such as radiation-induced sputtering or radiation-induced amorphization, which has been previously documented in the laboratory [3-9]. Some minerals containing water undergo dehydration under radiation exposure [10,11], and destruction of the crystalline structure may cause softening (which in some cases may be subsequently reversed through re-annealing if exposed to warmer temperatures).

Change in Leeb Hardness with radiation exposure

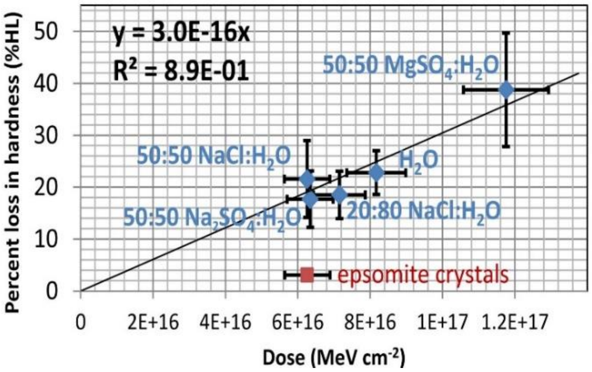

Figure 1. Radiation softening (as measured by percent loss of HL at 88 K) increases with electron dose (R^2=0.89) except in the case of the commercial epsomite crystals, which exhibited a negligible change in hardness. Vertical error bars represent ±1 standard deviation; horizontal error bars represent ±10% error in estimation of the dose. From Henderson et al. 2019 [12].

4. Conclusion

We find that the surface hardness of Europa analogs is increased by salt content and low temperatures but is reduced by exposure to radiation.

While radiation exposure could theoretically improve the mechanical workability of surface ice and make it somewhat easier for any lander instruments to retrieve samples on Europa, the areas that are *less* radiation-processed are thus far regarded as most useful for investigating subsurface ocean chemistry and habitability. Based on our results, we postulate that it may be more difficult to retrieve drilled samples from areas with less radiation processing. Regardless, future Europa lander designs may benefit from development of cutting and/or drilling technologies that can accommodate the "worst case scenario" hardness levels observed in our low-temperature and high-salt samples.

Acknowledgements

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