PRELIMINARY HARDNESS MEASUREMENTS OF EUROPA ICE ANALOGS UNDER MeV RADIATION.

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Introduction: With a potential lander mission to Europa being considered, characterization of its unique surface are now needed to aid in development of drilling and sample acquisition technologies. Europa's surface is exposed to high doses of radiation, and its extreme surface temperatures could make penetration of the ice shell difficult. To better understand some of the potential ice properties, we have used a commercial Leeb hardness tester to measure ice/salt mixtures at Europa-relevant temperatures and under 10.5 MeV to25 MeV electron bombardment. Electrons (and resulting secondary photons and electrons) at these high energies can penetrate farther than the corresponding high-energy protons or sulfur or oxygen ions and can propagate several centimeters to meters below the surface. We have determined that temperature, composition, and radiation exposure all affect the surface hardness of these materials.

Methods: Granular ice samples of varying salt content were prepared by continuous mixing during flash freezing with liquid nitrogen. These samples were loaded into 6.35 cm (2.5") diameter aluminum cylinders and fitted inside a custom, continuously-circulated liquid-nitrogen-cooled aluminum radiation chamber held at -185° C / 88 K (See **Figure 1**). The sample materials were tested at a variety of temperatures and under different irradiation conditions. Since the ice samples themselves are granular, and since radiation has been shown to increase the surface roughness of ice, we selected a Leeb rebound impact hardness tester that is compatible with rougher surfaces. This methodology has been used recently to probe weathering and degradation of rock and mineral surfaces [1-3]. During a measurement, the tester is in contact with the cold surface for only a fraction of a second (**Figure 1**), thus minimizing the amount of thermal transfer between the impactor and the ice surface. Leeb hardnesses (HL) were averaged from a minimum of 12 measurements and the mean and standard deviations were recorded.

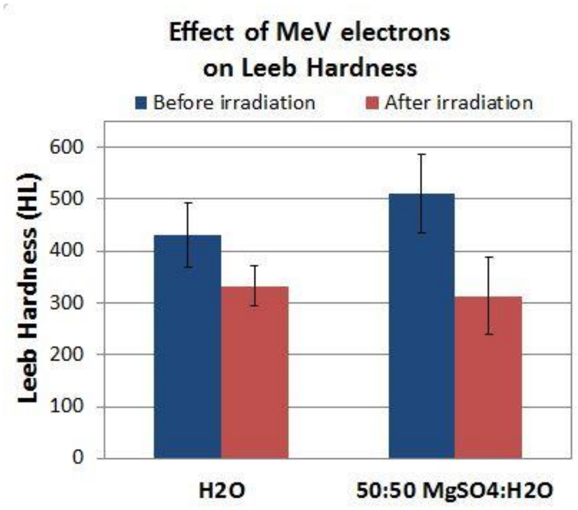

Figure 1. Changes in Leeb Hardness following bombardment of ice surfaces at 90 K with 10.5, 18, and 25 MeV energetic electrons. The 50:50 $MgSO_4$:H_2O sample was exposed to a dose of $6x10^{16}$ MeV cm^{-2} whereas the H_2O sample was exposed to $8x10^{16}$ MeV cm^{-2}. Error bars represent one standard deviation of the measured values. [For reference, Verwaal and Mulder [4] recently registered the Leeb Hardness of a sample of marble as 603 HL.]

Figure 2. Top: Photograph of the ice radiation chamber, held at ~88 K by constant flow of LN_2. Bottom: Testing surface roughness following bombardment of the ice surface with 10.5-25 MeV electrons at a total dose of ~8×10^{16} MeV cm^{-2}.

Results and Discussion: As expected, lower temperatures correlated with higher hardness readings. For pure water ice, hardness values at Europa-relevant temperatures (~90 K) were found to be roughly twice as high as those measured at ~215 K. Epsomite ices ($MgSO_4$*$7H_2O$), with a composition of nearly 50:50 $MgSO_4$:H_2O by mass, were harder than pure H_2O samples (see **Figure 2**), but irradiation of both pure ice and $MgSO_4$–containing samples with similar doses of 10.5 MeV to25 MeV electrons seemed to reverse these differences in hardness.

Conclusion: Cold, $MgSO_4$-rich Europa analogs were harder than pure frozen water samples at all temperatures we studied. However, our experiments involving MeV electron bombardment show that radiation softening could offset some of these effects at the surface. Considering electron energy fluxes from Paranicas et al. (maximum electron energy flux into the trailing hemisphere of $\sim 1\times10^8$ MeV $cm^{-2}s^{-1}$ [3]), we have calculated that this total dose (per square cm) represents approximately 2.5 years of radiation at the surface of the trailing hemisphere. More work is now underway to explore the effect of different salt concentrations and compositions on surface hardness.

References: [1] Aoki, H. and Matsukura, Y. (2008). *B. Eng. Geol. Environ. 67*(1): 23-29. [2] Mol, L. and Viles, H.A. (2012). *Earth Surf. Proc. Land. 37*(3): 301-314. [3] Wilhelm, K., et al. (2016). *Earth Surf. Proc. Land. 41*(8), 1027-1038. [4] Verwaal, W. and Mulder, A. (1993). *Int. J. Rock Mech. Min. 30*(6):659-662 [5] Paranicas, C. et al. (2009). Europa. *University of Arizona Press, Tucson* 529. [6] Paranicas, C. et al. (2007). *GRL 34*(15).

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