UNVEILING CHAOS TERRAIN FORMATION ON EUROPA THROUGH SYNTHESIZING ICE MIXTURES AND MODELING OF THE GALILEO NIMS REFLECTANCE DATA. S. Li[1], K. Robertson[2], and V. Z. Sun[3], [1]Hawai'i Institute of Geophysics and Planetology, University of Hawai'i. [2]Department of Earth, Environmental, and Planetary Sciences, Brown University. [3]Jet Propulsion Laboratory, California Institute of Technology. shuaili@hawaii.edu

Introduction: Chaos terrains are disrupted crustal units on Europa that are composed of 'rafts', 'matrices', and clear boundaries with surrounding terrains and range from several km (micro-chaos) to over 1000 km [1-3]. Understanding the formation of chaos terrains on Europa is critical for revealing surface and interior processes. There are two hypotheses for interpreting the formation of chaos terrains. (1) The chaos terrains could form from re-solidification of ice shell that has been melted through by interior thermal activities ('melt through model') [3]. (2) The chaos terrains are collapsed portions of the ice shell due to the mobilization of brines ('brine mobilization model') [2, 4]. The melt through model is compatible with any types of chaos terrains on Europa's surface, such as chaos terrains with/without preserved ridges. However, it is still unclear whether interior thermal activity could provide enough heat to melt through the ice shell (~20 km) [5]. The brine mobilization model is challenged by the uncertain source of brines that could mobilize and cause collapse of large areas of ice shell (> 1000 km in ranges).

Our objective is to test the two models by examining the mineral phases of rafts, matrices, boundaries, and undisrupted terrains. Our hypothesis is that if the melt through model is correct, the water ice content along chaos terrain boundaries and matrix should be higher than that of undisrupted terrains. If the brine mobilization model is true, we should observe higher abundances of brine minerals at chaos terrain boundaries and matrix than in undisrupted terrains. Both models predict that the mineral compositions of rafts should resemble those of undisrupted terrains.

To achieve these goals, we will first prepare endmember species (pure ice, hydrated salts, and acidic ices) that are possibly present on Europa's surface and measure their visible to near-infrared to mid infrared reflectance spectra in the laboratory. We will then prepare mixtures of these endmember species to test two non-linear spectral unmixing models that are commonly used in the planetary community [6, 7]. Lastly, we will apply these models to the Galileo Near-Infrared Mapping Spectrometer (NIMS) images over chaos terrain regions to test the two hypotheses.

Data & Methods: We performed a pilot study using the Galileo NIMS image 14e006ci (**Fig. 1**) in conjunction with Hapke's radiative transfer model. In the Hapke model, the reflectance can be described as a function of single scattering albedo (ω(λ), λ is the wavelength), solar incidence angle (*i*), emittance angle (*e*), back serge function (*B(g, ϕ), g* is the phase angle, *ϕ* is the porosity), phase function (*P(g)*), and multiple scattering function (*H,* for both down-welling and up-welling).

$$R = \frac{\omega_{ave}}{4\pi}\frac{\mu_0}{\mu_0+\mu}\{[1+B(g,\phi)]P(g)+H(\mu_0)H(\mu)-1\}S$$

where $\omega_{ave} = \sum_j \frac{M_j\omega_j}{\rho_j d_j} / \sum_j \frac{M_j}{\rho_j d_j}$ is the averaged single scattering albedo of mixtures, ω_j is the single scattering albedo of the j^{th} endmember, ρ: density, M: mass fraction, S accounts for the effect from surface roughness. All reflectance data can be converted to the average single scattering albedo that is linear combinations of endmember's single scattering albedo weighted by the endmember's densities if all endmembers have similar particle size. We tested thirteen endmembers in this pilot study: bloedite, epsomite, kieserite, hexahydrite, magnesium sulfate, brucite, magnesium chloride, sepiolite, sodium chloride, thenardite, mirabilite, melanterite, and water ice. The parameterization of Hapke's model used in this study is the same as that of [8, 9]. The model inputs are NIMS reflectance data after photometric correction, viewing geometry (*i, e, g*) from NIMS QUE files, endmember's single scattering albedo and densities. The model outputs are endmember abundances.

In future studies, we will add more endmembers, such as hydrated salts, acid ices, and silicate minerals, to better represent the endmember phases on Europa's surface. We will also test the spectral unmixing with the Hapke and Shkuratov models in conjunction with optical constants (*n* and *k*) of endmembers to better estimate the particle size of endmember phases on Europa. Lab synthesized mixtures of ice and silicate minerals are possibly applicable to other airless bodies such as Mercury, the Moon, and Ceres.

Results and Discussion: Our mapping results show that mineral and water ice abundance variations are observed among chaos terrain units, undisrupted terrains, ridges, and bands (**Fig. 1**). The abundances of different minerals in Figure 1 are relative quantities and uncertainties are unknown, which will be addressed in future work. Preliminary results from this pilot study suggest that epsomite is highly concentrated along chaos terrain boundaries (**Fig. 1c**); bloedite and mirabilite are abundant at chaos terrain matrix (**Fig. 1e-f**); while water ice is low at chaos terrain matrix and boundaries (**Fig. 1b**). Reflectance spectra of pixels showing high concentrations of brucite, epsomite, bloedite, and mirabilite are extracted from the NIMS image to compare with pure endmembers in Figure 2.

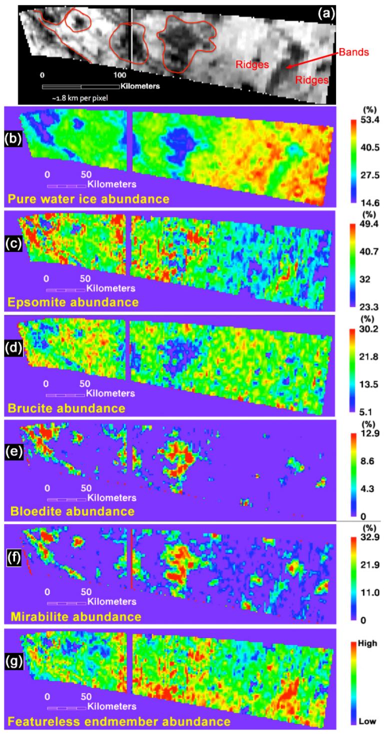

Fig. 1. (a). The NIMS image 14e006ci at 750 nm; (b-g). Mineral mapping results with Hapke's model, all spectrally neutral endmembers are shown in (g).

These preliminary mapping results are more consistent with brine mobilization model predictions. Epsomite, bloedite, and mirabilite might be the dominant mineral phases in brines. Because epsomite has higher solubility than bloedite and mirabilite at 0°C [10], epsomite mobilizes easily and gets concentrated at chaos terrain boundaries during the thermal event, while bloedite and mirabilite are residuals of brines. Interestingly, we also observe some bloedite and mirabilite at chaos terrain rafts that should resemble the mineral compositions of undisrupted terrains, but the latter shows no detectable mirabilite and bloedite (**Fig. 1e-f**). It is possible that the collapsed ice shell was contaminated by brine residuals (mirabilite and bloedite). Minor amounts of mirabilite are also observed at ridges. The presence of mirabilite at ridges might be attributed to different processes than mirabilite associated with chaos terrain matrix. Mirabilite might be initially buried in the ice shell due to its instability at Europa's surface conditions [11-13], and then it might be transported to the surface by the ocean water beneath the ice shell during ridge formation. The enrichment of water ice at ridges (**Fig. 1b**) may also indicate that water was transported from the ocean during the ridge formation.

The major mineral phases picked by our modeling (six out of thirteen) are consistent with the prediction of thermal dynamic models under the Europa's surface conditions. For the $MgSO_4$-H_2O and the Na-Mg-SO_4 system, epsomite, bloedite, and mirabilite are the most stable phases at Europa's surface temperature and at the weight percent of $MgSO_4$ [14, 15]. These mineral phase are stable through geologic timescales at Europa's surface conditions [16]. However, the results need to be reevaluated once more endmembers are added in future studies.

Conclusions: We performed spectral unmixing to understand chaos terrain formation on Europa's surface using Hapke's radiative transfer model in conjunction with NIMS data. The preliminary mapping results are consistent with the brine mobilization model. Epsomite, bloedite, and mirabilite might be the dominant mineral phases in brines. Epsomite mobilizes much more easily and gets concentrated along chaos terrain boundaries due to its higher solubility than bloedite and mirabilite. In future work, we will test more hydrated salts, acid ices, and silicate minerals to better represent endmember phases on Europa's surface.

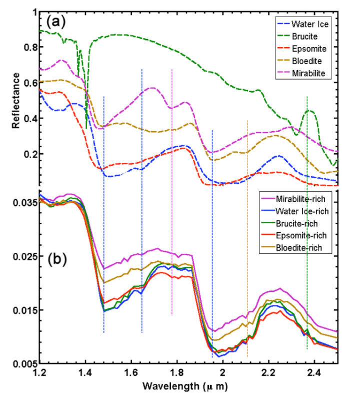

Fig. 2. The NIMS spectra (b) of units enriched in mirabilite, water ice, brucite, epsomite, and bloedite compared with endmember spectra (a).

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