

Surface Effects of Endogenic and Exogenic Processes on Europa

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Abstract

Surface deposits on Europa provide our most direct window to the composition of the putative subsurface ocean. Spectral models based on cryogenic reference spectra can now separate endogenic effects (aqueous geochemistry, internal convection, cryovolcanism) from exogenic effects (magnetospheric charged particle bombardment, ultraviolet photolysis, impacts) that contribute to the current surface composition. We have found sulfuric acid hydrate abundance to be independent of underlying geologic unit, while the relative proportions of the remaining materials are diagnostic of geology.

1. Introduction

The surface of Europa contains water ice, hydrated salts and sulfuric acid hydrate, and volatile ices such as SO₂ and CO₂ [1]. Jovian magnetospheric charged particles continuously overtake Europa in its orbit, preferentially striking the trailing hemisphere. The particles drive radiolytic chemistry, alter endogenic materials and implant a number of largely Iogenic elements including H, O, S, K, Na, and Cl. Separating exogenic processing from endogenic influences is critical to understanding surface and subsurface chemistry. Modeling of Galileo Near-Infrared Mapping Spectrometer (NIMS) observations using reflectance spectra measured at surface temperatures enables evaluation of surface abundances [2,3]. Previous work [3] demonstrated a gradient in H₂SO₄ hydrate abundance correlated with electron and sulfur ion fluxes at Europa's leading / trailing hemisphere boundary. Here we extend that analysis to more distant regions.

2. Methods

This work has three main aspects: (1), cryogenic reference spectra; (2), calibration and modeling of NIMS observations; and (3), modeling of incident electron and ion fluxes to determine total dose.

Cryogenic reflectance spectroscopy

Visible to near-infrared (VNIR, 0.3-2.5 μ m) laboratory reflectance spectra of candidate surface materials were obtained using cryogenic environment chambers [2]. Candidates included epsomite, hexahydrite, bloedite, mirabilite, undecahydrate, and MgSO₄ and Na₂SO₄ brines, measured at either 100 or 120K. H₂SO₄ hydrate spectra were measured at 80K and provided by R.W. Carlson [3] and synthetic 100K water ice spectra were generated using a Hapke reflectance model [2,3].

Calibration and Modeling

In prior work we applied an updated radiation noise removal method [4] to the NIMS 14ENSUCOMP01 observation, reducing the influence of noise spikes caused by radiation hits on the detectors. Here we augment those data with two additional observations: 17ENSUCOMP02, from a high latitude location on the leading side at 63° S, 120° W, and 15ENSUCOMP01, from an equatorial location, also on the leading side, at 7.8° N, 114° W. We applied a standard linear mixture model to match the NIMS spectra using linear combinations of candidate material spectra. A neutral dark component was included to account for shadowing and phase angle effects. The model used the χ^2 least-squares goodness-of-fit estimator and a simplex algorithm [2,4] to determine the best match.

Electron and ion flux estimates

The trailing hemisphere apex is expected to receive the highest concentration of Jovian magnetospheric ions and electrons, with fluxes decreasing toward the leading hemisphere apex. Modeling reveals a more complicated picture showing that the pattern depends on particle species and energy. One striking asymmetry is due to energetic electrons and sulfur ions preferentially bombarding the trailing hemisphere [5]. The electrons provide ionizing

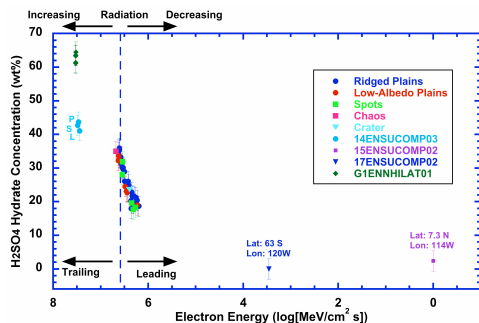


Figure 1. H_2SO_4 hydrate abundance vs. electron energy deposited into the surface.

energy, which both creates and destroys surface compounds. Implanted sulfur ions provide a raw source of elemental sulfur, complementary to possible geologic/oceanic sources.

3. Results

Our linear spectral model can distinguish material abundances within individual geologic units to ± 3 wt% in NIMS Europa observations [2,4]. Depending on underlying geologic unit, we found abundances of 8-20% of hydrated sulfate salts, 15-82% of water ice (grain size ~ 25 -250 μm), and up to 63% sulfuric acid hydrate. Models for the E15 and E17 observations yielded solutions invoking almost no sulfuric acid hydrate, except near dark linear features. Yet, even the iciest regions required some salt hydrate. Figure 1 contains estimated H_2SO_4 hydrate abundance from individual geologic units, compared to the estimated electron energy. The cluster of values near the 180° meridian between leading and trailing hemispheres are from ridged plains units in NIMS observation E14ENSUCOMP01[4]. Fig. 2 plots these abundances against the S ion flux at each location. The tighter correlation with electron energy suggests the electron energy exerts a greater influence on the equilibrium concentration of H_2SO_4 hydrate, yet does not act alone. New values for the leading hemisphere (E15, E17) are consistent with independent predictions [1,3,4] that the H_2SO_4 abundance approaches zero near the apex of the leading hemisphere, where the combined fluxes are lowest. Future work will incorporate contributions of electrons and major ions to predict sulfuric acid hydrate production.

4. Summary and Conclusions

Sulfuric acid hydrate abundance ultimately must be controlled by total cumulative energy dose, available

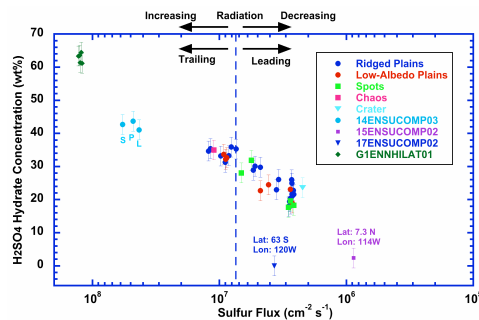


Figure 2. H_2SO_4 hydrate abundance vs. sulfur ion flux impinging upon the surface.

sulfur, or a combination of both. The depth into the surface at which we observe this material may also be relevant because charged particles have much different penetration depths. But separating the influence of energy and available sulfur may make it possible to utilize sulfuric acid hydrate abundance as a proxy for exposure age. This could prove highly valuable on sparsely cratered bodies like Europa.

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References

- [1] Dalton, J.B., Cruikshank, D.P., Stephan, K., McCord, T.B., Coustenis, A., Carlson, R.W., and Coradini, A.: Chemical composition of icy satellite surfaces, *Space Sci. Rev.* **153**:113-154, 2010.
- [2] Dalton, J.B.: Linear mixture modeling of Europa's non-ice material based upon cryogenic laboratory spectroscopy, *Geophys. Res. Lett.* **34**:L21205, 2007.
- [3] Carlson, R.W., Johnson, R.E., and Anderson, M.S.: Sulfuric acid on Europa and the radiolytic sulfur cycle, *Science* **286**:97-99, 1999.
- [4] Shirley, J.H., Dalton III, J.B., Prockter, L.M., and Kamp, L.W.: Europa's ridged plains and smooth low albedo plains: Distinctive compositions and compositional gradients at the leading side – trailing side boundary, *Icarus* **210**:358-384, 2010.
- [5] Paranicas, C.J., Cooper, J.F., Garrett, H.B., Johnson, R.E., and Sturmer, S.J.: Europa's radiation environment and its effects on the surface., in *Europa*, Univ. Arizona Press, Tucson, 529-544, 2010.