EUROPA’S SURFACE PROPERTIES AND PROCESSES. C. B. Phillips and J. L. Molaro, NASA Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109; Cynthia.b.phillips@jpl.nasa.gov

Introduction: The icy surface of Jupiter’s moon Europa presents an environment unlike other locations for previous in situ exploration in our solar system. An airless world with a very high integrated albedo of 0.97 [1] and a composition dominated by water ice, Europa likely possesses a top surface layer of disrupted regolith material overlaying a more solid surface ice layer, which extends down ~10-20 km to the top of Europa’s subsurface ocean. Embedded in Jupiter’s strong magnetic field, charged particle impacts as well as micrometeorites, sulfur ions ejected from Io, and other processes such as thermal segregation and degradation act to modify Europa’s surface. Europa’s unique surface properties and processes combine to produce a complex surface environment. With future exploration of Europa planned by Jupiter-orbiting missions such as NASA’s Europa Multiple Flyby Mission and ESA’s JUICE mission, and potentially even a Europa Lander, this work reviews what we know, and do not know, about Europa’s surface.

Background: Observations of Europa’s surface made from Earth-based telescopes, and later the Voyager and Galileo missions, revealed a bright, high-albedo surface with a composition dominated by water ice. Voyager images showed a surface covered with strange linear features, which later Galileo images proved to be long cracks and ridges with a likely tectonic origin [2]. Coupled with areas of iceberg-like, disrupted chaos terrain and a lack of impact craters, Europa’s geology suggests a young surface age (average surface age is suggested to be about 50 Myr), with potential for ongoing geologic activity.

Properties of Europa’s surface: To date, Europa’s surface has been studied by a variety of remote sensing techniques. Such methods necessarily rely on observations of only the very top portion of the surface, a region sometimes called the remote sensing layer [3]. The remote sensing depth is often wavelength dependent, and so depending on the observing technique used, the layer can vary in depth from microns to millimeters to as much as centimeters. It is important to keep this remote sensing depth in mind when evaluating results from different techniques, and remember that such remote sensing observations may not be that relevant when considering the bulk composition of the top meter or more of Europa’s surface.

Earth-based observations of Europa’s photometric function suggest a leading-trailing hemisphere asymmetry in porosity, ranging from 25% void space (leading) to 79% (trailing) [4]. Again, however, this measurement is only sensitive to the top mm or less of Europa’s surface, and models differ as to how well the assumptions required in photometric models actually approximate reality. Such models may be useful for relative comparisons between different portions of the same world, but may not be as accurate for direct correlation of modelled void space to actual porosity.

Color differences are another surface property which can be mapped using remote sensing techniques, and Europa’s leading-trailing color asymmetry was mapped in detail by [5] and attributed to sulfur ion implantation from Io which was enhanced in the trailing hemisphere. Color variations on Europa’s surface are also correlated with geologic features such as ridges and chaos terrain [2], but it is unclear whether the surface coloration is only a thin exogenic veneer on the surface, or reflects the subsurface composition. One possibility is that transparent non-ice materials are revealed at these locations and are processed by radiation to produce visible color variations [2].

Compositional data on Europa’s surface primarily comes from the Galileo NIMS instrument, which detected both water ice with a range of different sizes of particles, as well as non-ice materials which are through to be hydrated salts, sulfates such as magnesium sulfate, or sulfuric acid [2]. As with the other measurements described above, compositional data from spectrometers also only characterizes the top few microns of the surface, and requires speculative modeling of poorly-understood geologic processes to tie the measured surface composition in with assumptions about subsurface structure and ocean chemistry.

Temperature variations and surface thermal processes result in variations in grain size and crystal structure of Europa’s surface ice layer, as well. Equatorial ice on the leading hemisphere is generally fine grained (particle radii less than 50 microns [6]), but the trailing hemisphere ice is generally larger grained (particle radii greater than 200 microns [7]). The top layer of Europa’s ice is amorphous [8], likely due to irradiation and disruption of the original crystalline structure, although [9] suggest that IDP impacts could anneal amorphous ice grains back into crystalline grains.

Images of Europa’s surface: The few highest-resolution images we have of Europa’s surface from the Galileo mission show a surface that is oddly softened (Figure 1). At the middle left, a ridge is sheared by a newer fault, showing a subsurface cross section of the ridge that appears to have a thin bright layer at the very surface, perhaps a pixel or two wide. This tiny
layer, which would have to be at least 6 m thick to be visible in the image below, is almost three orders of magnitude thicker than the thickest estimate of the remote sensing layer depth of about 1 cm. Thus, any attempts to understand the bulk properties of Europa’s surface using remote sensing data, including imaging at tens-of-meters scale or higher, must take into account the unexamined nature of the near subsurface.

Figure 1: Single highest-resolution Galileo image of Europa’s surface, at 6 m/pixel. The vertical bar is a data gap. Galileo image number s0426272378.

Processes Affecting Europa’s surface: Europa’s unique surface is shaped by a number of dynamic processes, which act in combination with one another at rates that can vary in importance over time. Sputtering erosion due to charged particle impacts and impact grading from micrometeorite impacts can both serve to remove material from Europa’s surface, which can be redeposited nearby or lost into space entirely [3]. Rates of sputtering and gardening are not completely quantified, but it appears that sputtering and surface irradiation are a driving factor in surface modification and vary with location on the surface [10, 11]. As water molecules are redeposited elsewhere on Europa’s surface, they will form a loose frost that will sinter together with time and increase in density [12,13].

Other geologic processes that act on longer timescales to affect Europa’s surface include tidal deformation, tectonics, and perhaps even cryovolcanism. While tidal amplitudes may be as high as 56 meters at the equator on each orbit [14], the local slopes induced are low enough on a hemispheric scale to be unlikely to result in any mass movement. Tectonic activity could result in meter-scale motion along a fault over a 3.5-day orbital period, which could result in observable surface motion.

Thermal processes may result in significant mass motion and erosion on Europa’s surface. Sublimation and thermally-induced fracturing can result in mass wasting and erosion, eventually resulting in thermal segregation in which bright frost deposits migrate to cooler slope peaks, leaving behind darker lag deposits in lower valleys [3], as visible in Figure 1.

Implications for Future Exploration: Future exploration of Europa’s surface will reveal many of its secrets. Even after more thorough analysis of the surface from the Multiple Flyby Mission, however, landing on Europa’s surface will pose a unique challenge. Europa’s surface will be one of the most difficult landing locations in the solar system to be accomplished – the combination of an unknown icy regolith, plus the lack of any atmosphere to slow down a lander, will mean that there is little margin for error. Landing on Europa’s surface will require us to consider unknown surface properties such as strength, cohesion, compressibility, and other parameters to design a robust landing system in a way that we have not since the early Surveyor landings on the Moon.

Studies of Europa’s surface properties and dynamic processes, whether conducted in the laboratory with Europa-analog materials or in the field at Europa-analog sites, will be essential in preparing for an eventual landing. In addition, theoretical models that include the full range of dynamic processes under Europan conditions will be necessary to help bridge the gap between analog observations and actual conditions on this icy world. With future exploration of Europa finally on the horizon, the time is right for us to lay the groundwork for this characterization, to lead to an eventual landing on Europa’s surface.