THE EMERGING RESURFACING HISTORY OF EUROPA FROM POLE-TO-POLE GEOLOGIC MAPPING. P. H. Figueredo and R. Greeley, Department of Geological Sciences, Arizona State University, Tempe, AZ 85287-1404, e-mail: figueredo@asu.edu

Introduction

Geologic mapping of planetary surfaces provides information on the nature, sequence, and distribution of material units, from which one can assemble a geologic history [1]. With this goal in mind, the *Galileo* SSI camera acquired an important dataset of images of Europa at a resolution suitable for geologic reconnaissance and mapping. We performed mapping and analysis of pole-to-pole transects at 230 m/pixel (covering about 10% of the satellite) across the leading and trailing hemispheres of the satellite. Here we report the results on the spatial and temporal distribution of surface units, and their implications for the resurfacing history of Europa. We show that a) the style of tectonic and cryovolcanic resurfacing changed with time, and b) these changes could reflect the thickening of Europa s lithosphere during its recent geologic hi story.

Distribution, orientation, and timing of units

Analysis of the spatial distribution of units shows that ~50% of the mapped areas were resurfaced since the period of background ridged plains formation (i.e., the last 10^7 Myr. [2]): ~20% by chaotic disruption and ~30% by tectonic processes. The chaotic resurfacing estimate is broadly comparable to the 28% value obtained from the chaos distribution survey of [3]. The tectonic resurfacing estimate incorporates a correction (percentage extrapolation) for units preceding chaos material, whose formation uniformly obliterated preexisting units. The pre-chaos percentages do not show significant latitudinal asymmetries, but the chaos distribution is offset ~15^o from equatorial symmetry. This displacement is consistent with, albeit smaller than, the polar wander shift postulated by *Sarid et al.* [4]. The distribution of chaos broadly matches areas where the regional thermal gradient has been raised by tidal dissipation. Overall, there are no major hemispheric asymmetries in the latitudinal distribution of geologic units, although we document significant longitudinal variation. This observation suggests that only a limited smearing of geologic units by nonsynchronous rotation has occurred.

Expanding our previous analysis [5], we documented lineament rotation with time on both hemispheres. Rotation is mostly clockwise in the northern hemisphere and counter-clockwise in the southern one, consistent with the changes in the global stress field predicted by models combining tidal stresses and nonsynchronous rotation [6]. This result indicates that nonsynchronous rotation occurred during much of the recorded geologic history. Furthermore, the estimated amounts of rotation (~550^o on average) and the reconstructed longitudinal positions of the areas of study in the past suggest that Europa s crust completed at least a full rotation relative to the deformed interior, with additional rotations possibly recorded in the lineaments comprising the background ridged plains. An origin of lineaments by stresses predicted from polar wander models is not favored by the mapping data, although we acknowledge that a detailed analysis, exploring different pivoting points and crustal translation paths, is required to settle the case.

Stratigraphic studies indicate that the geologic record can be divided into four major periods (Figure 1). For analysis, we produced time steps of the resurfacing history by displaying separately the units formed at each stage. Our results reveal a change from tectonic- to cryovolcanic-dominated resurfacing with time. Furthermore, the style of tectonic processes changed with time, from intensive, closely spaced fracturing and ridge building to form background plains, to infilling of inter-plate gaps to produce broad bands, to gradually narrower and farther-spaced ridges and ridge complexes. The lack of lineaments overprinting impact structures (with the exception of Tyre) suggests that the intensity of tectonic resurfacing decreased rapidly after the formation of ridged plains, possibly reflecting a change in lithospheric properties or the resurfacing mode. The style of chaotic resurfacing also changed with time, although disruption-related units overprint one another, fragmenting much of the evidence for early cryovolcanic activity. We interpret areas of subdued, featureless plains as the earliest units possibly related to cryovolcanism. In some locations, these early chaos have been reworked to form younger chaos areas by the merging of small patches of disruption (see also [7]); the most recent chaos features appear to be slightly elevated with respect to the surrounding plains [8]. These observations suggest that chaos formed by disruption and emplacement of buoyant material from the subsurface, which became topographically and morphologically subdued with time.

Emerging scenario: Causes and implications

A possible interpretation of the observed trends in distribution and changes in the resurfacing styles is the gradual thickening of Europa s lithosphere throughout the visible geologic history, as illustrated in Figure 1:

(1) An originally thin, brittle ice shell could be pervasively fractured or molten through by tidal and endogenic processes. (2) The degree of fracturing and plate displacements decrease with time in a thickening shell, and lineaments become narrower and more widely spaced. (3) Formation of chaos regions can take place where the thickness threshold for solid-state convection is exceeded, and can be aided by preferential tidal heating of more ductile ice [e.g., 9]. (4) In a long-term context, it cannot be determined at this point whether this thickening trend reflects a drastic change in the thermal evolution of the satellite, or the presence of more stable cycles of tectonic and cryovolcanic activity (see also discussion in [10]). This determination has implications for the current state, fate, and astrobiological potential of Europa s outer shell. If the apparent late thickening continues indefinitely, then Europa undergoes total and irreversible freezing, shutting down surface activity. Alternatively, scenarios where cryovolcanic and tectonic (i.e., thickening and thinning?) processes alternate or coexist offer more opportunities for internal processes and the generation/preservation of potential niches for biology. In this context, early smooth plains and isolated highstanding knobs may possibly constitute fragmental evidence for early cryovolcanic resurfacing.

Conclusions, standing issues, and future work

Geologic mapping of regional mosaics on opposite sides of Europa shows changes in the styles of cryovolcanic and tectonic resurfacing mechanisms over the visible geologic history. These changes appear to reflect the effects of tidal and thermal processes on a thickening outer shell. Despite the similarity of the results from both of the mapped areas, we acknowledge that only a small fraction of the satellite has been studied at this level of detail in order to globally extrapolate these findings with confidence. We are currently working on establishing a global stratigraphic framework for Europa from global geologic mapping, which would enable correlation of events in time and space. Mapping and geophysical measurements of the current state of the lithosphere might provide the information needed to strengthen this emerging scenario and to resolve some of the outstanding issues.

[1] Wilhems, in *Planetary Mapping*, R. Greeley and R.M. Batson, eds., Cambridge, NY, pp. 208-260, 1990; **[2]** Zanhle et al., *Icarus*, 136: 202-222, 1998; **[3]** Riley et al., *JGR,* 105: 22599-22615, 2000; **[4]** Sarid et al., *Icarus*, 158: 24-41, 2002; **[5]** Figueredo and Greeley, *JGR*, 105: 22,629-22,646, 2000; **[6]** Greenberg et al., *Icarus*, 135: 64-78, 1998; **[7]** Spaun et al., *LPSC* XXX, abst. 1847, 1999; **[8]** Figueredo et al., *JGR*, 107, 10.1029/2001JE001591, 2002; **[9]** McKinnon et al., *GRL*, 26: 951-954, 1999; **[10]** Pappalardo et al., *JGR*, 104, 24015-24056, 1999.

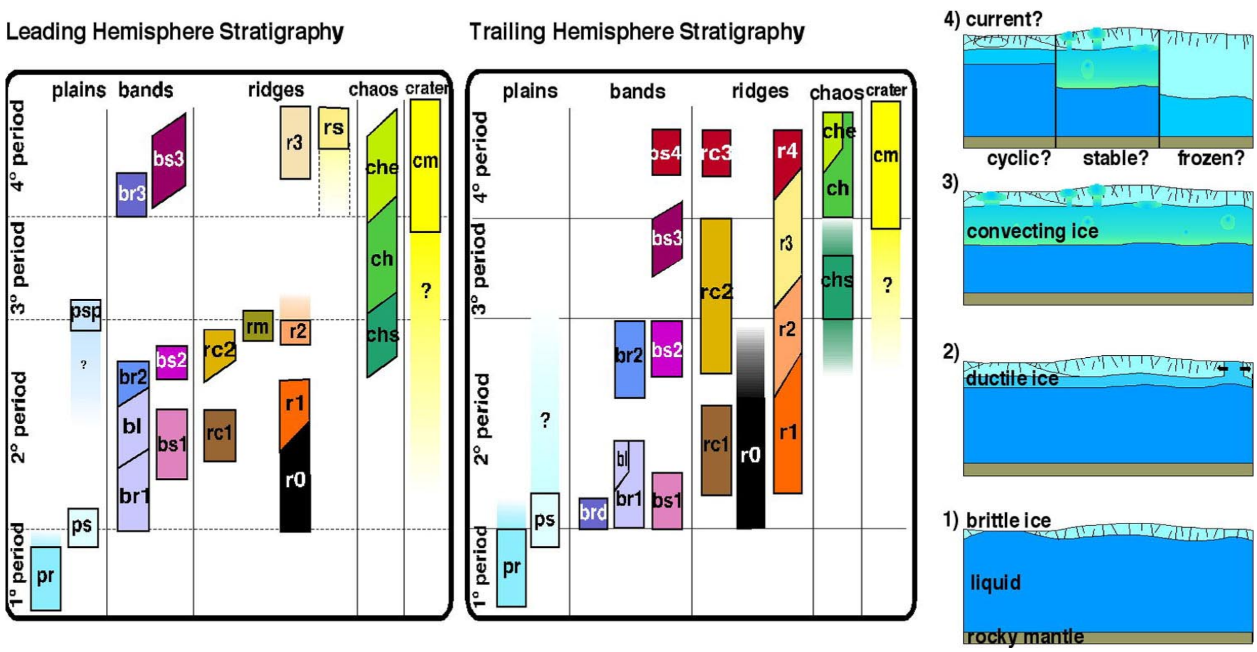

Figure 1. Stratigraphy of units for the leading and trailing hemispheres of Europa, as established from regional geologic mapping. The diagrams on the right illustrate the interpreted lithospheric evolution for the different periods of the visible geologic history.