Europa's chaos remains a challenge. A cautionary note is provided by attempts to simulate Earth's plate tectonics from first principles, which show that the interaction of convection with brittle deformation can depend sensitively on the adopted formulation for the brittle rheology (*Tackley,* 2000a,b,c; *Bercovici,* 2003). One may expect similar sensitivity in the interaction of convection with brittle deformation on Europa. A full understanding of whether, and how, convection can cause chaotic terrain will require future numerical studies that investigate compositional effects, partial melting, and a wider range of brittle rheologies.

6. DISCUSSION

Despite many advances in the knowledge of ice rheology, the behavior of solid-state convection, and the interaction between convection and lithospheric deformation, several aspects of the behavior of Europa's icy shell remain unexplained. Here, we describe several key gaps in knowledge about Europa, which are required to address the fundamental questions about Europa's icy shell posed in section 1: Can Europa's icy shell convect at present? How does tidal dissipation affect convection? Can convection drive resurfacing? What role does compositional heterogeneity play in driving motion in Europa's shell?

What is the thickness and thermal structure of Europa's icy shell? Further spacecraft data are needed to constrain the true thickness of Europa's icy shell, to characterize the topography inferred to form from convection (at both short and long wavelengths), and to determine the thermal structure of the icy shell (namely, the depth to warm ice). Global geophysical data obtained by an orbiter equipped with, for example, a laser altimeter, radar sounder, a near-infrared mapping spectrometer, and high-resolution imaging system are needed to answer many of the basic questions posed above. Such data would also provide constraints for more sophisticated modeling efforts suggested below.

Can convection cause resurfacing? Models published to date provide encouragement that at least some fraction of Europa's pits, uplifts, and chaos could result from convection in the icy shell, but the models are nevertheless far from explaining the actual observed properties of these features. Compositional convection allows pits and uplifts with the observed topography to be produced, but the simulated features are wider than most of Europa's pits and uplifts unless ice viscosities are extremely small. Convection models including simple parameterizations of brittle failure can produce some chaos-like behaviors, but they also produce behaviors that appear not to occur on Europa. A new generation of three-dimensional models including salinity, partial melting, and more realistic parameterizations of brittle failure can help determine whether pits, uplifts, and chaos can actually result from convection.

How does tidal flexing on Europa affect the microphysical structure and rheological behavior of ice? It is not known how the cyclical tidal flexing of Europa's ice shell affects the ice in its interior. The Maxwell model is perhaps an overly simplistic description of the behavior of Europa's ice. Laboratory experiments are needed to clarify how tidal dissipation occurs on a microphysical scale in ice, and to clarify whether cyclical flexing affects ice microstructure.

How does tidal flexing interact with mechanical, thermal, and compositional heterogeneity in the ice shell? Implicit in our discussion of the effects of tidal flexing on heat transfer has been the assumption that tidal dissipation is heterogeneous, and that tidal heating obeys the Maxwell model (equation (5)). The results of laboratory experiments must be combined with sophisticated geophysical techniques to study the localization of tidal strain and heating in model europan ice shells with thermal, mechanical, and compositional heterogeneity to more accurately model tidal dissipation and its link to resurfacing.

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