ORIGIN OF CHAOS TERRAIN. Paul E. Geissler, Astrogeology Program, U.S. Geological Survey, Flagstaff Field Center, 2255 N. Gemini Dr., Flagstaff, AZ 86001 USA. (pgeissler@usgs.gov).

A NASA press conference in April, 1997 heralded the "discovery of an ocean on Europa" based upon the initial interpretation of crustal fragments within Conamara Chaos as ice "rafts" that had floated on a near-surface layer of liquid water. Although later imaging and more detailed analyses turned up a variety of surface features that were likely formed by diverse mechanisms, subsequent Galileo data provided ample confirmation that Europa's ice shell has been disrupted many times by large bodies of near-surface liquid water. This talk will review the characteristics of chaos terrain, the photogeological evidence for ice rafting, and the implications of liquid water near the surface of Europa.

Chaos regions share several characteristics, including an irregular, rough matrix that has replaced the ridged terrain common on Europa. This matrix material is commonly dark brown in color and often occupies the floor of irregularly shaped depressions that are 200 to 300 meters lower than the surrounding ridged terrain and are generally bounded by steep scarps. Within the matrix are often found fragments of intact crust with ridges still visible on their upper surfaces. The orientations and locations of some of these fragments demonstrate that they shifted in position (rotated, translated, or tilted) when the surface was disrupted, indicating that the fragments were underlain by a mobile substrate such as liquid water or ductile ice. Because the last remaining crustal fragments within chaos regions often incorporate relatively large and heavy ridges, the substrate must be denser than the solid ice crust, i.e. liquid water. From shadow measurements we can determine that the height of the fragments above the matrix is typically 200 to 300 m, suggesting that these ice "bergs" are 2 to 3 km thick according to Archimedes' Principle. Fragment thicknesses estimated in this way are equal to their minimum lateral dimensions, consistent with their interpretation as floating ice rafts.

Chaos regions range in size from a few kilometers to several hundreds of kilometers across. The dimensions of the largest examples are greater than the maximum possible thickness of the solid ice shell. There are no indications that chaos regions formed in stages like the nested paterae of Io, although there are several instances of younger chaos that overprinted older, inactive chaos terrain. Hence, the bodies of liquid underlying the chaos must have been at least as extensive as the chaos regions themselves, and at least 2 to 3 km deep in order to float ice rafts of the thicknesses inferred. Such large bodies of water would be unstable as sills sandwiched within a thick ice shell, and would sink through the lower density ice or quickly drain through faults and fractures in the solid ice shell. More likely, the liquid layer beneath chaos terrain is a global subsurface sea that melted through the solid ice shell and thermally disrupted the surface (Greenberg et al., 1999, Icarus 141, 263). A mechanism of brine mobilization (Head and Pappalardo, 1999, JGR 104, 27143) has been suggested for creating a transient layer of liquid within a thick ice crust, but such a process ought to expend itself early in Europa's geologic history, as soon as the ice shell differentiated.

The youngest chaos regions are among the most recent features on Europa's surface, suggesting that chaos terrain could be forming even today. Chaos formation is not a new phenomenon, however. Ancient chaos terrain can be recognized that dates back to the beginning of Europa's (short) geological record. Chaos in various stages of degradation can be seen that is overprinted with tectonic fractures and ridges and sometimes younger chaos, which can lead to the curious situation of chaos atop ice rafts. The processes by which chaos is obscured are identical to the means by which impact craters are erased, and the difficulty of recognizing older features of either type does not imply that chaos or crater formation are new phenomena.

Two other mechanisms modify chaos regions after thermal disruption has ended. First, the newly formed features represent zones of weakness in the ice shell that are subject to horizontal compression as the shell accommodates expansion elsewhere. Second, the melted area must refreeze to the thickness of the surrounding ice shell, perhaps aided by infill via viscous flow of the ice below, while preserving the high frequency component of the surface topography. These processes probably account for the puzzling variations in chaos morphology, such as the elevated matrix material reported by Schenk and Pappalardo (LPSC 2002).

Chaos terrain is ubiquitous on Europa. It is somewhat more prevalent along the equator, but large chaos regions have been found even at the poles, suggesting either extensive heating at high latitudes (where the ice shell is expected to be thick) or that polar wander has taken place. Riley et al. (2000, JGR 105, 22599) estimate that ~30% of the surface of Europa is occupied by younger chaos, while another ~10% may be covered by older, partially obscured chaos regions. Chaos formation is thus an important resurfacing mechanism, competing with resurfacing by tectonism and ridge formation.

The presence of liquid water near the surface of Europa has important implications for exobiology and future spacecraft exploration. Melt-through provides a means of mixing surface materials into the interior, supplying oxidants and exogenic compounds that could help sustain life in the subsurface sea. It also exposes seawater at the surface of the satellite, yielding a means to determine the composition of the ocean hidden within. Active or recently formed chaos regions could one day provide a portal for access to Europa's ocean for direct exploration, an expedition that will be inevitable (if it is possible), given the nature of human curiosity.