BANDS ON JUPITER'S MOON EUROPA: GEOMETRIES, MORPHOLOGIES, CLASSIFICATION, AND FORMATION MECHANISMS. W. K. Zimmerman and S. A. Kattenhorn, Department of Geological Sciences, University of Alaska Anchorage (wkzimmerman@alaska.edu, skattenhorn@alaska.edu).

Introduction: The surface of Jupiter's moon Europa is disrupted by multiple types of geologic features. Bands form prominent extensional, tabular features with contrasting albedo and/or surface texture to the surrounding terrain [1-4]. They represent sites of new crustal creation through plate-like opening or spreading. The surface of Europa is geologically young (perhaps no more than ~90 my)[5], indicating that some combination of processes must rapidly resurface this icy moon. Bands may be a major contributor to this process.

Nonetheless, how and why bands form remains an open question. We have developed a new classification system for bands focused on geometry in relation to the breadth of morphologies observed and infer a range of potential top-driven formation mechanisms. Bands may change morphology across the width or along the length of the band. Geometric elements include band shapes, association with other structures, opening vectors, and the ratio of dilation to band length. By matching piercing points of older features along the margins of the bands and accounting for internal morphology changes, we reconstruct the dilation phases from initial opening of a pre-existing fracture to the current state of maximum dilation (up to ~30-40 km). We identify patterns where the morphology of a band changes from smooth to lineated in response to the opening vector becoming highly oblique, resulting in primarily lateral motions. This obliquity could have implications for the rate or mechanism by which material is transported to the surface. Understanding the driving mechanisms behind band formation will shed insight into how the surface of Europa was formed and possibly is still being resurfaced. If bands are a conduit through which material is transported to the surface from deeper and warmer portions of the ice shell, they may provide key sites for the search for life on Europa and priority targeting by future missions to this icy moon, such as NASA's Europa Clipper mission.

Geometric Band Classification: Bands can be classified geometrically based on distinct band shapes and associations with pre-existing weaknesses such as strike-slip faults, cycloids, ridges, or older bands. Although the majority of bands display distinct dilational evidence (i.e., piercing point indicators along opposing band margins) and can thus be simply reconstructed, band-like features may also form through convergence or non-dilational extensional deformation, and lack piercing point indicators.

Inherited, Arcuate: Arcuate bands are curvilinear dilational bands with curved or cuspate structures that form chains of arcuate segments linked at sharp cusps. Dilation may be orthogonal to the boundary, but is typically oblique given the changing orientation of the boundary relative to the opening direction.

Inherited, Non-Arcuate: Non-Arcuate bands do not adhere strictly to any specific geometry, but rather are dilation of a ridge or crack.

Inherited, Transform: Although associated with strike-slip faults, these do not originate between strike-slip segments, but rather it dilates the strike-slip fault itself.

Rhomboidal: Rhomboidal bands are always located between overlapping segments of laterally offset or en echelon strike-slip or transform faults. Bounding ridges typically define the long axis edges of rhomboidal bands, which also comprise the fault segments along which initial strike-slip motion occurred.

Wedge-shaped: Bands with a wedge-shaped geometry can be identified based on their differential opening widths along the length of the band. The wide end emanates from the tip of a linear discontinuity along which strike-slip motion is predominant. As such, these bands resemble tailcracks along terrestrial strike-slip faults (Kattenhorn and Marshall. 2006). Opening widths decrease somewhat linearly towards the distal tip of the band.

Braided: Braided bands are geometrically complex, with evidence of multiple distinct phases of band formation and with younger band boundaries crosscutting older band boundaries, resulting in an interweaving or braided pattern. Opposing margins of these bands cannot be matched or reconstructed (i.e., no identifiable piercing points). These bands may represent sites of local convergence or surface area removal.

Convergence Band: Convergence bands are identified by a distinct mismatch of terrain beyond their irregular non-symmetrical margins. Features truncated against convergence bands do not have matching piercing points and often the terrains on opposite sides of the band differ greatly.

Reconstruction of Bands: To fully understand the process of band formation it is necessary to reconstruct the band one phase of opening at a time. Phases of opening (ie dilation, lateral motion, etc.) can by identified in two ways, Piercing points, and cross-cutting relationships. Piercing points are features on opposite sides of the feature more than likely were in contact before separation of the band. Cross-cutting relationships are used to identify the order that each phase occurred in. By combining piercing points and cross-cutting relationships, we can close some bands in reverse sequence and see the motions that the microplates must have used to arrive where they are today (Figure 1).

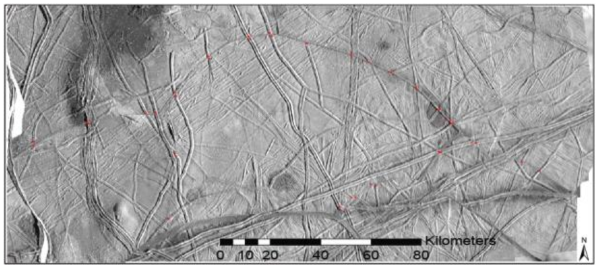

Figure 1 Reconstructed image of the eastern section of Phaedra Linea near Castalia Macula. Image shows what the region would have looked like before band formation. Red dots indicate piercing points that have been matched together to reconstruct the band. Initial conditions are double ridges with arcuate shapes that resemble smaller versions of cycloids, and narrow arcuate bands in the southern section.

Discussion and Conclusions: The contribution of dilational bands to the resurfacing process on Europa motivates the need for a clear understanding as to why band initiation even occurs. We find that band geometry is directly related to the underlying controls on band formation. Tailcracks between en echelon segments of a strike-slip fault open because of ongoing strike-slip motions, generally producing rhomboidal band geometries and isolated tailcracks form wedge-shaped bands.

Bands almost always utilize preexisting features to accommodate opening, often resulting in later phases of bands opening inside existing bands, identifiable through a change in morphology related to some unknown change in emplacement mechanism (e.g., spreading rate, ice chemistry, regional stress state, etc.).

Internal morphology of a band during a single phase of opening can be altered between lineated and smooth, with more lineation appearing as obliquity of opening vector to the band margin increases (Figure 2).

Microplate motion is consistent with a regional stress field interacting with cohesive rigid bodies. We thus infer that band dilation and infill from below is a passive response to a localized surface-driven process (e.g., plate motions; strike-slip activity), rather than being driven by thermodynamic instabilities in the underlying warmer ice, which may rather be a consequence of the dilation. Bands that form in close enough proximity to one another to mechanically interact can create linked networks of bands that define boundaries around isolated sections of the icy crust, forming small mobile units or microplates. Where this occurs, triple-junction band geometries may develop.

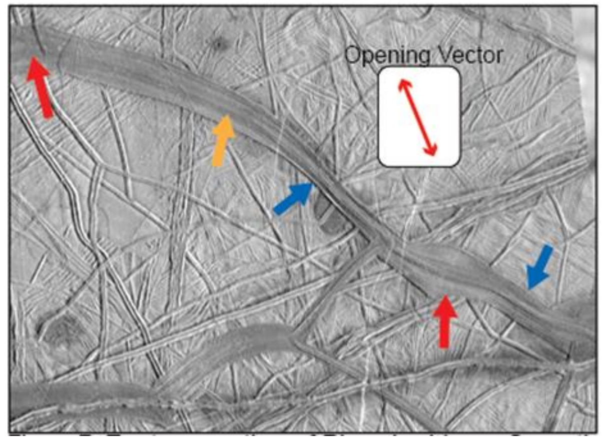

Figure 2. Eastern section of Phaedra Linea. Smooth morphology occurs where opening vectors are ~45-90º to the band margin (Red arrows). As obliquity reaches 45º (yellow arrow) lineations appear. At high obliquity (blue arrows) lineated morphology is dominant. Image modified from USGS Europa global mosaic.

Both the morphology and geometry of bands seem to be inherently linked to the formation mechanism and opening kinematics. Existing band classifications primarily focus on internal morphology [2, 10], the differences in which remain loosely explained. Both the morphology and geometry of bands seem to be inherently linked to the formation mechanism and opening kinematics.

References: [1] Greeley, R. et al. (2000). J. Geophys. Res. 105, 22559–22578. [2] Kattenhorn, S.A., Hurford, T.A. (2009). In: Europa (R.T. Pappalardo, W.B. McKinnon, K.K. Khurana, eds), pp. 199-236. [3] Tufts, B.R. et al. (2000). Icarus 146, 75-97. [4] Dogget, T. et al. (2009). In: Europa (R.T. Pappalardo, W.B. McKinnon, K.K. Khurana, eds), pp. 137-159. [5] Bierhaus B.E. et al. (2009). In: Europa (R.T. Pappalardo, W.B. McKinnon, K.K. Khurana, eds), pp. 161-180. [6] Prockter, L.M. et al. (2002). J. Geophys. Res. 107, E5, 5028, 1-28. [7] Kattenhorn, S.A. (2004). Icarus 172, 582-602. [8] Hoppa, G.V. et al. (1999). Science 285, 1899–1902. [9] Marshall, S.T., Kattenhorn, S.A. (2005). Icarus 177, 341-366. [10] Prockter, L.M., Patterson, G.W. (2009). In: Europa (R.T. Pappalardo, W.B. McKinnon, K.K. Khurana, eds), pp. 237-258. [11] Kattenhorn & Marshall, (2006). J.of Structural Geology, 2006, Vol 28, Iss 12. 2204-2221