BANDS ON EUROPA: A NEW GEOMETRY BASED CLASSIFICATION TO EXPLAIN WHY BANDS FORM.
W. K. Zimmerman and S. A. Kattenhorn, Department of Geological Sciences, University of Alaska Anchorage (wkzimmerman@alaska.edu, skattenhorn@alaska.edu).

Introduction: Jupiter's 4th largest natural satellite Europa is home to five primary terrain types, including craters, chaos, ridges, plains, and the focus of this work, bands. Bands are tabular features that are distinguished by their contrast in albedo and/or surface texture compared with the surrounding terrain [1]. They are generally thought to form as dilational features, although contractional and strike-slip related varieties have also been described [2]. Multiple formation mechanisms have resulted in morphologic variability between band types such as the margins of bands variably having sharp bounding ridges or no bounding features, or an internal structure of ridges and troughs oriented subparallel to both the boundaries of the band and each other, versus almost no internal structure and a sudden change in albedo or morphology relative to the surrounding terrain [2-4].

It is postulated that the surface of Europa is geologically young (perhaps no more than ~90 my) [5] indicating that some process must be involved to resurface the icy satellite. Despite the breadth of previous work on how bands contribute to this process [e.g., 6], a central issue of limited imaging coverage or high-resolution (<25 m/pixel) imagery has resulted in bands not being fully characterized or understood.

To address this problem, we utilize the USGS Europa Global mosaic and NASA's Galileo orbiter SSI camera images to map and describe bands and classify them based on geometry, morphology, and potential mechanisms driving them. Spatial and geometric analysis utilized Galileo SSI and Voyager 2 images input into an ArcGIS 10.6 environment and stitched together as a global mosaic with 3 projections to the Europa_2000 reference system (north pole, south pole, and Mercator). Images range in resolution from 28 to 250 m/pixel. This study focuses on three primary regions of Europa including Castalia Regio, Argadnel Regio, and northern Falga Regio. Details of broad scale features were mapped within the constraints of image resolutions and our ability to reconstruct or interpret features. Lower resolution images (500 m/pixel) were used to describe broad scale feature characteristics including albedo changes or regional geometry changes. Higher resolution images (~20-60 m/pixel) were used to describe detailed feature characteristics including polyphase band openings, internal morphologies, and variations in morphologies within the same band. Band opening vectors were measured using piercing points (matching features on opposite sides of a band), opening distance was measured parallel to the opening vectors, and band width was measured perpendicular to the band margins.

Band Geometry: In order to address the controlling factors on why bands are first initiated in the ice shell, we propose here a means to distinguish between distinct dilational band types based on their characteristic and disparate geometries, but independent of the morphological and kinematic characteristics, which we attribute to the nature of the infill process once dilation proceeds. These geometric classifications include (but are not necessarily restricted to) rhomboidal, arcuate, wedge-shaped, and braided.

Rhomboidal: Rhomboidal bands (Fig. 1) are always located between overlapping segments of en echelon strike-slip or transform boundaries. Bounding ridges typically define the long axis edges of rhomboidal bands, which also comprise the fault segments along which initial strike-slip motion occurred. Tailcracks from these en echelon segments of the fault create linkages between adjacent segments that subsequently dilate to form the short axis edges of the band [e.g., 7].

Arcuate: Arcuate bands (Fig. 2) are curvilinear dilational bands that appear to have taken advantage of a preexisting weaknesses in the ice formed by cycloids: curved or cuspate structures that form chains of arcuate segments linked at sharp cusps [8, 9]. Dilation may be orthogonal to the boundary, but is typically oblique given the changing orientation of the boundary relative to the opening direction.

Wedge-shaped: Bands with a wedge-shaped geometry (Fig. 2) [e.g., 3] can be identified based on their differential opening widths along the length of the band. The wide end is truncated against a linear discontinuity (a fault or a ridge) along which strike-slip motion occurred, with a somewhat linear reduction in band width towards the narrow end of the band, which may even end at a sharp tip. Wedge-shaped geometry bands are abundant in Argadnel Regio, commonly referred to as the "Wedges" region.

Braided: Braided bands are geometrically complex, identified based on evidence of multiple distinct phases of band formation with younger band boundaries crosscutting older band boundaries within the same feature. As a result, each margin of the band acquired an interweaving or braided pattern that no longer matches its opposite side (i.e., the sides cannot be simply reconstructed), even though some preexisting surface features on either side may be able to be matched.

Band Morphology: In the examples we examined, where band opening occurred perpendicular to the band margin, the band morphology tended to be smooth. Conversely, where the opening is more oblique to the band margin, or is dominated by strike-slip motion, a lineated band morphology is more common. Where the opening vector changes relative to the orientation of the band margins (e.g., in arcuate bands for which the opening vector remains constant but the band margin curves), band morphology may change from smooth to slightly ridged, to a fully lineated morphology in as little as ten kilometers if the opening vector changes from perpendicular to the margin to almost parallel over a short distance, such as across the cusp of a cycloid.

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. Arcuate geometries form where a band exploits old cycloid features during dilation, possibly driven by surrounding plate motions [10]. Braided geometries are the most enigmatic with no clear formation mechanism; however, they are generally associated with large strike-slip faults or regions where there is a large amount of overprinted band formation. This could indicate that braided geometries are the result of multiple complex phases of variable band growth resulting in irregular margins and morphologies. 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.). We thus infer that band dilation and infill from below is a passive response to a surface-driven process (e.g., plate motions), 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 seem to mechanically interact over large distances and form linked boundaries of bands around isolated sections of crust, forming small mobile units or microplates. Where this occurs, triple-junction band geometries may develop.

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, 11], the differences in which remain loosely explained. The geometry based classification described here provides greater insight to the mechanisms controlling why bands are able to form in the first place.

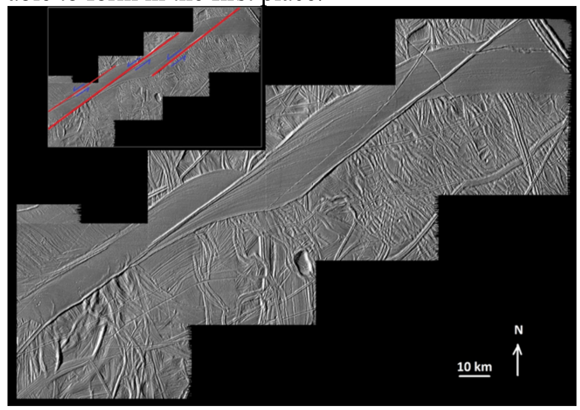

Figure 1. Image illustrates a rhomboidal band geometry along Astypalaea Linea. Top left inset: interpreted motion along strike-slip fault segments [7] with formation of rhomboidal bands between them. Band location: Lat/Long -64.7° /194.4°.

Figure 2. Image shows arcuate bands near Castalia Macula, identified in blue and red, that utilized preexisting cycloids to dilate. A brown colored band variably exhibits an arcuate geometry where labeled A, a rhomboidal geometry labeled B, and a wedge-shaped geometry labelled C. Image modified from USGS Europa global mosaic.

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] Patterson et al. (2006). *J. Struct. Geol.* 28, 2237-2258. [11] Prockter, L.M., Patterson, G.W. (2009). In: *Europa* (R.T. Pappalardo, W.B. McKinnon, K.K. Khurana, eds), pp. 237-258.