GEOLOGICALLY YOUNG TROUGHS ON EUROPA MAY BE ACTIVE. S. A. Kattenhorn and J. P. Kay*, Dept. of Geological Sciences, University of Idaho, Moscow, ID 83844-3022; simkat@uidaho.edu, jkay5@uic.edu.

Introduction: The Galileo mission to Jupiter revealed its icy moon Europa to be a pervasively fractured body. A diverse array of tectonic features, including ridge-flanked tension cracks, extensional spreading bands, strike-slip faults, and rare contractional features record 40-90 m.y. of geologic history primarily driven by tidally-induced stresses at its surface [1, and references therein]. During the observational period of the mission, however, no evidence was found to suggest that the moon is currently geologically active. In contrast, the Cassini mission to Saturn has revealed its small icy moon Enceladus to be a geologically active world with plumes of eruptive water ice emanating from prominent cracks straddling its south pole. Given the limited scope of observational surface coverage of Europa during the Galileo mission and its intense history of tectonic activity, the question remains as to whether or not Europa is currently tectonically active. Similar to Enceladus, the answer to this question lies with the geologically youngest cracks which, on Europa, are defined by subtle surface lineaments called troughs. We describe the types and distribution of troughs on Europa, then present models of contemporary stress fields and their relationships to trough orientations to make a case that, in some instances, the troughs may have formed in geologically recent times (within the past few thousands to tens of thousands of years) and have the potential to be currently active.

Troughs: Tidally-driven tensile stresses in the ice shell of Europa have resulted in the development of tension cracks called troughs [2-5]. These subtle features are only visible in high-resolution images (typically less than a few hundred meters per pixel) and crosscut all other geologic features (Fig. 1). An exception to this rule occurs where troughs have been disrupted by the formation of chaos: geologically young areas of surface disaggregation that are attributed to endogenic activity such as convection-driven ice diapirism. Nonetheless, some troughs noticeably crosscut chaos, implying that tectonic activity persisted throughout and beyond the age of chaos formation.

Unlike ridges, troughs lack raised edifices along their lengths. Nonetheless, they are likely the genetic precursors to ridges, suggesting that troughs undergo a prolonged period of activity after their initial formation, ultimately resulting in the construction of ridges to either side of the central crack. The exact process by which this occurs is still unclear [6], and may even be possible through multiple kinematic behaviors (extensional, contractional, or strike-slip motions). Regardless, the ridge formation process may take tens of thousands of years [1, 7-8]; therefore, any identification of troughs that formed within the past few tens of thousands of years may provide candidate sites for current activity.

Figure 1: Examples of troughs (marked by white arrows) in the E15RegMap region of Europa.

Troughs may form in response to a number of driving processes [1, 9], including tidal forcing, endogenic activity, folding, impacts, and flexure. We restrict our analysis to tectonic troughs caused by distortion of the ice shell by tidal forcing. These troughs can attain lengths of 100s of km and are a good proxy for global stress patterns induced by diurnal tides and nonsynchronous rotation (the latter being the dominant stress component for trough orientations) [9].

Mapped Trough Patterns: We mapped orientations, spatial patterns, and relative ages of troughs in 16 regions, targeting areas in the northern and southern plus leading and trailing hemispheres at image resolutions of 20-400 m/pix. An example of one resultant map is shown in Fig. 2. We classified all troughs by their type and age using color coding. This enabled us to identify the youngest tectonic troughs in any region for comparison to contemporary stress fields.
Contemporary Stress Models: Linear troughs are likely to have formed in response to a global stress field induced by nonsynchronous rotation (NSR). This stress is caused by a slow reorientation of the tidal bulge across the surface as the icy shell rotates relative to the solid interior, decoupled by a water ocean. The resultant stresses are greater than the diurnal tidal stresses and are thus more likely to cause linear fractures that can attain lengths of 100s of km. The NSR period of Europa is unknown but is likely to be sufficiently slow that the ice responds viscoelastically. We calculated stresses for a range of NSR periods (T), from 10,000 years (which is likely too low [1, 10]) to 5 million years, using the program SatStressGUI [11]: a graphics user interface developed at the University of Idaho based on the open-source code SatStress [12]. The maximum calculated stress magnitude is 3.4 MPa (for T=10,000 yrs).

Stress orientations can be plotted globally (Fig. 3) and compared to trough orientations. Because NSR occurs longitudinally (the shell rotates eastward), we can determine the minimum longitudinal angle between the current location of the troughs in the contemporary stress field and the location further west where the troughs match the stress field for a given T (i.e., the location relative to the tidal bulge where the troughs originally formed). Using this angle and T, the minimum length of time since initial trough formation can be calculated. For example, for the troughs at Tyre (Fig. 2), the most recent troughs formed 4400–972,000 years ago, depending on T. In Moytura Regio, young troughs may have formed 389–300,000 years ago. For T < 100,000 years, all young troughs examined may have formed within the past 50,000 years.

Discussion: Our comparative analysis of trough orientations and NSR stress fields suggests that many troughs may have formed <50,000 y.b.p. Troughs likely remain active long after their initial formation, ultimately constructing raised edifices (ridges) along their margins over 10s of 1000s of years; hence, it is conceivable that some troughs on Europa are currently active but have not yet constructed ridges. Current activity may involve primarily strike-slip motion and associated frictional heating [13]. However, if the trough cracks penetrate the entire thickness of the ice shell, the potential exists that material from a subsurface ocean could vent into space, akin to Enceladus, and could be observable by a passing spacecraft. Although diurnal tidal stresses are insufficient for cracks to overcome the weight of the ice and fully penetrate the shell, the addition of stresses from NSR and ice shell thickening could make it possible [14-16]. Although our analysis of young troughs is unavoidably limited by the existing coverage of Europa by the Galileo mission, several candidate sites for active cracks have nonetheless been identified that could be targeted in a future spacecraft mission. These include E17RegMap02_03, Bright Plains, Moytura Regio, and Tyre, although the best choices ultimately require a better knowledge of the value of T.

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