COMPRESSIVE ANTI-CRACKS AT THE TIPS OF STRIKE-SLIP FAULTS ON EUROPA AND IMPLICATIONS FOR FAULT MECHANICS. Simon A. Kattenhorn, Department of Geological Sciences, University of Idaho, Moscow, ID 83844-3022. (simkat@uidaho.edu)

Introduction: Secondary fractures, or tailcracks, at the tips of strike-slip faults are common on Europa [1] and form in response to high-magnitude tensile stresses induced by fault slip. However, linear elastic fracture mechanics theory (LEFM) predicts both extensional and compressive quadrants around fault tips [2]. Theoretically, these quadrants can be associated with tensile secondary fracturing (cracks) and compressive secondary fracturing (anti-cracks), respectively. The existence of such features in terrestrial rocks has been widely documented [3-4].

Tailcracks commonly manifest as dark bands that are readily identifiable; however, compression-related anti-cracks have not been previously described on Europa, possibly because their exact appearance in images is more subtle and hasn’t been specifically documented. The apparent dearth of compressive deformation features on Europa [5] is troubling considering the large amount of new crust that has formed by plate spreading-like mechanisms. Recent work [6-8] has indicated the possibility of missing portions of crust along strike-slip faults, ostensibly due to some form of crustal resorption process. In this work, I describe one potential mechanism by which this crustal resorption occurs, manifested as anti-cracks at the tips of strike-slip faults. The compressive anti-cracks occur in tandem with tensile tailcracks that form on the opposing sides of respective fault tips, reflecting differing styles of deformation in the compressive and extensional stress quadrants. The geometries and angular relationships of these features with respect to the plane of the fault create a fingerprint for the mechanics of fault slip (Fig. 1), as will be demonstrated with an example from Argadnel Regio (the “Wedges” region).

Secondary Cracks at Fault Tips: In response to motion along a strike-slip fault, perturbed stress fields are produced at the fault tips that are both greater in magnitude, and different in orientation, to the regional stress that caused the fault to slip. Resultant tailcracks propagate away from the fault tips in a direction governed by the characteristics of the perturbed stress state. The locations of tailcracks are governed by the locations of the regions of high tension (in extensional quadrants) at the tips, which occur to one side of each tip with an anti-symmetric pattern dependent on the slip sense. Mutually opposite sides of each tip zone experience a region of increased compression (compressive quadrants). The junction between the tailcrack and the fault defines a kink angle, \( \theta_t \) (where the subscript t stands for tensile) which, for pure sliding (mode II) motion in LEFM models, as well as in many terrestrial examples, is about 70° (Fig. 1).

A fault tip may also develop contractional features in the compressive quadrants to either side of the fault tips, commonly accompanying tailcracks in the extensional quadrants. These so-called anti-cracks [9] form perpendicular to the maximum compressive stress direction (unlike tailcracks) and are thus also governed by the characteristics of the near-tip, fault-perturbed stress field. Anti-cracks are most commonly described from rocks prone to solution, such as carbonate rocks or rock salt [3], forming solution surfaces.

For pure mode II motion (i.e., no opening along the shearing crack), the perturbed stress field produces anti-crack kink angles, \( \theta_c \) (where c stands for compression), that are identical to tailcracks (70°), resulting in a predicted 140° separation angle between tailcracks and anti-cracks that formed at the same fault tip, according to LEFM models (Fig. 1). This separation angle differs from that predicted in cohesive end-zone (CEZ) models of fault slip behavior in terrestrial rocks. These models hypothesize the existence of a zone of high friction near to a fault tip (the most recently formed portion of the fault). In response, the perturbed stress field is different to the LEFM scenario, with CEZ models predicting a 90° separation angle between tailcracks and anti-cracks [4].

As the ratio of mode I to mode II loading increases (i.e., as more opening accompanies slip) in LEFM models, the separation angle increases from 140° towards 180° due to changes in the respective kink angles of tailcracks and anti-cracks (Fig. 1); however, the separation angle remains constant at 90° for all loading.
conditions in CEZ models. The geometries of tail-cracks and anti-cracks thus provide important clues about fault motion history, particularly in terms of whether or not fault dilation accompanied sliding, and whether or not fault tips are regions of high friction.

Fig. 2. (a) Strike-slip faults in Argadnel Regio. (b) Dilated tailcracks in extensional quadrants at fault tips. (c) Anti-cracks in compressive quadrants.

Anti-cracks in Argadnel Regio: This region (Fig. 2a) contains numerous right-lateral strike-slip faults with dark bands at their tips that formed by dilation and intrusive infill of tailcracks. Locations of the faults and tailcracks, as well as tailcrack kink angles, θt, are shown in Fig. 2b. In each example, the tailcrack occurs on the predicted extensional quadrant side of the fault tip. The kink angles vary from 29° to 80°. Most of the tailcracks are tabular and facilitated the linkage of adjacent fault segments.

The compressive quadrant sides of each tip contain a class of secondary features (Fig. 2c) that somewhat resemble the tailcracks; however, they are both shorter and narrower than the tailcrack bands. I propose that these features represent convergence features, or anti-cracks, that helped accommodate contraction caused by motion along the faults. The anti-crack kink angles, θc, vary from 48° to 90° but tend to be at the higher end of this range. Very importantly, the tailcracks and anti-cracks define contrasting kink angles about identical fault tips (Fig. 2b-c). The separation angle between the tailcracks and anti-cracks at specific fault tips varies from 113° to 144°, with three of the four examples exhibiting angles greater than 128°.

A complete structural reconstruction of offset features along the middle fault proved to be impossible in the compressive quadrants. Gaps in the reconstruction demarcate zones of missing crust in the regions of the hypothesized anti-cracks, particularly at the western tip. These gaps are likely to be recording locations where parts of the surface were absorbed into the ice shell and recycled into the interior, similar to an effect described along “muscle-tissue” bands [7-8].

Discussion: In the tailcrack and anti-crack examples in Fig. 2, the separation angle is never 90°; rather, it is always closer to the 140° prediction for LEFM cracks (Fig. 1), strongly suggesting that CEZ assumptions are not appropriate for these faults. Thus, the Europan faults examined are unlikely to exhibit a zone of increased friction near the fault tip, suggesting that friction is homogeneous along the fault length. A comparison of individual kink angles with LEFM models indicates that a small amount of dilation accompanied slip along the fault surfaces in Fig. 2.

The existence of anti-cracks with predictable orientations at clearly defined fault tips provides justifiable evidence that zones of convergence at fault tips may partially accommodate the creation of new spreading-related surface area. Material is consumed within zones of high compression in the perturbed stress field at fault tips by an as yet undetermined mechanism. The maximum width of removed surface material does not exceed ~5 km whereas 27 km of new material developed within the dilating tailcracks in Fig. 2, resulting in a net surplus of new surface area.