

SEARCHING FOR EVIDENCE OF ACTIVE TECTONICS ON EUROPA. J. P. Kay and S. A. Kattenhorn, Department of Geological Sciences, University of Idaho, P.O. Box 443022, Moscow ID 83844-3022, USA. kay1829@vandals.uidaho.edu; simkat@uidaho.edu.

Introduction: Voyager and Galileo showed that the surface of Europa has undergone significant reworking at some point during the moon's history. The surface is covered in lineaments, which likely formed from the tides generated from Europa's eccentric orbit around Jupiter [1]. There is also a relative paucity of visible impact craters, suggesting a surface age of about 80 million years [2]. Therefore, all of the visible surface features have formed within that time frame. This yields a maximum age of the surface, but the search for a minimum age for tectonic activity is more challenging.

Ridgeless surface fractures [3] (also called troughs) are the youngest tectonic features on the surface, cross cutting all other fractures and occasionally regions of endogenic disruption (chaos). There have been several mechanisms to explain the formation of these fractures [1, 4-5], but the most likely of them seems to be formation by tectonic processes in the ice shell. The tectonic activity is likely caused by the tidal stress induced at the surface [1], but could also be a result of stresses induced by nonsynchronous rotation (NSR) of the ice shell, polar wander, or ice shell thickening.

Europa is a good candidate to be currently undergoing active tectonics. Searching for the evidence of recent tectonic activity logically starts with the geologically young, ridgeless surface fractures. This project will develop comprehensive fracture maps of the recent surface fractures using the program Arc GIS. Fractures have been mapped onto spatially-referenced images with each fracture having a unique identifier and embedded information about the length and orientation, the fracture classification (described below), and the crosscutting relationship (older or younger) between young fractures that intersect.

Preliminary mapping has identified at least six separate types of recent fractures that have distinct formation mechanisms: (1) tectonic fractures; (2) cycloidal fractures; (3) tailcracks; (4) endogenic process fractures; (5) flexure fractures; and (6) fold hinge fractures.

Fracture classification:

Tectonic Fractures: These fractures formed in response to a global stress (tidal or otherwise). Tectonic fractures have also been called regional fractures [6]. They can be >10 to 100s of km in length. Some of these fractures show segmentation along their lengths, or may show evidence of having formed by the coalescence of numerous segments. The temporal relationship of these features relative to the other surface fractures could yield a clear answer to recent tectonics on

the moon through comparisons to theoretical stress patterns.

Cycloidal Fractures: A type of tectonic fracture comprised of chains of arcuate lineaments that are individually up to 100s of km long and form in response to diurnal tidal stresses [7]. Their shapes potentially record the location of their formation (relative to the direction of Jupiter) due to the explicit, longitude-dependent stress field needed to account for their formation. Previous work has identified young cycloidal fractures [8] which could provide the most likely indicator of whether or not cycloid development has continued to the present day.

Tailcracks: Similar to terrestrial tailcracks, these cracks propagate from the tips of strike-slip faults and result from brittle failure from fault motion in the tensile quadrant at a fault tip. Tailcracks are secondary fractures that form in response to the locally perturbed stress field, and may not a good indicator of the global stress field at the time of formation, although they could conceivably indicate active strike-slip faulting.

Endogenic Process Fractures: These fractures are most commonly associated with a narrow strip of terrain around the rough edges of chaos regions. Endogenic process fractures appear to be the secondary cracks that form as a result of warping or disaggregation of the chaos region. Chaos regions result from local processes likely driven by thermal upwelling and diapirism in a convecting ice shell. This process disrupts the brittle volume above a diapir [9-10], forming regions of chaos or perhaps less developed lenticulae.

Flexure Fractures: These fractures are primarily found along the flanks of large ridges, the large weight of which impinges on the ice shell, causing elastic flexing that affects the local stress field. Billings and Kattenhorn (2005) showed that the tensile strength of ice could be exceeded by bending stresses from the flexing of the elastic portion of the ice shell [11].

Fold Hinge Fractures: Prockter and Pappalardo (2000) examined Astypalaea Linea and found a region of undulating folds across the surface of smooth band material in the fault zone [12]. They believed that the folding was due to contraction of the ice shell, causing tension cracks to form along the fold hinge.

Discussion: The fractures described above each formed as a result of different loading conditions. Therefore the presence of each type of fracture and their relationship to the other fractures can begin to build a temporal relationship of the stresses at the time of fracture formation. The interpreted stresses at the time of formation of the fractures can be compared to

the theoretical stress fields due to diurnal tidal effects and any contributions by nonsynchronous rotation. Not all of the fracture types are good indicators of the presence of active tectonics, however, due to the distinctly local nature of their formation mechanisms and because they are not relatable to a theoretical global stress state.

Tectonic fractures are likely to be the best indicator of recent tectonic activity. These are occasionally disrupted by chaos regions or lenticulae. In the analysis of fracture maps, determining whether there is evidence that tectonic fractures postdate chaos or lenticulae will be fundamental to making a case for active tectonics, especially if the orientations of these fractures can be reconciled with contemporary global stress fields.

Cycloids should form with specific orientations that are a function of the current stress field. A comparison of the most recent cycloids to the current stress field could be a litmus test for active tectonics of this type.

Tailcracks indicate the sense of motion (right-lateral or left-lateral) along the causal strike-slip fault. Therefore, if the sense of motion is compatible with the current stress field, this could be an indicator of active faulting. It is nonetheless possible that the tailcracks formed in an older stress state that is similar to the current state of stress, thereby providing a false positive test.

Endogenic fractures are not tectonic in origin; however, they form around geologically young regions of

crustal disruption and thus provide some age constraints on any other fractures that crosscut them. Flexure fractures may provide clues to whether ridge development continues to the present, if crosscutting relationships exist with other fracture types; however, they are unlikely to a good indicator of active tectonics.

Fold hinge fractures are rare and typically short. They are therefore of limited use in addressing the issue of active tectonics.

By understanding the formation mechanics behind the youngest fractures on the surface of Europa, it may ultimately be possible to address whether or not there is active tectonics on the moon.

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