CRATER-FRACTURE INTERACTIONS ON ENCELADUS: THE CONTROL OF CRATER SIZE ON PERTURBATIONS OF FRACTURE GROWTH. E. S. Martin and S. A. Kattenhorn, Department of Geological Sciences, University of Idaho, Moscow, ID 83844-30223, mart5652@vandals.uidaho.edu, simkat@uidaho.edu.

Introduction: The south polar thermal anomaly and plume activity [1,2] has dominated work focused on Enceladus. Little is known about the geologic history of Enceladus's surface beyond the south polar terrain (SPT) and minimal detailed fracture mapping has been attempted outside of the SPT. Morphologically distinct geological units have been mapped [3,4,5], revealing that adjacent terrains can vary widely. Heavily fractured terrains are centered on the leading and trailing hemispheres, separated by cratered terrains on the saturnian and anti-saturnian hemispheres. Understanding local heterogeneities of fracture and terrain types is critical for gaining perspective on Enceladus's global geologic history.

We aim to understand localized changes in fracture orientation seemingly caused by local perturbations in the stress field by craters within the cratered terrains [6,7,8], and whether or not these changes are dependent on crater size. Our results will begin to elucidate why some craters affect fractures but not others, and provide insights into the causes of local heterogeneities within the regional stress regimes on Enceladus.

Many fracture sets appear to be influenced by nearby craters. The mutually parallel trend of such fractures changes with increasing proximity to a crater, converging towards the crater in a somewhat radial pattern. The fractures then cut through and beyond the crater, returning to the original orientation of the fracture set at some distance past the crater (Fig. 1). On average, interacting fracture sets extend 10s of kilometers from crater centers. Craters that perturb fractures are both simple and complex craters, with some craters showing various stages of relaxation [8,9]. Fractures that experience reorientation by a crater appear relatively young, and many of them are pit chains, thought to be some of the youngest features on Enceladus [10]. Preliminary observations suggest that craters may influence fractures as far as ~5 crater diameters away from the crater center. Future work will quantify this observation over a range of crater sizes.

Crater-fracture interactions have been previously noted [6,7,8] and several formation mechanisms have been presented. Reorientation of fracture growth may be due to topographic loading by the crater rim [6]. This is not a favored mechanism, as craters appear to perturb fracture growth over large distances (~5 crater diameters), and rim topography may not be sufficient to influence local stresses at such a distance. Crater depth, controlled by relaxation, may create the proper conditions for fracture reorientation [8]. Another possibility is a source of internal pressure underneath the crater, such as thermally mobilized ice due to an impact, which would cause parallel fracture sets to reorient radially to the crater.

Methods: In our analysis, craters were selected where they were overprinted by one or more fractures. Because the influence of crater size was the target of this study, a wide range of crater sizes were examined where crosscutting fractures were observed, totaling 41 craters. Crater diameters were measured and each crater was assigned a 1 or 0 denoting whether or not crosscutting fractures experienced re-orientation as they passed across the crater.

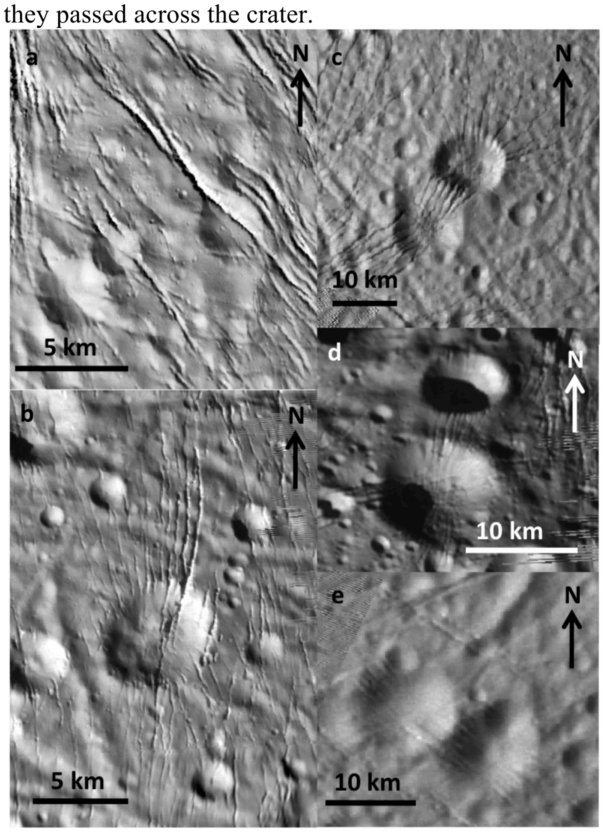

Figure 1: Crater-fracture interaction morphologies. **a** Centered at -3°, 136°. **b** Centered at 2°, 162°. **c** Centered at -23°, 156°. **d** Centered at 34°, 160°. **e** Centered at -34°, 152°. **a** and **e** show crater-fracture interactions where no fracture reorientation occurs. Craters in **b, c** and **d** show reorientation of fractures but to varying degrees of orientation change.

Crater-Fracture Morphologies: Interactions between craters and fractures take on two morphologies: fractures that crosscut craters with no orientation change (Fig. 1a,e), and fractures that crosscut craters with a quantifiable orientation change (Fig. 1b,c,d).

Fracture sets that demonstrate reorientation show a modification of parallel sets that converge towards the crater center. This can be a subtle change (Fig. 1d) or more pronounced (Fig. 1b). Fig. 1c shows two craters of nearly the same size interacting very differently with fractures; radial fractures emanate from the northern crater (which, when viewed from a larger spatial extent do not return to their original parallel orientation), while a parallel set crosscuts the southern crater. The same phenomenon was noted by [8] who suggest that the relaxation state of the crater may play a role in how fractures are perturbed.

Results: Fig. 2 shows the spatial distribution of craters on a global scale, classified by whether or not fractures reorient as they interact with the crater. There may be localized clustering of craters within the same group 1 or 0 (showing fracture reorientation and no change, respectively); however, the sample size must be increased to verify this result.

Fig. 3 shows the distribution of crater size within crater groups 1 and 0. The mean of crater group 1 is 10.4 km (with crater diameters ranging from 2.2-9.7 km) and the mean of crater group 0 is 6.1 km (with crater diameters ranging from 5.9-20.5 km). This data suggests that there is no concrete threshold at which crater size will begin to influence fracture growth, but rather a continuum of crater sizes in the range of 6-8 km. No dependence on crater diameter was found by [8] but it is unclear how rigorously this dependence was examined.

Discussion: We interpret our observations to suggest that there is a dependence on crater size in the reorientation of fracture growth in the vicinity of the craters examined here. No explicit threshold of crater diameter must be achieved to result in a perturbation of the local stress field in the crater vicinity, although a transition occurs in the crater size range of 6-8 km, beyond which fractures are consistently perturbed by the craters. This suggests a complex interaction between craters and fractures, with crater size being one parameter within a larger, more complex context.

What makes larger craters more capable of perturbing local stress fields than smaller craters? If an internal source of pressure beneath a crater is thermally mobilized ice induced by impact, a smaller impact crater may not sustain enough heat to affect fracture growth at some later time. What cannot be determined is the amount of time that lapsed between crater and fracture formation, which will vary between craters. The proximity of a newly formed crater to a simultaneously propagating fracture set may explain why some smaller craters (5-6 km) are able to reorient fractures where larger craters (8-9 km) cannot: smaller craters forming near propagating fracture sets may retain their heat long enough to perturb its local stress field and modify fracture growth.

Future Work: To further understand the extent of influence of craters on fractures on Enceladus, accurate measurements of the change of fracture orientation as a result of the craters' influence will be completed. We will examine whether such changes are also influenced by regional stress fields related to tidal deformation of the ice shell. The radial extent of each crater's influence will be measured to determine if larger craters (which seemingly are more capable of reorienting fractures) have a correspondingly wider influence on fracture growth and the spatial extent of the local stress perturbation.

References: [1] Porco et al. (2006) *Science, 311,* 1393-1401. [2] Spencer et al. (2006) *Science, 311,* 1401-1405. [3] Kargel & Pozio (1996) *Icarus, 119,* 385-404 [4] Crow-Willard & Pappalardo (2010) *41st LPSC* Abs. #2715. [5] Crow-Willard & Pappalardo (2010) *42nd DPS* Abs. #25.03. [6] Miller et al. (2007), *Ices, Oceans and Fire: LPI Contribution No. 1357,* p.95-96. [7] Barnash et al. (2006) *38th DPS* Abs. #24.06. [8] Bray et al. (2007) *38th LPSC,* Abs. #1873. [9] Kirchoff & Schenk (2009) *Icarus, 206,* 656-668. [10] Michaud et al. (2008) *39th LPSC* Abs. #1678.

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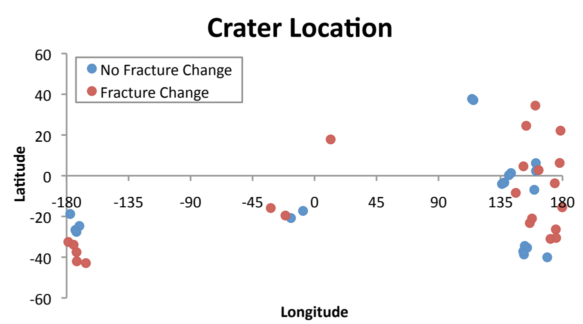

Figure 2: Spatial distribution of craters examined in this study. Blue indicates crater-fracture interactions where no fracture reorientation is observed, and red indicates where fractures have undergone reorientation.

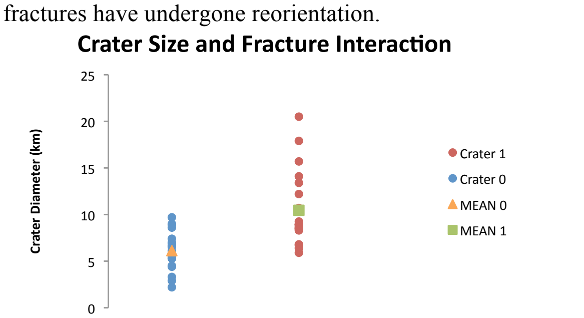

Figure 3: The distribution of crater size within groups 1 and 0 and their means (10.4 km and 6.1 km, respectively). There is no absolute threshold at which crater size dominates fracture reorientation, but a transition occurs within the 6-8 km crater diameter range.