AN INVESTIGATION OF THE RELATIONSHIPS BETWEEN DOUBLE RIDGES AND PITS ON EUROPA.
J. L. Noviello[1] and Z. A. Torrano[1], [1]School of Earth and Space Exploration, Arizona State University. Bateman Physical Sciences, F-Wing Room 686, Tempe, AZ 85287-1404. Jessica.Noviello@asu.edu

Introduction: Europa is an ocean world with compelling potential for habitability due to the large amount of water beneath its ice shell [1]. Ridges are plentiful on Europa's surface, and present themselves in a variety of morphologies [2,3]. In many cases these ridges appear as "redder" than the surrounding terrain due to the presence of salts on their crests [4]; this has been interpreted as evidence that ridges are associated with liquid water on Europa. Other features, notably chaos, also appear as redder than the surrounding terrain, suggesting they also are associated with briny water on Europa. Whether this water is from the subsurface ocean or sills [5,6] within the ice shell itself has yet to be determined.

One of the most common types of features on Europa is a ridge, commonly a double ridge. A double ridge is a linear feature described as a thin central trough is flanked by two raised edifices that are dominated by mass wasting processes [3,7,8]. Ridges in particular may be associated with liquid water within Europa's shell. Cracks starting at the ice shell's base may form as a result of an overpressurized ocean pushing back on the ice shell that constrains it [6]. These cracks would allow water to rise and ascend ~90% of the distance to the surface. The water would then spread out into an elliptical sill [5–8]. As the water freezes, the sill would need to expand, stressing the surface and causing it to deform in response. If the liquid water pocket is taller than it is wide (e.g., a dike-like water intrusion), then its crystallization and accompanying stresses could form the characteristics of a double ridge [8]. Later work [9] appears to corroborate this, as their models did not readily produce horizontal sills via cracking and fracturing.

Pits on Europa may also be connected to liquid water sills [5,6]. These sills models predict that the presence of liquid water in a saucer-shaped sill within Europa's ice shell and its evolution over time formed Europa's microfeatures (e.g., pits, domes, spots, hybrids, and small chaos) now observed [10]. First, liquid water enters a hollow area within the ice shell and begins to expand. If the weight of the sill is not sufficiently compensated by the ice shell, then the weight of the sill with cause the surface above to collapse, forming a pit. Eventually the liquid water will begin to freeze, and pits will reverse the downwarping and either return the surface to its previous elevation or let it become slightly domical. The implications of this model are such that there could currently be liquid water underneath pits, as the weight of liquid water is required to downwarp the ice above. One other prediction of [6] is that pits are clustered in space, which has been demonstrated with clustering studies done in [11], giving credence to the sills model for microfeature formation on Europa. The saucer-like shapes of these sills contrast with the linear, dike intrusion models detailed in [7,8].

If both pits and double ridges are associated with liquid water in Europa's ice shell, then they should exhibit a spatial relationship to each other on the surface; namely, they should be clustered together, and more pits should be found closer to double ridges. Here we investigate this prediction using previously published datasets [7]. We seek to estimate the average distance between pits and double ridges in four regions on Europa and assess whether this distance indicates that pits are more likely to be found near double ridges rather than randomly distributed on Europa's surface. We also look to see if the overall orientation of pits correlates with the distance from a ridge and if the pits align with the direction of the nearest ridge. If a relationship is found, then we need to more thoroughly consider how pits and ridges are related, likely through modeling how sills can extend laterally in Europa's ice shell [6,9] to form multiple types of ridges. If they are not associated, it suggests that they are formed through different methods on Europa which may or may not be related to liquid water trapped in the ice shell.

Methods: We map in four of the regional mosaic ("RegMap") areas of Europa: E15RegMap01, E15RegMap02, E17RegMap01, and E17RegMap02. We map and characterize the ridges in these RegMaps according to the descriptions in [2,3], paying special attention to the locations and abundances of double ridges. These ridges are mapped as linear features in ArcGIS and their general orientation is determined. We also characterized the ridges into one of the following groups: trough, single ridge, double ridge, ridge complex, band, and cycloid.

We use a previously published dataset [11] to obtain the locations of pits mapped in these RegMaps. Using tools native to ArcGIS, we convert the pits to points and measure the distance between each pit to its nearest double ridge and to its nearest ridge of any morphology. We first qualitatively examine the distribution of pit-to-double ridge distances and identify any notable findings. Finally, we perform quantitative tests including nearest-neighbor analysis [12] and basic linear regressions to determine if the average distance between pits and ridges is statistically significant and to

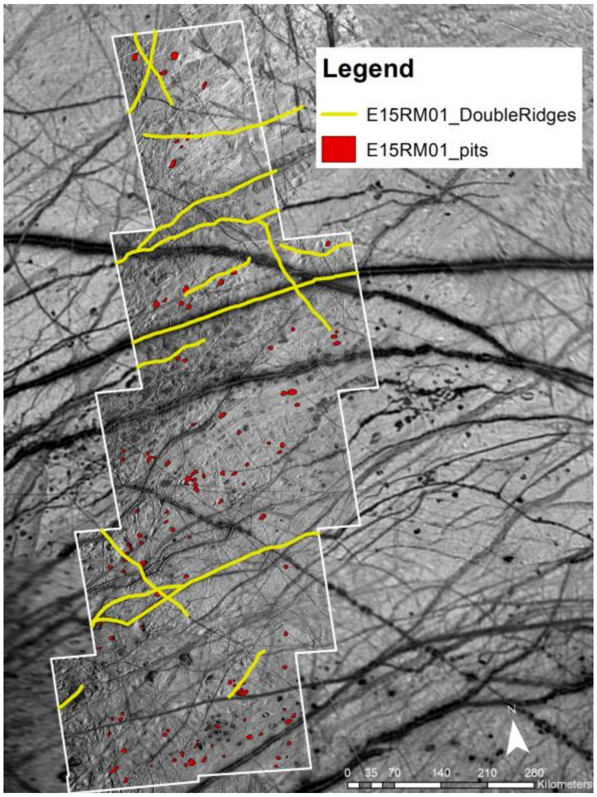

Figure 1: E15RegMap01 region (northwest quadrant of Europa) with double ridges and pits mapped. The white outline represents the extent of the E15RegMap01 mosaic.

study the degree of correlation between overall pit orientation and distance from a ridge.

Results: Some ridges show multiple morphologies along its total length; e.g., some double ridges change to a single ridge morphology, or double ridges change to ridge complexes. This supports the idea that ridges in general are genetically related to each other and have similar formation mechanisms [8]. There are also examples of single and double ridges that have clear cusps, as a cycloid would have. These ridges were classified as separate groups type from those named in the methods. Many of the ridges, at least in E15RegMap01 (Fig. 1), also cut across each other, which makes it difficult to accurately identify individual ridges and to trace their full extents.

Out of the 119 linear features mapped in the E15RegMap01 region, 15 of them were classified as double ridges. The double ridges are more numerous towards the northern extent of the region. There are 120 pits in the E15RegMap01 region. There is no preferred distance between pits and the nearest double ridge; distances to the nearest double ridge range from 0 km to 160 km (Fig. 2). There also appears to be no clear correlation between pit orientation and distance to nearest double ridge (n = 120, r_2 = 0.009, p-value = 0.297; Fig. 3), at least in this region of Europa.

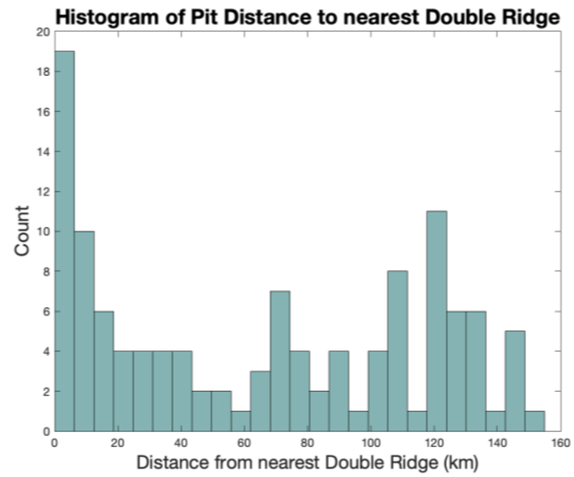

Figure 2: A histogram of distances between pits and the nearest double ridge. There is no clear preferred distance between pits and ridges, though is a peak for distances under 10 km.

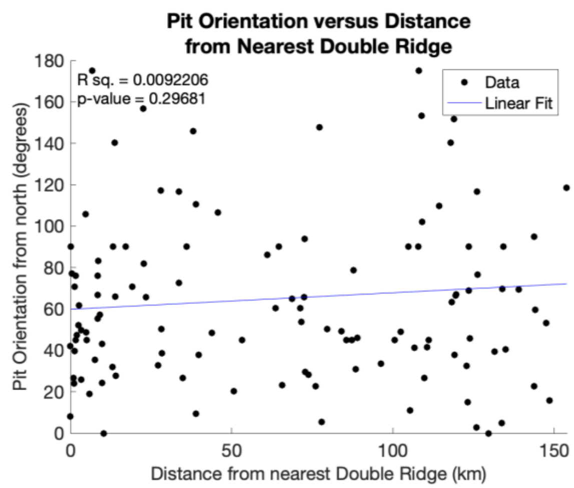

Figure 3: A scatter plot of the pit orientations versus distance from nearest double ridge in the E15RegMap01 region, with an overlain linear regression. There appears to be no clear correlation between pit orientation and distance to nearest double ridge.

References: [1] Chyba, C. F. and Phillips, C. B. (2007) *Planets and Life: The Emerging Science of Astrobiology*, 388–423. [2] Greeley, R. et al., (2000) *JGR, 105*, 22559–22578. [3] Kattenhorn, S. A. and Hurford, T. A. (2007) *Tectonics of Europa*, in: Europa, 199–236. [4] Hand, K. P. and Carlson, R. W. (2015) *GRL*, *42*, 3174–3178. [5] Schmidt, B. E. et al. (2011) *Nature Letters 479*, 502–505. [6] Manga, M. and Michaut, C. (2017) *Icarus*, *286*, 261–269. [7] Dombard, A. J. et al. (2013) *Icarus*, *223*, 74–81. [8] Johnston, S. A. and Montési, L. G. J. (2014) *Icarus*, *237*, 190–201. [9] Craft, K. L. et al. (2016) *Icarus*, *274*, 297–313. [10] Noviello, J. L. et al. (2019) *Icarus*, *329*, 101–123. [11] Noviello, J. L. (2019) Ph.D. Dissertation, Arizona State University. [12] Clark, P. J. and Evans, F. C. (1954) *Ecology*, *35*, 445–453.