EUROPA RIDGE MORPHOLOGY IS NOT CORRELATED WITH CURRENT SHEAR HEATING OR TIDAL STRESS. C. J. Berenbaum\textsuperscript{1}, L. G. Stenson\textsuperscript{1}, G. C. Collins\textsuperscript{1}, and N. P. Hammond\textsuperscript{2}, \textsuperscript{1}Wheaton College Massachusetts, Norton MA, \textsuperscript{2}Providence College, Providence RI.

Introduction: Most of the surface of Jupiter’s moon Europa is covered with tectonic features such as cracks, double ridges, and more complex ridges. Many model formation mechanisms have been proposed to explain the origin and development of ridge features (see summaries in [1, 2]) which all depend to some extent on the maximum tensile, compressive, or shear stress in the ice shell. Much of the work on understanding the stress state in Europa’s ice shell has concentrated on stresses raised by Jupiter’s tidal influence: diurnal tidal stresses alone, and stress from diurnal tides mixed with background stress from nonsynchronous rotation (NSR) or true polar wander (TPW). In this work we examine whether observed differences in the morphology of ridges is attributable to differences in the level of shear heating from diurnal tides, or from especially high or low levels of resolved tensile or compressive stress.

This abstract describes the process of mapping, classifying, and statistical correlation of ridge morphology. A companion abstract by our collaborators in Eakins et al. [3] describes the process of tidal stress modeling that was used in this work.

Data collection: The first step in this project was to create a database of recent tectonic features on Europa, sortable by morphology, location, and orientation. Ridges on Europa appear to lie along a morphological spectrum (Fig. 1), implying some kind of developmental relationship (e.g. [4]). Figure 1a shows troughs at one end of the spectrum, sometimes called cracks or fractures in other works, these are simple linear valleys cutting across Europa’s surface. Figure 1b shows an example of a feature we call “protoridge”, also called a raised-flank trough in other works, these are similar to troughs but have sides that are slightly elevated above the surrounding terrain. Figure 1c shows a double ridge, which is two parallel ridges raised above the surface. Figure 1d shows a complex ridge at the other end of the spectrum, which consists of several ridges that are parallel and/or interweaving. For the purposes of our classification scheme, we also included a fifth “other” category for occasional tectonic features for which their morphology did not fit into the four other categories.

We used a set of georeferenced Galileo mosaics [5] as our image basemaps. We examined all 64 Galileo mosaics acquired at pixel scales of 250 m or smaller, covering approximately 10% of Europa’s surface. We used this resolution cutoff because we could not confidently classify the morphology of tectonic features in images acquired at lower resolution. Due to the geographic distribution of Galileo imaging, there is a bias toward the antijovian hemisphere.

In each mosaic, we used cross-cutting relationships to identify the three most recent generations of tectonic features. Because the position and orientation of features on Europa may be altered over time by NSR, TPW, or plate motions (e.g. [6, 7]), only the most recent tectonic features can be compared with confidence to the current tidal stress state. We recognize that due to the uncertainty in using relative dating techniques in disconnected areas, there is no guarantee that the youngest feature in one area is near the same age as the youngest feature in another area. With this important caveat in mind, relative dating in disconnected areas is the best that can be done with currently available data.

Within each area, for tectonic features in the most recent three generations, points along the features were digitized with 0.5° spacing. Each point contains information about the geographic position, the azimuth of the feature averaged along that half degree length, the relative age generation, the morphology classification described above, as well as uncertainties in generation or morphology. Information was also attached to the points describing whether the feature accommodated

![Figure 1](https://example.com/figure1.png)

**Figure 1.** Examples of ridge morphology categories used in this study. (a) Trough, (b) Protoridge, (c) Double ridge, (d) Complex ridge.
tectonic offsets of pre-existing features, whether the feature was part of a cycloid, if the feature was significantly interrupted by later formation of chaos terrain, and whether there were image quality issues such as compression artifacts, data gaps, especially high or low solar incidence angle, or distortion due to high emission angle.

After completion, the database was sent to our collaborators to add information about resolved stress values on the fault planes, as well as predicted shear heating values, under stress scenarios of diurnal, diurnal with NSR, diurnal with TPW, and diurnal with obliquity, as described in [3].

**Results:** If shear heating is primarily responsible for the observed spectrum of Europa ridge morphology [8], then there should be a correlation between morphologically developed ridges and the predicted level of shear heating on each feature. In other words, troughs should exhibit the least heating and double ridges and/or complex ridges should exhibit the most. Figure 2 shows the summary of predicted heating values for all features in our database.

We found no statistically significant difference in shear heating across the morphology categories. The lack of statistically significant correlation held true in all of the stress scenarios tested by [3], as well as when the data was filtered by only using the most recent generation, or separating equatorial from polar regions (due to systematic differences in background stress), or filtering out data from mosaics with challenging lighting, viewing, or other data quality issues. We did not find any way to sort or filter the data that would produce a significant correlation between shear heating and morphology. Thus, we must accept the null hypothesis that shear heating and ridge morphology are unrelated.

To determine whether any of the morphological categories were statistically separable from the rest, the most applicable test was the Kruskal-Wallis rank sum test. We found that in most scenarios, complex ridges were separable from the other categories, and had lower shear heating values. Also, features (regardless of morphology) that accommodated offsets of pre-existing features were separable, and had lower shear heating values. Both of these results run counter to the hypotheses that shear heating develops more complex topography and can locally heat the shell to accommodate permanent offset. However, it is known that if the Kruskal-Wallis test is given unequal sample sizes, it can give biased results [9]. Complex ridges and features with offsets are both categories with much smaller numbers of features, and so the separability of these categories may be unreliable.

With the database and stress models in hand, we also ran a short study to test whether there was any correlation between ridge morphology and the maximum or minimum compressive stress experienced during a diurnal tidal cycle on Europa. Ridge formation models that involve compression, or that involve opening of tension fractures, would depend on such a relationship. We also found no statistically significant correlation between morphology and the maximum or minimum stress excursions during the tidal cycle.

**Outstanding questions:** The lack of any detectable correlations leaves us with several questions. Are ridges on Europa formed by a process that is unrelated to tidal stresses? Alternatively, are global tidal stresses overwhelmed by local stresses in many parts of Europa?

![Figure 2](https://example.com/figure2.png)

**Figure 2.** Predicted shear heating for features in each morphology category (all data plotted). Boxes show the median and interquartile range, dots are outliers. Differences between categories are statistically insignificant.

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