GLOBAL MICROFEATURE MAPPING ON EUROPA: CONSTRAINING MICROFEATURE FORMATION MODELS AND THE PRESENCE OF LIQUID WATER IN THE ICE SHELL.

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Introduction: Jupiter's moon Europa is an active target of research because of its unique geology and its potential for habitability. The data returned from the Galileo mission was enough to hint at a possibly dynamic world, but left significant holes in our understanding of Europa's geology, structure, and processes. To address these remaining questions, the NASA flagship mission Europa Clipper will return to Europa in the mid-2020s [1]. Europa's unique icy chaos features present as areas of disrupted terrain that are often, but not exclusively, associated with low albedo [2,3] and the presence of irradiated salts [4]. The fact that chaos disrupts and transforms the previous terrain indicates that some kind of melting is involved, and their association with salts suggests they may also be involved with material transport. Early models explained some characteristics of chaos features, but failed to explain all of them [3].

In addition to chaos, there are several types of endogenic surface features that are roughly the same size as the smallest confirmed chaos features [5–9]. We define these microfeatures as uplifts and domes, pits, spots (areas of consistently low albedo but no obvious topography), and hybrid features. We further restrict our definition to features <100km^2 in area; microfeatures other than chaos are rarely larger than this size. Formation models of microfeatures share similarities with those for chaos formation [10,11], invoking material transport and/or liquid water in Europa's shallow subsurface. Small chaos features may even form along a continuum with these other microfeature types [10,11].

The distribution of microfeatures is known in the areas of Europa's surface that are covered by the regional mosaics ("RegMaps"), made up of images with ~218-233 m/pix resolution, which cover ~10% of the surface [9,12,13]. The efforts to connect microfeature formation to any kind of heat transport in Europa are confounded by the fact that microfeatures are difficult to identify and accurately classify outside of RegMaps, where image resolutions are significantly lower (≥ 1.5 km/pix). Finding microfeatures outside of RegMaps would provide new observational constraints for microfeature formation models.

We have now conducted multiple studies of microfeatures in order to 1) identify quantifiable characteristics that differentiate microfeature types, 2) test methods of expanding microfeature mapping to low resolution images, and 3) investigate the spatial relationships between and among microfeature groups. Our overarching goals are to constrain the presence of liquid water in the ice shell and better understand heat and material transport from the ocean to the surface. This work will also allow us to make testable predictions ahead of the Europa Clipper mission, develop new ideas about microfeature formation, and gain a deeper understanding of how Europa operates.

Microfeature mapping: We first mapped all microfeatures across Europa's RegMaps. We then compared our dataset against three others [5,6,8]. The features included in the final analysis were those that were mapped in at least two out of the four datasets. Our digital database provides the community with the most robust dataset of Europa's microfeatures yet assembled [9]. We then collected morphological characteristics for all mapped features. Across all four regions mapped, we find that microchaos features are the most numerous, followed by pits and domes. Spots are the least common features, and the smallest, which might indicate an observational bias, as they may contain disruptions smaller than what is visible at this scale. Microchaos are also, on average, larger than other microfeatures. Because we have analyzed a subset of chaos, the global size average of chaos is likely larger. There is no evidence of domes, pits, or spots larger than 100 km^2 in area.

Multivariate statistical analyses: To quantitatively assess differences in microfeature types, we applied a statistical test called discriminant function analysis, or DFA [14], included in the software SPSS [15]. It is a test used to sort data points of unknown origin or morphology into groups. Using the quantitative measurements of all of the mapped features, we ran the DFAs to determine how well the chosen variables sorted between the groups, with the purpose of determining the most diagnostic variables. The application of this analysis to a mapping project further minimizes any variation caused by the subjective measurements of different mappers. It also creates a framework to quantitatively classify features that are mapped in future work, including features that have been and will be mapped outside of the RegMaps.

Previous work [12,13] provides evidence that, while it is easy for the analysis to separate between combined supergroups of chaos/spots/hybrids and pits/domes, it struggles to separate between the component groups. This result supports previous conclusions [3,10,11] that chaos, hybrids, and spots are genetically related.

Low-resolution mapping: The ability to find microfeatures outside of RegMaps is important for learning about heat transfer within Europa's ice shell, as different heating mechanisms will produce different distributions of microfeatures. With a global map of microfeatures, it will be possible to compare observations to predictions by models, and make testable predictions for the Europa Clipper mission to address. To this end, Leonard et al. [16] have produced a global map of chaos of all sizes, including microchaos. However, their assumption was that all visible microfeatures were chaos; no attempt was made to differentiate between chaos and other microfeatures. In an effort to determine the accuracy of the chaos map, and thus the observational constraints, we have also mapped one of the RegMap areas in low-resolution images. We first mapped and classified all the visible features in a way consistent with earlier methodology, then compare our results between the RegMap and low-resolution mapping efforts.

RegMap mapping: We selected E15RegMap01 for our analysis because it had the highest number of mapped features, 312. Of those, 285 are <100 km^2 in area, and thus considered microfeatures in our analysis. The resolution of the corresponding "low-resolution" images is around 1.5 km/pix, so we considered features > 7.5 km in diameter to be mappable. Out of the 285 classified microfeatures, 111 of them were over that resolution limit.

Low-resolution mapping: We mapped 216 features in the low-resolution images within the RegMap boundary. In total, we failed to map 195 of the original classified features; 154 of them (79%) were under the resolution limit. This means that we were able to recover some (41) of the original dataset despite the fact that they were under the 7.5 km diameter minimum. The numbers do not add up to the total number of microfeatures in the RegMap because 75 features that were mapped in low-resolution were unmapped areas in the RegMaps; in other words, false positives. 30 of these features were truly dark parts of ridges or ridge intersections, 4 were areas of rough/chaotic terrain where some chaos features were also present, 9 were the shadows of pits and domes, and 32 were areas that had no corresponding feature in the RegMap. This suggests that the lighting angles have a significant effect on the accuracy of mapping efforts, consistent with previous work [17].

Of all features originally mapped in the RegMap, we were able to find 82.1% of chaos, 73.9% of spots, 68.4% of hybrid features, 24.2% of domes, and 5% of pits in low-resolution mapping. Of the features that were large enough to find but were missed, 46.3% of them were pits, 29.3% were chaos, 12.2% were domes, 7.3% were mapped but unclassified, and 4.9% were hybrids. We mapped and classified 106 features as chaos in the low-resolution images, but only 62 (58.5%) of these features were verified as chaos in the RegMap. The features that turned out to be non-chaos were either hybrids (34.1%), spots (13.6%), or unmapped features (40.1%). These results show caution must be taken when mapping small chaos in low-resolution images, especially those with low incidence angles, as dark areas are not necessarily chaos.

It is important to note that while chaos may have been overestimated in the low-resolution dataset, it was very unlikely that a mapped feature was truly a dome or a pit because those features were either missed during mapping or rarely misidentified as chaos. Rather, as long as the feature in the global map is a microfeature (not a false positive), it is very likely chaos or a chaos-related feature. If the results of the DFA are taken into account and chaos, hybrids, and spots are considered a closely related class of features, then the accuracy of a potential chaos feature mapped in low-resolution actually belonging to that class rises from 58.5% to 78.3%. The main risk involved in low-resolution global mapping is the false positives (the unmapped features), and future work should determine the lighting conditions that minimize this number, as well as considering the global distribution of the other microfeature types.

Future Work: Aside from analysis on the lighting conditions of low-resolution images, planned future work will involve further analysis of the data using logistic regression [14,15]. A logistic regression analysis considers a question with a binary answer (e.g. is this unclassified feature mapped in a low-resolution image microchaos?), gives an answer, and attaches a probability to the answer. Logistic regression is a more sensitive analysis than DFA at the cost of a narrower focus, and the framework for performing it already exists from the multiple DFAs. We will apply this kind of analysis to the global map of chaos [16], thus creating more accurate observational constraints to be applied to microfeature formation models on a global scale and advance our knowledge of Europa's dynamics ahead of the Clipper mission.

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