

## Large Impact Features on Icy Galilean Satellites: Implications for ice shell thickness and Habitability

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Nowhere in the solar system are impact morphologies observed in greater variety than on the icy Galilean satellites. This is very likely a consequence of the structural and thermal state of the crust at the time of impact, and perhaps impact velocity. We have conducted a multi-disciplinary investigation to study how these features formed. The particular combination of geophysical factors and impactor characteristics that is shared by these satellites is likely responsible for these features. We have derived Digital Terrain Models for a number of these features, which have been used as a tool for producing facies maps. Impact features on Ganymede and Callisto are relatable to impact features on Europa, with implications for its ice shell history. We have identified two broad classes of these impact features: (a) *Crater forms*, which variously include pits, central domes, and crater rims; and (b) *Palimpsests (including pene-palimpsests)*, which all have smooth enclosed central plains, an extensive outer undulating plains unit, concentric arcuate ridges (in the case of pene-palimpsests), and no recognizable rim. The very large, measured volume of the undulating plains unit of the pene-palimpsest Buto, Ganymede, substantially exceeds the amount of target material that could have been both melted *and* excavated by the impact event itself. Therefore, we conclude that the undulating plains material was derived from a fluid or “slushy” layer in the near-surface target at the time of impact. The recognition of undulating plains as the dominant unit in Memphis and Nidaba, two other palimpsests on Ganymede that we have mapped (which display highly variable crater counts, with Buto being the least cratered), leads us to a working hypothesis that these plains only form where and when the target has substantial near surface fluid or “slush.” By extension, all other impact features on Ganymede and Callisto, such as those with central pits and central domes, formed in targets with no pre-existing, or at most inconsequential, amounts of fluid or “slush.” Supporting this conclusion, modeling by members of our group indicates that the present topography of impact features with central pits and domes can be largely explained by the behavior of ice alone, with no or little contribution from fluids. Our study supports explanations for the formation and final appearance of palimpsests (and pene-palimpsests) that are entirely applicable to this feature class, and sharply distinct from explanations for other impact features (crater forms) on Ganymede and Callisto.

### Implications for Europa

Tyre and Callanish, if analogues to pene-palimpsests, are much smaller than the Ganymede and Callisto features. The pene-palimpsests of Ganymede and Callisto formed within their ice crusts (and upper mantles) in the first ~15% (?) of Solar System history, whereas Europa’s features and crust represent events of the last ~1% of Solar System history. Is Tegid really analogous to dome craters on Ganymede and Callisto? Central domes are brighter and inferred to represent frozen impact-melt beneath the center of the craters. Can we see and map the extent of frozen sub crater impact-melt pools with GPR? Callisto and Ganymede’s upper non-ice crust composition and thicknesses may be different: we need more lab work with respect to fundamental radar properties. REASON “blind” observations of pene-palimpsests and dome craters on Ganymede and Callisto combined with RIME profiles of these features may be useful in determining how analogous Tyre, Callanish, and Tegid really are to the Ganymede and Callisto features.