Tectonic Deformation of Icy Surfaces: Application to Pluto and Charon. S.A. Kattenhorn, Department of Geological Sciences, University of Idaho, Moscow, ID 83844-3022, simkat@uidaho.edu.

Introduction: Spacecraft missions to the outer solar system have revealed a diverse range of icy moons, with surfaces sculpted by tectonism, cratering, mass wasting, thermally/compositionally driven endogenic processes, and deposition of loose material to form regolith. Many icy surfaces are pervasively tectonized, replete with fractures, faults, and significant topography (e.g., Europa, Ganymede, Enceladus, Dione, Rhea, Titan, Miranda, Ariel, Titania, Triton). Such features record a history of deformation in crosscutting relationships, with feature orientations indicating evolving stress conditions through time. Although extensional deformation appears to dominate, shear deformation (strike-slip faulting) and contractional deformation are also possible. The identification of surface deformation on Pluto and Charon, which have experienced stress conditions likely favorable for tectonism [1], requires knowledge of the range of deformation styles visible on other icy surfaces in the outer solar system.

Distribution of Deformation: Tectonic deformation of icy moons is usually driven by external forcing related to tides and orbital evolution; however, endogenic and local processes can also contribute (e.g., convection, flexure, stress perturbations around other structures) [2]. Tectonic deformation does not imply plate tectonics (which has only been identified on Earth). Deformation is thus broadly, if not globally, distributed on icy moons. Localization of deformation into narrow belts is still possible, analogous to terrestrial rift zones (e.g., Ganymede, Enceladus, Rhea, Dione) [3] and implies feedbacks between external forcing and interior processes, dictated by the thermal and mechanical properties of the ice shells.

Driving Stresses: Icy moons in eccentric orbits experience daily (diurnal) tidal stresses. Depending on the orbital dynamics and configuration of the moons and their host planets, these stresses may or may not be sufficiently large to deform the ice layer. Tidal deformation is enhanced if an outer ice layer is decoupled from an underlying liquid ocean. The tidal response of the ocean creates tidal bulges in the ice layer that oscillate longitudinally and in amplitude during the orbital period. The resultant diurnal tidal stress field rotates throughout the orbit. Any fractures growing in this time frame should thus be curved (e.g., Europa's cycloidal cracks) [2]. A decoupled ice layer may also undergo faster than synchronous rotation which may allow significant stress to accrue as the tidal bulges migrate relative to the surface. This nonsynchronous rotation (NSR) may explain long lineaments on Europa with different orientations through time [2], and has also been inferred on Enceladus [4]. Evolving tidal bulge heights driven by orbital recession (changing distance to parent body) and internal differentiation (changing Love numbers) create explicit stress fields that should be manifested in the deformation patterns [2]. Despinning will reduce flattening, providing an additional source of stress. Tidal bulges may also migrate latitudinally in response to polar wander [5], possibly explaining fracture patterns on some icy moons. If tidal deformation stresses are too small to overcome the strength of the ice shell, ice shell thickening could induce an isotropic tension [6] that augments other sources of stress, helping to drive deformation. On Pluto and Charon, tectonic deformation could have been driven by NSR, orbital recession, and despinning [1]; however, all possibilities should be considered.

Deformation Styles: Extensional features can result from absolute tension (dilational cracks) or differential tension (normal faults). Dilational cracks form subtle surface troughs on many icy bodies, and are the youngest type of deformation on Europa [7] and Enceladus [4]. Prolonged tectonic activity along troughs may result in constructional ridges to either side of the central crack (e.g., Europa, Enceladus, Triton). Normal faulting is a prevalent form of extension on icy moons (e.g., Europa, Ganymede, Enceladus, Dione, Rhea, Tethys, Miranda, Ariel, Titania) [3]. The development of significant topography requires normal faults to extend many kilometers deep, necessitating adequate differential stress to overcome the overburden. Fault systems may be 100s of km long, with segmented surface geometries characteristic of normal faults on solid planets. Shear stresses may cause cracks to accumulate strike-slip offsets over time (e.g., Europa, Ganymede, Enceladus, Triton), with associated shear heating contributing to the thermal state of the ice shell [8]. Contractional deformation should be manifested by thrust faulting, which requires larger differential stresses than normal faulting and is thus relatively uncommon on icy moons (e.g., possibly Io and Titan) [3, 9, 10].

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