Cartographic and topographic mapping of the icy satellites of the outer solar system

Since 1979, Voyager, Galileo, and now Cassini have revealed over a dozen new worlds. These moons of the outer planets are almost all dominated by icy mantles hundreds of kilometers thick. Although subject to similar geologic forces as on Earth or the Moon, their icy composition leads to geologic landforms that are both familiar and alien. Key to understanding these landforms and the geologic processes and stresses responsible for them are accurate cartographic and topographic tools and data sets. Several groups have been working on these problems, and here I report on new products generated by our group at the Lunar and Planetary Institute over the past decade.

Two topographic techniques are applied, either separately or in combination. Stereogrammetry has been the workhorse for these bodies, especially in the absence of altimetry instruments. Shape-from-shading (photoclinometry, PC) has greatly expanded areal coverage of topographic mapping but is not as stable at wavelengths longer than 50-100 pixels in the image plane. In many instances, stereo and PC overlap, allowing the former to control the uncertainties of the later. This merged stereo-PC technique has been especially profitable for Europa and the Saturnian satellites.

Jovian/Galilean/Medician Satellites

Unlike the new Cassini global mapping products for the icy satellites of Saturn, Galileo's crippled communications has a near-catastrophic impact on cartography and global and topographic mapping. Global mapping of the Galilean satellites was possible at 1 kilometer scale (not 100 meters), and these are now complete (mapping at 200-300 meters was also acquired but only for 5-20% of these surfaces). These maps now include near-global coverage in 3 colors. In addition, all Galileo high-resolution satellite images have been coregistered to these global maps, integrating them into the global digital map bases. These products will be published in 2008.

Topographic data of the Galilean satellites is very sparse but critical for understanding their geologic evolution. Topographic mapping is now essentially complete for all possible stereo and PC sites. Among the highlights is the unexpectedly high magnitude of relief on Europa. Often thought to have relief of only a few hundred meters, sites have been found where relief exceeds 800 meters, both above and below the local mean. In addition, regional scale variations are pronounced. Some regions of Europa are divided into topographic provinces, dominated by either flat or undulating ridged plains, plains pocked by numerous depressions, or by rugged disrupted terrains. Normal faults 350 meters high have been identified. The persistence of these high amplitude topographic features all point to an ice shell that is not thin or weak, but that can support topography.

On Ganymede, viscous relaxation of impact craters and furrows dominates ancient cratered terrains. Mapping of these craters indicates that relaxation and the higher heat flow responsible for it ceased (or declined) at or shortly after the time of bright terrain formation. Ancient large impact features are also radically different from similar sized

recently formed impact basins, showing a clear evolution with age. This variability also reveals the effects of high heat flow in the past. On Callisto, landform degradation dominates, creating "smooth" areas of dark material. The uniform albedo of these deposits allows us to use PC techniques. These units are not entirely "smooth," but are heavily cratered and in some areas feature undulating topography and linear ridges that could be compressional in origin.

Mid-sized Saturnian Satellites

Cassini imaging as of October 2007 allows for global cartographic control on the middle-sized icy satellites of Saturn. These include Phoebe, Iapetus, Rhea, Dione, Tethys, Enceladus, and Mimas. Global topographic maps have also been completed for Rhea and large parts of the other satellites at resolutions of 0.5 to 1 kilometer. Most of these satellites are heavily cratered and topography is dominated by impact effects. Large degraded basins 350-500 kilometers across (and not apparent in imaging) are revealed on Rhea and Dione. Topography also reveals radial gouges centered on several of these ancient impacts, as well as two crossing orthogonal sets of grooves or ridges on Rhea, indicating that this satellite was more active than the cratered surface might suggest. On Tethys, we see the topographic signature of smooth plains, despite the fact theses plains are heavily cratered. Topography also suggests the presence of a circumferential ridge 350-400 km beyond the rim of the Odysseus impact basin, indicating that this impact may have globally modified the shape of Tethys.

A major result of the Cassini topographic data is the extent of viscous relaxation on these satellites. Large ancient basins on Tethys and Rhea are partially relaxed, but the abundance of relaxed smaller craters on Dione, in association with smooth plains, indicates that heat flow was significantly higher in the past. Modeling indicates that residual impact heat beneath the crater floor is also required to explain the anomalously high central peaks seen on Dione, some of which rise 3 to 5 kilometers above the surrounding plains! Extensive relaxation of craters also occurs on Enceladus and mapping and modeling is in progress.

On a global scale, we confirm the depressed topography of the south polar terrains, but we also discover the existence of large scale "dimples" in the topography of Enceladus. These include at least two broad depressions roughly 100 km across and over 1 km deep. These are located near the equator and at roughly 40°N. Both are located within older cratered terrains or on the contact between cratered plains and very young ridged plains, indicating that there is no correlation of these features with geology. They could represent isostatic warping of the surface over irregularities in the rocky core or over downwelling/upwelling plumes in the icy mantle.