GEOLOGY AND INTERIORS OF MID-SIZED Icy BODIES FROM NEW/IMPROVED GLOBAL HIGH-RESOLUTION SHAPE MODELS. P. Schenk\textsuperscript{1}, A. Ermakov\textsuperscript{2}; \textsuperscript{1}Lunar and Planetary Institute/USRA, (pschenk@lpi.usra.edu), \textsuperscript{2}Department of Aeronautics and Astronautics, Stanford University (aie@stanford.edu).

Introduction: Mid-sized ice-rich bodies (diameters roughly between 400-2000 km) represent a distinct class of planetary bodies. Global mosaics and mapping reveal diverse geologic and thermal histories. Here we present new global high-resolution shape models referenced to the triaxial shapes of the 6 mid-sized icy moons of Saturn, updated shape models of 3 Uranian moons and Pluto's moon Charon, all derived from photogrammetric shape models and stereogrammetric DEMs. These allow us to compare topographic signatures of various geologic features of both exogeneous (e.g., large craters) and endogenous (potential cryovolcanic resurfacing) origin. In addition, we perform spectral analyses of the shape models to investigate differences in lithospheric properties among these bodies as relates to their thermal histories.

Photogrammetry/Stereogrammetry: Global shape models were constructed for the 6 mid-sized saturnian satellites using global Cassini imaging coverage at pixels scales from ~5 km to as low as 10 m. The only exception is Iapetus where only 2 close encounters were acquired on opposite hemispheres, resulting in 2 gap longitudes with lower resolution. We use the methods described in [1,2] involving construction of control networks with >5000 match point radii values distributed quasi-uniformly across their surfaces. Stereo DEMs were then constructed from the best available stereo pairs, which were then merged with the photogrammetric shape model to produce the global DEMs (Fig. 1). Global DEM spatial resolutions depend on imaging resolutions and hence vary from ~400 m for Enceladus [1] to ~1000 m for Iapetus and Rhea.

For the Uranian moons Ariel and Miranda and Pluto's moon Charon [3], we use similar procedures except that approach imaging was too low to obtain radius values, resulting in DEM coverage over only ~40-45% of their surfaces - where image resolutions are better than ~3 km. Registered global 3-color global maps for each moon have been also recreated using these revised control networks, as an aid to geologic interpretation.

Geology - Basins and Resurfacing: Each icy moon has a different topographic signature related to its geologic/thermal history [2]. Enceladus being an active moon with a floating ice shell has been treated separately and has a unique signature of latitudinal zonation and large non-geologic depressions related to ice shell variations and activity.

Large impact events formed prominent structures but, except for a few linear troughs, appear to have had minimal deformational effects on geology. Only at Evander and Odysseus (Dione and Tethys) are discreet ejecta deposits 1-2 km thick preserved today, though they likely formed at all impact basins larger than ~45 km [4]. The main exception is Odysseus which may have formed a prominent 2-km-high ridge, extensive scouring and possibly a global distortion on the opposite hemisphere. Except on Iapetus (and the unrelaxed Herschel basin on Mimas), very few ancient, degraded impact basins are evident, confirming that these have been thermally erased or never formed on the other icy moons.

Smooth plains have resulted in the obliteration of cratered terrains and topography on the leading hemisphere of Dione and trailing hemisphere of Tethys [4]. The plains are not uniformly level, however, with distortions prominent on Dione and perhaps subtly on Tethys. These include networks of shallow trough-like depressions similar to those on Charon and betray at least some of the resurfacing processes involved.

Each moon exhibits some tectonic activity. Despite its reputation, Rhea is distinctive in that the topography reveals at least three generations of more ancient cryptic deformation in the forms of disrupted block terrains on
the trailing hemisphere (perhaps similar to large mounds on Ceres), and a nearly great circle arc of en echelon fractures of unknown origin (Fig. 2).

Figure 2. Portion of Rhea global DEM highlighting dissected block terrain (white), and en echelon great circle troughs (black arrows).

Harmonic Analysis of the Icy Moon Shapes

A planetary shape can be represented in terms of spherical harmonic expansion:

\[ r(\lambda, \phi) = R \sum_{n=0}^{\infty} \sum_{m=0}^{n} \left\{ A_{nm} \cos(m\lambda) + B_{nm} \sin(m\lambda) \right\}, \]

where \( r \) is the radius, \( \phi \) is the latitude, \( \lambda \) is the longitude, \( R \) is the mean radius of the body, \( A_{nm} \) and \( B_{nm} \) are the normalized spherical harmonic coefficients, \( \phi_{nm} \) are the normalized associated Legendre functions, \( n \) is the spherical harmonic degree and \( m \) is the order. We expand the derived shapes of the icy moons in spherical harmonics and analyze their spectral properties. The topographic Root-Mean-Square (RMS) spectrum can be found using spherical harmonic coefficients as:

\[ M_n^{tt} = \left[ \sum_{m=0}^{n} A_{nm}^2 + B_{nm}^2 \right]^{1/2} \]

At high spherical harmonic degrees (short wavelengths), the shape RMS spectra can be well described by a power law [5]:

\[ M_n^{tt} = kn^{-\beta} \]

However, at lower harmonics, the planetary shape RMS spectra can be affected by isostasy and flexure, leading to a modified power law spectrum:

\[ M_n^{tt} = \left[ k n^{\beta} \right] F_n \]

where \( F_n \) depends on the thickness of the elastic layer as well as the density contrast between the ice and the underlying layer and the total shell thickness [6].

Figure 3 shows the computed RMS spectra using the global DEMs of the Saturnian moons. Since the surface gravity \( g \) is different between the moons, we normalized the RMS spectra by the Kaula scaling factor \( g^{-1} R^{-1} \), assuming the bodies have the same outer layer density (see discussion in [5], page 22). This normalization is needed to account for different magnitude of non-hydrostatic stresses due to topographic loads for bodies with different surface gravities.

Several features of interest are evident. At the short spatial wavelengths (10-20 km), RMS spectral converge to a similar spectrum. All moons expect Tethys exhibit a noticeable reduction in the topographic power at long wavelengths, which indicates that icy shells of these moons cannot elastically support loads of such long wavelengths, consistent with the lack of preserved deep basins except on Tethys. The transition to this reduced topographic power occurs at different wavelengths depending on the body. At Enceladus this transition occurs at wavelengths between 20 and 30 km. For Mimas, the transition occurs at wavelengths of 30-100 km, whereas for Dione and Rhea, the transition occurs between 150 and 500 km. Tethys does not appear to possess such a transition within the computed part of the RMS spectrum.

Thus, by developing a flexural model [6], we plan to constrain the parameters of the icy shells using the observed RMS spectra. However, care should be taken in the analysis of the shape models with heterogeneous data quality, especially at the high degrees that might not be globally supported by the available stereo-coverage. Finally, spectral-spatial location of the power spectra [7] will be used to study regional variations of the topographic power for the Saturnian Moons as well as analyze the topographic power for the Uranian moons Ariel and Miranda, and Charon, for which only partial global shape models with ~45% coverage are available.

Figure 3. The normalized RMS spectra of the Saturnian moon shapes. The shapes were expanded up to spherical harmonic degree 270. The spectra were normalized by the Kaula scaling factor [5].

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