CONTRACTIONAL DEFORMATION FOR THE FORMATION OF DORSA ON THE TRAILING HEMISPHERE OF ENCELADUS. R. T. Pappalardo1, D. A. Patthoff2, H. T. Chilton1,2, M. Golombek1, P. C. Thomas3. 1Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA (Patthoff@jpl.nasa.gov), 2Departments of Physics and Geology, California State University, Fullerton, CA, 3Center for Radiophysics and Space Research, Cornell University, Ithaca, NY.

Introduction: Saturn’s small icy moon Enceladus has received much attention since the discovery of jets of water erupting from the tectonically complex region near the south pole [1, 2]. However, most studies have focused on the activity in south polar terrain (SPT) while regions farther north (beyond ~55° S) have received much less attention. The less recently active, more northern regions can be broadly grouped into cratered terrains on the Saturnian and Anti-Saturnian hemispheres, and tectonized terrains on the leading and trailing hemispheres [3].

Here we focus on tectonic deformation within the Trailing Hemisphere Terrain of [3], which consists of semi-concentric tectonic terrains centered roughly along 0°, 285°W. The inner core region of deformation consists of striated plains composed of low-amplitude ridges and toughs [3, 4] surrounding a central tectonically deformed ridged unit. Standing up to ~1 km above their surroundings in a region of the trailing hemisphere that is slightly depressed, are several large ridges, or “dorsa.” The dorsa are ~2.5 km wide, and in map view they can bifurcate in a branching manner (Fig 1). Visible in high resolution images on the peaks of some dorsa are small (~300 m long) irregular crenulations. Those images also reveal talus at the base of some steep slopes along the dorsa flanks.

In cross section, the dorsa display broad, rounded tops and asymmetrical flanking slopes of ~15–30°. Ebony Dorsum (Fig 2) appears to have a dual-component slope on its southwest-facing flank, with the upper slope being steeper (20 – 35°) than the lower slope (12 – 18°).

Crosscutting relationships and the deformation of the striated plains on the southern flanks of Cufa Dorsa indicate that the dorsa are the youngest features in the region. Older structures of the striated plains are apparent on some ridge flanks suggesting uplift. On other ridge flanks the striated plains are not visible but instead truncate the older terrain and may represent fault scarp. These relationships are inconsistent with a cryovolcanic origin [5] of the dorsa. Instead, we favor a tectonic uplift model, likely thrust faulting, to create these prominent ridges.

Methods: Analysis of the dorsa includes expanding on previous geological mapping [3, 6] to define the basic characteristics, such as planform shape, length, and width. To determine the heights and slopes of the dorsa, we utilize a series of high-resolution limb profiles that transect ridges in Enceladus’s trailing hemisphere, notably the ridges Ebony and Cufa Dorsa. In places, local topography can be determined from limb images to a resolution of 10s of meters, and ridge slopes can be determined with better precision than through shadow measurements. However, in the limb profiles, foreground and background features can obscure the true topography along the length of the ground track (see [7] this meeting). To mitigate this, we use supplemental images to link features from the limb skyline to those identifiable in the Cassini ISS basemap and in unrectified images. This processes ensures the slopes and heights measured from the limb profiles are associated with the correct ridge features.

Tectonic Interpretation: The morphological characteristics of the dorsa suggest they are tectonic in origin and formed as a result of thrust faulting [5]. First, the dorsa are topographically high with respect to surrounding terrain, consistent with a contractional origin. Second, the rounded, asymmetrical cross-sectional profiles of the dorsa are consistent with the morphologies of typical thrust fault blocks found on Earth and modeled in analog experiments. Third, the dorsa characteristic broad arch capped by crenulations appears analogous to wrinkle ridges found on the Moon, Mars, and the Yakima Ridges in eastern Washington.

Fig 1. Dorsa in the trailing hemisphere of Enceladus. Image is a combination of the Cassini ISS basemap overlain by Cassini ISS image N1487302209.
which have been interpreted to have formed by high-level back thrusts in layered materials above a flat decollement. Fourth, the rounded nature of the dorsa is similar to the peaks of fault-propagation folds, where the tops are broad and relatively flat.

Two possible models for the formation of the dorsa are as 1) fault-bend folding, and 2) fault-propagation folding (favored). Fault-bend folds can occur in layered materials above a shallow, relatively flat-lying decollement. In such a model, the slope of the associated surface topography typically would be shallow and would reflect the step-up angle of the subsurface thrust fault as it rises from one decollement to another or flattens at the surface. If the dorsa are fault-bend folds, the length of the back limb would represent the amount of shortening (~1 km for the profile in Fig 2). Alternatively, fault-propagation folds can form when displacement across upward-propagating blind thrusts would be consumed by folding in layered material near the surface. In this model, folding of layers near the surface would accommodate the displacement across the upward-propagating blind thrust. The measured steep slopes of the dorsa (~35° in Fig 2) are more easily explained by fault-propagation folding, where high-level back thrusts create the observed steep topographic gradients.

The branching nature of the dorsa could be explained by multi-directional contractional strain, where the maximum compressional strain was oriented in a NE-SW direction and minimum compression was oriented NW-SE. The western termini of the Cufa Dorsa are against a prominent, long, gently arcuate tectonic trough, which may have served as a transcurrent fault that permitted north-south directed contraction.

Previous researchers, [3], suggest that contraction near the center of the Trailing Hemisphere Terrain is consistent with downward loading, such as could be due to downward collapse of the ice shell. Such loading might be induced by a thermal uplift that subsequently cooled and collapsed, or by melting beneath the region to cause thinning and lowering of the ice shell.

Conclusions: This area contains the first strong evidence for wrinkle-ridge analogues on an icy satellite. The cross-sectional shapes of the dorsa, and their crestal crenulations, provide strong lines of evidence that the dorsa are compressional features and could be similar to the wrinkle-ridges found elsewhere in the solar system. The morphology of dorsa (their heights, asymmetrical profiles, and rounded peaks) suggests they are accommodating contraction in the form of thrust blocks. Evidence for the possible source of the compressional stress comes from the central location of the late-stage stratigraphy that suggests a late-stage loading (cooling or downwarping) event in the trailing hemisphere. The bifurcation and cross-cutting relationships of the dorsa suggest that 3-D straining was important in their formation.


Fig 2. Limb profile over Ebony Dorsum. The top image (Cassini ISS basemap) shows the location of the profile A – A’. At bottom is the cross sectional profile (radial residual from mean ellipsoidal shape of Enceladus, with no vertical exaggeration) across the ridge, revealing a possible dual –component slope. A depression at the ridge crest is also apparent in the profile and corresponds to the shadowed region on the image. The limb profile is from Cassini ISS image # N1500057559.