

# INVISIBLE MOUNDS: OBSERVING THE EARLIEST STAGES OF LABYRINTH EVOLUTION ON TITAN WITH THE CASSINI RADAR.

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**Introduction:** The origin and evolution of Titan's labyrinth terrain remains an intriguing mystery, even after nearly two decades of study by the Cassini orbiter. Labyrinth terrain are highly dissected, locally elevated plateaus, believed to consist mostly of organic material similar to that of the undifferentiated plains [1][2]. In the past, labyrinth terrain has been subdivided into multiple types based on valley and upland width, valley or ridge geometry, unit margin geometry, or other characteristics [1]. In this work, we identify the earliest stages of radial labyrinth formation based on Cassini RADAR altimeter observations.

**Description of Radial Labyrinths:** Like other labyrinth terrains, radial labyrinths are highly dissected and seem to have a composition similar to that of the surrounding undifferentiated plains [3]. In SAR imagery they appear to be quasi-circular domes, and their valley systems form a radial pattern presumably centered near the summit. They are hundreds of meters tall, and approximately 100-200 km in diameter.

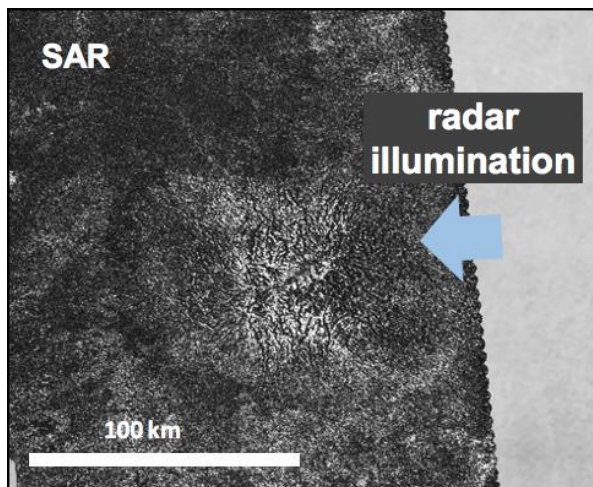


Figure 1: SAR image of a radial labyrinth (Anbus Labyrinthus) located at approximately 40°N, 145°E.

Radial Labyrinths are typically found in clusters, with two main groupings identified thus far. The first cluster is in the Afekan region, in the northern mid-latitudes of Titan. The second is located in the Tseghi region of the southern mid-latitudes.

**Radial Labyrinth Evolution:** The following scenario for radial labyrinth formation and evolution has been proposed [3][4][1]: first, organic-rich sedimentary

layers are uplifted to form a dome, possibly through subsurface cryovolcanic processes similar to laccoliths on Earth [4]. Once uplift occurs, sedimentary material on the surface begins to erode, possibly through fluvial dissection or dissolution processes [5]. Eventually, this dissection stops or slows greatly once a more resistant layer is reached, and the removal of overlying material continues until only narrow ridges remain on the surface [1].

This scenario is supported by SAR imagery, which shows radial labyrinths at various stages of dissection from narrowly incised valleys to isolated remnant ridges. The size, spacing, and clustering of radial labyrinths supports the hypothesis that they are uplifted by cryovolcanic intrusions [4]. However, until recently, we had not observed any radial labyrinths in their initial phase of evolution: post-uplift, but pre-dissection.

**Altimetry Observations:** Newly reprocessed radar altimetry data have allowed us to fill in the crucial gap in our observational record of labyrinth initiation. Using high resolution delay-doppler altimetry [6], we have identified multiple features that exhibit mound-like profiles and are similar in height and extent to radial labyrinths. In addition, they are found in close proximity to the previously identified labyrinth clusters. Unlike mature labyrinth plateaus, the mounds identified in altimetry data are indistinguishable from undifferentiated plains in SAR imagery, which has led to us informally labeling them “invisible mounds.”

Because SAR imagery is primarily sensitive to surface roughness, the dark SAR backscatter and texturally featureless appearance of the invisible mounds indicates that they likely have smooth surfaces, at least at SAR resolution. Similarities in size, shape, and proximity all strongly suggest that these featureless mounds are related to radial labyrinths. Their smooth surfaces, on the other hand, indicate that they have not undergone substantial dissection. This makes them obvious candidates for the earliest stage of radial labyrinth formation, when the surface has already been uplifted but has not yet been heavily eroded.

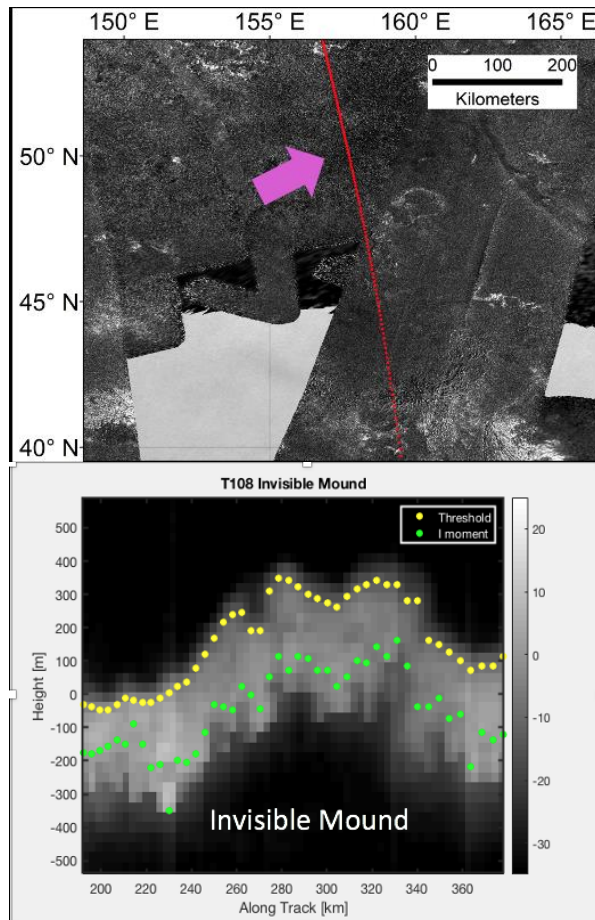


Figure 2: Top: SAR map showing the location of an invisible mound (pink arrow). Note the nearby mature radial labyrinth in the southeast portion of the image. Bottom: Delay-Doppler altimetry profile over the indicated location. The height (~400 m) and width (~140 km) are both consistent with measurements of radial labyrinths.

While SAR backscatter over invisible mounds is indistinguishable from surrounding plains, the same is not true of altimetric (nadir) backscatter. The nadir backscatter of invisible mounds is consistently 5-10 dB lower than the surrounding plains. Normally this would indicate that invisible mounds are slightly rougher than the surrounding plains. But if that were true, we would expect a difference in surface roughness to be apparent in SAR data as well, and that is clearly not the case for the invisible mounds.

One explanation for this discrepancy is that there is strong volume scattering in the observation area. Volume scattering is caused by reflections from small inclusions, air pockets, or fractures in the near subsurface of the target, and is nearly independent of incidence angle. Volume scattering is typically much weaker than surface scattering at nadir (altimetry) but

may be strong enough to dominate the surface backscatter at the higher incidence angles used for SAR observations. It is possible that small changes in surface roughness could affect the altimetric backscatter, but remain completely unobservable in SAR data due to the presence of strong volume scattering.

Indeed, by comparing radar backscatter as a function of incidence angle to a fractal scattering model, we find that the backscatter data over invisible mounds and the surrounding plains is best fit by high volume scattering and relatively small changes in surface roughness. The small increase in roughness over the invisible mounds may indicate that they have in fact undergone some erosion, just at scales too small to be observed in SAR. This finding suggests that there may be other landforms on Titan in addition to the invisible mounds that are “invisible” in SAR data due to volume scattering, but could be identified by investigating changes in altimetric backscatter.

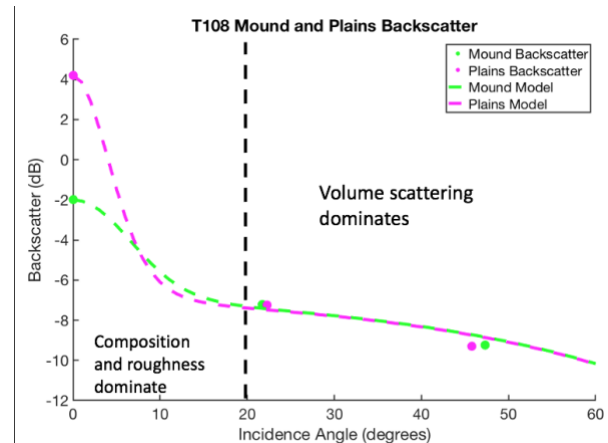


Figure 3: Radar Backscatter observations of the plains (pink) and the invisible mound shown in figure 2 (green) compared to a best fit fractal backscatter model. The best fit models found identical strong volume scattering for each terrain, but a slight increase in roughness over the invisible mound.

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**References:** [1] Malaska, M. J. et al., (2020) *Icarus*, 344. [2] Lopes, R. M. C. et al., (2020) *Nature Astronomy*, 4, 228-233. [3] Malaska, M. J. et al., (2019) *DPS-EPSC Joint Meeting* [4] Schurmeier, L. et al., (2017) *AGU Fall Meeting*, Abstract #P13D-2580. [5] Malaska, M. J. et al., (2016) *GSA Annual Meeting* [6] Poggiali, V. et al., (2019) *IEEE Trans. on Geoscience and Remote Sensing*, 1-7.