GEOLOGIC FEATURES ON TITAN'S SURFACE AS REVEALED BY THE CASSINI TITAN RADAR MAPPER. R.M. Lopes[1], E. R. Stofan[2], F. Paganelli[1], K. L. Mitchell[1], R. Kirk[3], R. Lorenz[4], J. Lunine[4], LA. Soderblom[3], S.D. Wall[1], C. Wood[5], J. Radebaugh[4], L.E. Robshaw[6], C. Elachi[1], and the Cassini RADAR Team. [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, Rosaly.M.Lopes@jpl.nasa.gov. [2]Proxemy Research, PO Box 338, Rectortown, VA 20140. [3]US Geological Survey, Flagstaff, AZ 86001. [4]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721. [5]Wheeling Jesuit University, WV 26003. [6]Environmental Sci. Dept., Lancaster University, LA1 4YQ, U.K.

Introduction: The Cassini Titan Radar Mapper is the only Orbiter instrument designed specifically for mapping the surface properties of Titan, by virtue of microwave's ability to penetrate its hazy and methane-rich atmosphere. The Titan Radar Mapper [1,2] operates as a passive radiometer, scatterometer, altimeter, and synthetic aperture radar (SAR). We review the diversity of geologic features and terrains revealed using SAR during four fly-bys (Ta: 10/2004, T3: 2/2005, T7: 9/2005, and T8: 10/2005).

Data: The SAR mode is used at altitudes under ~4,000 km, resulting in spatial resolution from ~ 350 m to >1 km. A swath 120-450 km wide is created from 5 antenna beams. Radar backscatter variations in SAR images can be interpreted in terms of variations of surface slope and surface roughness. The dielectric properties of the surface also affect the returned radar signal. On Titan, the likely surface materials (water ice, water-ammonia ice and other ice mixtures, liquid and solid hydrocarbons, and nitriles) are dramatically different from those of bodies previously imaged with radars. Indeed, volume scaterring may be significant, as indicated by radiometry [1], and this complicates interpretation. The SAR images, which cover about 4% of the surface, show that Titan is very geologically complex and has a relatively young surface [1,2]. A variety of landforms and surface units have been characterized morphologically and mapped, based on brightness variations, general planform shape and texture. The swaths locations can be seen in Fig. 1 in the abstract by Elachi et al. [2].

Geologic Features: Significant differences were seen in the geology among each of the four swaths. The Ta swath was at high northern latitudes, centered at ~ 50°N, 80°W. The units in the Ta swath appear relatively young and no impact craters were apparent. A variety of features which we argue to be cryovolcanic in origin were seen, including extensive flows, caldera-like features, and a circular feature (Ganesa Macula) interpreted as a volcanic dome [1,3,4]. Radar-bright braided and sinuous channels and associated deposits may be either fluvial or cryovolcanic in origin. Two linear features converging into a V-shape (the "arrow") were tentatively identified as tectonic in origin. Mapping of this and other swaths is ongoing [5]. The units that are broadly classified as plains units are the homogeneous unit (relatively low backscatter, but not completely featureless), bright homogeneous unit, the mottled unit (moderate backscatter, gradational boundaries), and the bright mottled unit. They are grouped as plains units as they all cover large expanses of terrain. They may be fractured or porous ice, or icy materials covered with organics [1].

The T3 swath [6] was centered at ~ 30°N, 70°W. This swath displayed some of the same units seen in Ta, except that cryovolcanic features seem to be absent. The most evident geologic features in T3 are a large impact (440 km diameter) basin, now named Menrva, and a smaller (80 km diameter) crater, named Sinlap. Ubiquitous dark lineated streaks, nicknamed "cat scratches" are seen on this swath, and are interpreted to be aeolian in origin [6,7]. Distinct sinuous channels, interpreted as fluvial in origin, are sparsely distributed and appear to drain into a catchment area. The dominant terrain unit in T3 is a bright mottled unit that may contain ubiquitous small (< 10 km across) topographic features. Features identified as hills on the basis of the sense of the radar illumination are more common in the T3 data than Ta.

The T7 and T8 data, including radiometry and scatterometry observations, are discussed in detail by Elachi et al. [2]. The T7 swath (relatively short segment due to the interruption of onboard recording) was located at high southern latitudes, centered at ~12^0 W and 51^0 S. The northernmost end of the T7 swath shows a hilly terrain that appears to be embayed by surrounding plains. Much of the swath is characterized by by fairly densely distributed channels interpreted to be fluvial in origin, some of which drain toward a very dark plains unit at the southernmost end of the swath (see Fig 5 in [2]). The large plains units are similar to those seen in other swaths, but the very high concentration of fluvial channels and clusters of hills are unique to T7 (see Fig. 4 in [2]).

The T8 swath was equatorial and extended from 7^0 N to 18^{0}S latitude and 179^0 W to 320^0 W longitude. The T8 swath has a high concentration of dark linear streaks interpreted to be dunes. They cover much of the swath, and are deflected by topographic obstacles. Located at the eastern end of the swath are long, parallel ridges that appear to be embayed by the surrouding

plains material. The origin of these ridges is not obvious, but they may be tectonic in origin.

All four swaths are characterized by extensive plains units that are either radar-dark, mottled or radar-bright. However, each swath has its own character, with Ta providing evidence for cryovolcanism, T3 exhibiting two impact craters and aeolian features, T7 dominated by fluvial features, and T8 by dunes (see Fig. 6 in [2]) and a set of ridges. Altimetry data [1,2] and radarclinometry [7] obtained so far indicate surface relief to be low (less than a few hundred meters). If this is typical, it implies that the balance between constructional and erosional processes favors the latter.

Geologic Processes: All four major planetary geologic processes – volcanism, tectonism, impact cratering and erosion – appear to have played a role in shaping Titan's complex surface. The interplay of the various geologic processes and the inference that they are still happening today, makes Titan more similar to Earth than any other known planetary body.

Impact cratering: To date, only two impact structures have been identified on Titan, Menrva and Sinlap. The terrain surrounding the impact basin Menrva indicates that erosional processes have degraded the SW outer rim in particular. Removal of impact craters by burial and erosion is likely, given the evidence for fluvial and cryovolcanic (see below) processes, and the relatively degraded appearance of hills and ridges.

Tectonism: The driving forces of tectonics on Titan are unclear at this point; most of the possible tectonic features do appear to be at least partially degraded and embayed by surrounding plains units. Among the possible tectonic features is the "arrow" in Ta and ridge-like features in T8 that may be chains of hills. Small hills are also seen at the eastern end of the T3 swath and are described in detail in [8].

Cryovolcanism: The SAR swaths revealed several features that likely resulted from cryovolcanism, including radar-bright flows, caldera-like features, and a circular volcanic construct (Ganesa). While several features interpreted as likely cryovolcanic were identified in the Ta swath, and numerous tentatively identified on the T8 swath, there were no features on T3 and T7 that were identified by as cryovolcanic in origin, though some tentative interpretations of cryovolcanic flows on T3 were made [6]. Thus evidence for cryovolcanism appears in both northern and southern hemispheres, but it is not ubiquitous. Models for the ascent and eruption of cryomagmas on Titan are currently being developed [4, 9,10].

Fluvial processes and possible surface liquids: Channels and dark, radar-smooth terrains are candidates for liquids, either past or present. There is plentiful morphological evidence that liquids have flowed on Titan [1, 6, 12, 13], but it is not straightforward to differentiate between cryovolcanisma and fluvial processes for the origin of some flows and channels, particularly when they are located on or near a cryovolcanic feature such as Ganesa [3]. A dark mottled unit first mapped in Ta [1] forms patches of tens to hundreds of kms across, commonly irregular in shape, though in several places they form arc or oxbow shapes. This dark patches within this unit may be organic solids or ponds of liquid hydrocarbons [1,14]. Another example of an area containing possible liquids is the dark area bound on one side by a "coastline" imaged in T7 [see Figure 5 in 2].

Aeolian processes: Dune-like features were identified in both the T3 and T8 swaths. The features cover regions 100s of kilometers in extent, suggesting a significant supply of sand-sized material. Most of this material is likely produced by fluvial erosion [13].

Each of the swaths has provided insights into the geologic processes that shape the complex and youthful surface of Titan. However, these snapshots await integration into the larger set of swaths to be obtained during the Cassini mission before a comprehensive model of the geologic evolution of Titan can be developed.

References: [1] Elachi, C. et al., 2005, Science 13, 970-4. [2] Elachi, C., et al., 2006, this volume. [3] Lopes, R., et al., in preparation. [4] Mitchell, K.,R. Lopes, et. al., 2006, this volume. [5] Stofan, E., et al., in preparation. [6] Elachi, C., et al., 2005, submitted to Nature. [7] Kirk, R., et al., 2005, LPS XXXVI, Abstract # 1682. [8] Radebaugh, J., et al., 2006, this volume. [9] Lorenz, R., et al., 2005, submitted to Science. [10] Mitchell, K.L., J. Kargel, et al., 2006, this volume. [11] Mitri, G., et al., 2006, this volume. [12] Tomasko, M. et al., 2005, Nature 438, 765-778. [13] Lorenz, R., et al., in preparation. [14] Stofan, E., et al., 2005, LPS XXXVI, Abstract #1714.

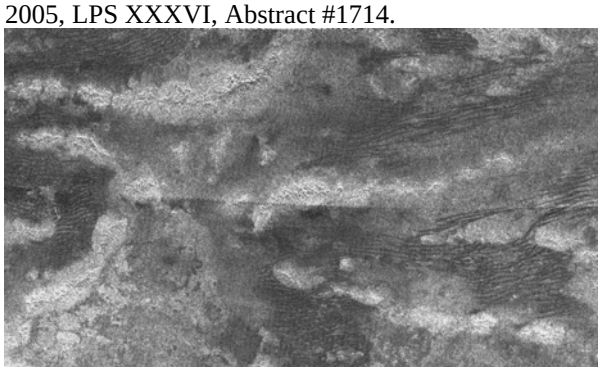

Fig. 1: Bright ridges seen in T8 SAR swath that may be tectonic in origin. The image is ~400 km across. See abstract by Elachi et al. [2] for additional SAR images.