MUCH LIKE EARTH: DISTRIBUTION AND INTERPLAY OF GEOLOGIC PROCESSES ON TITAN FROM CASSINI RADAR DATA. R.M.C. Lopes[1], E.R. Stofan[2], G. Mitri[1], L. E. Robshaw[3], K.L. Mitchell[1], C. A. Wood[4], J. Radebaugh[5], R.L. Kirk[6], S.D. Wall[1], R. Lorenz[7], J. I. Lunine[8], J. Craig[1], F. Paganelli[1], L. Soderblom[6], 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, Bowie, MD 20715, [3]Environmental Sciences Department, Lancaster University, Lancaster LA1 4YQ, UK, [4]Wheeling Jesuit University, Wheeling, WV 26003, [5]Geological Sciences Department, Brigham Young University, Provo, UT84602, [6]U.S. Geological Survey, Branch of Astrogeology, Flagstaff, AZ 86001, [7]Johns Hopkins Applied Physics Laboratory, Laurel, MD 20723, [8]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ85721.

1. Introduction: The variety of geological processses on Titan is rivaled in our Solar System only on Earth. Results from the Cassini-Huygens mission obtained so far have revealed a wide range of geologic and climatological processes, and a complex interaction between the surface and atmosphere [e.g. 1-13]. We use data obtained by Cassini's Titan Radar Mapper to analyze the distribution of different types of geologic processes occurring on Titan's surface, both endogenic and exogenic, and to derive temporal relationships between these processes, at least at local scales. The distribution and interplay of geologic processes is important to provide constraints on models of the interior and of surface-atmosphere interactions.

2. Data: Cassini carries a multimode Ku-band (13.78 GHz, λ=2.17 cm) radar instrument [1] that is used in a Synthetic Aperture Radar (SAR) mode at altitudes under ~4,000 km, resulting in spatial resolution ranging from ~350 m to >1 km. SAR coverage is dependent on spacecraft range and orbital geometry. Radar backscatter variations in SAR images can be interpreted in terms of variations of surface slope, near- surface roughness, or near-surface dielectric properties. On Titan, the likely surface materials (water ice, water-ammonia ice and other ice mixtures, hydrocarbons, tholins) are different from those of bodies previously imaged with planetary radars, and volume scattering may be significant [1,2,3]. The SAR images of Titan now comprise a rich dataset that covers ~15% of Titan's surface, well distributed in both latitude and longitude, although with more coverage on the leading hemisphere (0-180°). Although the coverage is still far from comprehensive, it is sufficient for revealing the geologic processes that shaped Titan's young surface. We mapped the SAR images in terms of characteristic morphology of geological features and their radar backscatter in order to determine possible emplacement sequences and the overall distribution of geologic processes with latitude and longitude. As with any geological mapping, the ultimate aim is to be able to interpret how geologic processes have affected a planetary surface in space and time and to provide constraints on the planet's interior structure and on exogenic processes that modify the surface.

3. Distribution of Geological Processes: All the major planetary geologic processes – volcanism, tectonism, impact cratering and erosion – appear to have played a role in shaping Titan's complex surface.

***Impact cratering*:** To date, only three impact structures have been conclusively identified on Titan: Menrva, Sinlap, and Ksa; and a few others have been tentatively identified [7]. All three craters definitely identified are on the leading hemisphere, which, as Lorenz et al. [7] discussed, is consistent with the impactor model of Korycansky and Zahnle [14]. However, the SAR coverage at present is insufficient to draw definite conclusions about global crater populations.

***Tectonism*:** Among the features interpreted to be of tectonic origin are ridge-like features and elevated blocks [8]. Individual mountains heights, estimated from radarclinometry, are mostly between 500m-1500 m [8]. Radebaugh et al. [8] discusses four possible origins for the mountains and blocks, including crustal compressional tectonism and upthrusting of blocks. The other possible origins are creation of high blocks and low grabens through extension, dissection and erosion of a pre-existing layer, and deposition of blocks as impact ejecta. Although all processes may be at work, we argue that mountain ridges, which are mostly in the equatorial regions, are compressional in origin. High-pressure ice polymorphs could exist on Titan between the ocean and the rocky interior [15]. Mitri and Showman [15] have shown that during the cooling of Titan, the radial expansion of the ice-I layer is, in general, counterbalanced by the radial contraction of the ice high pressure layer. Therefore, a global contraction of Titan could occur during its cooling and cause compressional tectonism [15].

Cryovolcanism: The SAR swaths revealed several features that likely resulted from cryovolcanism, including radar-bright flows, caldera-like features, and a circular volcanic feature named Ganesa Macula, plus several flows and craters identified as of possible cryovolcanic origin. VIMS data has identified other features [16, 17] and, in one case, provided further evidence for a RADAR identification [18]. Cryovolcanic features are not ubiquitous on Titan. There is an apparent concentration in the Ganesa Macula region, which has led to the suggestion that this may be a possible hot spot or even Tharsis analogue [4].

Erosional processes: Erosion appears to be widespread on Titan. Fluvial processes are extremely important on Titan and are a major factor in modifying the morphology of other geologic features. SAR data has revealed evidence of vast fields of aeolian deposits, which are well correlated with VIMS data [19].

Fluvial processes and possible surface liquids: Channels and radar-dark 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 cryovolcanism 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]. Lakes at high northern latitudes provide evidence for surface liquids [5]. Numerous channels are seen associated with these lakes and, in some cases, connecting them.

***Aeolian processes*:** Dune-like features were identified by SAR, covering regions 100s of kilometers in extent [6], suggesting a significant supply of sand-sized material, which is likely produced by fluvial erosion [13]. Dunes are concentrated in the equatorial regions, below latitudes of ~60°, consistent with lower latitudes being relatively dry [20].

4. Interplay of processes: Although stratigraphic relationships are hard to establish from the available data, they are sufficiently clear in places that a picture of Titan's geologic evolution is emerging. Erosion processes, both from fluvial and aeolian activity, play a major and ongoing role modifying Titan's surface.

Erosion of impact craters: Removal of impact craters by burial and erosion is likely, given the evidence for fluvial, aeolian, and cryovolcanic processes. The terrain surrounding the impact basin Menrva indicates that erosional processes have degraded the SW outer rim in particular. Several other tentatively identified impact craters have radar-bright rims and radar-dark interiors. Two examples, in particular, are seen to be partially covered by dune material. It is likely that numerous craters have been buried or partially buried by aeolian deposits; in some cases, only the rims are left exposed. Fluvial erosion also seems to have played a major role, particularly in areas such as Xanadu. Lorenz [7] pointed out that the size-density distribution of craters on Titan is similar to Earth's, indicating rapid obliteration by erosion and burial. It is not yet clear what the role of cryovolcanism has been on crater obliteration, as so far cryovolcanic processes are not seen to be as widespread as erosional processes.

Erosion of mountains: Peak morphologies and surrounding, diffuse blankets are suggestive of erosion [8]. Most of the possible tectonic features appear to be at least partially degraded and embayed by surrounding plains units. Radebaugh et al. [8] argue that fluvial runoff has played a significant role. Cassini VIMS data have identified that, at least for one mountainous area east of Xanadu, there are spectral differences between the mountainous area and the surrounding terrain [17], perhaps implying that material that coats the surrounding plains is not present on the mountains. The same analysis showed this to be the case for channels as well; perhaps the thin coating has been removed by erosion on channels and mountainous areas.

Cryovolcanism: a young process? The cryovolcanic features so far identified [4] are located mostly at high northern latitudes. It is unclear whether Ganesa Macula has suffered fluvial erosion, as the origin of channel-like features on its flanks could be volcanic or fluvial [4]. The large flow fields so far identified [1, 4] do not show any evidence of fluvial erosion, perhaps implying that they are quite young. Tobie et al. [21] suggested that extrusive activity and outgassing recommenced on Titan relatively recently (~500 Ma).

Wind and Liquids: the methanological cycle. Mapping of the currently available SAR data indicates that fluvial features are widespread in both latitude and longitude and appear at many different scales. At high latitudes, fluvial erosion appears to be the dominant modification process, at least at the high northern latitudes. Erosion by aeolian activity may dominate the lower latitudes and dunes are seen in places to overlay fluvial deposits.

Each of the SAR swaths has provided insights into the geologic processes that shape the complex and youthful surface of Titan. 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.

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