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Nature, distribution, and origin of Titan's Undifferentiated Plains

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ABSTRACT

The Undifferentiated Plains on Titan, first mapped by Lopes et al. (Lopes, R.M.C. et al., 2010. Icarus, 205, 540–588), are vast expanses of terrains that appear radar-dark and fairly uniform in Cassini Synthetic Aperture Radar (SAR) images. As a result, these terrains are often referred to as "blandlands". While the interpretation of several other geologic units on Titan – such as dunes, lakes, and well-preserved impact craters – has been relatively straightforward, the origin of the Undifferentiated Plains has remained elusive. SAR images show that these "blandlands" are mostly found at mid-latitudes and appear relatively featureless at radar wavelengths, with no major topographic features. Their gradational boundaries and paucity of recognizable features in SAR data make geologic interpretation particularly challenging. We have mapped the distribution of these terrains using SAR swaths up to flyby T92 (July 2013), which cover >50% of Titan's surface. We compared SAR images with other data sets where available, including topography derived from the SARTopo method and stereo DEMs, the response from RADAR radiometry, hyperspectral imaging data from Cassini's Visual and Infrared Mapping Spectrometer (VIMS), and near infrared imaging from the Imaging Science Subsystem (ISS). We examined and evaluated different formation mechanisms, including (i) cryovolcanic origin, consisting of overlapping flows of low relief or (ii) sedimentary origins, resulting from fluvial/lacustrine or aeolian deposition, or accumulation of photolysis products created in the atmosphere. Our analysis indicates that the Undifferentiated Plains unit is consistent with a composition predominantly containing organic rather than icy materials and formed by depositional and/or sedimentary processes. We conclude that aeolian processes played a major part in the formation of the Undifferentiated Plains; however, other processes (fluvial, deposition of photolysis products) are likely to have contributed, possibly in differing proportions depending on location.

1. Introduction

The Cassini–Huygens mission has revealed the surface of Titan in unprecedented detail. The Cassini Titan Radar Mapper (henceforth RADAR) is able to penetrate clouds and haze to provide high resolution (~350 m spatial resolution, with some areas reaching as high as ~240 m/pixel) views of the surface geology using its Synthetic Aperture Radar (SAR) mode at a wavelength of 2.2 cm (Elachi et al., 2005a, 2006). The instrument's other modes (altimetry, scatterometry, radiometry) also provide valuable data for interpreting the geology, as do other instruments on Cassini, in particular, the Visual and Infrared Mapping Spectrometer (VIMS, Brown et al., 2004) and the Imaging Science Subsystem (ISS, Porco et al., 2005). Although Cassini SAR coverage is not global (currently ~58% through July 2013), it is a particularly valuable dataset for interpreting surface geology because it has greater areal coverage at higher spatial resolution than other instruments and

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also provides information on topography and surface properties. Radar backscatter variations in SAR images can be interpreted in terms of variations of the surface slope distribution at scales of several wavelengths to the pixel resolution, surface roughness at the wavelength scale, subsurface volume scattering, subsurface layering and/or other organized structures, and near-surface effective dielectric properties. Candidate surface materials on Titan are water ice, water–ammonia ice and other water ice mixtures, hydrocarbon liquids, organic materials such as nitriles, alkynes, alkanes, aromatic ring compounds, and organic polymers related to laboratory tholins (e.g. Griffith et al., 2003; Negrao et al., 2006; Barnes et al., 2007a; Soderblom et al., 2007; McCord et al., 2008; Hirtzig et al., 2013). These materials are different from the rocky surfaces for which radar data are available, such as those on Venus and the Moon (e.g. Stofan et al., 2006; Cahill et al., 2014) or the nearly pure water ice surfaces seen on airless icy satellites (Dalton et al., 2010). In particular, the subsurface volume scattering at Titan is thought to be significant (e.g. Janssen et al., 2009, 2016). This can make the interpretation of surface geology particularly challenging. Nevertheless, previous studies have shown that the geology of Titan is remarkably Earth-like (Jaumann et al., 2009; Aharonson et al., 2014) in having relatively few impact craters (Wood et al., 2010; Neish and Lorenz, 2012), vast sand seas (Lorenz et al., 2006; Radebaugh et al., 2008), large bodies of liquids (Stofan et al., 2007; Hayes et al., 2008), mountains (Radebaugh et al., 2007; Mitri et al., 2010), and features thought to be extrusive volcanic constructs (Lopes et al., 2007, 2013).

The first study of Titan's global geology, based on RADAR observations (Lopes et al., 2010), used SAR data from Cassini Titan flybys Ta (October 2004) through T30 (May 2007), covering 20.1% of Titan's surface. The work established Titan's major geomorphologic terrain units, their distribution in the area covered, and how the units relate to each other in terms of geologic history. Those results showed that dunes and mountainous/hummocky terrains (defined as patches of radar-bright material including hills, mountain chains, and blocks, mostly isolated except for the Xanadu region) were more widespread than lakes/seas, putative cryovolcanic units, mottled plains (defined as intermixed, irregularly shaped patches of radar bright and radar dark terrains), and impact craters and crateriform structures thought to result from impacts. The unit having the largest areal coverage was designated "Undifferentiated Plains" (Fig. 1) and was described as vast expanses of relatively homogeneous, radar-dark terrain that appeared to be of low relief, and were not part of the Mottled Plains unit. Because the Undifferentiated Plains cover such a large portion of Titan's surface examined in that study (61.2% of the swaths Ta-T30), Lopes et al. (2010) pointed out that understanding their origin is key to understanding how different geologic processes have shaped Titan's surface. In this paper, we refine the description of this unit and examine Undifferentiated Plains at regional and local scales, using a much larger data set. We also use different datasets to understand the relationship between Undifferentiated Plains and other major geomorphologic units on Titan. We use RADAR radiometry data and VIMS data to constrain possible compositions for the materials and use topographic data to help discern embayment relationships.

2. Cassini data and mapping methodology

The main dataset used in our study is from the Cassini RADAR instrument, a multimode Ku-band (13.78 GHz, $\lambda = 2.2$ cm) radar instrument (Elachi et al., 2005b) designed to map the surface of Titan. Data from other Cassini instruments, the Visual and Infrared Mapping Spectrometer (VIMS) and the Imaging Science Subsystem (ISS) were also used.

Our mapping of the geomorphologic units on Titan is based on both structural/topographic differences seen in SAR and topographic data (such as crater rims, mountains, and plains) and differences and variations in near-IR spectral response, meaning that apparent differences between units can be due to either structure/topography or composition. Insight into surface properties such as composition, structure, and physical temperature can be inferred from (1) radiometry from RADAR, which can reveal differences between icy and non-icy materials (Janssen et al., 2009); (2) VIMS studies using a radiative transfer code that evaluates atmospheric contributions to extract pure surface albedos (Solomonidou et al., 2014); and (3) comparisons of SAR and VIMS data, as was done in the study of the Sotra Patera region (Lopes et al., 2013) and of several mountains and channel features (Barnes et al., 2007b).

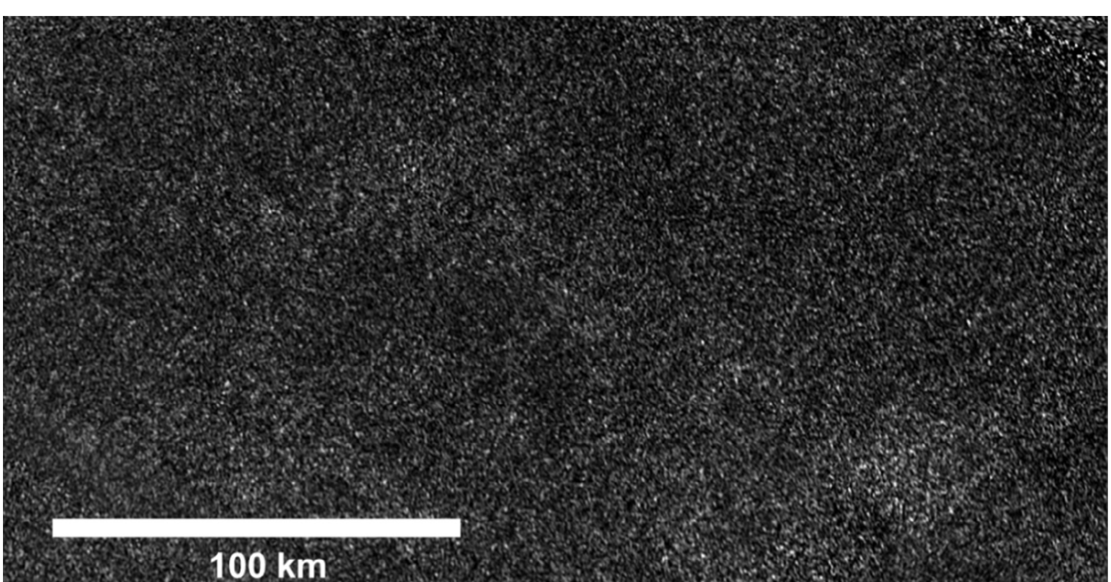

Fig. 1. Example of Undifferentiated Plains ("blandlands") in Cassini SAR data. These plains appear relatively homogeneous and dark in the SAR data. This image shows a nearly featureless area of ~36,000 km^2 centered near (16.3°N, 217°W).