CASSINI MISSION : RADAR SENSING OF CRATERS ON TITAN.

Ralph Lorenz, Lunar and Planetary Laboratory, Department of Planetary Sciences, University of Arizona, Tucson, AZ 85721, USA

Crater density and morphology offers useful insight into the bombardment, atmospheric and resurfacing history of a body. This information for Saturn's moon Titan has been hidden by the thick haze-laden atmosphere, but will be yielded by the forthcoming NASA/ESA Cassini mission. Here I review what we may expect to learn from orbiter radar and optical observations, noting their limitations due to incomplete areal coverage and atmospheric opacity, respectively, and from high-resolution (but localised) measurements from the Huygens probe. Radar mapping from orbit offers, most probably, the best prospects for crater science on Titan.

Crater densities have long been used to estimate the age of surface units and develop a resurfacing history of a planetary body. Further, the relative depletion of small craters is indicative of an atmosphere, and crater density plots can be used to deduce whether Titan's atmosphere has been thinner in the past: see [1] for discussion - the present-day atmosphere should lead to a depletion in craters with diameters smaller than 20km or so. The presence of an atmosphere modifies ejecta emplacement, and can lead to impactor breakup and crater clusters. Titan is unique in having a (probably) ice crust, and an atmosphere, usefully filling a gap between other icy satellites, Moon/Mercury and the planets with atmospheres. Measurement of crater profiles and depth-to-diameter ratios gives insight into crustal strength and rheology: an added dimension on Titan is that the presence of liquid hydrocarbons on the surface may give rise to crater lakes [2] with central islands. Clearly then, there is much to learn about Titan from its cratering record - with the Cassini mission and its instrumentation approaching launch, it is appropriate to review what the mission will tell us.

Although recent Hubble Space Telescope images have clearly indicated a bright feature on Titan [3], and demonstrated that Titan's surface can be imaged in certain spectral windows from space, the prospect of Cassini orbiter instrumentation (ISS - Imaging Science Subsystem, and VIMS - Visual and Infrared Mapping Spectrometer) mapping Titan's surface in detail should be treated with caution. Even in the 0.94 μm window, imaged by HST and covered by the ISS, the two-way optical depth [4] of the atmosphere is of the order of 2 (for paths at 30° to vertical).

Most of the illumination falling on Titan's surface is diffuse, therefore. It follows that shadow contrasts will be low (especially when the sun is at low elevations, where shadow-length measurements are most useful). Secondly, the contrasts seen on varying slopes will be low : photoclinometry will be very difficult. Even with small optical depths, it has been shown that errors in slope determination from photoclinometry can be large [5], assuming reasonable uncertainty in haze opacity, phase function and surface albedo.

Thus, while gross albedo variations (such as the bright feature) can be perceived from orbit, and spatial resolution of optical remote sensing could be high (of order 0.5km for VIMS, rather less for ISS, but this depends on target motion compensation) the determination of topography seems doubtful, especially since differential erosion of dark (organic) material and bright ice by methane rainfall [6], could generate significant optical albedo variations. Thus radar sensing offers the best prospects for evaluating topography (e.g. cratering) on Titan.

The Titan Radar Mapper on the Cassini Saturn orbiter will make radar images of 10-30% of Titan's surface, at resolutions of 0.3-1.0km. Although a greater coverage would be desired, only ~35 Titan flybys are possible in the 4 year mission, and only some of these can be devoted to radar sensing. However, it may be noted that the conclusions regarding cratering on Venus that had been obtained after 15% of the surface had been covered [7], namely that the surface was geologically young, and that small craters had been screened by the atmosphere, were confirmed after 89% of the planet had been mapped [8]. For example, extrapolating the 135 craters seen in 15% of the surface to the 89% yields 801 craters, whereas 842 were found. Thus, 15% of the surface seems a broadly adequate sample to characterise the cratering morphology and statistics of a planet. (It may be noted that the 15% of the Venus surface covered by Magellan by 1991 included an essentially crater-free young region, Sappho).

In imaging mode, operative during Titan flybys for ranges between 4000km and 950km, the radar will cover swaths between 100 and 400km wide, and a few thousand kilometres long. These swaths are distributed over various latitudes and orientations on Titan. The area coverered by each swath is modest, covering only about 10^6 km^2 , or about 1% of Titan's surface: over such an area, considering crater densities elsewhere in the Saturnian system, we might expect [1,10] 100- 200 craters of diameter >20km.Although the radar imaging coverage of the surface is limited, it should be noted that long, thin swaths are relatively efficient at 'hunting' for large craters : if a crater may be 'recognized' by projecting, say, 20km into a swath, then the sampling area of a swath for a 200km diameter crater (of which ~1 would be expected per swath, for an 'old' surface) is about 50% greater than the actual swath area : the corresponding sampling area for a square imaging area is only 30%. The improvement would be even more marked for craters of larger diameter. If a crater projects a distance h into a swath, with the edge of the swath cutting a chord length 2d on the crater, and d can be measured with an accuracy Δd, then the accuracy of estimation of the diameter of the crater is $\sim 2(d/h)\Delta d$, or for the radar imaging resolution of better than ~1km and the case described above, about 5%.

The altimetric mode of the radar, operating for ranges of 9000-4000km during Titan encounters, offers a vertical resolution of the order of 100m, and a footprint of ~25km. This is broadly comparable with that of the Pioneer Venus Orbiter : some useful parallels may be drawn with groundbased radar altimetry of Mercury. There are two additional modes, radiometry (measuring the emissivity of the surface, since the surface is expected to be isothermal, owing to the thick atmosphere) and scatterometry, measuring the target strength (reflectivity) of the surface: the extent and value of these measurements (which can take place at much longer ranges - 22500km or more) is still under discussion.

The Huygens probe should not be forgotten. Optical sensing by the DISR (Descent Imager - Spectral Radiometer) from the parachute deployment altitude of 170km down to the surface should offer higher-contrast, high-resolution (down to ~20cm) imaging of a small part of the surface. For the expected zonal wind profile on Titan, the DISR should map perhaps $\sim 2\text{x}10^4$ km^2, or 0.025% of the surface. The probe also carries a radar altimeter, which will operate from 30-50km down to the surface. The footprint of the beam (8° wide) varies down from about 3km : altimetric resolution will be a few metres to tens of metres, giving an accurate topographic profile along the probe's descent path (perhaps a groundtrack of 30km, if winds are as expected). Assuming the cratering density mentioned above, imaging will probably reveal a crater or two, but the altimeter probably will not.

Thus, the Cassini orbiter radar data will probably give us our best view of cratering on Titan. Much work, and doubtless many surprises, await us.

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