DEGRADED IMPACT CRATERS ON TITAN. C. A. Wood[1], J. I. Lunine[2], E. Stofan[3], R. Lorenz[4], R. Lopes[5], J. Radebaugh[6], S.D. Wall[5], Ph. Paillou[7], T. Farr[5], and the RADAR Science Team, [1]Planetary Science Institute, Tucson, AZ 85701 & Wheeling Jesuit University, Wheeling, WV 26003, chuckwood@cet.edu; [2]Lunar and Planetary Lab, University of Arizona, Tucson, AZ 85721-0092; [3]Proxemy Research, PO Box 338 Rectortown VA 20140; [4]JHU Applied Physics Laboratory, Laurel, Maryland 20723; [5]Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109; [6]Department of Geological Sciences, Brigham Young University, Provo, UT 84602, [7]Observatoire Aquitain des Sciences de l'Univers, UMR 5804, Floirac, France

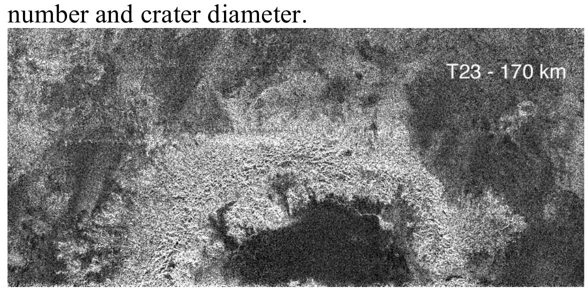
Introduction: Since the first Cassini Radar image in 2004 it has been known that impact craters are rare on Titan [1]. That conclusion still stands after 17 Radar passes that have revealed ~20% of Titan's surface. We have identified 70 circular landforms that may be degraded impact craters. The certainty of identification is variable; none are definite impacts, but none can be shown not to be. Even if all 70 are impacts, Titan still is very sparsely cratered. The inferred youthful surface age of Titan, and the various erosional states of its possible impact craters, demonstrate that dynamic processes have destroyed most of the early history of the world, and that one or more processes continue to strongly modify its surface. The existence of many potential impact craters with diameters less than 20 km raises questions about (a) models of the effectiveness of Titan's atmosphere in destroying small projectiles, (2) the permanence of the present atmosphere, or (3) the reality of the impact interpretation.

Identifying Impact Craters: Planetary scientists are familiar with impact craters because they occur throughout the solar system, having formed on many types of targets, and being modified by many processes. Complex fresh impact craters are immediately recognized by their near-circular outlines, low rims, deep interiors, flat floors, central peaks, terraced walls, and ejecta deposits. For a planet with active geological processes – volcanic, eolian, fluvial, or tectonic – the ejecta are quickly eroded or covered, the crater becomes more shallow, with the peaks often buried by sediments or volcanic materials, and the inner walls are smoothed by down slope movement. Subsequent impacts cut, churn and obliterate pre-existing craters. All of these processes are familiar, with variations such as isostatic shallowing and transformation of central peaks to central pits for worlds with icy crusts. The recognition of the impact origin of specific features is usually not in doubt on most planets and moons, because there are few competing processes that form similar circular features. In radar images, impact crater rims and peaks are usually bright due to their rough-textured surfaces, and crater floors often appear dark, being smoothed by infill of sediments or lava flows.

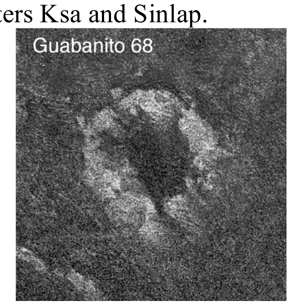
The handful of fresh craters on Titan (Ksa, Sinlap and the basin Menrva) have morphologies comparable to impact features on other worlds. But for circular features on Titan that don't have the canonical fresh morphologic signature, it is more difficult to determine the mode of origin. Any circular feature on Titan may be of possible impact origin, but we do not know all the forms of volcanism that may exist on Titan, nor what other processes may make circular landforms. Evidence that mitigates against an impact origin for particular features includes clustering of craters, and association with apparent lava flows. For most of the circular features on Titan we can assume that impact is a possible origin, but cannot rigorously exclude that other processes may be important.

Possible Impact Craters: Ksa, Sinlap and Menrva demonstrate that impact craters do form on Titan and can be preserved. No other circular structures on Titan have as many impact crater characteristics, so their origins are less certain. Nonetheless, in a survey of the approximately 22% of Titan now covered by Radar swaths, 70 additional crateriform features have been identified that are the best candidates to be additional impact craters. Note that these are nearly all of the features that reasonably can be interpreted as possible impacts, not just a few representative samples.

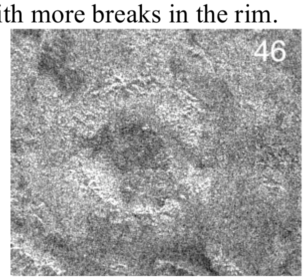
Crater Morphologies: A number of morphologies occur, but most features are apparently so degraded that a circular outline is sometimes the main criteria for inclusion. While the resolution of the Cassini Radar instrument is as good as 400 m, it is 1 to 1.5 km near the end of swaths, making detection of details difficult. Crater candidates are referred to by their Radar swath number and crater diameter.



Bright, Jagged Rims (above). The three largest potential impact structures have broad rims that are radar bright and highly textured; they look jagged and broken. T23-170 is a 170 km wide feature that is only half visible because it occurs on the edge of the T23 swath. It has a very dark interior with brightness at the swath edge suggesting a central peak. This feature strongly resembles impact craters with lava-flooded floors on Venus and is quite likely to be of impact origin. At least three other features (diameters 22, 75 and 90 km) have similar morphologies, and may be relatively youthful, but their jagged rims differ from the rims of the definite craters Ksa and Sinlap.

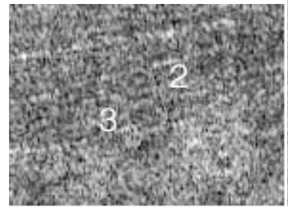


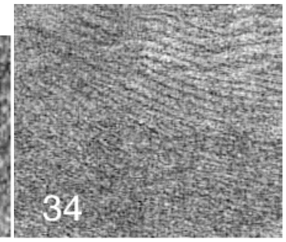
Guabanito Rims (above). The 68 km wide feature Guabanito (T13-68) has a broad bright rim but it is not jagged. It is rounded, smooth and structurally continuous rather than being made of adjacent peaks. The rim is pierced in two or more places and dark dunes, which surround the crater, are on the floor. The rim width is large compared to the feature's diameter, quite different from Ksa and Sinlap as well as known impact craters on other worlds, reducing the certainty that this is an impact crater. T23-36 appears to have similar morphology but with more breaks in the rim.



Ridge Rims (above). A number of possible impact craters occur on Xanadu and all look to be significantly degraded. T13-65 has a nearly complete circular rim made of ridges and other elevations. Unlike most of the putative craters on Titan this feature has a large bright central peak. The floor is mostly dark and a channel cuts through the southern rim and becomes braided on the floor. T13-46 (above) is somewhat similar. It has an almost perfectly circular narrow ridge rim with apparent talus extending onto the dark floor.

Raised Rims. Most features with diameters smaller than 20 km are too poorly resolved to allow careful descriptions of rims, but a number are clearly elevated and others appear to be so. T21-13 has a radar bright rim and opposite radar-shadowed rim – this is a beautiful little crater that may be a model for what other more poorly resolved features look like. T13-15 and T13-17 appear similar, with the 15 km wide feature having a bright floor and the other a dark one. T3-31 is another swath-edge crater, with a raised rim, and the smooth broad rim of T29-22 clearly rises above surrounding dunes.





Ink Spots (above left). Many small dark floored circular features occur on part of the T8 swath. Because these are clustered and are of similar size (2-5 km diameter typically [2]) they are unlikely to be primary impact craters. But there are similar, more isolated features in other parts of Titan. The image above left shows two narrow bright-rimmed tiny circles (2 and 3 km diameter) with dark floors and central peaks. They cut dunes and thus presumably are young. If these were detected anywhere else in the solar system they would be considered impact craters, but because of Titan's dense atmosphere it is thought than few craters smaller than 20 km should exist [e.g. 3]. Sixteen of the 70 craters in our survey are smaller than 10 km in diameter, and another 17 have diameters between 11 and 20 km.

Buried Craters (above right). The dunes that cover broad parts of Titan's equatorial region have apparently buried some possible impact craters. T3-34 (above) is a circular structure that has been covered by a more recent dune field. A number of other circular structures are partially covered by dunes, including Sinlap.

Bright Craters. T13-6 has a bright rim but it is surrounded by a very bright deposit 10-12 km in diameter. Two other small, bright haloed features have been detected. T13-6 is strongly similar to radar images of Meteor Crater on Earth and radar images of small craters on the Moon.

Conclusions: A sizeable number of these structures are likely to be degraded impact craters. They tend to be concentrated on bright terrains such as Xanadu, which are inferred to be ancient. Greatly reduced numbers of crater-like features on dunes and various other terrains imply that they are younger. If more than a few craters smaller than 20 km in diameter are impacts, then the atmosphere has not always been a filter, or the models of atmospheric filtering require modification.

References: [1] Elachi C. et al. (2005) *Science, 308,* 909–1072. [2] Lunine J. et al. *Icarus,* in press. [3] Artemieva N. et al. (2003) *Icarus 187*, 374-405.