THE SURFACE AGE OF TITAN.

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Introduction: Since its arrival at the Saturnian system, the Cassini spacecraft has made about 100 Titan fly-bys. The surface of Titan has been revealed almost globally by the Cassini observations in the infrared and regionally to about 25% in radar wavelengths [1,2,3] as well as locally by the Huygens optical instruments [4]. Extended dune fields, lakes, distinct landscapes of volcanic and tectonic origin, dendritic erosion patterns and deposited erosional remnants exhibit a geologically active surface indicating significant endogenic and exogenic processes leading to dynamic surface alteration. Consequently, impact craters are rare on Titan [5,6,7,8].

Impact Craters: So far five impact craters have been confirmed on Titan's surface (Tab. 1), and 42 possible impact-like features have been identified (Tab. 2, Fig.1) [2,6,9,10,11,12,13, 20].

Name	Lat (N)	Lon (W)	Diameter
Menrva	**20.1**	**87.2**	**392**
Afekan	**25.8**	**200.3**	**115**
Selk	**7.0**	**199.0**	**80**
Sinlap	**11.3**	**16.0**	**80**
Ksa	**14.0**	**65.4**	**29**

Tab. 1 Confirmed and named impact crates on Titan [5,6,7,8,9].

In general, they are circular and appear to have elevated rims and interiors. Many of the larger of these features show evidence of having been significantly eroded. Others are partially or nearly completely covered by dunes, fluvial channels have cut a few, and many are surrounded by talus. As on Earth there are multiple processes on Titan that can erode craters and significantly alter their appearance [5]. About half of the putative craters on Titan have diameters smaller than 30 km (Tab. 2). In the present atmosphere, projectiles that form craters of less than 20 km diameter should be disrupted. Larger fragments, however, as well as iron impactors may yield small craters [10]. On the other hand, structures of only a few km in diameter are difficult to identify in data with only a few hundert meters resolution.

Crater Frequency and Age Estimation: The area covered with sufficient resolutions by Cassini's Radar to resolve circular features is about 20% of Titan's surface. This is far from completion, but can be used to constrain the expected crater population. The distribution of so far identified impact craters, both confirmed and putative ones, is almost uniform over Titan's surface with a slight increase on the trailing site (Fig.1). This observation appears to coincide with the impactor model of Korycansky and Zahnle (2005) [10] who suggest that the leading hemisphere should have a crater frequency about 5 times higher than the trailing side assuming Titan has been in synchronous rotation throughout its history. However, this observation may change in the course of the mission with increasing high-resolution coverage which is so far poorer on the leading site. The cumulative crater frequency is shown in Fig. 2 for both the confirmed five craters and the total of the putative craters. The overall shape of the frequency distribution is relatively flat compared to those of other icy satellites, especially at smaller crater diameters. However, the cumulative crater frequency for larger diameters remarkably fits that of the basins on Iapetus for craters down to about 80 km diameter (Fig. 2), although the number of craters is lower by about an order of magnitude (Fig. 2). The crater frequency at sizes < 80 km is far lower by about a factor of up to 200.

Location	Lat (N)	Lon (W)	Ø km	Location	Lat (N)	Lon (W)	Ø km
W Shangri-La	-12	187	**5**	NE Shangri-La	3	145	**40**
Fensal	20	40	**5**	NE Shangri-La	2	137	**45**
N Polar	70	355	**8**	Shangri-La	-11	150	**55**
E Xanadu	-12	70	**10**	W Shangri-La	-10	187	**60**
S Tseghi	-60	10	**10**	Shangri-La	-10	190	**60**
W Fensal	13	100	**10**	Adiri	-6	202	**60**
W Fensal	15	95	**10**	Xanadu	-9	84	**70**
NE Shangri-La	11	138	**12**	Xanadu	-7	83	**70**
N Polar	55	10	**13**	N Temperate	39,6	214	**75**
Xanadu	-10	123	**15**	E Fensal	11,3	16	**80**
W Xanadu	-12	128	**18**	W Senkyo	-5	340	**80**
NW Xanadu	-2	135	**20**	NW Shangri-La	7,2	198	**95**
N Polar	78	265	**20**	E Tseghi	-30	7,7	**95**
Fensal	15	28	**20**	Adiri	-15	210	**100**
NE Shangri-La	12	137	**25**	Adiri	-5	207	**120**
Fensal	14	65,4	**29**	Aaru	5	340	**125**
W Quivira	-5	38	**30**	NE Adiri	-6	200	**150**
Aaru	25	330	**30**	NE Fensal	26,5	9	**180**
Shangri-La	-11	166	**30**	Fensal	20,1	87,2	**392**
Xanadu	-8	80	**35**	S Senkyo	-15	315	**400**
Shangri-La	-10	165	**40**	NW Shangri-La	5	212	**700**

Tab. 2 Putative impact crates on Titan [2,6,9,10,11,12,13, 20].

The similarity of the crater frequency with with large craters and those of older terrains on other icy Saturnian satellites indicates that the primary crust of Titan which holds the larger craters is old. The overall shape of Titan's crater frequency distribution for craters < 80km is even shallower than what would be expected for atmospheric shielding [14,15]. Therefore, erosion must have played a major role in obliterating craters on Titan. Compared to the crater frequency distribution on Earth, Titan shows a similar shape (Fig. 2).

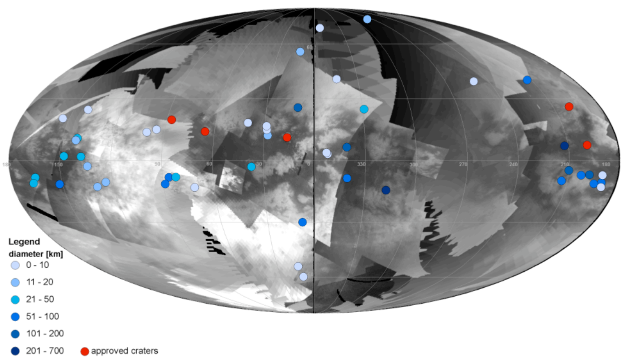

Fig. 1. Confirmed (red) and putative (blue) impact structures.

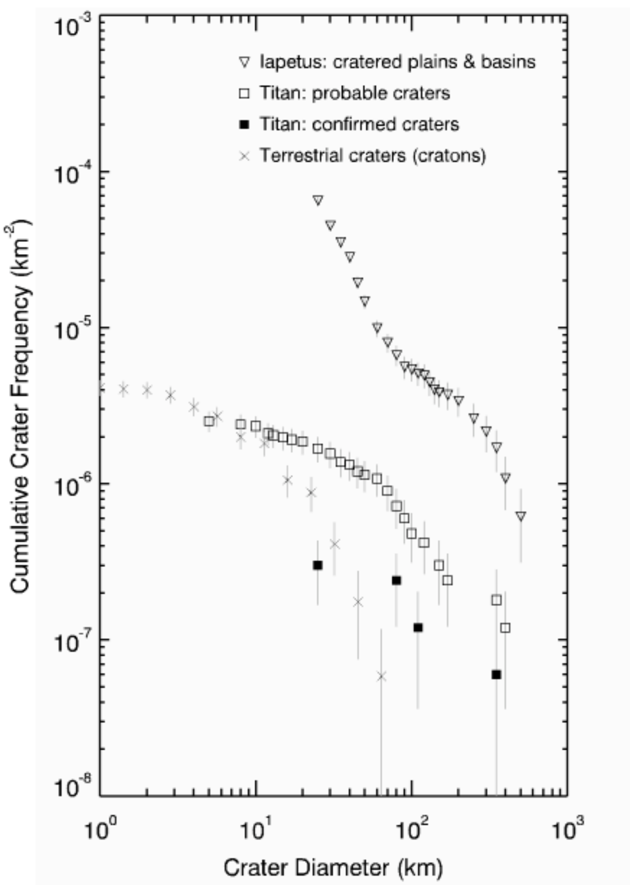

Fig. 2. Cumulative crater frequency of Titan (compared to Iapetus and Earth)

However, the density is about 5 to 10 times higher. Although the impactor population at Saturn might be different, this fact is mostly due to the lack of plate tectonics on Titan and to a lower heat flux driving erosion [16]. The absolute age model according to Neukum (1985) [17] and Neukum et al. (2005) [18] assumes a lunar-like impactor flux mainly of main-belt asteroids, whereas Zahnle et al. (2003) [19] and Korycansky and Zahnle (2005) [14] assume a constant impactor flux of cometary objects, either with a size distribution of Jupiter family comets (JFC) (case A), or with a size distribution of small comets in the Neptunian System (case B). In addition, Artemieva and Lunine (2005) [11] discuss a different model which, however, was derived from previous work of Zahnle [19]. According to the Neukum age model Titan's surface is as old as 3.9 Ga as derived from the larger-crater (> 80 km) frequencies. The Zahnle model yields surface ages of 3.5 Ga in case A and 1.4 Ga in case B. According to the Artemieva and Lunine model, Titan's surface appears as young as 500 – 100 Ma [15]. If only smaller craters, e.g. 10 km-sized craters, are taken into account for age determination, surface ages are 100 Ma according to the Neukum model, 8 Ma according to the Zahnle model case A, and 2 Ma for case B.

Although the statistical precision of the Titan cratering results is not very high and cratering models for absolut ages are controversial, it is obvious that Titan's surface is partly as old as the other Saturnian satellites reflecting an early crust still preserved and has been partly modified and heavily resurfaced even in recent times.

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