NUMERICAL MODELING OF IMPACT CRATERING ON TITAN WITH IMPLICATIONS FOR THE AGE OF TITAN'S SURFACE . J. Lunine[1], N. Artemieva[2] , R. Lorenz[1], and E. Flamini[3]. [1]Lunar and Planetary Laboratory, University of Arizona, rlorenz/jlunine@lpl.arizona.edu, [2]Institute for Dynamics of Geospheres, Moscow, artemeva@psi.edu, [3] Agenzia Spaziale Italiana, Rome-Italy, enrico.flamini@asi.it.

Introduction. Results reported from the first two close flybys of Titan reveal few if any impact craters exposed at the surface[1], suggesting that geological or atmospheric processes, or both, have worked to prevent the formation of craters or to hide or erase them after formation. Here we quantify some of these processes and use them to constrain the age of Titan's surface: atmospheric and oceanic shielding, flooding by the ocean beneath a thin crust, viscous relaxation, and burial by sedimenting atmospheric aerosols.

Numerical methods and initial conditions. We use the Eulerian two-dimensional hydrocode SALE [2,3]. The code is complemented by the Tillotson equation of state for water and ice [4] and by ice strength properties from published laboratory data [5]. Weak icy bodies (hereafter, "comets"), strike Titan vertically in the simulations with an average impact velocity on Titan of 11 km/s [6]. We use a detailed engineering model for the atmosphere stratification on Titan [7]. The surface temperature is assumed constant at 93 K. To model large impacts we include a water-ammonia ocean (dehydrate composition) beneath the crust with a temperature of 176 K. According to models [8] the thickness of the ice crust on Titan varies from 125 km (5% of ammonia) to 67 km (15% of ammonia). A recent study of Titan's orbit evolution [9] favors the higher content of ammonia, hence a thin crust and deep mantle ocean..

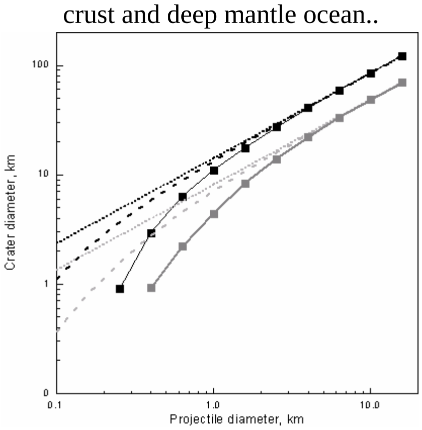

Fig.1 Final crater diameters for non-porous 15 km/s comet (black lines) and for porous 7 km/s comet (gray lines). Solid lines are for a disrupted comet, dashed lines for intact bodies, and dotted lines are for a hypothetical airless Titan.

Atmospheric shielding. Titan is the only natural satellite in the solar system that possesses an extensive, thick atmosphere; the surface pressure of 1.5 bar. Thus, the problem of comet deceleration and disruption has been investigated thoroughly [10-13]. At the same time we realize that the ancient atmosphere may have differed substantially from this one – there are models with lower [14] and higher surface pressures in the past [15]. However, recent impacts—those in the last few hundred million years—are of special interest here. Our models show that the difference in crater counts for Titan and a hypothetical "airless" Titan is negligible for impactors larger than 2 km (corresponding to crater diameter 20 km), and is profound for projectiles smaller than 0.5 km (crater diameter ~5 km) – see **Fig. 1**. More extensive shielding would take place for more porous comets (and a putatively denser atmosphere).

Impact into hydrocarbon seas. Laboratory experiments [16] and numerical simulations [17] have demonstrated that crater formation at the base of a liquid layer is strongly impeded by the overlying liquid if the ratio of the layer thickness to the projectile diameter is larger than 4. This mechanism is not relevant for Titan, where only km-sized comets could reach the surface and the possible thickness of putative hydrocarbon seas or lakes is at best hundreds of meters [18], i.e. the depth/projectile ratio is much less than 1.

Craters in a thin crust. The possible presence of a water-ammonia liquid layer below an ice I crust on Titan could impose an upper limit to the size of craters by flooding and hence destruction of the transient cavity, as was found in numerical models for Europa [19,20]. The limiting size, then, of a standard (with central uplift or central pit) complex crater is that for which the transient cavity diameter is comparable to the ice shell thickness. We made a few runs with crustal thickness of 50 km and projectile size from 10 to 100 km in diameter. Estimates of the transient cavity diameter based on the scaling laws for homogeneous target [21] and of the final crater diameter on the icy satellites [22] are summarized in the Table:

Comet D, km	TC, km	FC, km	Flooding
10	104	168	No
25	212	480	yes, minl
50	365	700	yes,
100	626	1280	yes

Only the smallest projectile creates a standard complex crater with a central pit and a few rings (**Fig.2**, upper panel). A 25-km-diameter projectile does not breach the crust; however, liquid penetrates to the surface during the crater collapse. Larger projectiles (such as the 100 km diameter shown in the lower panel) penetrate through the crust at the early stage of the crater growth, creating huge pools of liquid water-ammonia.

Viscous relaxation. Old impact craters on Ganymede show strong evidence for viscous relaxation [23,24]. Their rims are in places narrow and well preserved while their bottoms are about level with the surrounding terrain. As the relaxation process strongly depends on the poorly known properties of cold ice [25] and unknown thermal gradient in the crust, the relaxation times (where depths are reduced by a factor of *1/e*) in different models vary--for a 50-km-diameter crater they range from 0.35 Gyr [26] to orders of magnitude in excess of the age of the Solar system [27]. If methane photolysis has proceeded in steady state over the age of the solar system, part or all of the surface should be covered by deposits hundreds of meters thick of solid and liquid organic aerosols sedimented out of the stratosphere. Relaxation of craters to a shallow profile makes burial, completely or partially, by such deposits a relevant process for obscuring craters on Titan's surface. Central peaks, peak rings and rims may remain exposed, or be lost via erosion.

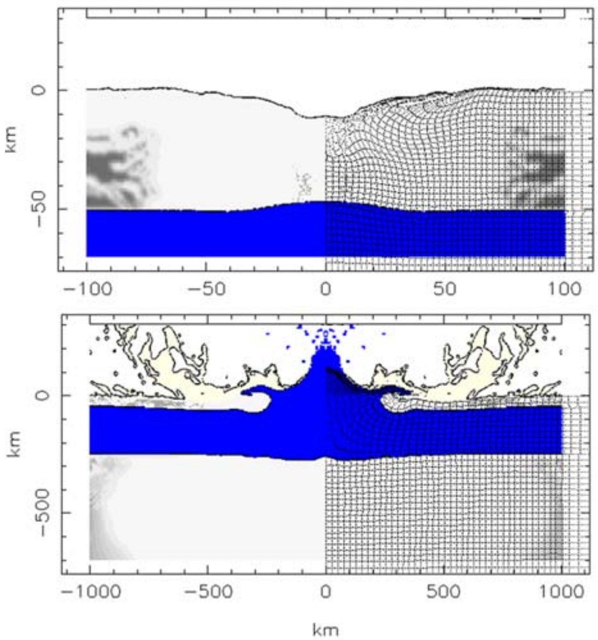

Fig.2 Flooding of craters with liquid ammonia-water (blue) on Titan. The projectile diameters are 10 (upper) and 100 km (lower). The ice crust (white) thickness is 50 km. Note scale change between the two panels. To give a sense of the numerical resolution, each square in the right half of the figure contains 25 computational cells.

Discussion. If Titan's atmosphere has always been the same density as it is at present, then only craters larger than 20 km may be found on the surface; smaller ones do not exist because of atmospheric shielding. If Titan's crust is thinner than 100 km, then only craters smaller than 200 km possess the expected topographic impact signatures. Viscous relaxation may be quick because of an expected strong thermal gradient in the crust. The cumulative number of craters retained over 1-4.5 Gyr is shown in **Fig. 3**. The dearth of impact craters seen in Cassini Orbiter radar and remote sensing data over the limited surface areas covered to date suggest an age for the surface of less than 1 Gyr.

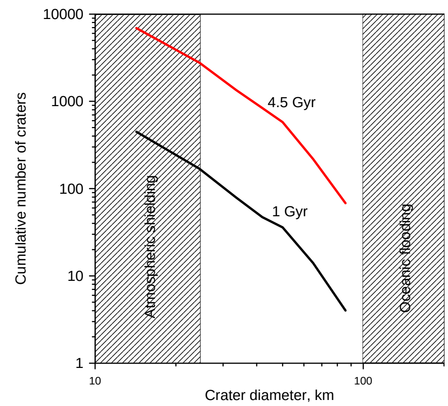

Fig. 3. Cumulative number of craters on Titan retained during the last 1 Gyr and 4.5 Gyr.

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