

TITAN'S IMPACT CRATERS AND ASSOCIATED FLUVIAL FEATURES: EVIDENCE FOR A SUBSURFACE OCEAN? A. E. Gilliam and D. M. Jurdy, Department of Earth and Planetary Sciences, Northwestern University, Evanston IL, 60208-3130 (ashley@earth.northwestern.edu).

Introduction: Impact craters may hold direct clues about Titan's subsurface ocean. Previous studies of Jupiter's moon Europa showed that impact craters could identify the thickness of the ice shell, and thus the proximity of its ocean to the surface. A careful investigation of Titan's surface craters could constrain the thickness of the ice layer, and give an indication of a subsurface ocean. A study of Titan's impact craters with associated fluvial features could determine the subsurface structure. Understanding the morphology of these fluvial features can give information about their origin, whether they be pluvial, created by sapping or seepage, or the result of a flood caused by a large impact. The latter may prove the most revealing, suggesting that the impactor was able to breach through the ice shell, releasing liquids from an internal reservoir or the subsurface ocean.

We take a geomorphological approach to examine craters on Titan, focusing on those that have features interpreted as fluvial in origin. Using a combination of *Cassini* RADAR, VIMS, and ISS data, we present measurements of the depth and diameter of Titan's impact craters. We also measure the stream order and length of the channels near three of Titan's confirmed impact craters to assess whether these features provide evidence for a subsurface ocean, which has implications for the distribution of environments that may support life.

Craters and Associated Fluvial Features: Although the very first *Cassini* radar image of Titan showed no impact craters, by 2012, as surface coverage increased to ~40%, 7 certain impact craters have been identified, as well as 52 nearly certain and probable craters [1, 2, 3]. From neighboring moons, Hyperion and Rhea, it was initially estimated that Titan should have 10,000 craters over its entire surface [4]. However, with only 59 detected as of 2012, an active process of burial and erosion must occur on the surface, removing a large number of craters [5].

The largest crater, Menrva, a 445 km wide double-ring impact basin, is heavily eroded and hosts a complex network of channels. On the western, more degraded side of the crater, channels cut through the outer rim. To the east of Menrva, a curious network of channels start near the rim crest and appear to have flowed away into a large catchment basin, a complex called Elivagar Flumina. Channels have also been observed near two other craters, Selk and Ksa. A halo of channels cut the outer rim of Selk, an 80 km diameter

crater with a small central peak. Also, Ksa, a 30 km diameter crater with a bright central peak and radial ejecta, displays a sinuous feature resembling a channel running north-south on the eastern edge of the crater ejecta.

Crater Morphology: It is difficult to infer crater depth on Titan from the scaling relations for craters on the terrestrial bodies due to the difference in surface composition (icy vs. rocky). Thus, we examine scaling relationships of other bodies in the outer Solar System in order to find a crater scaling relationship that could be used for Titan. Craters on Ganymede, an icy moon of Jupiter, have been identified as far back as the *Voyager* mission. Because of the similar geology, and because Ganymede is of comparable size to Titan and thus has a surface gravity close to Titan's, crater morphologies on Titan and Ganymede should be similar. Using a numerical relationship between crater depth and diameter for Ganymede [6] we estimate the depth of Titan's craters with known diameters. This suggests that the depth of Titan's largest crater, Menrva, reaches ~2.8 km, agreeing with another study that proposes craters larger than 60 km in diameter on Ganymede (and Titan) have a very small depth/diameter ratio of ~0.01 [7].

Channel Order and Origin: Titan's surface may reveal a connection with its subsurface ocean. If cratering penetrated through the surface and made a connection to the subsurface ocean, then we would expect to see low-order channels flowing away from the crater rim. Examination of Menrva reveals several radar-bright river tributaries flowing toward and away from the crater rim (Fig. 1). Channels surrounding Menrva display a low order, measuring one or two, occasionally up to three. This matches observations of two other confirmed impact craters with associated fluvial features, Selk and Ksa. These differ radically from the tree-shaped dendritic channels common on Titan, generally attributed to heavy rainfall. For example, the Xanadu region exhibits a very complex and dendritic network of channels that reach up to third order, although others have reported that channels in the western Xanadu region reach up to sixth or seventh order [8].

Using the Integrated Software for Imagers and Spectrometers (ISIS), we measure the length and width of the channels surrounding Menrva, Selk, and Ksa craters, as well as those associated with Elivagar Flumina. We compare these results with a dendritic

network of channels (the Xanadu region) and a canyon system with channels created by sapping. Analysis showed the dendritic network of channels in the Xanadu region had the longest length, with some channels reaching ~ 450 km. This contrasts with the channels near Menrva, Ksa, and Selk, where the longest length recorded was ~ 175 km. The channels associated with Elivagar Flumina also display a moderate length, the shortest being ~ 23 km in length, and the longest nearly 210 km. Channels near Titan's craters most resemble the canyon system of channels attributed to sapping, which has a maximum length of ~ 200 km. Channels created by sapping are usually much shorter and often wider than those created by precipitation. The canyon system of sapping channels reported in this paper have a stream order of up to two, and a considerable width of 5 km, unlike the narrow dendritic channels which have high stream orders [8].

Discussion and Conclusions: In this study, we investigate the craters on the surface of Titan and their associated fluvial features as possible evidence of a subsurface ocean. Using a scaling relationship for craters on Ganymede, we calculate a depth of Titan's largest crater, Menrva, of ~ 2.8 km. If Titan's crust has remained at a constant thickness of ~ 123 km over the course of its history, we find that it is unlikely that the impactor that created Menrva was able to break through to the ocean layer below, however, it cannot be ruled out, especially if there exists a localized subsurface reservoir of liquid closer to the surface.

A study of Menrva, Selk, and Ksa reveals the existence of several river tributaries flowing toward and

away from these craters. These low-order channels differ radically from the dendritic network of channels on Titan, as observed in the Xanadu region, where the channels can reach up to sixth or seventh order. Because dendritic channels are generally attributed to heavy rainfall, this hints that the channels near Titan's craters may have formed through another mechanism. This hypothesis is further supported by measurements of the length of these channels. The dendritic network of channels in the Xanadu region reach 450 km, in contrast to the channels associated with Menrva, Selk, and Ksa craters, with the longest length recorded only 175 km. The channels flowing into Elivagar Flumina also display a moderate length. These results are comparable to the canyon system of channels observed on the T16 swath, which are thought to have been created by sapping, further suggesting that the channels associated with Titan's largest craters may not be pluvial in origin, but instead may be the result of seepage or even record a flood.

References: [1] Wood C.A. et al. (2010) *Icarus*, 206, 334-344. [2] Soderblom J.M. et al. (2010) *Icarus*, 208, 905-912. [3] Neish C.D. and Lorenz R.D. (2012) *Planet. Space Sci.*, 60, 26-33. [4] Lorenz R.D. (1994) *Planet. Space Sci.*, 42, 1-4. [5] Lorenz R.D. et al. (2007) *Geophys. Res. Lett.*, 34, L07204, doi:10.1029/2006GL028971. [6] McKinnon W.B. and Schenk P.M. (1995) *Geophys. Res. Lett.*, 22, 1829-1832. [7] O'Brien D.P., Lorenz R.D., Lunine J.I. (2005) *Icarus*, 173, 243-253. [8] Langhans M.H. et al. (2012) *Planet. Space Sci.*, 60, 34-51.

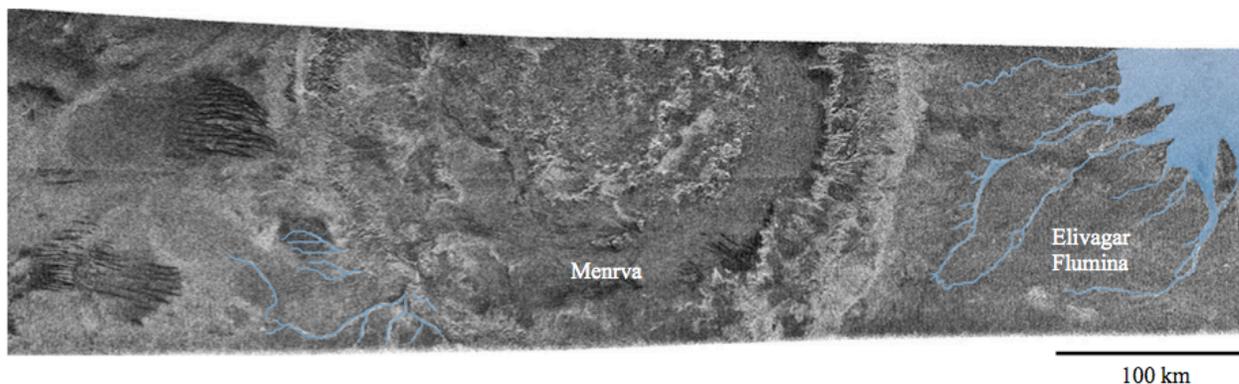


Fig. 1. Cassini RADAR image of Menrva and Elivagar Flumina taken during the T3 fly-by, showing the channels near Menrva and the catchment basin (highlighted in blue).