Material Properties of Tholin: Implications for Aeolian Processes on Titan Xinting Yu[1,2], Sarah M. Hörst[2], Chao He[2], Patricia McGuiggan[3], Xi Zhang[1], [1]Department of Earth and Planetary Sciences, University of California Santa Cruz, 1156 High Street, Santa Cruz, CA 95064 (xintingyu@ucsc.edu). [2]Department of Earth and Planetary Sciences, Johns Hopkins University, 3400 N. Charles Street, Baltimore, MD 21218. [3]Department of Materials Science and Engineering, Johns Hopkins University, 3400 N. Charles Street, Baltimore, MD 21218.

Introduction: Aeolian processes are prevalent on Earth and many planetary bodies in the solar system. With not only different environmental conditions but also transporting materials, the aeolian features on these bodies end up with similar geomorphology. On terrestrial bodies, the transporting materials are mainly silicates, while photochemically produced organics and ices are the main transporting materials on icy bodies. On Titan, the photochemistry-produced organic particles are the main transporting sediments that form the equatorial linear dunes [1]. Titan wind tunnel experiments have demonstrated that both environmental conditions and material properties have a big impact on the threshold wind speed required to initiate sand movement [3, 4]. While knowledge of the threshold wind speed is necessary for characterizing the surface wind and modeling dune migration and abrasion. An improved understanding of material properties of Titan surface materials is thus essential to better understand the threshold wind speed and the transportation capacity of the sand on Titan.

Many efforts have been made to study the chemical structure and spectroscopic properties of the Titan haze analogs. However, material properties such as mechanical and cohesive properties are less investigated, while these properties could shed light on how the organic aerosols are transformed to sand-sized particles and the transport scheme of the organic sand on the surface.

Methods: We produced the Titan aerosol analogs, 'tholin', using the Planetary HAZE Research (PHAZER) experimental system at Johns Hopkins University, with a CH_4/N_2 (5/95) cold gas mixture exposed to glow plasma discharge or UV irradiation. Tholin was deposited on smooth quartz discs and acid-washed glass spheres. The cohesive properties of tholin was measured with colloidal probe atomic force microscopy (AFM) by contacting and taking force curves between a coated tholin sphere and a flat tholin-coated surface. The surface energy of tholin, which is an indicator for cohesiveness of a material, was measured using contact angle analysis and surface force apparatus (SFA). The electrostatic forces are measured by the colloidal probe AFM after rubbing a coated tholin sphere on a flat coated tholin surface. The mechanical properties of tholin were measured by nanoindentation.

Results and Discussion

Cohesive properties. We used the colloidal probe AFM to directly measure cohesion forces between Titan "tholin" particles [4]. This is the first time that interparticle forces were measured directly between single particles of tholin. We found that the interparticle cohesion forces are much larger for tholin than for silicate sand and materials used in the Titan Wind Tunnel (TWT). This suggests that we should increase the interparticle forces in both analog experiments (TWT) and threshold models to correctly translate the results to real Titan conditions. The strong cohesion of tholin also indicates that Titan's sand could be formed by effective coagulation of small aerosol particles in the atmosphere.

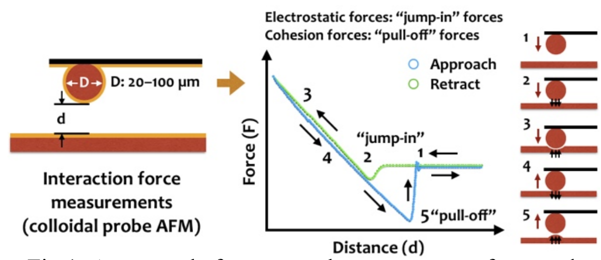

Fig 1: An example force curve between two surfaces and the interaction schemes during the contact and pull-off.

From the contact angle and the SFA measurements, we found that the tholins produced by cold plasma and UV irradiation have similar total surface energy of ~65–70 mJ/m^2 [4, 5]. The direct force measurements using SFA yield a total surface energy of ~66 mJ/m^2 for plasma tholin [5]. The surface energy of tholin is relatively high compared to common polymers, indicating its high cohesiveness. This also supports that the cohesion forces are strong between sand particles on Titan.

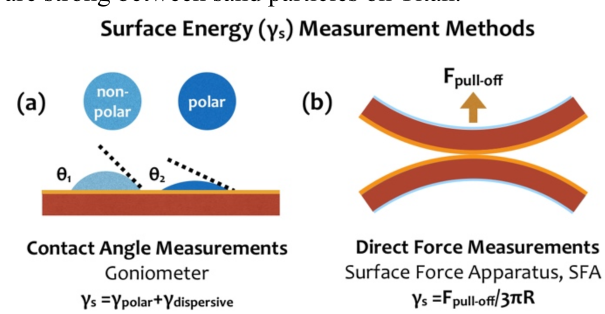

Fig 2. Surface energy measurements methods.

Electrostatic properties. When sand particles are transported on the surface, they could be triboelectrically charged by friction. The resulting electrostatic forces could affect particle trajectories and potentially trigger electrical discharge. Thus it is important to characterize the electrostatic charging capacity of the organic sand on Titan, so that we could assess the effect of sand charging on Titan.

We used the colloidal probe AFM technique to study triboelectric charging processes using Titan and Earth sand analogs. We found that it is easy to generate triboelectric charges between simple organics (naphthalene), polymers (polystyrene), and silicates (borosilicate glass). In contrast, tholin, the complex organic material, does not generate any detectable electrostatic within the detection limit of the instrument [6]. If Titan sand behaves more like tholin, this indicates that the tribocharging capacity of Titan sand is much weaker than Earth silicate sand and much less than previously measured by [7], where only simple organics were used for Titan sand analogs. Thus, triboelectrification may not contribute to increasing interparticle forces between sand particles on Titan as much as on Earth. Interparticle forces generated by other electrostatic processes or other interparticle forces such as van der Waals and capillary cohesion forces could be the dominant interparticle forces that govern Titan sand formation and sediment transportation on the surface. Titan sand is also unlikely to produce large electrical discharge through tribocharging to affect future missions to Titan's surface.

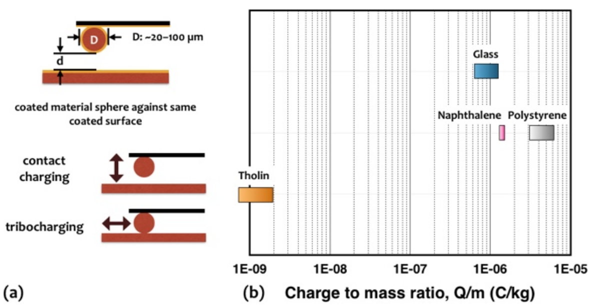

Fig 3: (a) Charging scheme used with the colloidal probe AFM. (b) Measured charge to mass ratio for silicates (glass), simple organics and polymers (polystyrene and naphthalene), and tholin.

Mechanical properties. It has also been a puzzle where Titan sand originates. There have been competing theories on whether small aerosol particles grow on their own ("dry" mechanism) or whether they need liquid hydrocarbons to facilitate their growth ("wet" mechanism) [8]. However, the Titan sand analog "tholin", is usually produced in low yields and is hard to characterize with bulk mechanical tests. We used a novel technique called nanoindentation to measure the mechanical properties of thin films of tholin and a range of known Earth sands. We measured the nanoindentation hardness, elastic modulus, and fracture toughness of tholin and common Earth sands [9]. We found that tholin is much softer and much more brittle than even the softest sand on Earth, which indicates that the sand on Titan is unlikely to sustain long distance travel (it will be ground to dust which is hard to mobilize). This indicates that the organic sand on Titan sand should be derived close to where it is located near the equatorial regions of Titan and is probably formed by the "dry" mechanism.

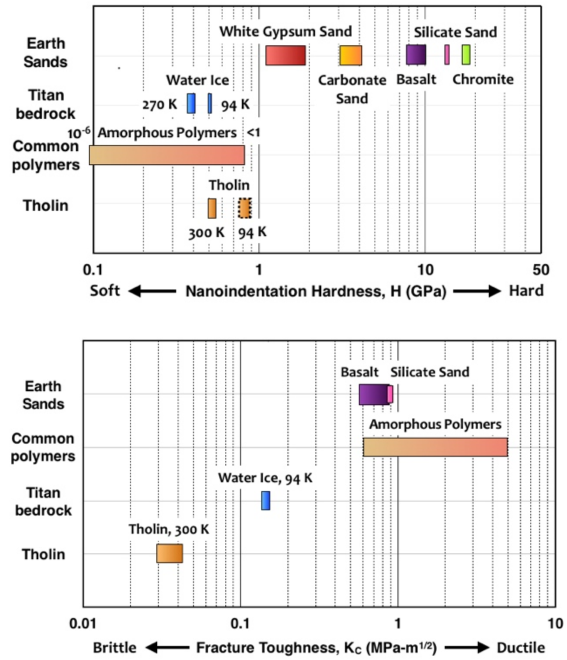

Fig 4. Nanoindentation harness and fracture toughness for tholin, amorphous polymers, and common Earth sand.

Conclusion: The above results suggest that it is more favorable for the Titan sand to be formed by "dry" agglomeration of small aerosol particles. Since the organics have higher cohesion and they are less likely to be formed in the polar liquid reservoirs on Titan by "wet" agglomeration, because they are not mechanically strong enough to transport long distances to form the equatorial dunes. The high cohesion between Titan sand particles also indicate that higher threshold wind speed is needed to saltate sand grains on Titan.

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