論文 / 著書情報
Article / Book Information

題目(和文)	タイタン上の有機物の表面エネルギーと弾性に関する実験的研究
Title(English)	Experimental study on surface energy and elasticity of organic materials on Titan
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Type(English)	Summary

（博士課程）
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論 文 要 旨

THESIS SUMMARY

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学生氏名： Student's Name	平井 英人	審査員主査： Chief Examiner	玄田 英典

要旨（英文800語程度）
Thesis Summary（approx.800 English Words ）

Saturn's largest moon, Titan, has a dense reducing atmosphere where organic aerosols are formed from methane (CH_4) and nitrogen (N_2) via photochemical reactions. These organic aerosols would settle on the surface, interacting with a CH_4-based hydrological cycle. Thick organic sediments exist as dunes in the low latitudes but are absent in the middle latitudes, where the H_2O ice crust may be exposed, suggesting that organic aerosols may have been transported spontaneously. Previous studies have considered that saltation of organic aerosols would occur only by strong wind during CH_4 storms in low latitudes due to highly cohesiveness of organic aerosols analogs at room temperature. However, cohesiveness would differ at Titan's surface temperature (~93 K) and among different organic materials. Nevertheless, the temperature and chemical structure dependence of cohesion has been poorly understood.

The objectives of the present study are to investigate the temperature and chemical structure dependence of both surface energy (cohesion force) and elasticity (elastic wave velocities) of organic analog materials on Titan.

In Chapter 2, three types of Titan's organic analogs were produced; (1) films and particles of Titan tholin, (2) films of altered tholin, and (3) films and solids of hydrothermal organics. Morphologies and the chemical structures of organic analogs were characterized by using FE-SEM, FT-IR, elemental analysis, UV/Vis spectroscopy, and HPLC. Our results suggest that Titan tholin and hydrothermal organics contain N-bearing polycyclic aromatic compounds (N-PACs) with polymer-like chains, while altered tholin has N-bearing heterocyclic aromatics with minimal aliphatic content. Hydrothermal organic solids are polyolefins rich in C=O bonds.

In Chapter 3, cohesion force and surface energy of organic analogs were measured using an atomic force microscope (AFM). Our results suggest that the surface energy of Titan tholin decreases as temperature decreases, following the Arrhenius equation with an activation energy (E_{surf}) of 1760 ± 190 J mol^{-1} and the surface energy at absolute zero γ_0 of 180 ± 20 mJ m^{-2}. This temperature dependence would be caused by reduced contact radius due to increased elasticity and/or decreased energy dissipation via molecular stick-slip mechanisms. Surface energy of altered tholin and hydrothermal organics are 159 ± 39 mJ m^{-2} or 226 ± 77 mJ m^{-2}, and 57 ± 8 mJ m^{-2}, respectively. Our results also suggest that the surface energy of organic materials depends on the elemental ratios, the abundance of unsaturated bond, and the molecular size.

In Chapter 4, the elastic wave velocities and elasticity of organic analog materials were constrained through synchrotron radiation X-ray and ultrasonic wave experiments. P-wave and S-wave velocities of Titan tholin at 300 K are determined to be 3260 ± 390 m/s and 1830 ± 60 m/s, while those of hydrothermal organics are 2830 ± 60 m/s and 1740 ± 40 m/s, respectively, based on the ultrasonic experiments. These values are consistent with those estimated from phonon dispersion determined by inelastic X-ray scattering (IXS) method. Diffraction patterns and phonon dispersion data suggest that the lattice structure of Titan tholin does not change significantly between 300 K and 93 K. Assuming a constant density, the temperature dependence of the longitudinal modulus of Titan tholin is estimated as M_0 = 7.3 ± 1.2 GPa and E_a = -500 ± 230 J mol^{-1} using the Arrhenius equation, and M_0 = 15 ± 2 GPa and T_m = 340 ± 110 K using a linear relationship by least-square fitting. Comparing Young's modulus across organic materials suggests that elasticity depends not only on elemental ratios but also on composition, functional groups, and molecular structure. Additionally, comparison of the phonon dispersion determined in IXS with ultrasonic wave measurements suggests that the long-wavelength approximation remains valid at the phonon scale of a few unit cells, which allows for the extrapolation of ultrasonic wave results to the 0.1–10 Hz frequency range of the seismometer onboard NASA's Dragonfly mission. At Titan's surface temperature (~93 K), the elastic modulus of organic materials is estimated as K = 11 ± 3.8 GPa, G = 6 ± 2.0 GPa for Titan tholin-like structures, and K = 9.1 ± 3.1 GPa, G = 6.9 ± 2.4 GPa for hydrothermal organic-like structures.

In Chapter 5, the saltation threshold wind speed (u*) on Titan's surface temperature was estimated with the temperature dependence of surface energy of Titan tholin constrained in Chapter 3. Our results suggest that u* becomes about three times lower than previously expected, suggesting that the saltation would occur by tidal winds in the summer at middle latitude. The estimated mass flux of sand transportation toward lower latitude exceeds the deposition rate of organic aerosols, explaining the absence of thick organic sediments in middle latitude, where H_2O ice crust may be exposed. To test this hypothesis, the active seismic survey during NASA's Dragonfly mission will be useful. A sensitivity study of the detection limit of depths of organic sediments in shallow subsurface to the elasticity of organic materials constrained in Chapter 4 was also performed using a rock physics model. Our results suggest that the detection limits would reach ~30 m at 10 Hz. The elastic wave velocities constrained in the present study are essential to estimate thickness of organic sediments from travel times of seismic echoes during NASA's Dragonfly mission.

In Chapter 6, the synthesis of the findings and implications for the collisional growth of dust particles and atmospheric haze are discussed.