Chemical effects of satellitesimal impacts on Titan's proto atmosphere - Consideration of impact origin of Titan's N2 atmosphere -

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Titan is the only object in the Solar system that has a thick N_2 atmosphere besides the Earth. It has not been clarified why Titan have such massive N_2 atmosphere. In recent years, the Huygens probe has made the first direct observations of the lower atmosphere. The primordial noble gases other than a trace of 36Ar were not detected by GCMS on the Huygens probe (Niemann et al., 2005). This implies that Titan captured initially its nitrogen in the form of probably NH_3 (Niemann et al., 2005). As a result, NH_3 probably constituted a Titan's initial atmosphere. Then, CH_4-NH_3 atmospheres were considered as a possible candidate for the Titan's proto atmosphere. The CH_4-NH_3 atmosphere is induced by accretion of CH_4-rich satellitesimals formed in the catalytically active region of subnebula. If so, there should be a mechanism for converting the proto NH_3 atmosphere to the present N_2 atmosphere. The previous studies (Jones and Lewis, 1987; McKay et al., 1988) have proposed the pyrolysis of NH_3 by shock heating due to high-velocity meteor impacts. These studies assumed that the gas heated by shock heating approaches rapidly to their high-T equilibrium state via chemical reactions; that is, the conversion from NH_3 to N_2 occurs efficiently. It has been known that the bow shocks formed in the terrestrial atmosphere heats the air to extreme high temperatures. Therefore N_2 production through shock heating was considered to work even on Titan. Their results showed that satellitesimal impacts on proto atmosphere during accretion of Titan can produce enough N_2.

However, we found that the shocked gas does not reach the thermodynamic equilibrium state by the impact shock on CH_4-NH_3 atmospheres. The reducing atmospheres such as CH_4-NH_3 atmosphere are not heated easily unlike the terrestrial atmosphere because of the large heat capacity of reducing gas, which have many vibrational modes. Thus, the formation of the N_2 atmosphere by impacts on CH_4-NH_3 atmospheres may be more difficult than previous studies suggested.

Although the previous studies assumed only CH_4 and NH_3 as the atmospheric composition, either CO_2 or H_2O may be other potential constitutes of a proto atmosphere. This is because the surface temperature of accreting Titan increases due to the blanketing effects of proto atmosphere. In this case, a hot steam atmosphere may have been formed on Titan by evaporation of H_2O ice (Kuramoto and Matsui, 1994). There is also a possibility that Titan formed by accretion of CO_2-rich satellitesimals, which were formed in the catalytically inactive region of subnebula. In this case, CO_2 may have become one of the major components of the proto atmosphere. Therefore, we investigated the case for impact on the proto atmospheres with H_2O and/or CO_2 by using our numerical model in which we incorporate a chemical kinetics model into a dynamics model. We discussed the plausibility of formation of the N_2 atmosphere form such proto atmospheres.

Our results show that impact shocks on proto atmospheres with H_2O and/or CO_2 are very favorable for the N_2 shock production. This is because inclusion of them decreases the heat capacity of shocked gas, which leads to the increase in the postshock temperature. They have few vibrational modes compared to reducing species. Then, the Titan's N_2 atmosphere may have been formed due to impacts on oxidizing atmospheres (CO_2-rich and/or steam atmospheres) rather than the reducing atmospheres which previous studies assumed, if the Titan's N_2 atmosphere was formed by satellitesimal impacts during accretion stage. Thus, the present N_2 atmosphere on Titan might suggest indirect evidence for existences of the steam atmosphere on early Titan or accretion of CO_2-rich satellitesimal formed in the Saturnian subnebula.