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# Optical properties in UV-visible regions and production rate of organic haze on early Earth

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Standard models of solar evolution predict that the Sun was ~25% less luminous at 3.8 Ga (Newman and Rood, 1977). If we assume that the atmosphere had a transmittance similar to the present, the average early Archean surface temperature would have been below the freezing point of water. However, the geologic record suggests that liquid water was present by at least 3.5 Ga and probably by 4.0 Ga (Sagan and Mullen, 1972, Schopf and Barghoorn, 1967). Thus, additional, strong greenhouse effects are required to make the early Earth habitable.

Sagan and Chyba (1997) argued that organic haze, such as that formed in Titan's atmosphere composed of N2 and CH4 (McKay et al., 1991), would have produced from CH4 photolysis in early Earth's atmosphere. Such early Earth haze might have shielded NH3 sufficiently that NH3 resupply rates were able to maintain surface temperatures above the freezing point (Sagan and Chyba, 1997; Wolf and Toon, 2010). However, the validity of the UV shielding hypothesis strongly depends on the optical property and production rate of organic haze formed in early Earth's atmosphere composed of N2, CO2, and CH4 (Pavlov et al., 2001).

Here, we investigate optical properties of photochemical haze on early Earth by laboratory experiments of haze production using a UV lamp from gas mixtures of N2, CH4, and CO2. Although a few laboratory experiments of haze production in early Earth's atmosphere has been conducted previously (Trainer et al., 2006), there is no experimental study to measure refractive indices of organic haze continuously from the UV to near-IR regions. In addition, the previous experiments used a deuterium lamp (Trainer et al., 2006), which has the wavelength peak at 160 nm. In this study, we use a UV lamp system using an electric discharge of H2/He gas mixtures, which produces a UV emission with the wavelength peak at 121.6 nm (i.e., Ly-alpha line) similar to the solar UV radiation. Based on spectroscopic ellipsometry, we obtain refractive indices and production rates of haze formed from various gas compositions. We also analyze intermediate gas products with a quadrupole mass spectroscopy. By comparing our results with those of the previously studies on Titan haze (Khare et al., 1984) and on early Earth haze (Hasenkopf et al., 2010), organic haze formed by our experiments has small imaginary refractive index. These results indicate that the optical depth of the organic haze is thin at the UV wavelengths, suggesting that the UV shielding by organic haze on the early Earth may have been less effective than previously thought.

References: Newman and Rood, 1977. Science 198,4321:Sagan and Mullen, 1972 Science 177 52: Schopf and Barghoorn, 1967 Science 156 3774: Hasenkopf et al., 2010. Icarus 207, 903: Khare et al., 1984. Icarus 60, 127: Pavlov et al., 2001. J. Geophys. Res. 106, 23267: McKay et al., 1991. Science 253, 1118: Sagan and Chyba, 1997. Science 276, 1217: Trainer et al., 2006. PNAS 103, 18035: Wolf and Toon, 2010 Science 328, 1266.