Spectral evidence for the distant origin and water-rock differentiation of large C-type asteroids

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The volatile compositions of asteroids tell us the dynamic history of the Solar System and the origins of Earth's habitability. Because the asteroids have experienced volatile loss to space via sublimation, their present-day compositions do not directly inform their initial states, which remained unsolved. Infrared spectra of the asteroids reflect surface mineralogy, which are the relics of past water-rock reactions in them. By combining the spectral observations of the main-belt asteroids and the modelling of water-rock reactions, we show that the asteroids having diagnostic 2.7, 3.1, and 3.4 micrometer absorption features experienced the reactions under the water-rock ratio (W/R) higher than unity as well as the presence of NH_3 and CO_2 with the quenching temperature around 0 C. These results suggest that many main-belt asteroids formed beyond the NH_3 and CO_2 snow lines, experienced water-rock differentiation but retained its water during the period of radioactive decay heating. The formation beyond the NH_3 and CO_2 snow lines requires the migration of small bodies due to gravitational scattering by giant planets. Alternatively, in situ formation might be also possible with the inward migration of snow lines in the late stage of protoplanetary disk evolution followed by ice pebble accretion. Carbonaceous chondrites (CCs), having a lower W/R, likely originate from the rock-dominated interiors of the differentiated bodies. Earth's H/C ratio higher than CCs may be explained by the supply of volatile elements from the water-rich progenitors of the main-belt asteroids during the early stage of planet formation before the sublimation of water to space.

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