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Dark Clasts as a Key to the Origin of Earth's Volatile Inventory

CYPRIEN CAMPLONG[1], ELISHEVAH VAN KOOTEN[1], KAZUHIDE NAGASHIMA[2], ALEXANDER N KROT[2], TUE HASSENKAM[3] AND MARTIN BIZZARRO[4]

[1]Centre for Star and Planet Formation, Globe Institute, University of Copenhagen

[2]Hawai'i Institute of Geophysics and Planetology, School of Ocean and Earth Science and Technology, University of Hawai'i at Mānoa

[3]University of Copenhagen

[4]Center for Star and Planet Formation, Globe Institute, University of Copenhagen

The origin of Earth's volatile elements, including hydrogen, carbon, and nitrogen, remains debated despite its fundamental importance for planetary evolution and the emergence of habitable environments [1, 2]. Identifying the nature of volatile-bearing materials and the processes responsible for their delivery to growing rocky planets is critical for understanding how planetary volatile inventories are established. Dark clasts, organic- and volatile-rich xenolithic inclusions preserved within meteorites, provide direct physical evidence for the inward transport of carbonaceous material into the inner solar system [3-6] and offer a unique opportunity to investigate volatile-rich reservoirs incorporated into bodies accreted in the terrestrial planet region. We analyzed a population of dark clasts hosted in ordinary chondrites (NWA 5697), ureilites (DaG 319, NWA 15299), and a polymict eucrite (NWA 8224). Using coordinated petrographic, spectroscopic, and isotopic measurements, we constrained their carbon, nitrogen, hydrogen, and water contents and determined their $\delta^{13}C$, $\delta^{15}N$, and δD signatures. Our results show that dark clasts represent a substantial and previously underappreciated reservoir of volatile elements in the inner solar system. Despite their minor abundance, mixing calculations indicate that incorporation of small fractions of dark clast–like material can supply significant amounts of hydrogen, carbon, and nitrogen, and likely water, to growing planets. These findings support a model in which inward-drifting carbonaceous material contributed efficiently to Earth's volatile inventory and highlight a fundamental mechanism linking disk-scale transport processes to the volatile budgets of rocky planets.

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