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Advanced Curation for Future Sample Return: Insights from Meteorites and Analogue Samples

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In the context of astromaterials – meteorites, cosmic dust, or samples returned from other planetary bodies by robotic or crewed missions – advanced curation is defined as a cross-disciplinary field of research that investigates and improves best practices for the storage, handling and analysis of astromaterials, and prepares for future opportunities [1]. Such opportunities include sample return missions, as well as meteorite fall events.

Cold curation is a type of advanced curation that seeks to balance the advantages of lower temperature (≤ 0 °C) for the preservation of volatile or reactive organic species and components, and mitigation of microbial activity, against such practical considerations as the comfort and dexterity of the sample processor [1,2]. The main driver for the development of cold curation is that astromaterials such as carbonaceous chondrites or other volatile-bearing samples formed in "environments strikingly different from that on the Earth's surface" [3]. Carbonaceous chondrites and similar astromaterials are disequilibrium assemblages, preserved for over 4.5 billion years due to low temperatures after the completion of the main phases of their petrogeneses: they have likely not been exposed to liquid water and/or high redox states since the completion of aqueous alteration on their parent bodies. Earth's surface conditions - heat, moisture, the oxidizing nature of the atmosphere, and the abundance of organic matter - are all risks to the preservation of these astromaterials, factors that advanced curation seeks to mitigate. The cutting edge of advanced curation is the combination of low temperature and controlled atmosphere, and the identification of contaminating microbial populations via gene sequencing [e.g. 1, 4]. These advances contribute to the knowledge required for the future analysis of more challenging samples, such as those returned from Mars [5], the lunar South Pole, comets, and other planetary bodies.

[1] F. M. McCubbin et al. (2019) *Space Sci. Rev.* 215, 48. [2] Herd, C.D.K. et al. (2016) *Meteorit. Planet. Sci.* 51, 499–519. [3] Allen, C. et al. (2011) *Chemie der Erde - Geochemistry* 71, 1–20. [4] Tunney, L.D. et al. (2025) *Meteorit. Planet. Sci.* 60, 1798–1813 (2025). [5] Carrier, B.L. et al. (2025) *Astrobiology* 10.1177/15311074251382248 (2025).