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Developing a Mineralogical Weathering Scale for Modern and Fossil I-Type Micrometeorites

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Iron (I-) type micrometeorites are cosmic spherules predominantly composed of Ni-bearing Fe-oxides [1] derived from FeNi-metal precursors (<2mm) that oxidize during atmospheric entry. During their brief molten state, metallic FeNi reacts with mesospheric oxygen and recrystallizes into magnetite- and wüstite-dominated assemblages enriched in Ni. As a result, the oxygen isotopic composition of I-types exclusively reflects the mesospheric composition at the time of their fall [2]. Consequently, Fossil I-types may provide a potential archive of paleo-atmospheric $d^{18}O$ and $D^{17}O$, which can be linked to long-term variations in CO_2 and global climate [2].

Although I-types are relatively resistant to terrestrial weathering (TW) due to their Fe-oxide-rich mineralogy, they are not immune to its effects. Secondary processes often involve progressive (re)oxidation of Fe-oxides and residual metal, and oxygen isotope exchange with meteoric or diagenetic fluids, depending on the depositional environment and age of the collection [3-5]. Such alteration may modify primary atmospheric isotopic signatures, complicating paleo-atmospheric reconstructions.

Key questions therefore arise: How can the degree of TW be consistently assessed across Antarctic, non-Antarctic, and fossil collections that experienced distinct post-depositional environments? And at what point can an I-type particle be considered sufficiently well-preserved for reliable oxygen isotope analysis? Here, we address these questions using Raman spectroscopy and SEM/EDS to characterize mineralogical changes (e.g. recrystallization, phase transformations), oxide phase proportions, Ni redistribution, and texture (e.g. etching, dissolution) in I-types from the AMGC-VUB collections. By quantifying the relative abundance of primary magnetite-wüstite assemblages versus secondary Fe-(hydr)oxides and alteration products, we develop a mineralogical-based weathering scale applicable across modern and fossil settings.

This standardized weathering scale enables objective comparison of preservation states across collections and provides a robust framework to identify “well-preserved” I-types for paleo-atmospheric oxygen isotope studies, thereby strengthening the use of fossil micrometeorites as archives of Earth’s atmospheric evolution.

[1] Genge, et al. (2017), *Geochimica et Cosmochimica Acta*, 218, 167-200. [2] Fischer, et al. (2021), *Paleoceanography and Paleoclimatology*, 36(3), e2020PA004159. [3] van Ginneken, et al. (2024), *Philosophical Transactions* A,382(2273), 20230195. [4] Suttle & Genge (2017), *Earth and Planetary Science Letters*, 476, 132-142. [5] Krämer Ruggiu, et al. (2025), *Geochimica et Cosmochimica Acta* 405, 114-131.

