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Phyllosilicate-enhanced preservation of primary biogeochemical heterogeneities in Archaean (~2.9 Ga) siliciclastic microbial mats

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Precambrian *Konservat-Lagerstätten* are primarily restricted to cherts, shales and phosphates, which promote the early, rapid and anoxic entombment of kerogenous materials in amorphous or fine-grained materials. Such horizons preserve biogeochemical heterogeneities over billions of years. Albeit rarely, siliciclastic sequences can also preserve organic traces of life with extremely high fidelity; however, the micro-scale geological mechanisms behind such preservation are poorly constrained. We here report the exceptional preservation of primary biogeochemistry in microbial mat horizons in sandstones from pristine core samples of the ~2.97–2.91 Ga Mosquito Creek Formation (Pilbara, Western Australia). Optical and electron microscopy (SEM, TEM, HRTEM) coupled with Raman and FTIR microspectroscopy shows that, despite the poorly sorted, fine–coarse sandy granulometry of most Mosquito Creek Formation siliciclastics, layers dominated by nanometric K-Al-phyllosilicates preserve microbial mats and wrinkle structures as fragments of kerogenous materials intercalated between elongate clay minerals. XRD analyses suggest that this phyllosilicate phase is either illite or kaolinite altered to illite. HRTEM elucidates the ultrastructure of the kerogen, showing that it comprises largely amorphous carbonaceous materials with some poorly crystalline domains (turbostratic and poorly graphitised carbon), and that is intimately associated with crystalline phyllosilicates. Geochemical characterisation using FTIR, NanoSIMS, EELS and STXM demonstrates the retention of primary organic heterogeneity including aromatic, aliphatic, and other heteroatomic C-, H- and N-bearing compounds, correlated C and N enrichments, and negative carbon isotope fractionations. Localised and/or temporally restricted quiescent periods of phyllosilicate deposition are proposed as instrumental to the preservation of organic materials in these coarse siliciclastics. This opens the possibility for further detailed studies of Early Precambrian sandstones as non-traditional biosignature repositories. Similar occurrences of organic materials in fine–coarse-grained sandstones and in association with phyllosilicates in Martian sedimentary sequences, such as deltas and other fluvio-lacustrine deposits, may provide similar havens of biosignature preservation potential. Such samples have already been collected by the Perseverance rover at Jezero crater and will be returned to Earth in the 2030s, whereupon a similar multi-technique approach to their characterisation may be applied.