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The impact of multi-stage metamorphism on preservation of traces of life in ~2.5 Ga banded iron formations, North China

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Biological organic molecules preserved within Precambrian banded iron formations (BIFs) can provide valuable information about the origin and evolution of life [1]. It is widely acknowledged that metamorphic alterations of biological organics result in an obstacle in identifying early life traces [2]. Nevertheless, the physiochemical mechanisms responsible for these alterations remain insufficiently comprehended. In this study, we present petrographic observations and nanogeochemical investigations on the carbonaceous matter (CM) in ~2.5 Ga BIFs from North China, which have undergone significant alteration during lower amphibolite-facies prograde metamorphism, and subsequent retrograde alteration. The CM is in paragenetic equilibrium with prograde mineral phases, and is often associated with apatite that occurs in Fe-rich bands parallel to layering. This implies that the CM is most likely inherited from syn-depositional biomass, as confirmed by the nanoscale infrared spectroscopy, which shows the presence of C=C, C–H, and C–N/N–H bonds. Raman spectroscopy reveals that the maximum metamorphic crystallization temperature is consistent with the metamorphic peak conditions of the host BIFs. The BIFs possess average bulk $^{13}C_{organic}$ values of −20.0‰ and $\delta^{13}C_{carbonate}$ values of −12.9‰, further indicating syngenetic biomass remineralization during prograde metamorphism. This thermal cracking process may have released gaseous hydrocarbons, as shown by secondary CH_4 fluid inclusions in quartz. We further use quantum mechanical simulations to assess the stability of organic chemical bonds during prograde metamorphism (0-600°C, 0-15 kbar). The relatively high thermal durability of C–H and the armoring effects of primary organic-phyllosilicate complexes may account for C–H preservation in BIFs. Furthermore, the electron microscopy reveals widespread nano-chlorite infiltration into CM during retrograde metamorphism, which is likely responsible for the absence of C–O bonds via nanopore-scale reactions. Our findings highlight the importance of evaluating metamorphic effects on the preservation of primordial microorganisms, particularly those found in ancient iron-rich sediments.

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