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Abiotic iron oxidation controlled the deposition of Neoproterozoic iron formations

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Following a billion-year depositional hiatus, iron formations (IFs) briefly reemerged during Neoproterozoic Snowball Earth glaciations. Unlike Archean-Paleoproterozoic **IF**s, Neoproterozoic IFs (NIFs) are uniquely associated with glaciogenic diamictites and dominated by authigenic hematite, yet the drivers of this mineralogical shift remain debated. Here, we present coupled iron-carbon isotope data from Sturtian-aged NIFs in the Fulu Formation (Nanhua Basin, South China). composed of alternating hematite, quartz, feldspar, Fe-chlorite, and rare siderite layers. The siderite exhibits exceptionally negative $\delta^{13}C_{carb}$ values (down to -19‰). Isotopic equilibrium modeling supports two hypotheses for this fractionation: (i) **a** diminished dissolved inorganic carbon (DIC) reservoir influenced by dissimilatory iron reduction (DIR), and (ii) Fe-mediated anaerobic oxidation of methane (AOM) driven by methane diffusion. Both scenarios align with suppressed primary productivity under ice-covered oceans, where microbial activity and organic burial were limited. This low-productivity regime explains the hematite-dominated mineralogy of NIFs, contrasting sharply with the diverse diagenetic phases (e.g., siderite, magnetite) in Archean-Paleoproterozoic IFs. Heavy $\delta^{56}Fe$ values (up to 2.03‰) further indicate abiotic Fe^{2+} oxidation via meltwater-derived oxygen, rather than biological pathways like photoferrotrophy. Overall, these results support a model of an anoxic Cryogenian ocean with minimal productivity during NIFs deposition, where Fe cycling was governed by glacially mediated redox dynamics.