Unveiling Iron Oxidation Reactions in Minnesota Banded Iron Formations: From Primary Assemblages to H Potential

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Résumé

Banded Iron Formations (BIFs), due to their high iron content, are promising candidates for natural hydrogen (H) production. However, the conditions required to trigger this reaction in BIFs remain poorly understood. Here, we characterize the petrology of drill core samples from the ~1.9 Ga Biwabik and Soudan BIFs (Minnesota, USA), to assess the mineralogy and fluid-rock interactions that are favourable for H generation. Scanning electron microscopy and electron microprobe analyses were used to obtain mineral geochemistry, while both laboratory and synchrotron-based X-ray microtomography provided 3D imaging of sample textures and allowed estimations of mineral proportions. Two samples display cherty facies, consisting of a siderite + minnesotaite + magnetite ± stilpnomelane ± ankerite assemblage within a quartz matrix. In contrast, another group of samples displays an amphibole + magnetite + calcite assemblage, attributed to > 1.0 Ga greenschist facies metamorphism. In the unmetamorphosed cherty facies, siderite grains form clusters with corroded textures which are crosscut by sub- to euhedral magnetite grains, suggesting the following reaction: 3 Siderite + HO → Magnetite + 3 CO + H. In one sample, fibrous minnesotaite crosscuts siderite, indicating the reaction: 3 Siderite + 4 SiO + HO → Minnesotaite + 3 CO. In another sample, late hematite overgrows both minnesotaite and siderite, consistent with: 2 Siderite + HO → Hematite + 2 CO + H and 2 Minnesotaite + HO → 3 Hematite + 8 SiO + 3 H. Thermodynamic calculations predict that magnetite can form from siderite in the presence of an anoxic, silica-poor fluid, under conditions where H remains stable. Conversely, high silica concentrations favour minnesotaite formation. Oxidizing fluids promote hematite crystallization, but in these conditions, the produced H is unstable and rapidly consumed. Moreover, the metamorphosed samples are stratigraphically equivalent

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to unmetamorphosed ones, suggesting that metamorphism under anoxic hydrothermal conditions could have enhanced magnetite formation from carbonates and silicates, along with amphibole crystallization. While these metamorphosed samples may have produced large amounts of H over a billion years ago (2–4 g/kg rock), the unmetamorphosed ones may still generate H if intersected by deep anoxic fluids, making them excellent targets for natural hydrogen exploration.

Mots-Clés: banded iron formations, natural hydrogen, siderite, magnetite, fluid, rock interactions